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Treatment of Leachates from Sanitary Landfills

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TREATMENT OF LEACHATES FROM SANITARY LANDFILLS

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ABSTRACT

TREATMENT OF LEACHATES FROM SANITARY LANDFILLS

Laboratory plant experiments concerning biological and chemical treatment of leachates from sanitary landfills are described. Leachates from eight landfills were evaluated for the fate of organics, heavy metals and other inorganic compounds. The biological treatability was studied using respiration tests. Leachate from two landfills were treated anaerobically and four aerobically.

The anaerobic treatment was carried out in three anaerobic filters. Three test series were performed on leachates with COD concentrations ranging from 3600 to 38800 mg/l. The results showed that the leachates could be treated successfully at organic loadings lower than about 0.7 kg COD/m^3 day and temperatures higher than 22°C. For the high strength leachates the COD removal efficiencies were as high as 98 percent. At organic loading 0.4 kg COD/m^3 day and 11°C no COD removal was observed.

Aerobic treatment was studied in fifteen test series. The treatment performance of biological treatment for both raw and chemically treated leachate at different organic loadings were investigated. The feasibilities of the processes activated sludge, aerated lagoons, trickling filter and biodisc in treating leachates were compared. The metal toxicities as well as the influence of temperature in the activated sludge process were also investigated.

Of the aerobic treatment systems examined the activated sludge process gave the best results. The treatment results showed that the high strength leachates allowed considerably higher organic removals than the low strength leachates. For all four leachate sources investigated the organic removals would drop sharply as organic loadings exceeded 0.3-0.4 kg COD/kg MLVSS day. The COD removals at low loadings varied from 35 to 98 percent. At organic loadings lower than about 0.3 kg COD/kg MLVSS day a high degree of nitrification was obtained. Due to the high ammonia to COD ratios in the low strength leachates the nitrification caused BOD removals in excess of 90 percent.

No difference in the treatment efficiencies was found in treating chemically precipitated or raw leachate. In spite of very low phosphorus concentrations in the raw leachate phosphorus was not found to limit the biode gradation.

Zinc was found to have a slight adverse effect on the COD removal at concentrations of 50 mg/l. Copper had drastic inhibitory effects at concentrations of 25 and 50 mg/l while concentrations of 10 mg/l gave a slight adverse effect. The study of the temperature effects showed that the COD removals and especially the degree of nitrification dropped sharply at process temperatures below 18°C.

Treatment by aerated lagoons at sufficient detention times gave slightly lower removal of organics and about the same degree of nitrification as the corresponding activated sludge treatment. Low loaded biodisc and trickling filter gave low organic removals and low degree of nitrification.

Chemical precipitation of raw leachate at high pH removed heavy metals efficiently. Alum, ferric chloride and lime precipitation all provided about 10 percent removal of organics.

Activated carbon adsorption of biologically treated plus precipitated leachate gave considerably lower residual organics than carbon adsorption of precipitated leachate. For all three leachate sources investigated the COD could be removed to a residual level of about 90 mg/l.

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CHAPTER I

INTRODUCTION

A. PROBLEM DEFINITION

The most common method of solid waste disposal today is the use of sanitary landfills. Unfortunately, leachate production in landfills often leads to pollution of our environment. The amount of leachates may be especially large in areas with humid climates as a result of infiltrating rain or upwelling ground water. The leachate from landfills can seriously degrade the quality of both surface and groundwater and hence can be a potential hazard for human health. In the last decade these problems have increased because of an increased production of disposable waste products and the use of more improper hydrogeological landfill sites. Therefore, more and more landfills must be built with provisions for collection and treatment of the leachate, thereby making the selection of the fill site and operation of the fill more flexible.

Composition and quantity of leachate produced from sanitary landfills have been investigated in several studies. In the United States guidelines for interception and collection of the leachate are given. However, little information is available for effective treatment of the collected leachate. This area of study has, in the past, received an amazingly low research priority. The treatment of leachates is a difficult problem because of the complexity and often highly toxic content of the leachate. There is, therefore, a need for more detailed knowledge regarding selection of proper treatment processes and design criteria for leachate treatment facilities.

The research described in this dissertation discusses the feasibility of biological and chemical treatment of leachate in laboratory scale. The studies were performed at the University of Washington, and the Norwegian Institute for Water Research.

B. RESEARCH OBJECTIVES

The leachate produced from sanitary landfills may have concentrations of dissolved organics and inorganics which are more than 100 times as strong as domestic wastewater. The concentrations can vary over a wide range depending on the conditions inside and outside the fill. With this in mind, a research program was developed so that the feasibilities of several treatment alternatives could be investigated. The research undertaken made an effort to accomplish the following objectives.

1) To investigate the use of the anaerobic filter process for treating high strength leachates. The influence of temperature and organic loading were studied.

2) To evaluate the feasibility of aerobic treatment for treating medium and low strength leachate. The processes of activated sludge, aerated lagoons, bio-disc and trickling filter were investigated. An effort was made to compare the treatment performance of biological treatment for both raw and chemically treated leachate at different organic loadings. The metal toxicities to the activated sludge was also given attention, together with a study of the influence of temperature in the activated sludge. Temperature is of special interest in Norway with its very cold winter climate.

3) Chemical treatment with alum, iron or lime has been suggested as a possible method for removal of organic matter and heavy metals in

the leachate. Jar tests using both raw and biologically treated leachates will be used to find what removals could normally be expected from chemical treatment. The feasibility of activated carbon treatment for removals of organics from chemically treated leachate and chemically plus biologically treated leachate was studied.

An effort also was made to investigate the performance of municipal primary chemical treatment plants with regard to phosphorus and organic removals with the additon of leachate in different doses.

4) To draw conclusions relatively to the applicability of the different treatment processes and give treatment recommendations.

CHAPTER II

LITERATURE REVIEW

A. GENERAL

Few studies have been reported in the literature on treatment of leachate from sanitary landfills. The composition of leachate is different from other types of wastewater and therefore experiences from other treatment studies may be difficult to transfer to treatment of leachate. However, literature was also reviewed in areas where treatment processes were expected to be related to treatment of leachate.

B. COMPOSITION AND PRODUCTION OF LEACHATE

The composition and quantity of the leachate will determine its potential pollution effect on nearby ground and surface water. They will also determine the type of treatment facilities which will have to be used for proper purification.

There is no general way to forecast the composition of the leachate. It varies from site to site and with the age of the fill. In addition, the variations of the leachate flow over the seasons also simultaneously change the composition. Therefore it is nearly impossible to attempt to define the characteristics of the leachate to be treated.

According to the report Development of Construction and Use Criteria for Saniary Landfills (1968), the most important factors which influence the composition of the leachate are:

1. Material in the fill (organic, inorganic, degradable, nondegradable, soluble, insoluble).
2. Conditions in the fill (temperature, pH, moisture, age of the fill).
3. Characteristics of incoming water.
4. Surrounding soil characteristics.

The average composition of domestic solid waste in the United States is shown in table 1.

Table 1. Solid waste composition

Component	% weight range
Newsprint	7-15
Cardboard	4-18
Other	26-37
Paper	37-60
Glass	6-12
Metallics	7-10
Synthetics	1-3
Wood	1-4
Yard	4-10
Other (Putrescibles)	12-18

Source: Recovery and Utilization of Municipal Solid Waste (Battelle Institute), EPA, (1971)

The composition of leachate varies so widely that definition of typical concentration ranges of the various constituents is almost impossible. However, Steiner et. al. (1971) report some useful composition ranges as in table 2. Compared to other literature sources the concentrations of phosphorus given in table 2 seem to be high.

Composition and characterization of leachate was undertaken by Chian et. al. (1974). The individual free fatty acids as well as lipids, carbohydrates, proteins, lignins, fluvic and humic acid were identified. The volatile acids contributed more than half of the total organic carbon. The contribution from

Table 2. Composition of typical leachates
(Steiner et al. (1971))

Constituent	Concentrations Range (mg/l)
Iron	200-1700
Zinc	1-135
Phosphate	5-130
Sulfate	25-500
Chloride	100-2400
Sodium	100-3800
Nitrogen	20-500
Hardness as $CaCO_3$	200-5250
COD	100-51000
Total Residue	1000-45000
Nickel	0.01-0.8
Copper	0.10-9.0
pH	4.00-8.5

tannic acid was also relatively high. The concentration of total organic carbon for this leachate sample was 13840 mg/l.

The variation of leachate concentration with time is large. Some of the components exert their peak concentrations early in the leaching period while other exert their peak concentrations later. The relative concentrations will therefore change considerably with time. In the report Investigation of Leaching of Sanitary Landfill (1954), concentration curves for different components in the leachate are given as a function of time. Also calculated were the quantities of these components leached from the fill in 10 and 18 months periods after the field capacity had been reached. The water added corresponded to 90 and 170 cm, following saturation. All the constituents investigated showed an apparent equilibrium after 10 months of leaching. Most of the concentrations were less than 3 times the peak values. The quantities of materials leached in the 10 and 18 months period are given in table 3.

Table 3. Leaching of fill materials

Parameter	First 10 months kg/m^3	Total 18 months kg/m^3
Sodium	0.423	0.590
Potassium	0.400	0.565
Calcium	0.570	0.645
Magnesium	0.082	0.115
Chloride	0.560	0.825
Sulfate	0.140	0.160
Alkalinity as $CaCO_3$	2.390	3.210

Source: Investigation of Leaching of Sanitary Landfill (1954).

The BOD from the leachate reached a peak of 33100 mg/l shortly after saturation. The decrease in BOD declined rapidly and after 12 months about 98 percent had been leached out. This corresponded to a leached quantity of 7.25 kg BOD/m^3. With an assumed dry weight density of 300 kg/m^3 this corresponds to 24.2 kg BOD/ton refuse. Total amount of water applied in the 12 months period was 112 cm.

Qasim and Burchinal (1970) studied chemical and pollutional characteristics of leachate from simulated landfills with different heights of refuse. The heights of the columns were 1.2, 2.4 and 3.6 m with diameters of 0.9 m. The fill consisted of mixed municipal refuse.

Leaching from the columns was initiated by adding equal amount of water to all the columns in volumes sufficient to saturate the refuse in the tallest one. During the test period, water was added every second week in volumes eqvivalent to an annual precipitation of 114 cm. The percolated water was collected and analyzed for chemical and bacterial quality. The total amounts of extracted materials in the 163 day test period are given in table 4.

Wigdel (1971) found that the total amounts of organics extracted over a 9 months period was 45 kg COD per tons of dry weight of solids. Similar concentrations were found by Rovers et al. (1973). Rovers also found that the leachate strength increased with an abrupt increase in infiltration.

Table 4. Quantities of extracted materials in kg per tons dry weight refuse (Quasim and Burchinal (1970)

Substances extracted \ Height of column m	1.2	2.4	3.6
BOD (5 days)	52.0	33.4	25.8
Organic nitrogen	0.88	0.81	0.70
Ammonia nitrogen	1.56	1.20	0.94
Phosphate	0.47	0.06	0.11
Sodium	21.2	15.9	9.8
Potassium	42.8	30.5	33.2
Calcium	10.68	6.05	2.71
Magnesium	0.67	0.49	0.36
Chloride	3.12	2.14	1.69
Sulfate	2.04	1.17	0.58
Iron	0.60	0.82	0.78
Tannin and lignin	1.51	1.22	1.06

The duration of the leaching studies given in the literature were too short to justify a calculation of total amount of materials leached from the fills.

Reinhardt and Ham (1972) have studied decomposition of milled and covered unprocessed solid waste. The leachate quality from the two wastes during the period of active decomposition was found to be comparable. For the milled waste, the COD concentration in the leachate was very high initially and dropped relatively quickly compared with the unprocessed waste. The higher decomposition rates of the milled waste was probably due to larger material surface areas and higher water supplies than in uncovered fills.

There exists a definite correlation between the total amounts of extracted materials and the leachate production or the water added to the refuse. The production of leachate depends on several factors. Of these the most important are: precipitation, evaporation, hydrogeologic conditions, type and performance of cover materials, vegetation, depth of fill, and initial moisture content of the waste.

Normally substantial quantities of leachate will only be produced after the whole depth of the fill has reached the field capacity (saturated with water). Exceptions are when part of the fill is below the ground water table or if upwelling water or surface water is entering the fill. Fungaroli (1971) has developed some field refuse capacity curves as a function of dry packed waste density. For a density of about 300 kg/m^3 and above, 65 to 75 cm of water are needed to saturate one meter of the refuse. For less densely packed wastes for instance 150 kg/m^3, the corresponding number is 55 to 65 cm. Therefore if we know the precipitation and the fraction which is infiltrating the fill, it is possible to calculate what time the fill will start to produce leachate.

Klother and Hantge (1969) measured the leachate production from a covered landfill in Germany with area of 9 ha. They found an average leachate production of 0.5 l/sec corresponding to 0.06 l/sec ha. Reuss (1971) studied leachate production from research landfills in Germany. These 150 m^2 fills gave a leachate production of 10 and 26 percent of the yearly precipitation from covered and uncovered fills respectively. With a total precipitation of 800 mm per year this gives a leachate production of 0.025 and 0.06 l/sec ha.

If no measurements of leachate production are available Knoch and Stegmann (1971) recommend that a leachate production of 0.05 to 0.1 l/sec ha. be used for dimensioning purposes. These numbers should be used only for well constructed landfills located in Germany.

Conclusions. No general numbers can be given for composition and production of leachates because they vary over a wide range depending on parameters such as the design and operation of the landfills, type of waste, and climate. The composition is also dependent on the age of the fills. Thus most of the leachate constituents show decreasing concentrations with the age of the fill.

C. TREATMENT OF LEACHATE

The composition and production of leachate vary so widely from fill to fill that general recommendations for special treatment processes for leachate are not possible. Where the landfills are located near a municipal sewer system the leachate may be discharged to the sewers and treated in the municipal treatment plant. Pretreatment of the leachate prior to this discharge may be necessary, however, in many cases the leachate may have to be treated separately before discharge to the municipal sewer system.

To obtain sufficiently high quality of the treated leachate a combination of different treatment processes may be necessary. Usually the leachates have very high concentrations of dissolved organics. Therefore biological treatment processes probably will be the most important treatment methods. In the following a literature review of some of the most prominent processes for treatment of leachate will be undertaken.

1. Anaerobic Treatment

a. General. Anaerobic waste treatment has advantages which should make this method suitable for treatment of leachate with specially high concentrations of organics.

McCarty (1964a) (1964b) (1964c) (1964d) has in a series of articles described chemistry, microbiology, environmental requirements and toxicity controls of anaerobic treatment processes. The main advantages compared with aerobic treatment are:

1. High degree of stabilization of the organics. In anaerobic systems the free energy yield per g of COD utilized is only 100-300 cal while the corresponding number in aerobic systems are about 3000 cal. Therefore in anaerobic processes less energy is available for microbial growth. The main free energy fraction is stored in the CH_4 gas.
2. Because less energy is available for microbial growth the production of biological solids is considerably lower in anaerobic processes.
3. In spite of slower growth of anaerobic than aerobic bacteria a higher organic loading often is possible. The reason is that considerably higher concentrations of volatile solids can be maintained in anaerobic systems.
4. Because of the very low production of biological solids the nutrient requirements are also low.
5. In special cases high concentrations of toxic heavy metals can be tolerated. The toxicity limit of the heavy metals is related to the concentration of sulfides available to combine with the heavy metals to form insoluble sulfide salts.

The most important disadvantages compared with aerobic treatment are:

1. High temperatures are required for optimum operation.
2. Because of their slow growth rate of the methane producing bacteria require a longer time for process adjustment and they are more sensitive to shock loadings than mixed aerobic cultures.

3. For dilute wastes with low temperatures the process is not economical.

b. Temperature Effects. The most important factor of the above mentioned is the temperature. In general much research has been done at temperatures above 20 °C but little is done at lower temperatures. Most of the research at low temperatures has shown that little or no stabilization occurs below 15-20 °C. However, there are indications that much lower temperatures can be used if the systems are adequately designed.

Buswell (1957) in a general article about anaerobic treatment fundamentals reported that no specific temperature limitation was observed in the range of 0 to 55 °C.

Pfeffer et. al. (1967) discussed the temperature effects on the utilization rate of organics in anaerobic and aerobic treatment. Their paper gives the following BOD removal rates of domestic waste utilization as a function of temperature.

Table 5. Temperature effects on anaerobic and aerobic treatment (Pfeffer et al.(1967))

Temperature °C	Fraction of BOD removal rate at 35 °C	
	Anaerobic treatment	Aerobic treatment
2.5	-	0.02
5	0.1	0.05
15	0.4	0.25
25	0.8	0.5
35	1.0	1.0

The values in table 5 must not be compared for aerobic - anaerobic treatment, the numbers are only relative to the value at 35 °C. The table shows that anaerobic treatment is more sensitive to a decrease in temperature at low temperatures than aerobic treatment. The two fold increase in the rate for aerobic treatment from 15 to 25°C and from 25 to 35°C is suspiciously high (see later).

Schroepfer and Ziemke (1959) found in studies with the anaerobic contact process that a temperature rise from 25 to 35°C increased the process rate 2.5 times for packing plant wastes and 3.5 times for synthetic mill waste. They also found that the process was considerably more sensitive to shock loads at 25°C than at 35°C. Speece and Clark (1970) investigated the effects of short term temperature variations on methane production. They found no gas production below 20°C. Between 20 and 45°C the rate of gas production was proportional to the temperature. With temperature drops down to 10°C for 15 minutes the gas production also dropped but was restored quickly after the temperatures was increased.

Malina (1964) investigated the thermal effects on completely mixed anaerobic digestion with temperatures ranging from 30 to 55°C. The largest gas production occurred at 30°C. Between 40 and 50°C gas production was inhibited. Coulter et al. (1957) treated municipal wastewater in an anaerobic filter. The filter was operated at 4°C for 15 weeks. Before and after this period the filter had been operated at 25°C. The BOD removal efficiencies for these two periods were in average 67 and 82 percent at 4 and 25°C respectively. Thaulow (1974) also investigated the feasibility of the anaerobic filter for municipal wastewater. The filters were operated in two periods each of 2 weeks duration. Temperatures in the first period was 14°C and for the second 7°C. A control filter was operated at an ambient temperature of 21°C. The organic loadings varied from 0.06 to 0.18 kg COD/m^3 day. The results showed that the filters were resistant to changes in hydraulic and organic loadings as well as temperature changes. For all the temperatures the COD removal efficiencies were within the range of 75 to 85 percent. The short duration of this experiment and the active biomass from a previous study for treatment of brewery waste make it difficult to draw definite conclusions regarding the temperature effects. The absence of gas production at the lowest temperature may indicate that COD removal was caused simply by adsorption effects of the sludge.

c. Toxic Materials. Leachate from sanitary landfills may contain high concentrations of toxic materials. Of these, heavy metals are among the most important. In anaerobic treatment processes toxic heavy metals can be tolerated in concentrations related to the concentrations of sulfides available to form insoluble sulfide salts. These sulfide salts are quite inert and do not adversely affect the microorganisms. The role of sulfide in preventing heavy metal toxicity in anaerobic treatment is discussed by Lawrence et al. (1965). They report that the quantity of sulfide required is approximately 0.5 mg/l for each mg/l of the toxic heavy metal present. The addition of sulfide allowed the presence of more than 10 percent of heavy metals on a dried volatile solids basis without inhibiting the digestion process. They also concluded that it is not necessary to consider iron in evaluating the possibility of heavy metal effects on anaerobic waste treatment.

The factors affecting the availability of heavy metals to anaerobic processes have also been discussed by Mosey et al. (1971). The effects of the pH values on inhibition by cadmium, nickel, copper and zinc were studied in batch digesters digesting municipal sludge. The results are given in figure 1.

The results in figure 1 shows that the soluble sulfide concentration is insufficient to account completely for the high concentrations of heavy metals tolerated. According to the numbers given by Lawrence the concentration of the sulfides are far too low to prevent heavy metal toxicity. Mosey concluded that the most important factors to reduce the availability of heavy metals in anaerobic treatment were sufficient high concentrations of: soluble sulfides, ferrous sulfides, chlorides, carbonates and hence high pH values. The above mentioned factors are partly related to the operation conditions. For instance by increasing the detention time higher portions of sulfur compounds will be converted to hydrogen sulfide. A higher portion of the protein nitrogen will also be converted to ammonia and hence increase the pH values.

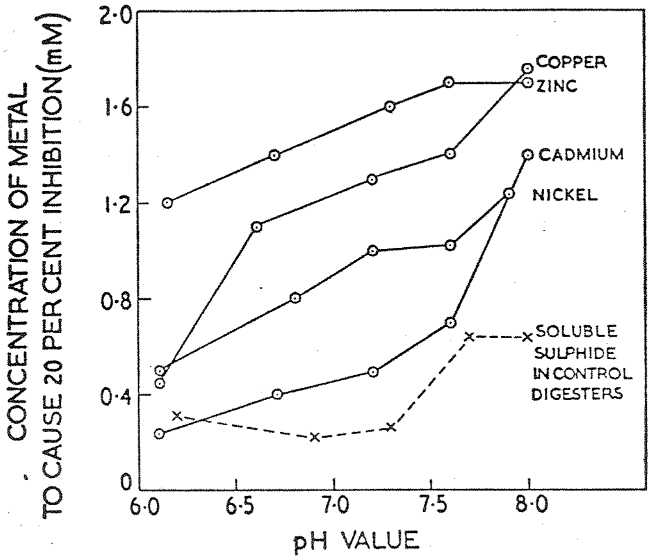


Figure 1. Effect of pH value on metal toxicity.

Of toxic materials other than heavy metals Loehr (1971) reports that salts in the concentration range of 1000 to 5000 mg/l have an inhibitory effect on anaerobic processes. Leachates very seldom reach salt concentrations as high as the numbers given above. However, the salt toxicity numbers should be kept in mind. Loehr found that ammonia concentrations of 1000 mg/l had no adverse effect. At concentrations of 3000 mg/l the effects were acute at any pH.

Volatile acid toxicity in anaerobic processes have been discussed by Buswell and Morgan (1954). They showed that propionic acid is much more toxic to bacteria than for, instance, acetic acid. Therefore the total concentration of volatile acids in anaerobic processes is of less significance than the concentrations of a specific toxic acid such as propionic acid. Experiments by McCarty and McKinney (1961a) (1961b) showed that the decreased activity of the methane producing bacteria after a rapid increase in volatile acids is due not so much to the acids as to salt toxicity associated with certain catious. The catious in order of increasing toxicity based on equivalent concentrations were calcium, magresium, sodium, potassium and ammonium.

McCarty (1964c) reports that concentrations of soluble sulfide of 100 mg/l can be tolerated in anaerobic treatment with little or no acclimation. With continuous operation concentrations up to 200 mg/l of soluble sulfides can be tolerated with no significant inhibitory effects.

d. Treatment of Leachate by Anaerobic Filter. The anaerobic treatment process of special interest in treatment of leachate is the anaerobic filter. The anaerobic filter process was studied by McCarty (1968) with methanol as a waste. A comprehensive study of the anaerobic filters was performed by Young (1968). According to this study the anaerobic filter should be better suited for treatment of soluble wastes than the anaerobic contact process.

By using the anaerobic contact processes for soluble wastes the biological solids often remain dispersed or lightly flocculated. A significant fraction may therefore be lost with the effluent. In the anaerobic filter where the waste is fed into the bottom and flows upward the biological solids are retained in the void spaces in the filter media.

The treatment of leachate by anaerobic processes was first studied by Boyle et. al. (1972). Four liter glass bottles supplied with gas collection equipment were used. Analyses performed on the withdrawn supernatant included BOD_5, COD, alkalinity, pH and solids. The anaerobic digesters operated in a temperature range of 23 to 30°C. Because of changes in leachate concentrations from the fill the organic loading varied. Results obtained from the two units from the last part of the test periode are summarized in table 6.

Table 6. Anaerobic treatment performance

Unit	Detention time, days	COD infl	COD load, kg COD/m^3 day	COD % Removal	Gas prod m^3/kg COD
1	10	10600	1.10	93.4	0.43
2	12.5	10600	0.88	94.5	0.44

The results from these studies showed that anaerobic processes were able to treat leachate with high organic removal efficiencies. Increased loadings showed little effect on COD removal. It was also found that the sludge build up in the anaerobic system was negligible.

In a later phase of the study, the organic loadings were varied in order to find the optimum loading. The organic loading varied from 0.43 to 2.16 kg COD/m^3 day which gave COD removal efficiencies from 96.0 to 90.0%. An investigation of the influence of temperature showed a decrease in COD removal efficiency from 86% to 20% at a decrease in temperature from 22°C to 11°C.

Foree and Reid (1973) also studied anaerobic treatment of leachate water. Two treatment systems, the anaerobic digester and the anaerobic trickling filter, were evaluated. The leachate used in this study had a COD concentration of 12900 mg/l.

Five 2-liter anaerobic digesters were used. The experimental setup was as follows:

Table 7. Experimental setup
(Foree and Reid (1973))

Unit	Organic loading kg COD/m^3 day	Additions to leachate	Detention time, days	Temperature °C
1	0.64	nutrients	20	35
2	0.64	nutrients	20	20
3	0.64	lime	20	35
4	0.64	nothing	20	35
5	1.28	nutrients	10	35

The results from this study show substantial COD reductions in all digesters. All units except No 2 had COD removal efficiencies greater than 90%. Unit No 2, which operated at 20°C, had a COD removal of about 77%. These data show the significance of relatively high temperatures in anaerobic treatment. The results also show that the nutrient and buffer additives did not contribute significantly to COD removal.

Treatment of the same leachate was also studied in a 33.4 liter anaerobic filter. The filter was operated with raw leachate at a loading of 1.28 kg COD/m^3 day. The filter gave a COD reduction of 96.1% which was higher than the anaerobic digesters operating at half the loading. The higher removal efficiency in the anaerobic filter is probably due to the difference in flow pattern between the two systems. From theoretical considerations, the reaction rates in a plug flow system are always higher than in a completely mixed system.

The effluent from the anaerobic filter was further stabilized in an aerobic activated sludge system. After a detention time of 4 days the effluent was stabilized from COD values of 510 to 400 mg/l. This indicates a relatively stable effluent from the anaerobic filter and relatively little is gained by further aerobic stabilization.

e. Conclusions. The few studies done in treatment of leachate show that the organics can be reduced efficiently by anaerobic processes. However, at low temperatures the performance of the anaerobic treatment processes seem to be reduced severely. The literature data regarding the temperature sensitivity are also somewhat contradictory. Most studies report no gas production and very low organic removal efficiencies at low temperatures while other investigations report no gas production but relatively good organic removal efficiencies. The good organic removal efficiencies at low temperatures may simply be explained by adsorption of the organics to the sludge. No long term experiments were found where good organic removal efficiencies were obtained. Therefore low temperature effects will probably be the most critical item in treatment of leachate by anaerobic processes.

According to the literature most toxic materials seem to be relatively easy to control in anaerobic treatment.

2. Aerobic Treatment

a. General. In aerobic treatment only a portion of the original organics in the waste is oxidized to low energy compounds such as NO_3^-, $SO_4^=$ and CO_2. The remainder is synthesized into cellular material. Therefore, for leachate with sufficient high concentrations of organics, the sludge production will be so high or the oxygen consumption so large that aerobic processes will prove to costly. However, for wastewaters with medium or low concentrations of organics biological aerobic processes are probably the most efficient and cheapest processes to reduce organics. Although aerobic treatment of municipal wastewater is relatively straightforward, leachate, with its unique composition, may not necessarily respond easily to such treatment.

b. Toxic materials. The heavy metals in the leachate are probably the toxic constituents which should be given the biggest attention.

Heukelekian and Gellmann (1955) described the toxicity effect of copper, nickel, zinc, cadmium, trivalent and hexavalent chromium and cobalt on aerobic decomposition of sewage. The influence of a number of variables such as pH and sewage concentrations on toxicity were also studied.

Table 8 summarizes the concentrations in mg/l of the different heavy metals required to produce 10, 50 and 90% reduction of biochemical oxidation demand of domestic sewage at 1 and 5 days incubation.

Table 8 shows that for 1 day the order of decreasing metal toxicity was nickel, copper, cobalt, cadmium, zinc, trivalent and hexavalent chromium.

Table 8 Reduction of BOD as function of heavy metal concentrations mg/l

(Heukelekian and Gellmann (1955))

Metal ion added	Reduction of BOD					
	10%		50%		90%	
	1 day	5 day	1 day	5 day	1 day	5 day
Cu	1	1	3	35	5	45
Ni	1	1	3	15	5	25
Zn	3	3	30	62.5	60	100
Cd	3	3	10	55	35	75
Cr (III)	12.5	20	17.5	62.5	100	100
Cr (VI)	10	25	100	100	100	100
Co	1	1	5	25	20	42.5

Table 8 shows that for 1 day the order of decreasing metal toxicity was nickel, copper, cobalt, cadmium, zinc, trivalent and hexavalent chromium.

The authors also showed that it was possible to develop a flora capable of oxidizing sewage in the presence of increasing concentrations of heavy metals. For instance, samples acclimated for copper at a concentration of 25 mg/l showed more than a 3 fold increase in one day BOD compared with unacclimated samples. On the fifth day the corresponding increase in BOD was only about 40%. Similar results were also found for chromium.

The effect of sewage concentration on the chromium and copper ion toxicity were also studied. The results showed considerable increase in toxicity with decreasing sewage concentrations. Sewage with a BOD value of 300 mg/l was used. Table 9 summarizes the results for the reduction in BOD with heavy metal concentrations of 25 mg/l. The numbers are expressed as percent of control 5 days BOD in the control sample.

Table 9. Relative reduction in BOD as function of sewage concentrations
(Heukelekian and Gellmann (1955))

Metal ion added	Incubation days	Control	Sewage concentration 100%	25%
		percent of 5 days BOD		
Chromium	1	57	31	1
Chromium	5	100	73	24
Copper	1	56	7	3
Copper	5	100	63	11

Heukelekian, et. al. (1955) also investigated the effect of pH on the metal ion toxicity. The results given in table 10 are in percent of the 5 days BOD control.

Table 10. Relative toxicity as function of pH
(Heukelekian and Gellmann (1955))

Metal ion	Days	Control		Metal ion 25 mg/l			
		pH 5	pH 7	pH 5	pH 6	pH 7	pH 8
		percent of 5 days BOD					
Chromium	1		54	9	0	19	30
Chromium	5		100	37	25	74	78
Copper	1	60	55	7	5	2	1
Copper	5	109	100	16	60	62	60

The higher values obtained at high pH and 5 day BOD can be explained by the decreasing solubility of the metals at increasing pH. The critical pH range where the toxicity has a minimum coincide with the sharp change in the metal solubility.

An investigation of toxicity of metal ions added to sewage activated sludge mixtures was also performed. The results from this study showed less inhibition compared to those added to sewage alone. In the activated sludge -

sewage mixture the inhibitory effect takes place after prolonged periods of oxidation rather than during the initial period as for the mixture of sewage-heavy metal.

Barth et. al. (1963) (1965) studied the effects of copper, chromium, nickel and zinc individually and in combination with the biological processes in an activated sludge pilot plant. The plant treated domestic waste water with a BOD concentration of about 300 mg/l at a organic loading of 0.5 kg BOD_5/ kg MLVSS day.

They report the significance of adding the heavy metals in the influent to the primary clarifier instead of directly into the aeration chamber. Dosing to the influent will decrease the toxicity because the total metal content of the primary effluent is less than that of the influent sewage. The metals are removed by the sludge, and the sewage alters the form of the soluble metal ions that are introduced. This was especially true for zinc where 90% of the added zinc was converted to an insoluble form. For chromium, nickel and copper the corresponding numbers were about 20, 50 and 60 percent respectively.

For the activated sludge process acclimated for the investigated heavy metal, Barth et. al. give the values in table 11 for a continuous dose of metal which reduced the COD removal efficiencies about 4 percent.

Table 11. Heavy metal doses required in mg/l to reduce the COD removal efficiencies about 4 percent
(Barth et al. 1965)

Metal	Concentration in influent mg/l
Chromium (VI)	10
Copper	1
Nickel	1 to 2.5
Zinc	5 to 10

The reaction pattern of the activated sludge process was the same for each of the metals studied. A small dose of metal gave a significant reduction in the treatment efficiency, but larger doses did not further reduce the removal efficiency significantly. Copper for instance, reduced the overall COD reduction by 3, 9 and 12 percent for dosages of 1.2, 5 and 10 mg/l respectively.

A metal mixture of copper, chromium, nickel and zinc with a total concentration of 8.9 mg/l also was tried. This gave an increase of 30 percent in the COD values which normally were approximately 50 mg/l. This amount to a a 4 percent reduction in the COD removal.

The conclusion from this study is that biological treatment can tolerate roughly about 10 mg/l of the heavy metal either alone or in combination with other heavy metals without reducing the over all COD removal efficiency more than about 5 percent.

Slug dosages of metals to the activated sludge process were also studied. In this experiment, they defined the slug dosages as the required amount of the metal added over a 4 hour period which gave an effluent COD value the next 24 hours higher than in the 98 percent frequency distribution from the control unit. The results for these concentrations are given in table 12.

Table 12. Slug dosages of heavy metals required to significantly reduce COD removal efficiency
(Barth et al.(1965))

Metal	Concentrations in influent mg/l
Chromium (VI)	500
Copper	75
Nickel	> 50, < 200

A material balance for heavy metals was also performed. A large fraction of the metals were removed in the excess activated sludge. For chromium, copper, nickel and zinc the average numbers were 27, 55, 15 and 63 percent respectively. The numbers varied greatly and are strongly dependent on the organic loading.

Stones (1961) also studied the influence of metallic compounds on the BOD of sewage. He found the following decreasing toxicity of the metals: silver, mercury, copper, chromium (III), nickel, lead, cadmium, chromium (VI) and zinc.

Poon and Bhayani (1971) examined the toxicity of zinc, copper, chromium and nickel on sewage bacteria and the fungus, Geotrichum candidum. The latter often dominate activated sludge processes receiving domestic sewage with high concentrations of heavy metals. For the sewage bacteria they found that the zinc, copper and chromium toxicity were moderate as long as the concentrations were below 25 mg/l. Nickel was most toxic and at 10 mg/l the toxicity was significant.

Tabata (1969a) studied the factors controlling the solubility of Zn and the toxicity of zinc precipitate. He found that zinc precipitate had negligible toxicity on Japanese killifish, Gobies and Daphnia. In contrast, Mylilus edulis, a sedimentary filter feeder, was killed by the precipitate.

In another experiment (1969b), the same author examined toxicity antagonism between components of water hardness and heavy metal ions. When water hardness was increased eight fold by adding CaCl and $MgSO_4$ the toxicity limit of the metals, Cu, Zn, Ni, Co and Cd, increased more than two fold. Sodium also increased the toxicity limit of the metals mentioned above. Potassim on the other hand, had no effect on the toxicity.

In the same experiment series as above, Nishikawa and Tabata (1969) studied the decrease in the toxicity of heavy metals due to metal complexes.

They found that sodium thiosulfate and sodium nitrate decreased the toxicity considerably.

Leachate from sanitary landfills may have high salt concentrations. Kincannon and Gaudy (1968) investigated the response of the activated sludge to changes in salt concentrations. The plant was fed with synthetic waste water consisting of 1000 mg/l glucose and the necessary inorganics. The detention time was 8 hours. Sodium chloride was used since it is a major inorganic constituent in wastes from several industrial processes. The results from the study showed that the treatment process could not maintain a high substrate removal efficiency during the period of increasing salt concentration up to 30000 mg/l. However, after an acclimation period the system could nearly obtain the same removal efficiency with dosages of 30000 mg/l as without salt. They also found that a significant rise (approximately 75 percent) in cell yield occurred at salt additions of 8000-10000 mg/l.

Ludzack and Noran (1965) studied the tolerance of high salinities by the activated sludge process treating a mixture of domestic waste and fishmeal slurry.

The activated sludge units operated at 0.6 kg COD/kg MLVSS day showed minor effects of continuous sodium chloride concentrations up to 5000-8000 mg/l. A salt concentration of 20000 mg/l was also used. With loadings less than 0.5 kg COD/kg MLVSS day, the waste could be treated with relatively small reductions in removal efficiency. Salt concentrations higher than 20000 mg/l caused poor flocculation, higher effluent solids and reduced COD removal efficiencies.

Mills and Wheatland (1962) investigated the effect of saline water on the performance of percolating filters. They found that continuous addition of sodium chloride in concentrations of 6600 mg/l caused no reduction in

BOD removal efficiency. Sewage containing as much as 20000 mg NaCl per liter could also be satisfactorily treated without seriously deteriorating the effluent quality. However, intermittent application of 6600 and 20000 mg/l NaCl appeared to lower the effluent quality significantly.

c. Temperature Effects. Generally aerobic treatment processes are far less sensitive to low temperatures and temperature changes than anaerobic treatment processes. The magnitude of the temperature effects depend mainly on type of treatment processes used, composition of the wastewater and organic loadings.

Hunter et al. (1966) studied the temperature effect on the activated sludge process using a batch treatment unit fed with synthetic waste high in BOD and suspended solids. The aeration time was 16 hours. The impact on the treatment process at temperatures of 4, 20, 28, 35, 45 and 55°C was studied.

The study showed a BOD reduction of 79.1 and 92.3 percent at 4 and 20 °C respectively. An increase in temperature above 20 °C did not change the BOD reduction significantly except at 55 °C where it decreased to 83.9 percent. A similar trend was also found for suspended solids. For the sludge volume index, no particular influence of temperature was found.

The temperature had a significant effect on the sludge composition. As the temperature increased to 45 °C the contents of volatile suspended solids and carbohydrates decreased while the content of organic nitrogen increased. The DNA contents showed no particular pattern with changing temperatures. They also found lower filamentous and rotifer populations as the temperature increased.

Ludzack et al. (1961) investigated temperature effects on the activated sludge process. They used continuous units fed with four different types of wastewaters with various degrees of suspended solids and soluble organics. The sludge loading was 0.4 kg BOD/kg MLVSS day. A comparison was made of the performance of the process at 5 and 30°C.

The adjustment of the sludge to the different wastes was rapid at 30°C, but about 2 weeks were required to obtain equilibrium at 5°C. Therefore, in studying performance variations due to temperature changes on activated sludge, long term continuous testing is necessary. They also found that acclimation to different test feeds required about five times as long an adaption time at 5° as at 30°C.

The mixed liquor activated sludge had a darker color and flocculated much better at 30°C than at 5°C. However, after 30 minutes settling both the 30°C and 5°C samples showed effective sedimentation, but the 5°C sample exhibited greater sludge volume and supernatant solids. The sludge production expressed as kg solids/kg BOD was also substantially higher at 5°C than 30°C. The volatile fraction of the sludge was about 5 percent higher at 5°C than at 30°C and the same organic loading. The waste richest in soluble organics was much more sensitive to low temperatures and had poorer settling properties than waste with higher content of suspended solids. BOD and COD removals were about 10 percent higher at 30 than at 5°C.

The effects of radical temperature changes of 25°C were also studied. The units were moved from the 5°C room to the 30°C room and vice versa. Both units slowly approached the type of microorganisms which were characterized earlier at the respective operation temperature. The sudden temperature change caused a BOD and COD removal reduction of about 15 percent which decreased after adaption.

Microscopic examination of the sludge showed that Sphaerotilus had a better competitive position at 5 °C than at 30 °C. The study also noted increased difficulties with foaming at lower temperatures.

Carpenter et. al. (1968) investigated temperature relationships in treatment of pulp and paper wastes in aerated lagoons. The empirical formula

$$k = k_{20}\,\Theta^{(t-20)}$$

was used to express the temperature dependency. In the formula k is the oxygen and Θ the thermal correction coefficient. A value of 1.016 and 0.2 for Θ and k_{20} respectively was found applicable to both raw and treated mill effluents. The highest substrate utilization rate was found at 37 °C with a following decrease as the temperature was increased further.

Eckenfelder (1967) has given the following values for the thermal correction coefficient Θ for domestic waste water.

Table 13. Thermal correction coefficient for domestic waste water (Eckenfelder (1957))

Process	Θ
Activated sludge	
Low loading	1.0
High loading	1.02
Trickling filters	1.035
Aerated lagoons	1.06-1.08

The difference in Θ between the processes is explained by the difference in the mechanisms of the oxygen transfer. At low temperatures the penetration of oxygen into the biological floc is insufficient and the Θ value increases.

The oxygen transfer in a trickling filter is less efficient than in the activated sludge process. This is because the oxygen diffuses into the biological growth through the liquid passing over it, and not from the gas phase as in activated sludge. The high value of Θ for aerated lagoons is due to the dispersed nature of the biological floc.

Benedict (1968) investigated the relationship between organic loading and the temperature sensitivity of biological oxidation. The following results on laboratory scale activated sludge units were obtained.

a. The temperature coefficient, Θ, based on respiration, was found to be 1.078. Θ was independent of organic loading.

b. The sludge yield coefficient, a, increased with increasing temperature. This means a greater portion of the applied organic material is utilized for energi at low temperatures.

c. The rate of endogenous metabolism increases with temperature.

d. At low loadings sludge settleability is not adversely affected by operating between 4 °C and 32 °C.

d. Aerobic Treatment of Leachate. Boyle and Ham (1974) studied aerobic treated of leachate in four 0.5-1.0 liter batch units operated on a fill and draw basis. Only one of the units (no 3) was operated to simulate an activated sludge plant. For the other units the sludge was not settled during the fill and draw periode. The results from the aerobic treatment experiment are shown in table 14.

Table 14. Aeration study results (Boyle and Ham (1974))

Unit No	Detendion time, days	BOD_5 infl	Organic loading kg BOD_5/m^3 day	BOD_5 removal percent
1	5	1550	0.30	.90
2	5	2900	0.58	93
3	1	8000	5.28	2.5
4	5	7010	1.39	80

The results showed a considerable reduction in organic removal efficiencies with increasing organic loadings. The authors stated that aerobic treatment was encouraging but had several disadvantages including high power requirements and foaming problems. Therefore the major effort was directed toward anaerobic processes.

The mixed liquor suspended solids from the aeration chambers are not given. Because settling was not used in the operation cycle in reactors 1, 2 and 4, the sludge concentrations were probably very low compared with concentrations normally used in the activated sludge process. Therefore the organic loadings calculated as kg COD/kg MLVSS day would be much higher than those normally used in the activated sludge process. For instance Stewart (1964) reports normal organic loadings for the conventional activated sludge and the contact stabilization processes as 0.55 and 1.10 kg BOD/m^3 day respectively. The relatively high BOD removal efficiencies obtained at the lowest organic loadings are therefore surprisingly high.

Boyle and Ham (1974) also investigated the effects of leachate addition to domestic wastewater treated in an extended aeration process. Results from this investigation showed that leachate could be added at 0.38 kg BOD/m^3 day without significantly affecting the extended aeration process. Higher leachate additions caused serious sludge bulking and poorer effluent qualities.

Foree and Cook (1972) studied treatment of leachate in 5 batch activated sludge units. They were operated by the fill and draw method. The leachate used for this study had BOD and COD concentrations of 9500 and 17500 mg/l respectively. The BOD_5:N ratio was found to be 43:1 compared with the recommended ratio of 20:1. Because of these high ratios, they added 500 mg/l N and 100 mg/l P to some of the Units. Because of low pH (5.5), they also added 250 mg/l of lime to obtain optimum environmental conditions.

The results from this study showed that all the units with 10 days detention time gave COD removal efficiencies higher than 97 percent. No significant difference in the COD removal efficiencies was found between the unit fed with raw leachate and units with addition of lime and nutrients.

In the units with 5 and 2 days detention time, the BOD removal failed rapidly because of overloading.

Knoch (1972) studied the use of aerated lagoons in the treatment of leachate from sanitary landfills. The system consisted of an aerated lagoon followed by a nonaerated polishing pond, each with a detention time of 14 days. The BOD concentrations in the aerated lagoon was reduced from 500 to 40 mg/l corresponding a BOD_5 removal efficiency of about 90 percent. The effluent from the polishing pond had a BOD concentration of about 30 mg/l corresponding 25 percent removal efficiency. The reduction of ammonium in both lagoons was about 40 percent. The oxygen requirement in the aerated lagoon was found to be 0.58-0.70 g O_2/g BOD_5. The spread was due to variation in temperatures.

Knoch (1973) treated leachate with activated sludge, trickling filter and in combination with domestic wastewater in activated sludge plants. Three sources of leachate were investigated which varied in BOD_5 concentrations from 136 to 10400 mg/l. The organic loadings applied varied from 0.03 to 1.20 kg BOD_5/m^3 day. The BOD removal efficiencies varied from 76 to 99 percent while the corresponding efficiencies based on TOC were between 9 to 60 percent. These big differences were due to high concentrations of non biodegradable organics in the treated leachate. The oxygen requirement in the activated sludge process was found to be 0.5-0.7 kg O_2/kg BOD_5 reduced.

The organic loadings applied for th trickling filter were 10 and 50 g BOD_5/m^2 day. For the period with the lowest organic loading the organic removal efficiencies based on BOD_5 and TOC were about 38 and 20 percent respectively. The corresponding numbers for the activated sludge process were about 95 and 60 percent.

The experiments of treating leachate in combination with domestic wastewater in activated sludge plants gave good results up to leachate additions of 5 percent by volume.

e. Conclusions. Few investigations on aerobic treatment of leachate have been reported in the literature. Both successful and unsuccessful results have been described. In some of these studies the unsatisfactory results were simply caused by overloading. Usually little or no attention has been given to explain the process failures.

Composition of high strength leachate and experience from aerobic treatment of wastewater with relatively high concentrations of heavy metals may indicate that heavy metal toxicity will be one of the most critial factors. However, the factors which determine the heavy metal toxicity are so many and complicated that experience from other treatment studies may be used only as rough indicators.

3. Chemical-,Physical Treatment of Leachate

a. General. The studies of aerobic and anaerobic biological processes have shown that these treatment processes alone are not adequate for treatment of leachate. Treatment of leachate should probably be accomplished first by a biological process for the removal of a portion of the organics and secondly by physical-chemical treatment for removal of residual organics, inorganics, color, odor and various other impurities.

b. Chemical Precipitation. Thornton and Blanc (1973) studied the possibilities of treating raw leachate by chemical precipitation. They investigated the removal efficiency of biochemical oxygen demand, iron,calcium and magnesium. Jar tests were used with alum and lime as precipitants. The COD concentration of the raw leachate used in the experiment was 5033 mg/l.

The results with alum as precipitant showed approximately 50 percent removal of suspended material with an alum dosage of 300 mg/l. The precipitation was performed at pH 6.4. Little or no decrease was found with further increase in dosages. No removal of color was found even at higher alum concentrations.

The precipitation of leachate with lime gave more successful results than alum. Lime doses higher than 500 mg/l gave about 80 percent removal of suspended solids. The original brownish color of the leachate turned green with the green color becoming more intense with increasing lime dosages until it turned clear at dosages of 900 mg/l or greater. The pH was then 9.7. The COD removal varied from 8.2 to 23.5 percent at a lime dosage of 1500 mg/l (pH = 11.5). This reduction was mainly due to the trapping of suspended organic matter by the floc particles. As expected, no removal of the soluble fraction of BOD was found. Iron, in contrast to magnesium, was almost completely removed with a lime dosage of 450 mg/l (pH = 7.9). Total solids and total dissolved solids were not greatly reduced. A combination of ferric chloride and lime did not improve the removal efficiencies. The results from this study shows that the treatment of leachate with alum or lime can only be effective if it is coupled with other treatment processes.

Ho et. al. (1974) also studied precipitation of raw leachate with lime, sodium sulfide, ferric chloride and alum. The removal efficiencies for the parameters studied are shown in the table 15.

Table 14 a. Results from chemical precipitation of raw leachate (Ho. et. al.(1974))

	Lime	Sodium sulfide	Alum	Ferric chloride
Dosages mg/l	400-1750	10-1000	10-1000	100-1000
Final pH	8.5-12	6.0-6.3	7.1	5-7
COD removal	none	none	none	up to 15%
Iron removal	65-100%	80% at 1000 mg/l	97% at 1000 mg/l	98% at 1000 mg/l
Color removal	clear at 750 mg/l	none	clear at 1000 mg/l	clear at 1000 mg/l
Chloride removal	none	none	none	0-10%
Total solids removal	no major change	3% at 500 mg/l	none	none

The results shows that none of the precipitants or coagulants were effective in treatment of leachate even at very high dosage levels. In general COD and dissolved solids were not readily removed by chemicals whereas multivalent cations color and suspended solids could be removed.

c. Activated Carbon Treatment. Ho et. al. (1974) also studied treatment of raw leachate by lime precipitation followed by activated carbon adsorption. In the first test run jar tests were used with carbon dosages up to 2000 mg/l. Color and odor removal were effective at all carbon doses applied. At high carbon doses iron was also removed relatively efficiently. The COD removal increased with increasing carbon doses. However, the best COD removal obtained was 34 percent. In a second test run activated carbon column studies were undertaken. The column studies showed a maximal COD removal efficiency of 55 percent at contact times greater than 22 minutes. The results from this study should indicate that chemical precipitation plus activated carbon treatment alone are inefficient in removal of organics. Westermark (1973) and Rubhun and Streit (1974) have shown that a high fraction of the organics not adsorbed by the activated carbon treatment consist of dissolved carbohydrates and organic acids. Therefore for leachates with high concentrations of organic acids low organic removal efficiencies may be expected in a carbon treatment process.

Pohland and Kang (1974) studied the efficiency of powdered activated carbon in batch treatment of biologically treated leachate. With a carbon dosage of 4000 mg/l the COD removal efficiency in the carbon treatment process was about 90 percent. The Freundlich isotherm plot gave an adsorption of 540 mg COD per gram of carbon.

d. Chemical Oxidation. Ho et. al. (1974) also studied chemical oxidation of raw leachate by chlorine and calcium permanganate. The results shows that extremely high dosages were necessary to bring about even modest COD reductions. For instance at a chlorine dosage of 1200 mg/l the COD values were reduced from 340 to 257 mg/l. In the experiment with calium permanganate and a dosage of 10000 mg/l the COD values were reduced from 10650 to 8860 mg/l.

Foree and Cook (1972) investigated the feasibilities of chemical oxidation of biologically treated leachate by Clorox additions. Clorox was added until the color of the treated leachate was eliminated. The COD removal varied greatly and showed that Clorox would be effective for color removal but not effective for COD removal.

e. Conclusions. From the above literature it can be concluded that chemical precipitation could efficiently reduce suspended solids. However, because of the high concentrations of soluble organics in leachate the concentrations of organics cannot be reduced significantly. Chemical oxidation also seems to be relatively inefficient in removal of organics. Thus very high doses of the oxidants gave insigifnicant reduction of organics. Removal of organics by activated carbon gave relatively high removal of organics. However, because of the high organic strength of the leachate this process in combination with chemical precipitation alone would probably be prohibitively expensive in practice. Therefore biological treatment will be a basic unit in treatment of leachate.

CHAPTER III

ANALYTICAL PROCEDURES

Most analyses were conducted in accordance with Standard Methods for the Examination of Water and Wastewater, Thirteenth Edition (1971). Discussion in this chapter is limited to those analytical methods where Standard Methods presents alternative methods or when other methods were used.

1. Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand was determined by the manometric method developed by the Hach Company and described in the Instruction Manual for Manometric BOD Apparatus, Model 2173.

The advantage of this method for leachates is that it is possible to follow the process from day to day. The 5 or 7 day BOD normally is low compared to the ultimate value. This is because of the large contributions of BOD from oxidation of biodegradable organics and subsequent oxidation of ammonia to nitrate.

The standard deviation for these manometric BOD measurements is reported by the Hach Company to be approximately 10%.

2. Organic Carbon

Organic carbon was determined with an organic carbon analyzer (Oceanography International Limited). The method is described in Instruction and Procedures Manual, Oceanography International Corporation, Texas.

The standard deviation for these measurements is approximately 10%.

3. Total Nitrogen, Ammonia and Nitrates

For concentrations of total nitrogen below 100 mg N/l the method described by Koroleff (1973) was used. For higher concentrations, total nitrogen was determined as the sum of ammonia and organic nitrogens plus nitrites and nitrates. Ammonia and organic nitrogen tests were performed according to procedures described by Jønnson (1966).

Ammonia nitrogen alone was determined by the direct Nesslerization procedure described in Standard Methods. The standard deviation for this test seems to be related to the constituents of the leachates.

The method used for determination of nitrate nitrogen is described by Wood et al. (1967).

4. Total Phosphorus

Total phosphorus was determined by the ascorbic acid method described in Standard Methods. In the digestion step persulfate was used.

5. Suspended and Volatile Suspended Solids

Suspended and volatile suspended solids were determined by filtering samples through glass fiber filters in gooch crucibles. The method is described in Standard Methods. To determine the solids in the activated sludge a volume of 10 ml was used. The corresponding volume for the effluent varied from 40 to 200 ml depending on how fast the filter clogged.

The standard deviation for the suspended solids will vary with the concentrations. Standard Methods reports this value as 1.4 mg for sewage and some industrial wastes and 0.4 mg for settled sewage.

6. pH

A Radiometer, Type PHM equipped with a glass electrode was used for the pH determinations.

7. Alkalinity

The method used to determine the alkalinity is described in Standard Methods. Due to difficult color interference at the methyl orange endpoint, total alkalinity was determined by titration down to pH 3.7. As titrant 0.1-N H_2SO_4 was used. The sample size was 25 or 50 ml depending on the magnitude of the alkalinity.

For settled sewage the standard deviation is given by Standard Methods as 0.07 ml. For leachate this should correspond to a standard deviation of about 2%.

8. Spesific Conductance

The specific conductance was measured with a conductance instrument, made by Electronic Switchgear, Type MC1.

9. Metals

A Perkin Elmer 506 atomic absorption instrument was used for metal analyses.

For determination of heavy metals in the sludge, 10 ml of sludge were withdrawn added 10 ml concentrated HCl, and 0.25 ml 30% H_2SO_4. The samples were then digested at atmospheric pressure for 30 minutes.

For the leachates a sample size of 20 ml was used. To these samples were added 0.2 g $K_2S_2O_8$ and 0.25 ml 30% H_2SO_4. The leachate samples were digested at 1.3 kp/cm^2 for 30 minutes.

10. Chloride

For determination of chloride the potentiometric method described in Standard Methods, was used.

11. Sulfate

Sulfate was determined by the turbidimetric method described in Standard Methods.

The standard deviation for this test is about ± 10%.

12. Organic Acids

Individual organic acids were determined by gas chromatography. The instrument used was a Pye Unicam, Type 104. This was equipped with a glass column 1.8 m in length by 6 mm diameter. The packing of the column was: 10% SP 1200/1% H_3PO_4 Chromosorb WAW 80/100. The operating, and injection temperatures were 125 and 175°C respectively.

13. Total Carbohydrates

The method used for determination of total carbohydrates is described by Ramanathan et al. (1968).

14. Dissolved Oxygen

Disolved oxygen was measured with a YS1 oxygen meter, model 54. At full scale readings the standard deviation is given as 1%.

15. Oxygen Uptake Rate

The oxygen uptake rate was determined with YS1 oxygen meter and a 200 ml sample flask with magnetic stirrer. The oxygen meter was connected to a recorder which plotted the dissolved oxygen as function of time. From this plotting the value of the oxygen uptake can be found as the slope of the line.

16. Specific Resistance to Filtration

The dewatering properties of the activated sludge were studied by determining the specific resistance to filtration in a Buchner funnel apparatus.

Whatman no.1 filter paper with a 9 cm diameter was used throughout the test period. The vacuum applied varied from 0.5 to 0.55 kp/cm^2. The method is described by Gale (1971).

17. Settling Properties

The settling properties of the sludges were studied in 1 liters graduated cylinders.

18. Microscopic Examinations

To identify the different types of microorganisms prevailing in the different plants, microscopic examinations were performed.

19. Chlorophyll $\bar{a}$

Chlorophyll $\bar{a}$ was determined by the method described by Strickland et al. (1969).

20. Number and Volume of Algae

A Coulter Counter Z.D. was used for determinations of number and volume of algae.

CHAPTER IV

DESCRIPTION OF THE LANDFILLS

Leachate samples were collected from six different sanitary landfills in southeast Norway and two from the Seattle area in United States. In the following a short description of the eight landfills will be given.

Table 15 is presented to show relations between the leachate composition and conditions of the landfills. The sanitary landfills from the United States are not included due to lack of sufficient information. Five of the fills are conventional sanitary landfills while Taranrød is a landfill for milled refuse. Average annual precipitation in the areas for the landfills from Norway are 825 mm.

Of the landfills in table 15, only Yggeseth and Isi II have a design making it possible to relatively efficiently avoid ground and surface water entrance into the fill.

Grønmo is located on a swamp several meters deep. There are no barriers between the waste and the ground. Therefore the leachate is highly diluted with ground water.

Isi I is also a landfill with poor design. Water enters the landfill from an upland drainage area. Leaks in culvert joints also allow water to enter the fill.

For the landfill at Branasdalen, the water from upland surface drainage is diverted through the fill in culverts. However, leaks in the culverts permit water to enter the fill or the leachates to seep into the culverts.

Taranrød is located in a narrow rocky valley. The surface water diversion is very poor. Thus in the snow melting period, or during heavy

Table 15. Characterization of the sanitary landfills.

Name of landfill	County	In use from	Type of waste	Disposal of sludge total m³	Operation		Total volume of waste m³	Height of fill m	Area of fill 10³ m²	Area of upland surface water, drainage, 10³ m²	Ground underneath fill	Control of outside water sources	Comments
					Thickness of waste layer m	Compactor tonn							
Grønmo	Oslo	June 1969	1/3 Residential 2/3 Industrial	$9200^{1)}$ dewatered	2-2.5	25 35	2.-2.5 mil. compressed	Max. 18.5 Average:18	200	280	Swamp land	Stream through fill in culvert	No surface water drainage. Parts of fill under ground water table.
Yggeseth	Asker	Jan. 1972	Residential	None	Varies	9.2	135 000 uncompressed	Max. :4.5 Average:3.0	9	15	Silty clay	Stream through fill in plastic pipes. Surface water drainage	Effective upland drainage.
Isi I	Bærum	Aug. 1967 (June 1974)	2/3 Residential 1/3 Industrial	$13\ 000^{2)}$ dewatered	Max. 2.5	16	800 000 uncompressed	Max. :22 Average:12-15	65	100	Clay loam	Stream through fill in culvert. Surface water drainage.	Two ground water streams into fill. Culverts leak.
Isi II	Bærum	June 1974	1/2 Residential 1/2 Industrial	$2\ 100^{3)}$	Max. 2.5	32	50 000 compressed	Max. : 5 Average: 3	5	100	Silty clay	Stream diverted outside fill. Surface water frainage.	Effective upland drainage.
Brånåsdalen	Skedsmo	Jan. 1971	3/5 Residential 2/5 Industrial	$20\ 000^{4)}$ dewatered	2	16	380 000 uncompressed	Max, : 8 Average: 5	29	450	Clay	Stream through fill in culvert	Some leaks from culvert. Upland surface drainage.
Taranrød	Sem	March 1973	Residential	None	Milled refuse	7.5	13 000 compressed	Max. : 4 Average:2.5	7.5	130	Gravel sand-rock	Stream through fill in culvert. No upland surface drainage.	Culverts leak. Poor control of surface drainage.

1) Sludge disposed in heaps. 2) Sludge disposed on top of fill. 3) Sludge spread in layers. 4) Sludge disposed in heaps.

rain falls, large quantities of water enter the landfill. A stream diverted through the landfill via culverts also causes water addition to the fill material.

Common for most of the landfills in Norway seems to be bad surface upland drainage and insufficient diversion of streams. In most cases, tight joints were not used in concrete culverts.

The sanitary landfill at Cedar Hills, Washington, is located on a hill. Therefore no problem with upland surface water drainage exists. The only water source is precipitation which infiltrates through the cover materials. Due to this limiting water supply the leachate from this fill normally has high constituent concentrations.

The Kent Highland, Washington, sanitary landfill is located in a ravine. Parts of the site floor is poorly drained and swampy. A small stream is flowing through the fill in pipes. This stream is fed in part by springs along the foot of the northern slope and by surface runoff. The pollutant concentrations in leachate from this fill varies considerably with precipitation. Average annual precipitation for the landfills from the Seattle area is 950 mm.

CHAPTER V

COMPOSITION OF LEACHATES

For all the land fills the leachate samples were collected in manholes or pumpsumps downstream from the fills. The samples were either analyzed immediately or preserved and stored at refrigeration temperature for analyses later.

The composition of leachate constituents for all the landfills is given in table 16.

For the landfills in Norway the samples were taken on the same day. One week without precipitation existed prior to the sampling date August 9, 1974. The samples from the sanitary landfills in Washington were taken in the summer of 1973. Dry weather prevailed a long period before the sampling.

For all the landfills the concentrations varied considerably from time to time. To illustrate this, analyses from other sampling days are given in table 58 Appendix A.

The variations in the leachate concentrations are mainly due to the dilution effects by outside water sources. Only one of the landfills, Grønmo, was provided with equipment for measurement of the leachate volumes.

1. COD, BOD and TOC

These parameters are all used to determine the content of organic matter. Before the results of the analyses of the different leachates are discussed a short discussion of the most important substances contributing to the COD and BOD values will be given.

Leachates from sanitary landfills are normally anaerobic and have a different composition than domestic sewage. For leachates the COD is primarily dependent on the amount of organic matter, but inorganics can also contribute substantially to the COD. Of the inorganics, ferrous iron is normally the main contributor. Oxidation of ferrous to ferric iron can be expressed by the following equation:

$$4Fe^{2+} + O_2 + 4H^+ = 4Fe^{3+} + 2H_2O$$

Thus, for a leachate sample containing 100 mg iron per liter, 14 mg O/l are required. Other inorganics besides iron normally contribute little to the COD values.

The BOD tests for leachates are normally associated with several problems including inhibitory effects and will be discussed later.

Ammonia is the prevailing nitrogen compound in leachates. In a BOD test with sufficient incubation time ammonia nitrogen will be converted to nitrates. Normally leachates from sanitary landfills have high concentrations of ammonia. Consequently the contributions to BOD from this oxidation can be considerable. This oxygen consumption can be calculated from the following equations:

$$2NH_4^+ + 3O_2 = 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 = 2NO_3^-$$

The equations illustrate an oxygen demand of four moles for oxidation of two moles of ammonia. Thus complete oxidation of an ammonia concentration of 100 mgN/l requires 457 mg O/l.

Table 16. Dry Weather Analysis of Leachates from Norway and the Pacific Northwest.

Fill Parameter		NORWAY						USA	
		Grønmo	Brånåsdalen	Yggeseth	Isi I	Isi II	Taranrød	Ceder Hills	Kent Highland
COD	mg O/l	476	1080	9425	824	112	3456	38800	3800
BOD total	mg O/l	320	870	5250	590	50	2300	24500	2460
TOC	mg C/l	100	250	1700	180	30	800		
Total N	mg N/l	182	254	250	155	16.6	156	630	56
NH_4-N	mg N/l	120	225	227	141	10.2	84		
NO_3-N	mg N/l	0.04	0.01	0.04	0.02	0.79	0.68		
Organic N^x	mg N/l	62	29	23	14	6	71		
Total P	mg P/l	0.6	1.7	7.7	3.3	0.1	1.6	11.25	5.9
Suspended solids	mg/l	140	397	466	270	68	1079	310	220
Volatile suspended solids	mg/l	85	98	182	229	11	602	170	90
Total solids	mg/l	2963	2730	4164	3883	609	3162		
Total volatile solids	mg/l	762	1005	2178	888	146	1673		
pH		6.8	6.9	5.9	7.0	6.4	6.2	5.4	6.4
Alkalinity	mg $CaCO_3$/l	1500	2050	1960	1530	310	1080	6480	1280
Spec.conductance	μS/cm	3310	3210	3380	3050	654	2370		
Ca	mg Ca/l	188	198	400	173	99	218		
Mg	mg Mg/l	66	96	54	58	13	40		
Na	mg Na/l	462	229	206	312	34.8	197		
K	mg K/l	200	172	187	219	21.3	214		
Chloride	mg Cl/l	680	280	370	590	68	340		
Sulphate	mg SO_4/l	30	10	100	37	41	100		
Fe	mg Fe/l	67.6	78.0	234	37.7	11.5	68.9	810	245
Zn	mg Zn/l	0.055	0.095	0.65	0.085	0.12	2.65	155.0	5.30
Cr	mg Cr/l	0.023	0.035	0.06	0.027	0.002	0.17	1.0	0.05
Ni	mg Ni/l	<0.1	0.02	0.03	0.015	0.005	0.12	1.2	0.10
Cu	mg Cu/l	0.085	0.011	0.022	0.009	0.008	0.021	1.30	0.18
Cd	mg Cd/l	0.0005	0.0001	0.0009	0.002	0.0005	0.0008	0.03	0.01
Pb	mg Pb/l	0.004	0.001	0.01	0.001	0.001	0.015	1.4	<0.1
Co	mg Co/l	-	0.009	0.07	0.018	0.004	0.033	-	-

[x] Calculated as the differance between total N and NH_4-N.

Oxidation of ammonia does not take place in a COD test. Therefore the ratio of COD to BOD can vary considerably. The high BOD from oxidation of ammonia sometimes causes a total BOD value higher than the COD value.

In most of leachate samples the nitrification process start after an incubation period of about ten days. A conventional BOD analysis of five or seven days may therefore measure only a small fraction of the total BOD value, depending on the ratios between the concentrations of biodegradable organics and ammonia.

Another factor which makes the BOD value difficult to predict is the low biological assimilability of the organic matter in some of the leachates. The oxidation of organics will go much slower than in ordinary sewage. Also some compounds in the leachate are inhibitory. Therefore high dilutions are required which decrease the accuracy of the test.

BOD curves for some of the leachate samples given in table 16, are drawn in figures 2 to 6. The figures illustrate well the influence of the nitrification processes and dilution effects.

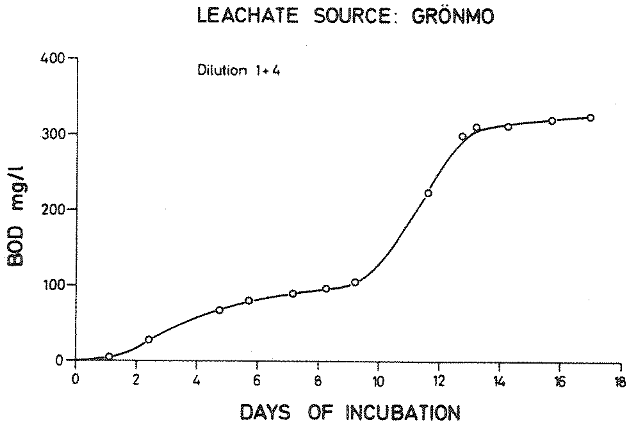


Figure 2. BOD vs. incubation time, Grønmo

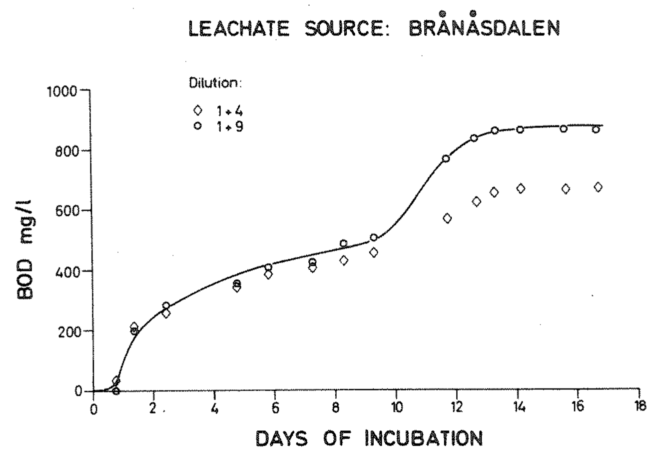


Figure 3. BOD vs. incubation time, Branasdalen

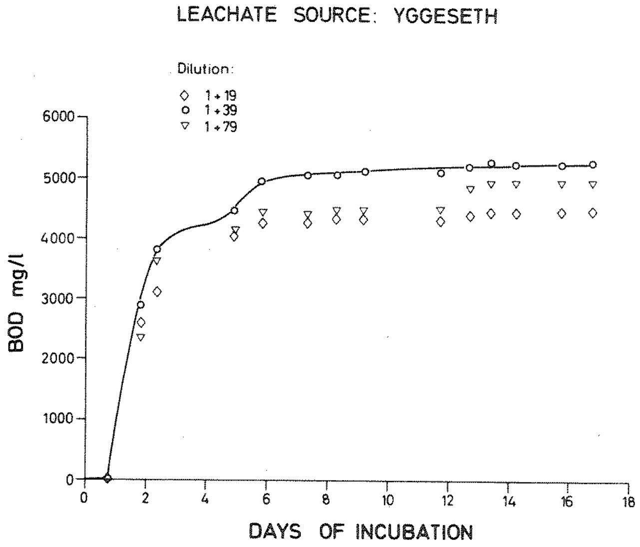


Figure 4. BOD vs. incubation time, Yggeseth

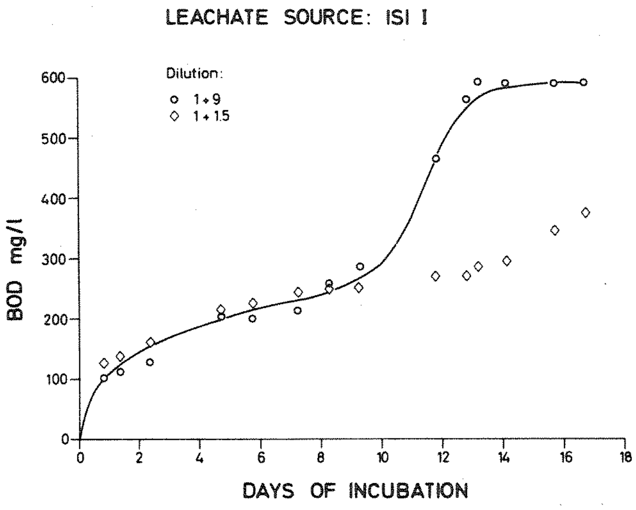


Figure 5. BOD vs. incubation, time, Isi I

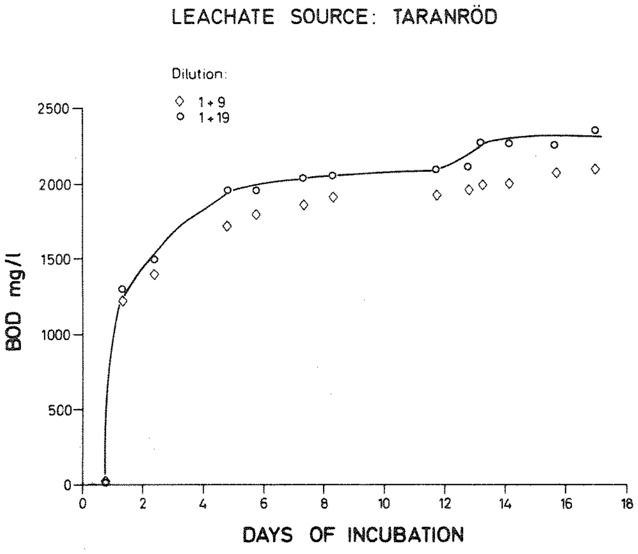


Figure 6. BOD vs. incubation time, Taranrød

Because the BOD is not a reliable parameter for organic content, COD was chosen as the main parameter for measuring organic content. Some samples were also analyzed for total organic carbon.

The data for the different leachate sources in table 16 exhibit a significant range of values. As an example, the COD of the leachates from Grønmo and Cedar Hills varied between 476 and 38800 mg/l. The variations of the parameters mentioned above are strongly influenced by the construction of the fill. Cedar Hills and Yggeseth both receive little water from outside sources. Therefore less dilution of the leachate occurs and thus higher concentrations of organics are found.

For Isi II which is a newly opened landfill the concentrations are especially low. In this fill the decomposition processes are in the starting phase so little organic material is extracted from the garbage. For such fills the contribution of organics to the leachate is mainly due to initial moisture content.

Table 58 in Appendix A also show a considerable variation in the individual values of COD, BOD and TOC. This is especially true for the landfills with insufficient control of outside water sources. For instance, during a wet weather period, the COD values in the leachate from Taranrød decreased from 3456 to 244 mg/l. During this wet period large volumes of upland surface water flowed into the fill. On the other hand the concentrations of the leachate from Yggeseth during wet periods remained nearly the same as the concentrations obtained during dry weather.

The concentrations of COD, BOD and TOC from Grønmo remained relatively low and constant. In this fill, which is located on a swamp, the leachate seeps down into the ground water and a dilution occurs. The leachates used drained from this magazine. Therefore fairly constant concentrations of COD, BOD and TOC exist.

The ratio of COD to TOC will tell something about the condition of the fills. Leachate samples with low COD to TOC ratios indicate a more oxidized state of the organic carbon. Therefore low ratios normally indicate old fills where the organics are less readily available for biological degradation. For the landfills from Norway the COD to TOC ratios in the leachates varied from 4.32 to 5.54 for Branasdalen and Yggeseth respectively. A treatability study of these two leachate sources confirmed this. Leachate from Branásdalen was not as easy to treat biologically as leachate from Yggeseth. In spite of the considerable higher concentrations of organics in the raw leachate from Yggeseth this leachate had a lower concentration of refractory organics after treatment than the leachate from Branasdalen.

2. Nitrogen Compounds

Of the different nitrogen compounds ammonia contributes up to 60-90 percent of total nitrogen. This is also expected because of the reduced environment inside the landfills. The concentrations of nitrates are nearly zero. The tabulated values for organic nitrogen are calculated as the difference between total nitrogen and ammonia. Due to the relatively small differences between total nitrogen and ammonia large errors in the values for organic nitrogen may exist.

For the landfills with relatively low BOD values a comparison between BOD and total nitrogen in table 16 indicates that the main contribution to the BOD are attributed to the oxidation of ammonia to nitrates. Compared to the variations in the values of COD and TOC from the different fills the variations in the nitrogen compounds are small.

3. Solids

A comparison between suspended solids and total solids shows that most of the solids are in the dissolved state. The concentrations of suspended solids are approximately the same as in domestic wastewater while the concentrations of total solids are roughly 10 times higher.

4. pH

The pH values of the leachates are lower than 7.0 except for Isi II. The pH is very important because it influences the solubility of different metals. The pH can also be used as an indication of the type of degradation processes occurring. Low pH indicates that first stage anaerobic decomposition is occuring. This results in partially decomposed organic substances including organic acids.

The variation in pH may be attributed to the difference in biological activity in the different fills. Carbonic acid resulting from carbon dioxide will lower the pH. This acid will, in turn, cause the leachate to become laden with trace metals and other ions.

5. Alkalinity

The alkalinity varies from 310 to 6480 mg $CaCO_3$/l. For most of the landfills the values were in the range of 1000 to 2000 mg $CaCO_3$/l. Figure 7 shows three typical titration curves for the leachate sources Grønmo, Brånåsdalen and Yggeseth.

6. Specific Conductance

Specific conductance is a gross indicator of the total concentration of dissolved inorganic matter or ions. The values for the specific conductance

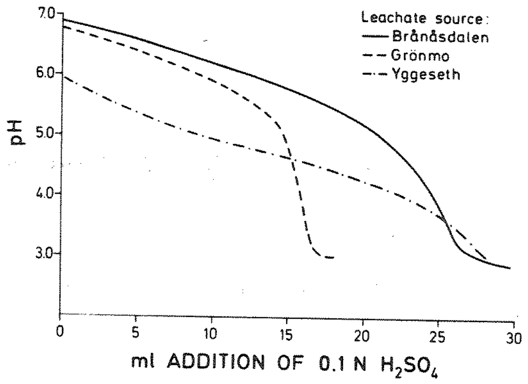


Figure 7. Titration curves.

in table 16 appear to have relatively little variation from fill to fill.

7. Ca, Mg, Na and K

These are the major metals contributing to specific conductance. Therefore a good correlation exists between the sum of the equivalent concentrations of these parameters and specific conductance. The values in table 16 confirm this.

The dissolved metal concentrations are a function of the pH, the concentrations of the carbonate species and complex formation due to organics in the leachate. Normally the metal concentrations are proportional to the concentrations of the hydrogen ion raised to a power and inverse proportional to the total carbonate species also raised to a power. This can be evaluated from the model of dissolved carbonate equilibria and the equilibrium reactions of the metal carbonates and hydroxides (Stumm and Morgan (1970)).

The factors mentioned above may explain why the metal concentrations in the leachate samples from Grønmo and Yggeseth are so close. The alkalinity and pH indicate that the sample from Yggeseth have higher concentrations of carbonate species than the sample from Grønmo. The pH value for the leachate from Yggeseth is also lower than in the leachate from Grønmo.

8. Chloride and Sulfate

With the exception of Iso II all the leachate cources have relatively high concentrations of chlorides.

The concentrations of sulfates are roughly the same as in domestic sewage.

9. Heavy Metals

The concentrations of the heavy metals are a function of pH, concentrations of carbonate species and chelating agents.

a. Iron. Iron represents the bulk of the heavy metals. In the leachate from Yggeseth, concentrations were found as high as 234 mg Fe/l. The high concentrations of iron are probably due to low pH and complex formation with organics.

In the reduced conditions in the fills the iron is present in soluble forms. For the leachate sample from Yggeseth the oxygen demand for oxidizing the ferric iron to ferrous form require 33 mg O/l. This value accounts for about 0.3 percent of the COD value. For the leachate from Grønmo the corresponding number is 2.0 percent.

b. Zn, Cr, Ni, Cu, Cd, Pb and Co. Concentrations of Zn were relatively high in the leachate sources from USA. In Norway the heavy metal concentrations in leachates with the exception of iron, are all low.

10. Identification of the Organics in Leachate

To identify the organics in the leachate sources analyses for organic

Table 17. Dry Weather Organic Analyses of Leachates from Norway and the Pacific Northwest.

Landfill / Parameter	NORWAY												USA			
	Grønmo		Brånåsdalen		Yggeseth		Taranrød		Isi I		Isi II		Cedar Hills		Kent Highland	
	mg/l	mg C/l	mg/l	mg C/l	mg/l	mg C/l	mg/l	mg C/l	mg/l	mg C/l	mg/l	mg C/l	mg/l	mg C/l	mg/l	mg C/l
TOC	100		250		1700		800		180		30		8600		840	
Total carbohydrate	24	10	37	15	54	22	113	46	57	23	6	2				
Total protein			181	58	144	46	443	142	88	28	38	12				
Acetic acids	<10		129	52	420	168	421	169	100	40	30	12	2750	1100	300	120
Propionic acids	<10		37	18	231	111	282	136	67	32	<10		4375	2100	380	182
Butyric acids	<10		12	7	681	368	318	172	14	8	<10		5875	3173	260	140
Iso butyric acids	<10		<10		78	42	32	17	<10		<10					
Valeric acids	<10		<10		219	129	87	51	<10		<10		550	324	190	112
Iso valeric acids	<10		<10		241	142	19	11	<10		<10					
Caproic acids													600	372	90	56
Total organics identified				149		1028		743		131		26		7069		610
Per cent identified				60		60		93		73		87		82		73

acids and carbohydrates were run. The results are given in table 17. All the values are converted to mg carbon per liter. A comparison of these values with the value of TOC make it possible to calculate how much each parameter is contributing to the total organics.

For the leachate samples from the sanitary landfills Cedar Hills and Kent Highland no analyses were run for TOC. Therefore the values given in table 17 are calculated as a fraction of COD. The factor 4.5 used in this calculation, is the average COD/TOC ratio for all the other leachate sources which varied from 4.32 to 5.54.

The values for total protein are calculated from the values of organic nitrogen in table 16. According to Sawyer et al. (1967) the nitrogen content of all proteins falls within the range of 15-18 percent. The protein contents are therefore determined by multiplying the concentrations of organic nitrogen by the factor of 100/16. To determine the carbon content of the proteins the ratio of the mol weight of carbons to total mol weight in the general structure of amino acids are used. Since relatively small differences exist between total nitrogen and ammonia the absolute error in the organic nitrogen may be large. Therefore the concentrations of the proteins in table 17 must be considered as approximate values. With the exception of the leachate from Grønmo the contribution of the proteins to total organic carbon is relatively low. Therefore a relatively large error in the estimation of the protein are not significant in the determination of organics. For the leachate source from Grønmo the calculated protein content was found to be 388 mg/l. This number is obviously wrong because it is contributing to more than 100 percent of TOC. This can be explained by the fact that a ten percent error in the determination of total nitrogen and ammonia make it possible to reduce the existing value of organic nitrogen by one half.

For the leachate sources with high concentrations of total organics the organic acids make up the largest fraction of the total organics. Acetic propionic, and butyric acids are the most important of these, contributing up to 75 percent of the total organics. The characteristic bad odor from leachate is due to the high concentration of butyric acid.

The concentrations of organic acids depend on the biological activity in the fill. High concentrations indicate a high rate of first stage anaerobic decomposition where complex organics are converted to organic acids. Low concentrations of organic acids indicate a very slow decomposition rate or an effective leachate stabilization taking place in the second stage of the anaerobic processes. The latter is not usual due to unfavorable environmental conditions.

For the leachate samples with low concentrations of organic acids the contributions to the organics are probably more due to an extraction and washing process than actual decomposition.

Chian et al. (1974) found, in a study for identification of organics in leachates, significant concentrations of humic acids, lignins and other cellulose like materials. The remainder of the organics not identified in this study therefore probably consist of the above mentioned compounds.

CHAPTER VI

DESCRIPTION OF EQUIPMENT

Several laboratory scale treatment plants were used in this experimental study performed at the University of Washington and at the Norwegian Institute for Water Research.

A. LABORATORY PLANTS USED AT THE UNIVERSITY OF WASHINGTON

The laboratory plants used at the University of Washington consisted of three anaerobic filters and five batch and three continuous activated sludge units.

1. Anaerobic Filters

The three anaerobic filters were constructed of plexiglass tubes with a diameter of 16 cm and a height of 45 cm. The units were filled with crushed lime stone with a diameter of 1 to 1.5 inches and then sealed at the top and bottom. Total volumes were 7.2 liters and the void space 3.5 liters. Three dispersion rings were cemented at equal spacing inside the filter to minimize short circuiting of the waste.

An influent feed port was located at the bottom of the filter and an effluent port at the top. The gas and the treated leachate were separated by a T tube arrangement. The gas then streamed to a carboy filled with water. Here the gas volumes replaced equal volumes of water which was measured in a graduated cylinder. Figure 8 shows a picture of the filter unit and the filters with necessary equipment.

a. Feed System. In the first test run the filters were fed on a fill and draw basis. In the two last test runs a continuous feed system was used. This continuous feed system consisted of a 15 liter storage vessel for raw leachate, dosing pump, inlet pipe arrangement, magnetic valves and timer equipment. A refrigeration unit kept the temperature of the raw leachate in the storage vessel at 4 ± 1 °C. A mixing unit installed in the storage vessel provided good circulation.

The feeding of leachate operated by a timer, occured in the following steps:

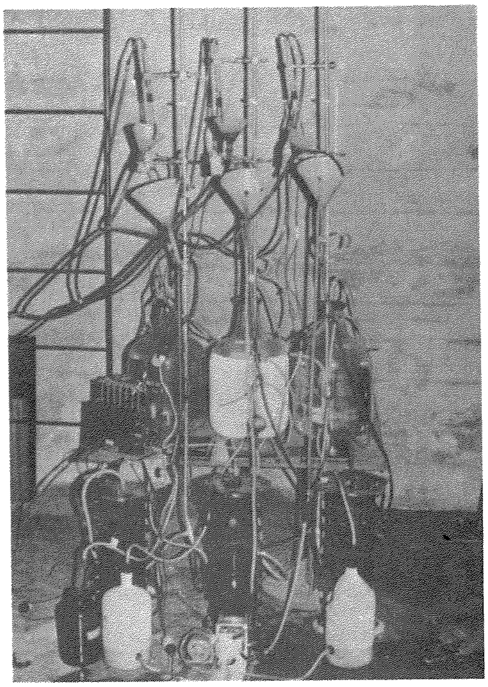
1. The timer started the dosing pump which filled the inlet pipes to a fixed volume

2. The dosing pump stopped and the magnetic valves opened and emptied the inlet pipes

3. The magnetic valves closed and,after a preset time interval, the dosing pump was again started

This feed system was also used for most of the aerobic treatment studies described later. The feed system worked excellently, and it was not sensitive to deposits in the inlet pipes. The inlet pipe over flow system as designed permitted the maintenance of a fixed dosage volume.

In the study of anaerobic treatment of leachate the interval between each feeding was 60 minutes.



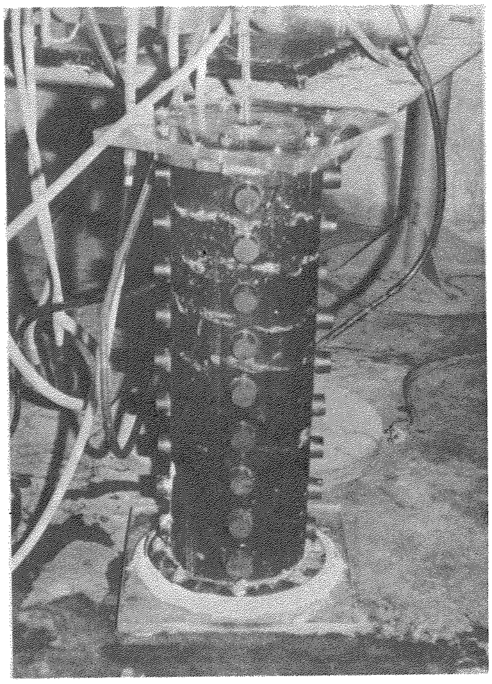
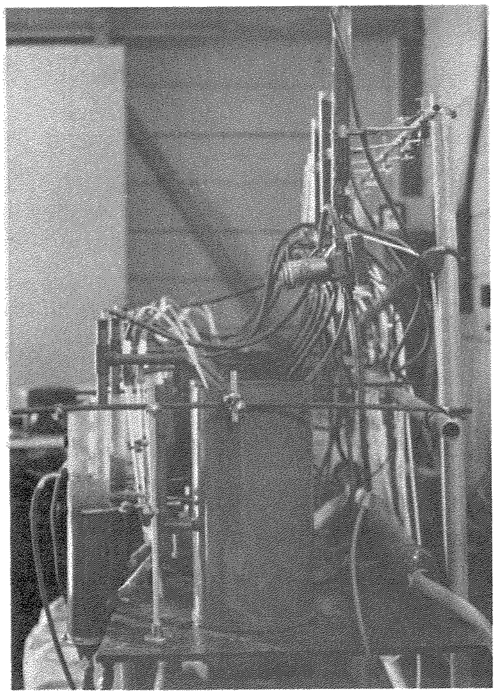


FIGURE 8 ANAEROBIC FILLERS



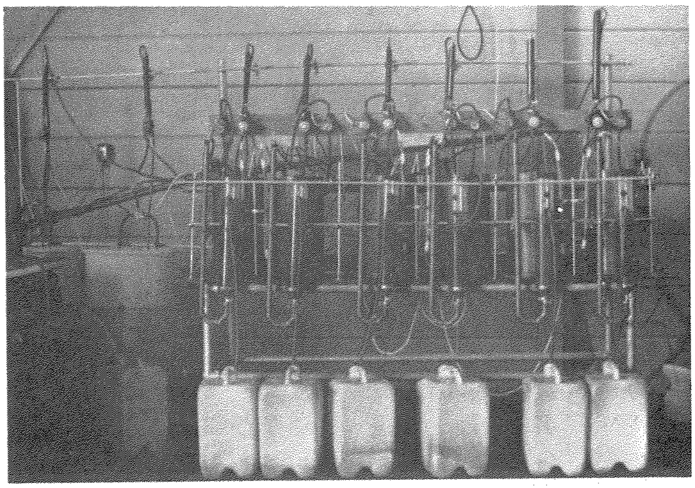
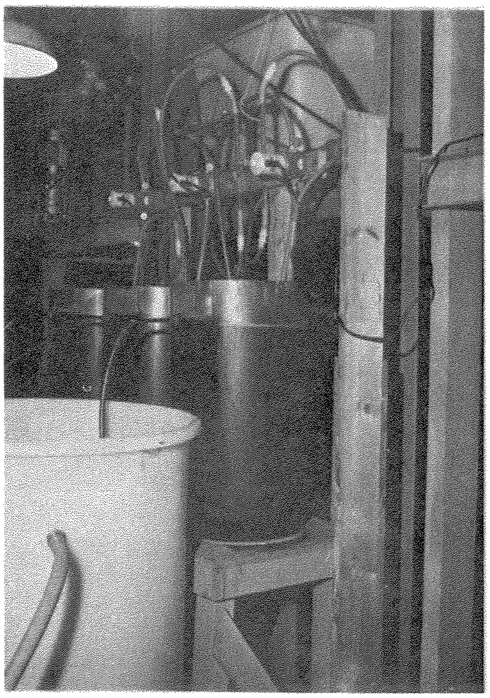


FIGURE 9 ACTIVATED SLUDGE PLANTS
GROUP NO. 2.



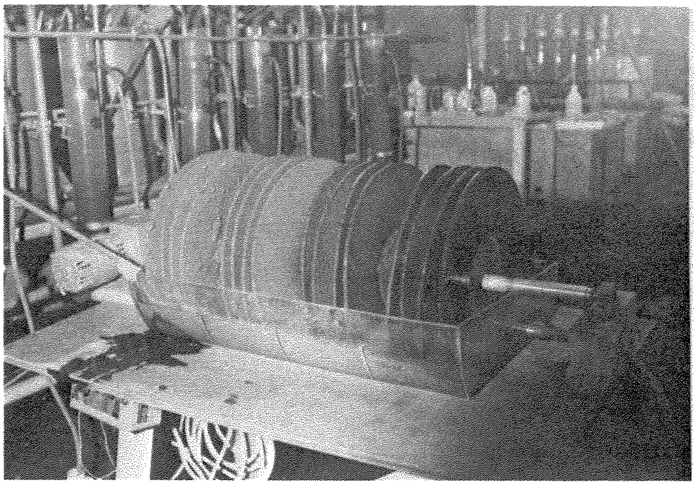
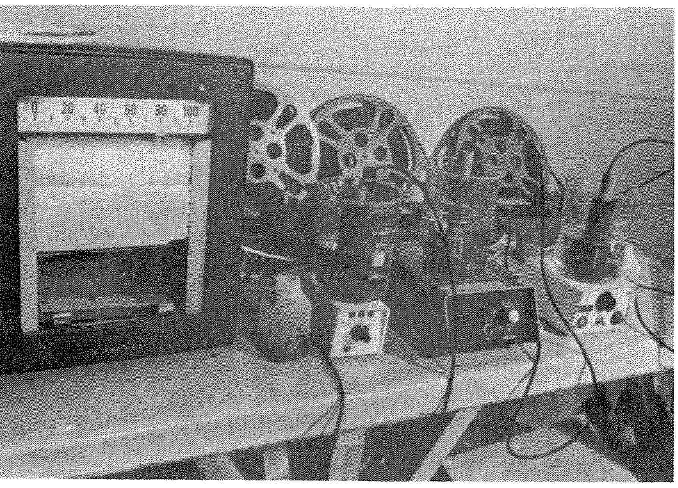


FIGURE 11 BIODISC

FIGURE 10 ACTIVATED SLUDGE PLANTS
GROUP NO. 1



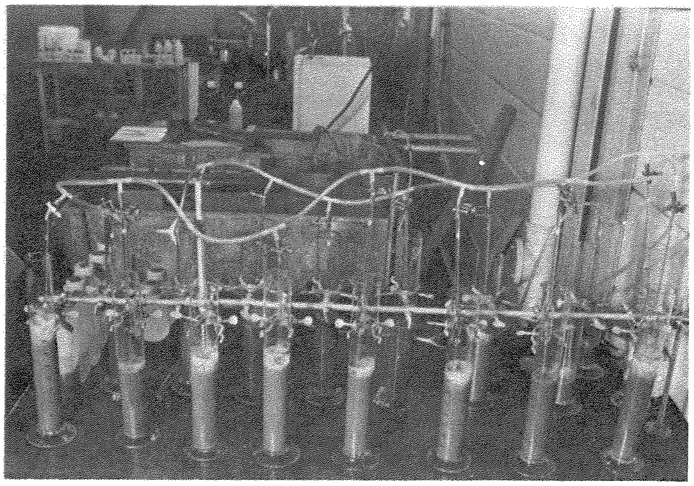


FIGURE 12 EQUIPMENT FOR MEASURING
OXYGEN UPTAKE RATE

FIGURE 13 EQUIPMENT USED IN THE
STUDIES OF HEAVY METAL
TOXIERITIES

2. Activated Sludge Units

a. Batch Units. In the first study five activated sludge units were used to evaluate aerobic treatability of sanitary landfill leachate. Four of these units consisted of 10 liter carboys while the fifth had a volume of 8 liters. All units had air stones installed in the base.

Feed System. The five units were operating on a fill and draw basis. After 0.5 hour of sedimentation a prefixed volume of the supernatant was withdrawn. A corresponding volume of leachate was then added and the air supply started. The units were fed three times per day.

b. Continuous Units. Treatment of leachate was also studied in continuous activated sludge units. These were developed by Benedict (1968). The units consisted of a two liter volume aeration tank and a 0.83 liter settling chamber. To improve the settling a stirrer with a rotational speed of 3 r.p.m. was installed into the clarifier. Recyling of the activated sludge was carried out by a peristaltic pump operated by a timer.

Feed System. The continuous activated sludge units had the same timer operated feeding system as the anaerobic filters.

B LABORATORY PLANTS USED AT THE NORWEGIAN INSTITUTE FOR WATER RESEARCH

The laboratory plants used in Norway consisted of two groups of activated sludge units, one of three and one of six individual units, two aerated lagoons, one biodisc and one trickling filter. With the exception of three activated sludge units all plants were designed and fabricated for this study.

1. Activated Sludge Units, Group No. 1

Three of the activated sludge units were employed in an earlier study and consequently built for that purpose. The plants, which were constructed of plexiglass are shown in figure 10.

The reactors are a modification of Ludzack's (1964) laboratory model. To minimize scale effects the unit volume was increased to 37 liters. The dimensions of the aeration and sedimentation units are shown in table 18 Different volumes of the settling chambers were chosen to obtain as equal hydraulic conditions as possible in the three plants at different loadings.

Table 18. Volumes of activated sludge plants

Plant no	Aeration chamber l	Settling chamber l
1	28.8	8.2
2	30.8	6.2
3	32.3	4.7

Compressed air was supplied to the plants through sintered glass diffusers. The diffusers were attached to a plexiglass tube and placed in the bottom of the aeration chamber. The quantity of air blown through the diffuser was measured and controlled by a flow meter. To avoid disturbance in the settling chamber the air supply was kept as low as possible, just sufficient to avoid settling in the aeration chamber. However, this appeared to give sufficient oxygen concentrations in the aeration unit.

a. Feed System. In the test series where biological treatment of chemically precipitated leachate was studied, the plants were installed to treat leachate from a full scale chemical precipitation plant. In this case, part of the effluent from the full scale plant flowed through a distribution chamber. From this chamber the leachate was supplied to the pilot plants through magnetic valves operated by a timber. There were two different types of timing arrangements: one, which was common to all three plants, regulated the interval between each impulse of supply; the other, which all plants were equipped with, regulated the opening time of the magnetic valves. The interval between each supply was hence the same for all reactors and in the range of 2-8 minutes. The opening time could be between 5 to 30 sec. This form for continuous feeding gave some operational problems. Deposits of oxidized iron in the leachate gave a decreasing flow through the valves. The pipes and valves therefore had to be cleaned frequently.

When these treatment plants were operated on other types of leachate the same feeding system was used as for the activated sludge plants in group no. two.

2. Activated Sludge Units, Group No. 2

Six activated sludge units were built for this study. The aeration units and pipes for sludge return were constructed of PVC. To be able to follow the settling process the settling chamber was constructed of plexiglass. The plants are shown in figure 9.

The plants consisted of an aeration chamber (1), settling chamber (2), air lift pump (3) to recycle the activated sludge, and feeding arrangement (4). The aeration chamber consisted of a 25 liter PVC container with a diameter of 25 cm. To avoid settling, three diffuser stones were placed on the bottom of the containers. The air supply was measured by flow meters and held constant. The air stones gradually clogged and had to be replaced at two week intervals.

The air lift pump for recycling of activated sludge was operated by a timing arrangement. This was necessary because continuous recycling gave a sludge with poor sedimentation properties. The interval between each recycling varied from 6-60 minutes with a pumping time of about 3 minutes.

The settling chamber consisted of an 8 cm diameter plexiglass tube 60 cm in height. The effluent could be drawn from three different heights. This gave three possible volumes for the aeration chamber as well as for the settling chambers. In these experiments two volumes of the aeration chambers, 15.1 l and 19.1 l, were used. The corresponding volumes of the settling chambers were 1.7 l and 2.1 l.

a. Feed System. A similar feed system as the timer operated system used for the anaerobic filters were built for these activated sludge units. The raw leachate was stored in a plastic vessel with a volume of 1000 liters. The storage vessel was also used as a feed tank. A refrigeration unit kept the temperature of the stored leachate at 5 ± 1°C. This cooling unit also provided good circulation in the vessel.

The interval between each feeding varied from 6 to 60 minutes.

3. Aerated Lagoons

The two aerated lagoons consisted of 200 liter plastic tanks filled to a level corresponding 140 liters of leachate. The diameter at the bottom was 48 cm and the liquid height 70 cm. Air was supplied through two sintered diffusers placed at the bottom of the tanks.

The system for leachate feeding was the same as for the activated sludge units, group no. two.

4. Biodisc

The biodisc consisted of a half cylindrical trough of plexiglass, discs of wood fixed to a steel axis and a slow rotating motor. The trough was divided in four chambers where groups of four discs were partly submerged. With a disc diameter of 36 cm the total wetted area became 3.3 m^2. The rotation speed was 0.8 r/min. Leachate was supplied to one end of the plant and flowed through the four chambers in sequence before discharging. No recycling of the treated leachate was applied. Figure 11 show a picture of the biodisc.

The biodisc was first installed to treat chemically precipitated leachate and had then the same feeding system as the activated sludge plants in group no. one. Later it treated raw leachate with the same feeding system as the activated sludge plants in group no. two.

5. Trickling Filter

The trickling filter consisted of a wooden frame filled with Floccor filter media. The plastic filter measured 0.6 x 0.6 x 1.8 m. This gave a filter volume of 650 liters. In the bottom the tower was equipped with a collecting tray which drained to a sump.

From the sump the treated leachate was discharged. The sump also was a collecting box for recirculation of leachate. Due to low feeding volumes and high capacity of the recycle pump the recirculation ratio was in the order of 100.

The trickling filter was fed with chemically precipitated leachate. Due to high hydraulic capacity the filter was fed continually through a pipe connected to the earlier mentioned distribution chamber. The feed was simply regulated by a clamp arrangement. This feed system was not quite reliable but supervision every day made it acceptable.

CHAPTER VII

EXPERIMENTAL RESULTS

To study the treatability of leachate both biological and chemical treatment were investigated. The influence of leachate addition to primary chemical treatment of municipal waste water was also studied. Prior to the treatment studies respiration and algal tests were performed to study the degradation and toxicity of different leachate sources. In this chapter the above mentioned studies will be reported.

A. RESPIRATION TESTS

Respiration tests were performed to provide information on toxicity effects, biological treatability and degradability of the different leachate sources. For these tests, leachate at different dosages were added to samples of domestic sewage. The volumes added to each sample were adjusted so that the additions of the leachate should contribute a prefixed amount of organics. The leachate volume added to each sample are given in table 19.

Table 19. Leachate volumes added to domestic sewage, percent

Landfill	Percent TOC contribution of leachate in sample				
	15	30	45	65	75
Grønmo	5.0	12.0	20.0		
Brånåsdalen	2.0	5.0	8.0	18.0	
Yggeseth			1.2	2.6	5.0
Taranrød		1.5	2.5	5.7	
Isi I		6.3	11.0	25.0	

The leachate samples used in these tests are identical with those whose analyses are given in table 16 (BOD curves in figures 2 to 6). The domestic sewage was primarily treated and had the following concentrations:

COD = 120 mg/l
TOC = 30 mg C/l
Tot-N = 16.8 mg N/l
Tot-P = 4.5 mg P/l
The BOD curve of the domestic sewage is given in figure 14.

The results of the respiration tests are given in figures 15 to 20. A comparison of the BOD curves for different additions of leachate will give information about the response of the leachates to biological degradation. Depression of the BOD values when leachate is added to the domestic wastewater may be caused by:

1. The organics in the leachate are very resistant to biological degradation but not toxic. In this case the depression is simply caused by dilution. The increase in BOD after incubation times of 10-15 days may be due to nitrification.

2. The leachates may have toxicity effects which depress the BOD values.

Note that the leachates from Grønmo and Isi I are very resistant to biological degradation or have high toxicity effects. More discussion will follow later.

A comparison of the respiration results of the different leachate sources are given in figures 20 to 23. These figures are all drawn with the domestic sewage as a reference. That is, the respiration values are reduced as if the samples had contained the same content of organics

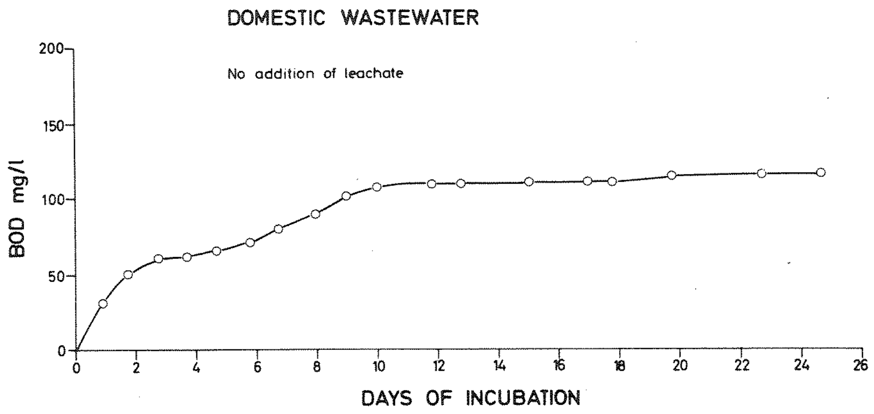


Figure 14. BOD vs. incubation time, domestic wastewater.

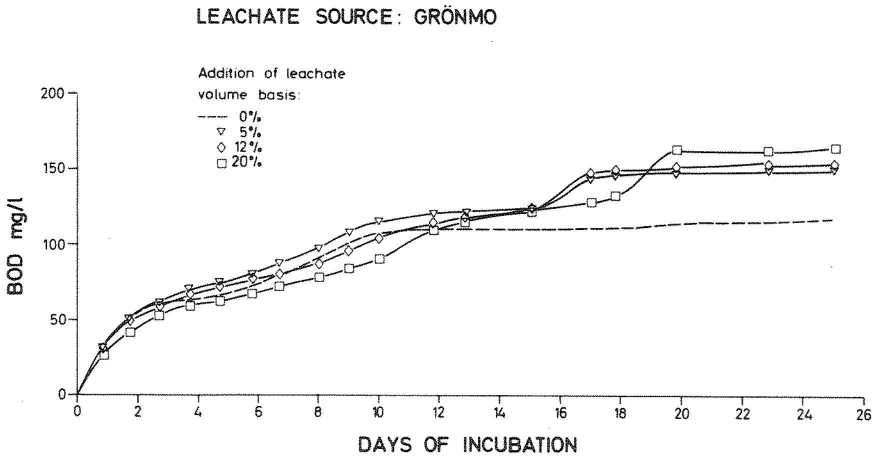


Figure 15. BOD curves of leachate + domestic wastewater, Grønmo.

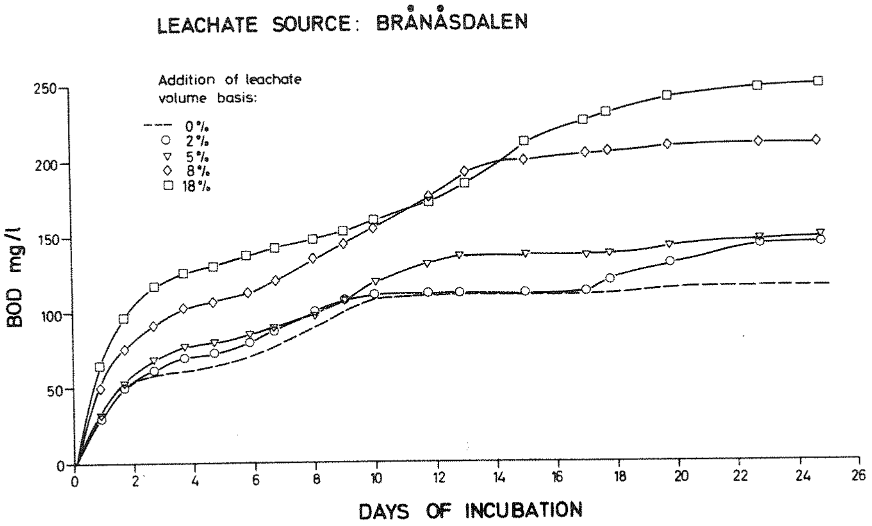


Figure 16. BOD curves of leachate + domestic wastewater, Brånåsdalen.

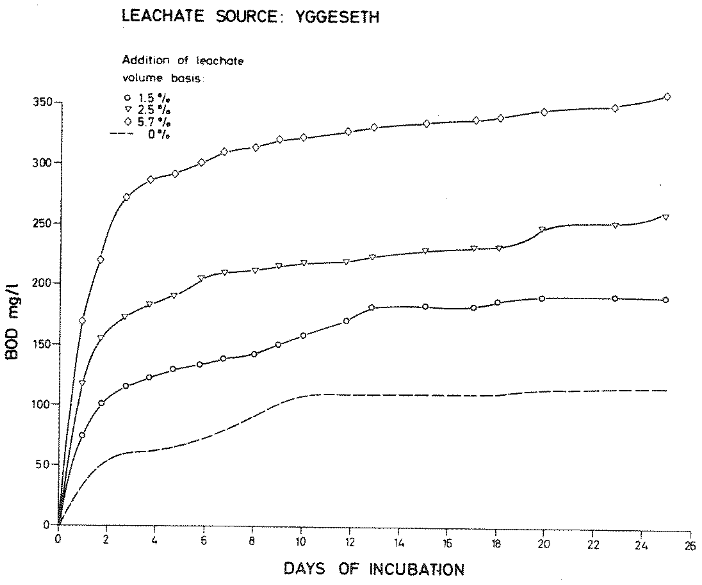


Figure 17. BOD curves of leachate + domestic wastewater, Yggeseth.

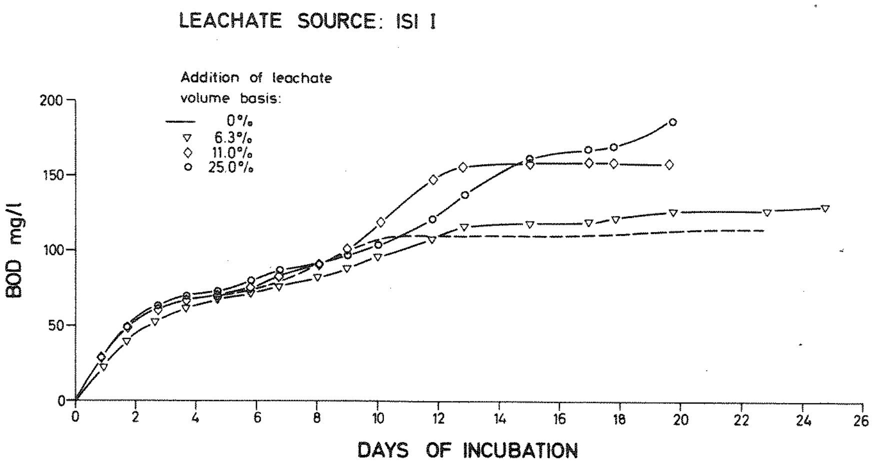


Figure 18. BOD curves of leachate + domestic wastewater, Isi I.

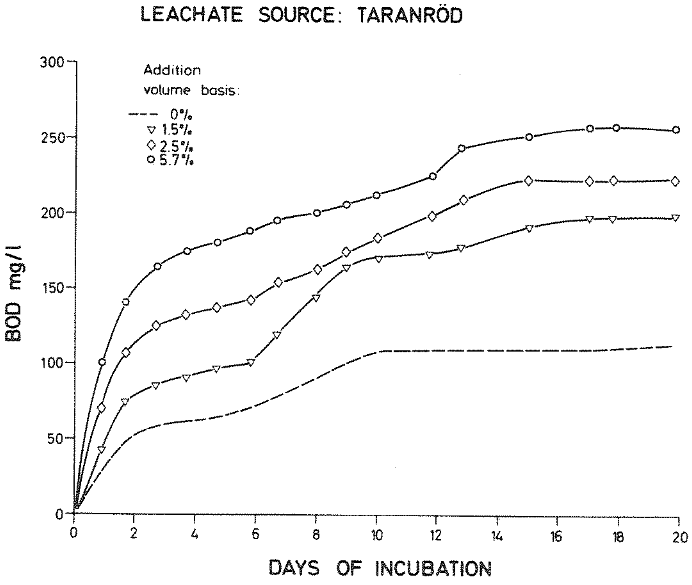


Figure 19. BOD curves of leachate + domestic wastewater, Taranrød.

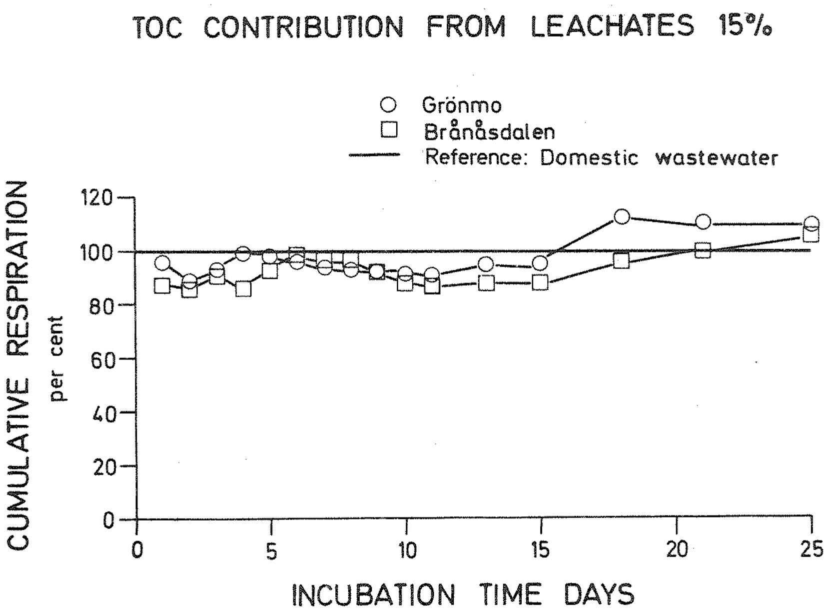


Figure 20. Relative resipiration vs. incubation time TOC contribution from leachates 15%.

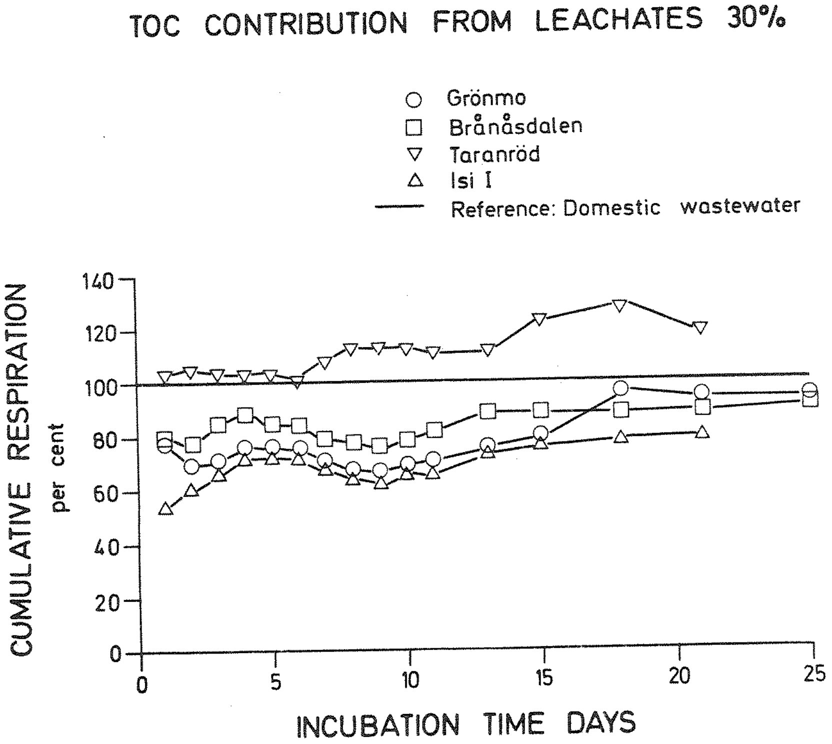


Figure 21. Relative respiration vs. incubation time TOC contribution from leachates 30%.

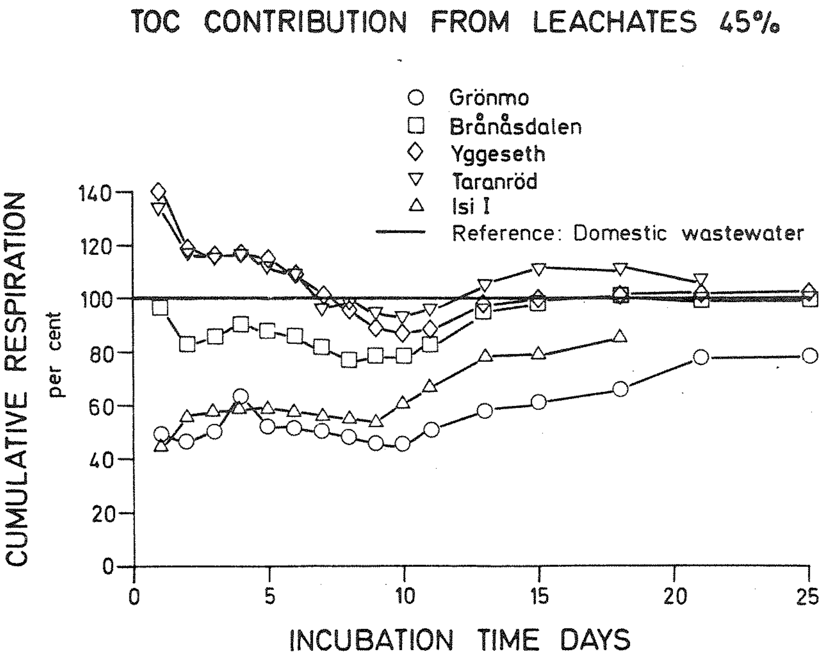


Figure 22. Relative respiration vs. incubation time TOC contribution from leachates 45%.

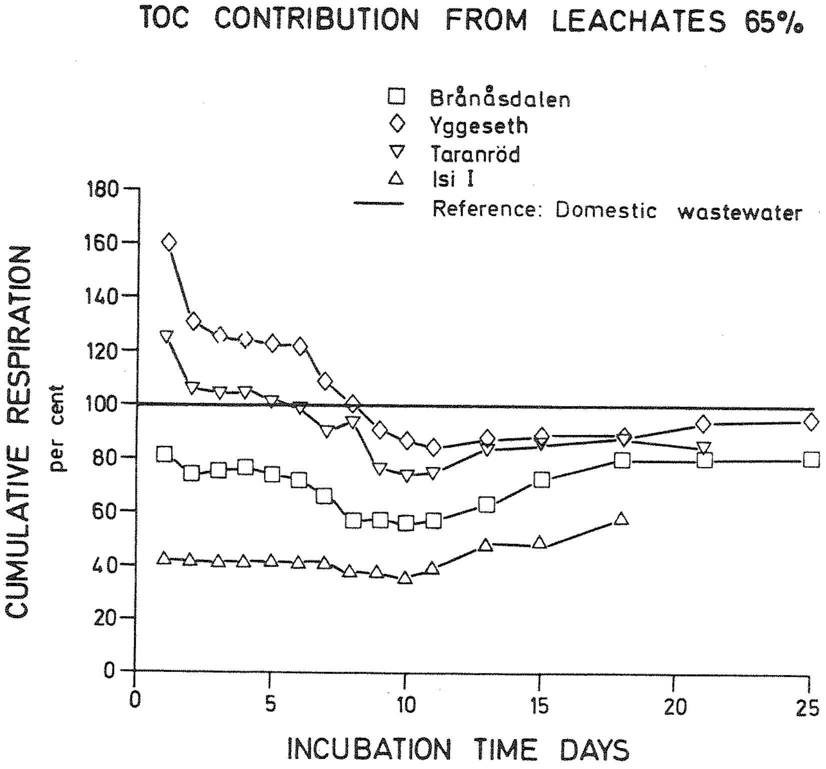


Figure 23. Relative respiration vs. incubation time TOC contribution from leachates 65%.

calculated as TOC. This is done by reducing the respiration values of the samples containing leachate by a factor: TOC domestic sewage/TOC for the actual sample added leachate.

In figure 20 the TOC contribution from leachate is 15%. Little effect on the BOD removal rate can be shown. After an incubation time of 15 to 20 days the BOD values for the samples with leachate show higher BOD values than the reference sample (domestic wastewater). This is due to a considerable higher nitrogen content in the leachates. Without nitrification and with the same fraction of biodegradable organics the curves would have approached the same value.

Figures 22 and 23 show how the respirations are suppressed or stimulated by increasing amounts of leachates. For instance, figure 22 shows stimulated respiration when adding leachates from the landfills Yggeseth and Tarandrød. On the other hand the BOD curves are significantly suppressed for the samples receiving leachates from the landfills at Grønmo and Isi I. A comparison between the different respiration curves gives information regarding the treatability and biodegradability of the different leachate sources.

If we define the relative treatability of the samples as the first day respiration value corrected to the same TOC content and use the domestic wastewater as a reference the curves in figure 24 appear. Figure 24 shows considerably better treatability for the samples containing leachate from Yggeseth and Taranrød than for leachate from Branasdalen, Grønmo and Isi I.

Figure 25 is similar to figure 24 except that the seven day respiration instead of one day is shown. These values are thought to be a measure of the biodegradability of the organics in the leachate sources.

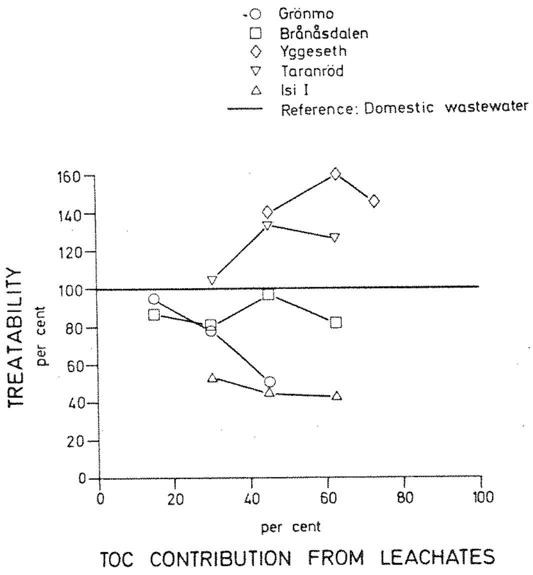


Figure 24. Treatability vs. TOC contribution from leachates.

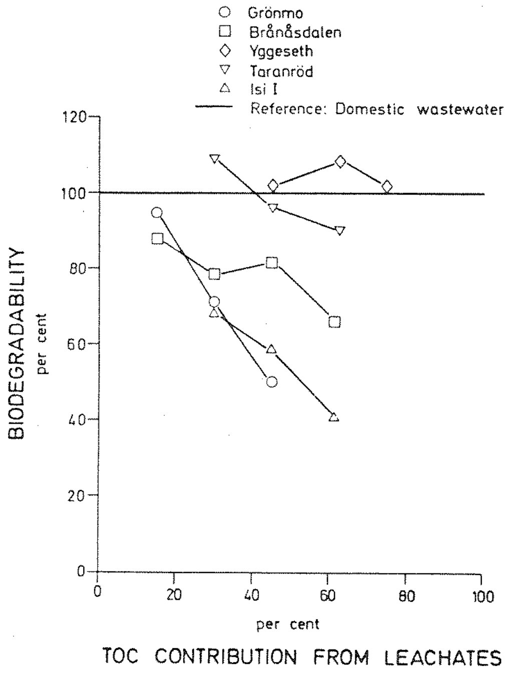


Figure 25. Biodegradability vs. TOC contribution from leachates.

A better value would have been obtained by using longer incubation times but this is omitted because of the influence of nitrification. Another problem in using this method as a measure of biodegradability is the influence of toxicity. With large additions of leachates the influence may be considerable. Figure 25 will therefore only give a rough indication of the different biodegradabilities of the leachates. The curves in figure 25 show decreasing biodegradabilities of the leachates in the following order: Yggeseth, Taranrød, Branasdalen, Isi I and Grønmo. These results were confirmed by later experiments with biological treatment. Treatment with the activated sludge process gave removal efficiencies of 98, 60-70 and 35 percent for the leachates from Yggeseth, Branasdalen and Grønmo respectively.

A measure of the biodegradabilities of the different leachate sources could also be obtained by calculating the ratios of the carboaceous BOD to TOC. These values are shown in table 20. The BOD values are found from figures 2 to 6 and the TOC values from table 16. The toxicity effects are eliminated in these ratios due to sufficient high dilutions in the BOD tests.

Table 20. BOD to TOC ratios in the different leachate sources

Ratio	Landfill					Wastewater sample
	Grønmo	Isi I	Brånåsdalen	Yggeseth	Taranrød	
$\frac{BOD}{TOC}$	1.00	1.27	2.00	2.47	2.62	2.33

For the leachate from Grønmo and Iso I landfills, which show the highest suppression of the respiration values, figures 24 and 25 show a nearly linear relation. This may indicate that the depression in the respiration values in figures 20 to 25 simply were caused by the resistance of the organics to biooxidation. However, toxicity effects occurred which could be calculated from table 20. For instance the respiration value for the mixture of 45 percent TOC from Grønmo and 55 percent TOC from the domestic wastewater should be: $1.00/2.33 \cdot 45 + 1 \cdot 55 = 74$ percent. In figure 25 this value was about 50 percent. Therefore the difference inthe respiration between 74 and 50 percent should be caused by toxicity effects from the leachate. Similar calculations as shown above proved toxicity effects for all the leachate sources at the highest additions. The toxicity effects in the leachates from Yggeseth and Taranrød at the highest leachate additions may be caused by volatile acid toxicities.

The results discussed in this chapter cannot be used for sizing biological treatment plants. However, they give information regarding toxicity effects, treatability and biodegradability of the different leachate sources treated separately or in combination with domestic wastewater.

Another way to measure the treatability is to claculate the BOD reaction velocity constant k, for each of the individual leachate sources. The method of moments described by Moore (1950) is used. This method assumes a first order reactions of the BOD. The reaction can be expressed as

$$\frac{dS}{dt} = -k \cdot S$$

where S is the amount of BOD remaining in the water, and k is the reaction velocity constant.

The method of moments applied to figures 2 to 6 and figure 14 gave the reaction velocity constants in table 21 (Moore (1950)).

Table 21. BOD reaction velocity constants

Leachate source	Reaction velocity constant $k \frac{1}{\text{day}}$
Grønmo	0.11
Brånåsdalen	0.15
Isi I	0.21
Taranrød	0.26
Yggeseth	0.30
Domestic wastewater (reference)	0.27

With the exception of the leachate source from Isi I the results agree well with the results discussed earlier in this chapter. The method of finding the k values is relatively inaccurate. A little change in the BOD curves causes large differences in the k values. Therefore the method described in the first part of this chapter is probably better and gives more information.

B. ALGAL ASSAY

The results of the respiration tests previously described seemed to indicate considerably toxic effects for some of the leachate sources. To get more information of the toxicity effects the impact of leachate on algal growth was studied. This was done to see if the toxicity effects were different for heterotrophic and autotrophic growth. It was also of interest to study the toxicity of leachate on algal growth in general, because all the landfills described are discharging their leachates to brooks or streams.

The different leachate sources were added to a standard algal nutrient solution, 5% Z 8, in different volumes. The volumes added were based on the concentrations of total organic carbon in the leachates. The dosages are given in table 22.

Table 22. Leachate volumes added to standard nutrient solution percent

Landfill	TOC additions from leachates mg/l							
	5	12.5	25	40	50	80	100	160
Grønmo	5	12.5	25		50			
Brånåsdalen		5	10		20		40	
Yggeseth				2.4		4.8		9.6
Taranrød			3.2		6.4		12.8	
Isi I		7	14		28		56	

As test organisms the species Selenastrum capricornutum and Chlamydomonas reinhardii were chosen. The samples were seeded so that they contained 1 million cells per liter from each of the test species. The culture bottles were then placed on a shaker table and incubated at 20 °C under continuous light of about 6000 lux.

The algal growth was measured every day by electronic particle counting. This continued 7 days until no further growth was observed. The concentrations of chlorophyll $\bar{a}$ and algal volume were then measured. Simultaneously the ratio Selenastrum/Chlamydomonas was determined on basis of numbers.

The results of these bio assay tests are shown in figures 26 to 30. Figure 26 show typical growth curves for leachate addions corresponding to additions of total organic carbon equal 25 mg/l. For all incubation days the growth curves based on number of cells show significant inhibitory effects.

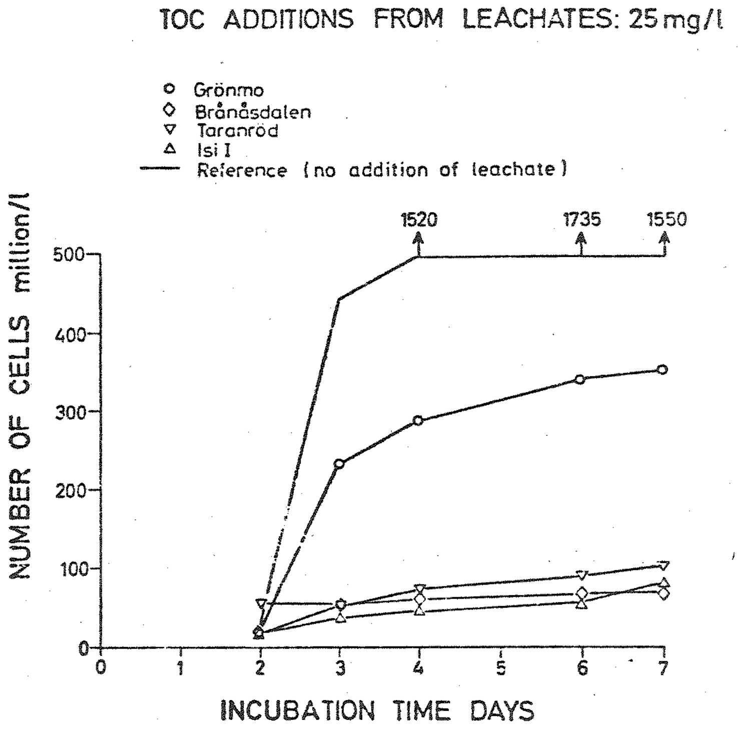


Figure 26. Number of cells vs. incubation time, TOC additions from leachates: 25 mg/l.

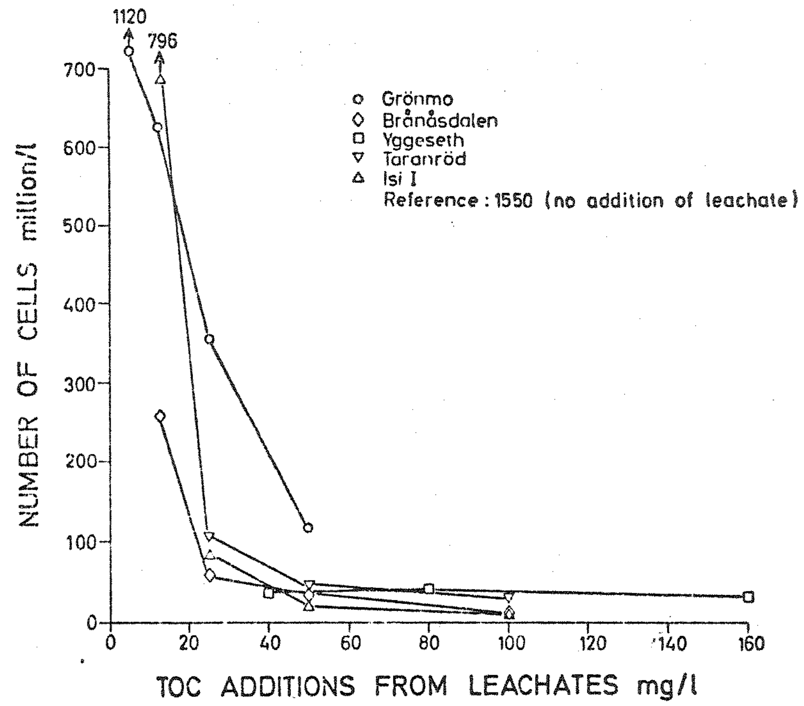


Figure 27. Number of cells vs. TOC additions from leachates.

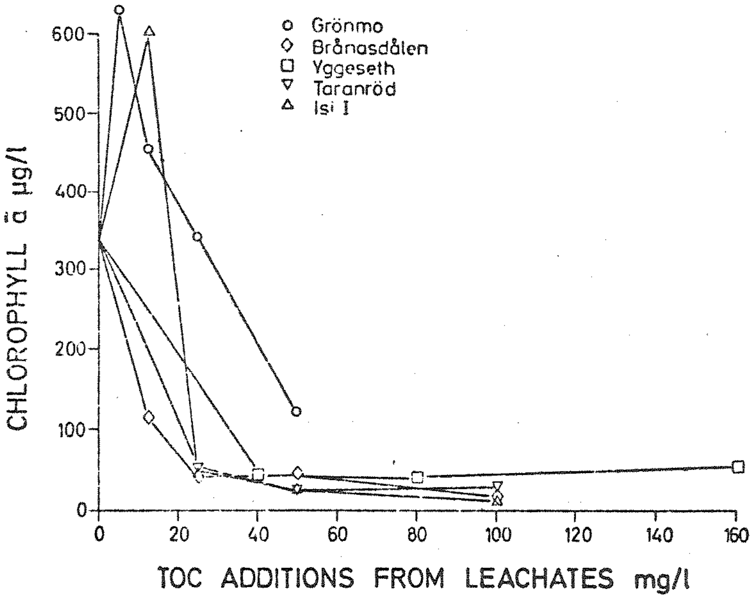


Figure 28. Chlorophyll $\bar{a}$ vs. TOC additions from leachates.

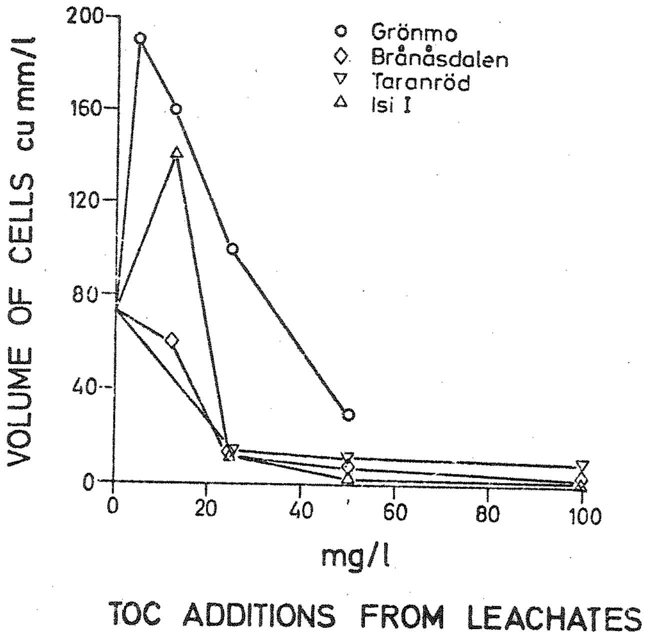


Figure 29. Volume of cells vs. TOC additions from leachates.

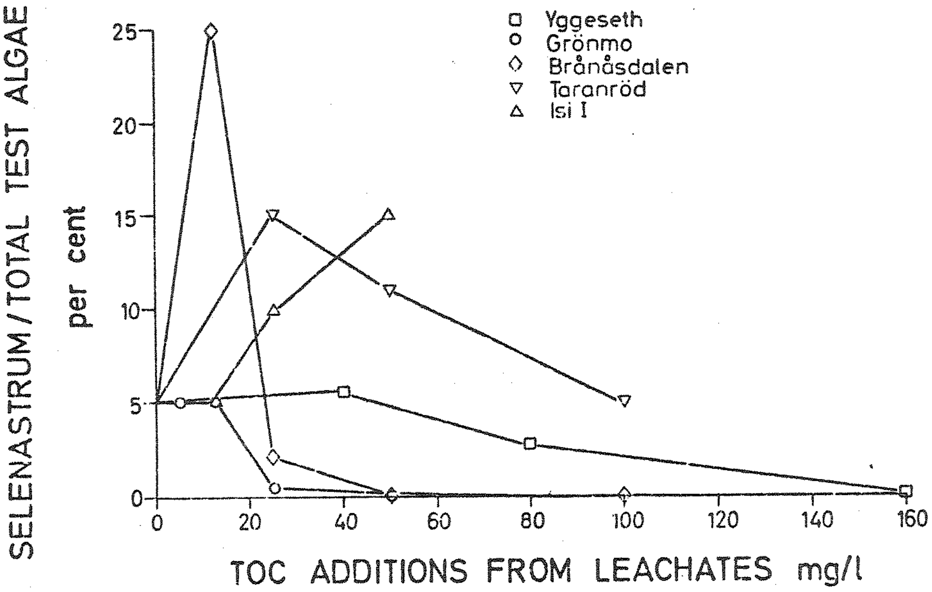


Figure 30. Selenastrum/Total test algae vs. TOC additions from leachates.

Figures 27 to 29 show the seven day values of the total algal growth. The biomass is expressed respectively as: number of cells, concentration of chlorophyll $\bar{a}$ and volume of cells. The growth based on chlorophyll $\bar{a}$ and volume of cells agree very well. The discrepancy between these two figures and figure 27 can partly be explained by the difference in volumes and the ratio of the two species of algae. Another important factor is the influence of the leachate on cell morphology. Thus the cell volumes of Clamydomonas varied from 50 to 250 cu µ depending on leachate source and percent addition. With large leachate additions cell division is suppressed and large cells develop.

Figure 30 which shows the ratio of the two test algae, indicates that Chlamydomonas suppressed Selenastrum. This suppression occours also in the standard solution with no addition of leachates. With the exception of the leachate source from Isi I the fraction of Selenastrum was suppressed with increasing addition of leachates.

From figures 28 and 29 it can be seen that the leachate source from Grønmo and Isi I at low additions have a stimulating effects on the algal growth. These effects may be caused by different nutrients in the leachates. As the additions are increased all the leachate sources show significant inhibitory effects. The leachates from Taranrød and Yggeseth have relatively high concentrations of organic acids. At the highest additions the organic acids may inhibit the algal growth. These result were different from those found in the respiration tests where the leachates from Taranrød and Yggeseth both stimulated the respiration.

The concentrations of heavy metals are so low that heavy metal toxicity seems to be unlikely. Thus for the test samples with addition of leachates from Yggeseth the heavy metal concentrations reached the concentrations given in table 23.

Table 23. Maximum heavy metal concentrations in algal tests

Metal	Concentrations µg/l
Zn	65
Cr	6
Ni	3
Cu	2
Cd	0.1
Pb	1
Co	7

Källquist (1974) has studied the toxicity of Zn, Cu, Cr, Cd and Ag to the algal species used in this algal assay. When testing for the metals separately he found no significant suppression of growth at concentrations considerably higher than those used in this test.

The complex organics in the leachate also increase the presence of chelating agents. The chelating agents bind the metals in complexes not available to the organisms. A study of heavy metal toxicity in activated sludge, described later in this work, showed that heavy metal concentrations in considerable higher concentrations than those used in the respiration and algal tests had little adverse effect.

Most of the leachate sources showed toxic effects on heterotrophic as well as autotrophic growth. Considerable efforts were put into the identification of the toxic materials without much success. Thus for the leachate from Grønmo the total concentrations of hydrocarbons were less than 0.4 mg/l. Cyanides were present in concentrations less than 2 mg/l and phenols at 35 µg/l. Further, no detectable concentrations of oils were found. The toxicity is probably due to several factors. It could be a combination of both organic and inorganic toxic compounds.

C. TREATMENT OF LEACHATE FROM KENT HIGHLANDS SANITARY LANDFILL

Leachate from Kent Highland was treated by anaerobic filters and by the activated sludge process. These treatment studies carried out at the University of Washington were intended to provide preliminary information prior to more intensive research at the Norwegian Institute for Water Research.

1. Anaerobic Filters (Test run no. 1)

The object of this study, denoted as test run no. 1, was to investigate the filter performance over a range of loading conditions and at two temperatures.

One of the filters, denoted A.F.1., was operated at room temperature 24-26°C. The other two filters, denoted A.F.2 and A.F.3, were placed in a cold room at 11°C. The operation at 11°C was of special interest as indicative of winter operations.

To obtain an anaerobic bacterial population as quickly as possible the filters were seeded with anaerobic digested sludge from West Point municipal treatment plant. The void space was completely filled with sludge. Therefore relatively rapid steady state conditions were expected. In this test run the filters were operated on a draw and fill basis. The filters were fed with leachate three times a day. The organic loadings on an empty bed basis were 1.2, 0.4 and 0.8 kg COD/m^3 day for respectively A.F.1, A.F.2 and A.F.3. This corresponded to liquid detention times of 1.4, 4.4 and 2.2 days respectively.

Tables 59 and 60 Appendix B present a summary of the physical and chemical characteristics of the treated and raw leachate. The values given represent the values for the total volume of the effluent collected for the given interval. Because of the relatively slow acclimation of the bacterial population, very few samples were taken at the beginning of the test period.

The results of the most important parameters are shown in the figures 31, 32 and 33.

a. COD Removals. The first plot of figures 31 to 33 show the COD removal of the filters. After 30 days of operation the effluent from the filter A.F.1 reached a COD value of about 1900 mg/l. This gives a COD removal efficiency of about 50%. There was little difference between the COD values of the filtered and unfiltered effluent indicating that nearly all organics were dissolved. The COD effluent values from the filter A.F.1 seemed to decrease in the last part of the test run. This decrease is probably due to a steady increase of the bacterial population in the filter sludge. This assumption was later supported by sludge examinations in test run no.4 and 5.

The filters A.F.2 and A.F.3, operating at 11°C, did not reduce the COD values significantly in spite of a much lower organic loading than for A.F.1. These results show the significance of temperature on COD removal efficiency. The filters operating at 11°C and organic loading of 0.4 and 0.8 kg COD/m^3 day failed in treating the leachate while the filter operating at 25°C and 1.2 kg COD/m^3 day gave about 50% reduction in COD. The latter reduction is also moderate and indicates that lower organic loadings or higher temperatures have to be applied for satisfactory COD removals.

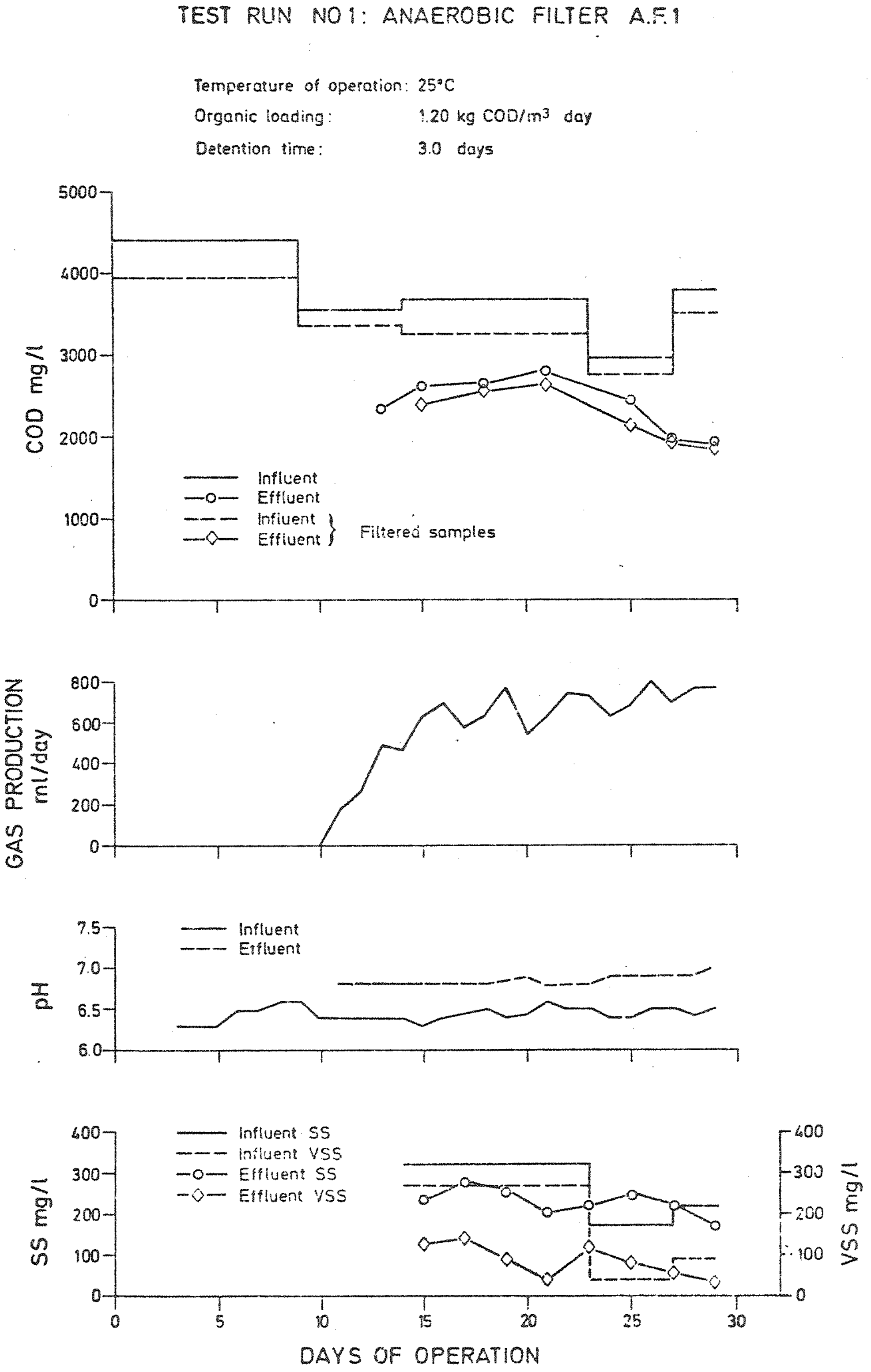


Figure 31. Experimental results, test run no 1, A.F.1.

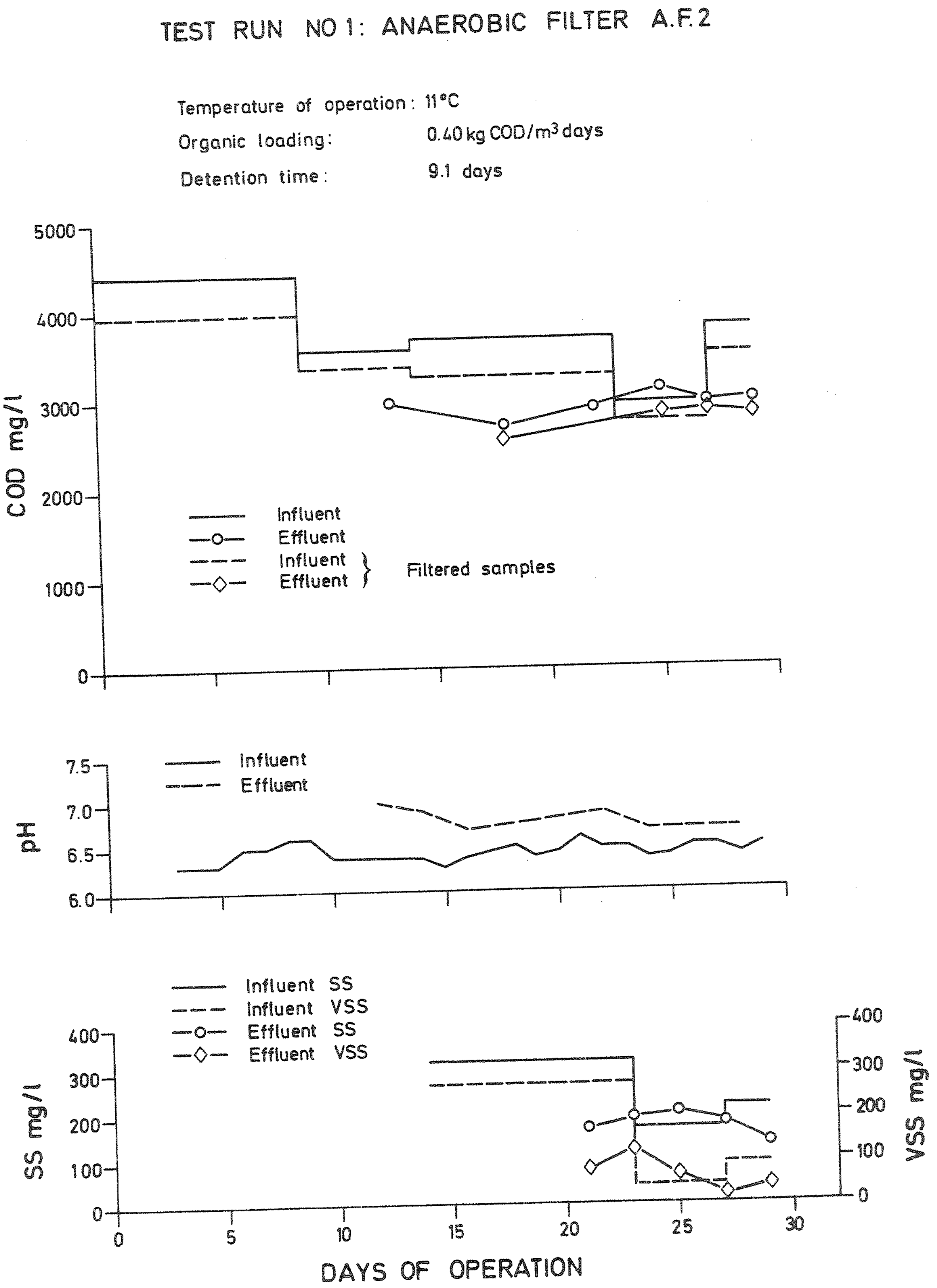


Figure 32. Experimental results, test run no 1, A.F.2.

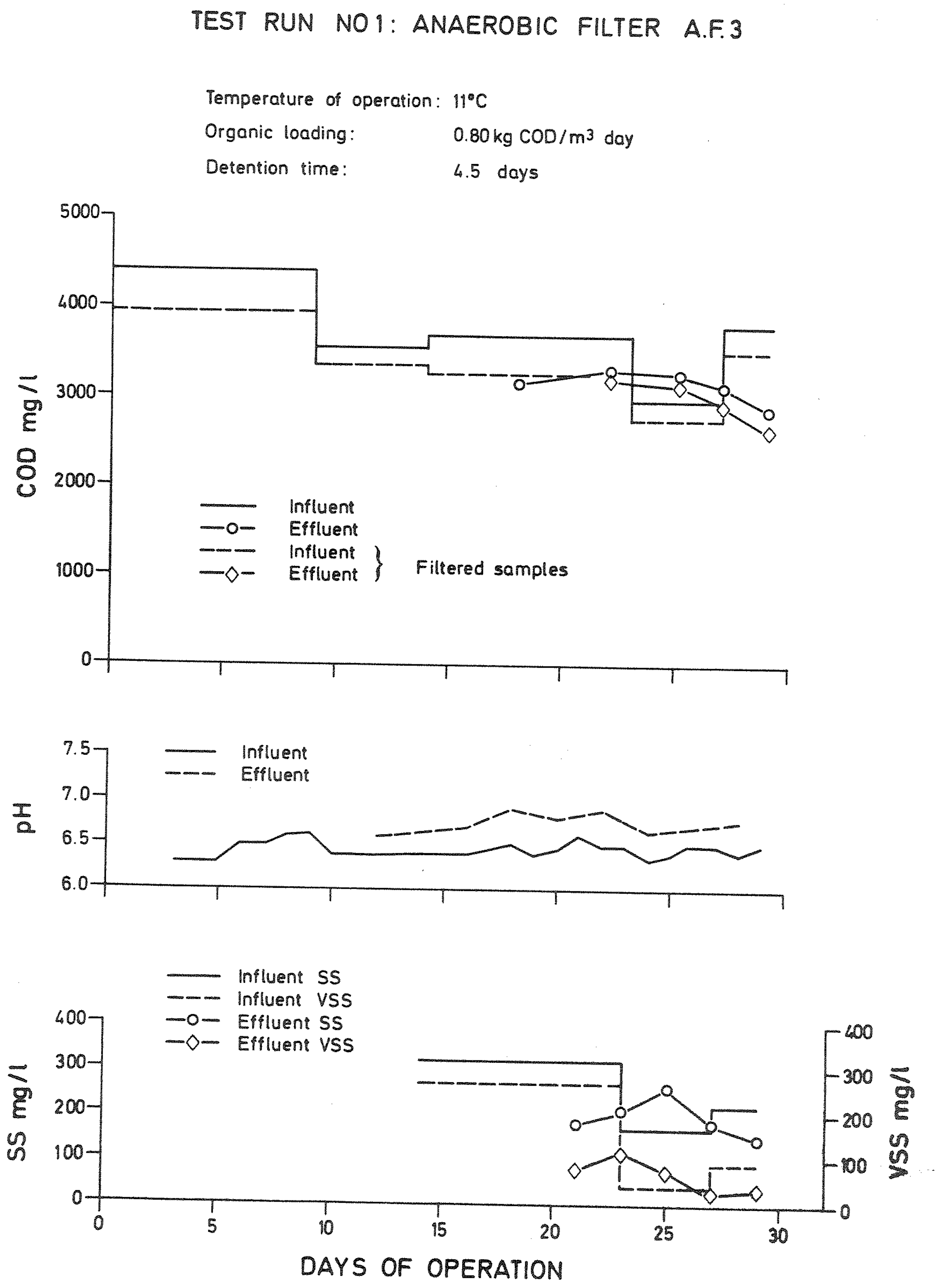


Figure 33. Experimental results, test run no 1, A.F.3.

b. Gas Production. Gas production is related to COD reduction. Only the filter, A.F.1, operating at 25°C produced gas. The gas production leveled out between 15-20 days of operation, indicating that steady state conditions were obtained.

The gas production varied from day to day. This can be explained by the tendency of the gas to be trapped by the filter stones and then released when the bubbles became large enough.

The theoretical COD reduction can be calculated based on gas production. Buswell and Mueller (1952) have shown in experiments that the ultimate oxygen demand of the waste being degraded is equal to the ultimate oxygen demand of the methane gas produced. The ultimate oxygen demand of methane gas can be found from the following equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

One mol of methane therefore have an ultimate oxygen demand of 64 gram, or 22.4 ml methane require 64 mg oxygen for its oxidation.

Under proper anaerobic digestion of domestic sewage sludge the CO_2 and CH_4 content in the gas should range from 30 to 35 percent and 65 to 70 percent respectively (WPCF manual Anaerobic Sludge Digestion (1968)). In the leachate from Kent Highland, acetic, propionic and butyric acids contributed to the main fraction of organics. The theoretical methane production from the organic acids can be calculated from the equation:

$$CH_3(CH_2)_xCOOH + y\ H_2O = z\ CO_2 + u\ CH_4$$

A stoichiometric balance of this equation for acetic, propionic and butyric acids show a methane fraction of 50, 58 and 63 percent respectively. The methane fraction increases with the chain length of the acids up to a value of about 70 percent. In the calculations of the theoretical oxygen demand by means of the gas production a methane content of 60 percent in the gas was used.

The measured gas production at steady state from the filter A.F.1 was 750 ml/day. With a 60 percent methane content in the gas the methane production should amount to an ultimate oxygen demand of:

$$750 \cdot 0.6 \cdot \frac{64}{22.4} \cdot \frac{273}{273+25} = 1178 \text{ mg O/day}$$

The hydraulic loading for this filter was 0.8 liter per day. The theoretical oxygen demand was therefore 1178/0.8 = 1483 mg O/l. In the last part of this test run the COD reduction was about 1875 mg O/l. The theoretical and actual oxygen demand is therefore very close. The number 1875 mg O/l corresponds to a methane content of 67 percent in the gas.

c. pH. The pH of the raw and treated leachate is shown in figures 31 to 33. The pH of the influent was relatively constant during the test period with an average value of 6.5. For the filter operating at 25°C the pH of the effluent reached a steady state value of 6.8. This increase was caused primarily by bacterial activity in the methane producing stage and an increase due to buffering effects of the filtermedia which consisted of crushed lime stones. McCarty (1964a) reports the optimum pH range for anaerobic treatment from 7.0 to 7.2. Thus the pH values of the effluent is below optimum, indicating that the methane forming stage barely could keep up with the organic acid production. Good filter performance in later studies gave pH values of the effluent of 7.5 to 8.0.

For the filters A.F.2 and A.F.3 operating at 11°C, the increase in pH was not so high as for filter A.F.1. This could be caused by less bacterial activity in the methane producing step in these two filters.

d. Suspended Solids. For an anaerobic filter operating under optimum conditions the concentrations of suspended solids are a result of bioligical growth resulting from the decompositions of carbohydrates, proteins and fatty acids. The filters operating in this test run all had high concentrations of suspended and volatile suspended solids in the effluent. However, in this test run with relatively low bacterial activity, the high concentrations of suspended solids was mainly due to low retainment of influent solids in the filter.

e. Heavy Metals. The heavy metal concentrations in the raw leachate in table shows low concentrations with the exception of iron and zinc. The concentrations of zinc are also so low that significant toxic effects were not expected.

In a study of heavy metal toxicity in anaerobic treatment it was shown that iron was non-toxic even in an environment without sulfides (Lawrence et al. (1965)). They concluded that it was not necessary to consider iron in evaluating the possibility of heavy metal effects on anaerobic waste treatment.

f. Conclusions. The results from this test run showed that the filters were somewhat overloaded. Thus the COD removals obtained at an organic loading of 1.2 kg COD/m^3 day was only about 50 percent. However, this COD removal was higher than those found at corresponding loadings in treatment of leachate from Cedar Hills Sanitary landfill (see later). For treatment of this leachate source high COD removals were obtained up to an organic loading of about 0.8 kg COD/m^3 day. Therefore at lower organic loadings and sufficient high temperatures, high COD removals would probably also have been obtained in the treatment of the leachate from Kent Highland.

The results showed that the anaerobic filter process was very sensitive to low temperatures. Thus no reduction of organics and no gas production was found when the filters were operating at 11°C and low organic leadings. If anaerobic treatment of leachates should be feasible it would probably be necessary to keep the temperature at a minimum of 20°C.

2. Activated Sludge - Batch (Test run no. 2)

The purpose of this study, denoted test run no. 2, was to study the behavior and treatment efficiencies of the activated sludge process during different loadings. The influence of pretreatment of the raw leachate was also studied. Thus chemically precipitated and raw leachate was fed to parallel units operating with the same organic loading.

The composition of the raw and chemically coagulated leachates are given in tables 61 and 63. As precipitant, alum $Al_2(SO_4)_3 \cdot 18H_2O$ in doeses 200 mg/l was used. A jar test apparatus was used for the chemical treatment tests. The flocculation time was 15 minutes with a settling time of 20 minutes. The reductions of heavy metals were roughly 50 percent.

The BOD:N:P ratios of the raw leachate were about 500:13:1. The ratio where the nutrients are equally limiting the growth is often given as about 100:5:1.

The activated sludge units were started with activated sludge from Renton municipal treatment plant. The concentrations of mixed liquor volatile suspended solids (MLVSS) were adjusted with tap water to 2500 mg/l. The units were fed on a fill and draw basis three times per day. The experimental conditions for test run no. 2 are given in table 24.

Table 24. Experimental conditions, Test run no 2

Batch unit	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$	Feed
1	0.26	Chemically precipitated
2	0.37	Chemically precipitated
3	0.40	Raw
4	0.56	Chemically precipitated
5	0.80	Chemically precipitated

The experimental results are presented in tables 61 to 65 Appendix B. The most important results are drawn on figures 34 to 37.

a. COD and BOD Removals. The batch units fed with chemically coagulated leachate at organic loadings 0.26 and 0.37 kg COD/kg MLVSS day showed average COD reductions of 97 and 96 percent. The control unit fed with raw leachate at an organic loading of 0.4 kg COD/kg MLVSS day also gave a COD reduction of 96 percent. Therefore chemical pretreatment of the leachate had no beneficial effects on the organic removal rate. The high COD removals show that this leachate can be almost completely biodegraded by the activated sludge process. The high organic removal efficiencies also indicate that the leachate is not nutrient limiting.

The units which were fed with chemically precipitated leachate at loadings 0.56 and 0.80 kg COD/kg MLVSS day both failed. The units were simply overloaded. The results show that the COD removal efficiencies start to fall severely at an organic loading of about 0.5 kg COD/kg MLVSS day.

The COD reductions obtained in the batch units cannot directly be transferred to units operating on a continuous basis. A batch unit where the reactions are of the plug flow type have normally faster reaction rates

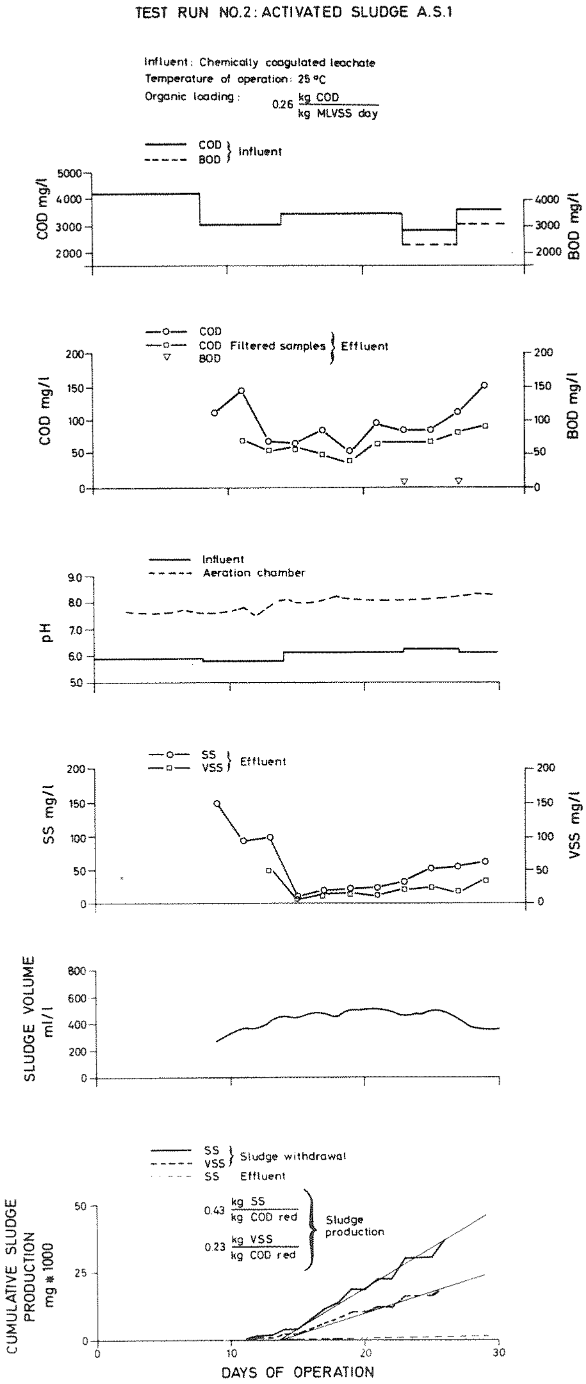


Figure 34. Experimental results, rest run no 2, A.S.1.

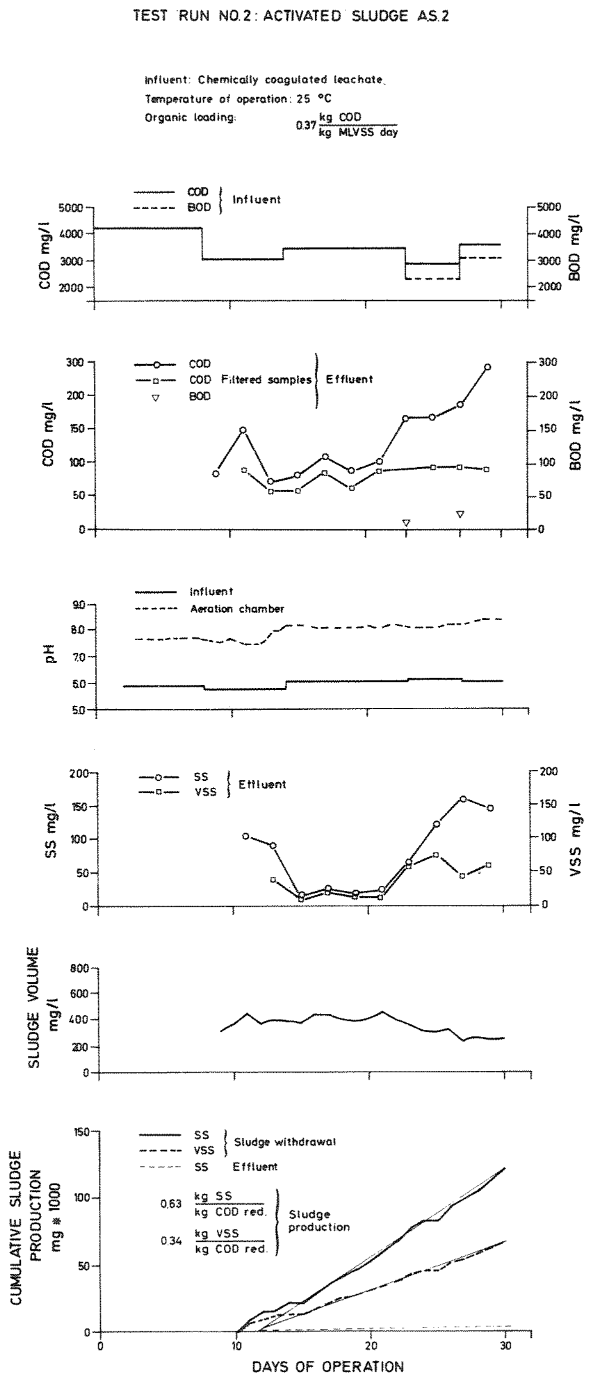


Figure 35. Experimental results, test run no 2, A.S.2.

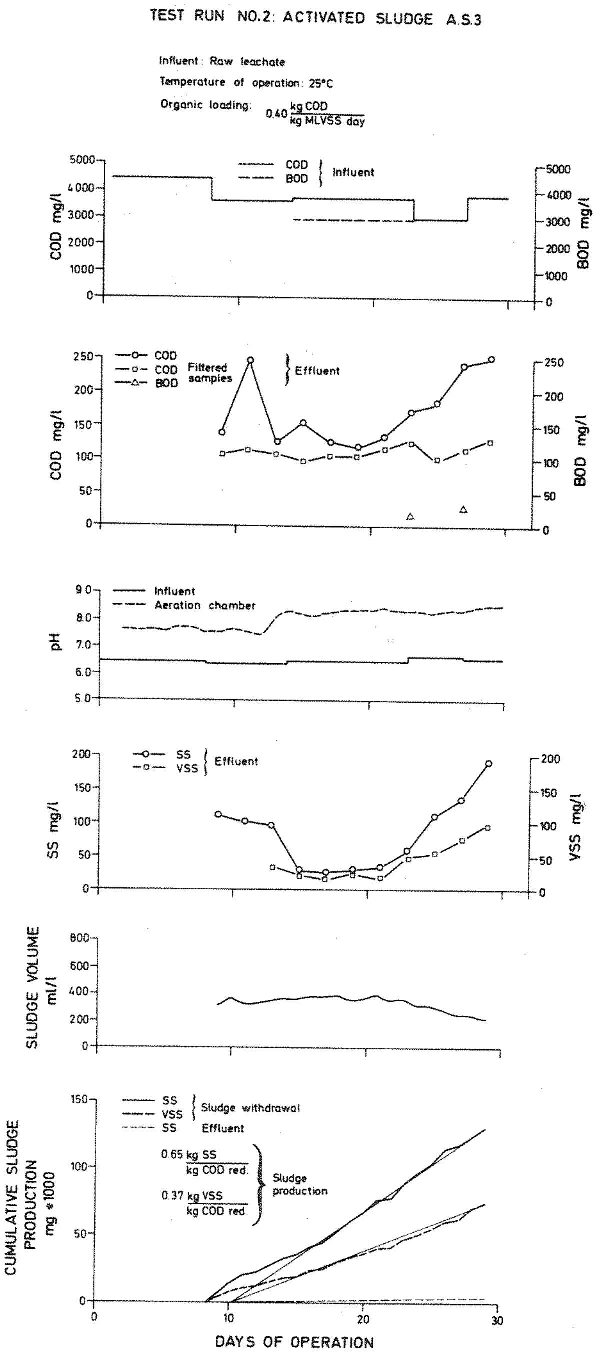


Figure 36. Experimental results, test run no 2, A.S.3.

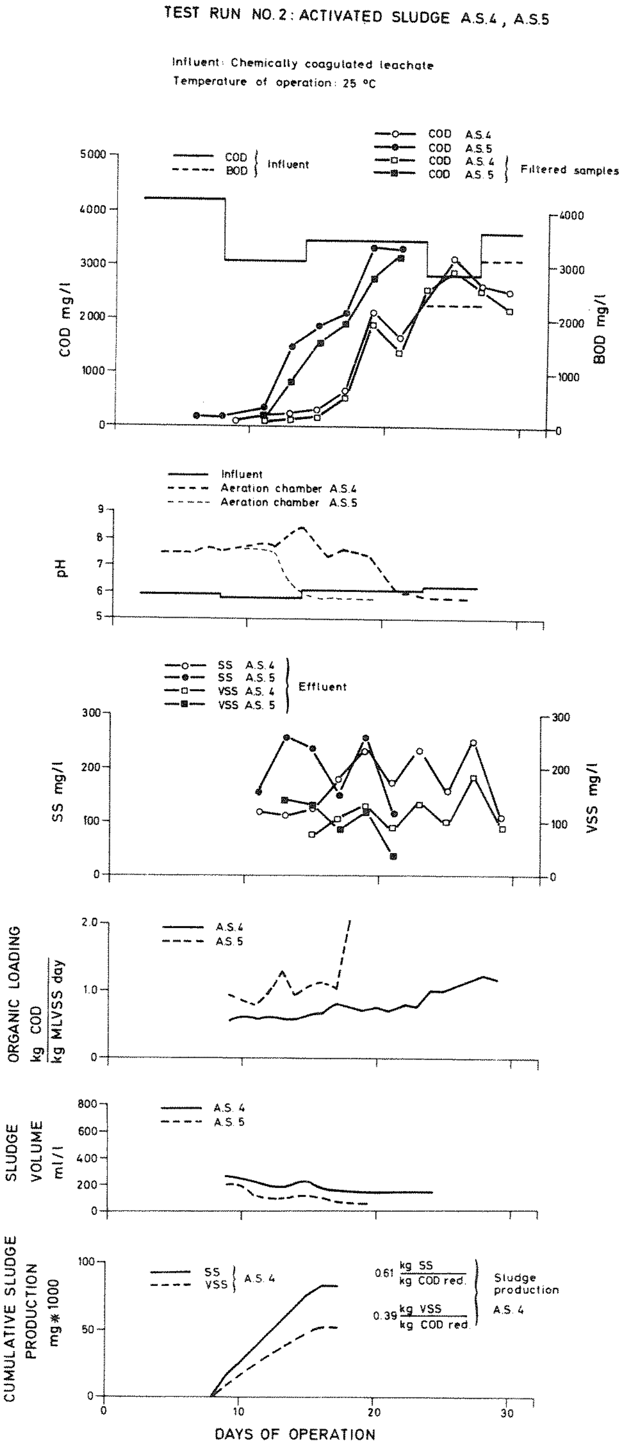


Figure 37. Experimental results, test run no 2, A.S.4, A.S. 5.

than in a completely mixed system. Therefore the COD removals in a batch system are expected to be slightly better than in a continuous system. On the other hand the batch system is more sensitive to toxicants and to shock loadings.

Since COD was used to indicate the performance of the units, BOD was checked only few times. In the units with the lowest organic loading the BOD_5 was reduced to a level of 10-20 mg/l. This corresponds to a BOD reduction of about 99 percent. The relatively high COD/BOD ratio of about 10 indicates that the treated leachate has relatively high concentrations of residual organics.

b. pH. In the three units that operated well the pH in the aeration chambers was about 8. The increase from pH 6 in the influent to about 8 is mainly due to the degradation of organic acids. The high aeration intensities and long detention times in these small units also cause low CO_2 levels which will raise the pH values.

For the overloaded units A.S.4 and A.S.5 the pH started to decrease at the same time the effluent COD values began to increase. For the units with the highest organic loading the pH decreased from a steady state value of 7.3 to the influent value of about 6 within three days. For the other overloaded unit A.S.4 the decrease was slower.

The decrease in the pH was probably caused by organic acids. When the units became overloaded the degradation of the acids ceases resulting in a decrease of pH.

c. Suspended Solids. The well operating units gave an effluent with relatively high concentrations of suspended solids. Average values were 57, 78 and 76 mg/l for A.S.1, A.S.2 and A.S.3 respectively. Thus it was no different for the solids concentrations from the units treating raw and chemically treated leachate.

For the units with low organic removal efficiency the effluent concentrations of suspended solids were very high. This was caused by poor flocculation of the activated sludge.

d. Settleability. The settleability of the activated sludge was good for all loadings. The highest value of the sludge volumes 520 ml/l was observed in the unit with the lowest organic loading. That corresponded to a sludge volume index of 92. For the higher organic loadings the settleability was still better. Thus for the units A.S.2 and A.S.3 the sludge volume indexes averaged 66 and 59 respectively.

The good settleability of the activated sludge may be caused by the character of the leachate. Normally leachates have low contents of simple hydrocarbons and, therefore, little filamentous growth is expected. The high concentrations of iron in the feed will also contribute to low sludge volume indexes. The improvement of the settleability caused by iron has been studied by Pfeffer (1967) and Carter et al. (1973). They found that an insufficient supply of nutrients often resulted in a bulky sludge. They concluded that iron very often was the most deficient nutrient because growth studies showed optimum growth at iron concentrations of about 10 mg/l.

Neufeld et al. (1973) also discussed the improved settleability caused by iron, but noted that deflocculation also may occur. The deflocculation increases with increasing metal concentrations. This agrees well with the results found in this study. The activated sludge settled rapidly but the supernatant contained relatively high concentrations of suspended solids. This was specially a problem for the units operating at high organic loadings. The severe deflocculation gave a loss of cells such that the activated sludge concentrations could not be maintained.

e. Sludge Production. The last graphs on the figures 34 to 37 show the MLSS and MLVSS productions for the batch units throughout the time of operation. Figure 38 show the sludge production as a function of organic loading. The ratio of the suspended and volatile suspended solids in the sludge may vary somewhat. This is due to different accumulations of inorganics mainly iron, in the sludge.

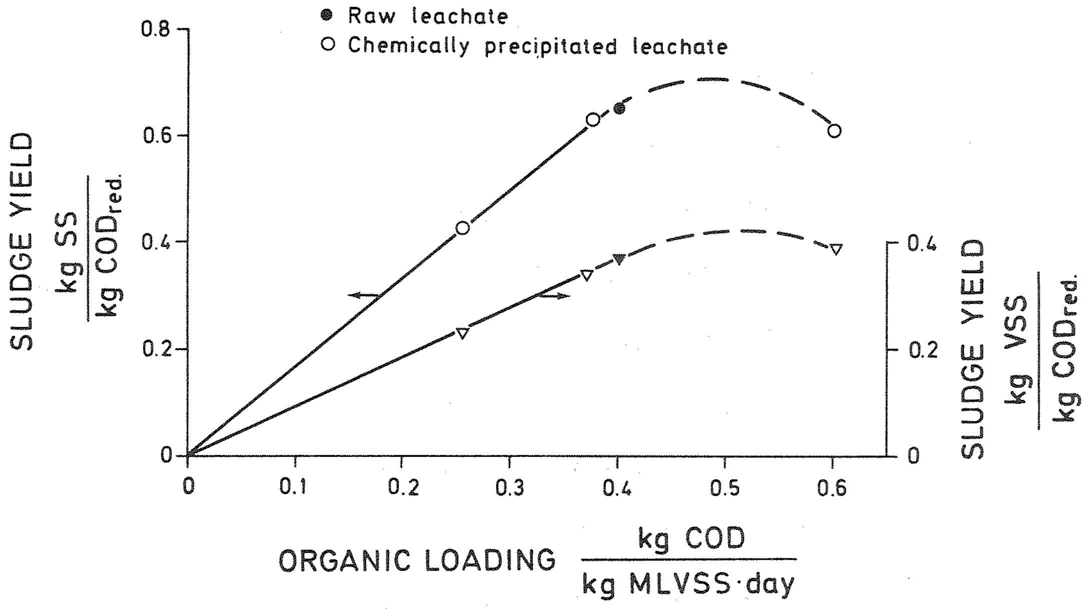


Figure 38. Sludge production vs. organic loading.

f. Microscopic Examination. Microscopic examinations of the activated sludge were performed for all the units.

For the well operating units a relatively well flocculated sludge existed.

Both stalked and free swimming ciliates were present in large numbers. Amoeba and rotifers also existed but in smaller numbers. Filamentous bacteria were not observed.

For the overloaded units the sludge was not so well flocculated. A large number of the bacteria were free swimming. Protozoa also existed but in relatively small numbers. The sludge in the overloaded activated sludge units was not well flocculated which caused loss of sludge through the supernatant.

3. Activated Sludge - Continuous (Test run no. 3)

The results from the previous test run gave same results which were desirable to study in more detail. Especially the decrease in pH simultaneously with the decreasing COD removal was of interest. The effects of the decrease in pH is different in a continuous and a batch system. A batch system will normally be more sensitive to toxic materials added suddenly in large quantities. Therefore a continuous system may accept a higher organic loading because of the continuous degradation of toxicants. This study, denoted test run no. 3, was intended to determine whether the continuous system could be loaded higher than the batch system. Of special interest were also the factors which caused the decrease in pH when the units were failing. To investigate the above mentioned factors the treatment processes in three continuous laboratory activated sludge units were studied.

Activated sludge from the batch units treating raw leachate, was transferred to the continuous units. Thus a relatively quick acclimation to the different loadings was expected. The three units were all fed with raw leachate and were given the following loadings:

Table 25. Experimental conditions, Test run no 3

Unit no	Organic loading kg COD/kg MLVSS day
1	0.28
2	0.49
3	0.70

The leachate was collected from the same leachate source as that used in the previous test run. Due to stable weather the composition and concentrations of the raw leachate was nearly the same. The small volume of the plants made it necessary to use as long feed intervals as long as one hour. However, the small volumes fed at each interval of the long detention times causes a nearly continuous feed.

The results from this test run are given in tables 66 to 68 appendix B and drawn in figure 39 to 41.

a. COD Removals. The unit operated at an organic loading 0.28 kg COD/kg MLVSS day and gave COD reductions in the range of 92 to 97 percent.

The units loaded at 0.49 and 0.70 kg COD/kg MLVSS day were overloaded. In the first part of the test period the COD removals were good because of the large microbial population used to start the units. But the systems were soon overloaded and after eleven days of operation the effluent COD started to increase. The concentrations of activated sludge also decreased because of poor flocculation of the sludge.

In the previous test run the pH started to decrease simultanously as the effluent COD started to increase. In this test run no significant decrease in pH due to overloading was observed. Concentrations of organic acids in the

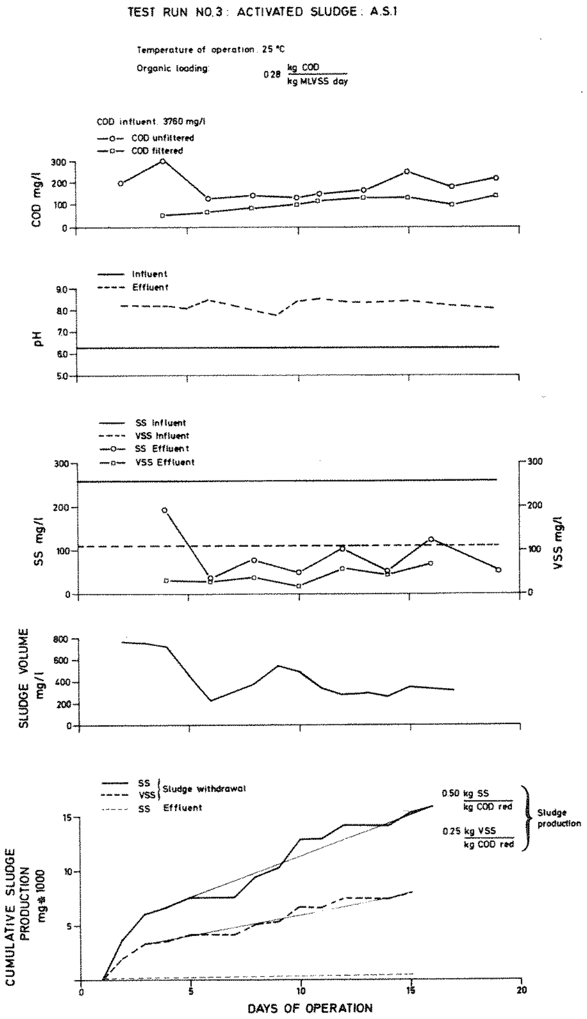


Figure 39. Experimental results, test run no 3, A.S.1.

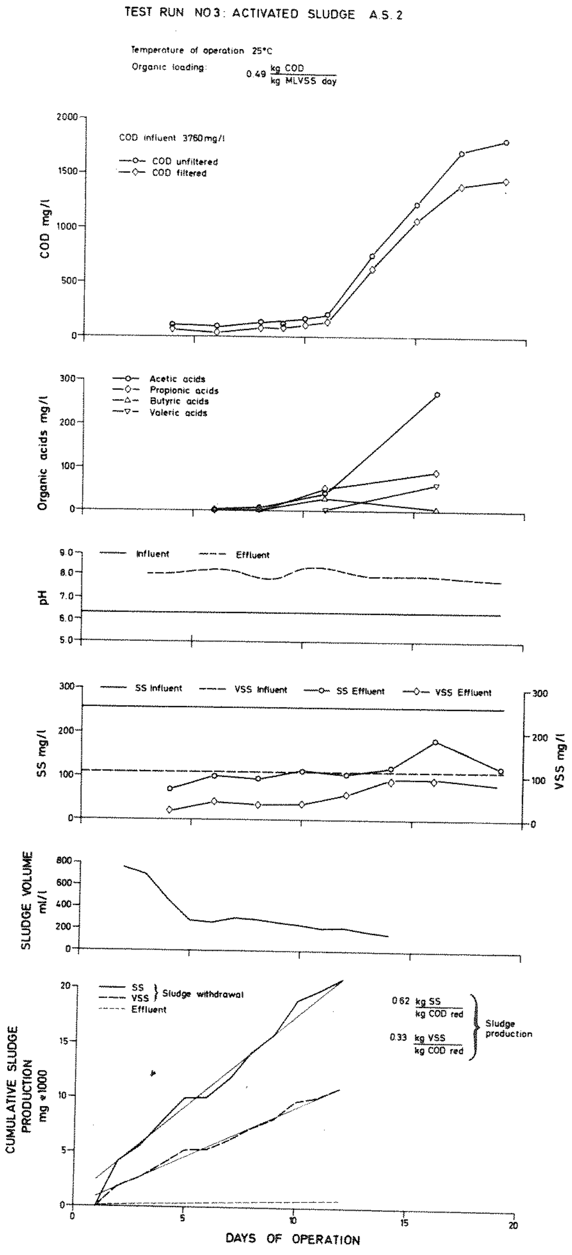


Figure 40. Experimental results, test run no 3, A.S.2.

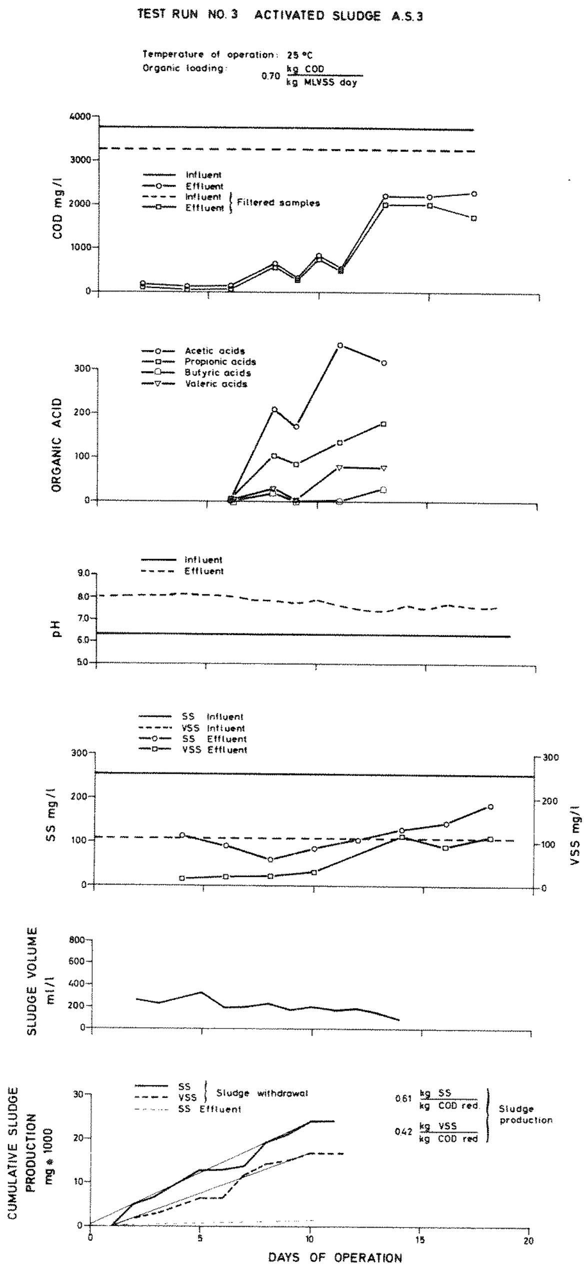


Figure 41. Experimental results, test run no 3, A.S.3.

effluent were also measured. The results in figure 40 and 41 showed that the effluent concentrations of organic acids and COD started to increase simultanously.

A carbon balance of the effluent for the unit A.S.2 is shown in table 26. The values given are for samples taken after 21 days of operation. In the calculations a ratio of COD/TOC of 3.5 is used.

Table 26. Carbon balance for treated leachate

Organic acids	mg acid/l	mg C/l
Acetic acids	270	108
Propionic acids	190	90
Valeric acids	110	65
Butyric acids	5	3

Total organics identified 266 mg C/l
Measured COD: 1240 mg O/l = 354 mg C/l

The effluent carbon balance at failure shows that the organic acids predominate the organics.

b. pH. In the well operated unit the pH in the aeration chamber was relatively stable. The influent pH of 6.3 was raised to an average value of 8.3.

For the two units which failed the pH dropped somewhat but not as much as supposed. The increase in organic acids in the last part of the test run was so high that the pH of the effluent was expected to decrease nearly to the influent value.

c. Suspended Solids. The concentrations of suspended solids for the plant with good performance ranged from 37 to 195 mg/l. The average concentration was 83 mg/l. A small laboratory plant is very sensitive to loss of sludge so the large range of the effluent suspended solids was not unexpected.

For the overloaded units the concentrations of suspended solids increased with time of operation.

d. Settleability. The settleabilities were good for all the units. Thus the sludge volume index for A.S.1 averaged 74.

e. Sludge Production. The sludge productions were found to be 0.25, 0.33 and 0.42 kg VSS/kg COD reduced. The corresponding organic loadings were 0.28, 0.49 and 0.70 kg COD/kg MLVSS day. The latter two sludge yields are doubtful due to overloading of the corresponding units.

f. Metals. The concentrations of heavy metals in the influent were so low that inhibitory effects is unlikely. Some reduction took place due to precipitation and accumulation in the sludge.

Heavy metal analyses of the sludge at the end of the test run showed the following concentrations:

Table 27. Heavy metal analyses of raw leachate and activated sludge, A.S.1

Heavy metal		Fe	Zn	Cu	Ni	Cd	Cr	Pb
Activated sludge^x	mg/l	43.0	15.8	9.9	2.5	0.06	0.20	1.0
Raw leachate	mg/l	23.0	3.7	1.3	0.4	0.03	0.65	<1.0

^{x}MLSS: 5410 mg/l
MLVSS: 2380 mg/l

The results show that precipitation and adsorption of the metals in the sludge with subsequent sludge withdrawal is an important mechanism for heavy metal removals from the leachate.

g. Microscopic Examination. The microscopic examination showed similar results to the previous test run. That is, in the well operating unit, bacteria, amoebae, protozoa and rotifers were present. In the units which failed smaller number of the higher organisms existed and the flocculation of the bacteria was poor.

4. Comparison of the Results from the Batch and Continuous Activated Sludge Process

The results from test run no 2 and 3 showed that leachate from Kent Highland sanitary landfill could be treated sucessfully by the activated sludge process.

The organic removal efficiencies for test run no 2 and 3 are shown in figure 41. The dots and circles are results from treating raw respectively chemically treated leachate. The figure shows that the activated sludge process give very high COD removals up to a loading between 0.4-0.5 kg COD/kg MLVSS day. When overloading occured the results showed that an increase in the organic acids occured. The high concentrations of the acids in the effluent reflected little or no degradation.

The results also proved that no difference in COD removal efficiencies existed in treating raw or chemically precipitated leachate. In spite of big differences in the concentrations of suspended solids in the raw and chemically precipitated leachate no significant differences in the solids

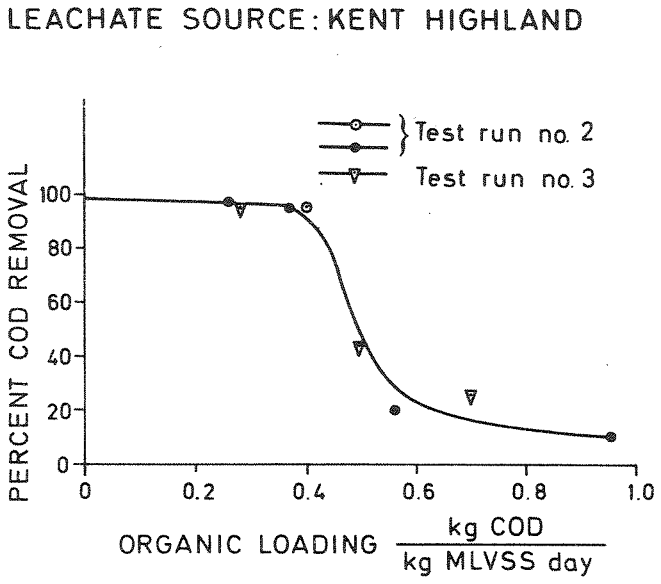


Figure 42. COD removal vs. organic loading.

concentrations of the biologically treated leachates were observed. The solids in the feed were efficiently removed by sedimentation and degradation. The relatively high concentrations of suspended solids in the effluent mainly consisted of microbial growth.

Pretreatment of leachate with high concentrations of heavy metals will probably be of advantage. However, high concentrations of iron in the leachate and high pH in the aeration chambers would normally give a favorable environment for precipitation. Heavy metal analyses of the activated sludge proved that the metals accumulated in the sludge. Therefore some reduction of heavy metals took place by accumulation and sludge withdrawal. Due to this removal mechanism the reduction of heavy metals must be a function of the organic loading. That is removal will increase with the increasing excess sludge.

The settleability of the avtivated sludge was good. However, the clarified supernatant contained relatively high concentrations of suspended solids.

This suspended solids mainly consisted of microbial growth. With increasing organic loading the activated sludge flocculated poorly. Above the critical loading the flocculation was so poor that the concentrations of activated sludge could not be maintained.

D. TREATMENT OF LEACHATE FROM CEDAR HILLS SANITARY LANDFILL BY ANAEROBIC FILTERS

In test run no 4 and 5 the treatability of leachate from the sanitary landfill at Cedar Hills was investigated using anaerobic filters. The leachate had an organic content of about ten times higher than for the previously investigated leachate. The characterization and composition of the leachate used in test run no 4 are given in table 16 and 17.

Immediately after test run no 1 was accomplished the filters were installed in a room at 22°C. An automatic feed system was installed which fed the filters once every hour.

Work done by Caudill (1968), Young (1968) and Force et al. (1973) showed that the majority of the waste stabilization occured in the bottom of the filters. They suggested that the upper part of the filter was quite inactive. To investigate the possibilities and results of utilizing the whole filter depth it was decided to install a recirculation pump. This should pump treated effluents into the filter in order to get a better utilization of the filter. By utilizing more of the filter height it should be possible to use a higher organic load or obtain a higher organic removal efficiency. To avoid too violent recirculation or washing out of the bacterial growth the recirculation pump was operated by a timer which put the pump in operation four times an hour. The total recirculation volume was 60 ml/hr.

With the experience from test run no 1 it was decided to reduce the organic loadings. To compare the efficiency of the recirculation, two of the filters were given the same organic loading but one of them without recirculation. Due to the long detention times in test run no 4 the filters were started with 1.5 liters of leachate. Test run no 5 was started immediately after test run no 4.

The result from test run no 4 and no 5 are drawn in figures 43 and 47. The data are given in tables 65 to 74, appendix B. The raw leachate used in test run no 5 was collected in the winter during a wet period. Therefore the concentrations of the different parameters were much lower than in test run no 4. The organic loadings used in test run no 4 and 5 are given in table 28.

Table 28. Experimental conditions for test run no 4 and 5

Test run no	Filter unit	Recirculation of effluent	COD operation mg/l	Days of operation	Organic loading $\frac{kg\ COD}{m^3\ day}$	Liquid detention time days
4	A.F.1	No	38800	52	0.25	73
4	A.F.2	No	38800	52	0.73	26
4	A.F.3	Yes	38800	52	0.73	26
5	A.F.1	No	9100	40	0.16	28
5	A.F.1	No	9100	29	0.29	15
5	A.F.2	Yes	9100	40	0.37	12
5	A.F.2	No	9100	29	0.53	8.3
5	A.F.3	No	9100	31	0.36	12
5	A.F.3	No	9100	13	0.24	18
5	A.F.3	No	9100	29	0.76	5.7

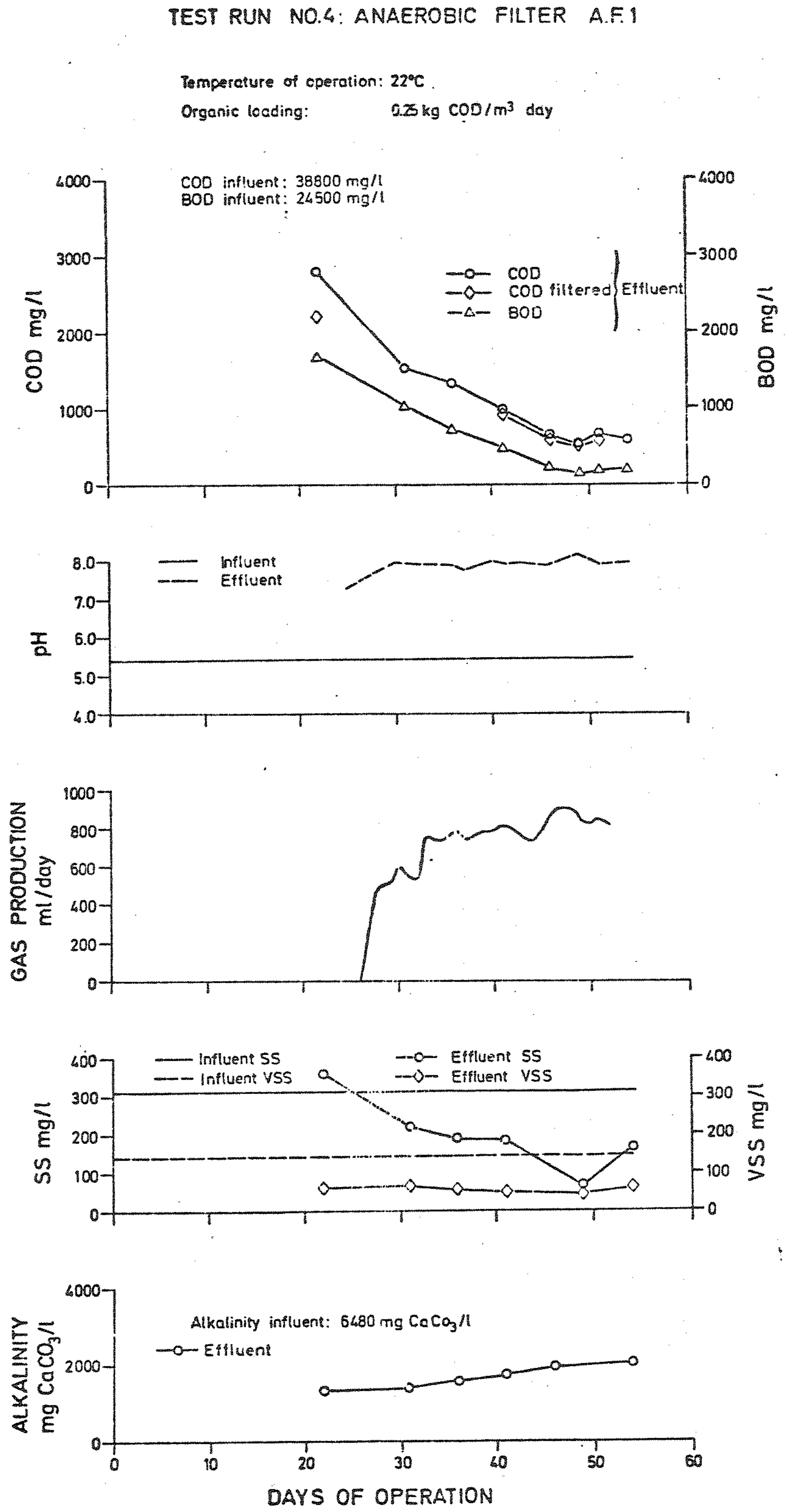


Figure 43. Experimental results, test run no 4, A.F.1.

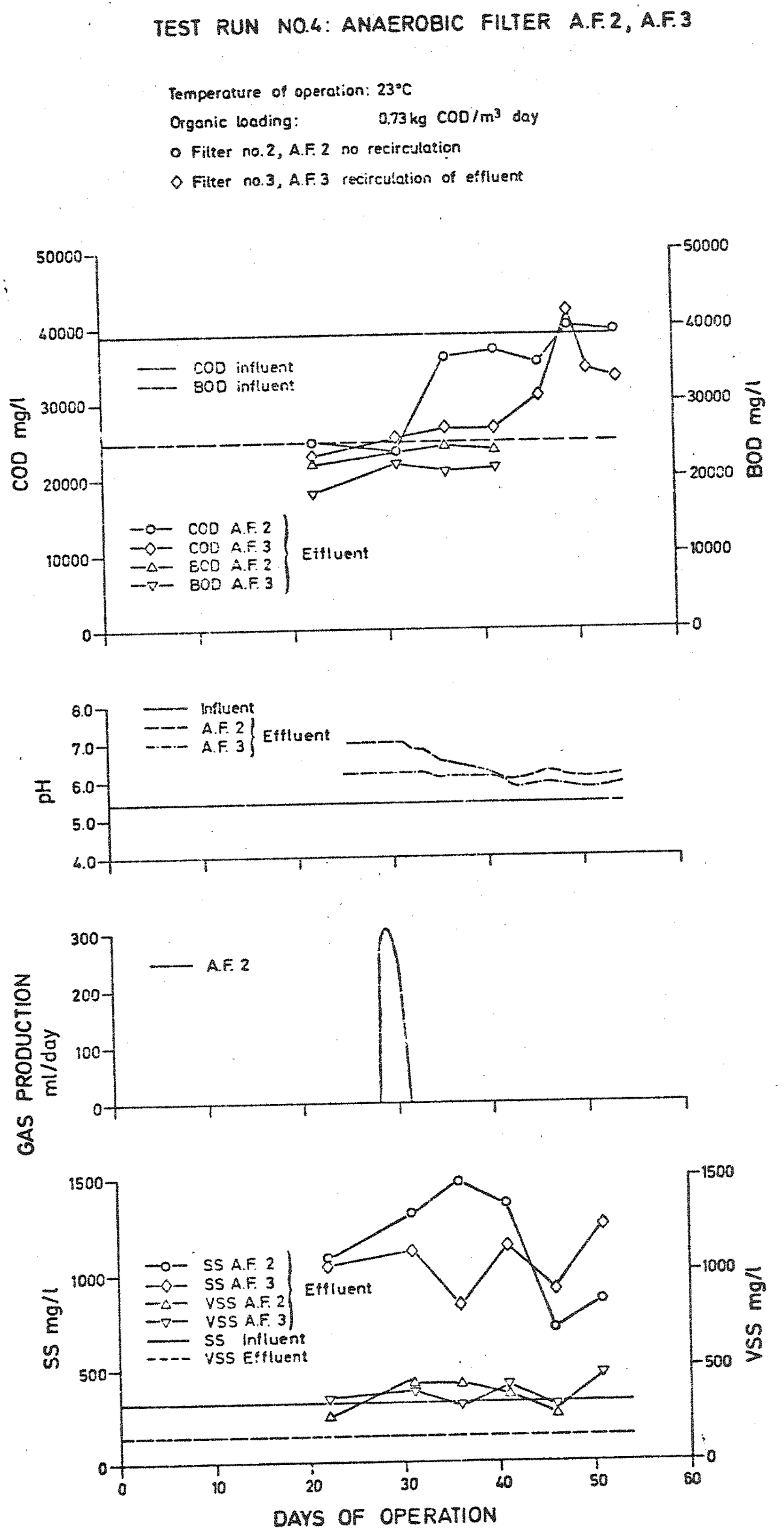


Figure 44. Experimental results, test run no 4, A.F.2, A.F.3.

1. COD and BOD Removals

a. Test Run No 4. For the anaerobic filter A.F.1, operating at an organic loading of 0.25 kg COD/m^3 day, the COD or BOD in the effluent steadily decreased. After about 45 days of operation the COD and BOD values seemed to level out. The COD of the influent was reduced from 38 800 mg/l to about 600 mg/l. This corresponds to a COD removal efficiency higher than 98 percent. The COD values of the filtered and unfiltered effluent samples show that nearly all the residual organics were dissolved.

The effluent BOD curve for A.F.1 (figure 43) shows the same pattern as the COD curve. The BOD values were reduced from 24 500 mg/l to about 180 mg/l. This is a BOD reduction higher than 99 percent. The relatively high ratio between the COD and BOD values of the effluent is due to a high fraction of non biodegradable organics. Sulfides also contribute to an increased ratio of COD to BOD.

The anaerobic filters A.F.2 and A.F.3 with organic loading 0.73 kg COD/m^3 day both gave low organic removal. The filters with and without recirculation gave the same results. These results were not expected because a higher organic loading in test run no 1 gave about fifty percent reduction of organics. The critical loading, or the loading where the organic removal efficiency starts to fall sharply was less than 0.73 kg COD/m^3 day. Both the filters with and without recirculation failed at the same loading, no conclusion can therefore be drawn on the effects of recirculation.

b. Test Run No 5. The filters in test run no 5 were operating with a relatively low organic loadings. Therefore good COD removal efficiencies were obtained.

The figures 45 to 47 show a steadily increase in the COD removal efficiency

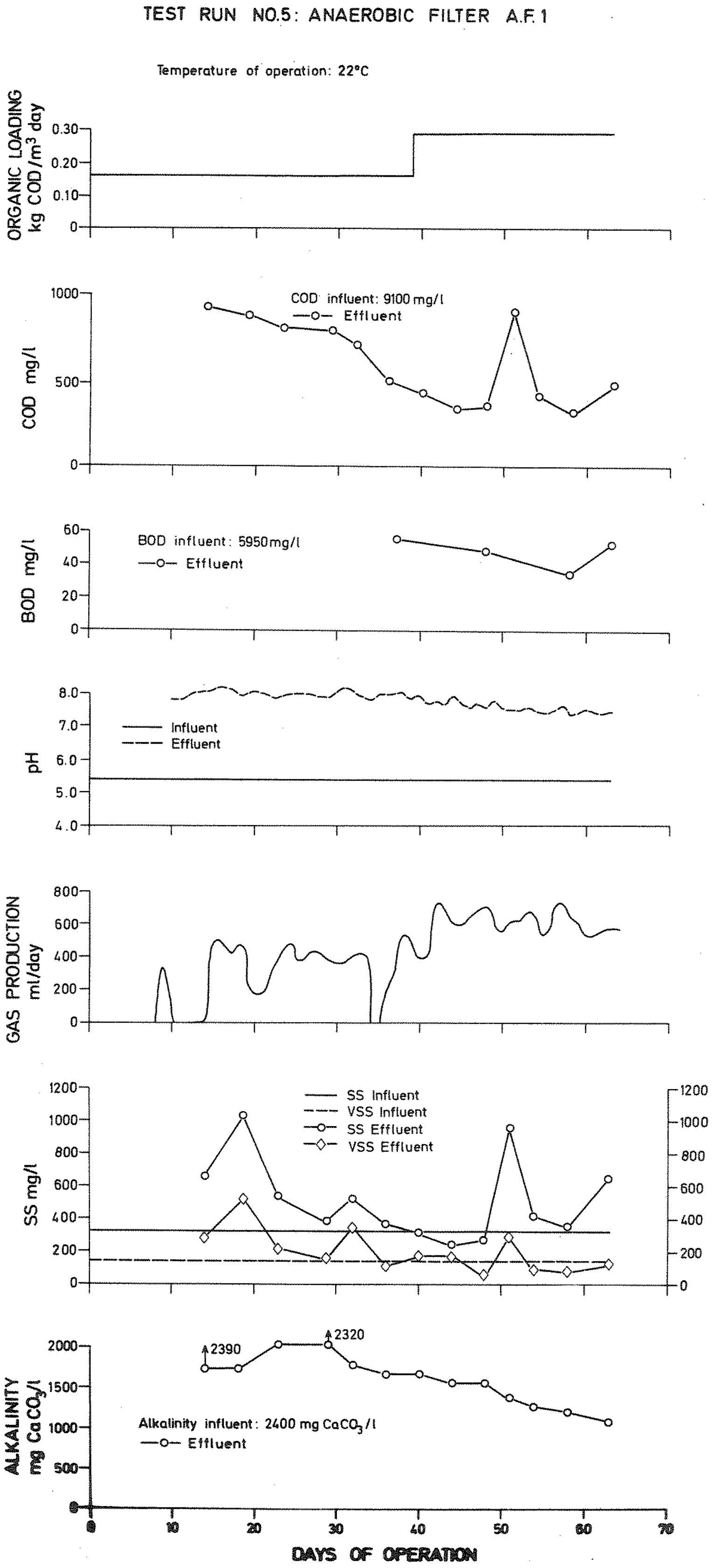


Figure 45. Experimental results, test run no 5, A.F.1.

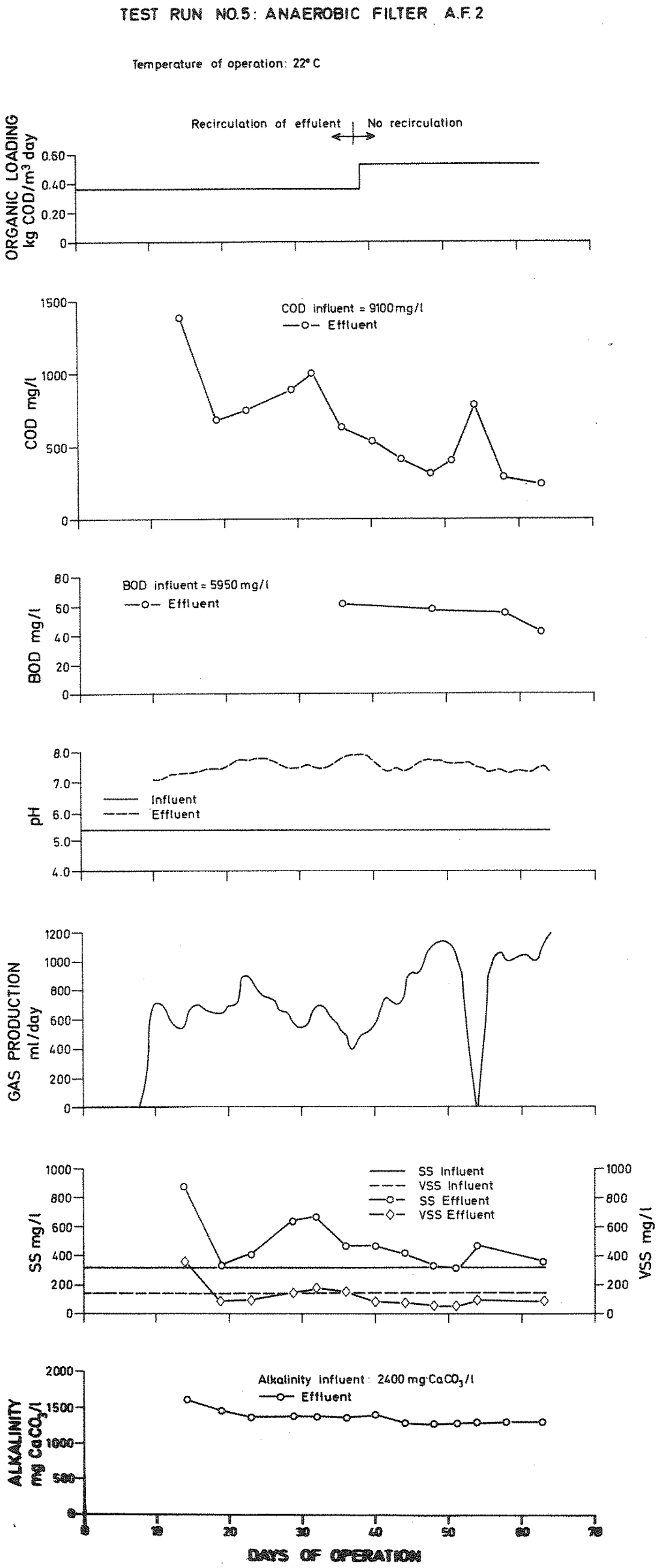
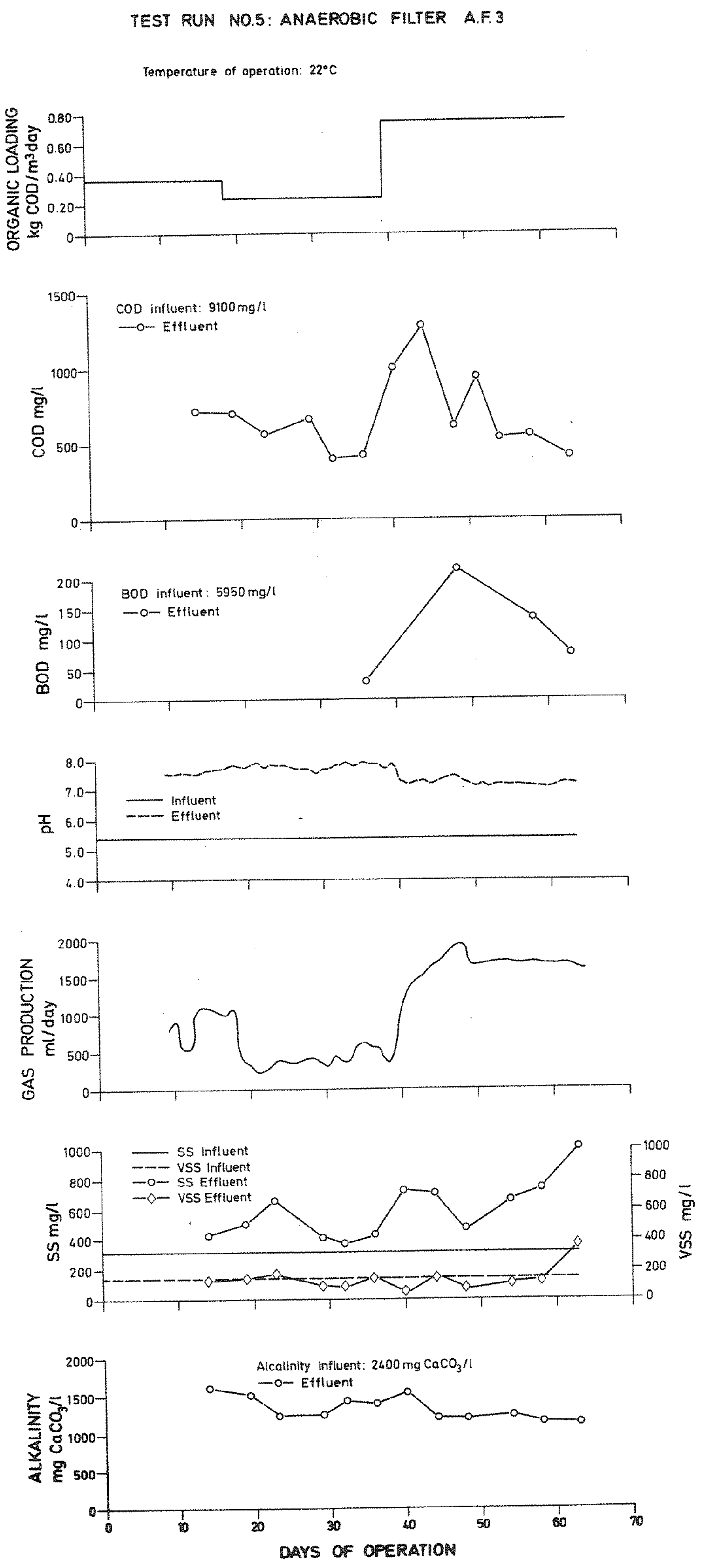


Figure 46. Experimental results, test run no 5, A.F.2.



TEST RUN NO.5: ANAEROBIC FILTER A.F.3

Temperature of operation: 22°C

Figure 47. Experimental results, test run no 5, A.F. 3.

in the first part of the test run. The filter A.F.1 operating at an organic loading of 0.16 kg COD/m^3 day seemed to reach a COD level of about 400 mg/l or a BOD value of about 50 mg/l. This corresponded to removal efficiencies of about 96 and 99 percent for COD and BOD. When the organic loading was increased to 0.29 kg COD/m^3 day an initial increase in the COD value of the effluent was found. But the COD values soon decreased to the same level as for the lower loading.

For the filter with an organic loading of 0.37 kg COD/m^3 day and recirculation of the effluent, a longer time was required to reach steady state conditions than a corresponding filter A.F.3 with no recirculation.

None of the experiments with effluent recirculation gave higher organic removal efficiency than for filters with corresponding loadings and no recirculation. By recirculating the effluent the plug flow pattern is partly lost resulting in a lower organic removal rate. All the results also showed that at the same loading the higher strength leachate resulted in higher COD removals. Recirculation of the effluent dilutes the influent resulting in a lower filter performance. On the other hand effluent recirculation may give a more effective mixing of the sludge resulting in better utilization of the filter.

Recirculation in filter A.F.2 was stopped after 38 days of operation. At the same time the organic loading was increased to 0.53 kg COD/m^3 day. In spite of the increased organic loading the COD values of the effluent continued to decrease and leveled out at about 400 mg/l. The corresponding BOD value was about 50 mg/l.

For filter A.F.3, the organic loading was decreased after 18 days of operation to a value of 0.24 kg COD/m^3 day. With this loading the COD value of the effluent also reached a level of 400 mg/l. After 38 days of operation the organic loading was increased to 0.76 kg COD/m^3 day. This resulted in an increase in the COD values of the effluent. The filter soon recovered and the COD values of the effluent leveled out to about 500 mg/l or a BOD value of about 100 mg/l.

The seven different organic loadings in test run no 5 all showed that the leachate from Cedar Hills with a COD concentration of 9100 mg/l could be successfully treated by anaerobic filters. With the exception of the highest organic loading of 0.76 kg COD/m^3 day, all gave about the same oxygen demand of the effluent. This was about 400 or 40 mg/l expressed as COD or BOD respectively. These values correspond to COD and BOD removal efficiencies of about 96 and 99 percent. The highest organic loading 0.76 kg COD/m^3 day gave a slightly lower organic removal efficiency. This indicates that the critical organic loading for treating this special leachate probably was around 1 kg COD/m^3 day.

2. Gas Production

In test run no 4 only filter A.F.1 produced gas. The gas production for this filter started after 26 days of operation and increased until steady state was obtained after about 45 days of operation. If the same theoretical considerations for the ultimate oxygen demand are done as described in test run no 1 the gas production account for an oxygen demand of:

$$830 \cdot 0.6 \cdot \frac{64}{22.4} \; \frac{273}{273+22} = 1317 \text{ mg O/day}$$

With a feed of 48 ml per day this corresponded to a COD reduction of 1317/0.048 = 27430 mg O/l. The actual COD reduction was about 38800 - 600 = 38200 mg O/l.

Figure 44 shows that the filter with an organic loading of 0.73 kg COD/m^3 day produced gas in the middle of the test run. However, this lasted for only three days. The filter with equipment for recirculation and organic loading 0.73 kg COD/m^3 day did not produce gas during the whole test run. The reduction of organics in these two filters also indicate that little or no gas should be produced.

The same COD-methane balance as described above was also done for test run no 5. Figure 48 summarizes the results from both test runs.

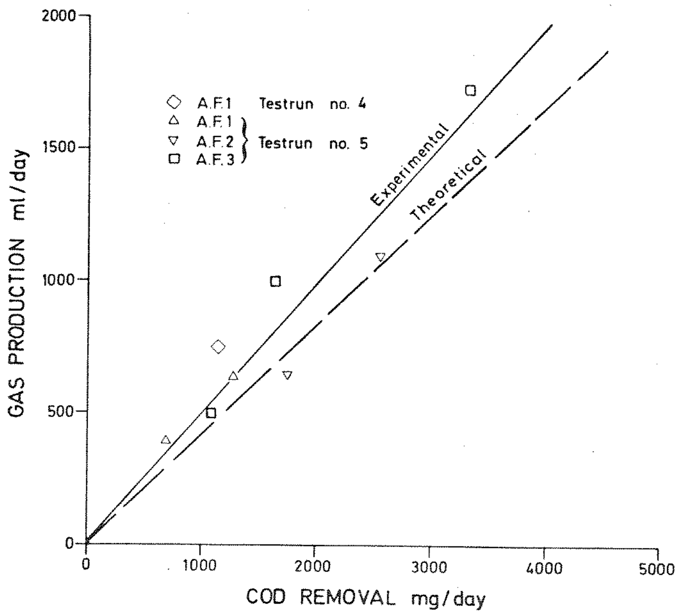


Figure 48. COD-methane balance.

Since the methane production is so well correlated with the COD removal the methane production can be used as measure of overall filter performance. The results from test run no 5 showed that when the loadings were increased the gas production increased rapidly to the expected level. For instance, with an increase in the organic loading from 0.24 to 0.76 kg COD/m^3 day the gas production increased to the theoretical level within 3-4 days.

3. pH

In test run no 4 on filter A.F.1 which was operating with high organic removal efficiency, the pH increased from 5.4 in the influent to a value of 7.9-8.0 in the effluent. The increase in pH through the treatment process is partly due to the buffering effects of the lime stones and decomposition of the organic acids.

For the filter with an organic loading 0.73 kg COD/m^3 day and no recirculation the pH decreased. This decrease indicates that the sensitive methane forming processes could not keep up with the organic acid production. The filter was overloaded. For the filter with recirculation of the effluent the pH was more stable but far below the optimum range for the methane forming processes.

For all the experiments in test run no 5 the pH of the treated leachate was within the range of 7.4 to 8.1. Thus the methane producing stage always kept up with the acid producing stage.

4. Alkalinity

In test run no 4 the filter A.F.1 provided reduction of the alkalinity from 6480 to about 2000 mg $CaCO_3$/l. This reduction was mainly due to the reductions of organic acids. For the overloaded filters no reduction in the alkalinity was observed.

In test run no 5 the alkalinity was reduced from 2400 to 1000-1200 mg $CaCO_3$/l.

5. Suspended Solids

In test run no 4, the filter A.F.1 with an organic loading of 0.25 kg COD/m^3 day gave a removal of suspended solids from 310 mg/l to about 150 mg/l. A high fraction of the solids were probably excess sludge from the filter. For the filters which failed the suspended solids in the effluents were higher than in the influent. In this case the main fraction probably consisted of sludge washed out from the filter and bacterial growth from the acid forming stage.

In test run no 5 the suspended solids of the effluent was in all experiments high. On the average the concentrations were 300 mg/l or higher. A large fraction of these solids consisted of excess sludge from the filters.

6. Heavy Metals

In test run no 4 the raw leachate had extremely high concentrations of zinc. Whether or not this concentration is toxic to the bacterial growth depends upon the concentration in which it is available to the organisms. The availability or solubility is controlled by the redox potential, pH and concentrations of carbonate and sulfur species. The presence of sulfides results in formation of metal sulfides which, with exception of chromium, are extremely insoluble salts. For instance the solubility product of ZnS is as low as $1.2 \cdot 10^{-23}$.

The concentrations of heavy metals in the effluent showed relatively low concentrations for both test run no 4 and 5. This should indicate that the metals were accumulated within the filter as a precipitate.

7. Characterization of the Biological Solids

After completion of test run no 4 the biological solids from the filter

A.F.1 with high organic removal efficiencies was investigated. The solids within the filter flocculated well. The particles were granular in shape and settled very fast. The physical characteristics showed that the solids were not attached to the filter media but simply stayed loosely in the interstitial spaces. The biological solids were not carried up through the filter due to their good settlability and to catchment by the overlying stones.

The biological solids from A.F.1 were analyzed for heavy metals, suspended and volatile suspended solids. The results are given in table .

Table 29. Concentrations of heavy metals in biological solids, test run no 4

	mg/l	Percent by weight
Suspended solids (SS)	9520	100
Volatile suspended solids	4830	50.7
Fe	48	0.50
Zn	153	1.61
Cu	39	0.41
Cr	5.5	0.58
Cd	0.7	0.07
Pb	2.0	0.21
Ni	8.5	0.89

Because the time of operation was too close to the liquid detention time it is difficult from the results above to determine whether the heavy metals were accumulated in the sludge. Therefore the concentrations of the heavy metals in the sludge are relatively close to the heavy metals in the influent.

After completion of test run no 5 the filters were dismantled so that the concentration of biological solids could be measured. The sludge had the same appearance and settling properties as the sludge investigated in the previous test run. The biological solids were analyzed for heavy metals, suspended and volatile suspended solids. The results are given in table 30.

Table 30. Concentrations of heavy metals in biological solids, test run no 5

	A.F.1		A.F.2		A.F.3	
	mg/l	% by wt.	mg/l	% by wt.	mg/l	% by wt.
Suspended solids (SS)	68730	100	53760	100	71700	100
Volatile suspended solids	24780	36.0	19980	37.1	26130	36.4
Fe	19.6	0.03	15.2	0.03	19.2	0.03
Zn	174.0	0.25	270.0	0.50	296	0.41
Cu	65.0	0.09	30.5	0.06	78.5	0.11
Cr	20.1	0.03	13.3	0.03	18.7	0.03
Cd	2.4	0.004	2.3	0.004	2.8	0.004
Pb	7.5	0.01	6.0	0.01	8.5	0.01

Table 30 shows very high sludge concentrations. The sludge concentration corresponds to sludge ages of about 2000 days. Similar high values were reported by Thaulow (1974) and Young (1968). From the previous test run the biological solids in filter A.F.1 had increased from 9520 to 68730 mg/l. The other two filters showed similar levels. Young (1968) in treating synthetic protein-carbohydrate waste also found a considerable increase in the biological solids. He found that sludge had to be withdrawn otherwise the filter would be filled or clogged. In his experiments the filter was filled after 340 days of operation. At the time the filter is filled an increase in the effluent suspended solids occurs.

At a fixed COD removal the increase in biological solids should also make the filters capable of receiving a higher organic loading. Therefore the results obtained in the first and fifth test run cannot be directly compared. That is, at the same organic loading, the actual sludge loading is much higher in test run no 1 than no 5.

Table 30 also shows the concentrations of the heavy metals. Compared with the previous test run the concentrations of heavy metals with the exception of iron increased considerably. This shows that an accumulation of the metals in the sludge occurred. However, the heavy metal concentrations in the effluent (tables 72 to 74) show that no efficient removal of the heavy metals had taken place.

8. Conclusions

The results from this study showed that leachates from the Cedar Hills landfill could be treated successfully by the anaerobic filter at room temperatures. If the filters were not overloaded a considerable reduction of COD or BOD was obtained. The results of the organic removals are summarized in figure 49.

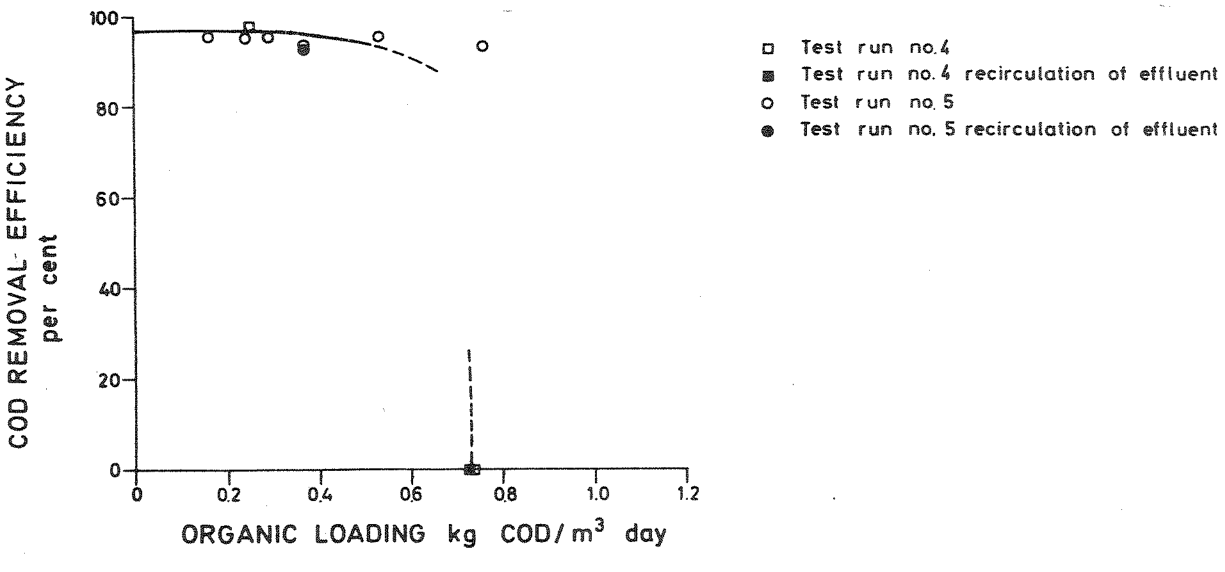


Figure 49. COD removal vs. organic loading, test run no 4 and 5.

For test run no 4 the filters failed at an organic loading of 0.73 kg COD/m^3 day. However, in test run no 5 an organic loading of 0.78 kg

COD/m^3 day gave a COD removal efficiency of about 95 percent. The reason why the filters failed at a lower organic loading in test run no 4 is probably a lower content of active microorganisms. This was supported by analyses of the sludge in the filters taken at the end of each test run.

Figure 49 shows a higher COD removal for treatment of the high strength leachate at low organic laodings. The results indicated that the COD values in the effluent reached nearly the same COD levels, 400-500 mg/l, in both test runs. Therefore the COD removal efficiency was higher for the leachate high in organics.

For both the test runs a relatively high COD/BOD ratio in the treated leachate existed. This was probably due to reduced inorganics and not biodegradable organics. In test run no 4 where the raw leachate had a COD concentration of 38800 mg/l, the BOD values of the effluent reached a threshold value of about 150 mg/l. This was equal to a COD/BOD ratio in the effluent of about 4. The corresponding value from test run no 5 was about 10, equal to a BOD effluent value of about 50 mg/l.

The COD-methane balance performed on the two test runs showed that the estimated and obtained values agreed very well. Since the methane production is so well correlated to the COD removal, the methane production can be used as a measure of overall filter performance.

The results proved that the anaerobic filter could treat leachate with high concentrations of heavy metals. The presence of sulfides in the leachate results in formations of metal sulfides which are extremely insoluble salts, and consequently not available to the organisms. The removals of zinc were relatively good while removal of other heavy metals were poor. Analyses of the sludge proved that the heavy metals were accumulated in the sludge as precipitates.

Excess sludge also had to be withdrawn from the anaerobic filters, otherwise the filter would be clogged or solids would be drawn off with the effluent. The interval between each sludge withdrawal is long, however, roughly in the order of months. The treated effluents had relatively high contents of suspended solids.

E. TREATMENT OF LEACHATE FROM GRØNMO SANITARY LANDFILL

Leachate from Grønmo sanitary landfill was treated by the activated sludge process, aerated lagoons, biodisc and trickling filter. Both treatment of raw and chemically precipitated leachate were studied. Thus three activated sludge units, one biodisc and one trickling filter were installed to treat leachate from an existing full scale chemical precipitation plant. Treatment of raw leachate was investigated in six activated sludge units and two aerated lagoons. The treatment of raw and chemically precipitated leachate was performed simultaneously. Polishing of the biologically treated leachate by chemical precipitation and activated carbon treatment was also studied.

The biological treatment studies were run as shown in table 31.

1. Treatment of Raw Leachate by the Activated Sludge Process

(Test run no I and no II)

The treatment of raw leachate was studied in two sequential test runs denoted as test run no I and no II. The main difference between these two test runs was the difference in applied loadings. Thus in test run no II considerably higher organic loadings were applied.

The composition of the raw leachate is given in tables 75 and 82, appendix B.

Table 31. Experimental conditions

Test run no	Type of treatment	No of plants	Influent	Days of operation	Range of organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$
I	Activated sludge	6	RL[1)]	49	0.03-0.31
II	Activated sludge	6	RL	35	0.07-1.05
III	Activated sludge	3	CPL[2)]	95	0.05-0.15
IV	Activated sludge	3	CPL	57	0.17-0.43
V	Biodisc	1	CPL	113	6.23[3)]
VI	Trickling filter	1	CPL	94	0.98[4)]
VII	Aerated lagoon	2	RL	63	11-42[5)]

1) RL: Raw leachate 2) CPL: Chemically coagulated leachate 3) $\frac{\text{g COD}}{\text{m}^2 \text{ day}}$

4) $\frac{\text{kg COD}}{\text{m}^3 \text{ day}}$ 5) $\frac{\text{g COD}}{\text{m}^3 \text{ day}}$

Compared with the other leachate sources the leachate from Grønmo has relatively low COD values, high alkalinity and high concentrations of nitrogen compounds. With the exception of iron the concentrations of heavy metals are low. The BOD_5:N:P ratios were about 100:300:1. Thus the leachate from Grønmo has extremely high concentrations of total nitrogen.

The treatment units were started with activated sludge from a municipal treatment plant. The mixed liquor volatile suspended solids were adjusted to about 2500 mg/l.

Originally the plants in test run no I were thought to be loaded at 0.05, 0.1, 0.2, 0.3, 0.5 and 0.8 kg COD/kg MLVSS day. To avoid too rigorous changes of the microbial environment and get a gradual acclimation to the leachate the plants were started with about half of the organic loading mentioned above. In the starting phase the plants with the lowest loading showed significant higher COD removals. Therefore the initial hydraulic loadings were maintained during the whole period of test run no I. Test run no II was started immediately after the accomplishment of test run no I.

The results from test run no I and no II are given in tables 76 to 88 appendix B. The most important parameters are shown graphically in figures 50 to 61.

a. Organic Removals. For test run no I the COD removals show a quite different trend for each of the six units. For the reactors with the lowest organic loading the COD removals efficiencies were good in the beginning of the test run but gradually decreased. For the reactors with the highest organic loading the picture was the reverse. That is, the removal efficiencies were very low in the beginning but with an increasing trend. Between 10 to 20 days of operation steady state conditions were reached. At steady state no significant difference in the effluent COD values were found. The values ranged from 336 to 353 mg/l. The lowest value, 336 mg/l, was found at the lowest organic loading. On the average the organic loading ranged from 0.03 to 0.31 kg COD/kg MLVSS day.

The results from test run no. I indicate that it was impossible to obtain high organic removals by the activated sludge process. In spite of extremely long detention times, a COD value lower than about 300 mg/l was not obtained. The high effluent COD values caused very low COD removal efficiencies with average values ranging from 32.1 to 35.4 percent. The results agree well with the respiration tests described previously. In the respiration studies the results showed that the leachate source from Grønmo was very resistant to biodegradation.

In test run no II steady state conditions were reached relatively soon. This was expected because of the acclimation to the leachate in the previous test run. The organic loadings applied in this test run were on the average 0.07, 0.12, 0.17, 0.26, 0.34 and 1.05 kg COD/kg MLVSS day. The average

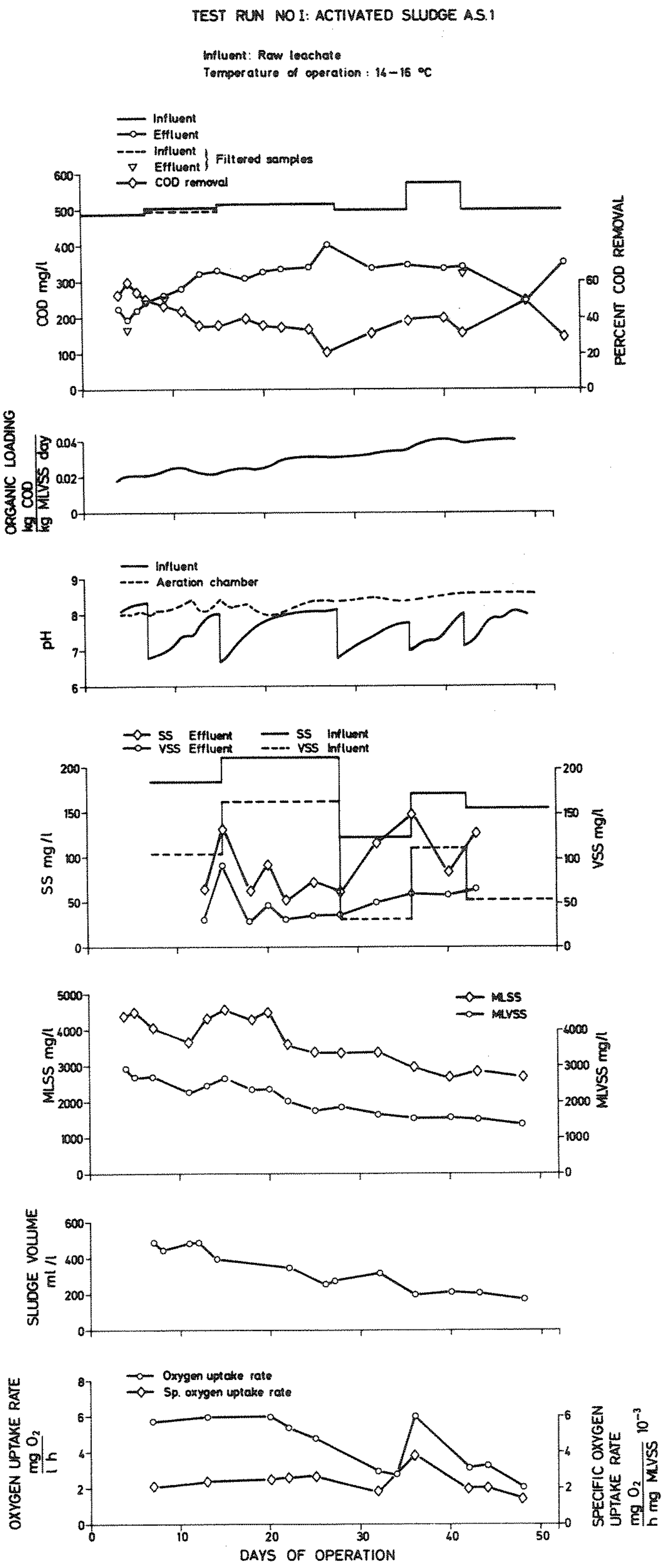


Figure 50. Experimental results, test run no I, A.S.1.

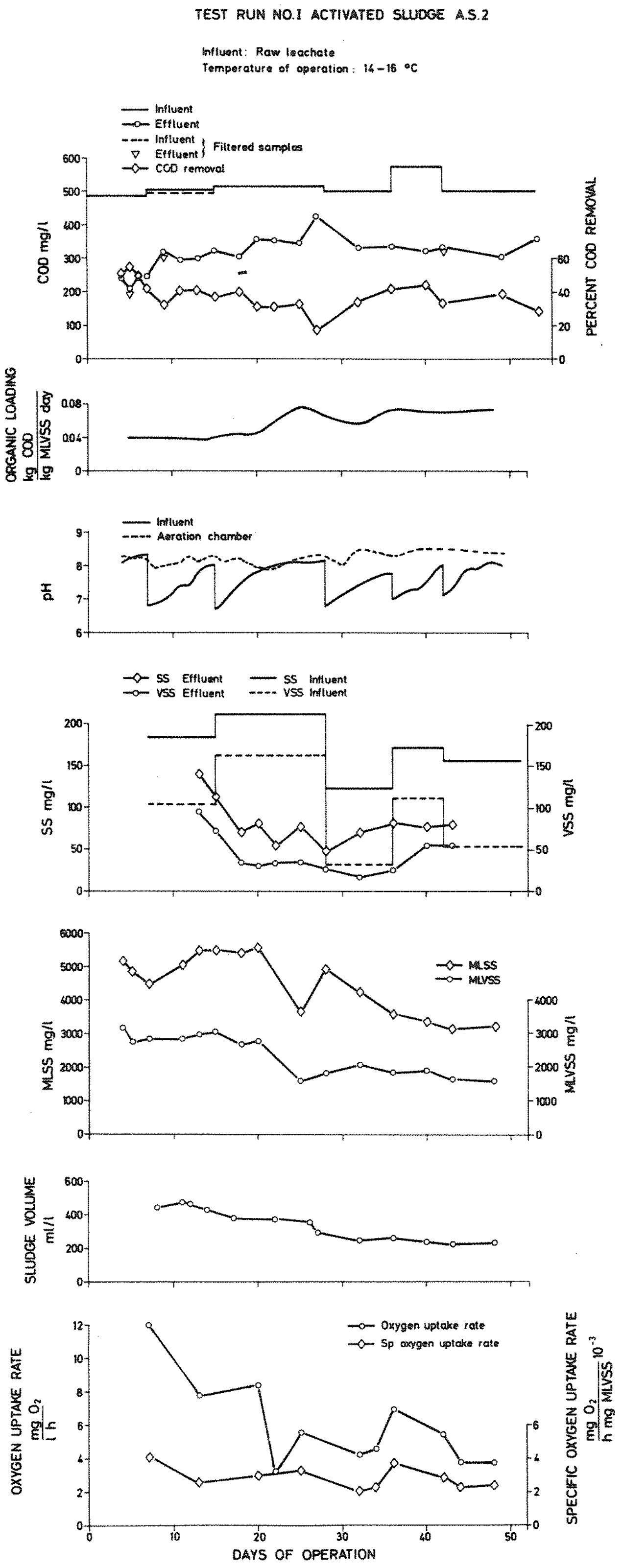


Figure 51. Experimental results, test run no I, A.S.2.

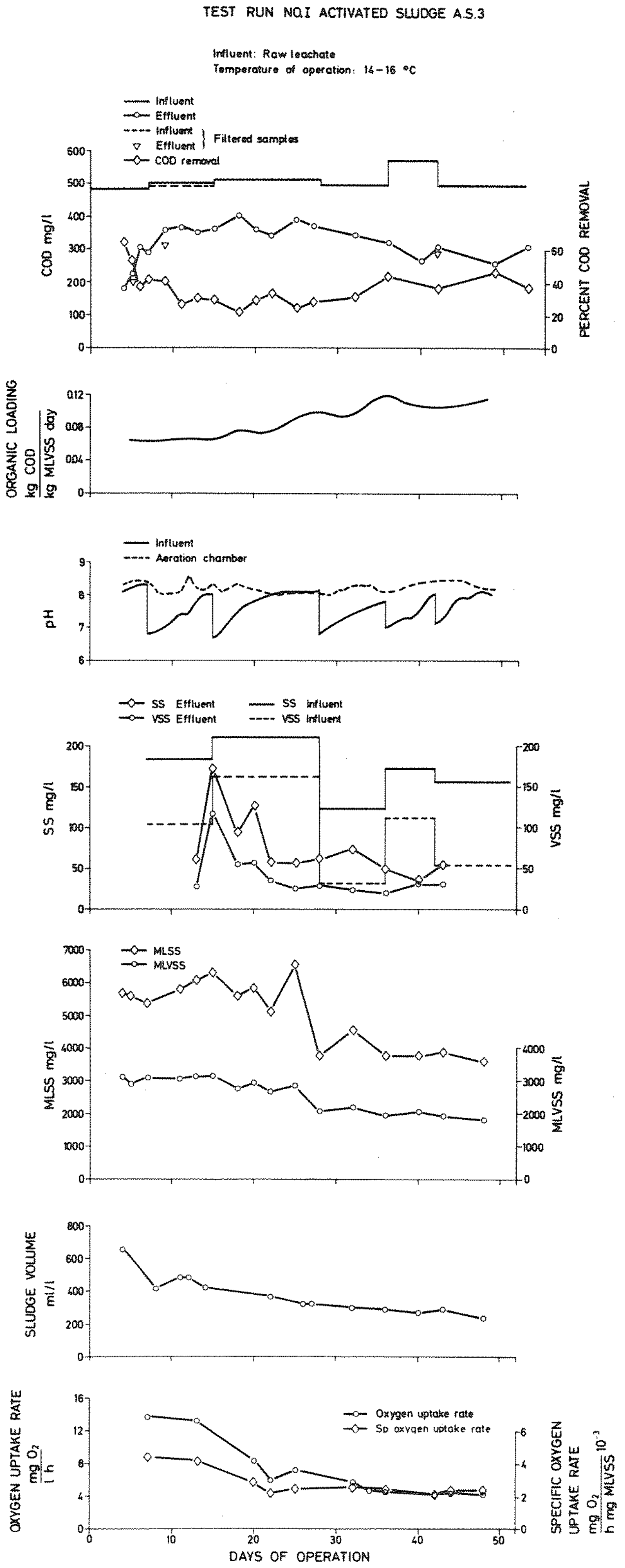


Figure 52. Experimental results, test run no I, A.S.3.

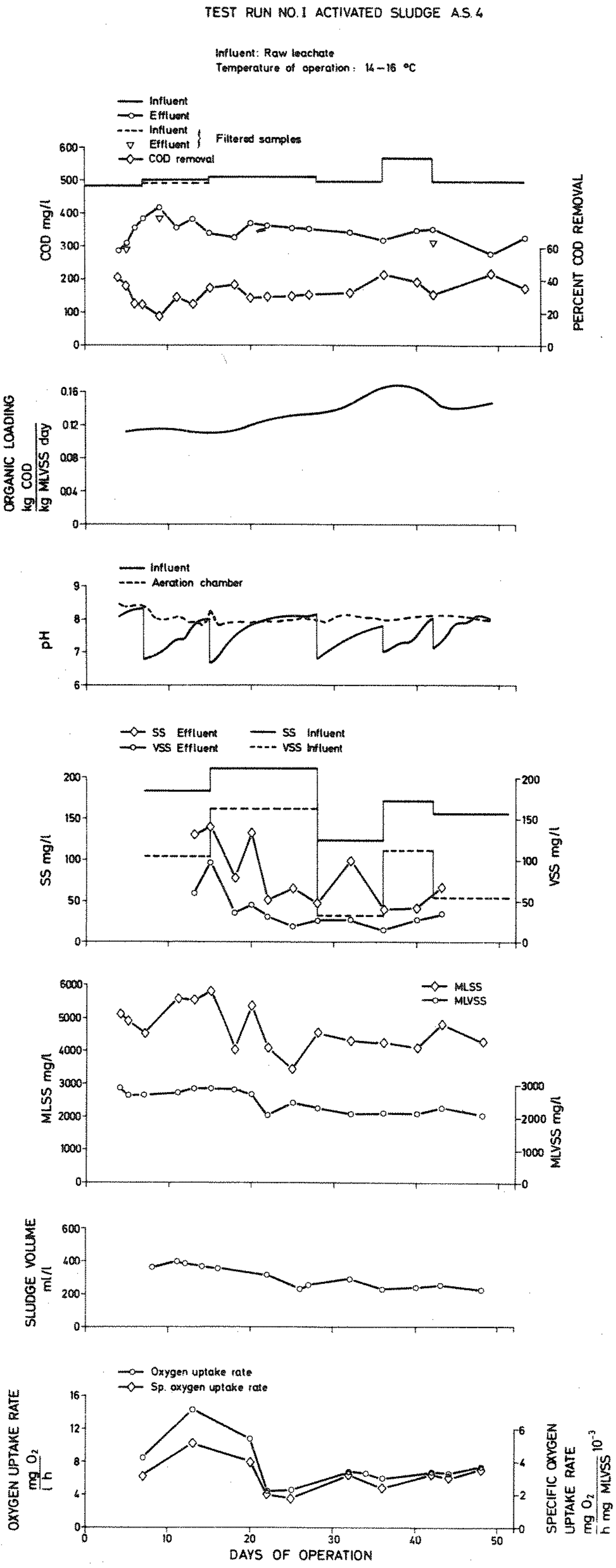


Figure 53. Experimental results, test run no I, A.S. 4.

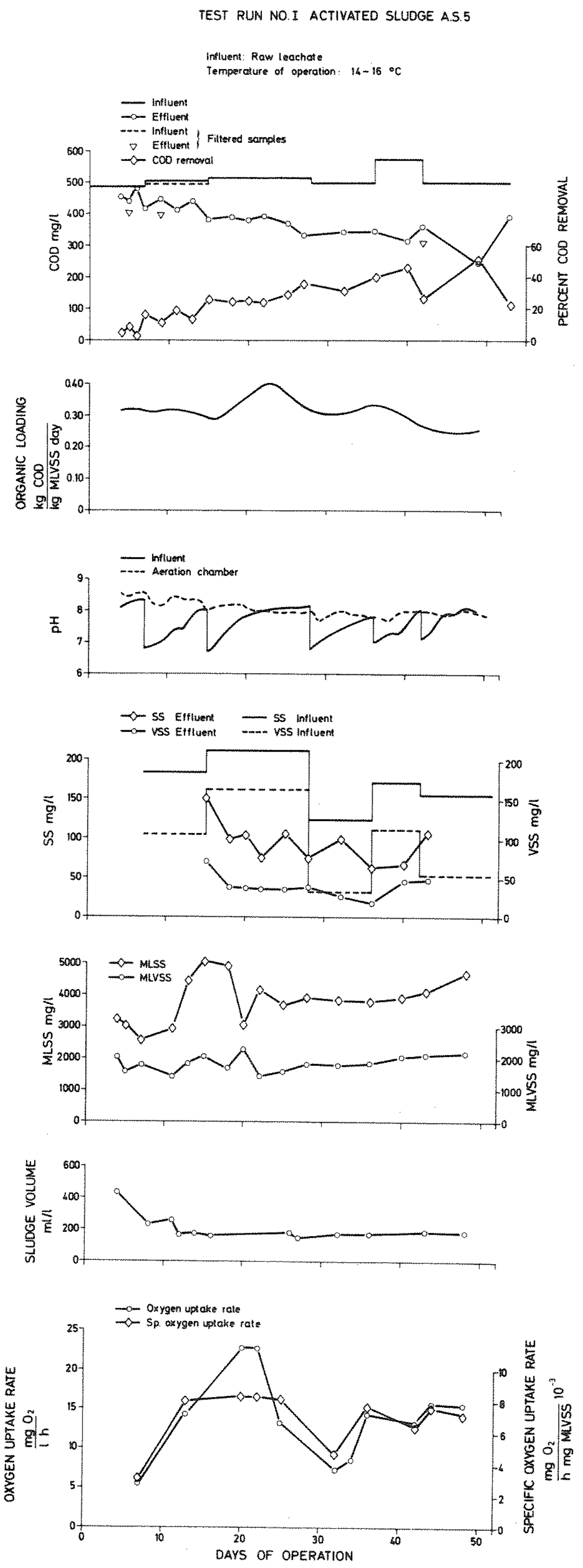


Figure 54. Experimental results, test run no I, A.S.5.

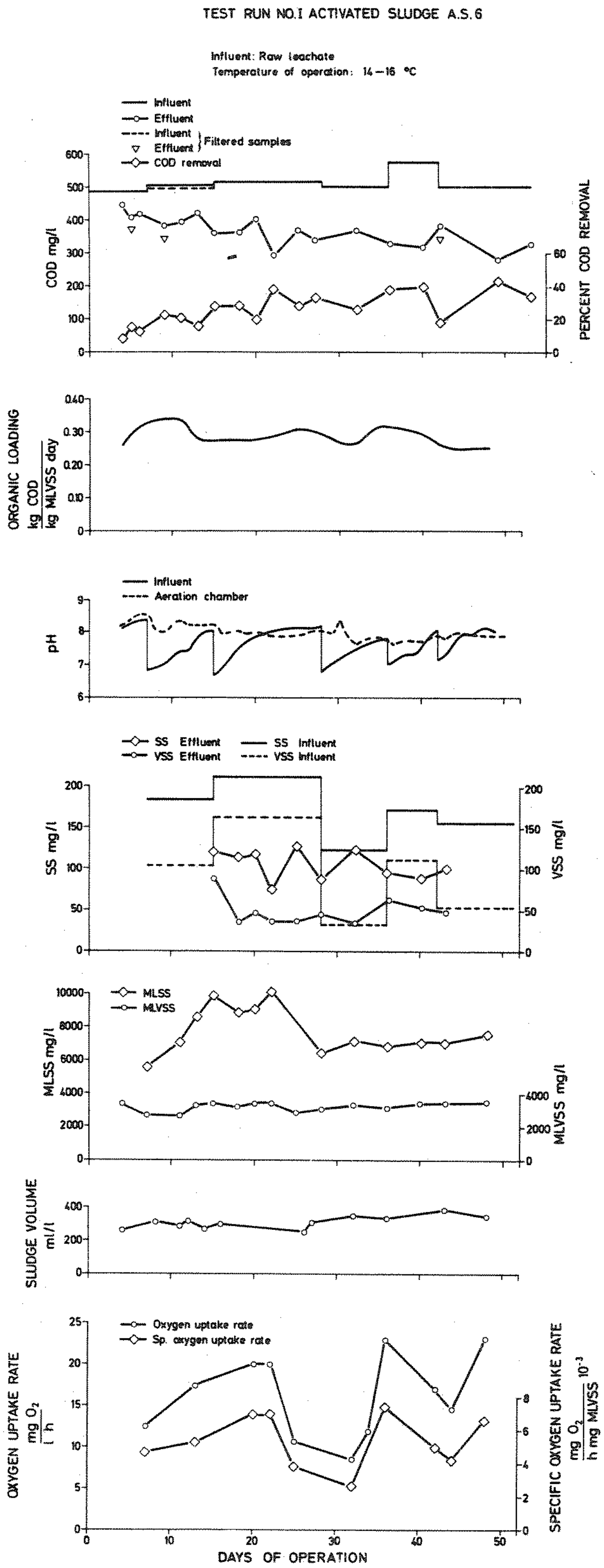


Figure 55. Experimental results, test run no I, A.S.6.

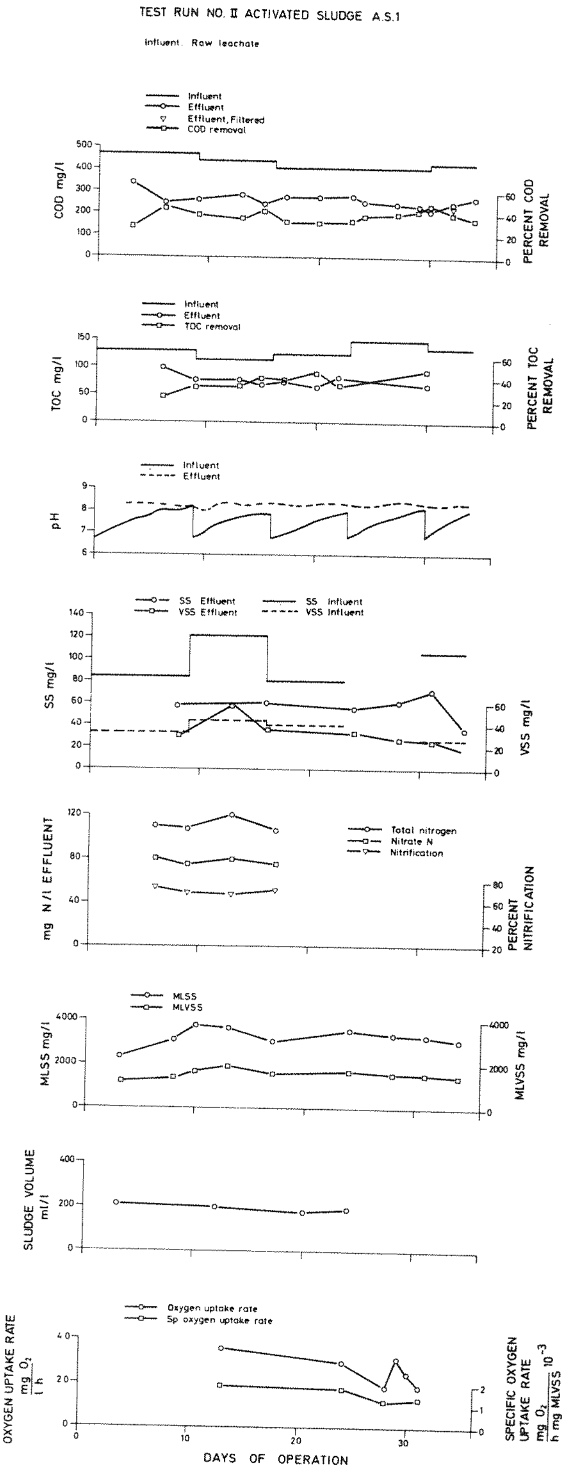


Figure 56. Experimental results, test run no II, A.S.1.

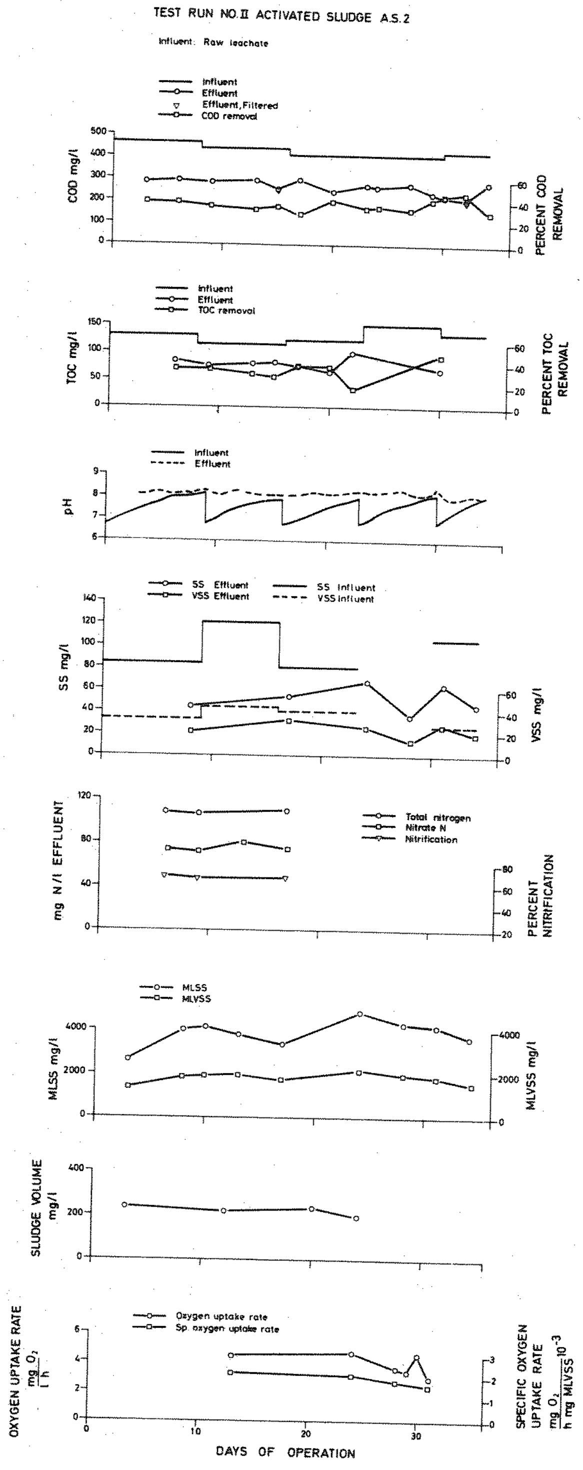


Figure 57. Experimental results, test run no II, A.S.2.

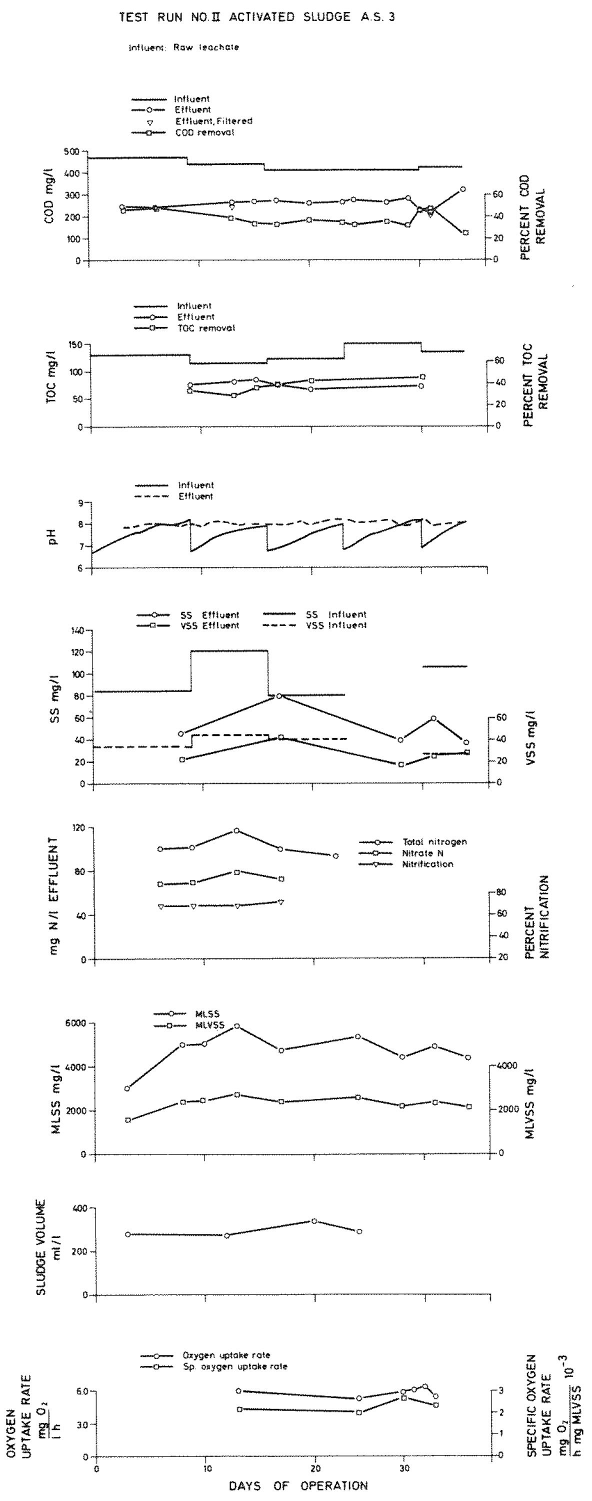


Figure 58. Experimental results, test run no II, A.S.3.

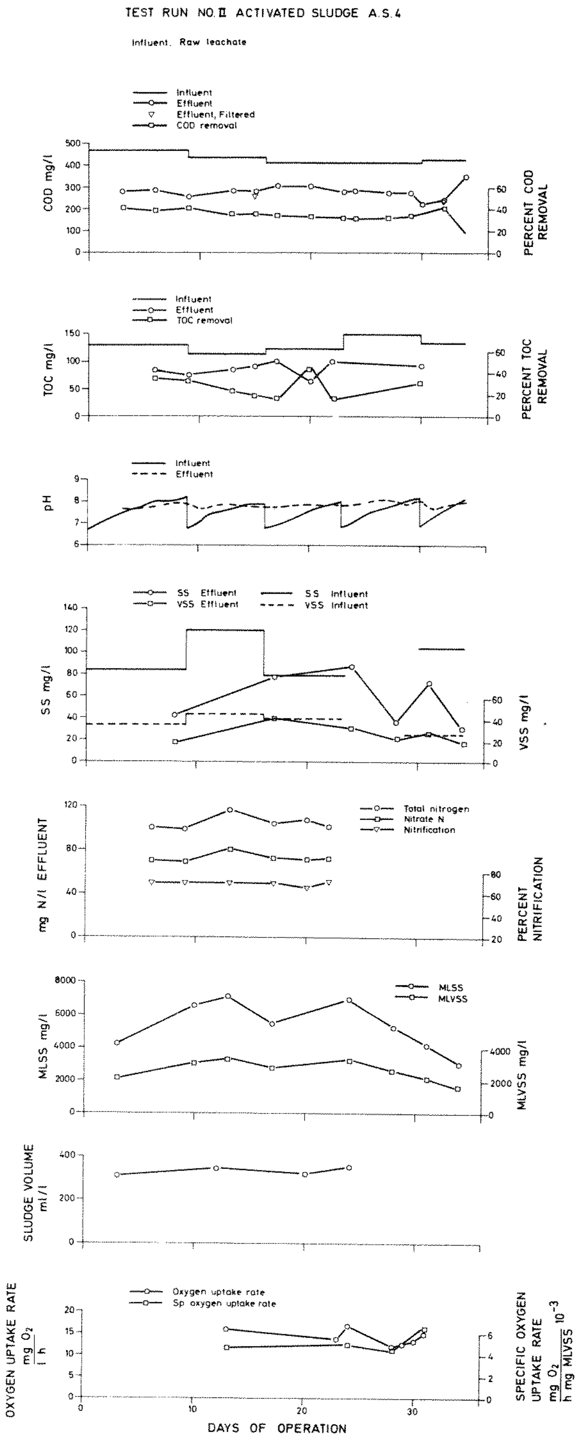


Figure 59. Experimental results, test run no II, A.S.4.

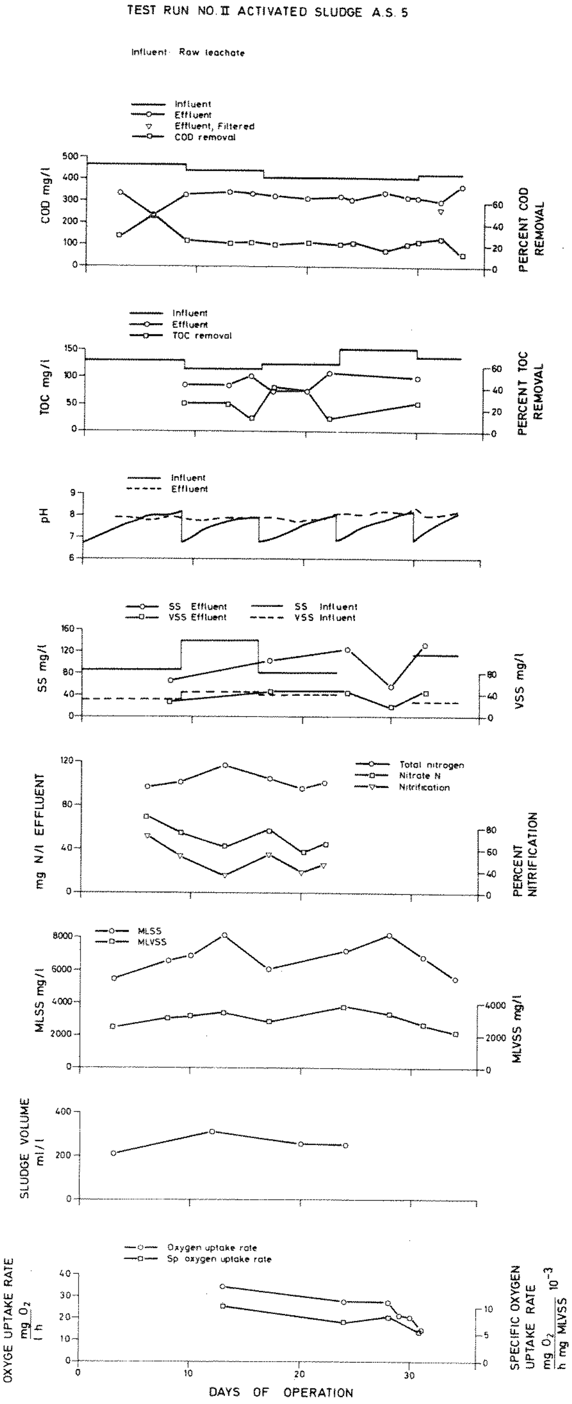


Figure 60. Experimental results, rest run no II, A.S.5.

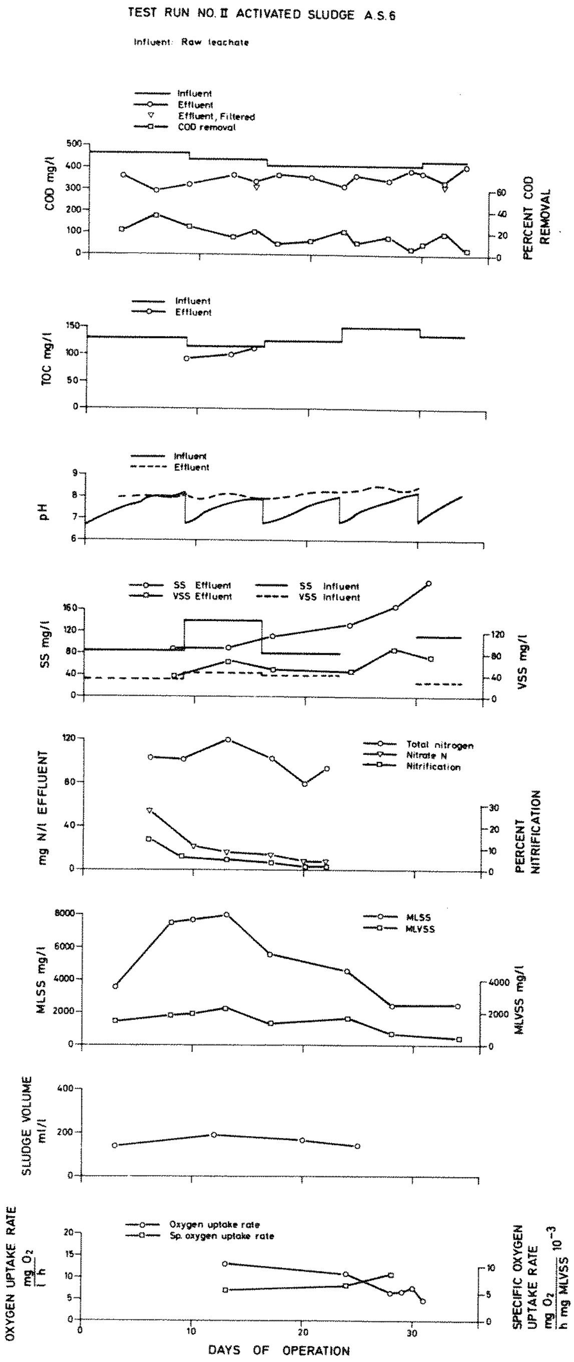


Figure 61. Experimental results, test run no II, A.S.6.

organic removals based on COD analyses ranged from the highest to the lowest organic loadings from 17.6 to 38.2 percent respectively. In test run no II many TOC analyses for influent and effluent samples were performed. The figures or the data in the appendix B show very good correlations between the COD and TOC data. Thus the removal of organics based on the two different parameters are nearly identical.

In test run no I some analyses of the filtered effluent were performed. The results showed only slight differences between the COD values based on unfiltered and filtered samples. Thus nearly all the residue organics were dissolved.

In the last part of test run no I some BOD samples of the influent and effluents were run. Typical results from these BOD measurements are drawn in figure 62.

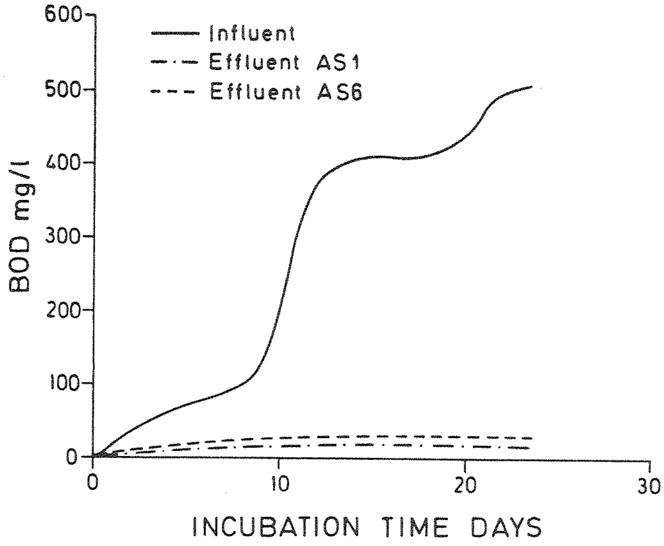


Figure 62. BOD curves from test run no I.

The BOD curve for the influent seems to consist of three parts. The first part of the BOD curve represents the oxygen requirements for the oxidation of the organics. If the curve is extended, a plateau value of about 100 mg/l will be reached. Thus the oxygen requirement for complete biooxidation of the organics is about 100 mg/l. The second part of the curve starts after about 9 days of incubation. This curve increases sharply and after about 14 days of operation it levels out to a plateau value of about 420 mg/l. This curve represents the nitrification processes. After about 20 days of incubation the third part of the curve appears. This curve probably also represents contribution from nitrification. The delay or lag may be explained by organism succession. The second curve may represent the oxidation of ammonia to nitrites caused by the bacteria group Nitrosomonas. The third curve probably represents the oxidation of nitrites to nitrates caused by the bacteria group Nitrobacter. For instance a complete oxidation of ammonia at a concentration of 100 mg N/l requires 343 mg O/l in the nitrite forming stage and 114 mg O/l in the nitrate forming stage. Thus the ratio of the oxygen demand of the two stages are about 3. The figure shows an oxygen demand of 310 mg/l in the second stage curve and about 100 mg/l in the third stage curve. The obtained values therefore support the assumption of two separate stages of ammonia conversion. The total nitrogen of the influent was 130 mg N/l, with concentrations of nitrites and nitrates below 1 mg/l. A complete oxidation of ammonia in concentrations 130 mg N/l require 594 mg O/l. In this BOD test the oxygen requirement for the oxidation of the nitrogen compounds was 410 mg/l.

Figure 62 also shows the BOD effluent values of the treatment plants A.S.1 and A.S.6. These operated at average organic loadings 0.03 and 0.28 kg COD/kg MLVSS day respectively. The 25 day BOD values for the effluent from A.S.1 and A.S.6 were 20 and 33 mg/l respectively.

A comparison of the influent and effluent BOD curves show some interesting results. For instance the 5 or 7 day BOD values of the influent contribute only a small fraction of the total BOD. The BOD removal efficiencies based on 5 days incubation times gave removals of about 60 and 70 percent for A.S.1 and A.S.5 respectively. After 25 days of incubation the corresponding BOD removals are increased to 93 and 96 percent. Nearly all of the BOD reductions at these high removals are attributed to the biooxidation of the nitrogen compounds.

The above mentioned influent samples had a COD value of 575 mg/l. For the effluents from A.S.1 and A.S.6 the COD values were 339 and 345 mg/l corresponding to COD removals of 40 and 41 percent respectively. The large difference in the removals based on COD and BOD is caused by the high fraction of non biodegradable organics, and that the oxidation of ammonia to nitrates do not take place in the COD tests.

b. Oxidation of Nitrogen Compounds. The leachate from Grønmo sanitary landfill has a very high nitrogen content. These compounds are mainly present in the ammonia form. As discussed earlier, the oxidation of ammonia compounds for the leachate from Grønmo gives biological oxygen demand higher than the chemical oxygen demand. To reduce the biological oxygen demand of the treated water it is therefore important to apply sufficient low organic loadings to the treatment plants so that a high degree of oxidation of the nitrogen compounds can be achieved.

In the treatment of leachate from Grønmo insignificant removal of nitrogen took place. Therefore the amount of oxidized nitrogen formed during nitrification is about the same as the organic nitrogen and ammonia removed. With no nitrates in the raw leachate the degree of nitrification can therefore be expressed as the ratio of the nitrates in the effluent to the concentration of the total nitrogen in the influent. This ratio is nearly the same as the ratio of nitrates to total nitrogen in the effluent.

In test run no II the oxidation of the nitrogen compounds as a function of organic loading was studied. The fifth graph on figures 56 to 61 shows the effluent values for total nitrogen, nitrate concentrations and the degree of nitrification. The figures show a relatively constant degree of nitrification up to a certain organic loading where it begins to fall sharply. The maximum obtained degree of nitrification seems to be about 70 percent. Thus about 30 percent of the nitrogen compounds in the leachate are not biologically degradable.

A more complete discussion of the oxidation of the nitrogen compounds and nitrogen removals will be given later when the treatment results from the chemically coagulated leachate are discussed.

c. pH, Alkalinity. The pH values in the aeration chambers for all units were high. It ranged from 7.9 to 8.4 with the highest value for the units subjected to the lowest loading. The relatively high pH values resulted in the precipitation of metals.

The pH values of the raw leachate increased slightly during storage at 4°C. The increase was probably due to the aeration caused by mixing and circulation.

For the plants with the lowest organic removals the alkalinity was reduced from about 1400 mg $CaCO_3$/l to values of about 500 mg $CaCO_3$/l. This reduction was caused by nitrification and degradation of organics.

d. Heavy Metals. The concentrations of heavy metals in the raw leachate are given in tables 75 and 82 appendix B. However, the storage and recirculation of leachate caused the pH to increase. This caused precipitation of the metals which deposited in quiet zones and in the pipes. Therefore the concentrations of heavy metals in the influent decreased until new leachate was hauled from the landfill.

Table 32 shows the concentrations of zinc and iron in the influent and effluent in test run no I. The values given are for composite samples.

Table 32. Zinc and iron concentrations in influents and effluents

	Metal	Period of sampling			
		1/8-7/8	7/8-15/8	15/8-23/8	23/8-30/8
Influent	Fe	36.5	25.7	51.7	29.1
	Zn	0.4	0.3	0.9	0.36
Effluent A.S.1	Fe	6.9	5.4	10.6	12.8
	Zn	0.3	0.3	0.3	0.4
Effluent A.S.2	Fe	8.4	6.7	8.2	14.2
	Zn	0.3	0.3	0.2	0.4
Effluent A.S.3	Fe	11.4	9.6	9.2	8.1
	Zn	0.4	0.3	0.2	0.3
Effluent A.S.4	Fe	16.1	12.4	7.4	7.9
	Zn	0.3	0.4	0.2	0.1
Effluent A.S.5	Fe	22.4	18.1	16.5	11.7
	Zn	0.2	0.2	0.2	0.2
Effluent A.S.6	Fe	24.5	23.1	20.5	17.5
	Zn	0.2	0.2	0.2	0.2

For Cu, Cr, Cd, Pb and Ni the values were all below 0.1 mg/l.

Table 32 shows that iron and zinc are partly removed. For the plants, operating at the lowest organic loadings, the removal of iron was in the range of 50-80 percent. At the highest organic loadings the removal of iron was considerably lower. The reduction of zinc was low for all the loadings.

In table 33 the concentrations of heavy metals in the activated sludges are given. The results show high concentrations of iron. This should prove that the heavy metals partly are removed by precipitation and accumulation

Table 33. Heavy metal concentrations accumulated in the activated sludge, mg/l, test run no I

Plant	Metal MLSS	Period of sampling			
		1/8-7/8	7/8-15/8	15/8-23/8	23/8-30/8
A.S.1	Fe	221	213	250	230
	Zn	5.1	5.3	6.0	5.0
	Cu	3.9	4.6	5.4	3.9
	Cr	0.1	0.2	0.1	0.1
	Cd	<0.1	<0.1	<0.1	<0.1
	Pb	0.9	1.1	0.9	0.4
	Ni	1.0	2.3	1.8	1.2
	MLSS	4463	3437	3160	2775
A.S.2	Fe	294	304	265	
	Zn	4.7	5.9	7.1	4.9
	Cu	3.3	4.6	5.0	3.3
	Cr	0.2	0.2	0.2	0.2
	Cd	<0.1	<0.1	<0.1	<0.1
	Pb	0.7	0.7	1.3	1.3
	Ni	1.0	0.4	0.7	0.7
	MLSS	5473	5548	3905	3220
A.S.3	Fe	322	324	324	357
	Zn	4.3	5.8	6.2	4.7
	Cu	2.5	3.8	4.7	2.5
	Cr	0.2	0.1	0.2	0.2
	Cd	<0.1	<0.1	<0.1	<0.1
	Pb	0.9	1.1	1.1	0.8
	Ni	0.3	1.5	0.3	0.6
	MLSS	5923	5167	4140	3810
A.S.4	Fe	572	430	310	465
	Zn	5.0	4.9	4.5	5.0
	Cu	2.0	2.6	2.8	1.8
	Cr	0.2	0.2	0.2	0.2
	Cd	<0.1	<0.1	<0.1	<0.1
	Pb	0.5	1.3	0.9	1.0
	Ni	1.7	1.4	0.7	0.9
	MLSS	5096	4083	4300	4455
A.S.5	Fe	664	466	321	641
	Zn	4.6	3.1	3.4	4.0
	Cu	1.1	1.2	1.6	0.9
	Cr	0.2	0.2	0.1	0.2
	Cd	<0.1	<0.1	<0.1	<0.1
	Pb	0.4	0.7	0.8	1.1
	Ni	1.3	1.6	0.7	0.4
	MLSS	4370	3903	3820	4060
A.S.6	Fe	918	699	677	883
	Zn	7.1	5.6	5.4	6.2
	Cu	4.6	2.1	1.9	1.7
	Cr	0.2	0.2	0.2	0.3
	Cd	<0.1	<0.1	<0.1	<0.1
	Pb	1.1	0.9	0.9	1.1
	Ni	2.3	0.7	0.6	0.7
	MLSS	9303	6767	7024	7060

in the sludge. The concentrations of other heavy metals than iron in the sludges were low. This was also expected due to the low concentrations of those metals in the influent.

e. Solids. In test run no I the units were started with concentrations of activated sludge in the range of 2500-3000 mg MLVSS/l. The figures show a steady decrease in the MLVSS values for all units except A.S.5 and A.S.6. Thus for A.S.1 which had the lowest organic loading, the MLVSS concentrations decreased from about 2900 to 1400 mg/l. No sludge withdrawal was undertaken during the 48 days of operation. Hence a serious loss of cells occurred in units subjected to lower loadings. For the units A.S.5 and A.S.6 with average loadings of 0.31 and 0.28 kg COD/kg MLVSS day respectively the concentrations of MLVSS were about constant. The reason for the deleterious loss of cells in the reactors with the lowest loading was a combination of poor flocculation and a high degree of endogenous respiration. The COD removals also show that only a small portion of the organics in the influent can be utilized for microbial growth. Therefore the actual organic loadings based on utilizable organics are much lower than the numbers for the organic loadings indicate. In test run no I the decrease in the concentrations of activated sludge caused an increase in the organic loading. Only the reactors A.S.5 and A.S.6 had a relative stable organic loading.

For test run no II the concentrations of activated sludge measured as mixed liquor volatile suspended solids were nearly constant for all plants. Therefore the organic loadings could be held relatively constant. This was different from the previous test run where a steady loss of sludge in the lowest loaded units caused a considerable increase in the organic loadings. The difference was attributed to the acclimation of the activated sludge. In test run no I where the activated sludge were transferred from treating domestic sewage to treating leachate the changes in the environment were so severe that a considerable loss of sludges occurred. In the start of test run no II the acclimation to the leachate had already taken place.

A comparison of the ratio of suspended to volatile suspended solids in the sludge showed very high values. This was caused by the accumulation of iron and other inorganic materials. Due to the high ratios mentioned above it is important to use the volatile suspended solids instead of suspended solids to characterize the concentrations of organisms in the sludge.

The average effluent concentrations of suspended solids ranged in test run no I from 68 to 103 mg/l. The corresponding numbers in test run no II ranged from 54 to 97 mg/l. The units with the lowest loadings had usually the lowest concentrations. The values mentioned above are slightly higher than the average values from the well operating plants treating leachate from Kent Highland sanitary landfill.

f. Sludge Characteristics. In both test runs the settleability of the activated sludge was very good. Thus after a few days of operation the sludge volume index was always below 100. The dewatering properties expressed as specific resistance to filtration ranged in average values between $1.15\text{-}9.6 \cdot 10^{12}$ m/kg. The corresponding values, reported by Ford (1969) for domestic activated sludge are about $3 \cdot 10^{14}$ m/kg. The values found above are according to the same reference equal the specific resistance of activated sludge flocculated with 10 weight percent $FeCl_3$.

The activated sludge from this study also had very high concentrations of iron. Heavy metal analyses of the sludge from the different plants are given in table 33. The results show concentrations of iron ranging from 213 to 918 mg/l. Calculated as $FeCl_3$, these concentrations corresponded to iron contents of from 14 to 36 percent by weight which may be higher than the optimum values for flocculation.

g. Oxygen Uptake Rates. The oxygen uptake rates of the activated sludges in test run no I and no II are shown on the last graph in figures 50 to 61. The graphs show relatively stable values of the specific oxygen uptake rate. This indicates that the activity of the sludge was nearly the same during the whole test run. In test run no I the four reactors with the lowest loadings showed that the total oxygen uptake rate decreased with the time of operation. This was caused by the steady decrease in the concentration of MLVSS.

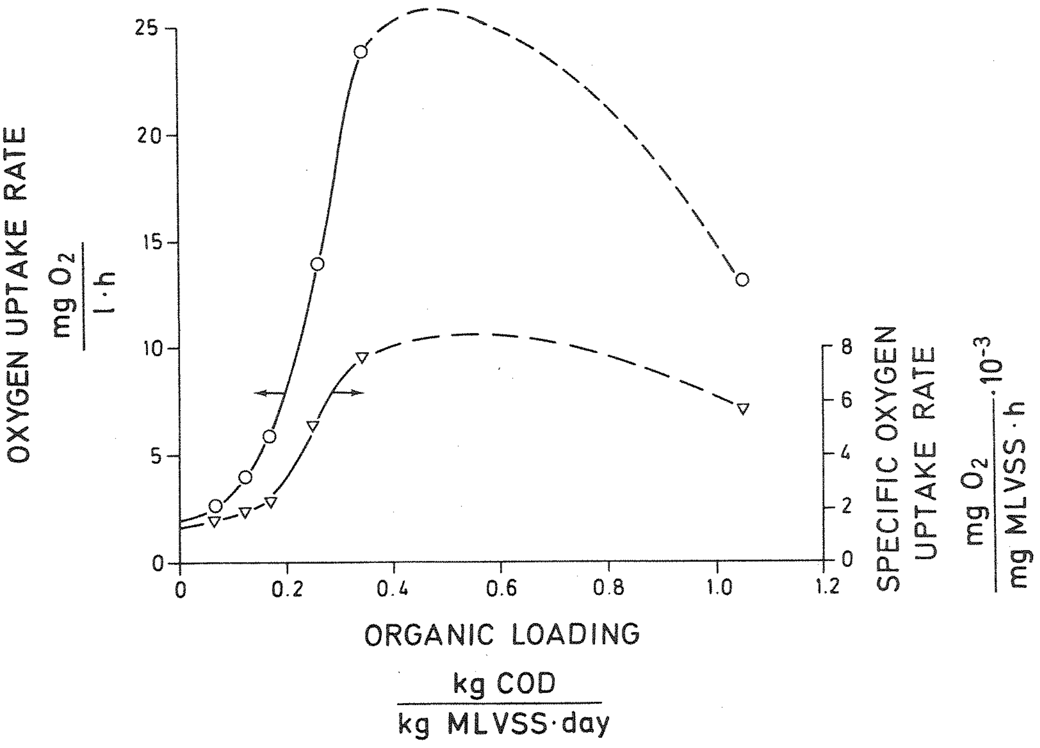


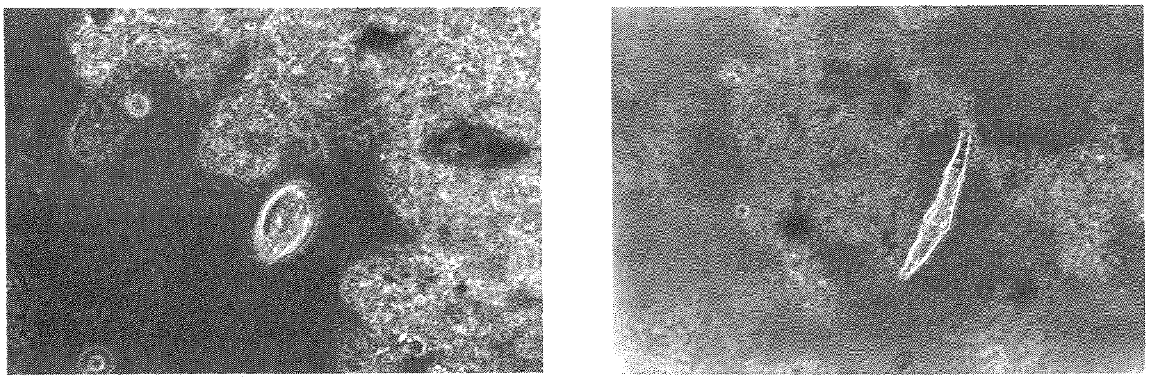
Figure 63. Oxygen uptake rates, test run no II.

Figure 63 shows the oxygen uptake rates in test run no II. At the lowest organic loadings the oxygen uptake rates did not change very much. Here endogenous respiration accounts for the main fraction of the oxygen uptake. At loadings exceeding about 0.2 kg COD/kg MLVSS day the oxygen uptake increased sharply. At the highest loading applied the plant was overloaded and had therefore a relatively low oxygen consumption.

h. Microscopic Examination. Microscopic examinations of the activated sludges were performed both in test run no I and II. At the corresponding organic loadings no significant difference in the microbial population was found. Because test run no II covered a wider range of organic loadings than test run no I only the microscopic examination from test run no II will be discussed.

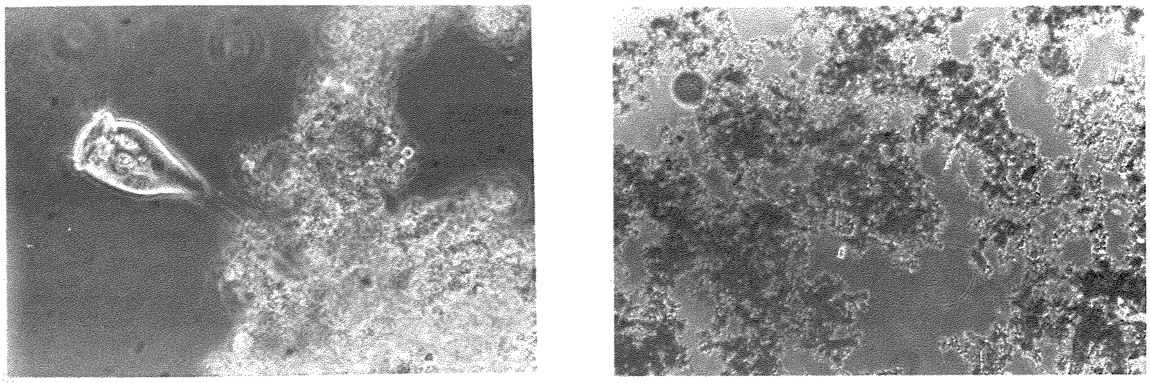
Microscopic examinations showed that the composition of the biota was a function of the applied organic loading. Typical micrographs of the activated sludge as a function of organic loadings are shown in figures 65 to 66. Table 34 shows a summary of the results from the microscopic examinations. No effort was made to identify the different species of the higher organisms. Plants operating at the lowest organic loadings had a considerably higher number and species diversity of higher organisms than the plants operating at the highest organic loadings. The higher organisms are usually very effective in consuming dispersed and flocculated bacteria. Their presence therefore indicates efficient purification of the effluent. Thus this may explain why the effluent from the plants operating at the highest organic loading contained very high concentrations of free swimming bacteria.

The dominating species of the higher organisms were the free swimming ciliate species Aspedisca. The stalked ciliate species Vorticella was also frequently found. Very few filamentous bacteria were observed in the samples.



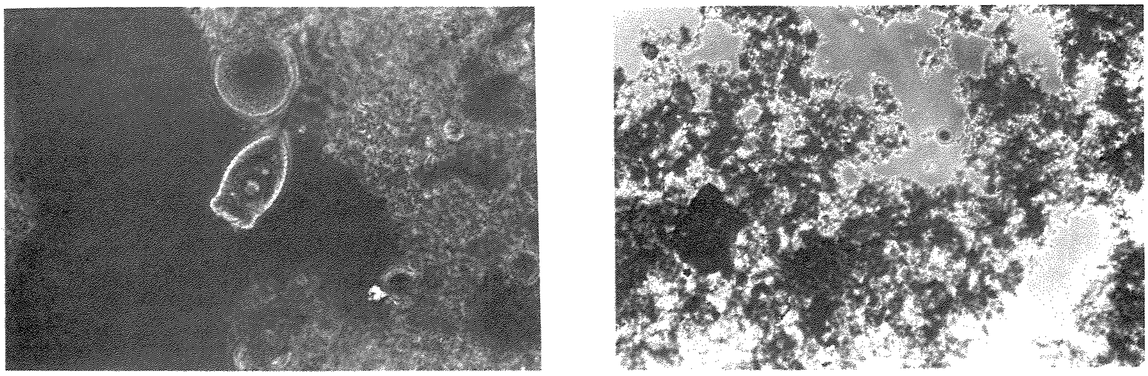
A.S.1.
0.07 kg COD/kg MLVSS day x170

A.S.1.
F=0.07 kg COD/kg MLVSS day x170



A.S.2.
0.12 kg COD/kg MLVSS day x170

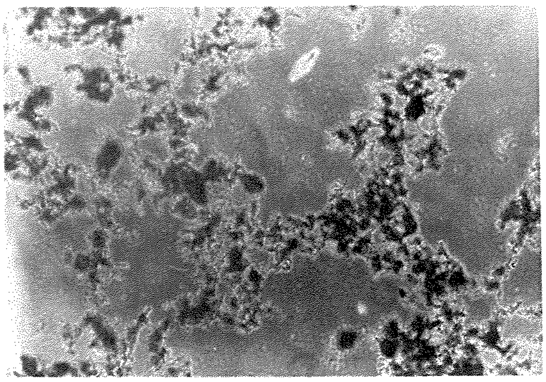
A.S.2.
0.12 kg COD/kg MLVSS day x 43



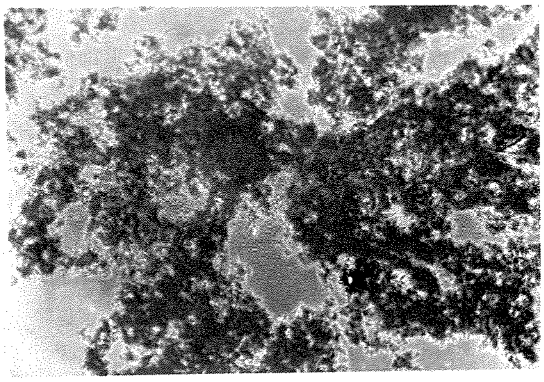
A.S.3.
0.17 kg COD/kg MLVSS day x170

A.S.3.
0.17 kg COD/kg MLVSS day x 43

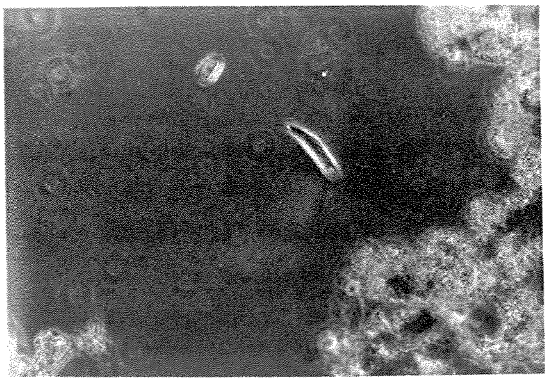
FIGURE 65. Activated sludge. Test run No.II



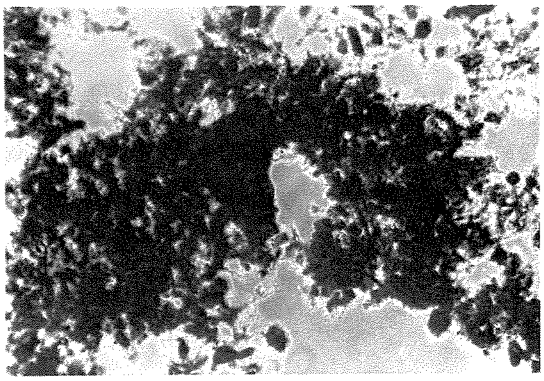
A.S.4
F=0.26 kg COD/kg MLVSS day x 43



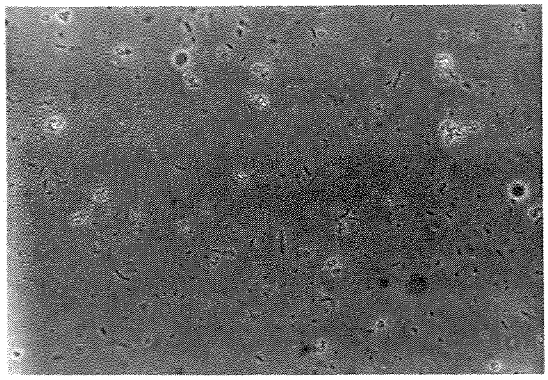
A.S.4.
F=0.26 kg COD/kg MLVSS day X 43



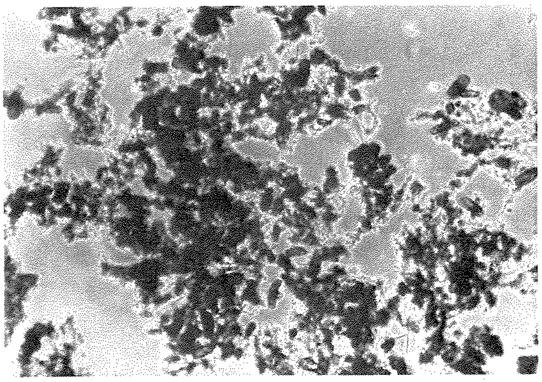
A.S.5.
F=0.34 kg COD/kg MLVSS day x170



A.S.5.
F=0.34 kg COD/kg MLVSS day x 43



A.S.6
F=1.05 kg COD/kg MLVSS day x170



A.S.6
F=I.05 kg COD/kg MLVSS day x 43

FIGURE 66. Activated sludge. Test run No. II

Tabell 34. Microscopic examinations. test run no II

Plant	Organic loading kg COD kg MLVSS day	Protozoa		Flagel-lates	Roti-fiers	Nema-todes	Free Swim bacteria	Filamen-tous bacteria	Size of floes	Dispersed materials or defloc-culation
		Swim	Stalked							
A.S.1		2	1	+	1	0	2	1	Medium	Some
A.S.2		2	1	1	1	0	2	1	Medium	Some
A.S.3		2	1	1	1	0	2	1	Medium	Some
A.S.4		2	1	1	2	0	3	1	Medium	Some +
A.S.5		+	+	0	+	0	4	1	Medium	High -
A.S.6		+	+	0	0	0	4	1	Small	High

Relative number of higher microorganisms. (used at Norwegian Institute of Water Research)

5.	Dominating:	Dominating the sample completely
4.	Many:	Many organisms in each field of vision
3.	Usual:	Some organisms in each field of vision
2.	Some:	Occurs often but not in each field of vision
1.	Few	Few organisms observed
+	Very few:	Very few organisms observed
0		Not observed

With the exception of the plants with the highest organic loadings the density, shape and floc size of the sludge was normal. However, iron deposits in the sludge caused a dark color. At the highest organic loadings the sludge also contained high concentrations of separate deposited iron particles.

2. Treatment of Chemically Treated Leachate by the Activated Sludge Process (Test run no III and no IV)

In test runs no III and IV, biological treatment of chemically precipitated leachate from Grønmo was studied. The difference in the experimental conditions between the two test runs were differences only in the organic loadings. The precipitated leachate used in the treatment studies was supplied from an existing full scale treatment plant. The precipitation in this plant was brought about by the iron in the raw leachate. This was done by increasing the pH in the raw leachate with sodium hydroxide to 8.0-8.5. Then a short aeration period caused an oxidation of the ferrous iron to ferric iron. A polyelectrolyte added in the flocculator gave very efficient flocculation. The flocculated particles settled effectively in a tube settler. The iron concentrations of the raw leachate were in the range of 50-100 mg Fe/l.

Analyses of the raw and chemically precipitated leachate showed efficient removals of iron. Thus for nine samples taken over a period of three months the iron concentrations of the treated leachate, ranged from 1.1 to 2.8 mg/l with an average value of 1.8 mg/l. The concentrations of heavy metals in the raw leachate were very low for all investigated samples. Therefore removals of heavy metals in the precipitation process were not investigated.

Because the majority of the organics in the leachate were in the dissolved state precipitation were expected to give poor organic removal efficiencies. Samples of the raw and precipitated leachate analyzed for COD or TOC also showed very low removals. Normally the COD or TOC removals were less than 10 percent.

The total phosphorus concentrations in the chemically treated leachate were normally less than 0.1 mg/l. The BOD values for bio oxidation of the organics in the leachate were roughly 100 mg/l. This gives a BOD:P ratio of about 1000:1, which should indicate a phosphorus deficiency. Because of this high BOD:P ratio phosphorus was added to the plant A.S.II in test run no III. The adjusted BOD:P ratio was 50:1.

The three activated sludge plants were filled with activated sludge from a plant treating domestic sewage. The starting problems in this test run were the same as in the starting phase of treating raw leachate. That is, a steady loss of activated sludge was acclimated and the concentrations of activated sludge could be maintained.

The treatment results from test run nos III and IV are given in tables 89 to 96. The most important results are drawn in figures 67 to 72.

a. Organic Removals. The organic removal efficiencies for chemically treated leachate expressed as reduction in COD or TOC, were nearly the same as when treating raw leachate.

In test run no III the average COD removals were 30.8, 27.0 and 25.7 percent at organic loadings equal to 0.05, 0.10 and 0.15 kg COD/kg MLVSS day. The plant, A.S. II, to which was added phosphorus to a BOD:P ratio of 50:1, did not give higher organic removals than the plants with no phosphorus addition.

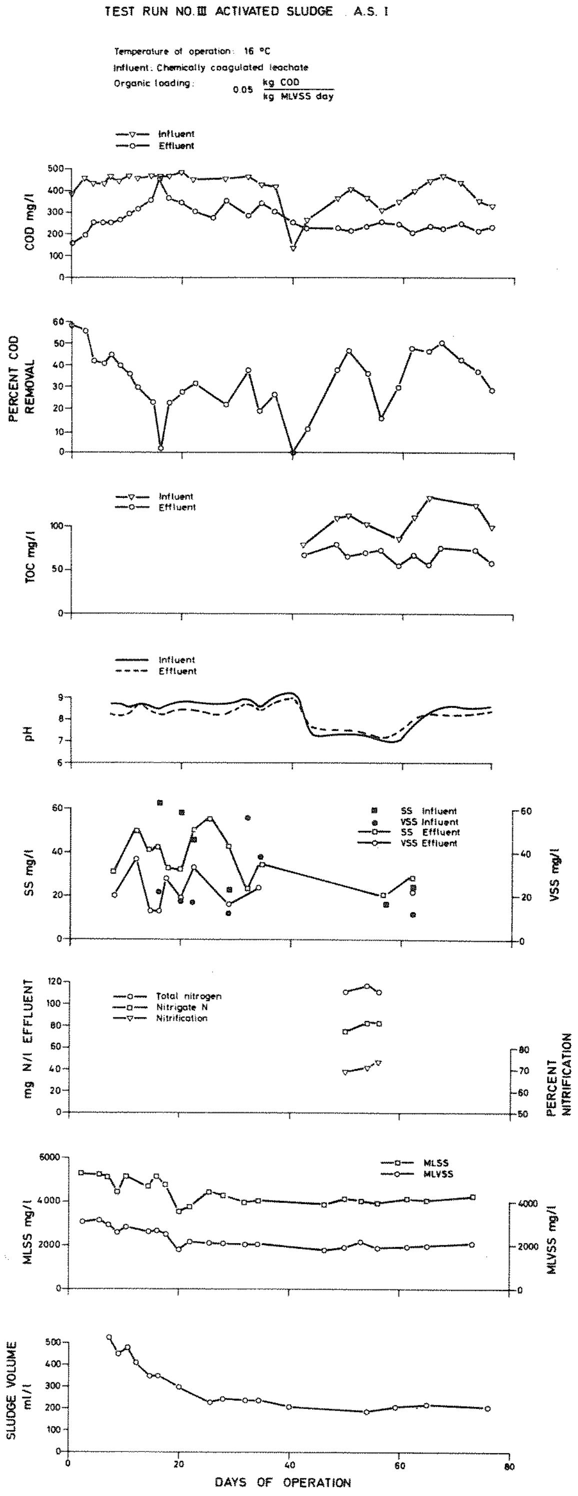


Figure 67. Experimental results, Test run no III, A.S.I.

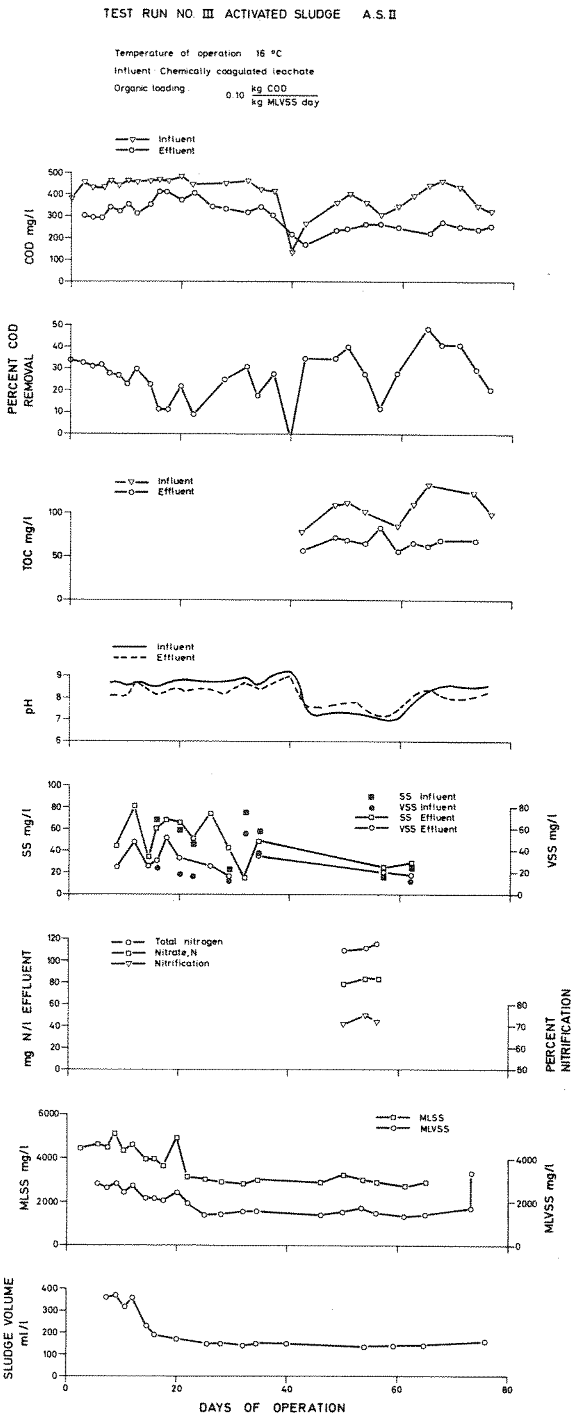


Figure 68. Experimental results, Test run no III, A.S.II.

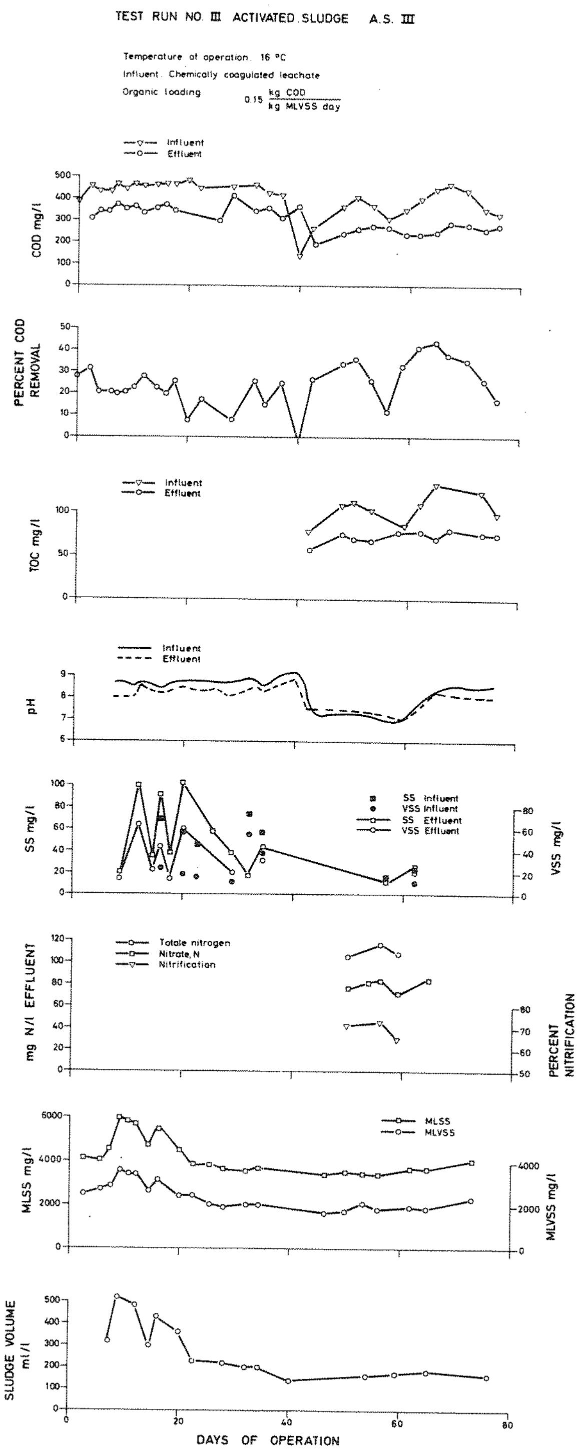


Figure 69. Experimental results, Test run no III, A.S.III.

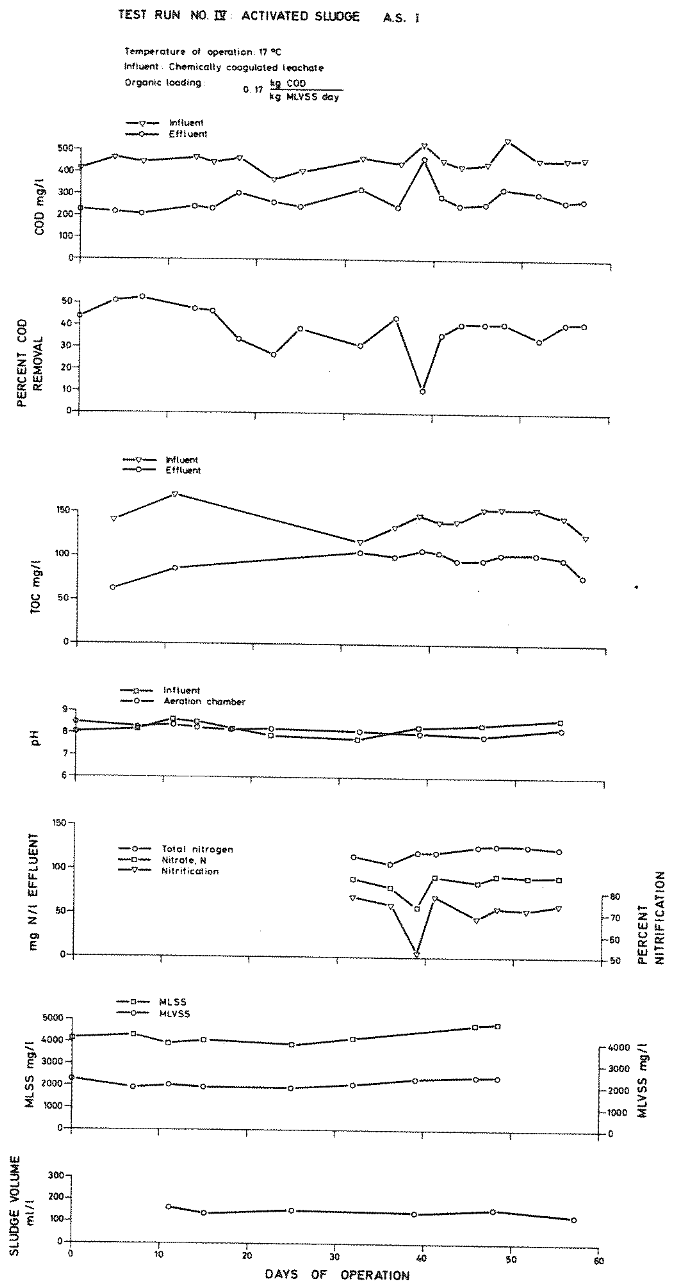


Figure 70. Experimental results, Test run IV, A.S.I.

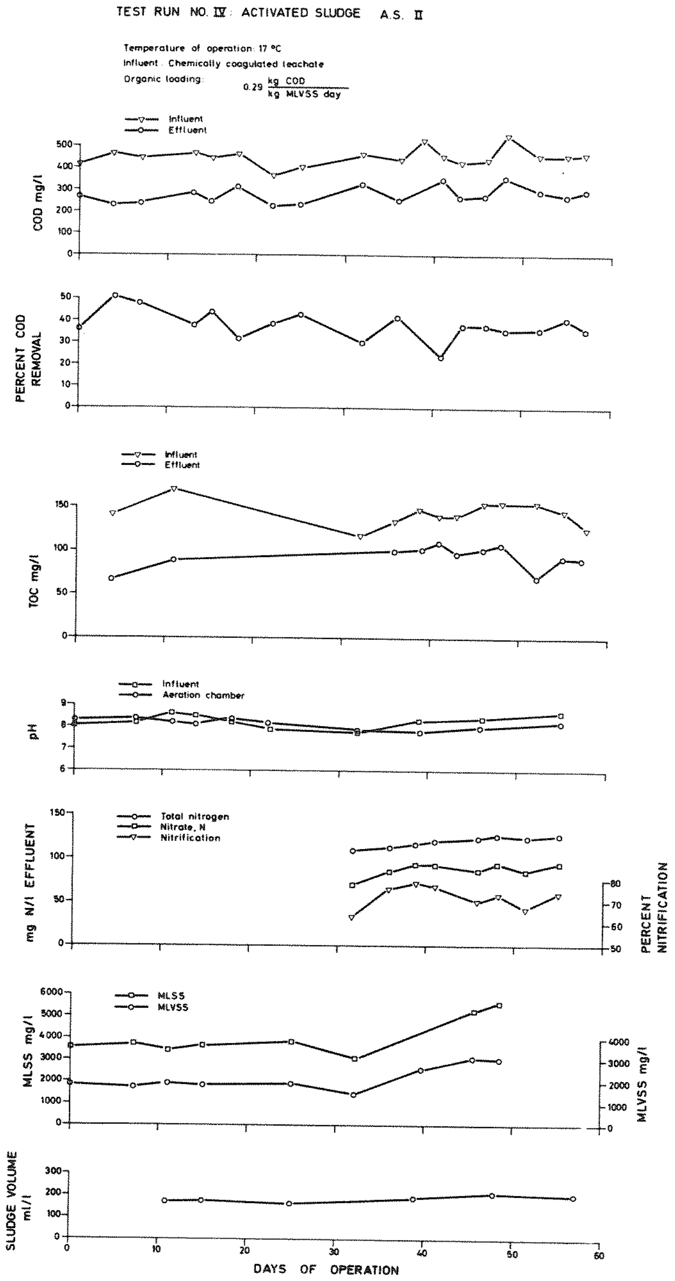


Figure 71. Experimental results, Test run no IV, A.S.II.

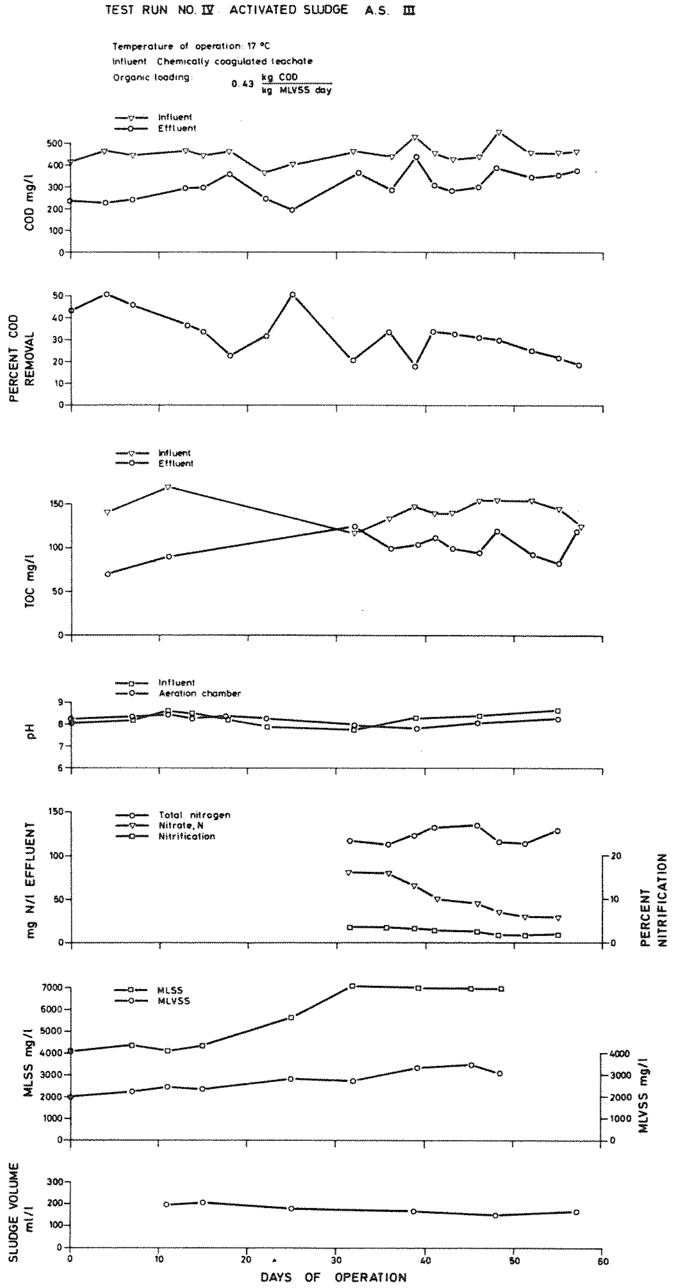


Figure 72. Experimental results, Test run no IV, A.S.III.

In test run no IV the average COD removals were 37.8, 36.9 and 29.6 percent for organic loadings 0.17, 0.29 and 0.43 kg COD/kg MLVSS day respectively. In spite of higher organic loadings, test run no IV gave higher COD removals than the average COD removals obtained in test run no III. This was caused by higher COD influent values in test run no IV.

Organic removals based on TOC analysis also gave about the same removal efficiencies as those based on COD analyses.

Figures 73 to 74 show some BOD curves from test run no IV. The BOD samples were taken at about one week interval. A comparison of these BOD curves with the BOD curves obtained from test run no II show at corresponding organic loadings the same shape and about the same values. That is the chemical precipitation process does not seem to improve oxidation of the organics.

In figure 74 the BOD curve of the effluent sample from A.S. III shows a sharp increase after an incubation time of about 8 days. The average organic loading for the plant A.S. III was 0.43 kg COD/kg MLVSS day. Figures 73 and 74 both show that this organic loading was too high to assure a high degree of nitrification. Compared with the effluent BOD curve from A.S. III the influent BOD curve shows a lag phase. Thus for incubation times up to about 30 days the effluent value is higher than the influent values. When the incubation times are extended, the nitrate forming stage of the influent is included, which causes a higher ultimate BOD value than for the effluent from A.S. III.

For the BOD curves representing the effluents from the plants A.S. I and A.S. II the values were low for all incubation times. The average organic loadings were for A.S. I and A.S. II 0.17 and 0.29 kg COD/kg MLVSS day, respectively. These organic loadings were low enough to convert all

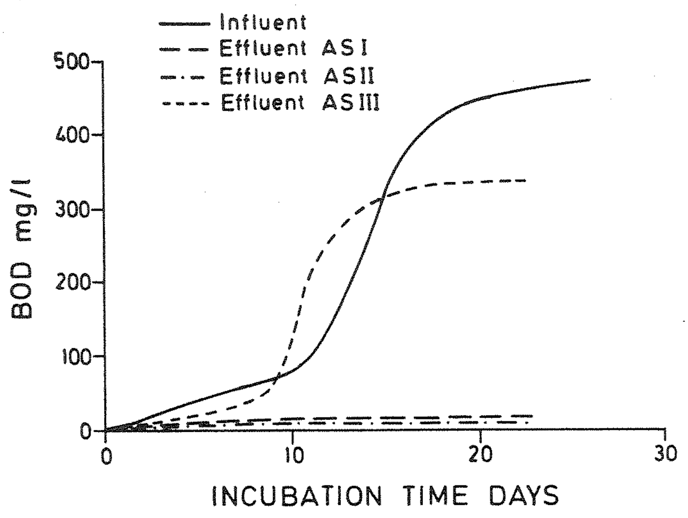


Figure 73. BOD curves, test run no IV (1).

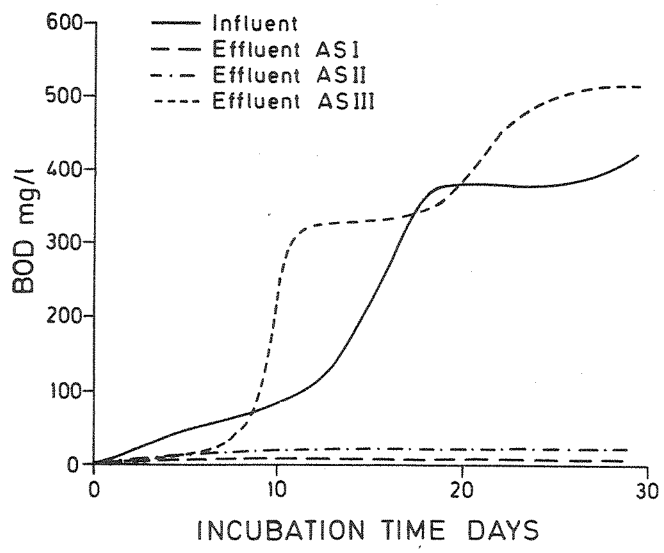


Figure 74. BOD curves, test run no IV (2).

the biological oxidizable nitrogen compounds to nitrates. Therefore the effluent samples at these low organic loadings showed low BOD values.

The results of the BOD tests clearly show the significance of the incubation time. To characterize the removal of BOD of leachate sufficient long incubation times should be used to be sure to include the nitrification processes.

b. Oxidation of Nitrogen Compounds. The BOD curves of the raw and chemically precipitated leachate shown in figures 62, 73 and 74 appear to have the same relative values and the same shape. The degree of nitrification was the same for both raw and chemically precipitated leachate. Further discussion will follow.

c. Microscopic Examination. The results of the microscopic examination of the activated sludge from test runs no III and IV are given in table 35. Figure 75 shows same typical picture of organisms present in the sludge. The microscopic examinations were performed in the last part of test run no IV.

The microscopic examinations from test run no III showed relatively little species diversity of higher organisms. In the plant A.S. II which was loaded at an average organic loading of 0.15 kg COD/kg MLVSS day nematodes were present in relatively high concentrations. These were not observed in samples from A.S. III. The samples from all three plants showed very few free swimming bacteria. The size and shape of the flocs were normal with good flocculation properties.

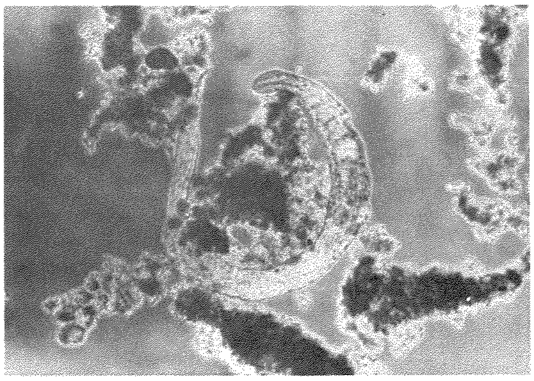
In the samples from test run no IV where the organic loadings were considerably higher the composition and concentrations of the higher organisms were to some extent altered. In the plants A.S. I and A.S. II operating at

Table 35. Microscopic Examinations. Test run no III and IV

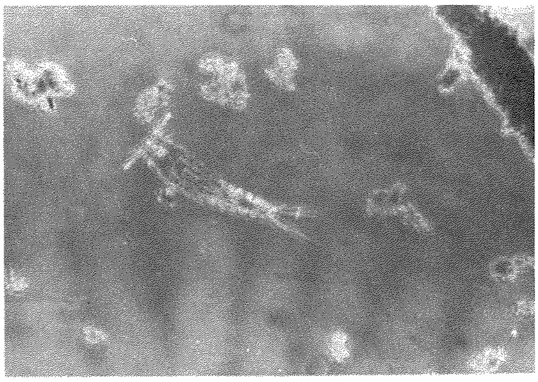
	Plant	Organic loading kg COD kg MLVSS day	Protozoa		Flagellates	Rotifiers	Nematodes	Free Swimming bacteria	Filamentous bacteria	Size of floc	Degree or deflocculation
			Swimming	Stalked							
Test run no III	A.S. I	0.05	+	0	0	1	0	+	1	Medium	None
	A.S. II	0.10	+	+	0	+	+	+	1	Medium	None
	A.S.III	0.15	+	+	0	-	3	+	1	Medium	None
Test run no IV	A.S. I	0.17	1	1	0	0	3	+	1	Large	None
	A.S. II	0.29	1	1	0	0	3	+	1	Medium	None
	A.S.III	0.43	0	0	0	0	0	1	1	Small	Some

Relative number of higher microorganisms.

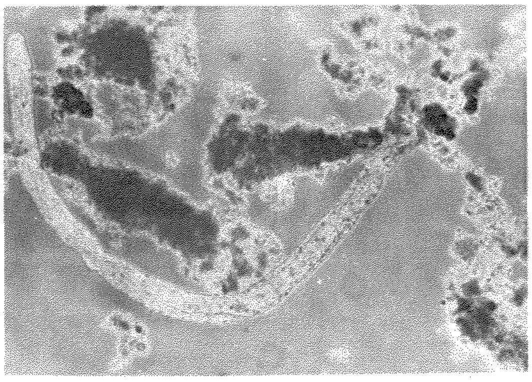
5. Dominating: Dominating the sample completely
4. Many: Many organisms in each field of vision
3. Usual: Some organisms in each field of vision
2. Some: Occurs often but not in each field of vision
1. Few Few organisms observed
\+ Very few: Very few organisms observed
0 Not observed



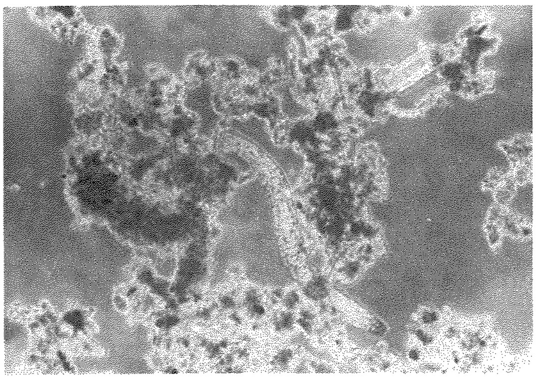
A.S.I
0.17 kg COD/kg MLVSS day x 43



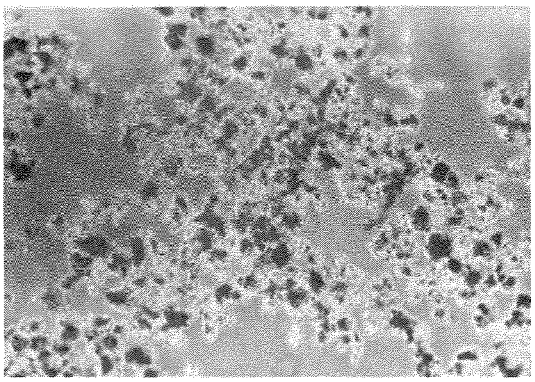
A.S.I
0.17 kg COD/kg MLVSS day x 43



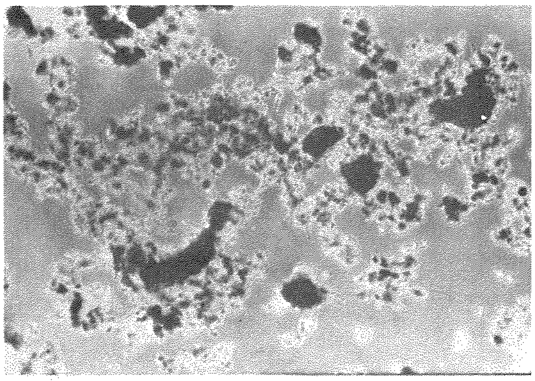
A.S.II
0.29 kg COD/kg MLVSS day x 43



A.S.II
0.29 kg COD/kg MLVSS day x 43



A.S.III
0.43 kg COD/kg MLVSS day x 43



A.S.III
0.43 kg COD/kg MLVSS day x 43

FIGURE 76 Activated sludge. Test run No.IV average organic loadings of 0.17 and 0.29 kg COD/kg MLVSS the nematodes dominated. Some protozoa were also present. In A.S. I also same copepods were observed. In the plant A.S. III which operated at an organic loading of 0.43 kg COD/kg MLVSS no higher organisms were observed. At the start of this test run the nematodes were present in high concentrations. The size of the floc in A.S. III were also smaller than in the plants A.S. I and A.S. II.

3. Comparison of the Results from Treating Raw and Chemical Treated Leachate by Activated Sludge

a. Organic Removals. The organic removal with activated sludge treatment of leachate from Grønmo sanitary landfill is shown in figures 76 and 77. The figures show no significant differences in the organic removal efficiencies when treating raw or chemically treated leachate. The somewhat different results from the different test runs were related to the concentrations of organics in the influent. The results showed that the organics could be removed to a threshold value. The test series with low strength leachate gave the lowest organic removal efficiencies. Based on COD the threshold value was about 250-300 mg/l.

The results show very low COD or TOC removal efficiencies. Organic loadings as low as 0.03 kg COD/kg MLVSS day did not give higher efficiencies than about 35 percent. The organic removal efficiencies based on COD and TOC were nearly identical. Therefore COD analysis can be used to characterize the organic removals.

The BOD removal efficiencies at low organic loadings were normally higher than 90%. The main contributor to these high BOD removal efficiencies were the oxidation of the ammonia compounds in the leachate. A comparison of

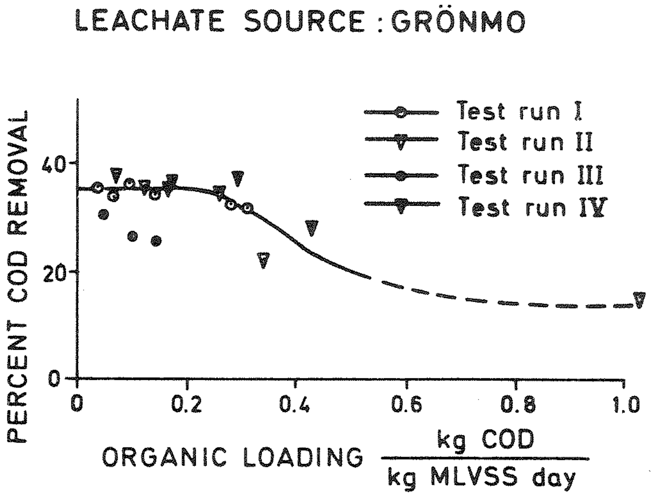


Figure 76. COD removal vs. organic loading.

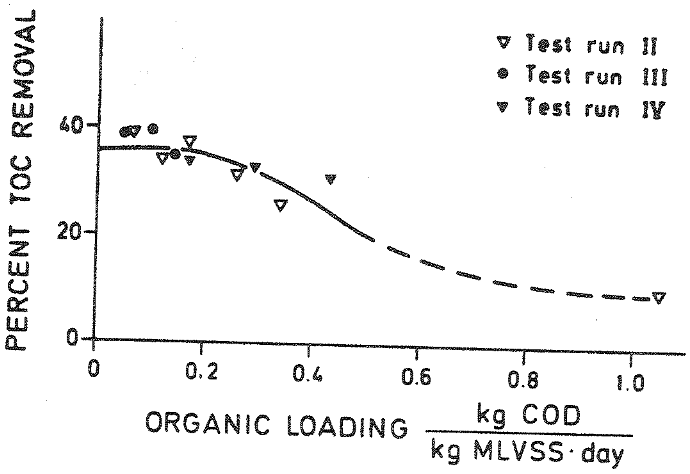


Figure 77. TOC removal vs. organic loading.

the effluent COD or TOC values with the BOD values show that a very high fraction of the organics were inert to biological degradation.

The studies also showed that phosphorus, in spite of very low concentrations, did not limit the treatment processes.

b. Oxidation of Nitrogen Compounds. Figure 78 shows the ratio of nitrates to total nitrogen in the effluent as a function of organic loading. Because no nitrogen removal took place the above ratio is equal to the degree of nitrification.

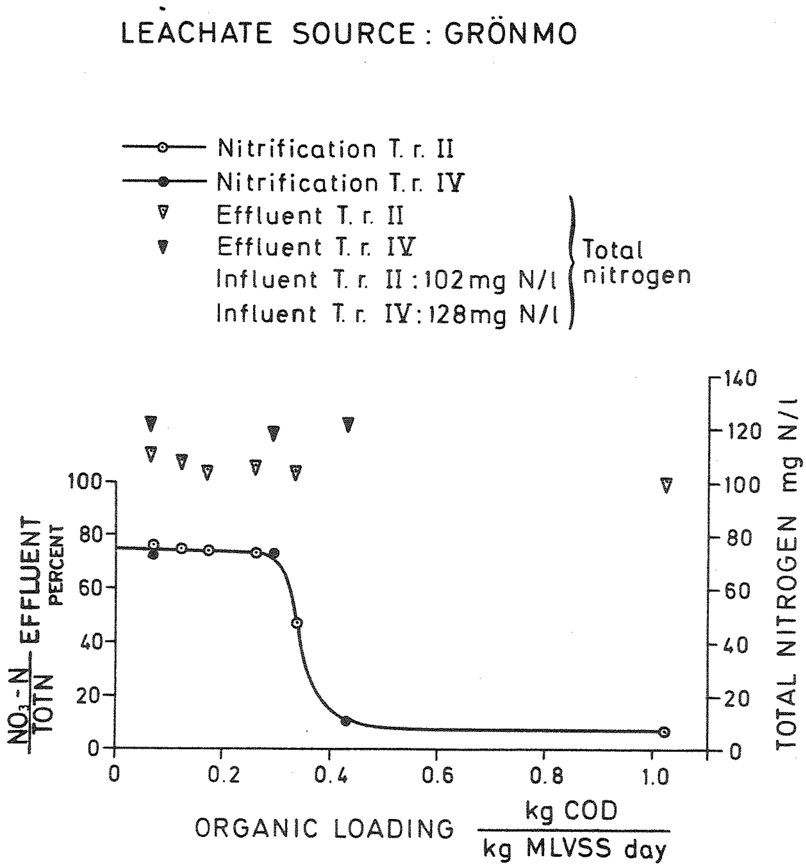


Figure 78. Oxidation of nitrogen compounds vs. organic loading.

The maximum obtainable degree of nitrification seems to be about 70 percent. At organic loadings higher than about 0.3-0.4 kg COD/kg MLVSS day the degree of nitrification falls drastically. To obtain high BOD removals it is therefore necessary to apply organic loadings lower than about 0.3 kg COD/kg MLVSS day. The results show no difference in the degree of nitrification for treatment of raw or chemically treated leachate.

c. Solids. The biological treatment of raw and chemically precipitated leachate gave relatively large differences in the effluent concentrations of suspended solids. Thus in test run no II and IV the average suspended solids concentrations ranged from 54-97 mg/l and 20-26 mg/l respectively.

The difference was probably due to the deflocculation of the activated sludge which took place in the treatment of raw leachate.

d. Activated Sludge Characteristics. In the biological treatment of raw or chemically treated leachate the settleability of the activated sludge was good at all organic loadings. For instance the sludge volume index was very seldom higher than 100.

The microscopic examinations from the activated sludge treatment of raw and chemically precipitated leachate showed some differences. In the treatment of raw leachate nematodes were not observed. At low organic loadings protozoas were more abundant in the plants treating raw leachate than in the treatment of chemically precipitated leachate. At the highest organic loadings no higher organisms were present in either the treatment of raw nor chemically precipitated leachate.

The physical character of the activated sludge differed also. In the treatment of raw leachate the sludge flocculated poorly compared to treatment of chemically precipitated leachate. Thus the number of free swimming bacteria was higher in the treatment of raw leachate. Filamentous bacteria did not exist or were present in very small concentrations in all the studies.

4. Biodisc (Test run no V)

Chemically precipitated leachate from Grønmo was also treated by a rotating biodisc. To obtain attached microbial growth rapidly the biodisc was first used to treat municipal sewage. After three weeks of operation on municipal sewage the feed to the unit was switched to chemically precipitated leachate at an organic loading of 6.2 g COD/m^2 day. This is a low loading compared to the organic loadings normally applied in treatment of domestic waste water.

The results obtained in test run no V are given in tables 97 and 98, Appendix B. The most important parameters are shown in figure 79.

The COD or TOC removal efficiencies were very low. Thus the average COD removal efficiency over the whole test period was not higher than 15.9 percent. The average degree of nitrification in the same period was 2 percent.

The low biodisc performance compared with the results obtained by the activated sludge process is probably due to unfavorable conditions in the starting phase. In an activated sludge plant it is possible to have high concentrations of activated sludge at the start of the treatment. For a biodisc these concentrations were lower and unfavorable environments cause a loss of the attached growth.

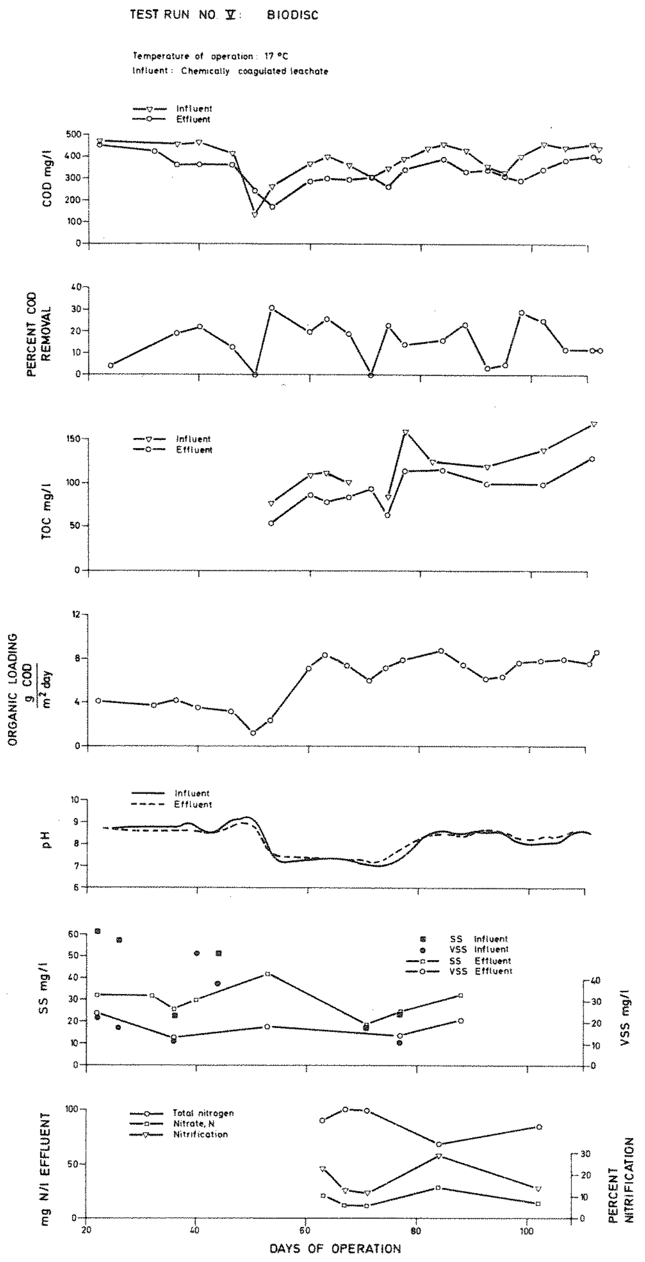


Figure 79. Experimental results, test run no V, biodisc.

5. Trickling Filter (Test run no VI)

In test run no VI treatment of chemically precipitated leachate from Grønmo was treated in a trickling filter. No attempt was made to obtain attached growth prior to the treatment of leachate.

The organic loading applied was about 1.0 kg COD/m^3 day. This corresponds to an activated sludge loading of 0.15 kg COD/kg MLVSS day. (Lehr und Handbuch der Abwassertechnic (1969)).

The experimental results for test run no VI are given in tables 99 and 100 Appendix B. The results are also drawn graphically in figure 80.

During the 94 days of operation the filter showed no significant reduction of organics. Thus the reductions of COD or TOC averaged only 7.4 and 7.5 percent. The results also showed that no nitrification had taken place.

No attached growth was observed during the whole test run. The only thing which could be observed on the filter media was small and hard particles of iron deposits.

6. Aerated Lagoons (Test run no VII)

In test run no VII raw leachate was treated in aerated lagoons. The results from these treatment studies are given in tables 101 to 103 Appendix B. The most important results are drawn in figures 81 and 82.

At the start two loagoons were partly filled with treated leachate from the activated sludge units treating raw leachate. This was done to reach steady state conditions rapidly. The detention times in the lagoons were 10 and 37 days corresponding to organic loadings of 41 and 11 g COD/m^3 day.

The average organic removals expressed on a COD basis were 32.7 and 27.4 percent for the lagoons A.L.1 and A.L.2 respectively. The corresponding

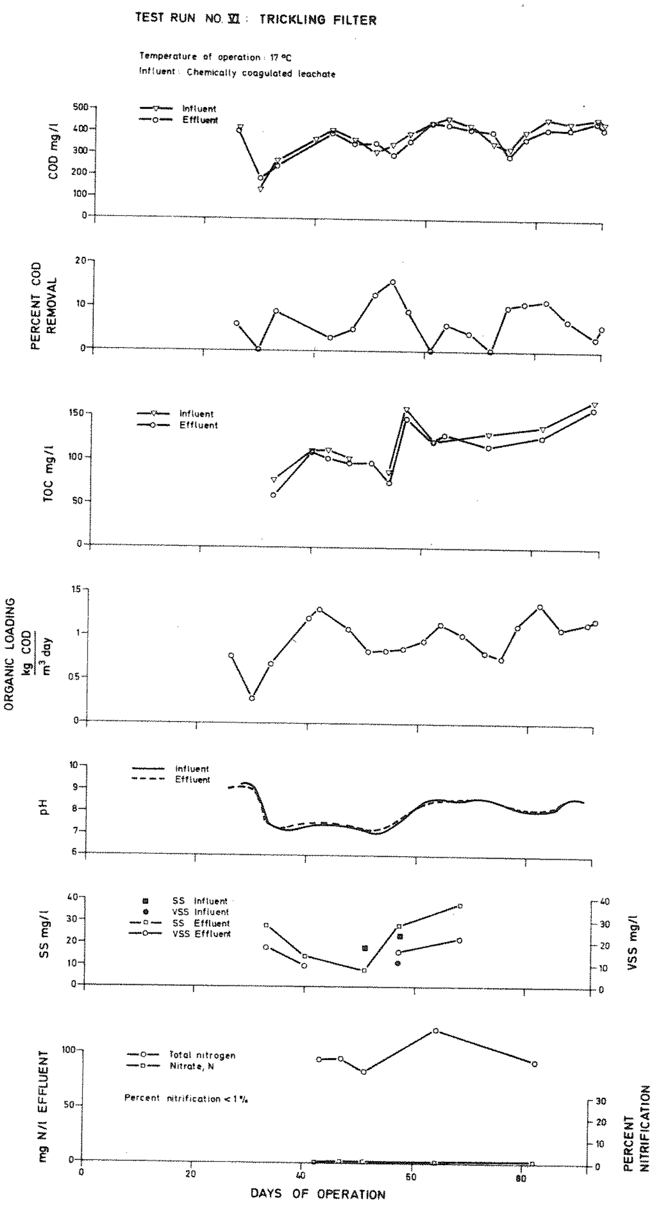


Figure 80. Experimental results, trickling filter.

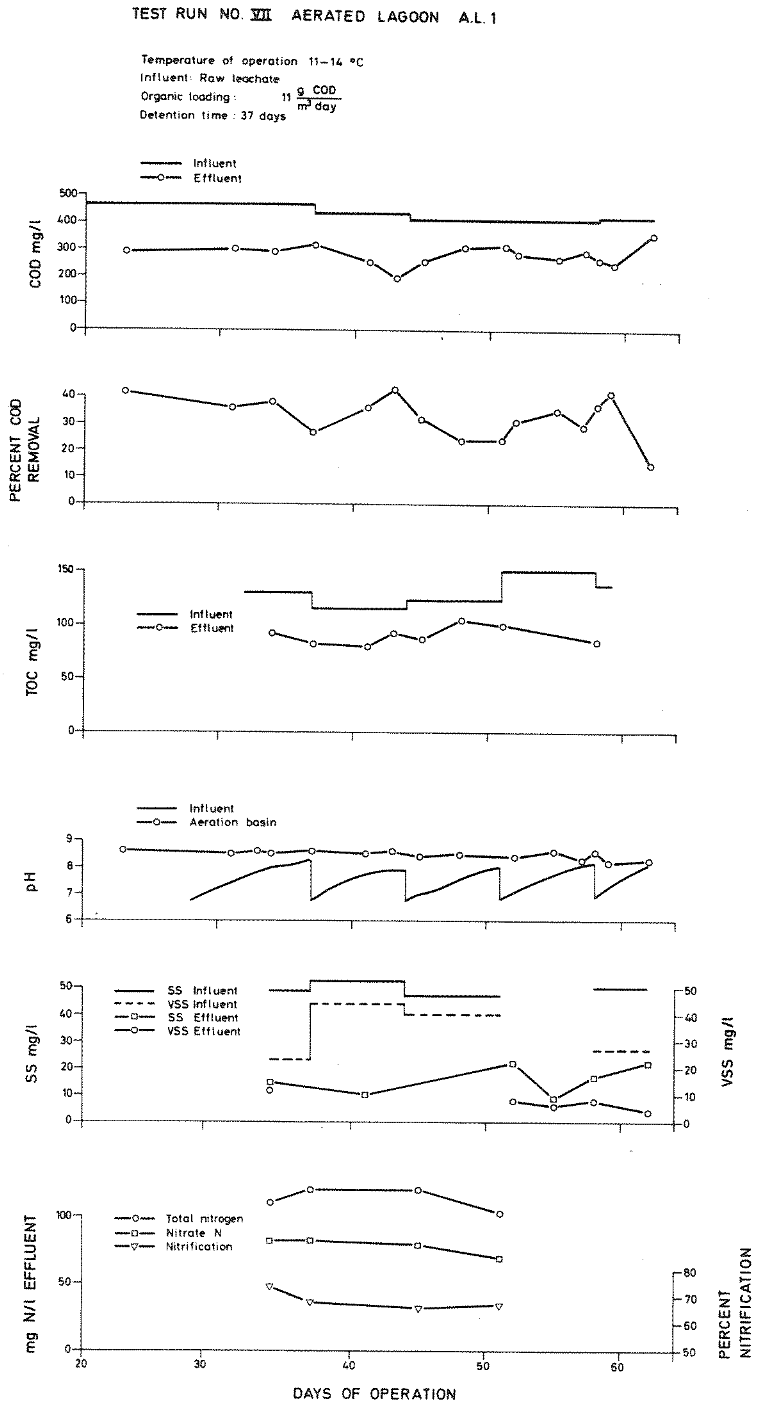


Figure 81. Experimental results, test run no VII, A.L.1.

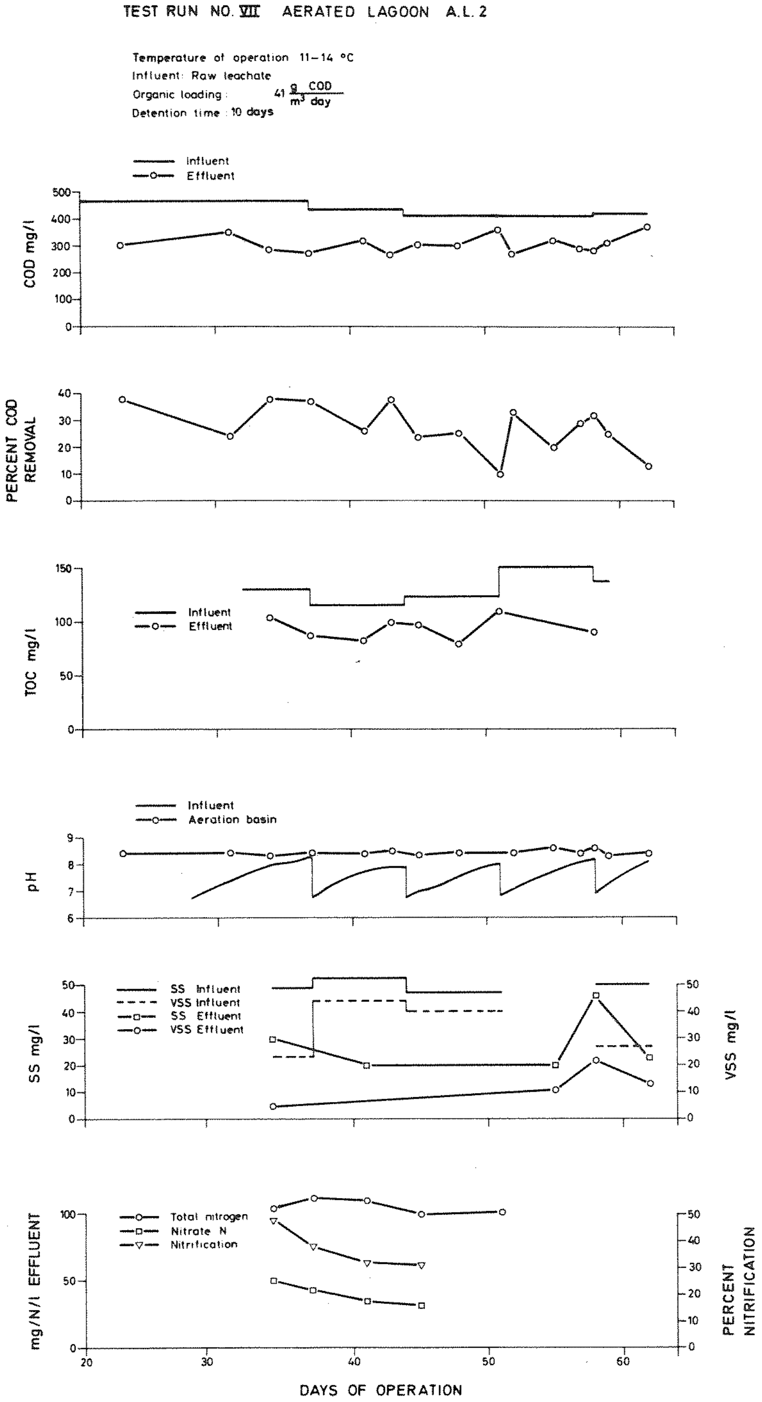


Figure 82. Experimental results, test run no VII, A.L.2.

numbers based on TOC were 27.8 and 25.1 percent.

In test run no II where the same leachate was treated by the activated sludge process the average COD removals ranged from 38.2 to 17.6 percent. The organic loading was then in the range of 0.07 to 1.05 kg COD/kg MLVSS day.

The degree of nitrification was 68.8 percent in the lagoon operating with a detention time of 37 days. This is the same as the maximum obtained by the activated sludge process in test run no II. For the aerated lagoon operating with a detention time of 10 days the average degree of nitrification was 37.2 percent.

The effluent concentrations of suspended solids were very low. Thus for the lagoons A.L.1 and A.L.2 the average concentrations were 15.8 and 27.8 mg/l respectively. These are surprisingly low values compared with the suspended solids concentrations obtained by the activated sludge process in test run no II. In test run no II the suspended solids concentrations were in the range of 54 to 97 mg/l. The difference could be attributed to the poor flocculation of the sludge in the activated sludge units.

7. Chemical Treatment of Raw and Biologically Treated Leachate

The purpose of this study was to examine the possibilities of treating raw and biologically treated leachate by chemical precipitation. Of special interest were the removals of organics and heavy metals.

The precipitation studies were investigated using jar test apparatus. The chemicals and the leachate were mixed at high paddle speed for two minutes, flocculated for 15 minutes and settled for 30 minutes. As precipitants were used alum, $Al_2(SO_4)_3 \cdot 18H_2O$, ferric chloride, $FeCl_3 \cdot 6H_2O$, and lime, $Ca(OH)_2$. For adjustment of pH, lime and hydrochloric acid were used. Precipitation with alum and ferric chloride was performed at pH 6.0 and 9.0 respectively and without pH adjustment.

a. Chemical Treatment of Raw Leachate. Chemical treatment of raw leachate was performed in four treatment series. The results from test series no 1, 2 and 3 are given in tables 36 to 38. The results from test series no 4 are given in table 129 Appendix C.

With the exception of iron the concentrations of heavy metals in the raw leachate were low. Thus the concentrations of Cu, Cr, Cd, Pb and Ni were all below 0.1 mg/l. Therefore in the three first test series the removal of these metals was not studied.

The results from test series no 1, 2 and 3, given in tables 36 to 38 show very low reductions of COD for all series. Table 39 summarizes the COD removals obtained in each of the test series. The average values seem to indicate that precipitation with lime at pH 11 and 12 gave the highest COD removals. The table shows no significant difference in COD removal between the precipitates, alum and ferric chloride. pH adjustment in the coagulation process did not improve the COD removal. Further, there was no significant difference between the lowest and highest doses. Roughly, the COD removals obtained by precipitation with alum and ferric chloride were about 10 percent. Lime precipitation at pH 11 and 12 gave COD removals of about 15 percent.

In test series no 1, 2 and 3 ferric chloride, alum and lime all gave high removal efficiencies for iron. Zinc was also reduced to low concentrations. However, the zinc concentrations in the raw leachate were so low that the removal efficiencies for zinc were difficult to study. Lime

Table 36. Chemical treatment of raw leachate, test series no. 1

Precipitant	pH	COD mg/l	COD red. %	Fe mg/l	Zn mg/l
Influent	7.8	521		90.2	0.82
Alum 150	7.8	461	11.5	0.82	<0.1
" 200	7.6			1.57	0.23
" 300	7.4			1.42	<0.1
Alum 400	7.2	479	8.1	0.83	"
Ferric chloride 150	7.6	469	10.0	1.20	<0.1
" " 200	7.5			0.87	0.17
" " 300	7.3			1.60	0.28
Ferric chloride 400	7.1	456	12.5	1.82	0.35
Lime	9.0	462	11.3	5.57	<0.1
"	10.0			<0.1	"
"	11.0			"	"
Lime	12.0	361	30.7	<0.1	<0.1

Alum as $Al_2(SO_4)_3 \cdot 18H_2O$

Ferric chloride as $FeCl_3 \cdot 6H_2O$

Doses in mg/l

Table 37. Chemical treatment of raw leachate, test series no 2

Precipitant	pH	COD mg/l	COD red. %	Fe mg/l	Zn mg/l
Influent	7.7	533		80.5	0.16
Ferric chloride 150	9.0	467	12.4	0.60	<0.1
" " 250	9.0	483	9.4	0.65	<0.1
" " 150	7.5	498	6.6	0.85	0.15
Ferric chloride 250	7.3	512	3.9	0.83	<0.1
Alum 150	6.0	499	6.4	0.81	"
" 250	6.0	483	9.4	0.38	"
" 150	7.6	492	7.7	0.42	"
Alum 250	7.4	475	10.9	0.44	"
Lime	9.0	506	5.1	1.20	"
"	10.0	488	8.4	1.12	"
"	11.0	456	14.4	<0.1	"
Lime	12.0	453	15.0	<0.1	<0.1

Table 38. Chemical treatment of raw leachate, test series no 3

Precipitant	pH	COD mg/l	COD red. %	TOC mg/l	TOC red. %	Fe mg/l	Zn mg/l
Influent	7.6	547		147.5		29.12	0.36
Ferric chloride 150	9.0	461	15.7			0.8	<0.1
" " 250	9.0	486	11.1	115	22.0	0.6	"
" " 150	7.3	480	22.8			1.2	"
Ferric chloride 250	7.1	463	15.3			0.9	"
Alum 150	6.0	489	10.6			1.9	"
" 250	6.0	486	11.1	115	22.0	1.0	"
" 150	7.6	490	10.4			0.6	"
Alum 250	7.5	463	15.3			1.0	"
Lime	9.0	507	7.3			3.7	"
"	10.0	488	10.8			1.7	"
"	11.0	456	16.6			<0.1	"
Lime	12.0	446	18.4	112.5	23.7	<0.1	<0.1

Table 39. Percent COD removals

	COD removals %				Average COD removals %	
Test service No	1	2	3	4	2-3-4	2-3
Alum 150	11.5	7.7	10.4			9.1
" 250		10.9	15.3			13.1
" 400	8.1					
" 150 pH 6		6.4	10.6	6.3	7.8	8.5
" 250 " "		9.4	11.1	11.3	10.6	10.3
" 400 " "				8.5		
Ferric chloride 150	10.0	6.6	22.8			14.7
" " 250		3.9	15.3			9.6
" " 400	12.5					
" " 150 pH 9		12.4	15.7	3.6	10.6	14.1
" " 250 " "		9.4	11.1	5.4	8.6	10.3
" " 400 " "				12.6		
Lime pH 9	11.3	5.1	7.3	12.6	8.2	6.2
" " 10		8.4	10.8	11.7	10.3	9.6
" " 11		14.4	16.6	17.6	16.2	15.5
" " 12	30.7	15.0	18.4	18.5	17.3	16.7

precipitation at pH 9 seemed to give the lowest heavy metal removals while lime precipitation at pH 11 and 12 gave the highest removals. Precipitation with ferric chloride and pH adjustment to 9.0 gave slightly better removal of heavy metals than precipitation without pH adjustment. Without pH adjustment no significant difference in the removal efficiencies were found between the precipitants alum and ferric chloride.

To make it possible to study the precipitation of the heavy metals Zn(II), Cu(II), Cr(III), Cd(II), Pb(II) and Ni(II) these were added to the raw leachate. The concentrations of the heavy metals in the leachate became as shown in table 129 Appendix C. The results from the studies are given in the same table. The removals of the different heavy metals as function of doses are given in figures 83 to 86.

The metals can be precipitated by taking advantages of the low solubilities of the metal hydroxides or metal carbonates. The general equations for evaluations of the metal hydroxide solubilities of n valence metals are :

1. $Me(OH)_n(s) + nH^+ \rightleftarrows Me^{n+} + nH_2$
2. $Me^{n+} + xH_2O \rightleftarrows Me(OH)_x^{n-x} + xH^+$

The solubilities of pure metal hydroxides at three different pH values are calculated in table 40. The solubility products and the complex constants of the hydroxides are taken from Sillén (1964).

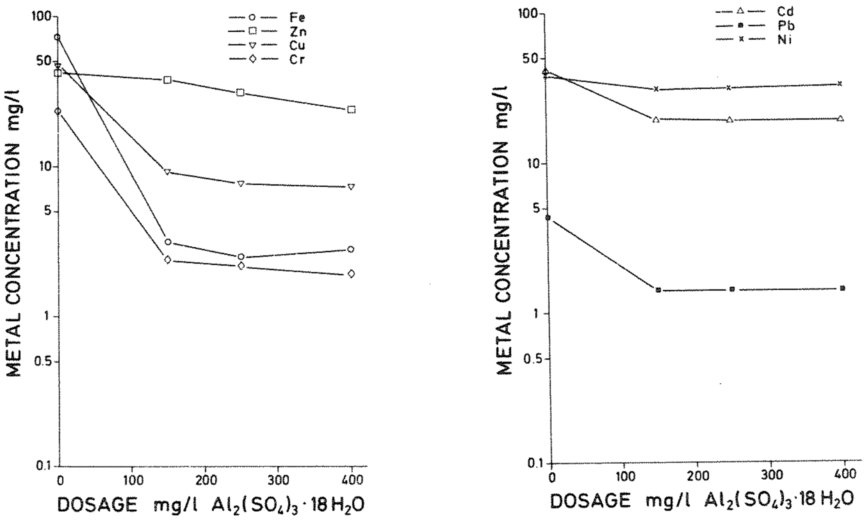


Figure 83. Precipitation with alum.

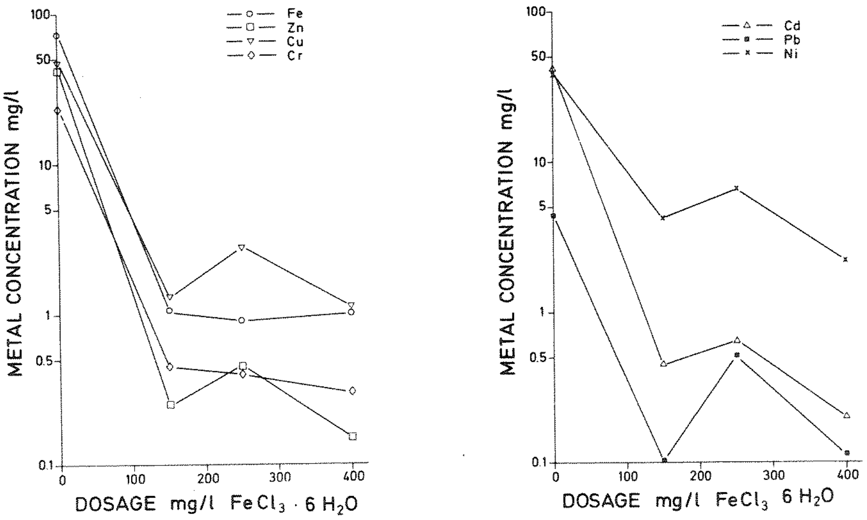


Figure 84. Precipitation with ferric chloride.

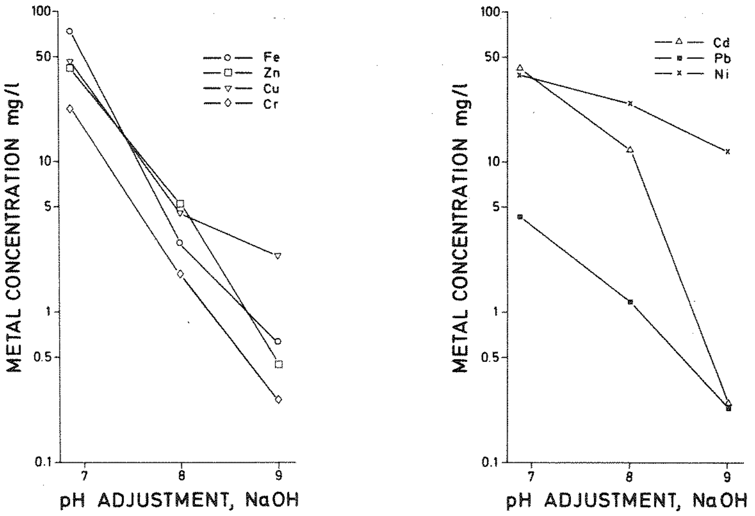


Figure 85. Precipitation by pH adjustment.

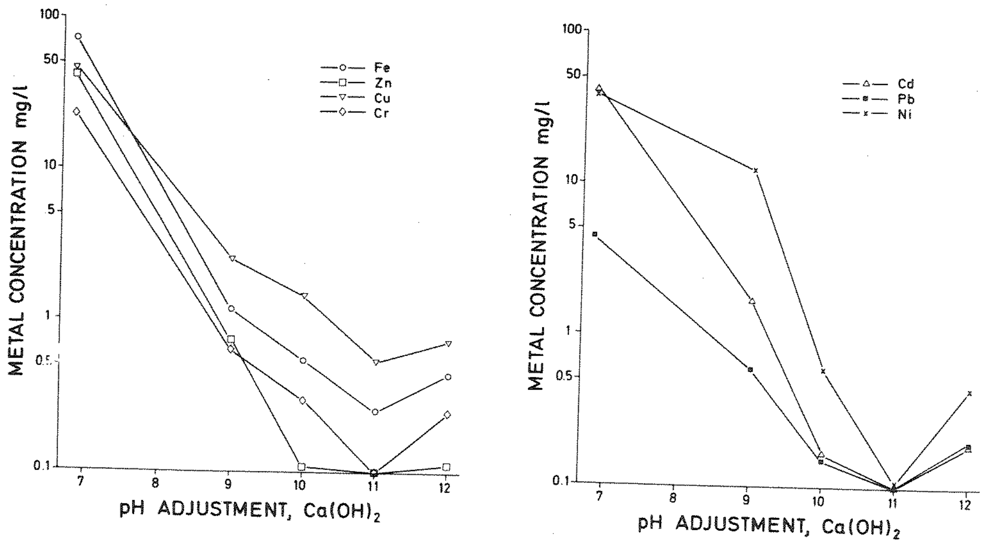


Figure 86. Precipitation with lime.

Table 40. Solubility of pure metal hydroxides, mg/l

Metal	pH 6	pH 8	pH 10
Cr(III)	8	0.1	1.6
Zn(II)	>500	10	0.2
Cd(II)	>500	>500	0.5
Ni(II)	>500	100	0.05
Cu(II)	500	0.5	<0.01
Pb(II)	200	0.1	<0.01

The solubilities of the metal concentrations are also influenced by concentrations of other metals, chelating substances and inorganic complexes. Normally the solubilities will increase with increasing concentrations of the above mentioned conctituents. Nilsson (1970) has investigated the influence of strong chelating substances on precipitation. He found that the solubilities of lead and copper increased considerably. For other metals the increases in solubility were relatively small.

The results of the precipitation studies showed that precipitation with lime and high pH gave the best removals. Thus at pH 11 the metals were removed to concentrations lower than 1 mg/l. The results in figure 86 agree relatively well with table 40 at pH 10. At pH 6 and pH 8 the solubilities of the metals are so high that the solubilities for some of the metals exceed the total metal concentration. The relatively high concentrations of copper and lead at pH 10 may be caused by chelating substances (Nilsson (1970)).

The results of the precipitation with NaOH adjustment to pH 8 and 9 are shown in figure 85. This was done because the existing full scale precipitation plant is using this method for removal of metals. With the exception of nickel a fairly good metal removal efficiency was obtained espesially at pH 9.

Figure 84 shows efficient precipitation with ferric chloride at pH 9 for all the metals except nickel.

Precipitation with alum at pH 6 gave poor removals for most of the metals. Especially low removals were obtained for zinc, cadmium and nickel. This was not unexpected due to high solubilities of the metals at low pH values.

b. Chemical Treatment of Biologically Treated Leachate. Chemical treatment of biologically treated leachate was studied in three test series. The results from these test series are given in table 41, 42 and 43.

Table 41. Chemical treatment of biologically treated leachate, test series no 1

Precipitant	pH	COD mg/l	COD red. %	Fe mg/l	Zn mg/l
Biologically treated	8.5	340		23.1	0.25
Alum 150	7.8	297	12.6	1.02	<0.1
" 200	7.4	-	-	0.65	"
" 300	7.2	-	-	1.20	"
Alum 400	6.6	290	14.7	0.50	<0.1
Ferric chloride 150	7.3	299	12.0	-	0.30
" " 200	7.1	-	-	1.10	0.22
Ferric chloride 300	6.9	-	-	1.35	0.25
Lime	9	319	6.2	1.02	<0.1
"	10	-		0.65	"
"	11	-		1.20	"
Lime	12	288	15.3	0.50	<0.1

Alum as $Al_2(SO_4)_3 \cdot 18H_2O$

Ferric chloride as $FeCl_3 \cdot 6H_2O$

Doses in mg/l

Table 42. Chemical treatment of biologically treated leachate, test series no 2

	pH	COD mg/l	COD red. %	Fe mg/l	Zn mg/l
Biologically treated	8.4	402		20.52	0.22
" " + filtered	8.4	365	9.2		
Alum 150	7.6	357	11.2	0.60	<0.1
" 250	7.4	382	4.9	0.68	"
" 150	6.0	355	11.7	0.84	"
Alum 250	6.0	355	11.7	0.38	<0.1
Ferric chloride 150	7.3	369	8.2	1.42	0.11
" " 250	7.0	357	11.2	0.92	0.21
" " 150	9.0	324	19.4	0.18	<0.1
Ferric chloride 250	9.0	335	16.6	0.62	"
Lime	9	365	9.2	3.58	"
"	10	357	11.2	0.95	"
"	11	375	6.7	0.16	"
Lime	12	332	17.4	<0.1	<0.1

Table 43. Chemical treatment of biologically treated leachate, test series no 3

Precipitant	pH	COD mg/l	COD red %	TOC mg/l	TOC red %	Fe mg/l	Zn mg/l
Biologically treated	8.4	412		100		14.20	0.37
" " + filtered	8.4	345	16.3				
Alum 150	7.4	350	15.0			0.29	<0.1
" 250	7.2	344	16.5			0.64	0.12
" 150	6.0	401	2.7	62.5	37.5	0.57	0.10
" 250	6.0	354	14.1	85.0	15	0.37	<0.1
Ferric chloride 150	7.1	354	14.1			0.78	0.23
" " 250	6.9	342	17.0			0.94	0.30
" " 150	9.0	374	9.2			0.42	0.10
" " 250	9.0	374	9.2	90	10	0.40	<0.1
Lime	9	374	9.2	102.5	0	2.09	"
"	10	381	7.5			1.17	"
"	11	348	15.5			0.67	"
"	12	376	8.7	77.5	22.5	0.19	<0.1

Tables 41 to 43 show no significant differences in the COD removal efficiencies between the different precipitants and doses. pH adjustments to pH 9 and pH 6 when using ferric chloride and alum respectively did not seem to make any difference on the COD removals.

With the exception of iron the concentrations of heavy metals in the biologically treated leachate were low. For Cu, Cr, Cd, Pb and Ni the concentrations were lower than 0.1 mg/l. The removal efficiencies for these metals were therefore not studied. The removal efficiencies for zinc are also inaccurate due to the low concentrations in the biologically treated leachate.

The removal efficiencies for iron were good in all the test series. Lime precipitation at high pH seemed to give slightly better removals than precipitation with alum and ferric chloride.

8. Activated Carbon Treatment

Treatment of leachate from Grønmo by precipitation showed that only slight removal of organics could be achieved by these processes. Biological treatment removed the organic material more efficiently although the effluent still contained high concentrations of refractory organics. To achieve better removal of the organics from leachate, activated carbon was used in batch kinetic tests. The tests were performed only to determine whether carbon treatment could be applied to leachate from Grønmo and not to establish design criteria for a carbon treatment plant. The carbon treatment studies were performed on chemically treated leachate and chemically plus biologically treated leachate.

The chemical treatment of the raw leachate consisted of precipitation with lime at pH 11.5. Before carbon adsorption the samples were neutralized to pH 7.0.

The biologically treated leachate was precipitated with alum. Doses of 200 mg/l as $Al_2(SO_4)_3 \cdot 18H_2O$ at pH 6.0 were used. None of the samples was filtered prior to the activated carbon test.

The adsorption isotherm test was performed with a powdered activated carbon frequently used in water treatment processes. The characteristics of the carbon are given below.

Table 44. Powdered carbon properties

Surface Area m^2/g: 1600
Pore Volume cm^3/g:
Diamter: < 75 Å: 1.595 cm^3/g
Diameter: 75-7500 Å: 1.719 cm^2/g
Producer: Lurgi Apparate - Technik GMBH, Frankfurt W. Germany
Brand: Hydrafin CP

Different dosages of carbon were added to the treated leachate samples and the carbon-leachate mixtures were stirred in a "Jar"-test apparatus. A rapid mixing at 110 rpm in 2 minutes was followed by a mixing time of 30 minutes at 50 rpm. The mixtures were then settled for 30 minutes before decanting. The decanted samples were then filtered through Whatman GF/C filter paper prior to analysis. The filtered samples were analyzed for total organic carbon and chemical oxygen demand.

The data obtained fitted the Freundlich adsorption isotherm model quite well. This model can be written as:

$$q_e = KC^{\frac{1}{n}}$$

or

$$\log q_e = \log K + \frac{1}{n} \log C$$

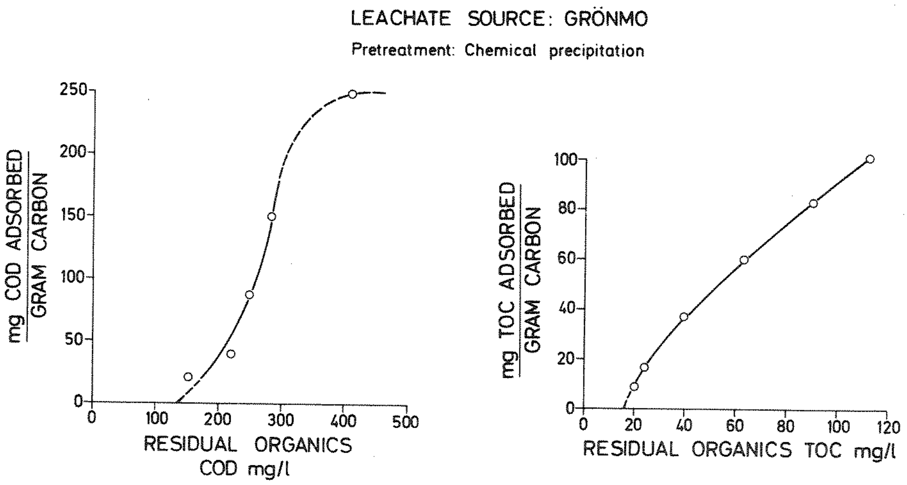
were:

q_e = amount of solutes adsorbed per unit weight of solid adsorbant

C = equilibrium liquid phase concentrations

K and $\frac{1}{n}$ = constants which can be found from a log-log plot

The adsorption isotherm data for the chemically precipitated leachate and for the biologically treated and chemically precipitated leachate are given in tables 130 and 131 Appendix D. The results of the adsorption isotherm tests are presented on a linear plot in figures 87 and 88.


LEACHATE SOURCE: GRÖNMO

Pretreatment: Chemical precipitation

Figure 87. Organics adsorbed per gram of carbon vs. residual organics chemically precipitated leachate.

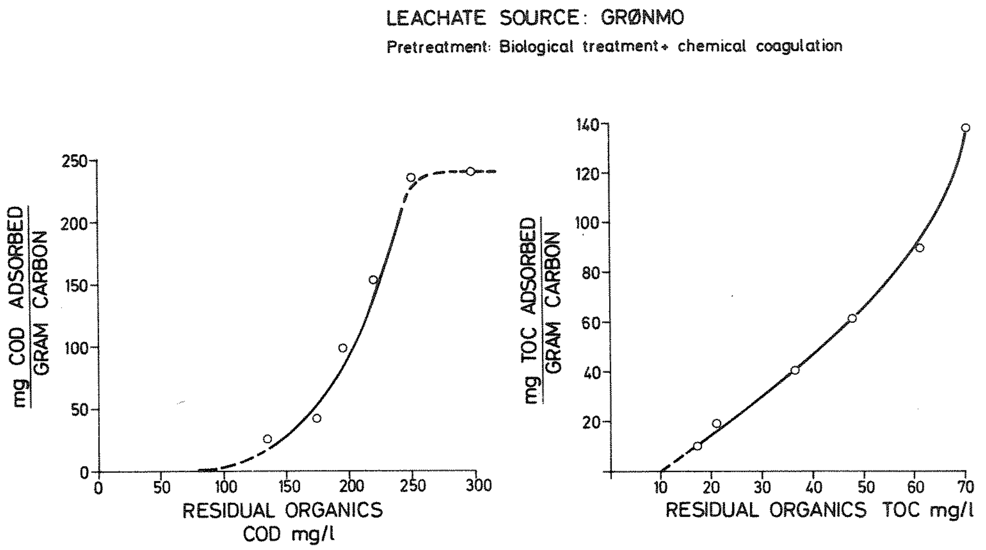


Figure 88. Organics adsorbed per gram of carbon vs. residual organics biologically and chemically treated leachate.

From the isotherm data plotted in linear scale the fraction of organics which cannot be removed by carbon adsorption can be found. These residual concentrations together with the influent values are summarized in table 45.

Table 45. <u>COD and TOC values before and after carbon adsorption</u>

Type of pretreatment	Organics before carbon adsorption		Residual organics after carbon adsorption (M=∞)	
	TOC mg/l	COD mg/l	TOC mg/l	COD mg/l
Chemical precipitaton	153	508	18	135
Biological treatment + chemical precipitation	98	344	10	90

The results show that a high fraction of the organics cannot be removed by activated carbon. Biologically and chemically precipitated leachate, with activated carbon treatment, resulted in a lower concentrations of organics than treatment consisting of chemical precipitation and carbon adsorption. The relatively high concentrations of the organic residuals in the carbon treated water may be attributed to several factors. Polar low molecular weight organics, organic acids and dissolved carbohydrates are known to be adsorbed very poorly by activated carbon (Westmark (1973) and Rebhum (1974)). These compounds are normally easy to remove by biological treatment. This explains the difference in the concentrations of residuals in table 45 for the two types of pretreatment.

The COD:TOC ratio of the refractory organics in the carbon treated water are quite different from the corresponding ratios for the raw, biologically or chemically treated leachate. This may be explained by the different adsorption efficiencies for the different compounds. For instance Weber (1972) states that adsorption of an aliphatic series of organic acids increases in the order of formic-acetic-propionic and butyric. The C/O ratio will then change and consequently the ratio of COD:TOC. However, the highest COD:TOC ratios calculated from table 45 are suspiciously high.

The residual organics in the carbon filtered leachate at very high dosages will vary insignificantly with the type of carbon normally used in water treatments. The organic removals obtained in these tests are therefore the maximum achievable in a full scale plant.

The TOC values given in table 45 give removal efficiencies at very high carbon dosages of about 90 percent. The corresponding values based on COD are about 75 percent. The organic removal efficiencies based on TOC or COD were found to be nearly the same for both types of pretreatment. The table also show that the threshold organics in the leachate treated by biological treatment, chemical precipitation and carbon adsorption had considerably lower values than corresponding leachate treated by chemical precipitation and carbon adsorption. Chemical precipitation as the only type of pretreatment also requires heavy dosages of carbon to obtain good organic removal efficiency. The activated carbon process should therefore be a supplement to biological treatment.

The adsorption isotherms, in a linear plot, show, with the exception of the second curve in figure 87, unfavorable adsorption characteristics. The isotherms indicate a decreasing adsorption capacity with increasing carbon dosages. Thus massive dosages are necessary to reduce high fractions of removable organics. At sufficiently high values of organics adsorbed per mg carbon (qe) the isotherm curves will level out to a constant value. This value represents the maximum amounts of organics adsorbed per unit weight of carbon. This saturation value for q_e can be found by plotting the adsorption isotherm in log-log scale. For the carbon treated leachate with pretreatment chemical precipitation this plotting is shown in figure 89.

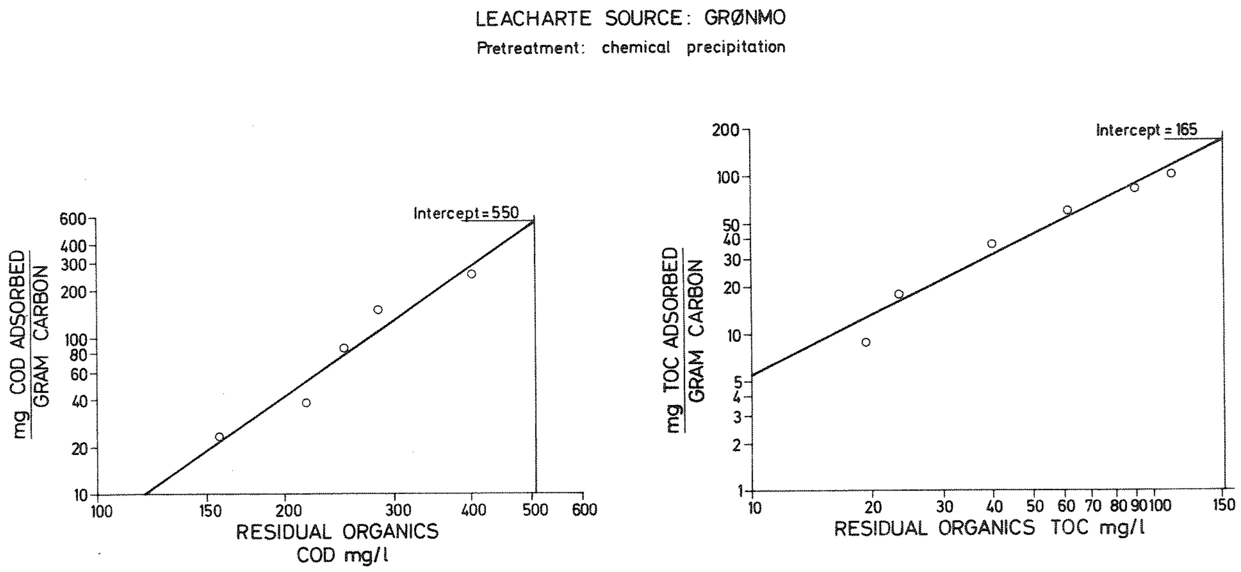


Figure 89. Organics adsorbed per gram of carbon vs. residual organics chemically precipitated leachate, log scale.

Figure 90 shows a corresponding plot for the leachate with pretreatment biological treatment plus chemical precipitation.

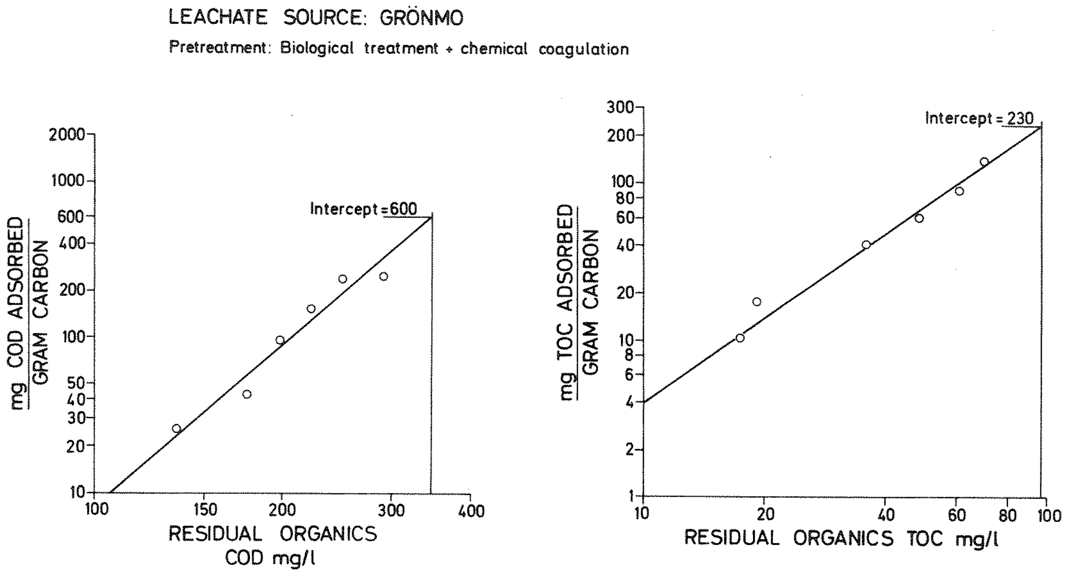


Figure 90. Organics adsorbed per gram of carbon vs. residual organics, biologically and chemically treated leachate, log scale.

The maximum amounts of organics adsorbed per unit weight of carbon for the leachate with pretreatment consisting of chemical precipitation were 550 mg COD/g carbon or 165 mg TOC/g carbon. The corresponding values for biological plus chemical precipitated leachate were 600 mg COD/g carbon and 230 mg TOC/g carbon.

The maximum amounts of organics adsorbed per unit weight of carbon will vary with type of carbon. The plotting of the isotherm data to determine this value is therefore performed to choose the optimal type of carbon. The values found from figures 90 and 91 must therefore be considered only to be of informative value.

9. Conclusions

The results of the treatment studies showed that leachate from Grønmo can be treated biologically, although a large fraction of the organics can not be degraded. Of the biological treatment systems investigated the activated sludge process gave the best results. Aerated lagoons gave nearly the same organic removals as the activated sludge process. Treatment by biodisc and trickling filter both gave very low treatment efficiencies.

The maximum obtained organic removal efficiencies based on COD or TOC were for the activated sludge process about 35 percent. This organic removal efficiency could be achieved up to an organic loading of about 0.3 kg COD/kg MLVSS day. At higher loadings the removal efficiencies start to decrease relatively rapidly. The same organic removal efficiencies were obtained for treatment of raw and chemically precipitated leachate. Because of the large fraction of organics not subjected to biological degradation the actual organic loading based on carbonacious BOD is much lower than the organic loadings based on COD. This should be kept in mind when comparing treatment results from the different leachate sources.

The concentrations of nitrogen compounds in the leachate were high. Results from BOD tests showed that up to 80 percent of the ultimate BOD value was caused by nitrification. To obtain high BOD removals the biological treatment units should therefore be given low organic loadings. The results showed that the maximum degree of nitrification obtained in the activated sludge process was about 70 percent. This degree of nitrification was constant up to an organic loading of about 0.3 kg COD/kg MLVSS day. At higher organic loading than about 0.3 kg COD/kg MLVSS day the degree of nitrification fell drastically. At lower organic loading than about 0.3 kg COD/kg MLVSS day the reductions of total BOD was about 90 percent. The removal efficiency of total nitrogen was very poor. The nitrate concentrations in the biologically treated leachate was therefore high.

In spite of extremely high ratios of BOD:P in the raw and chemically precipitated leachate, phosphorus did not seem to be a limiting nutrient.

Poor flocculation of activated sludge caused severe loss of bacterial growth in the effluent. At the lowest organic loadings the concentration of activated sludge could hardly be maintained. This loss was more pronounced in the treatment of raw leachate than chemically precipitated leachate. However, for each organic loading the change in the concentrations of MLVSS was about the same when treating raw or chemically precipitated leachate.

Chemical precipitation of raw leachate by alum and ferric chloride gave removals of organics of about 10-15 percent. Lime precipitation gave about the same or slightly higher organic removals. Precipitation with lime at pH 11 or higher gave the best removals of heavy metals. Precipitation with alum at pH 6.0 gave low removals for most of the heavy metals.

Precipitation of biologically treated leachate by alum and ferric chloride and precipitation with lime gave about the same organic removal efficiencies as that obtained for corresponding treatment of raw leachate. The removal of iron by precipitation with alum, ferric chloride and lime all gave high efficiencies.

Activated carbon treatment of precipitated leachate and biologically plus precipitated leachate gave high organic removal efficiencies. However, the residual organics in the leachate treated by biological treatment, chemical precipitation and carbon adsorption had considerable lower values than corresponding leachate treated by chemical precipitation and carbon adsorption.

F TREATMENT OF LEACHATE FROM YGGESETH SANITARY LANDFILL

Leachate from Yggeseth sanitary landfill was treated by the activated sludge process. Heavy metal toxicity during aerobic treatment was also studied. In one of the studies zinc was added to the activated sludge process in different concentrations. In another test the response of respiration as a function of type of heavy metals and concentrations was studied. Activated carbon treatment of the biologically treated water was also investigated.

1. Activated Sludge (Test run no VIII)

The objective of this study was to investigate the treatability of raw leachate and study the performance of the activated sludge process operating at different organic loadings. To accomplish this three activated sludge units were used which earlier were described as group no 2.

The composition of the raw leachate used in this test run is identical with that given in table 16 and 17 . The results show that the leachate had very high concentrations of organics and low concentrations of heavy metals. Table 17 show that the organic acids identified contribute to about 60 percent of the organics. Because of the relatively high biological assimilability of the organic acids good organic removal efficiencies would be expected. The BOD_5:N:P ratios were about 600:30:1.

The treatment units had previously been used to treat raw leachate from Grønmo sanitary landfill. The organic loadings applied were 0.08, 0.16 and 0.28 kg COD/kg MLVSS day.

The results from this test run are given in tables 104 to 107 Appendix B. The most important parameters are shown graphically in figures 91 to 93.

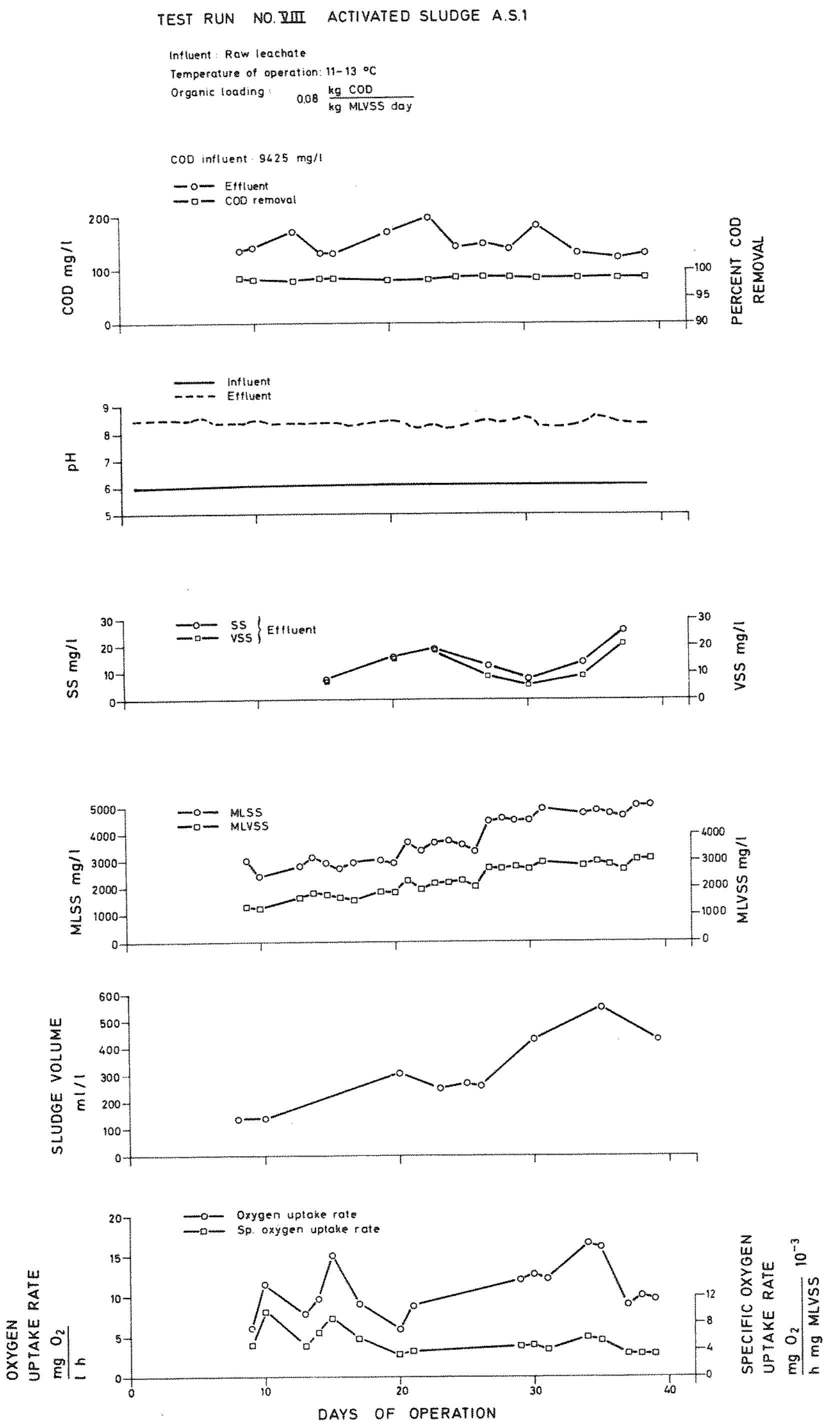


Figure 91. Experimental results, test run no VIII, A.S.1.

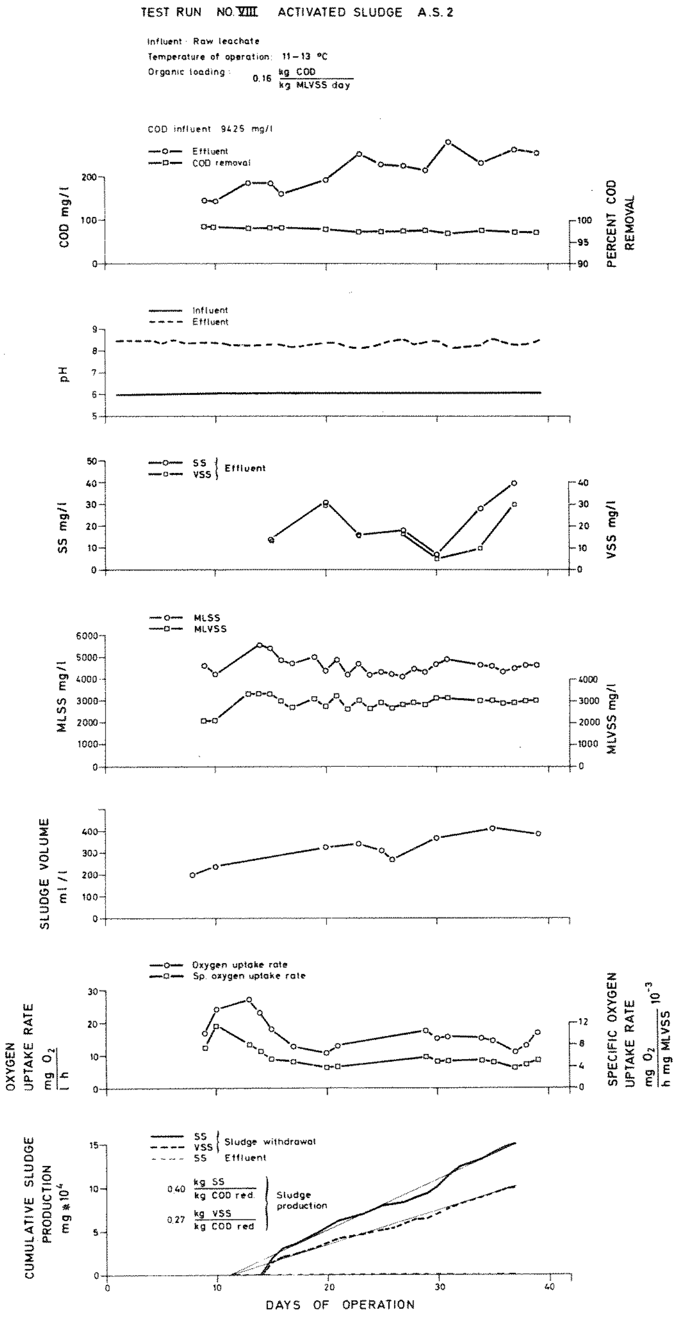


Figure 92. Experimental results, test run no VIII, A.S.2.

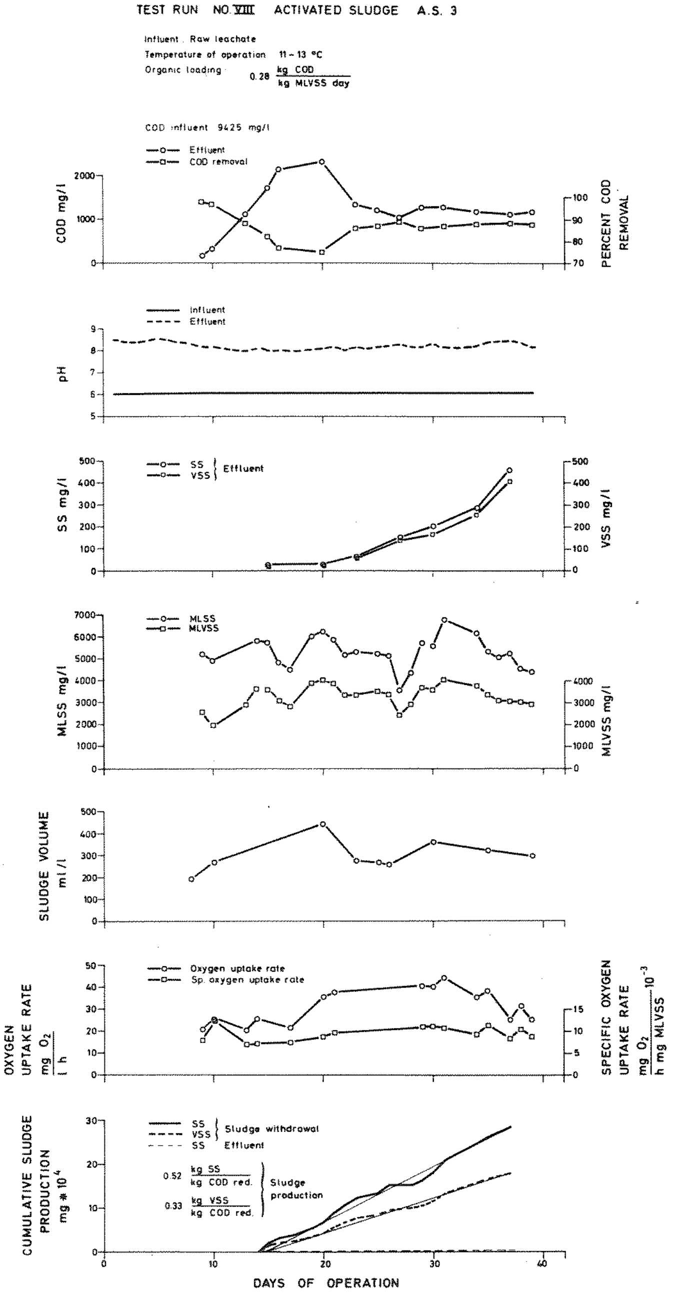


Figure 93. Experimental results, test run no VIII, A.S.3.

a. Organic Removals. The COD removals presented in the graphs show very high removal efficiencies for the two units with the lowest organic loadings. Thus at organic loadings of 0.08 and 0.16 kg COD/kg MLVSS day the COD values were reduced from 9425 mg/l to average values of 153 and 238 mg/l respectively. At the organic loading 0.28 kg COD/kg MLVSS day the corresponding COD value was 1206 mg/l.

Figure 94 shows the COD removal efficiency as a function of organic loading. At organic loadings lower than about 0.2 kg COD/kg MLVSS day the figure shows COD removal efficienices of about 98 percent. At organic loadings higher than 0.2-0.3 the removal efficiencies start to decrease. Some samples were also analyzed for TOC. The tables 104 to 107 show that the samples analyzed for both COD and TOC gave nearly identical removal efficiencies. Analyses performed on unfiltered and filtered effluent samples gave nearly the same results. This means that nearly all the residual organics were in the dissolved state.

b. Nitrification - Denitrification. The analysis of the raw leachate shows that nearly all nitrogen compounds are present as ammonia. The oxidation of these ammonia compounds contributes about 20 percent of the total biological oxygen demand. Compared to the leachate from Grønmo this contribution is relatively low.

Figure 95 shows the removal of total nitrogen and the ratios of nitrates to total nitrogen in the effluent as a function of organic loading. At low organic loadings the figure shows very high removals of total nitrogen. Thus at an organic loading of 0.08 kg COD/kg MLVSS day the total nitrogen is reduced from 250 mg N/l to an average value of 14 mg N/l. This corresponds to a nitrogen removal efficiency of about 95 percent. At higher organic

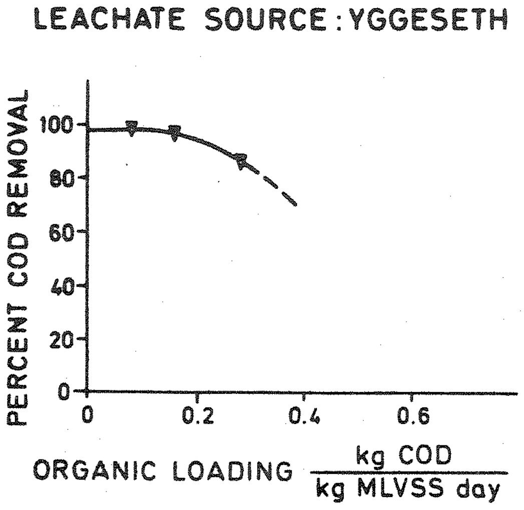


Figure 94. COD removal vs. organic loading.

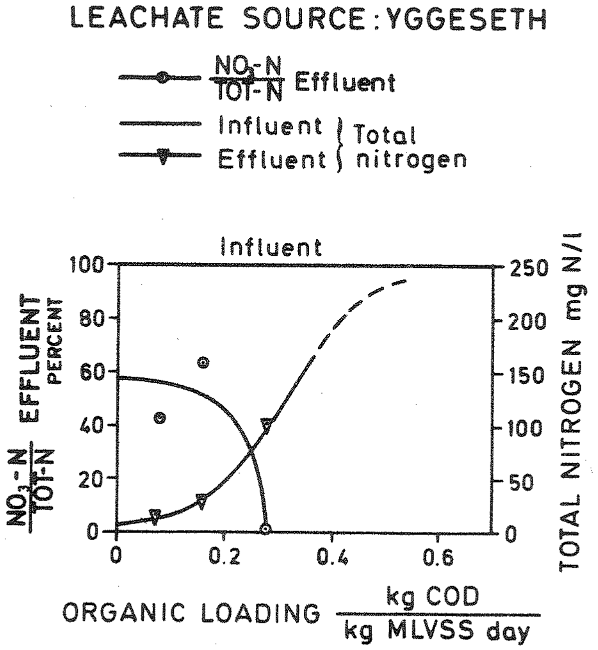


Figure 95. Oxidation of nitrogen compounds and removal of nitrogen vs. organic loading.

loadings than about 0.2 kg COD/kg MLVSS day the nitrogen removal efficiency starts to fall sharply.

At the two lowest organic loadings applied the degree of nitrification was nearly 100 percent. At the organic loading of 0.28 kg COD/kg MLVSS day the concentrations of nitrates in the effluent were nearly zero. Therefore at this loading or higher the degree of nitrification was approximately equal to the removal efficiencies of total nitrogen.

The high nitrogen removal efficiency at low loadings resulted from a special arrangement for the recirculation of the activated sludge. To avoid vigorous recirculation of sludge from the settling chambers, the recirculation pumps were timer operated with an interval of 1 hour between each recirculation and with a pumping time of three minutes. Therefore very little oxygenation took place in the settling chambers. This provided efficient denitrification. The organics in the treated leachate must also have been readily available for the denitrification processes. The high ratio of organics to total nitrogen in the raw leachate also caused some removal of nitrogen with sludge withdrawal. However, this contribution was small compared to the nitrogen removal caused by the denitrification processes. At the low loadings the effluent concentrations of nitrates were very low. This indicates an efficient denitrification process was operating.

c. pH, Alkalinity. The pH in the aeration chambers was high for all three units. The pH increased from an influent value of 5.9 to approximately 8.2 to 8.4 in the effluent with the lowest value for the highest loaded units.

The alkalinity was reduced from a value of 1960 mg $CaCO_3$/l to values ranging from 465 to 893 mg $CaCO_3$/l. These reductions were caused primarily by removals of organic acids and nitrogen.

d. Solids. The effluent suspended and volatile suspended solids were low for the two units with the lowest organic loadings. Thus the average effluent concentrations of suspended solids were 15 and 29 mg/l. For the plant operating at the highest organic loading the effluent concentrations of suspended solids were high. The high concentrations were caused by microbial growth which was drawn off with the effluent.

For the two plants with the highest organic loading the concentrations of the activated sludge measured as volatile suspended solids increased rapidly. At steady state condition sludge therefore had to be withdrawaled frequently. Figure 96 shows the sludge production as a function of organic loading.

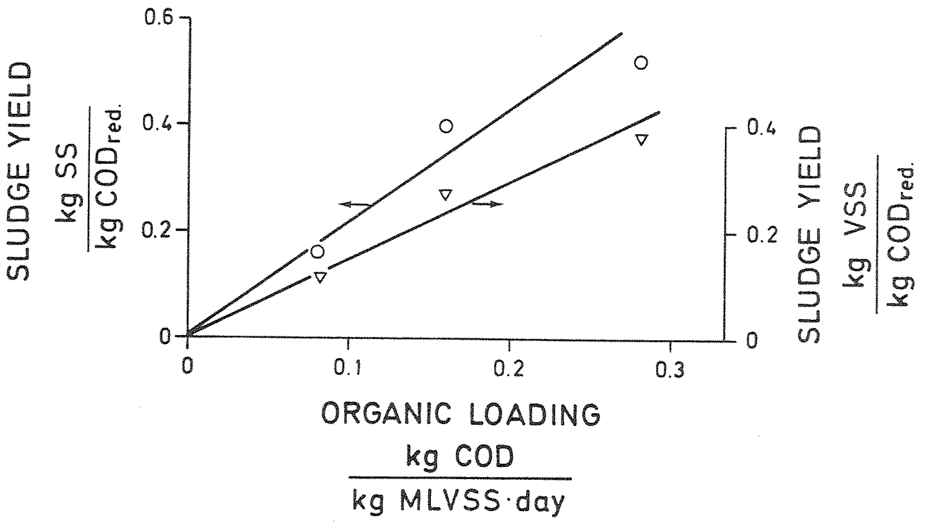


Figure 96. Sludge yield vs. organic loading.

e. Sludge Characteristics. The settleability of the activated sludge was good. The sludge volume index was always below 150. The dewatering properties expressed as specific resistance to filtration ranged on the average between $1.4-3.3 \cdot 10^{12}$ m/kg. The values increased slightly with increased organic loading.

f. Oxygen Uptake Rate. The oxygen uptake rate of the activated sludge units are shown on figures 91 to 93. The specific oxygen uptake rate appears to be relatively constant with the time of operation. This means a nearly constant microbial activity was maintained during the test run.

Figure 97 shows the oxygen uptake rates as a function of organic loading. At corresponding organic loadings the values in this figure show considerably higher values than those found in the treatment of leachate from Grønmo. This was also expected because of better treatability of this leachate compared with the leachate from Grønmo.

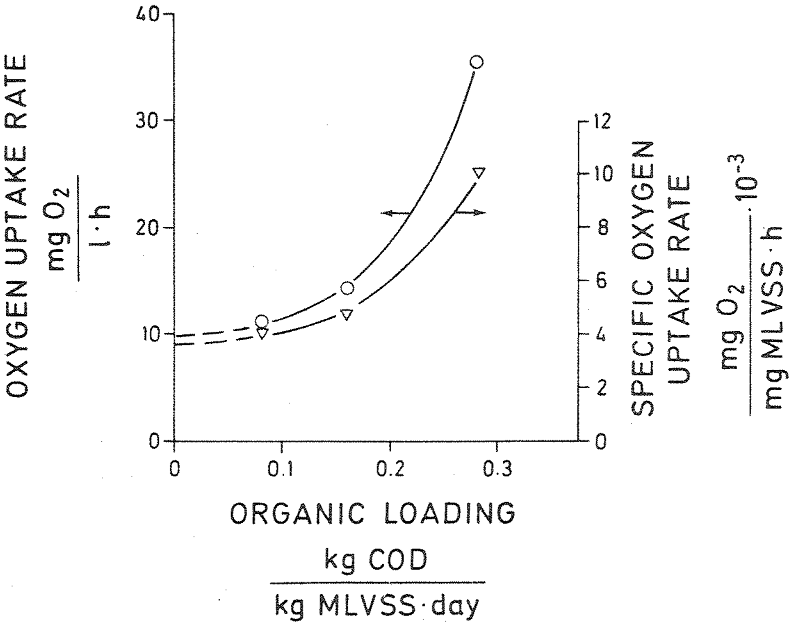


Figure 97. Oxygen uptake rate vs. organic loading.

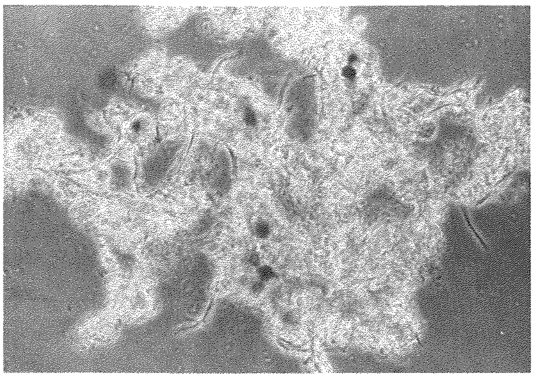
g. Microscopic Examination. Microscopic examination of the activated sludge was performed in the last part of the test run. Figure 98 shows typical micrographs of the activated sludge from the three treatment plants. Table 46 shows a summary of the results from the microscopic examinations.

For the sludge from the plants operating at organic loadings 0.08 and 0.16 kg COD/kg MLVSS the microscopic examination showed high species diversity for higher organisms. Protozoa were present in large numbers (see table 46). The stalked and free swimming protozoa were dominated by the species Vorticella and Aspedisca respectively. Some flagellates and rotifers were also present but in smaller numbers.

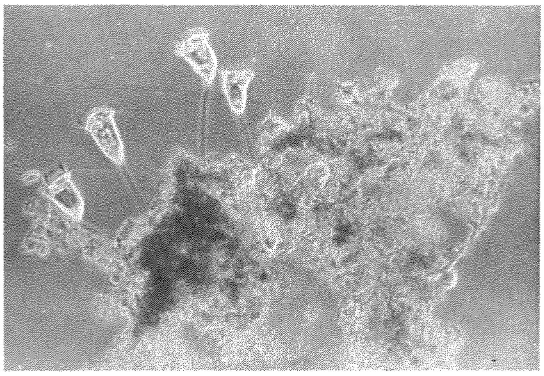
The composition of bacteria from the same two plants showed a high concentration of Zoogloea species. Accordingly the samples showed relatively large and dense flocs. The samples also contained high contents of iron oxidizing bacteria. These appeared as rod shaped bacteria covered with iron deposits. When the iron was reduced by means of oxalic acid addition the iron deposit disappeared and the shape of the bacteria appeared. A micrograph of these bacteria species is shown in the first picture of figure 98.

For the plant operating at an organic loading of 0.28 kg COD/kg MLVSS day the diversity of higher organisms were not as high as for the plants operating at lower organic loadings. A green algae of the species Chlamydomonas and a flagellate species small in size dominated the sample. The sample also contained protozoa but in small numbers.

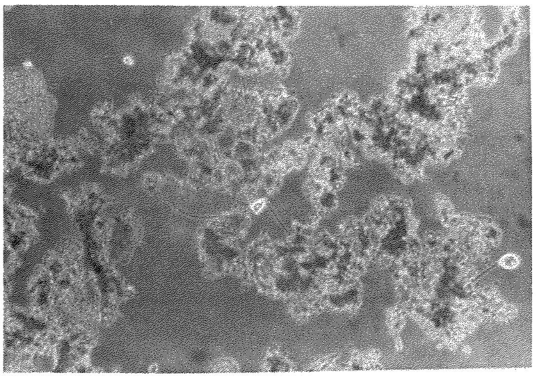
Of the bacteria the Zoogloea species were dominate which give a dense floc. Iron oxidizing bacteria were also present in this sample but not so abundant as in the samples from the lower organic loadings. The concentrations of free swimming bacteria were relatively high.



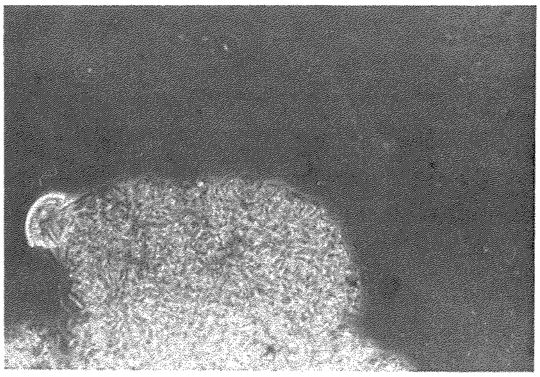
A.S.1
0.08 kg COD/kg MLVSS day x107



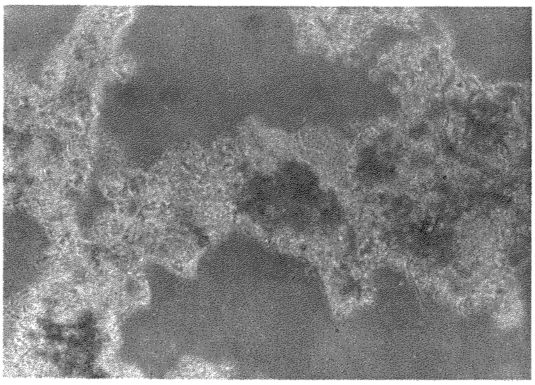
A.S.1
0.08 kg COD/kg MLVSS day x107



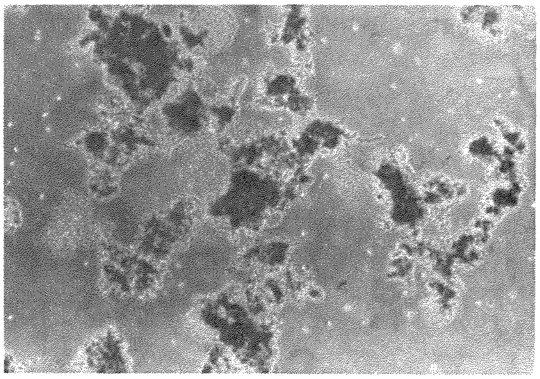
A.S.2
0.16 kg COD/kg MLVSS day x 43



A.S.2
0.16 kg COD/kg MLVSS day x273



A.S.3
0.28 kg COD/kg MLVSS day x107



A.S.3
0.28 kg COD/kg MLVSS day x 43

FIGURE 98 Activated sludge. Test run No.VIII

Table 46. Microscopic examinations.Test run no VIII

Plant	Organic loading kg COD kg MLVSS day	Protozoa		Flagel-lates	Roti-fiers	Nema-todes	Free Swimming bacteria	Filamen-tous bacteria	Size of floc	Degree of deflocculation
		Swim-ming	Stalked							
A.S.1	0.08	3	4	1	1	0	2	1	Medium	None x
A.S.2	0.16	3	4	1	1	0	2	1	Medium	None x
A.S.3	0.28	1	1	5	0	0	4	1	Medium	Some xx

x High content of iron oxidizing bacteria
xx High content of green algae

Relative number of higher microorganisms.

5.	Dominating:	Dominating the sample completely
4.	Many:	Many organisms in each field of vision
3.	Usual:	Some organisms in each field of vision
2.	Some:	Occurs often but not in each field of vision
1.	Few	Few organisms observed
+	Very few:	Very few organisms observed
0		Not observed

2. Activated Carbon Treatment

Activated carbon treatment of biologically treated leachate from Yggeseth was also studied. Prior to carbon treatment the biologically treated leachate was precipitated with alum. The procedure used for the precipitation and carbon treatment was just the same as described for the activiated carbon treatment of the leachate from Grønmo (see page 191).

The adsorption isotherm data are given in table 132, Appendix D, and plotted in figures 99 and 100. The first curve in figure 99 disregards the data point for the highest concentrations of C. This can be justified by the large percent error for data points at low C_o-C values. The adsorption isotherms show relatively high concentrations of organics which cannot be removed by carbon adsorption. Figure 99 shows residual organics at extremely high carbon doses of about 95 and 8 mg/l based on COD and TOC respectively. This corresponds to removal efficiencies in the activated carbon step of 60 and 87 percent. The high ratio of COD to TOC in the carbon treated water was about the same as that found for the carbon treatment of biologically treated leachate from Grønmo.

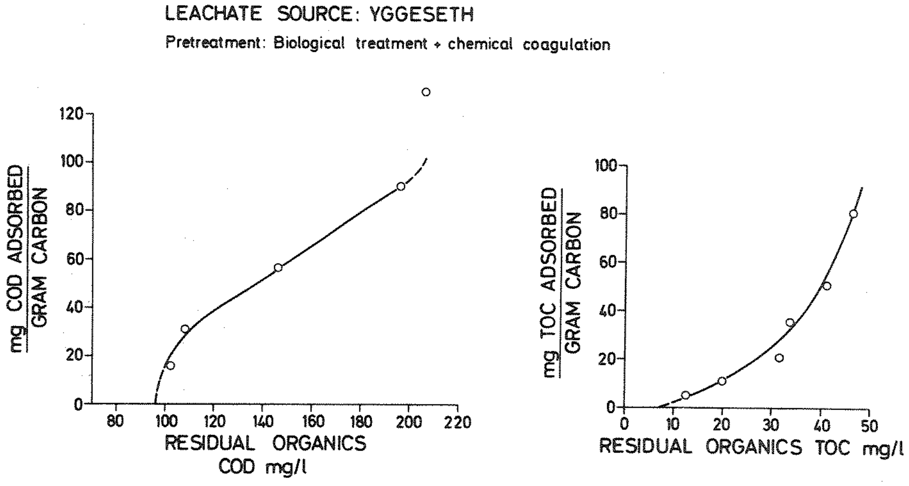


Figure 99. Organics adsorbed per gram of carbon vs. residual organics, linear plot.

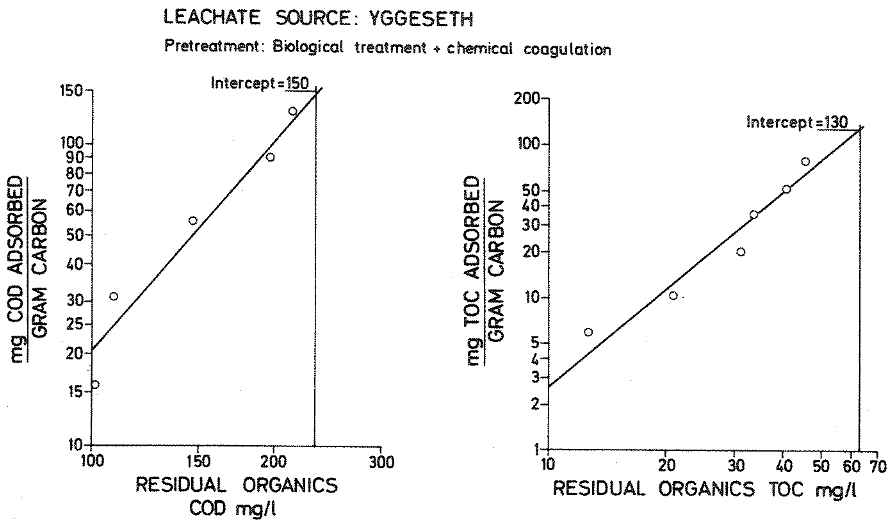


Figure 100. Organics adsorbed per gram of carbon vs. residual organics, log-scale.

The adsorption isotherms for the carbon treated leachate is given in log-log scale in figure 100. The figure shows that the maximum amount of organics adsorbed per unit weight of carbon was found to be 150 mg COD/g carbon or 130 mg TOC/g carbon. These close numbers may be caused by a more effective adsorption of organics expressed as TOC than COD. However, the ratios of COD to TOC are so high that a systematic error in one of the parameters seems reasonable. The persulfate digestion is probably too mild for digestion of complex organics in leachates, which gives to low TOC values that are too low. Compared with the carbon treatment of leachate from Grønmo the amounts of organics adsorbed per unit weight of carbon was small.

3. Heavy Metal Toxicity

The toxicity of the heavy metal zinc to the activated sludge process was studied in a separate test run. The toxicities of zinc, copper, chromium, cadmium, lead and nickel were also studied by measuring oxygen uptake rates.

a. Activated sludge. (Test run no IX). The study of zinc toxicity in the activated sludge process was started immediately after test run no VIII was finished. The leachate used was identical with that used in the previous test run. The toxicity of zinc to the activated sludge process was investigated because zinc next to iron normally is the prevailing heavy metal in leachate.

The three activated sludge plants used in this investigation were given equal organic loadings. One of the plants was used as a reference, that is no zinc was added. The two other plants operated under the same conditions but in addition zinc was added. The zinc was added continuously by means of small peristaltic pumps. The amounts added were so that they corresponded to zinc concentrations in the influent of 10 and 30 mg/l. At the start of this test run, zinc was added in slug doses to the two plants so that the zinc concentrations in the aeration chambers became half of the influent values. This was done to reach steady state conditions more rapidly.

The results of this test run are given in tables 108 to 111, Appendix B. The most interesting results are shown in figures 101 to 103.

The curves for the COD removals shows high efficiencies for all the plants. Thus the average COD removals were 94.5, 96.4 and 97.1 percent for the plants with zinc additions of 0, 10 and 30 mg/l respectively.

The lower COD removals at zero zinc additions may simply be explained by a slightly lower organic loadings (0.30 vs. 0.28 kg COD/kg MLVSS day for this unit).

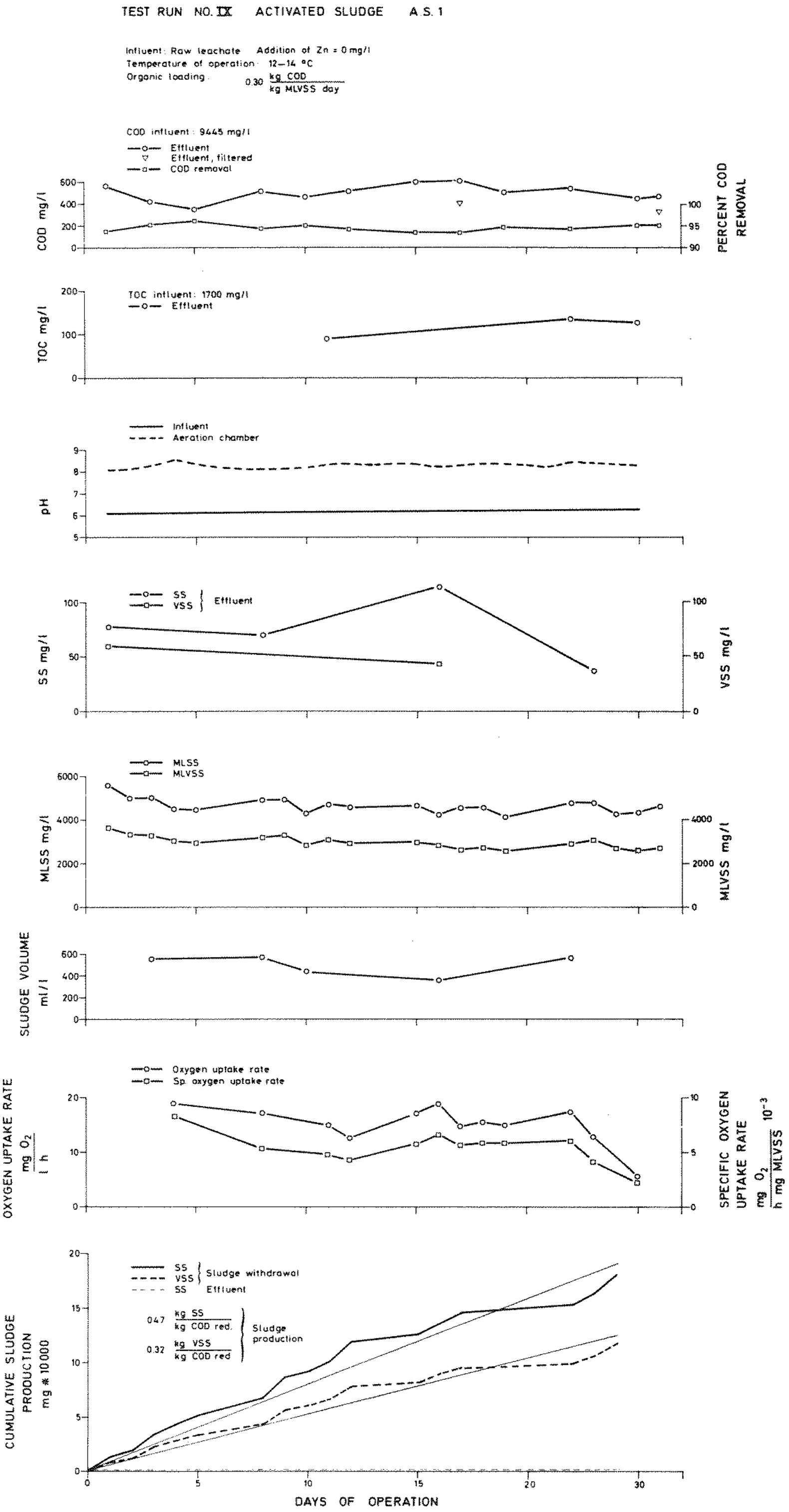


Figure 101. Experimental results, test run no IX, A.S.1.

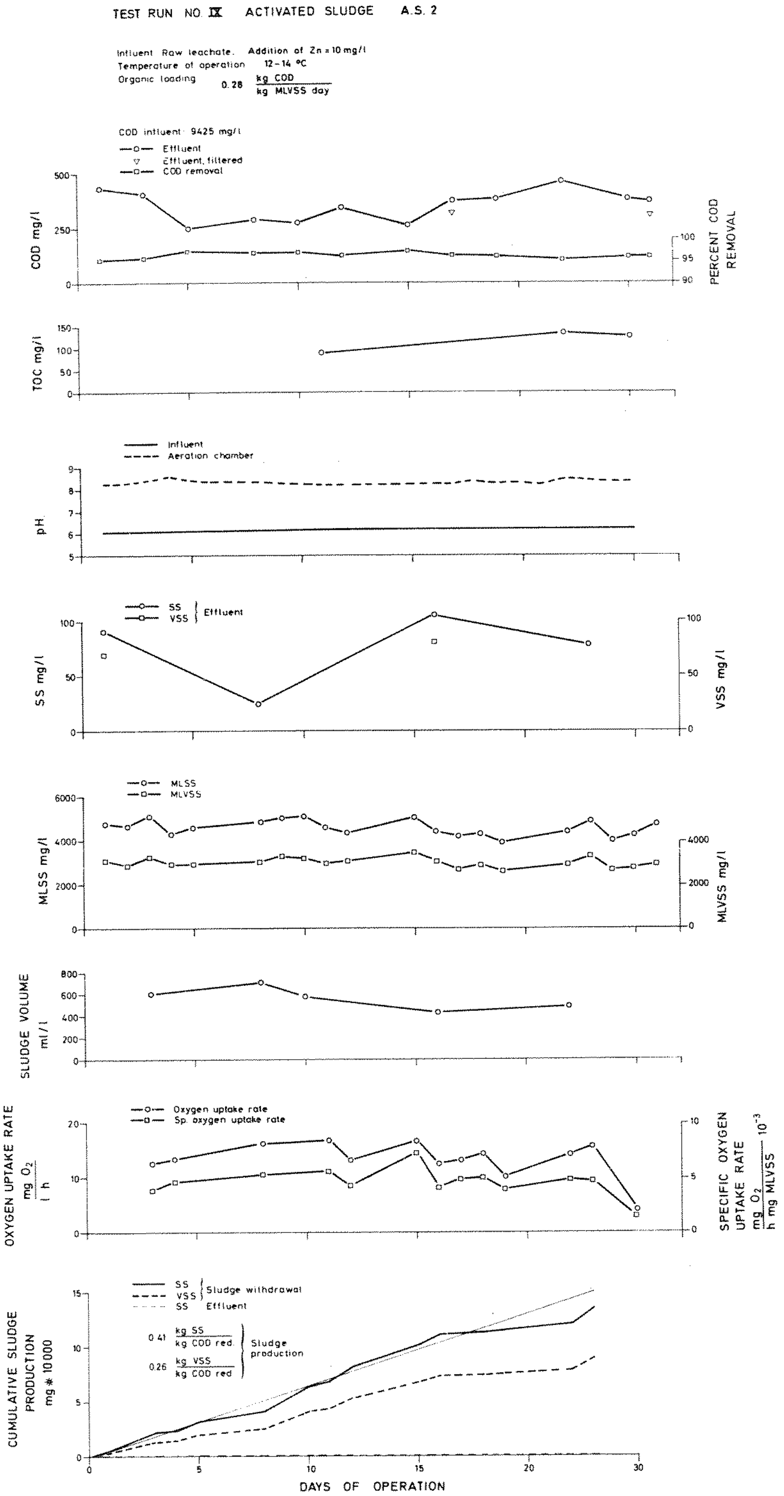


Figure 102. Experimental results, test run no IX, A.S.2.

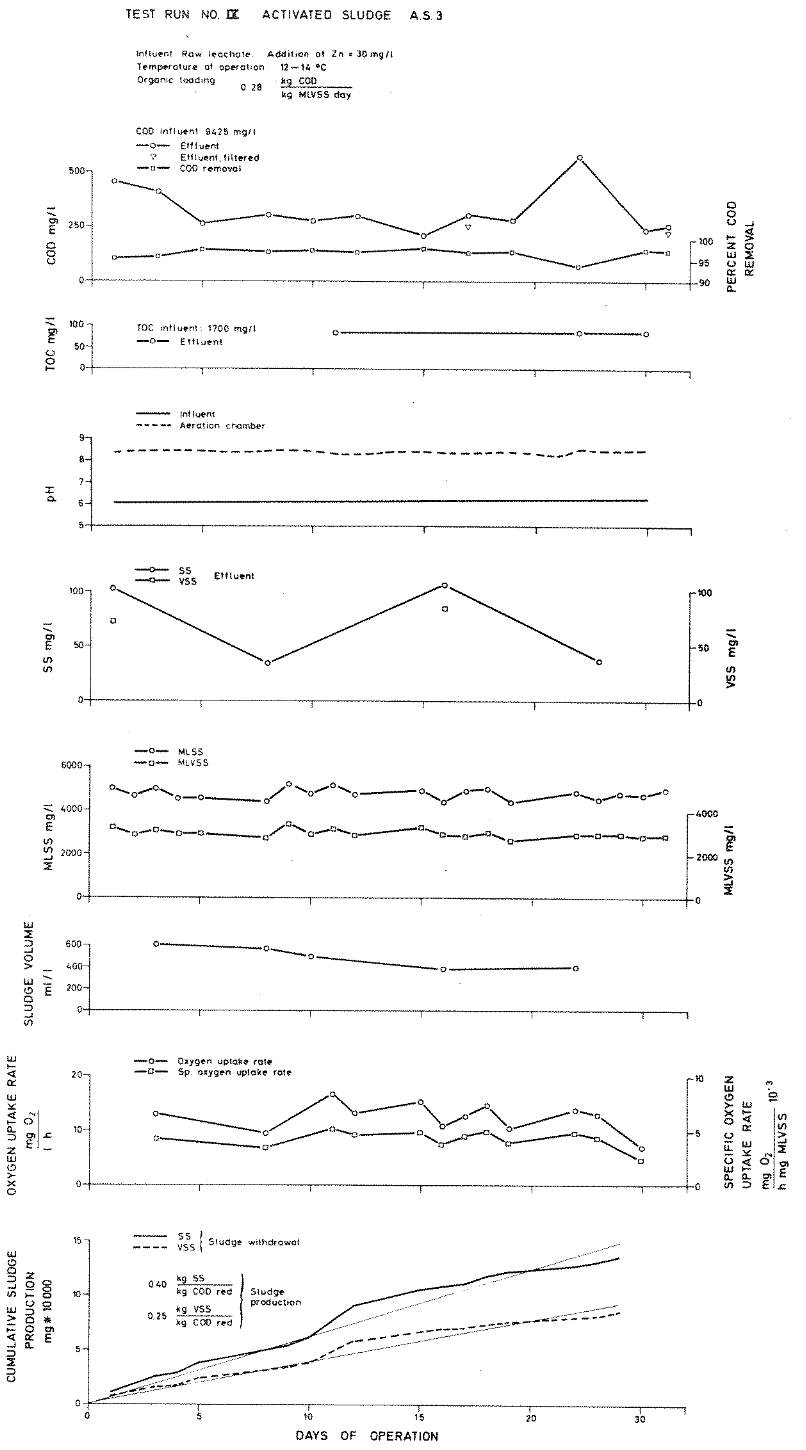


Figure 103. Experimental results, test run no IX, A.S.3.

The insignificant zinc toxicity effects on the activated sludge processes may be explained by the relatively high pH 8.4-8.5 in the aeration chambers. At this pH the solubility of pure zinc hydroxides are about 7 mg/l. The chelating substances in the leachate are expected to given a slight increase of the above number. The low solubility of zinc hydroxides may explain why zinc additions as high as 30 mg/l did not affect the organic removal rate.

The average oxygen uptake rates of the three plants were also very close. Thus the values were 12.4, 14.1 and 12.4 mg O_2/l h for the plants operating at zinc concentrations of 0, 10 and 30 mg/l. The corresponding numbers for the specific oxygen uptake rates were $4.2 \cdot 10^{-3}$, $4.7 \cdot 10^{-3}$ and $4.2 \cdot 10^{-3}$ mg O_2/h·mg MLVSS. This should indicate that zinc concentrations as high as 30 mg/l did not affect the rate of biodegradation of organics.

Nitrification did not take place in any of the three treatment plants. However, this was expected due to relatively high organic loadings. The samples showed few numbers of higher organisms. Only free swimming ciliates and flagellates were observed. The low species diversity was probably caused by the high organic loadings. All the samples also showed high contents of filamentous- and free swimming bacteria. The samples had all relatively large flocs which were caused by a high proportion of the bacterial species Zoogloea.

The activated sludge from the three plants was analyzed for heavy metals in the last part of the test run. The results are given in table 48. The corresponding values for the biologically treated leachate are given in table 49.

Tables 48 and 49 show that the heavy metals were accumulated in the sludge. This was possibly due to the precipitation caused by the high pH in the aeration chambers. The accumulation of zinc did not seem to increase significantly with time of operation. However, a high removal efficiency of zinc was possibly due to the accumulation in the sludge and withdrawal of excess sludge. At zinc concentrations in the influent of 10 mg/l table 49 shows that this concentration was reduced to values below 0.1 mg/l. The corresponding number for an influent zinc concentration of 30 mg/l was about 0.3 mg/l. Due to the mechanism of accumulation and sludge withdrawal the efficiency of the heavy metal removals will be a function of the organic loading. High sludge production will therefore give the best removals.

b. Oxygen Uptake Studies. Toxicity to the activated sludge process because of zinc, copper, chromium(III), cadmium, lead and nickel was studied by using oxygen uptake studies. Activated sludge from the plant which had been fed with leachate without addition of zinc (test run no IX A.S.1) was transferred to 500 ml measure cylinders equipped with injection pipes for aeration (see figure 13). The cylinders were filled to a volume of 350 ml and the above mentioned heavy metals were added so that the metal concentrations became 10, 20 and 40 mg/l. The samples were then aerated and the oxygen uptake rates were measured. By comparing the respiration rate of samples with different heavy metal concentrations a measure of the toxicity effect could be found. To increase the accuracy of the average respiration values three reference samples were used. The pH in the activated sludge remained between 8.2 to 8.6 in all tests. The graduated cylinders with equipment for aeration are shown in figure 13, and the instruments for measurement of oxygen uptake rates in figure 12, page 63.

Table 47. Microscopic examination. Test run no IX

Plant	Zn influent mg/l	Organic loading kg COD kg MLVSS day	Protozoa		Flagel-lates	Roti-fiers	Nema-todes	Free Swimming bacteria	Filamen-tous bacteria	Size of floc	Degree of defloc-culation
			Swim-ming	Stalked							
A.S.1	0	0.30	1	0	0	0	0	2	4	Medium	Some
A.S.2	10	0.28	0	0	1	0	0	2	4	Medium	Some
A.S.3	20	0.28	0	0	1	0	0	2	4	Medium	Some

Relative number of higher microorganisms.

5. Dominating: Dominating the sample completely
4. Many: Many organisms in each field of vision
3. Usual: Some organisms in each field of vision
2. Some: Occurs often but not in each field of vision
1. Few: Few organisms observed
\+ Very few: Very few organisms observed
0 Not observed

Table 48. Heavy metals in activated sludge. Test run No. IX

Plant - Date	Addition of Zn mg/l	MLSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
A.S.1 15/12	0	4800	203	2.4	0.3	0.1	<0.1	0.2	<0.1
" 17/12	0	4290	190	2.5	0.3	<0.1	<0.1	0.5	0.2
A.S.1 19/12	0	4370	178	2.0	0.3	<0.1	<0.1	0.2	<0.1
A.S.2 15/12	10	4460	215	7.8	0.3	0.1	<0.1	0.4	0.1
" 17/12	10	4030	200	7.6	0.3	<0.1	<0.1	0.4	<0.1
A.S.2 19/12	10	4290	195	10.4	0.3	<0.1	<0.1	0.11	0.2
A.S.3 15/12	30	4850	235	28.5	0.3	<0.1	<0.1	0.4	0.2
" 17/12	30	4780	228	29.8	0.3	0.1	<0.1	0.5	<0.1
A.S.3 19/12	30	4700	215	30.0	0.4	<0.1	<0.1	0.15	0.2

Table 49. Heavy metals in treated leachate. Test run No. IX

Plant - Date	Addition of Zn mg/l	Fe	Zn
A.S.1 15/12	0	4.6	<0.1
" 17/12	0	5.7	<0.1
A.S.1 19/12	0	7.8	<0.1
A.S.2 15/12	10	4.0	<0.1
" 17/12	10	5.2	<0.1
A.S.2 19/12	10	6.1	<0.1
A.S.3 15/12	30	6.6	0.4
" 17/12	30	3.6	0.2
A.S.3 19/12	30	4.2	0.3

For Cu, Cr, Cd, Pb and Ni the concentrations were lower than 0.1 mg/l.

Figures 104 and 105 show the relative respiration values of the activated sludge samples receiving different heavy metals at two or three different concentrations. Only two oxygen uptake series were performed. The results show a higher depression of the oxygen uptake rate at 1 hour than at 24 hours of aeration. Both at 1 and 24 hours of aeration copper had the greatest effect on the oxygen uptake rate. Thus at a copper concentration

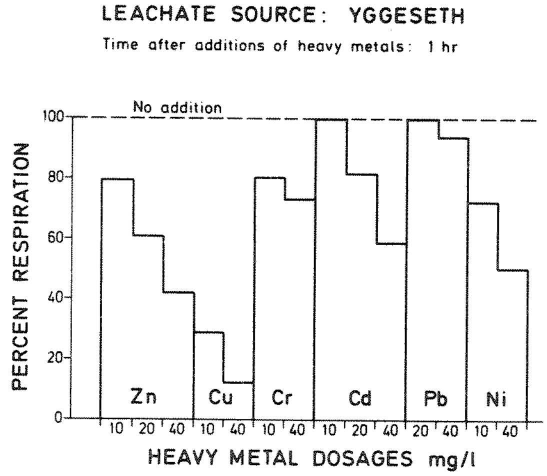


Figure 104. Respiration rates vs. heavy metal dosages, time after additions of heavy metals:1 hr.

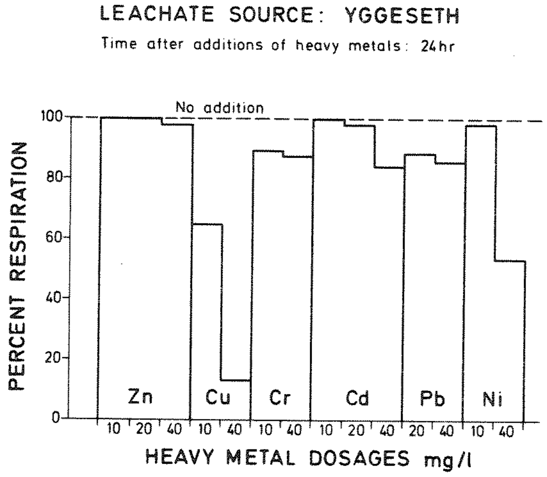


Figure 105. Respiration rates vs. heavy metal dosages, time after additions of heavy metals: 24 hr.

of 40 mg/l the oxygen uptake rate was only 13 percent of that of the sample without addition of copper. Next to copper nickel seemed to be the most toxic heavy metal.

At pH 8.4-8.6 the solubility of pure copper oxides are considerably lower than 1 mg/l. However, the chelating substances in the leachate probably cause a considerably higher solubility. This is supported by the results because doses of 40 mg/l give considerably higher toxicity effects than 10 mg/l.

If leachate also had been added as substrate together with the heavy metals the toxicity effects may have been changed. The low toxicities obtained for most of the metals in this experiment may indicate that endogenous respiration has little sensitivity to most heavy metals.

4. Conclusions

The results of these treatment studies showed that leachate from Yggeseth could be treated successfully by the activated sludge process. Thus at organic loadings lower than about 0.2 kg COD/kg MLVSS day the obtained COD removal efficiencies were higher than about 97 percent. At higher loadings than about 0.3 kg COD/kg MLVSS day the COD removals start to decrease quite rapidly. Therefore higher organic loadings than about 0.25 kg COD/kg MLVSS day should not be applied.

At lower organic loadings than about 0.2 kg COD/kg MLVSS day nitrogen removals higher than about 80 percent were achieved. This was possibly due to efficient denitrification in the settling chambers.

To reduce the refractory organics in the biologically treated leachate activated carbon treatment was investigated. Although the removal efficiencies based on COD and TOC at very high carbon doses were found to 60 and 87 percent respectively, relatively high concentrations of organics could not be removed by the activated carbon process.

Zinc did not seem to have an adverse effect on removal of organics at zinc concentrations as high as 30 mg/l. This was probably due to low residual zinc concentrations caused by a high pH and high iron concentration in the aeration chambers. The relatively high organic loadings caused high sludge production which removed approximately 90 percent of the metals.

The toxicity of zinc, copper, chromium, cadmium, lead and nickel was studied by measuring oxygen uptake rates. The highest concentrations investigated were 40 mg/l. Of the metals investigated copper appeared to be the most toxic. Zinc, chromium, cadmium and lead seemed to have relatively little toxic effect as long as the concentrations were below 40 mg/l.

G TREATMENT OF LEACHATE FROM BRÅNÅSDALEN SANITARY LANDFILL

Leachate from Brånåsdalen sanitary landfill was treated by aerobic treatment processes and physical chemical treatment processes. The performance of the activated sludge process operating at different organic loadings, different temperatures and additions of zinc and copper in different concentrations were studied. Heavy metal toxicities were also studied by measuring the effects on the oxygen uptake rate. The physical chemical treatment processes investigated consisted of precipitation and activated carbon treatment. In the following the results of these treatment studies will be discussed.

1. Activated Sludge. (Test run no X)

The objective of this study was to investigate the treatability of the raw leachate and study the performance of the activated sludge process at different organic loadings. To accomplish this three activated sludge plants were used. These plants are described earlier as group no 2.

The composition of the raw leachate is given in table 112 Appendix B. The table shows especially high concentrations of nitrogen compounds, and iron and low phosphorus concentrations.

The treatment plants used had previously been treating raw leachate from Grønmo sanitary landfill. The plants were started with the activated sludge from that treatment study. The organic loadings applied were 0.14, 0.25 and 0.48 kg COD/kg MLVSS day.

The results from this treatment study is given in tables 112 to 115 Appendix B. The most important results are drawn in figures 106 to 108.

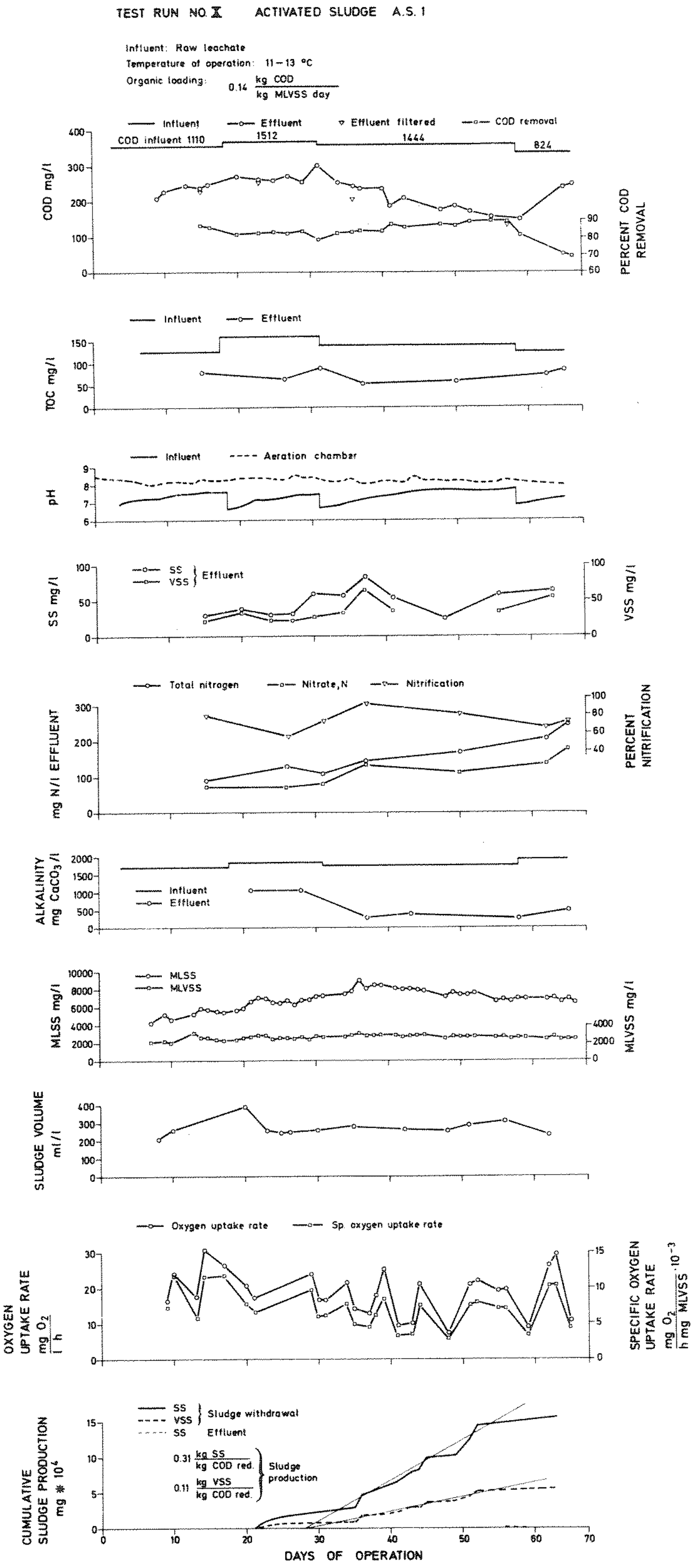


Figure 106. Experimental results, test run no X, A.S.1.

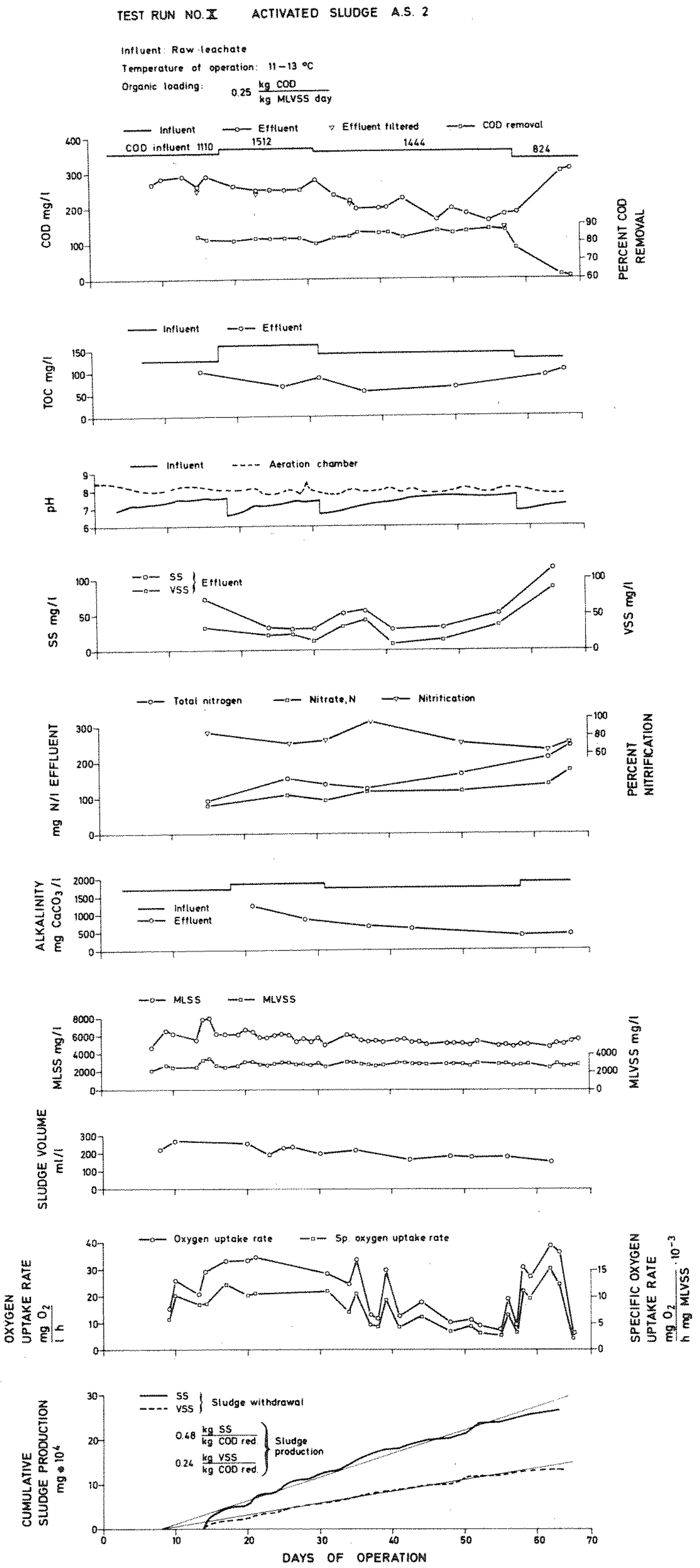


Figure 107. Experimental results, test run no X, A.S.2.

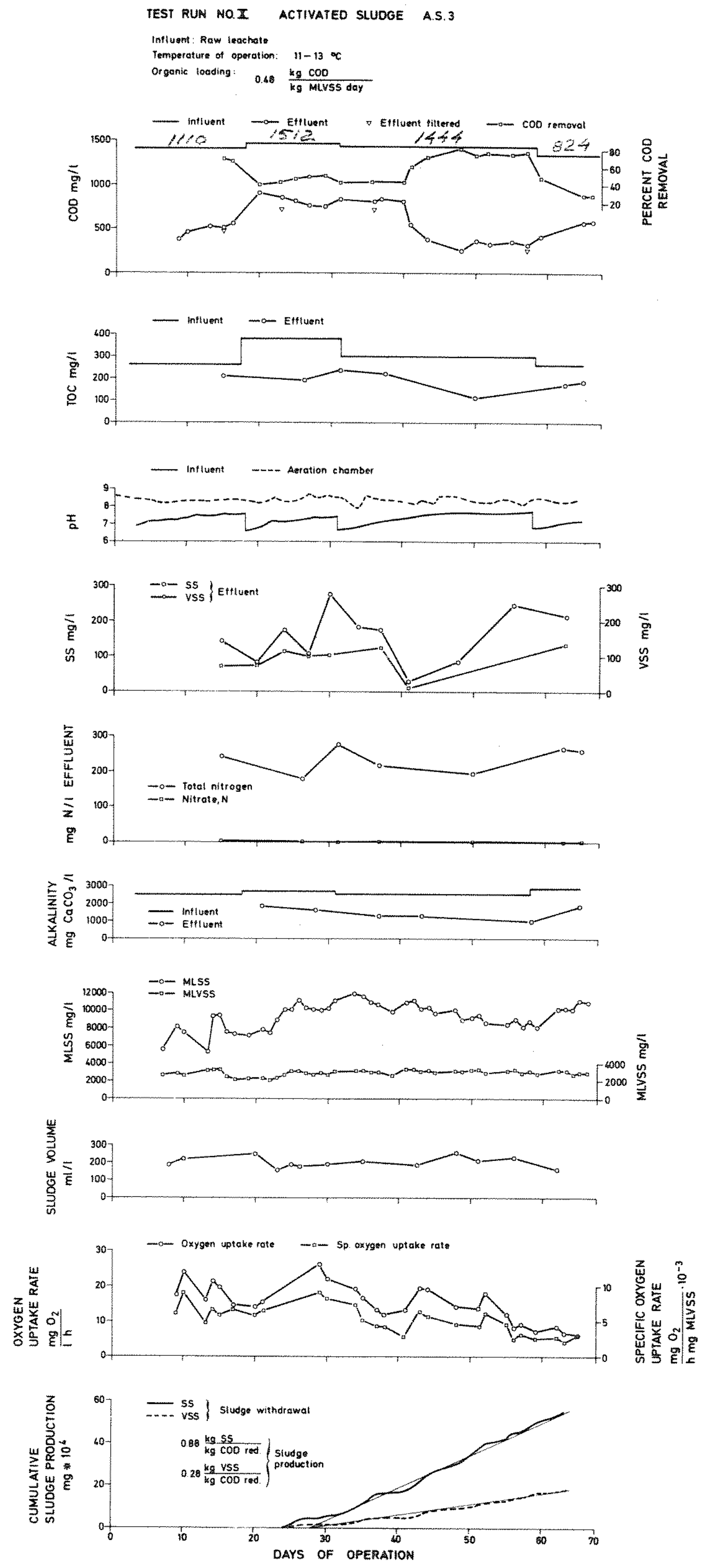


Figure 108. Experimental results, test run no X, A.S.3.

a. Organic Removals. Figure 109 shows the COD removal efficiencies as a function of organic loadings. The average COD removals for the plants operating at organic loadings of 0.14 and 0.25 kg COD/kg MLVSS day were 83.0 and 82 percent. The corresponding removals for TOC were 76 and 73 percent. The COD effluent values were in the range of 200 to 300 mg/l and remained relatively constant. Therefore when the values of the influent COD decreased the COD removal efficiency also decreased. This is shown in the first curve in figures 106 to 108.

At the organic loading of 0.48 kg COD/kg MLVSS day the average COD removal efficiency was 54 percent. Figure 109 shows that the COD removal efficiencies remained fairly constant up to an organic loading of about 0.3 kg COD/kg MLVSS day. At higher loadings the efficiencies start to fall more sharply.

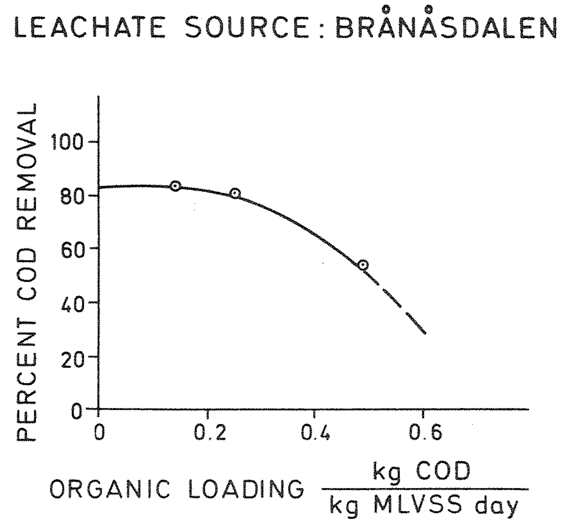


Figure 109. COD removal vs. organic loading.

Figures 106 to 108 show that filtered and unfiltered effluent samples gave nearly the same COD removal efficiencies. This means that nearly all the residual organics were in the dissolved state.

b. Oxidation of Nitrogen Compounds. The composition of the raw leachate in table 112 shows high concentrations of total nitrogen. Nearly all of the nitrogen compounds are in the ammonia form. The oxidation of the ammonia will exert a high biochemical oxygen demand. The average ammonia influent value of 262 mg N/l needs 1197 mg O/l for complete biooxidation. This number is nearly as high as the average COD influent value. As we recall similar relations were also found for the leachate from Grønmo.

Figure 110 shows the ratio of nitrates to ammonia in the effluent as a function of organic loading. The removal of total nitrogen is also drawn on the same figure. At the lowest organic loading, 0.14 kg COD/kg MLVSS day, the removal of total nitrogen was about 25 percent. The efficiency decreased with increasing loading and was approximately zero at an organic loading of 0.48 kg COD/kg MLVSS day.

The ratio of nitrates to toal nitrogen in the effluent were at the two lowest organic loadings about 75 percent. This ratio and the removal of total

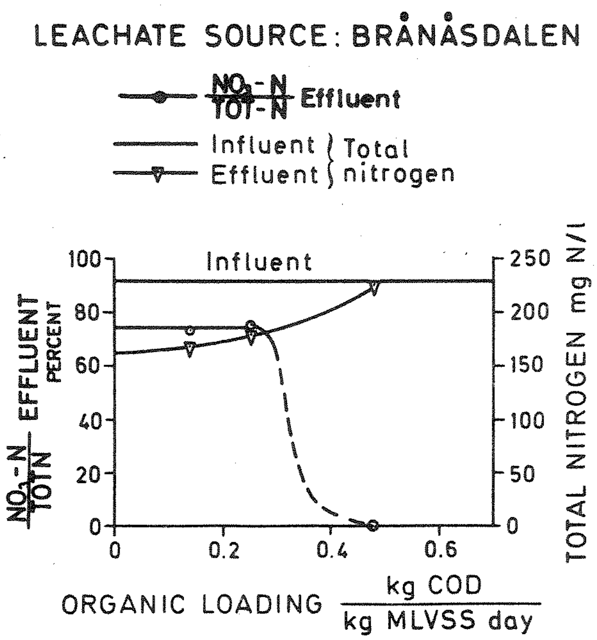


Figure 110. Oxidation of nitrogen compounds and removal of nitrogen vs. organic loading.

nitrogen gives a degree of nitrification at the lowest loadings of about 80 percent. The nitrification remains fairly constant up to an organic loading of 0.25 kg COD/kg MLVSS day where it decreases sharply to zero at an organic loading of 0.48 kg COD/kg MLVSS day. In this test run the same arrangement and the same time interval for the recirculation of the sludge was used as in the treatment studies of leachate from Yggeseth. Compared with the results from the treatment of leachate from Yggeseth the removal of total nitrogen was very low. Evidently the environment in the treatment units when treating leachate from Branasdalen landfill, was not well suited for denitrification.

c. pH, Alkalinity. The pH in the aeration chambers was high for all the units. The pH of the influent was raised from a value of 6.8 to values between 8.1-8.4 in the effluent.

The alaklinity was reduced from influent values of 2700 mg $CaCO_3$/l to effluent values of 610-1500 mg $CaCO_3$/l.

d. Solids. The average effluent suspended solids were 50 and 66 mg/l for the two plants with organic loadings 0.14 and 0.25 kg COD/kg MLVSS day respectively. At the highest organic loading applied, 0.48 kg COD/kg MLVSS day, the concentrations of suspended solids in the effluent were very high. The average value for suspended solids was 168 mg/l. The high effluent values of suspended solids were caused by poor flocculation. This was probably caused by the high iron content in the leachate.

The concentrations of volatile suspended solids in the activated sludge increased rapidly. Therefore sludge had to be withdrawn frequently. Figure 111 shows the sludge production as function of organic loading. The difference in the sludge production measured as suspended and volatile suspended

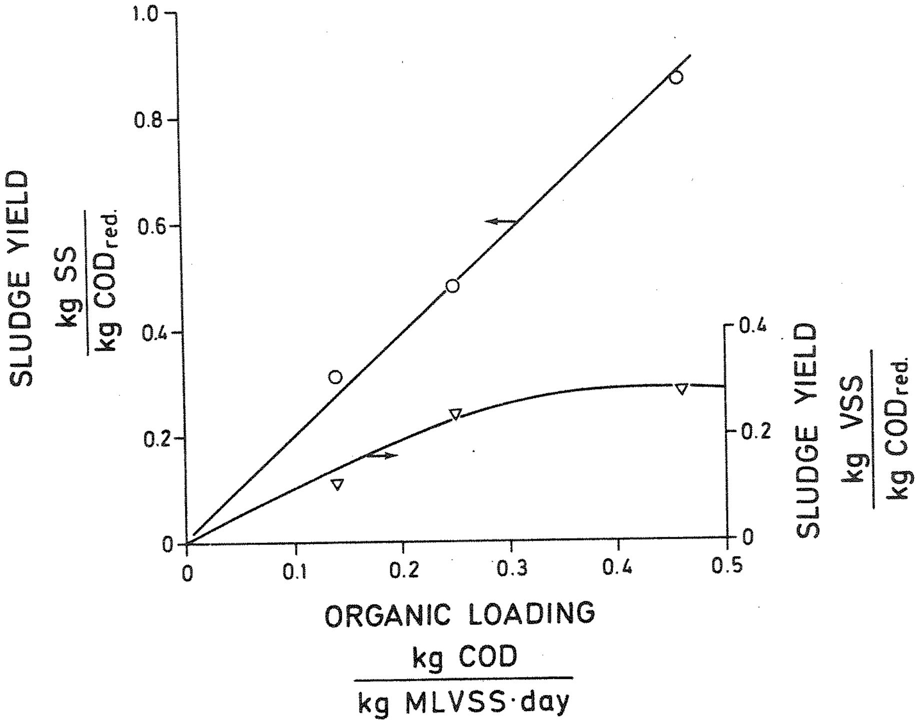


Figure 111. Sludge yield vs. organic loading.

solids was caused by accumulation of inorganics in the sludge. This was especially noticeable at high organic loadings.

e. <u>Sludge Characteristics</u>. The settleability of the activated sludge was good. The highest sludge volume measured was 315 ml/l. This corresponded to a sludge volume index of about 45 ml/mg.

The dewatering properties expressed as specific resistance to filtration ranged between average values of $8.5 \cdot 10^{11}$ to $2.2 \cdot 10^{12}$ m/kg. These values are about the same as those found in the treatment studies of leachate from Grønmo and Yggeseth.

f. Oxygen Uptake Rate. In figures 106 to 108 the oxygen uptake rates are also shown. The average values as a function of organic loading are shown in figure 112.

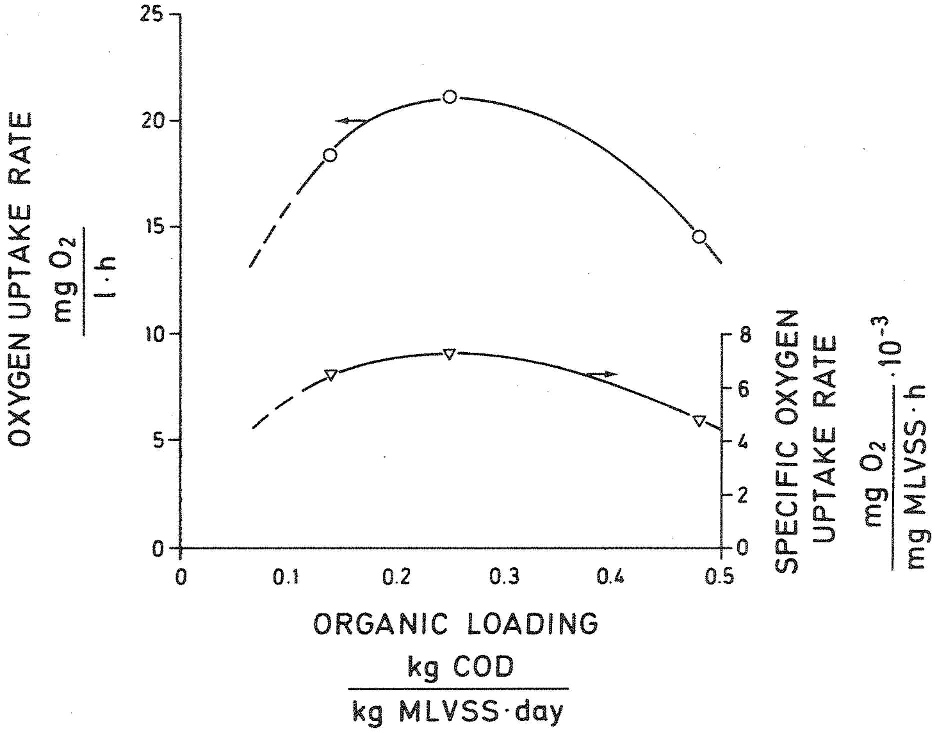


Figure 112. Oxygen uptake rate vs. organic loading.

The values for the specific oxygen uptake rate are somewhat higher than those measured at the corresponding organic loadings in the treatment of leachate from Grønmo. However, the values are considerable lower than corresponding values found in the treatment of leachate from Yggeseth. This was expected because the leachate from Yggeseth showed a better treatability than the leachate from Brånåsdalen and Grønmo.

g. Microscopic Examination. Microscopic examinations of the activated sludge from the different treatment plants were performed in the last part of the test run. Table 50 shows a summary of the results from the microscopic

Table 50. Microscopic Examination. Test run no X

Plant	Organic loading kg COD kg MLVSS day	Protozoa		Flagel-lates	Roti-fiers	Nema-todes	Free Swimming bacteria	Filamen-tous bacteria	Size of floc	Degree of defloc-culation
		Swim-ming	Stalked							
A.S.1	0.14	2	2	0	0	0	1	1	Small	Some
A.S.2	0.25	2	3	0	0	0	2	1	Small	Some
A.S.3	0.46	0	0	0	0	0	4	1	Medium	High

Relative number of higher microorganisms.

5. Dominating: Dominating the sample completely
4. Many: Many organisms in each field of vision
3. Usual: Some organisms in each field of vision
2. Some: Occurs often but not in each field of vision
1. Few Few organisms observed
\+ Very few: Very few organisms observed
0 Not observed

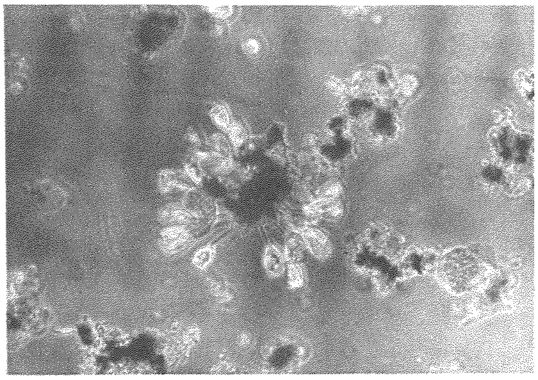


FIGURE 113 TEST RUN No.IX x107 A.S.1.

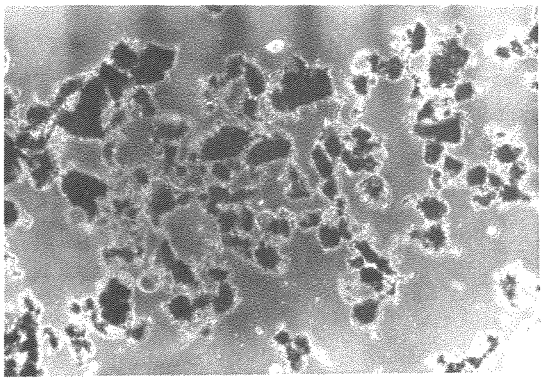


FIGURE 114 TEST RUN No.IX x 43 A.S.2.

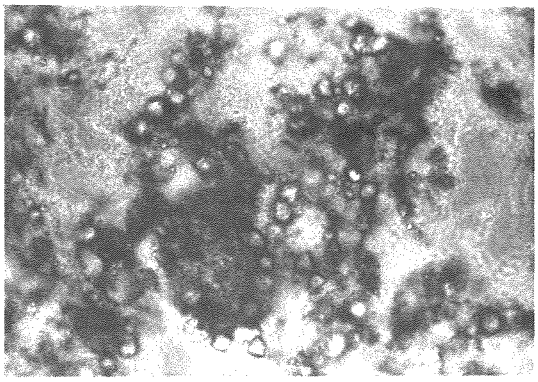


FIGURE 115 TEST RUN No.IX x 43 A.S.3.

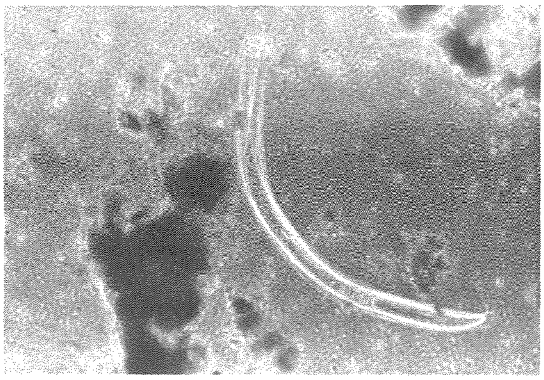


FIGURE 116 TEST RUN No.XIII First disc x107

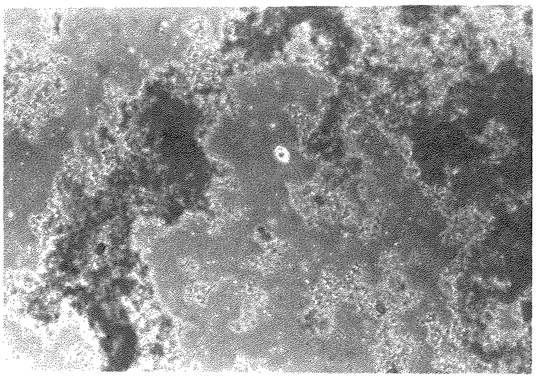


FIGURE 117 TEST RUN No.XIII Last disc x 43

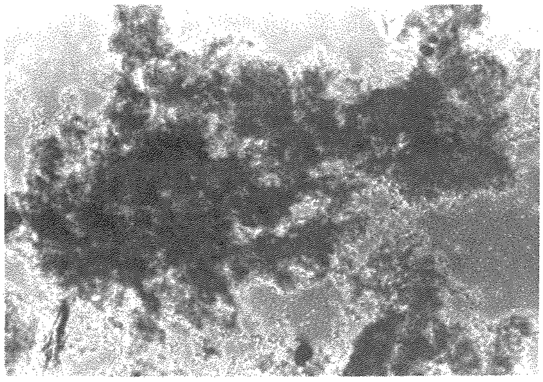


FIGURE 118 TEST RUN No.XIII Last disc x 43

examinations. Figures 113 to 115 show some micrographs of the activated sludge from the three treatment plants.

The microscopic examinations showed that the activated sludge from the plant operating at an organic loading of 0.14 kg COD/kg MLVSS day contained realtively high numbers of protozoa. Of these stalked Vorticella were the dominating species. Three or four species of freeswimming ciliates were also observed. No flagellates, rotifers and nematodes were observed.

The number of free swimming bacteria were relatively small. Of the bacteria the Zoogloea species seemed to dominate. The flocs were relatively small and their density seemed to be relatively high.

The microscopic sample from the plant operating at an organic loading of 0.25 kg COD/kg MLVSS day showed a content of higher organisms comparable to the previously described sample. The number of freeswimming bacteria was higher in this sample. The iron deposits were also more dominating.

At the highest organic loading no higher organisms could be observed in the activated sludge. The number of free swimming bacteria was high and the sample had a high content of dispersed material. The colonies of Zoogloea bacteria were not so dominant as in the samples from the other plants. Characteristic for the sample was the very high concentrations of iron deposits.

2. Activated Sludge - Effects of Temperature (Test run no XI)

The objective of this study was to investigate the influence of different temperatures on the performance of the activated sludge process. Five activated sludge plants of the type described as group no 2, were run in parallel and with equal organic loading. The temperature of operation was held constant by thermostatically regulated cooling and heating equipment. The temperature investigated were 5, 10, 18 and 25°C. In addition to this one plant was operated at room temperatures which varied from 10 to 14°C.

The plants were seeded with activated sludge from the previous test run which also had been treating leachate from Branasdalen. Due to small differences in the concentrations of activated sludge in the test period the average organic loading varied from 0.16 to 0.19 kg COD/kg MLVSS day.

The results from this study, denoted test run no XI, are given in tables 116 to 121 Appendix B. The most important results are given in figures 119 to 123.

The curves for the COD removals show quite different values. As expected significantly higher removal efficiencies were obtained at higher temperatures of operation. The average COD removals as a function of organic loading are shown in figure 124. The curve shows sharply decreasing removal efficiencies at temperatures lower than about 15°C. At temperatures higher than about 20°C the curve seems to level out to nearly constant removal efficiencies. The maximum organic removal efficiencies obtained in this test run were considerably lower than those obtained in the preceding test run. The leachate source was the same but the influent concentrations of organics were considerably higher in the first study. The effluent values of the residual organics in the two test runs were about the same. Therefore the organic removal efficiencies were considerably higher in the first test run.

The pH in the aeration chambers were considerably lower in the units which operated at the highest temperatures. Thus the average pH values varied from 7.9 to 8.6. This difference was caused by higher biological activity and thus higher CO_2 production at high temperatures.

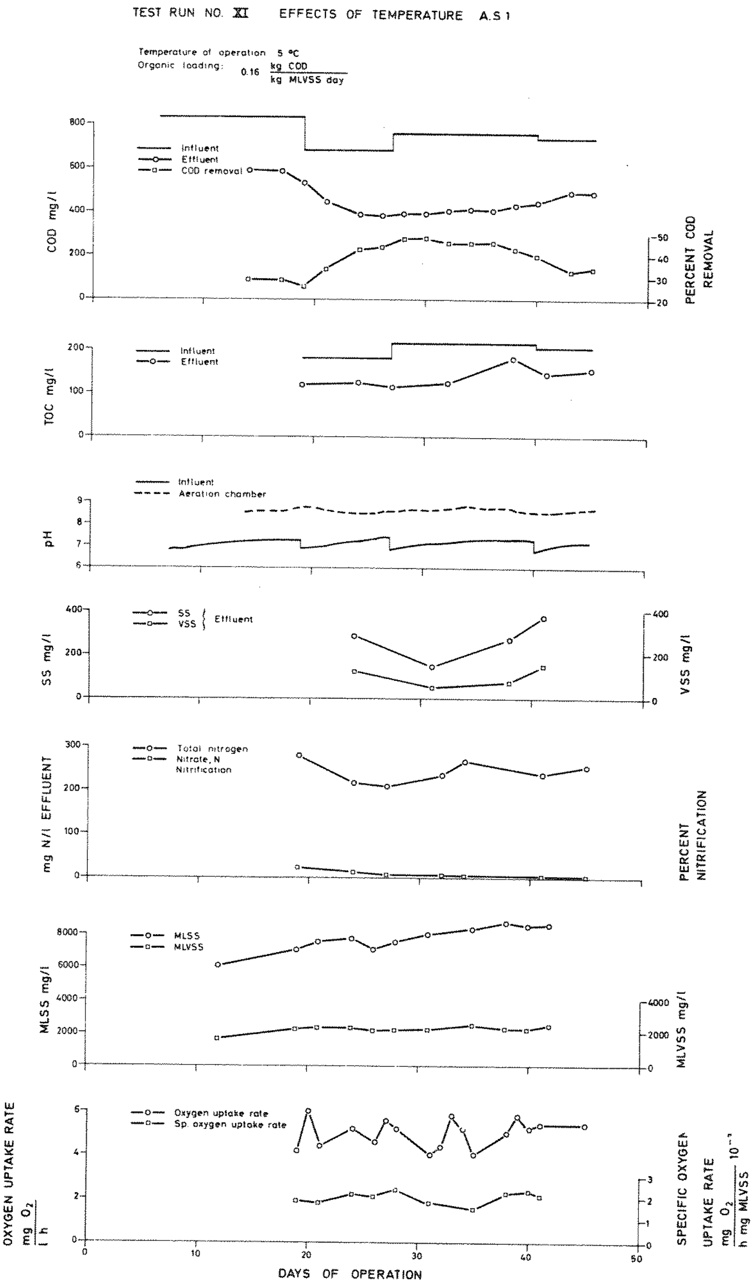


Figure 119. Experimental results, test run no XI, A.S.1.

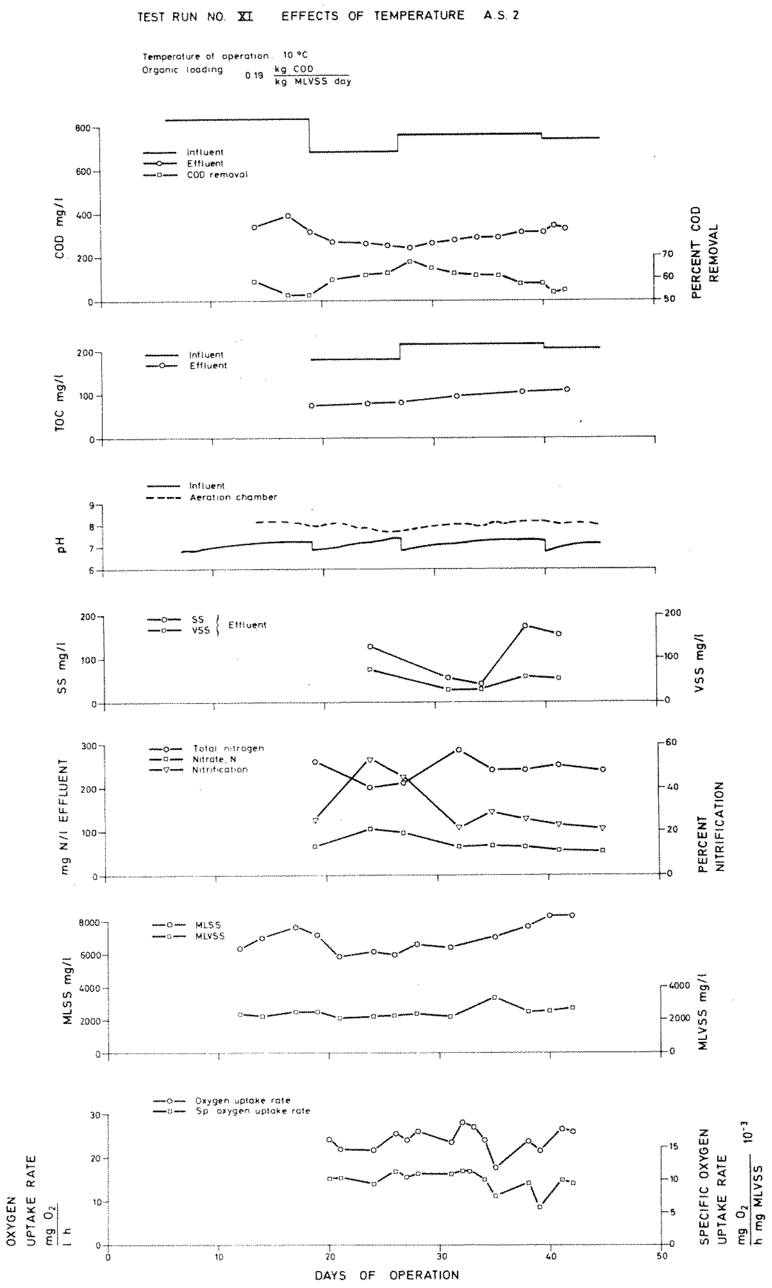


Figure 120. Experimental results, test run no XI, A.S.2.

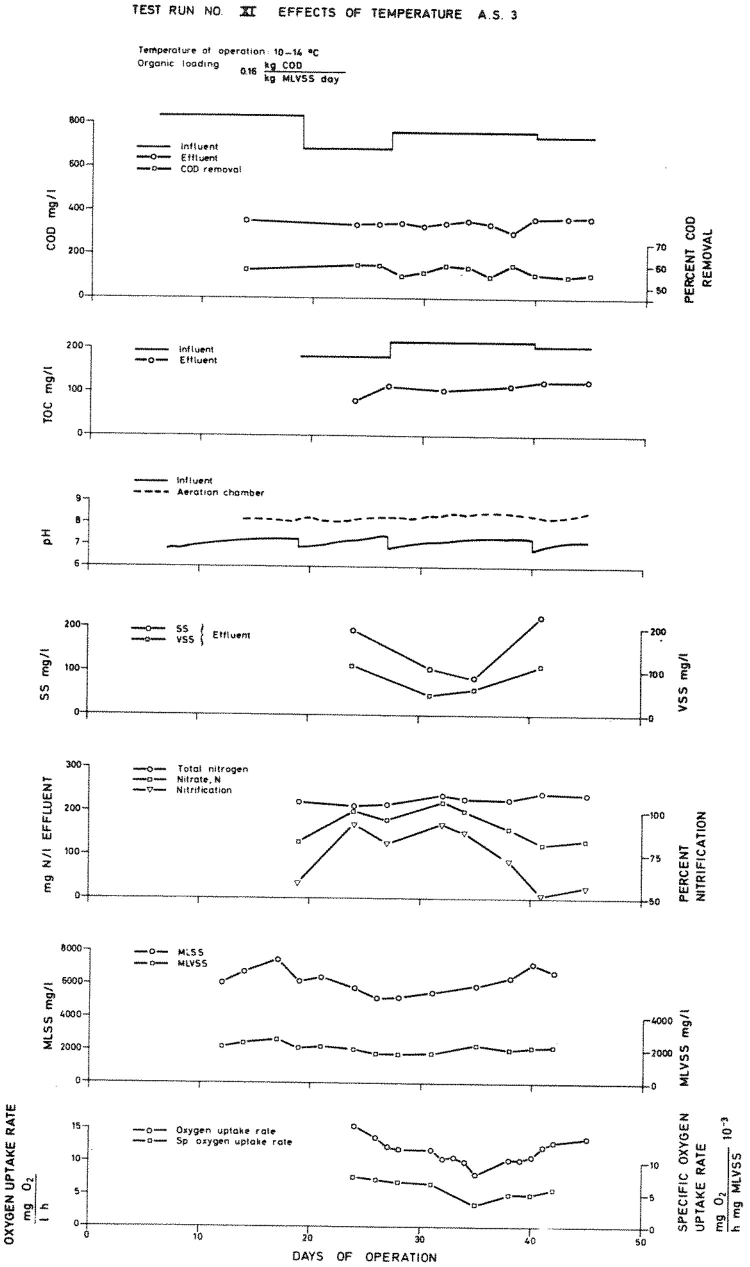


Figure 121. Experimental results, test run no XI, A.S.3.

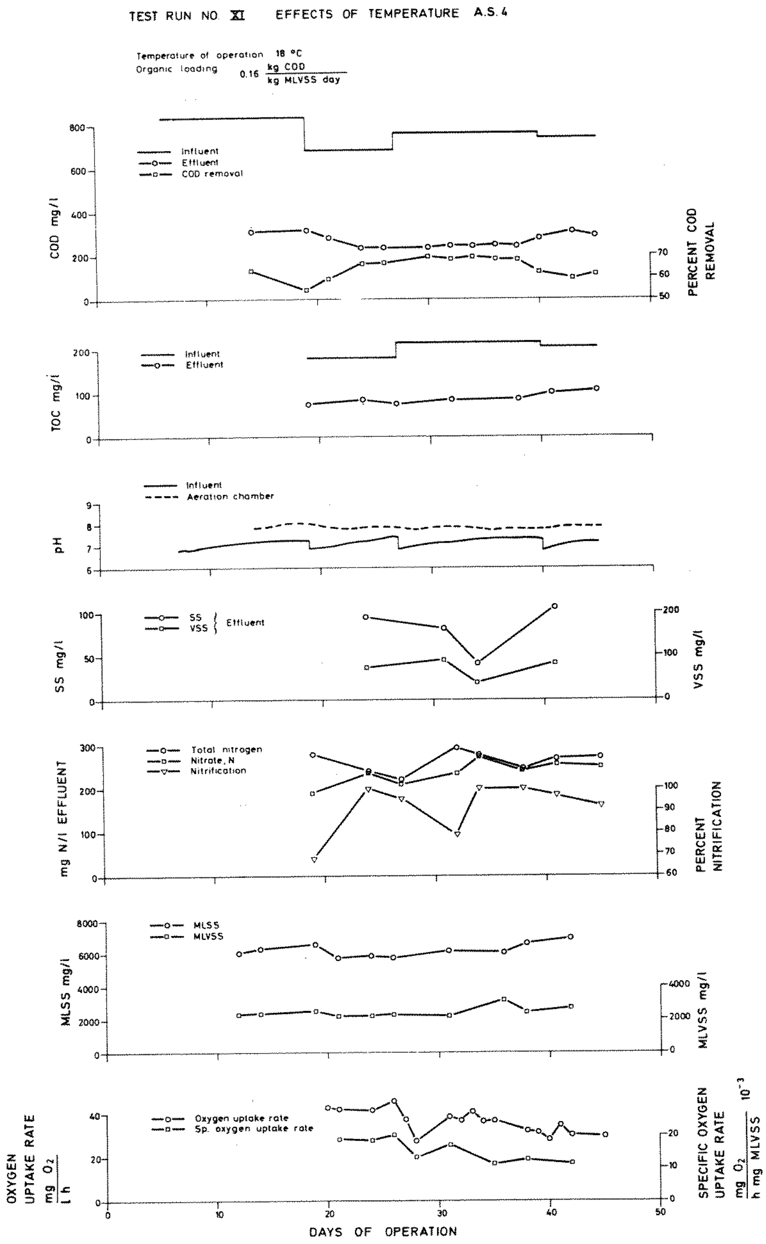


Figure 122. Experimental results, test run no XI, A.S.4.

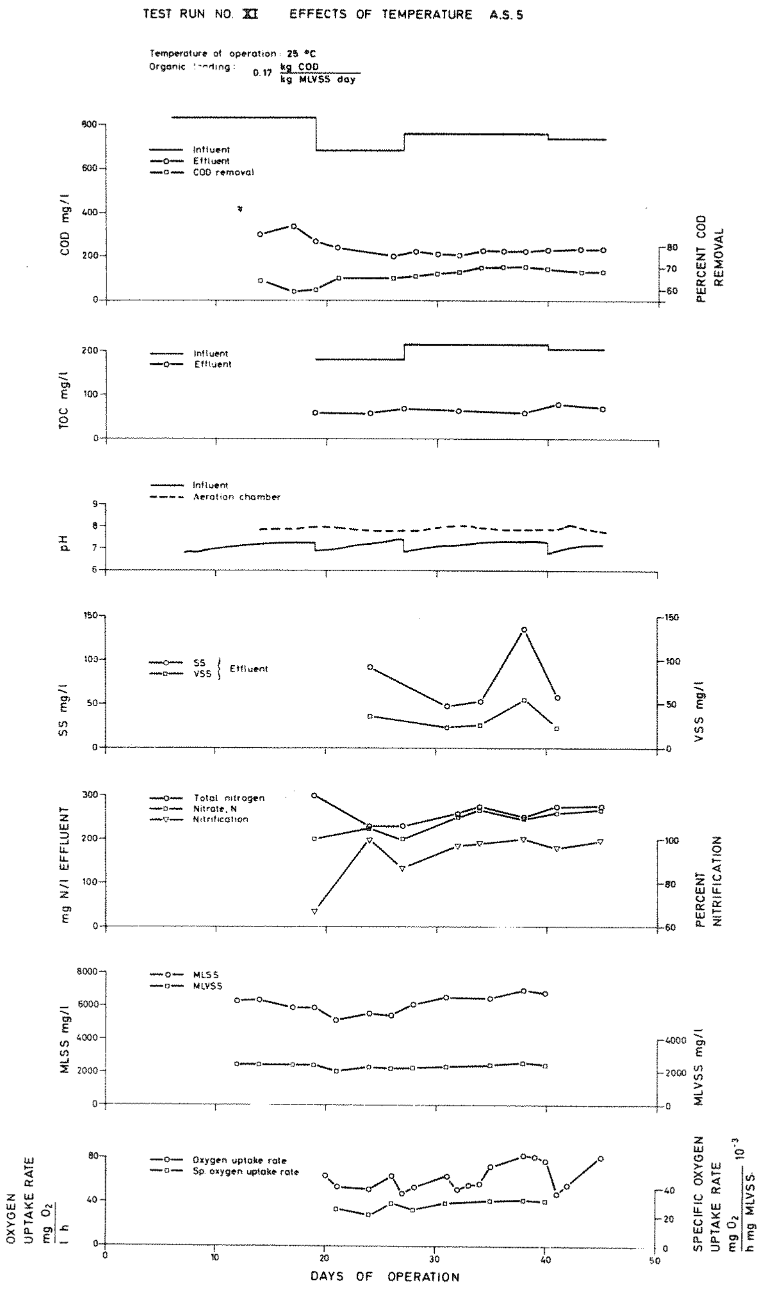


Figure 123. Experimental results, test run no XI, A.S.5.

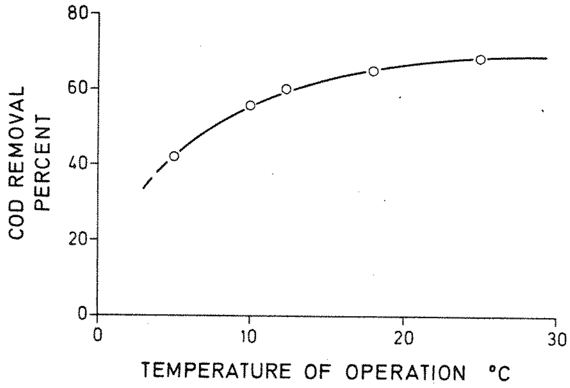


Figure 124. COD removal vs. temperature of operation.

The nitrification bacteria are very sensitive to low temperatures. Therefore the degree of nitrification is strongly dependent on the temperatures. Figure125 shows the degree of nitrification as function of temperatures. The results shows that the degree of nitrification decreases rapidly below temperatures of about 15 °C. This critical temperature will be a function of the organic loading. Therefore at organic loadings lower than those applied in this study, the above critical temperature will be lower.

The maximum obtained degree of nitrification was higher in this study than in the preceding study. One possible explination may be that the temperatures of operation where these high degrees of nitrification were obtained were considerable higher than in the preceding.treatment study with leachate from Brånåsdalen.

The results show that the different treatment parameters are considerably influenced by the temperature. In general variations in reaction rate as a function of temperature can usually be represented by the Arrhenius equation:

$$\ln k = \ln A_f - \frac{E_a}{RT}$$

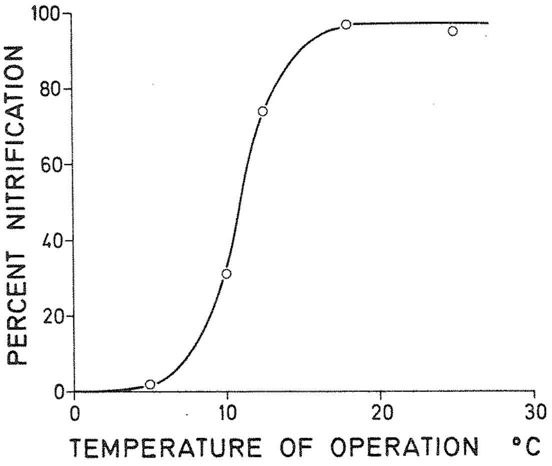


Figure 125. Nitrification vs. temperature of operation

In this equation k represents the reaction rate, A_f the Arrhenius frequency factor, E_a the activation energy, R the universal gas constant and T the absolute temperature. Since A_f, E_a and C are constants it follows that there is a linear relationship between the logarithm of the reaction rate and the inverse of the absolute temperature.

In figure 126 the specific oxygen uptake rates as a function of temperatures are plotted in terms of the Arrhenius equation. The figure shows a nearly linear relationship between the oxygen uptake rate and the inverse of the absolute temperature over a certain part of the temperature range. The slope of the linear part of the curve, or the activation energy, can be used to find how the oxygen uptake rate depends on the temperature.

According to figure 126 a $10^{\circ}C$ increment in temperatures causes a six fold increase in the specific oxygen uptake rate. The specific oxygen uptake rate is proportional to specific growth rate plus oxygen requirement for endogenous respiration. Therefore the specific oxygen uptake rate cannot be used directly as a measure of specific growth rate.

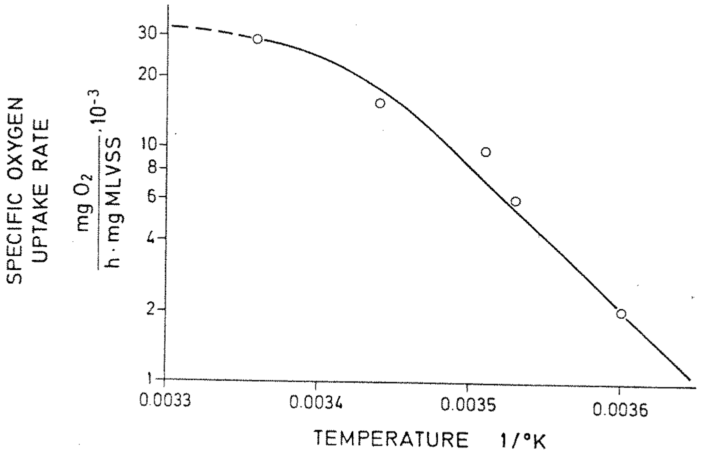


Figure 126. Oxygen uptake vs. temperature of operation.

Microscopic examinations of the activated sludge in the plants operating at the different temperatures showed large differences in the number of higher organisms. The results are summarized in table 51. Figure 127 shows some typical micrographs.

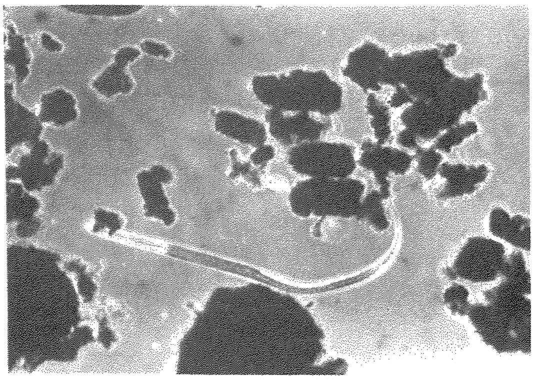
The plants operating at the lowest temperatures showed a very low species diversity. For instance of higher organisms the plant operating at 5 °C contained only a few species of free swimming ciliates. These consisted mainly of the species Aspedisca and Thrachelophyllum. The bacteria species Zoogloea present but far from dominating the sample. Therefore free swimming bacteria were present in large numbers. The plants operating at 10°C and 10-14°C showed about the same species diversity of higher organisms as the plant operating at 5 °C. The number of free swimming bacteria were also high in these plants.

Table 51. Microscopic examination. Test run no XI

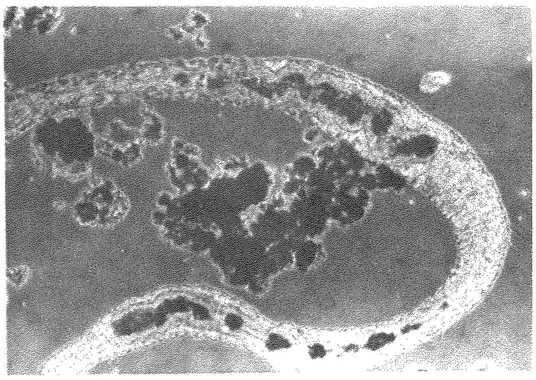
Plant	Temp of oper °C	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$	Protozoa		Flagellates	Rotifiers	Nematodes	Free Swimming bacteria	Filamentous bacteria	Size of floc	Degree of deflocculation
			Swimming	Stalked							
A.S.1	5	0.16	+	0	0	0	0	4	1	Small	High
A.S.2	10	0.19	1	0	0	0	0	4	1	Small	High
A.S.3	10-14	0.16	1	0	0	0	0	2	1	Small	Some
A.S.4	18	0.16	+	1	0	+	3	1	1	Large	None
A.S.5	25	0.17	+	1	0	1	3	1	1	Large	None

Relative number of higher microorganisms.

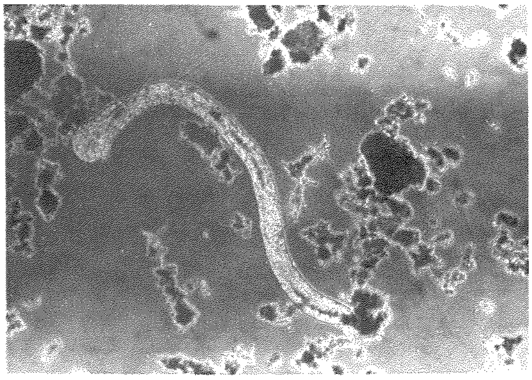
5.	Dominating:	Dominating the sample completely
4.	Many:	Many organisms in each field of vision
3.	Usual:	Some organisms in each field of vision
2.	Some:	Occurs often but not in each field of vision
1.	Few	Few organisms observed
+	Very few:	Very few organisms observed
0		Not observed



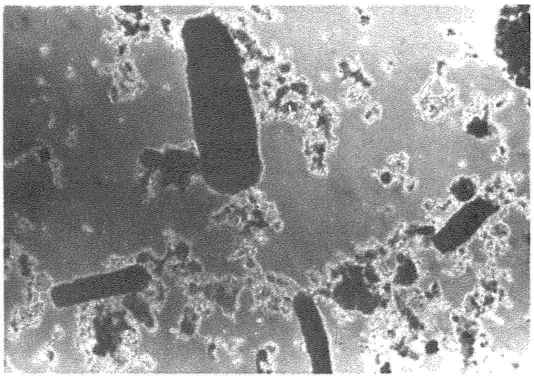
25°C x 43



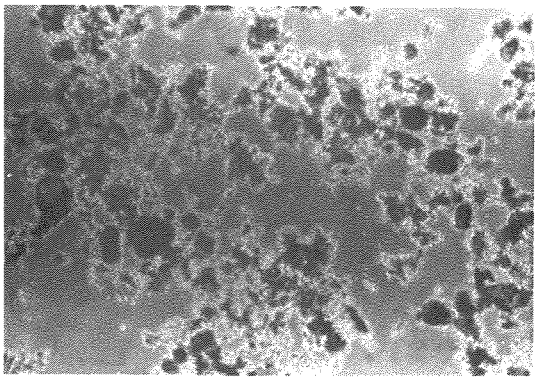
18°C x 43



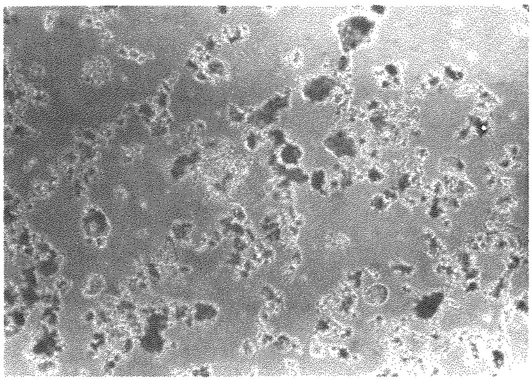
18°C x 43



10 - 14°C x 43



10°C x 43



5°C x 43

FIGURE 127 Activated sludge. Test run No.XI

The plants operating at 18°C and 25°C showed a relatively high species diversity of higher organisms. Nematodes dominated in both samples. Rotifers and protozoa were also present but in smaller numbers. The high numbers of nematodes were polishing the effluent so that the free swimming bacteria were kept down to a low content. The size of the flocs were large and very little dispersed material was present. All the activated sludge samples showed deposits of large iron particles.

3. Heavy Metal Toxicity

The toxicity of the heavy metals, Zn and Cu, was studied in a separate test run. The toxicity of the same metals plus the heavy metals, chromium, cadmium, lead and nickel, was also studied by measuring oxygen uptake rates.

a. Activated Sludge - Zinc Toxicity (Test run no XII). The toxicity of zinc was investigated in five activated sludge units. Zinc was added to the influent by means of peristaltic pumps. The doses were such that the zinc concentrations became 10, 25 and 50 mg/l. One of the plants was used as a reference, that is no zinc was added.

The plants were at the start given equal organic loadings. Due to variations in the MLVSS concentrations the organic loadings varied from 0.13 to 0.17 kg COD/kg MLVSS day. The additions of zinc was started after the plants had been in operation for 14 days.

The results from this test run are given in tables 122 to 126 Appendix B. The most interesting results are drawn in figures 128 to 131.

Zinc concentrations in the influent of 10 and 25 mg/l showed no significant effect in reducing the COD removal efficiency. At zinc concentrations of 50 mg/l inhibitory effects increased with time of operation

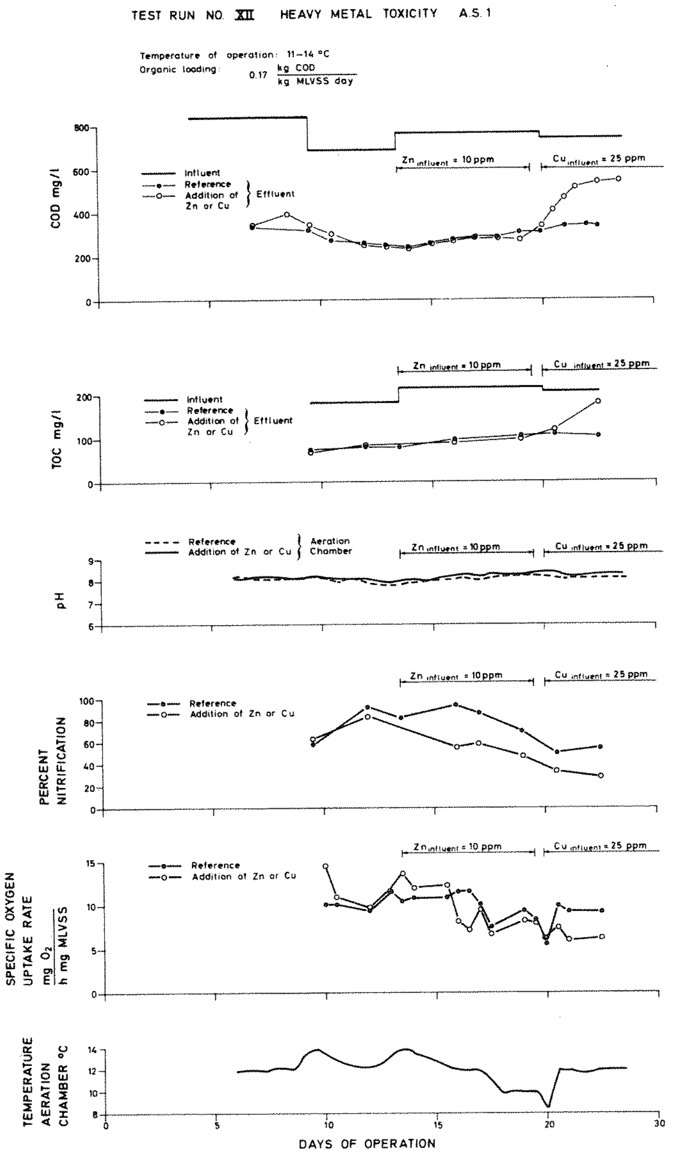


Figure 128. Experimental results, test run no XII, A.S.1.

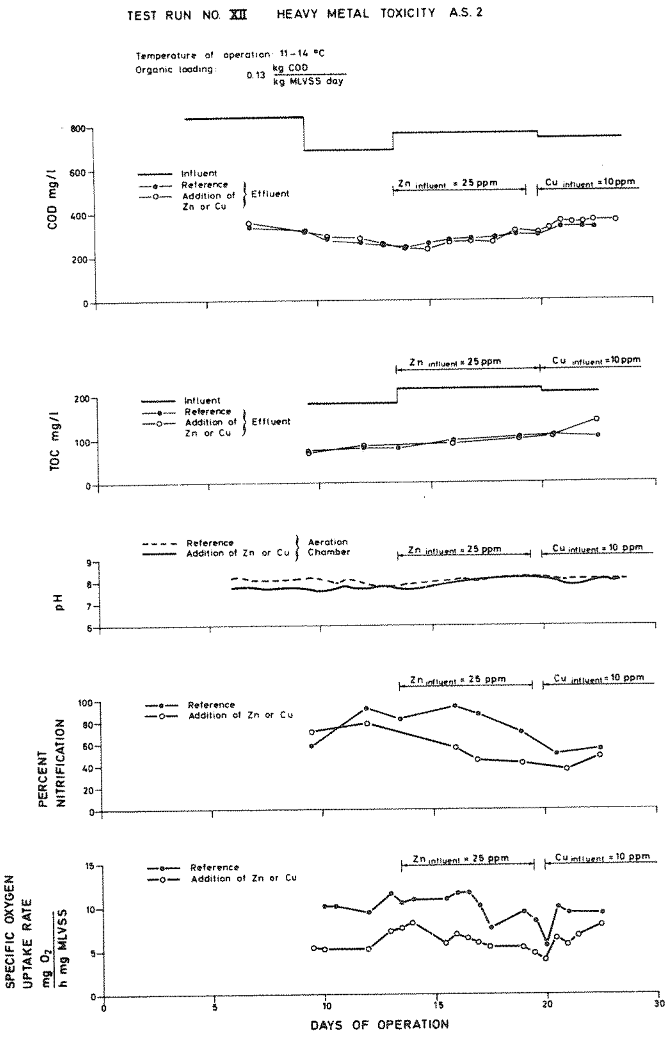


Figure 129. Experimental results, test run no XII, A.S.2.

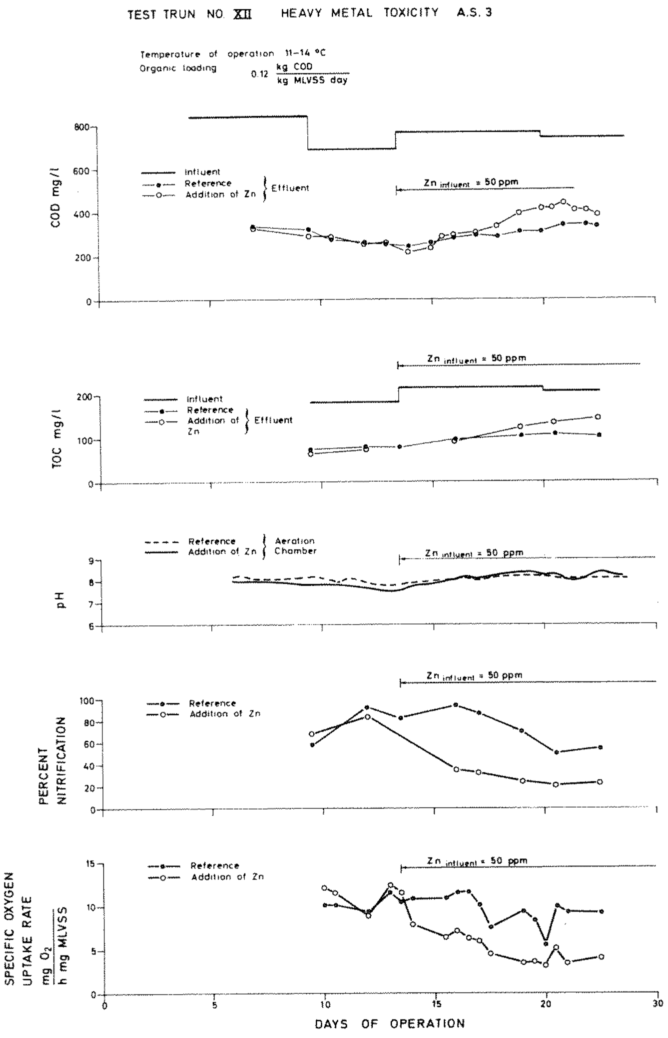


Figure 130. Experimental results, test run no XII, A.S.3.

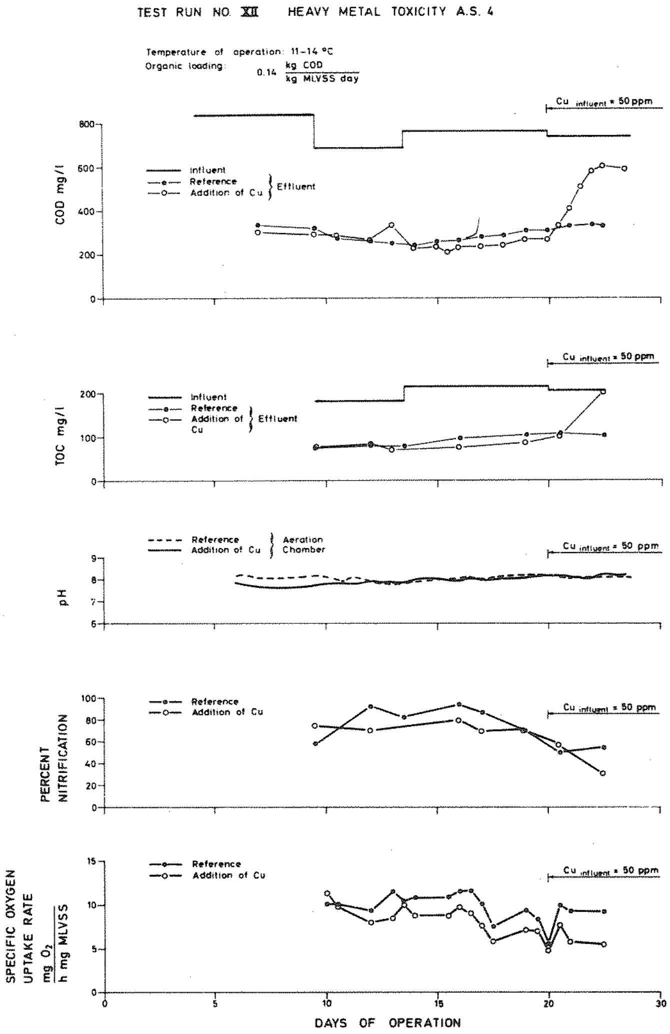


Figure 131. Experimental results, test run no XII, A.S.4.

until a nearly constant effects were reached in the last part of the test run. Over a certain time of operation where the toxicity had maximum effects the COD removal efficiency was reduced from 55 to 44 percent.

Figure 132 shows how the additions of zinc suppressed the degree of nitrification. At zinc concentrations of 25 mg/l in the influent the degree of nitrification are reduced from 84 to 48 percent. The nitrification bacteria are among the most sensitive bacteria species to heavy metal toxicity. This explains why the plant operating at zinc concentrations of 25 mg/l had little effect in reduction of the COD removal efficiency and a significant effect in reducing the degree of nitrification. At influent zinc concentrations of 50 mg/l the average degree of nitrification was reduced from 84 to 30 percent.

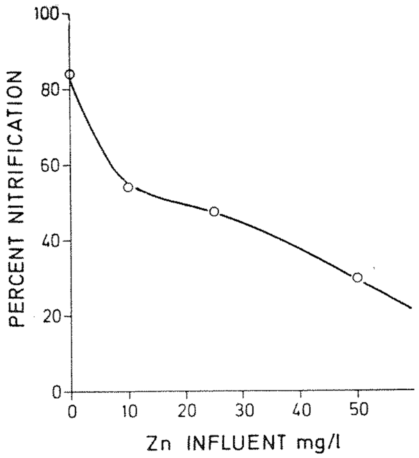


Figure 132. Nitrification vs. zinc doses.

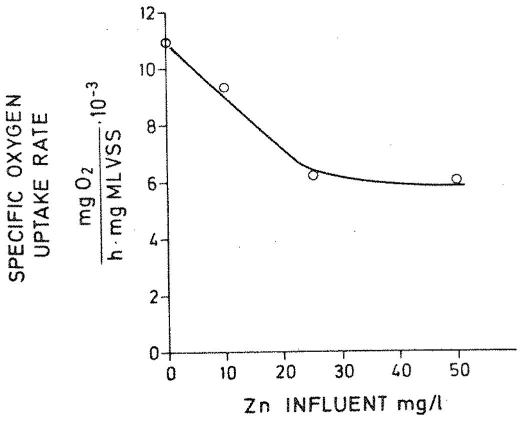


Figure 133. Oxygen uptake rate vs. zinc doses.

In figure 133 the average specific oxygen uptake rate is drawn as a function of the zinc concentrations in the influent. The curve shows that the oxygen uptake rate is suppressed with increasing zinc concentrations. Thus at zinc concentrations of 50 mg/l the uptake rate decreased from a reference value of 10.9 to a value of 6.1 mg O/h mg MLVSS $\cdot$ 10^{-3}.

The microscopic examination of the activated sludge from the plants operating at different zinc concentrations showed a decreasing species diversity with increasing zinc concentrations. Thus in the sludge sample operating at zinc concentrations of 50 mg/l the only higher organisms observed were a very few free swimming ciliates. The number of free swimming bacteria was also high in this sample.

In the sludge sample from the plant operating at zinc concentrations of 25 mg/l the number of higher organisms was also small but higher than in the previously described sample.

The microscopic examinations of sludge from the reference plant and the plant which operated at zinc concentrations of 10 mg/l showed no difference in the composition of higher organisms. In these samples both stalked and free swimming protozoa were present. Of the stalked protozoa the species Vorticella were dominated. The free swimming protozoa were dominated by the species Paramecium and Trachelophyllum. The number of higher organisms was considerably higher than in the samples from the plants which operated at zinc concentrations of 25 and 50 mg/l.

b. Activated Sludge - Copper Toxicity (Test run no XII). After the study of zinc toxicity to the activated sludge process was finished the same activated sludge plants were used for studying the effect of copper toxicity. The results from this study are given in the same tables and in the same main figures as for the preceding study.

The plants which operated at copper concentrations of 10 and 25 mg/l had previously been operated at zinc concentrations of 25 and 10 mg/l respectively. Therefore the residual concentrations of zinc and the added copper may cause synergistic effects. The toxicity effects obtained at copper concentrations of 10 and 25 mg/l may therefore be larger than if the same plants not had been used in the previous zinc toxicity study.

The results show that the plant A.S.2 operating at copper concentrations of 10 mg/l gave a slightly lower COD removal efficiency than the reference plant. However, at copper concentrations of 25 and 50 mg/l the COD removal efficiencies were reduced severely. At copper concentrations of 25 mg/l the COD removal efficiencies were reduced from 54 to 30 percent. The corresponding reduction at copper concentrations 50 mg/l were from 54 to 19 percent.

The suppression of nitrification as a function of copper concentrations in the influent is shown in figure 134. The data points are average values of the two last analyses in the test run. At copper concentrations of 50 mg/l the degree of nitrification was expected to be lower than 30 percent. With longer times of operation the suppression could probably have been larger. The degree of nitrification given in figures 128 to 131 shows a relatively large variation for the samples from the plants receiving heavy metals as well as for the reference plant. Therefore the nitrification results obtained in this study should not be over emphasized.

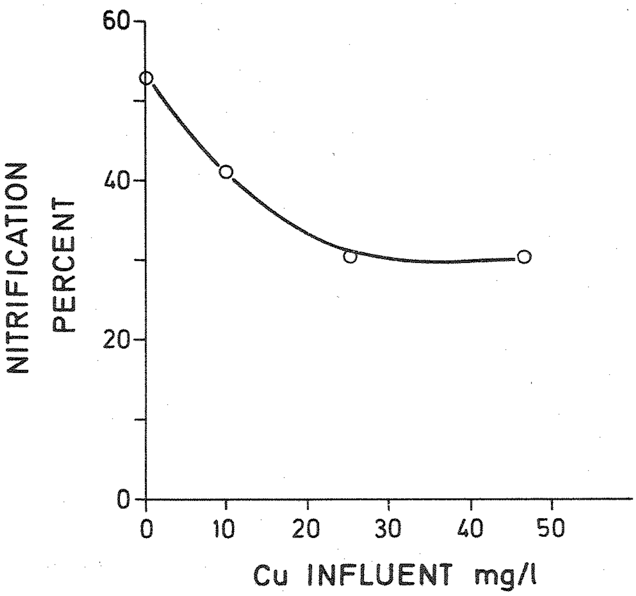


Figure 134. Nitrification vs. copper doses.

Figure 135 shows the specific oxygen uptake rate as a function of copper concentrations in the influent. At copper concentrations of 50 mg/l the uptake rate is suppressed from a reference value of 9.2 to a value of 5.6 mg O/mg MLVSS · h · 10^{-3}.

The results from this study should indicate that the solubility of copper ions are much higher than calculated from the solubility of pure copper hydroxides. At pH 8.2 this solubility is only about 0.5 mg/l.

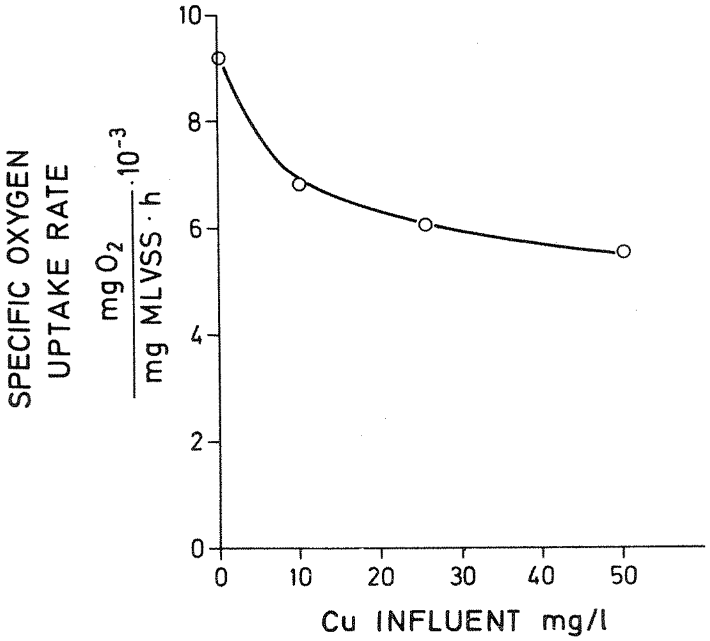


Figure 135. Oxygen uptake rate vs. copper doses.

c. Oxygen Uptake Studies. The toxicity of zinc, copper, chromium, cadmium, lead and nickel to the activated sludge process was studied by using oxygen uptake studies. The same method was used as described for the toxicity studies to the activated sludge treating leachate from Yggeseth.

Sludge from the reference plant was transferred to the 500 ml aerated measure cylinders and heavy metals added at concentrations of 25 and 50 mg/l.

The respiration values were then determined after 1, 24 and 48 hours of aeration. These results are given in figures 136 to 138.

Compared with the reference samples the oxygen uptake rates are suppressed with increasing aeration time. In other words the toxicity effects are higher after 48 than 1 hours of aeration. After 48 hours of aeration copper seems to have the highest toxicity effects. There existed little difference in the respiration values between the samples receiving 25 and 50 mg/l. This agrees well with the results from the previous study (see figure 135) where the specific oxygen uptake rate was found to be nearly the same at copper doses of 25 and 50 mg/l. This means that the toxicity effects are increasing with increasing heavy metal doses but not proportionally. Besides copper, lead and nickel had also high toxicity effects.

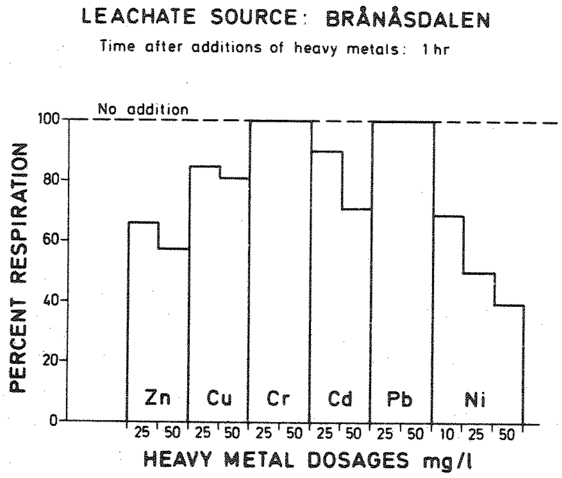


Figure 136. Respiration rates vs. heavy metal dosages, time after addition of heavy metals: 1 hr.

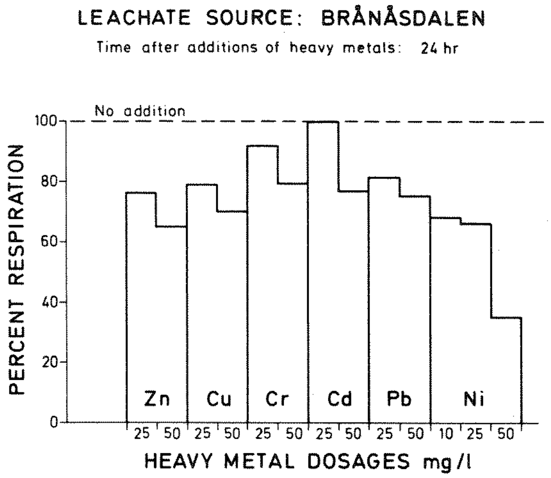


Figure 137. Respiration rates vs. heavy metal dosages, time after addition of heavy metals:24 hr.

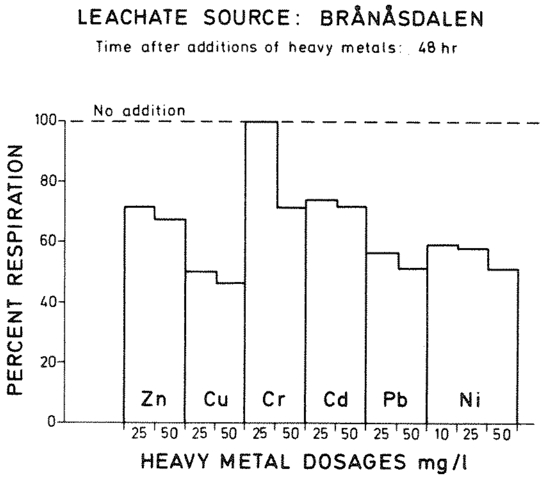


Figure 138. Respiration rates vs. heavy metal dosages, time after addition of heavy metals: 48 hr.

4. Chemical Treatment of Raw and Biologically Treated Leachate

The chemical coagulation and precipitation of raw and biologically treated leachate were investigated in jar tests. The procedure was the same as that previously described on page 181.

a. Chemical Treatment of Raw Leachate. The results of the chemical treatment of raw leachate are shown in table 52.

Table 52. Chemical treatment of raw leachate

Precipitant	pH	COD mg/l	COD-red %	Fe mg/l	Zn mg/l
Raw leachate		1450		89.4	6.7
Alum 150		1328	8.4	11.1	0.9
" 250		1324	8.7	14.3	0.7
" 400		1316	9.2	8.6	0.9
" 150	6.0	1368	5.6	30.2	1.9
" 250	6.0	1348	7.0	20.9	1.0
Alum 400	6.0	1320	8.9	13.6	0.5
Ferric chloride 150		1256	13.4	14.6	0.9
" " 250		1296	10.6	10.2	0.8
" " 400		1232	15.0	5.6	0.7
" " 150	9	1248	13.9	1.5	<0.1
" " 250	9	1320	9.0	2.6	0.1
Ferric chloride 400	9	1304	10.1	1.7	0.1
Lime	9	1303	10.1	18.4	1.0
"	10	1290	11.0	6.6	0.5
"	11	1245	14.1	1.5	<0.1
Lime	12	1286	11.3	0.7	<0.1

Alum as $Al_2(SO_4)_3 \cdot 18H_2O$

Ferric chloride as $FeCl_3 \cdot 6H_2O$

Doses in mg/l

The results show only 10-15 percent removal of COD. The values are about the same as that found in the chemical treatment studies of leachate from Grønmo. The results seem to indicate that lime gave slightly better COD removals than alum and ferric chloride.

With the exception of iron and zinc the concentrations of heavy metals were below 0.1 mg/l. Therefore only the removal efficiencies of iron and zinc were studied. The removal efficiencies of iron were relatively poor when alum and ferric chloride at low pH were used. This was probably caused by the increased solubility of metal hydroxides at low pH. Chemical precipitation at high pH gave high removal efficiencies of iron. The results are somewhat different from those found in the treatment of leachate from Grønmo. In that study the removal efficiencies of iron were also relatively good by precipitation at low pH values.

Alum, ferric chloride and lime all gave relatively high removal efficiencies for zinc. However, lime precipitation at high pH gave slightly better removals than alum and ferric chloride.

b. Chemical Treatment of Biologically Treated Leachate. Chemical treatment of biologically treated leachate was studied in two test series. The results from these test series are given in table 53 and 54.

Both the test series showed TOC removals of about 10-20 percent. The average values showed no significant difference in the removal efficiencies between the different chemicals and dosages. The organic removal efficiencies based on TOC or COD was about the same.

With the exception of iron the concentrations of the heavy metals in the biologically treated leachate were low. For Cu, Cr, Cd, Pb and Ni the concentrations were lower than 0.1 mg/l. The removal efficiencies for these

Table 53. Chemical treatment of biologically treated leachate, test series no 1

Precipitant	pH	TOC mg/l	TOC-red %	Fe mg/l	Zn mg/l
Biologically treated leachate		70.0		5.60	0.36
Alum 150		55.0	21.0	0.3	<0.1
" 250		65.0	7.1	0.5	0.16
" 400		62.5	10.7	0.5	<0.1
" 150	6.0	57.5	17.8	0.2	0.1
" 250	6.0	57.5	17.8	0.2	<0.1
Alum 400	6.0	60.0	14.2	0.7	0.3
Ferric chloride 150		70.0	0	0.5	0.2
" " 250		70.0	0	0.7	0.2
" " 400		65.0	7.1	0.7	0.4
" " 150	9.0	72.5	0	0.3	<0.1
" " 250	9.0	67.5	3.5	0.3	<0.1
Ferric chloride 400	9.0	60.0	14.2	0.2	<0.1
Lime	9.0	62.5	10.7	0.7	0.2
"	10.0	72.5	0	0.4	<0.1
"	11.0	65	7.1	<0.1	<0.1
Lime	12.0	57.5	17.8	<0.1	<0.1

Alum as $Al_2(SO_4)_3 \cdot 18H_2O$

Ferric chloride as $FeCl_3 \cdot 6H_2O$

Doses in mg/l

Table 54. Chemical treatment of biologically treated leachate, test series no 2

Precipitant	pH	COD mg/l	COD red %	TOC mg/l	TOC red %	Colour mg Pt/l	Turb JTU	Fe mg/l
Raw leachate		168		50.0		367	59	4.6
Alum 150	6.0	159	5.3	42.5	15.0	61	4	0.1
" 250	6.0	126	25.0	37.5	25.0	50	4	0.1
Alum 400	6.0	124	26.0	35.0	30.0	50	5	0.2
Ferric chloride 150	9.0	153	8.9	45.0	10.0	105	12	0.3
" " 250	"	137	18.4	42.5	15.0	121	12	0.6
Ferric chloride 400	9.0	135	19.6	45.0	10.0	61	5	0.4
Lime	9.0	113	3.0	52.5	0	216	38	0.8
"	10.0	147	12.5	47.5	5.0	256	53	0.6
"	11.0	135	19.6	45.0	10.0	212	29	0.2
Lime	12.0	104	38.0	35.0	30.0	61	5	<0.1

metals were therefore not studied. In one of the test series the concentrations of zinc were also below 0.1 mg/l.

The removal efficiency for iron was good in both test series. Precipitation with lime at high pH gave the best rsults. Thus in the precipitation at pH 12 the concentrations of iron in the effluent was below 0.1 mg/l. The reductions of zinc were also relatively good.

5. Activated Carbon Treatment

Treatment by activated carbon was studied on chemically treated leachate and chemically plus biologically treated leachate. The objectives and procedures for these studies were the same as described for the activated carbon treatment of leachate from Grønmo.

The adsorption isotherms for the chemically precipitated leachate and for the biologically treated and chemically precipitated leachate are given in tables 132 and 134 Appendix D. The adsorption isotherm data are presented on a linear plot in figures 139 and 140.

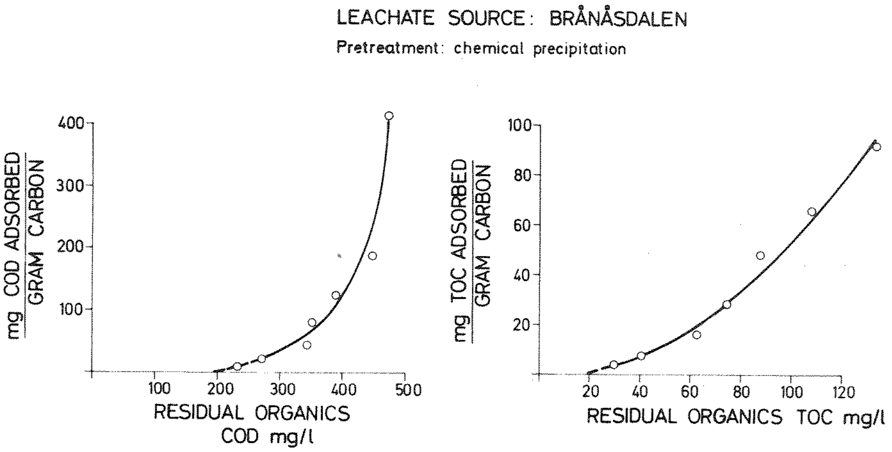
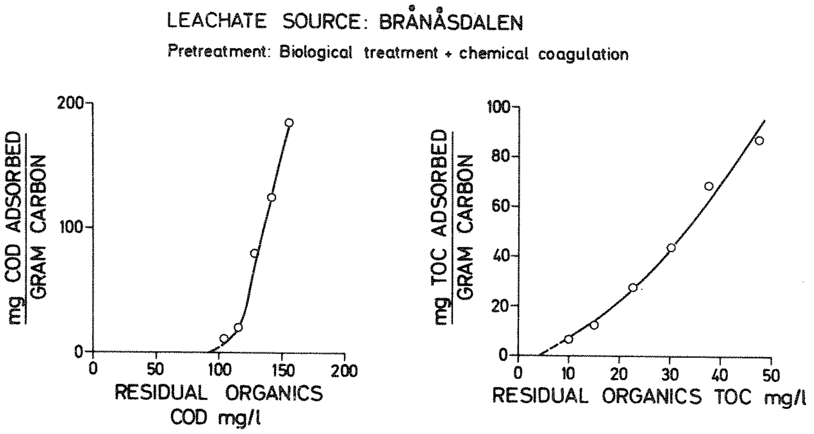


Figure 139. Organics adsorbed per gram of carbon vs. residual organics, chemical precipitated.



LEACHATE SOURCE: BRÅNÅSDALEN
Pretreatment: Biological treatment + chemical coagulation

Figure 140. Organics adsorbed per gram of carbon vs. residual organics, biological plus chemical precipitation.

Figures 139 and 140 show that high fractions of organics cannot be removed by activated carbon treatment. At very high carbon dosages the residual organics found from the figures are summarized in table 55.

Table 55. COD and TOC values before and after carbon adsorption.

Type of pretreatment	Organics before carbon adsorption		Refractory organics after carbon adsorption (M= ∞)	
	TOC mg/l	COD mg/l	TOC mg/l	COD mg/l
Chemical precipitation	160	594	20	200
Biological treatment + chemical precipitation	65	192	5	90

Table 55 shows relatively high removals of organics in the activated carbon treatment. However, the residual organics are relatively high especially for the carbon treated leachate with pretreatment consisting of chemical precipitation only. The high ratios of COD to TOC in the treated leachate are about the same as those found at corresponding treatment of leachate from Grønmo and Yggeseth.

In figures 141 and 142 the adsorption isotherm data are plotted on a log-log scale. The maximum amounts of organics adsorbed per unit weight of carbon for the leachate with pretreatment consisting of chemical precipitation were 800 mg COD/gram carbon or 140 mg TOC/gram of carbon. The corresponding numbers for leachate after biological plus chemical treatment were 600 mg COD/gram of carbon and 165 mg TOC/gram of carbon. These values are about the same as those found for the leachate from Grønmo. The values above are slightly higher than those normally found in carbon treatment of domestic wastewater.

6. Biodisc. (Test run no XIII)

The objective of this treatment was to investigate the feasability of treating leachate from Brånåsdalen with a biodisc. This test run was operated in parallel with test run no XI. Therefore a comparison of the performance of the activated sludge plants and the biodisc could be made.

The organic loading applied was 1.8 g COD/m^2 day. This number is only about one fifth of the organic loadings normally applied in treatment of domestic wastewater. Prior to this test run the biodisc had been treated leachate from Brånåsdalen for about one month. This was done to build up attached growth on the discs.

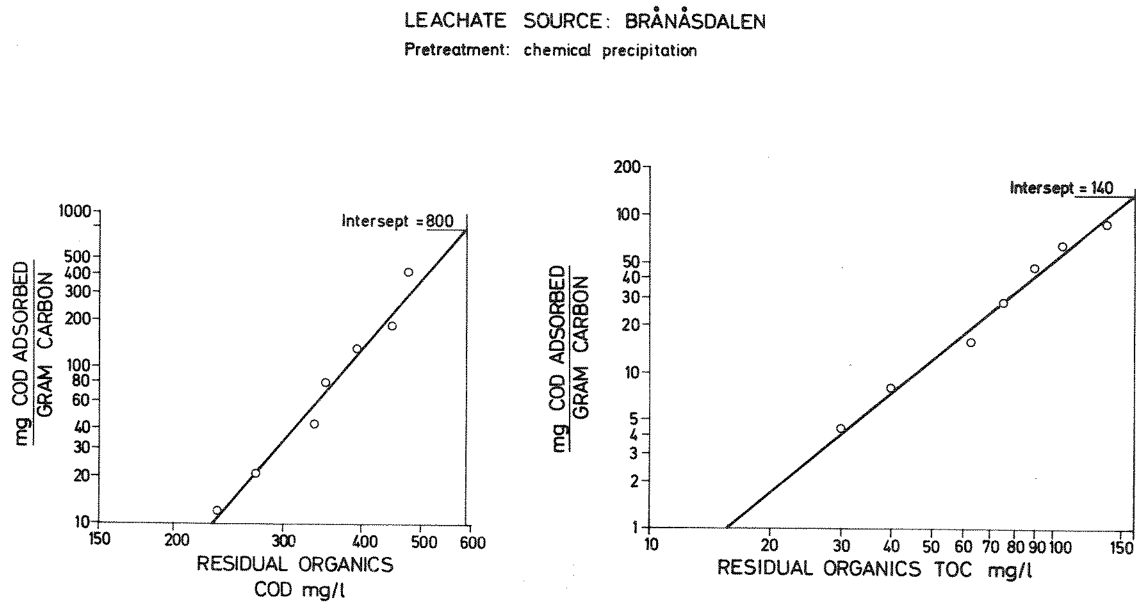


Figure 141. Organics adsorbed per gram of carbon vs. residual organics, chemically precipitated, log scale.

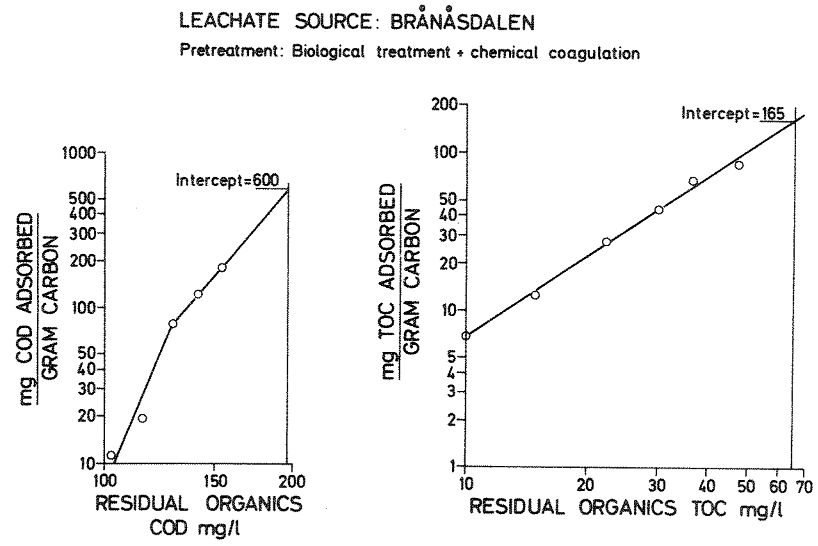


Figure 142. Organics adsorbed per gram of carbon vs. residual organics, biologically plus chemically precipitated, log scale.

The results from this test run are given in tables 127 and 128 Appendix B. The most interesting results are shown in figure 143.

The average COD removal efficiency during the test period was 47.1 percent. The activated sludge plant operating at an organic loading of 0.16 kg COD/kg MLVSS day and the same temperature gave a COD removal efficiency of 59.9 percent. Thus on the average the activated sludge process gave 12.8 percent higher COD removals than the biodisc.

The results shows that no nitrification took place. During the same period the average degree of nitrification in the activated sludge plant was 74 percent.

Microscopic examinations of the attached growth were performed on samples from the discs at the inlet and outlet side. Some micrographs from this examination are shown in figures 116 to 118, page 235.

The sample from the disc at the inlet showed large deposits of iron. The sample contained relatively many nematodes and flagellates. No protozoa were observed. The sampled had a high content of free swimming bacteria. Filamentous bacteria were also present but in smaller numbers.

The sample from the disc at the outlet, or from the forth stage, showed that nematodes and protozoa were present but in smaller numbers than in the sample from the inlet side. This sample also contained a high number of free swimming bacteria. The sample also had a high content of iron deposits.

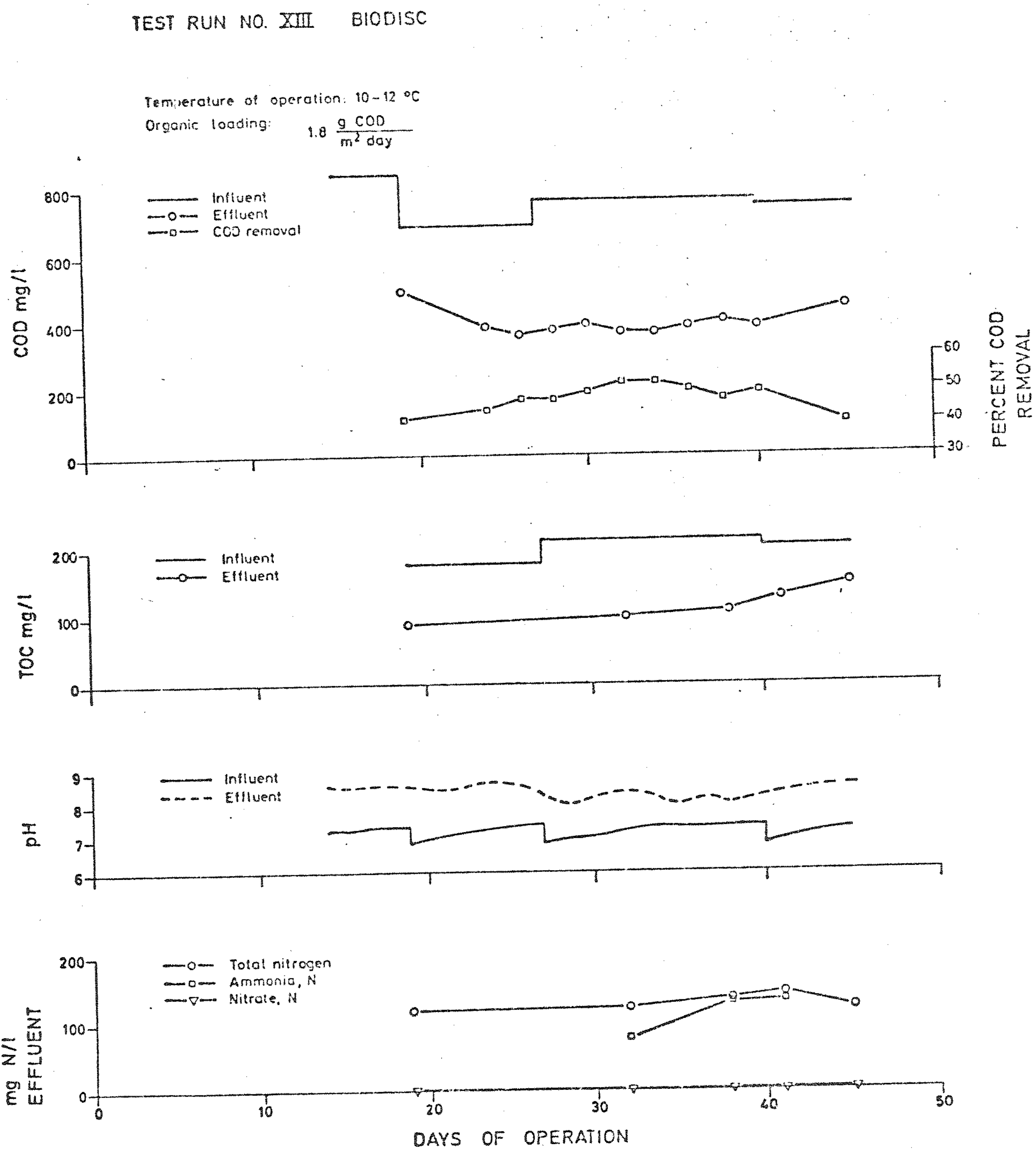


Figure 143. Experimental results, biodisc.

7. Conclusions

The results of the treatment studies showed that leachate from Brånåsdalen sanitary landfill could be treated biologically. Both the activated sludge and the biodisc process was investigated. Of these the activated sludge process gave the best results.

The activated sludge studies showed that the COD effluent values were nearly independent of the COD influent values as long as the organic loading was constant. Therefore the COD removal efficiencies could be considerably higher in the test series where the raw leachate had high concentrations of organics. For instance in one of the test runs the raw leachate had an average COD value of 1260 mg/l. At an organic loading of 0.14 kg COD/kg MLVSS day the average COD removal efficiency of 83 percent was obtained. In a later test run where the raw leachate had a COD value of 731 mg/l the obtained COD removal at the corresponding organic loading as mentioned above was 60 percent. The results showed that the COD removal efficiencies were relatively constant up to organic loadings of about 0.3 kg COD/kg MLVSS day. At higher loadings the efficiencies started to fall sharply.

The concentration of nitrogen compounds in the leachate was high. To obtain high BOD removals it is therefore necessary to obtain high degrees of nitrification. The results showed that the maximum obtained degree of nitrification was about 80 percent at an organic loading of about 0.3 kg COD/kg MLVSS day and lower. At low organic loadings the removal of total nitrogen was about 30 percent.

The performance of the activated sludge process was very sensitive to low temperatures. For instance at organic loadings of about 0.17 kg COD/kg MLVSS day the COD removal efficiencies were 42 and 65 percent at temperatures of 5 and 18 °C respectively. At these temperatures the degree of nitrification were 2 and 95 percent respectively.

Addition of zinc to the activated sludge process operating at organic loadings of about 0.15 kg COD/kg MLVSS day did not seem to have adverse effects at zinc concentrations 10 and 25 mg/l. At zinc concentrations 50 mg/l the COD removal efficiencies were reduced from 55 to 44 percent. The adverse effects were higher on the nitrification process. At zinc concentrations of 50 mg/l the degree of nitrification was reduced from 84 to 30 percent.

The toxicity of copper to the activated sludge process was higher than for zinc. At copper concentrations of 25 mg/l the COD removal efficiencies were reduced from 54 to 30 percent.

The toxicity of zinc, copper, chromium, cadmium, lead and nickel was studied by measuring oxygen uptake rates. These studies showed that copper had the highest toxic effect. Next to copper, lead and nickel had the highest effects.

Chemical treatment of raw and biologically treated leachate proved to be of little value. COD removal efficiencies in the range of 10-15 percent was obtained. Precipitation at high pH values gave high removal efficiencies of iron.

Activated carbon treatment of precipitated leachate and precipitated plus biologically treated leachate gave relatively high organic removal efficiencies. However, the residual organics in the leachate treated by biological treatment, precipitation and carbon adsorption had considerably lower values than corresponding leachate treated by chemical precipitation and carbon adsorption.

The treatment of raw leachate by the biodisc gave lower treatment performance than the activated sludge process. Thus at organic loadings of 1.8 g COD/m^2 day and 0.16 kg COD/kg MLVSS day the COD removals were 47 and 60 percent for the biodisc and the activated sludge process respectively. During the same period no nitrification was taking place when using the biodisc while the corresponding number for the activated sludge process was 74 percent.

H. ADDITIONS OF LEACHATE TO MUNICIPAL PRIMARY CHEMICAL TREATMENT PROCESSES

In water pollution control the eutrophication caused by phosphorus enrichment is a major problem to be solved. In Norway the usual method to reduce the phosphorus in domestic wastewater is chemical treatment of primary treated wastewater. Jar tests were used to investigate whether leachates from sanitary landfills would influence the above mentioned precipitation processes when leachate was added to domestic wastewater.

Leachate was added to domestic wastewater in different doses, and precipitation with alum and lime was studied. The composition of the domestic wastewater and the three leachate sources are given in table 56.

Table 56. Composition of domestic wastewater and leachates

Parameter		Domestic wastewater	Landfill Grønmo	 Brånåsdalen	 Yggeseth
COD	mg O/l	212	490	1550	9425
TOC	mg C/l	40		300	1700
Total P	mg P/l	3.4	0.5	0.7	9.0
Orto P	mg P/l	1.2	0.02	0.04	1.0
Fe	mg Fe/l	0.9	95	85	234

Leachates were added in different volume percentages to the presettled wastewater. The standard jar tests procedure described on page   was used. Precipitation with alum at concentrations 175 mg/l at pH 6.0 and precipitation with lime at pH 11.3 were studied. For pH adjustment during alum precipitation hydrochloric acid was used. The results are given in table 135, Appendix E. The most important results are shown in figures 144 to 149.

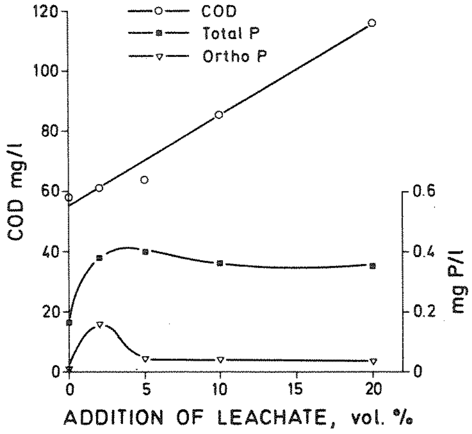


Figure 144. Precipitation with alum, domestic wastewater + leachate from Grønmo.

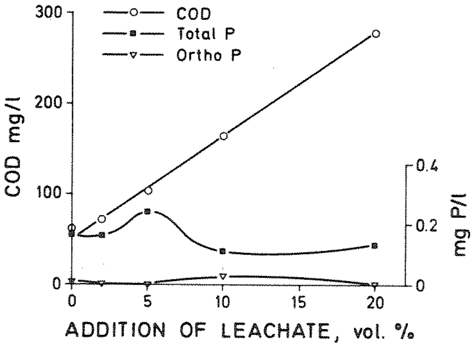


Figure 145. Precipitation with alum, domestic wastewater + leachate from Brånåsdalen.

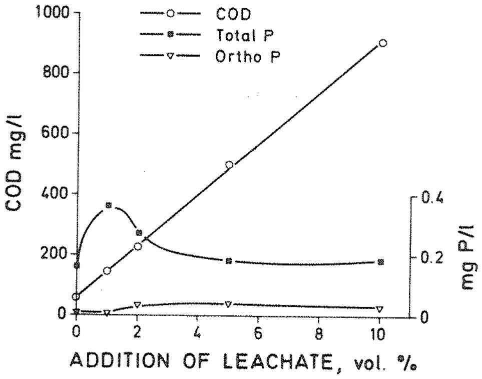


Figure 146. Precipitation with alum, domestic wastewater + leachate from Yggeseth.

As can be seen from figure 144 addition of leachate from Grønmo showed some adverse effects on the alum precipitation of phosphorus. However, the negative effects caused by the leachate additions were not severe. Phosphorus concentration below 0.4 mg/l could be maintained at all the leachate additions investigated.

For the five percent leachate addition from Branasdalen figure 145 shows a slightly negative effect on the phosphorus precipitation. However, at the other additions investigated, the leachate caused improved phosphorus removal. This improvement could probably be explained by the relatively high iron content in the leachate.

The leachate additions from Yggeseth shown in figure 146 gave a slight negative effect at one and two percent additions. At all additions the concentrations of total phosphorus were below 0.4 mg/l.

The phosphorus precipitation with lime at pH 11.3 gave much lower phosphorus removal than precipitation with alum. The concentration of total phosphorus of 3.4 mg P/l in the domestic wastewater was reduced to a value of 1.7 mg P/l. The reason for this low removal efficiency may be that the pH value used may be below the optimum value for this wastewater.

Figures 147 and 149 show improved phosphorus precipitation with increasing additions of leachates. With the exception of the two lowest additions of leachate, figure 148 also shows improved phosphorus removals with increased leachate additions. The improvements may be caused by increased lime doses with increasing leachate additions to obtain the same pH. To illustrate this a sample containing domestic wastewater received the same amount of lime as the sample with 20 percent leachate additions from Grønmo. When the pH in the sample containing leachate

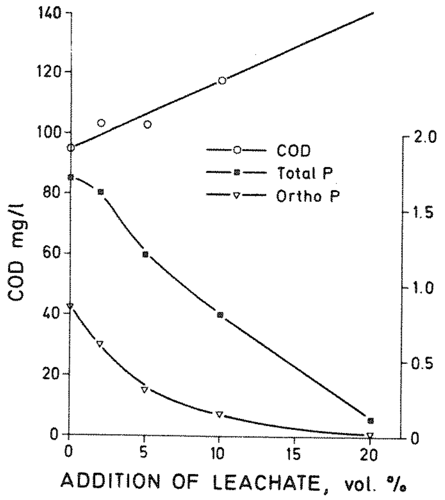


Figure 147. Precipitation with lime, domestic wastewater + leachate from Grønmo

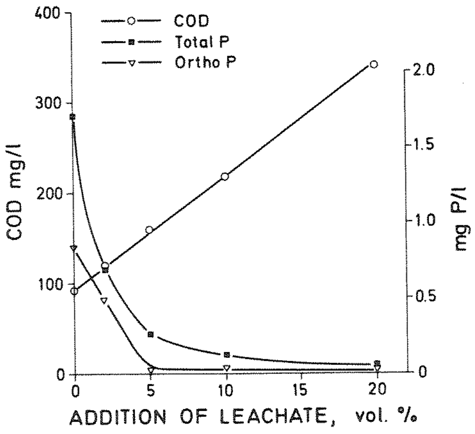


Figure 148. Precipitation with lime, domestic wastewater + leachate from Branasdalen

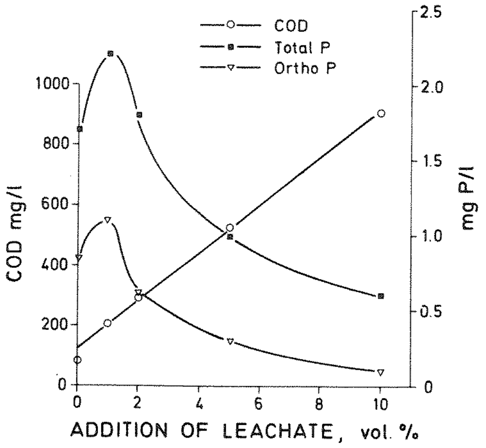


Figure 149. Precipitation with lime, domestic wastewater + Leachate from Yggeseth

reached a pH of 11.3 the pH in the sample without leachate had reached a value of 12.3. Another factor contributing to the improved phosphorus removals with increasing leachate additions may be increased controls of magnesium. At the highest additions this contribution was about 10 mg Mg/l.

Alum and lime precipitation gave COD removals of the wastewater without leachate additions of 72.6 and 59.9 percent respectively. The figures all show a linear relation between the effluent COD values and the addition of leachates. This should indicate that only a certain fraction of the organics in the leachate are removed in the precipitation processes. Assuming this some interesting calculations can be done to find out if separate precipitation of the leachates or if a combined treatment together with domestic wastewater give the best overall removals of organics. For example, lime precipitation of domestic wastewater added 20 volume percent leachates from Branasdalen the removal, x, of organics in the leachate can be calculated as follows:

$$(1 - x) \cdot 0.2 \cdot 1550 + (1 - 0.599) \cdot 0.8 \cdot 212 = 345$$

where 1550 = COD in leachate

212 = COD in domestic wastewater

345 = obtained COD value taken from figure 145.

The above equation gives x = 0.122 or 12.2 percent. By doing the same for the other leachate sources the values in table 57 appear

Table 57. COD removal efficiencies of leachate

Precipitant	Leachate source Grønmo	 Brånåsdalen	 Yggeseth
Alum	28.9	18.7	8.4
Lime	26.5	12.2	10.7

The COD removal efficiencies given in table 57 for the leachate source from Grønmo are slightly better than the COD removal efficienices obtained when the leachate was precipitated separately with the corresponding precipitants and doses (see page 184). For the leachate from Branasdalen the COD removal efficiencies were about the same as the results found in the separate treatment studies. Therefore the overall removals of organics including both the leachate and the domestic wastewater are about the same as if the leachate and the domestic wastewater are precipitated separately.

The conclusions of this study are that the leachate additions to primary chemical treatment processes do not significantly disturb the phosphorus removals when alum is used as precipitant. When lime was used the phosphorus removals were improved with increasing leachate additions. This was probably caused by increasing lime doses with increasing leachate additions and contribution of magnesium from the leachates.

Nearly all the organics in the leachates are in dissolved form and therefore not removed in precipitation processes. The results also show decreasing efficiencies of organic removal with increasing additions of leachates.

CHAPTER VIII

OVERALL SUMMARY AND DESIGN RECOMMENDATIONS

The results of this research provide valuable information on the design of treatment systems for leachates from sanitary landfills. Biological treatabilities of high strength as well as low strength leachates have been investigated. Both anaerobic and aerobic treatment systems were used to study plant operation under various loading and temperature conditions as well as to note toxicity effects for metals such as zinc and copper. Physical-chemical treatment of leachates from three landfills has also been investigated. These studies were investigated individually and in combination with biological treatment.

The results from the biological treatment studies have illustrated large differences in the treatabilities of leachates from different landfills. Investigations of different aerobic treatment systems applied to the leachates with low treatabilities have also shown large differences in the feasibilities of the different treatment systems. The evaluation of design criteria for leachate treatment is therefore difficult since leachate constituents vary widely in concentrations from landfill to landfill and they vary with time. Therefore generally no design recommendations can be given for treatment of leachate. However, the results of this research have illustrated differences and similarities amongst the compositions and the treatabilities of leachates from different landfills. The research provides insight into process mechanisms for design criteria and selection of the best overall treatment systems.

On the basis of a required quality of treated leachate the best combination of unit processes is to be developed to provide the necessary treatment. In the following a short discussion will be given to illustrate feasible treatment approaches and where possible provide design criteria for the different treatment facilities.

1. Biological Treatment

Leachates from sanitary landfills normally have very high concentrations of dissolved organics and reduced nitrogen compounds. Therefore anaerobic or aerobic treatment systems would normally be the most important treatment units. Whether anaerobic or aerobic treatment should be applied depends mainly on the concentrations of organics in the leachates. For leachates with very high concentrations of organics the sludge production will be so high and the sludge handling so expensive that anaerobic treatment may be more favorable.

a. Anaerobic Treatment. Anaerobic treatment of leachate was studied in three separate test runs at different organic loadings and temperatures. Recirculation of the effluent for better utilization of the filter was also studied. The COD concentrations of the raw leachate in the three test runs were 3650, 9100 and 38800 mg/l respectively. For the two latter test runs the results showed that the anaerobic filters could treat the leachates with COD removal efficiencies higher than 95 percent as long as the organic loadings were less than about 0.7 kg COD/m^3 day. In the first test run where the COD of the influent was about 3650 mg/l the filters were somewhat overloaded. Thus at an organic loading of about 1.2 kg COD/m^3 day gave COD removals of about 50 percent. The results also showed that filters operating at organic loadings of 0.4 kg COD/m^3 day at 11°C gave no

COD removals. Therefore in the treatment of leachate the anaerobic treatment processes are probably limited to temperatures above 20°C. At lower temperatures the anaerobic reaction rates are so slow that the use of these processes is not economical. The studies also showed that recirculation of the effluent to obtain better utilization of the filter depth did not improve the treatment performance.

In practice the use of anaerobic filters is probably limited to treatment of high strength leachates with BOD concentrations higher than about 10000 mg/l. In designing anaerobic filters for treatment of leachate the variations in the organic concentrations with time should be kept in mind. The filters should probably be designed for an organic loading of about 0.5 kg COD/m^3 day. Recommendations for starting the filter include the use of anaerobic digester sludge as seed and the use of a relatively low organic landing in the initial operations phase. The filters must be provided with equipment for heating the leachate at temperatures of at least 20°C.

Normally the sulfide concentrations in high strength leachates are sufficiently high to prevent heavy metal toxicities in anaerobic treatment.

The ammonia concentrations in leachate treated by anaerobic filters will normally be very high. Discharge of anaerobically treated leachate to small streams may therefore be harmful to fish, for whom low levels of ammonia is toxic. Because of the small volumes in question and the relatively high temperatures of anaerobically treated leachate the cheapest method for removal of ammonia is probably ammonia stripping. The removal of ammonia may also be necessary where high BOD removals are required.

b. Aerobic Treatment. Leachates from four of the landfills were treated aerobically. In the treatment studies the following treatment methods were investigated:

Kent Highland: activated sludge

Grønmo: activated sludge, biodisc, trickling filter and aerated lagoons

Branasdalen: activated sludge, biodisc

Yggeseth: activated sludge

The results showed a considerably difference in the treatabilities of the different leachate sources as well as between the different treatment systems. A first orientation of the treatabilities can be obtained by calculating the ratio of carbonaceous BOD to TOC or carbonaceous BOD to COD. A BOD to TOC ratio lower than about 1.5 indicates low treatability and a ratio higher than about 2 indicates relatively good treatabilities.

The activated sludge experiments showed a relatively sharp decrease in the organic removal efficiencies expressed as COD at organic loadings higher than about 0.4 kg COD/kg MLVSS day. This corresponded to organic loadings based on carbonaceous BOD of about 0.20, 0.10, 0.15 and 0.20 kg BOD/kg MLVSS day for the landfills; Kent Highland, Grønmo, Branasdalen and Yggeseth respectively. The COD removals showed a definite correlation between the influent COD values and the obtained COD removals. For the individual leachate sources the effluent COD values at organic loadings lower than about 0.3 kg COD/kg MLVSS day seemed to be nearly independent of the influent COD values. This means that the organics could be removed to a certain threshold value. These threshold COD values were in the range of about 150 to 300 mg/l with the highest values corresponding to the low strength leachates. Because of this phenomenon the COD removals at low loadings varied for the different leachate sources from 35 to 98 percent.

The leachate sources all had very high concentrations of reduced nitrogen compounds. For the low strength leachates the oxidation of ammonia contributed to a higher BOD fraction than biooxidation of the organics. To reduce the effluent BOD values it is therefore necessary to apply sufficiently low organic loadings to obtain a high degree of nitrification. The results showed that at organic loadings lower than about 0.3 kg COD/kg MLVSS day the oxidation of the ammonia was very efficient. Thus, at this loading the BOD removal efficiencies were higher than 90 percent in the activated sludge treatment of leachate from all four landfills.

The results also showed that the treatment performance was nearly independent of the organic loading as long as this was kept below 0.3 kg COD/kg MLVSS day. Therefore activated sludge plants for treatment of leachate should not be designed for higher organic loadings than about 0.3 kg COD/kg MLVSS day.

The results of treatment of leachate from Branasdalen by biodisc and the leachate from Grønmo by biodisc and trickling filter all operated at low organic loading gave lower organic removals than by the activated sludge process. The degree of nitrification obtained by these processes was also very low compared with those from the low loaded activated sludge processes. Therefore the use of the biodisc and trickling filter in treatment of leachate is not recommended.

The aerated lagoons treating low strength leachate gave, at organic loading 11 g COD/m^3 day, a slightly lower organic removal efficiency than the low loaded activated sludge plants. However, at the above mentioned loadings the degree of nitrification seemed to be about the same for the lagoon and the activated sludge process. Because aerated lagoons are resistant to shock loadings and require little operation and maintenance this treatment system should be well suited for treatment of leachate.

2. Physical-Chemical Treatment.

Physical-chemical treatment, consisting of chemical precipitation and carbon adsorption, was investigated both separately and in combination with biological treatment.

a. Chemical Precipitation. Chemical precipitation prior to biological treatment did not improve the organic removal efficiencies and the degree of nitrification in the biological treatment units. Chemical precipitation of raw leachate by the precipitants alum, ferric chloride and lime gave COD removals of about 10 percent with a slightly better removal with lime. The removals of heavy metals were most efficient by lime precipitation at pH 10 and 11. Under such alkaline conditions the metals were removed to residual concentrations lower than 0.1 mg/l. Precipitation with alum and ferric chloride at low pH showed low metal removals.

Chemical precipitation of biologically treated leachate gave about the same removal efficiencies for organics and metals as for precipitation of raw leachate. The best over all results with regard to removals of organics, heavy metals, color and turbidity was obtained by biological treatment following chemical precipitation at pH 10 to 11. Whether the chemical precipitation unit is necessary or not depends mainly on the accepted metal concentrations in the effluent.

In the treatment of the low strength leachates by biological and chemical precipitation the residual organics were so high that treatment by activated carbon could be necessary.

b. Activated Carbon Treatment. Activated carbon treatment was studied in combination with chemical precipitation and with biological treatment prior to chemical precipitation.

For biological treatment followed by chemical precipitation with alum and carbon adsorption the organics could be removed to a threshold value of about 90 mg COD/l. This value was found for all the three leachate types that were investigated (Grønmo, Branasdalen and Yggeseth).

Because of low adsorption capacities for low molecular organics, organic acids and dissolved carbohydrates the removal of organics in leachate treatment by chemical precipitation following activated carbon showed considerably higher COD threshold values than the treatment combination of biological treatment, chemical precipitation and activated carbon adsorption. The activated carbon used in these treatment studies showed an adsorption capacity in the treatment of the low strength leachates of about 600 mg COD/g carbon. The same value was found for both treatment combinations. For the treatment of the high strength leachate the corresponding number was as low as 150 mg COD/g carbon.

The results from the activated carbon treatment studies indicate that activated carbon treatment should be applied in combination with biological treatment. Chemical precipitation and carbon adsorption alone require large carbon doses and give for low strength leachates only slightly better organic removals than the activated sludge process. Because of high contents of organic acids in high strength leachates chemical precipitation following activated carbon adsorption will give lower organic removals than the activated sludge process alone.

CHAPTER IX

CONCLUSIONS

The following conclusions can be made from the results of this research.

1. The composition of the eight leachate sources investigated showed a significant range of values.

2. In the high strength leachates organic acids contributed up to 30 percent of the total organics.

3. High concentrations of nitrogen compounds mainly as ammonia prevailed in all the leachate sources.

4. Of the heavy metals iron was found in high concentrations in all the leachate sources. Next to iron, zinc had the highest concentrations. For Cr, Ni, Cu, Cd and Pb the concentrations were low.

5. Leachates that were high in organics could successfully be treated by anaerobic filters. At an organic loading of 0.7 kg COD/m^3 day or lower the filters performed a COD removal higher than 95 percent. For the leachates highest in COD concentrations the COD was removed to values of about 500 mg/l (150 mg BOD$_5$/l).

6. No organic removal was measured in filters operated at temperatures 11°C and organic loading 0.4 kg COD/m^3 day. The lowest feasible temperature for anaerobic treatment seemed to be 20°C.

7. Good correlation existed between the gas production and the COD removals. A gas production of 0.5 ml per mg COD removed was found. This number is close to the theoretical value calculated from the ultimate oxygen demand of the methane gas produced. Since the methane production is so well correlated to the COD removal the methane production can be used as a measure of the overall filter performance.

8. The presence of sulfides resulted in formation of metal sulfides which are extremely insoluble. Therefore no heavy metal toxicity was observed in the anaerobic filter processes. Analyses of the sludge showed that the heavy metals were accumulated in the sludge as precipitates.

9. Excess sludge should be withdrawn from the anaerobic filters. Otherwise the filters will clog or the sludge will be discharged with the effluent. The interval between each required sludge withdrawal is long in the order of months.

10. Because of high ammonia content in the anaerobically treated leachate subsequent nitrogen removal may be necessary. Relatively high temperatures of the treated leachate effluent and the rather small volumes may favor ammonia stripping.

11. Respiration tests performed on the leachate from landfills in Norway showed a significant difference in the treatabilities and biodegradabilities.

12. The results of the respiration tests to study the treatability and biodegradability of the different leachates coincided very well with the results from the treatment studies obtained by the activated sludge process.

13. A good measure of treatability may also be obtained by comparing the ratios of the carbonaceous BOD to TOC with that in domestic wastewater. High values indicates good treatability.

14. Of the aerobic treatment systems examined the activated sludge process gave the most promising results.

15. The results of the treatment studies showed large differences in the organic removal efficiencies of the leachates from the different landfills. The removal efficiencies increased significantly with increasing concentrations of organics in the influent. At low loadings the COD

removal efficiencies increased from about 35 to 98 percent for leachates with COD concentrations of about 400 and 9400 mg/l respectively. However, due to very high ratios of the concentrations of ammonia to COD in the low strength leachates the nitrification at sufficient low loadings caused BOD removal efficiencies higher than 90 percent for all the leachate sources.

16. In the treatment of leachates from all landfills the activated sludge process showed a relatively sharp decrease in the organic removal efficiencies at organic loadings higher than about 0.4 kg COD/kg MLVSS day. At loadings lower than about 0.3 kg COD/kg MLVSS day the effluent COD values were relatively insensitive to changes in organic loadings.

17. At sufficient low organic loadings the degree of nitrification in the activated sludge process varied from about 70 to nearly 100 percent. The highest values were obtained in treatment of the high strength leachates. In the treatment of leachate from all landfills the degree of nitrification was nearly constant at organic loadings lower than about 0.3 kg COD/kg MLVSS day.

18. For the leachate with highest concentrations of organics, denitrification in the settling chamber caused nitrogen removal higher than 90 percent. The organic loading was below 0.2 kg COD/kg MLVSS day. For the other leachate sources investigated the nitrogen removal was low.

19. No difference in the treatment efficiencies was found in treating chemically precipitated or raw leachate.

20. In spite of very low phosphorus concentrations in the raw leachate phosphorus was not found to limit biodegradation.

21. Treatment of the leachates low in organics resulted in poor flocculation of the activated sludge. This was probably caused by high iron contents in the leachates. For the leachate with lowest concentrations

of organics the loss of sludge was so large that no sludge had to be withdrawn as excess sludge.

22. The activated sludge did not show bulky character in any of the treatment studies.

23. The effect of temperature on the performance of the activated sludge process showed a significant reduction on the COD removals and degree of nitrification at temperatures below 18°C. At organic loadings of about 0.18 kg COD/kg MLVSS day the COD removals were reduced from a value of 65 percent at 18°C to a value of about 42 percent at 5°C. The corresponding degree of nitrification dropped from 98 to 3 percent. A temperature of 25°C slightly improved the treatment performance compared to operation at 18°C. Over a certain temperature range a linear relationship existed between the oxygen uptake rate and the inverse of the absolute temperature. Microscopic examination of the activated sludge in the plants operating at the different temperatures showed large differences in the numbers of higher organisms.

24. Zinc added to the activated sludge units had a slight adverse effect on the COD removals at concentrations of 50 mg/l. However, the degree of nitrification and the oxygen uptake rate were reduced significantly at all the three concentrations 10, 25 and 50 mg/l, investigated. Microscopic examinations showed a decreasing species diversity with increasing zinc concentrations.

25. Copper showed toxic effects at all three concentrations 10, 25 and 50 mg/l, investigated. The removal of COD was only slightly reduced at copper concentrations of 10 mg/l, which copper concentrations of 50 mg/l reduced the COD removals from 54 to 19 percent. The degree of nitrification and the oxygen uptake rates were reduced significantly at all three

copper concentrations.

26. Treatment by aerated lagoons at sufficient detention times provided removal of organics slightly lower than corresponding activated sludge treatment. The highest degree of nitrification that was achieved in the two treatment systems appeared to be the same.

27. Treatment by rotating biodisc and trickling filter was found to be inferior in terms of organic removal and degree of nitrification.

28. Chemical precipitation of raw leachates by the precipitants alum, ferric chloride and lime all gave COD removals of about 10 percent. Best removals of heavy metals were obtained at pH around 11.0. Precipitation with alum and ferric chloride at low pH both gave poor heavy metal removals. Best overall results by a combination of chemical precipitation and biological treatment was obtained by chemical treatment subsequent to biological process.

29. Activated carbon treatment provided high organic removal efficiencies both for treatment of precipitated leachate and for treatment of biological subsequent precipitated leachate. However the residual organics in the leachate treated by biological treatment, chemical precipitation and carbon adsorption had considerably lower values than had the corresponding leachate treated by chemical precipitation and carbon adsorption. Leachates from the three landfills investigated showed in all cases that the COD could be removed to threshold value of about 90 mg/l.

CHAPTER X

RECOMMENDATIONS FOR FUTURE STUDY

The following recommendations for future studies are made:

1. Leachates from sanitary landfills have normally very high contents of nitrogen compounds. Therefore physical, chemical as well as biological treatment processes for nitrogen removals applied on leachates should be investigated.

2. Excess sludge from physical, chamical or biological treatment of leachates may have high concentrations of heavy metals. The release of heavy metals during different storage conditions of the sludge should be studied.

3. Leachate pumping back to the landfill and treatment of excess leachate by the anaerobic filter process should be studied. This would probably speed up the decomposition rates in the fill and give a high strength leachate which could be treated inexpensively by an anaerobic filters.

4. Studies should be made to evaluate the feasibilities of treating leachates by infiltration through different types of soils. The determination of the time for saturation of the ion complexes in different depths will indicate the capabilities of the soils to treat leachates.

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APPENDIX A

Table 58.

Fill / Parameter	GRØNMO								BRAANÅSDALEN							YGGESETH	TARANRØD	ISI I	ISI II
	16/7	25/7	2/8	8/8	22/8	13/9	26/11	18/12	13/9	18/10	2/11	15/11	3/12	22/1	10/2				
COD mg O/l	490	504	512	554	604	446	535	522	1080	1114	1522	1432	824	688	743	9729	244	214	145
TOC mg C/l	146	140	150	110	150	100	160	150	250	260	380	300	260	180	205	1550	60	80	50
Total N mg N/l	128	119	124	167	130	182	159	155	254	264	284	148	254	288	312	305	24	80	12
NH_4 - N mg N/l						120.2	124	132	225	290	278	137	216	238	304	286	5.0	76	9.3
NO_3 - N mg N/l						0.04	0.16	0.05	0.01			0.02	0.01	1.4	0.7	0.04	0.05	0.04	1.1
Total P mg P/l	0.14	0.70	0.55	0.80	2.4	0.6	0.5	0.6	1.7	1.0	1.0	0.5	0.9	1.0	1.1	10.0	0.5	0.5	0.09
Suspended solids mg/l			190			230		140		280				145					
Volatile suspended solids mg/l			85			70		80		165				105					
Total solids mg/l		3211	2916	3336	3396	2963			2730		3313					5102			
Total volatile solids mg/l				808	708	762			1005		1240					2821			
pH	6.8	6.7	6.7	6.8	6.8	6.7	6.7	6.8	6.8	6.9	6.7	6.7	6.9	6.8		5.8			
Alkalinity mg $CaCO_3$/l	1300	1050	1350	1300	1400	1500	1475		2540	2500	2700	2510		2000		2780	195	980	240
Spec.conductance ηS/cm	5200	4400	2290	4005	4100	3310		1200	3210	3200	3650	2650	4250	3750		4600	395	2200	555
Ca mg Ca/l	182	177	166	168	177	188		189	198	335	439	215	295			440	47.3	200	75.4
Mg mg Mg/l	73	75	61	74	72	66		93	9.6	94	99	62	102			78	6.9	44.5	9.1
Na mg Na/l	450	430	410	480	527	462		520	229	278	297	200	270			260	20.5	150	22
K mg K/l	234	225	204	206	208	200		240	172	214	242	150	218			268	17	99	11
Chloride mg Cl/l	880	800	840	900	840	680		2800	280	320	370	240	340			510	41	440	46
Sulphate mg SO_4/l	15	<2	<2		<2	30		4	10			17	<2			30	5.1	33	22
Fe mg Fe/l	104.0	90.2	71.8	134.6	118.6	67.6	95.0	84.3	78	115	125	101	42.7	60.8	94.8	258	10.1	10.1	6.8
Zn mg Zn/l	0.2	0.48	0.24	0.68	0.54	0.055	0.075	1.46	0.095	0.95	0.20	4.40	5.0	5.40	4.5	2.36	0.12	0.18	0.22
Cr mg Cr/l	<0.1	<0.1	<0.1	<0.1	<0.1	0.023	0.033	<0.1	0.035	0.05	<0.1	<0.1	0.17	0.12	<0.1	<0.1	<0.1	<0.1	<0.1
Ni mg Ni/l	"	"	"	"	"	-	0.040	"	0.020	0.037	"	"	<0.1	<0.1	"	"	"	"	"
Cu mg Cu/l	"	"	"	"	"	0.005	0.006	"	0.011	-	"	"	"	"	"	"	"	"	"
Cd mg Cd/l	"	"	"	"	"	0.0005	0.0003	"	0.0001	0.0009	"	"	"	"	"	"	"	"	"
Pb mg Pb/l	<0.1	<0.1	<0.1	<0.1	<0.1	0.004	0.0005	<0.1	0.009	0.002	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

APPENDIX B

Table 59

LEACHATE SOURCE: KENT HIGHLAND TEST RUN NO 1: ANAEROBIC FILTER, A.F.1

Duration of experiment: August 2-September 2, 1973. Temperature of operation: 25 °C.

	Periode of sampling (Days/Month)	Organic loading $\frac{kg\ COD}{m^3\ day}$	Gas prod. ml/day	pH	Alka-linity mg $CaCO_3$	SS mg/l	VSS mg/l	COD mg/l	COD Filt. mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	11/8-13/8	1.20	320	6.8									15.0				0,01	0.35	<1.0
	13/8-15/8	"	540	6.8				2 350					"				"	"	"
	15/8-17/8	"	650	6.8		235	125	2 600	2 400	2 075			"				"	"	"
	17/8-19/8	"	660	6.8		280	140	2 650	2 550				15.0				0.01	0.35	<1,0
	19/8-21/8	"	640	6.85		260	90												
	21/8-23/8	"	710	6.8		205	40	2 800	2 650										
	23/8-25/8	"	670	6.85		220	115						14.0	1.05	0.17	0.20	0.01	0.43	<1.0
	25/8-27/8	"	740	6.9		250	30	2 450	2 150				"	"	"	"	"	"	"
	27/8-29/8	"	750	6.9		225	55	1 950	1 900				"	"	"	"	"	"	"
	29/8-2/9	1.20	770	7.0		170	30	1 900	1 800	1 500			14.0	1,05	0.17	0.20	0.01	0.43	<1.0
Influent	2/8-9/8			6.3				4 410			4.25		22.0	4.88	0.05		0.01	0.05	<1.0
	9/8-14/8			6.4				3 550			6.25		20.0	4.25	0.22	1.20	0.01	3.15	-
	14/8-23/8			6.3	1 520	320	270	3 620		2 900		76	21.0	4.92	0.42	0.63	0.01	0.53	-
	23/8-27/8			6.4	1 280	170	40	2 910			5.88	56	18.5	5.50	0.45	0.70	0.02	0.36	
	27/8-2/9			6.4		220	90	3 800		2 460			24.5	5.30	0.18	-	0.01	-	-

Table 60

LEACHATE SOURCE: KENT HIGHLAND

TEST RUN NO 1: ANAEROBIC FILTER, A.F. 2, A.F.3

Duration of experiment August 2-September 2 1973. Temperature of operation: 11 °C.

	Period of sampling (Day/Month)	Organic loading $\frac{\text{kg COD}}{\text{m}^3\text{ day}}$	Gas prod. ml/day	pH	SS mg/l	VSS mg/l	COD mg/l	COD Filt. mg/l	BOD mg/l
Effluent A.F.3	11/8-18/8	0.80	0	6.7					
	18/8-21/8	"	"	6.8			3 150		1 920
	21/8-23/8	"	"	6.9	180	80			
	23/8-25/8	"	"	6.7	210	115	3 300	3 200	
	25/8-27/8	"	"	6.7	260	75	3 250	3 100	
	27/8-29/8	"	"	6.7	180	25	3 150	2 900	
	29/8-2/9	0.80	0	6.8	150	35	2 850	2 650	2 133
Effluent A.F.2	11/8-18/8	0.40	0	6.8			2 950		
	18/8-21/8	"	"	6.8			2 700	2 550	2 075
	21/8-23/8	"	"	6.8	170	80			
	23/8-25/8	"	"	6.8	190	120	2 900		
	25/8-27/8	"	"	6.7	205	65	3 100	2 800	
	27/8-29/8	"	"	6.7	185	20	2 950	2 850	
	29/8-2/9	0.40	0	6.7	135	40	2 970	2 800	2 055

Influent see table 59

Table 61

LEACHATE SOURCE: KENT HIGHLAND TEST RUN NO 2: ACTIVATED SLUDGE A.S.1

Influent: Chemically coagulated leachate. Duration of experiment August 2-August 30, 1973. Temperature of operation: 24 °C.

Organic loading: 0.26 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$.

	Date of Sampling (Day Month)	pH	Feed l/day	COD mg/l	COD Filt. mg/l	BOD mg/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Sludge with-drawel l	Sludge with-drawel mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawel mg VSS	Cumu-lative sl.w.d. mg VSS	F mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	9/8	7.6	2.4	114					3 480	2 520	280	0												
	10	7.6	2.4	114			150		4 150	2 240	320	0						13.0	4.90	0.67	0.70	0.01	0.45	-
	11	7.7	2.4	144	72		95		3 800	2 510	370	0						5.0	1.70	0.19	0.60	0.01	0.08	-
	12	1.5	2.4	144	72		95		4 630	2 590	370	0.4	1 852	1 852	1 036	1 036		"	"	"	"	"	"	-
	13	7.8	2.4	70	53		100	55	4 500	2 470	420	0	0	1 852	0	1 036		"	"	"	"	"	"	-
	14	8.1	2.4	70	53		100	55	4 510	2 680	460	0.5	2 255	4 107	1 340	2 376		"	"	"	"	"	"	-
	15	8.0	2.0	69	61		13	9	4 710	2 470	440	0	0	4 107	0	2 376		"	"	"	"	"	"	-
	16	8.0	2.0	69	61		13	9	4 770	2 970	480	0.8	3 816	7 923	2 376	4 752		"	"	"	"	"	"	-
	17	8.1	2.0	86	49		20	15	5 230	2 710	490	0.8	4 184	12 107	2 168	6 920		"	"	"	"	"	"	-
	18	8.2	2.0	86	49		20	15	5 250	2 670	450	0.5	2 625	14 732	1 335	8 255		"	"	"	"	"	"	-
	19	8.1	2.0	54	39		22	17	5 390	2 720	500	0.8	4 312	19 044	2 176	10 431		"	"	"	"	"	"	-
	20	8.1	2.0	54	39		22	17	4 750	2 380	510	0	0	19 044	0	10 431		5.0	1.70	0.19	0.60	0.01	0.08	-
	21	8.15	2.0	97	69		23	12	5 650	2 670	520	0.8	4 520	23 564	2 136	12 567								
	22	8.1	2.0	97	69		23	12	5 660	2 490	500	0	0	23 564	0	12 517								
	23	8.1	2.0	85		8	32	22	6 120	3 180	460	1.3	7 956	31 520	4 134	16 701		6.0	1.25	0.14	0.30	0.01	0.01	-
	24	8.1	2.4	85			32	22	5 410	2 560	470	0	0	31 520	0	16 701		"	"	"	"	"	"	-
	25	8.1	2.4	85	69		51	24	4 520	2 740	500	0	0	31 520	0	16 701		"	"	"	"	"	"	-
	26	8.1	2.4	85	69		51	24	6 400	3 070	485	1.0	6 400	37 920	3 070	19 771		"	"	"	"	"	"	-
	27	8.2	2.4	116	81	10	56	17	4 980	2 790	420	0.7	3 486	41 406	1 953	21 724		"	"	"	"	"	"	-
	28	8.2	2.0	116	81		56	17	5 410	2 690	370	0.4	2 164	43 570	1 076	22 800		"	"	"	"	"	"	-
	29	8.3	2.0	156	92		63	39	5 520	2 680	360	0.6	3 312	46 882	1 608	24 408		"	"	"	"	"	"	-
	30/8	8.3	2.0	156	92		63	39	5 380	2 940	350	0	0					6.0	1.25	0.14	0.30	0.01	0.01	-
Influent	2/8-8/8	5.9		4 210																				
	8/8-14/8	5.8		3 060													5.9	15.0	3.05	0.06	0.30	<0.01	0.83	<1.0
	14/8-23/8	6.1		3 480													3.0	19.5	3.70	0.60	1.20	0.01	-	<1.0
	23/8-27/8	6.2		2 830		2 280											5.0	13.0	2.80	0.19	0.30	0.01	0.25	<1.0
	28/8-2/9	6.1		3 610		3 130											3.6	18.0	2.90	0.09	0	<0.01	-	<1.0
Influent	Mean S.dev. No 15/8-30/8	6.0 0.2 5		3 438 533 5													4.3 1.3 4	16.4 2.9 4	3.1 0.4 4	0.23 0.24 4	0.6 0.5 4	<0.1	0.54	<0.1

Table 62

LEACHATE SOURCE : KENT HIGHLAND TEST RUN NO 2: ACTIVATED SLUDGE, A.S.2

Influent: Chemically coagulated leachate. Duration of experiment: August 2-August 30, 1973. Temperature of operation: 24 °C
Organic loading: 0.37 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$.

	Date of Samling (Day/Month)	pH	Feed l/day	COD mg/l	COD filt. mg/l	BOD mg/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Sludge with-drawal l	Sludge with-drawal mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawal mg VSS	Cumu-lative sl.w.d. mg VSS	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	9/8	7.6	3.2	84					3 960	2 600	300	0											
	10	7.7	3.2	84					4 920	2 660	360	0					7.50	1.45	0.47	1.20	0.01	0.1	1.0
	11	7.5	3.2	150	88		112		4 840	3 180	440	2.0	9 680	9 680	6 360	6 360	3.0	1.75	0.26	0.30	0.03	0.8	<1.0
	12	7.5	3.2	150	88		80		4 810	2 770	360	1.0	4 810	14 490	2 770	9 130	"	"	"	"	"	"	"
	13	7.7	3.2	73	58		90	40	4 430	2 600	390	0.5	2 215	16 705	1 300	10 430	"	"	"	"	"	"	"
	14	8.2	3.2	73	58		90	40	4 810	2 820	380	1.0	4 810	21 515	2 820	13 250	"	"	"	"	"	"	"
	15	8.2	3.2	82	69		16	12	4 320	2 480	370	0	0	21 515	0	13 250	"	"	"	"	"	"	"
	16	8.2	3.2	82	69		16	12	5 020	3 210	430	1.4	7 028	28 543	4 494	17 744	"	"	"	"	"	"	"
	17	8.1	3.2	110	86		24	21	5 680	3 010	430	1.4	7 952	36 495	4 214	21 958	"	"	"	"	"	"	"
	18	8.2	3.2	110	86		24	21	4 780	2 600	400	1.0	4 780	41 275	2 600	24 558	"	"	"	"	"	"	"
	19	8.2	3.2	89	62		20	17	5 660	2 870	390	1.0	5 660	46 935	2 870	27 428	"	"	"	"	"	"	"
	20	8.15	3.2	89	62		20	17	5 630	2 850	400	1.0	5 630	52 565	2 850	30 278	3.0	1.75	0.26	0.30	0.03	0.8	<1.0
	21	8.1	3.2	104	89		23	12	5 920	2 950	450	1.4	8 288	60 853	4 130	34 408							
	22	8.1	3.2	104	89		23	12	5 720	2 830	390	1.1	6 292	67 145	3 113	37 521							
	23	8.2	3.9	170		14	65	62	5 890	3 270	350	1.7	10 013	77 158	5 559	43 080	16.0	1.50	0.28	0.50	0.01	0.1	<1.0
	24	8.2	3.9	170			65	62	5 440	2 830	300	1.0	5 440	82 598	2 830	45 910	"	"	"	"	"	"	
	25	8.1	3.9	170	93		120	75	4 340	2 740	300	0	0	82 598	0	45 910	"	"	"	"	"	"	
	26	8.2	3.9	170	93		120	75	6 680	3 480	320	1.7	11 356	93 954	5 916	51 826	"	"	"	"	"	"	
	27	8.3	3.9	189	93	25	160	45	5 050	2 940	230	1.0	5 050	99 004	2 940	54 766	"	"	"	"	"	"	
	28	8.3	3.9	189	93		160	45	5 670	2 920	250	1.0	5 670	104 674	2 920	57 686	"	"	"	"	"	"	
	29	8.5	3.9	248	88		145	80	5 940	3 080	220	1.5	8 910	113 584	4 620	62 306	"	"	"	"	"	"	
	30/8						145	80	5 800	3 050	230	1.3	7 540	121 124	3 965	66 271	16.0	1.50	0.28	0.50	0.01	0.1	<1.0
	Mean	8.2		142	83		71	40	5 470	2 944	345												
	S.dev.	0.1		62	12		60	28	624	247	80												
	No 15/8 - 30/8	15		7	7		8	8	16	16	16												

Influent see table 61

Table 63

LEACHATE SOURCE : KENT HIGHLAND TEST RUN NO 2. ACTIVATED SLUDGE, A.S.3

Influent: Raw leachate. Duration of experiment: August 2-August 30, 1973. Temperature of operation: 24 °C. Organic loading: 0.40 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$.

	Date of sampling (Day/Month)	pH	Feed	COD	COD Filt.	BOD	SS	VSS	MLSS	MLVSS	SV	Sludge with-drawal	Sludge with-drawal	Cumu-lative sl.w.d.	Sludge with-drawal	Cumu-lative sl.w.d.	P	N	Fe	Zn	Cu	Ni	Cd	Cr	Pb	Alkali-nity
			l	l/day	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ml/l	l	mg SS	mg SS	mg VSS	mg VSS	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	$\frac{\text{mg CaCO}_3}{\text{l}}$
Effluent	9/8	7.5	3.2	118	84		110		4 600	2 960	310	1.5	6 900	6 900	4 440	4 440										
	10	7.6	"	118	84		100		5 280	3 010	360	1.7	8 976	15 876	5 117	9 557			26.0	2.45	1.44	0.40	0.01	0.5	<1.0	
	11	7.5	"	224	92		85		4 520	2 790	320	1.1	4 972	20 848	3 069	12 626			6.5	1.40	0.12	0.60	<0.01	0.2	<1.0	
	12	7.4	"	224	92		85		4 980	2 600	320	0.5	2 490	23 338	1 300	13 926			"	"	"	"	"	"	"	
	13	8.0	"	103	86		95	35	5 310	2 850	340	1.0	5 310	28 648	2 850	16 776			"	"	"	"	"	"	"	
	14	8.3	"	103	86		95	35	5 060	2 830	350	1.0	5 060	33 708	2 830	19 606			"	"	"	"	"	"	"	
	15	8.2	"	131	78		26	21	5 170	2 580	360	0.5	2 585	36 293	1 290	20 896			"	"	"	"	"	"	"	
	16	8.1	"	131	78		26	21	4 650	3 040	370	1.4	6 510	42 803	4 256	25 152			"	"	"	"	"	"	"	
	17	8.2	"	102	82		23	16	5 480	2 760	370	0.5	2 740	45 543	1 380	26 532			"	"	"	"	"	"	"	
	18	8.3	"	102	82		23	16	5 840	3 040	380	1.4	8 176	53 719	4 256	30 788			"	"	"	"	"	"	"	
	19	8.3	"	97	81		29	21	6 210	3 030	350	1.4	8 694	62 413	4 242	35 030			"	"	"	"	"	"	"	
	20	8.3	"	97	81		29	21	5 920	2 800	360	1.0	5 920	68 333	2 800	37 830			6.5	1.40	0.12	0.60	<0.01	0.2	<1.0	
	21	8.3	"	112	93		32	16	6 280	2 880	380	1.4	8 792	77 125	4 032	41 862										
	22	8.2	"	112	93		32	16	5 190	2 520	340	0.0	0	77 125	0	41 862										
	23	8.3	"	150	108		57	50	6 780	3 540	360	2.0	13 560	90 685	7 080	48 942			3.5	1.50	0.11	0.40	<0.01	0.1	<1.0	
	24	8.3	"	150	108		57	50	5 520	2 940	300	1.2	6 624	97 309	3 528	52 470			"	"	"	"	"	"	"	
	25	8.4	"	162	73		110	55	5 420	3 010	300	1.3	7 046	104 355	3 913	56 383			"	"	"	"	"	"	"	
	26	8.3	"	162	73		110	55	6 350	3 190	265	1.7	10 795	115 150	5 423	61 806			"	"	"	"	"	"	"	
	27	8.5	"	220	97		135	75	5 210	2 730	230	0.5	2 605	117 755	1 365	63 171			"	"	"	"	"	"	"	
	28	8.4	"	220	97		135	75	5 910	3 020	240	1.2	7 092	124 847	8 510	71 681			"	"	"	"	"	"	"	
	29	8.6	3.2	232	116		190	100	5 650	2 900	210	1.2	6 780	131 627	3 480	75 161			3.5	1.50	0.11	0.40	<0.01	0.1	<1.0	
	30			232	116		190	100																		
Influent	2/8-8/8	6.3		4 410															22.0	4.88	0.05	-	0.01	0.50	<1.0	
	8/8-14/8	6.4		3 550													6.3		20.0	4.25	0.22	1.20	0.01	3.15	-	
	14/8-23/8	6.3		3 620		2 900	320	270									6.0	76	21.0	4.92	0.42	0.63	0.01	0.53	-	1 520
	23/8-27/8	6.4		2 910			170	40									9.3	56	18.5	5.50	0.45	0.70	0.02	0.36	<0.1	1 230
	27/8-2/9	6.4		3 800		2 460	220	90									5.9	56	24.5	5.30	0.18	0.10	0.01	0.50	1.0	
	Mean S.dev No	6.4 0.1 5		3 658 538 5			237 76 3										6.9 1.6 4	63 11 3	21.2 2.2 5	5.0 0.5 5	0.26 0.17 5	0.65 0.4 4	0.01 0.00 5	1.00 1.00 5		1 400

Table 64

TEST TRUN NO 2: ACTIVATED SLUDGE, A.S.4

LEACHATE SOURCE:KENT HIGHLAND

Influent: Chemically coagulated leachate. Duration of experiment: August 2-August 30, 1973. Temperature of operation: 24 °C.

	Date of Sampling (Day/Month)	pH	Feed l/day	COD mg/l	COD Filtr mg/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	VS ml/l	Sludge with-drawal l	Sludge with-drawal mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawal mg VSS	Cumu-lative sl.w.d. mg VSS	Organic loading mg COD / mg MLVSS/day	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	9/8	7.5	6.4	118				5 340	3 520	260	3.0	16 020	16 020	10 560	10 560	0.56							
	10	7.5	6.4	118				5 190	3 140	240	2.0	10 380	26 400	6 280	16 840	0.62	10.0	1.80	0.59	0.40	0.01	0.2	-
	11	7.6	6.4	188	100	120		4 680	3 260	220	2.0	9 360	35 760	6 520	23 360	0.60	38.0	2.30	0.16	0.50	0.01	0.1	-
	12	7.7	6.4	188	100	120		5 060	3 100	200	2.0	10 120	45 880	6 200	29 560	0.63	"	"	"	"	"	"	
	13	8.1	6.4	186	129	110		5 530	3 240	130	2.0	11 060	56 940	6 480	36 040	0.60	"	"	"	"	"	"	
	14	3.4	6.4	186	129	110		4 960	3 270		2.0	9 920	66 860	6 540	42 580	0.60	"	"	"	"	"	"	
	15	7.9	6.4	286	155	120	70	5 450	3 050	220	2.0	10 900	77 760	6 100	48 680	0.64	"	"	"	"	"	"	
	16	7.3	6.4	286	155	120	70	4 380	2 900	160	1.5	6 570	84 330	4 350	53 030	0.68	"	"	"	"	"	"	
	17	7.6	6.4	648	570	180	105	4 180	2 390	160	0					0.82	"	"	"	"	"	"	
	18	7.5	6.4	648	570	180	105	4 420	2 540	150	0					0.77	"	"	"	"	"	"	
	19	7.4	6.4	2 177	1 945	245	135	4 710	2 740	150	0					0.71	"	"	"	"	"	"	
	20	6.7	6.4	2 177	1 945	245	135	4 550	2 550	140	0					0.76	38.0	2.30	0.16	0.50	0.01	0.1	-
	21	6.2	6.4	1 683	1 343	170	80	4 950	2 740	150	0					0.71							
	22	6.0	6.4	1 683	1 343	170	80	4 580	2 460	150	0					0.80							
	23	5.9	6.4		2 516	245	145	4 180	2 520	150	0					0.78	23.0	1.50	0.38	0.70	0.02	0.1	-
	24	8.0	6.4		2 516	245	145	3 650	1 900	150						1.03	"	"	"	"	"	"	
	25	8.7	6.4	3 242	2 933	155	95	3 900	1 800	180						1.03	"	"	"	"	"	"	
	26	8.4	6.4	3 242	2 933	155	95	4 220	1 820	230						1.09	"	"	"	"	"	"	
	27	8.6	6.4	2 671	2 624	255	190	4 980	1 660	240						1.18	"	"	"	"	"	"	
	28	8.0	6.4	2 671	2 624	255	190	5 200	1 580	270						1.24	"	"	"	"	"	"	
	29	7.9	6.4	2 528	2 240	105	90	5 720	1 700	260						1.15	23.0	1.50	0.38	0.70	0.02	0.1	-
	30/8	7.9	6.4	2 528	2 240	105	90																

Influent see table 61.

Table 65

TEST RUN NO 2 ACTIVATED SLUDGE, A.S.5

LEACHATE SOURCE : KENT HIGHLAND

Influent: Chemically coagulated leachate. Duration of experiment: August 2-August 30, 1973. Temperature of operation: 24 °C

Date of Sampling (Day/Month)	pH	Feed 1/day	COD mg/1	COD Filtr. mg/1	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Sludge with-drawal 1	Sludge with-drawal mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawal mg VSS	Cumu-lative sl.w.d. mg VSS	Organic loading mg COD / mg MLVSS/day	Fe mg/1	Zn mg/1	Cu mg/1	Ni mg/1	Cd mg/1	Cr mg/1	Pb mg/1
6/8	7.5		150																			
7	7.6		150																			
8	7.5	8	134																			
9	7.6	8	134				4 720	3 200	200	2.0	9 440	9 440	6 400	6 400	0.95							
10	7.6	8					6 100	3 510	200	2.3	14 030	23 470	8 073	14 473	0.87	14.0	1.95	1.50	0.30	0.01		
11	7.5	8	348	252	155		5 240	3 820	120	2.7	14 148	37 618	10 314	24 787	0.80	89.0	2.95	0.39	0.80	0.01		
12	7.5	8	348	252	330		4 800	3 150	110	1.6	7 680	45 298	5 040	29 827	0.97	"	"	"	"	"		
13	6.5	8	1 563	833	260	135	4 100	2 350	100	0	0	45 298	0	29 827	1.30	"	"	"	"	"		
14	6.1	8	1 563	833	260	135	4 680	3 320	120	2.0	9 360	54 658	6 640	36 467	0.93	"	"	"	"	"		
15	5.8		1 901	1 623	235	125	3 440	2 280	120	0					1.08	"	"	"	"	"		
16	5.8	5.7	1 901	1 623	235	125	3 000	2 220	100	0					1.12	"	"	"	"	"		
17	5.8	5.6	2 162	1 930	150	85	3 380	2 380	70	0					1.04	89.0	2.95	0.39	0.80	0.01		
18	5.9		2 162	1 930	150	85	1 960	1 200	70						2.06							
19	5.8		3 489	2 794	255	120	2 260	1 200	65													
20	5.9		3 489	2 794	255	120	2 060	900	55													
21/8			3 422	3 268	110	30	2 200	910	45													

Influent see table 61

Table 66

LEACHATE SOURCE : KENT HIGHLAND

TEST RUN NO 3: ACTIVATED SLUDGE, A.S.1

Influent: Raw leachate. Duration of experiment: September 9-September 28, 1973. Temperature of operation: 24 °C.

Organic loading: 0.28 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$.

Date of Sampling (Day/Month)	pH	Feed 1/day	COD mg/l	COD Filt. mg/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Sludge with-drawal l	Sludge with-drawal mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawal mg VSS	Cumu-lative sl.w.d. mg VCS	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
11/9		0.42	200				6 420	3 520	760	0.6	3 852	3 852	2 112	2 112			13.5	1.45	0.70	0.9	0.01	0.01	
12	8.25	"					6 030	3 200	720	0.4	2 412	6 264	1 280	3 392			"	"	"	"	"	"	
13	8.2	"	304	56	195	25	4 450	2 690	460	0.1	445	6 709	269	3 661			"	"	"	"	"	"	
14	8.1	"					4 580	2 680	232	0.18	824	7 533	482	4 143			"	"	"	"	"	"	
15	8.5	"	128	68	37	27	4 610	2 430	300	0	0	7 533	0	4 143			"	"	"	"	"	"	
16	8.3	"					5 200	2 560	384	0	0	7 533	0	4 143			"	"	"	"	"	"	
17	8.0	"	144	84	80	37	6 490	3 020	540	0.3	1 947	9 480	906	5 049			"	"	"	"	"	"	
18	7.8	"		116	45	17	5 490	2 710	492	0.15	824	10 304	407	5 456			"	"	"	"	"	"	
19	8.45	"	136	100	50		6 680	3 320	328	0.4	2 672	12 976	1 328	6 784			"	"	"	"	"	"	
20	8.55	"	152	120			4 910	2 510	280	0	0	12 976	0	6 784			13.5	1.45	0.70	0.9	0.01	0.01	
21	8.45	"			105	60	4 850	2 930	296	0.25	1 212	14 188	733	7 517			22.0	1.75	1.34	0.90	0.01	0.30	
22	8.4	"	168	132			4 260	2 400	300	0	0	14 188	0	7 517			"	"	"	"	"	"	
23	8.45	"			55	50	4 480	2 580	260	0	0	14 188	0	7 517			"	"	"	"	"	"	
24	8.5	"	252	132			6 040	2 800	336	0.2	1 208	15 396	560	8 077			"	"	"	"	"	"	
25	8.4	"			125	70	5 300	2 630	320	0.1	530	15 926	263	8 340			"	"	"	"	"	"	
26	8.3	"	184	100			4 980	2 510	300								"	"	"	"	"	"	
27		"															"	"	"	"	"	"	
28/9	8.1	0.42	228	144	55		5 800	2 650									22.0	1.75	1.34	0.90	0.01	0.30	
Mean	8.3		174	111	69	43	5 274	2 696	345														
S.dev.	0.2		44	25	31	20	774	262	86														
No 15/9-28/9	11		8	9	8	6	13	13															
Influent	6.3		3 760	3 280	210	65									5.9	70	23.0	3.7	1.35	0.40	0.03	0.65	<1.0

Table 67

LEACHATE SOURCE : KENT HIGHLAND

TEST RUN NO 3 : ACTIVATED SLUDGE, A.S, 2

Influent: Raw leachate. Duration of experiment: September 9-September 28, 1973. Temperature of operation: 24 °C.

Organic loading: 0.50 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$.

	Date of Sampling (Day/Month)	pH	Feed 1/day	COD mg/l	COD Filtr. mg/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Sludge with-drawel l	Sludge with-drawel mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawel mg VSS	Cumu-lative sl.w.d. mg VSS	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l
Effluent	11/9		0.74					8 320	3 840	760	0.5	4 160	4 160	1 920	1 920	18.0	1.45	0.65	0.60	0.01	0.25
	12	8.1	"					5 870	2 880	700	0.25	1 468	5 628	720	2 640	"	"	"	"	"	"
	13	8.1	"	108	68	69	20	5 720	3 350	460	0.4	2 288	7 916	1 356	3 996	"	"	"	"	"	"
	14	8.2	"					5 420	3 120	280	0.4	2 168	10 084	1 248	5 244	"	"	"	"	"	"
	15	8.3	"	88	40	100	40	5 010	2 520	260	0	0	10 084	0	5 244	"	"	"	"	"	"
	16	8.2	"					5 860	2 900	300	0.3	1 758	11 842	870	6 114	"	"	"	"	"	"
	17	7.9	"	132	84	95	37	6 240	3 140	292	0.4	2 496	14 338	1 256	7 370	"	"	"	"	"	"
	18	7.9	"	120	80			6 030	2 830	256	0.25	1 508	15 846	707	8 077	"	"	"	"	"	"
	19	8.35	"	168	112	115	36	6 340	3 530	232	0.5	3 170	19 016	1 765	9 842	"	"	"	"	"	"
	20	8.4	"	204	140			5 540	2 920	204	0.150	831	19 847	438	10 280	18.0	1.45	0.65	0.60	0.01	0.25
	21	8.2	"			105	60	5 120	2 780	208	0.2	1 024	20 871	556	10 836	23.0	0.80	0.57	0.30	0.01	0.08
	22	8.0	"	760	627			4 760	2 440	195	0					"	"	"	"	"	"
	23	8.0	"			120	95	4 820	2 540	165	0					"	"	"	"	"	"
	24	8.0	"	1 232	1 072			5 030	2 530		0					"	"	"	"	"	"
	25	8.0	"			185	95	5 200	2 580		0					"	"	"	"	"	"
	26	7.85	"	1 704	1 392			5 120	2 490		0					"	"	"	"	"	"
	27										0					"	"	"	"	"	"
	28		0.74	1 808	1 552	120	80	4 960	2 410		0					23.0	0.80	0.57	0.30	0.01	0.08
	Mean	8.1				120	63	5 380	2 739	234											
	S.dev	0.2				30	26	550	325	45											
	No	12				7	7	13	13	9											

Influent see table 66

Table 68

TEST RUN NO 3 : ACTIVATED SLUDGE A.S. 3

LEACHATE SOURCE : KENT HIGHLAND
Influent: Raw leachate. Duration of experiment: September 9-September 28, 1973. Temperature of operation: 24 °C.
Organic loading: 0.71 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$.

	Date of Sampling (Day/Month)	pH	Feed 1/day	COD mg/l	COD Filt mg/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Sludge with-drawal l	Sludge with-drawal mg SS	Cumu-lative sl.w.d. mg SS	Sludge with-drawal mg VSS	Cumu-lative sl.w.d. mg VSS	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l
Effluent			1.45																	
	11/9		1.18	184				8 480	3 180	260	0.6	5 088	5 088	1 908	1 908	12.5	1.75	1.38	0.4	0.01
	12	8.1	"					6 090	3 280	230	0.3	1 827	6 915	984	2 892	"	"	"	"	"
	13	8.2	"	148	60	115	15	6 340	3 740	280	0.5	3 170	10 085	1 870	4 762	"	"	"	"	"
	14							5 490	3 290	328	0.5	2 745	12 830	1 645	6 407	"	"	"	"	"
	15	8.1	"	164	124	90	20	4 360	2 500	192	0	0	12 830	0	6 407	"	"	"	"	"
	16	7.9	"					5 030	2 750	200	0.2	1 006	13 836	5 400	11 807	"	"	"	"	"
	17	7.9	"	692	636	60	22	8 380	3 850	220	0.65	5 447	19 283	2 502	14 309	"	"	"	"	"
	18	7.85	"	352	293			6 300	2 930	176	0.3	1 890	21 173	879	15 188	"	"	"	"	"
	19	7.9	"	872	748	83	32	6 080	3 350	200	0.5	3 040	24 213	1 675	16 863	"	"	"	"	"
	20	7.6	"	568	540			4 840	2 480	190	0					12.5	1.75	1.38	0.4	0.01
	21	7.5	"			105		4 550	2 430	180						16.0	2.95	0.54	1.8	0.01
	22	7.4	"	2 240	2 048			4 580	2 250	140						"	"	"	"	"
	23	7.65	"			130	115	4 880	2 400	80						"	"	"	"	"
	24	7.55	"	2 250	2 090			5 420	2 400							"	"	"	"	"
	25	7.75	"			145	90	5 170	2 410							"	"	"	"	"
	26	7.65	"	2 336	1 744			5 410	2 380							"	"	"	"	"
	27															"	"	"	"	"
	28	8.0	1.18			185	115		2 160							16.0	2.95	0.54	1.8	0.01
	Mean	7.8				112	66	5 417	2 638	175										
	S.dev.	0.2				38	46	1 103	480	42										
	No	13				7	6	12	13	9										
	15/9 - 28/9																			

Influent: se table 66

Table 69

LEACHATE COURCE: CEDAR HILLS

TEST RUN NO 4.: **ANAEROBIC FILTER, A.F.1**

Duration of experiment: November 2-December 24, 1973. Temperature of operation: 22 °C.

	Period of sampling (Days/Month)	Organic loading $\frac{kg\ COD}{m^3\ day}$	Gas prod. ml/day	pH	Alka-linity mg $CaCO_3$	SS mg/l	VSS mg/l	COD mg/l	COD Filtr. mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	22/11-2/12	0.25		7.8	1 280	365	55	2 736	2 272		3.75		25.0	1.25	0.17	0.3	0.02	0.25	1.4
	2/12-6/12	"	710	7.9	1 320	220	65	1 528		1 034		728	25.0	1.25	0.17	0.3	0.02	0.25	1.4
	6/12-12/12	"	780	7.9	1 520	190	50	1 320		755	3.63		10.0	1.50	0.23	0.3	0.01	0.12	1.3
	12/12-15/12	"	740	7.9	1 770	185	50	992	960	483			10.0	1.50	0.23	0.3	0.01	0.12	1.3
	15/12-19/12	"	850	7.9	1 970			624	600	226	6.7		7.50	0.95	0.22	0.1	0.03	0.15	
	19/12-21/12	"	840	8.0		70	40	568	536	136			7.50	0.95	0.22	0.1	0.03	0.15	
	21/12-24/12	0.25	810	7.9	2 080	170	60	664	520	181	9.3		15.0	2.50	0.26	0.5	0.03	0.10	
Influent				5.4	6 480	310	140	38 800		24 500	11.25	630	81.0	155.0	1.30	1.2	0.03	1.00	1.4

Table 70

LEACHATE SOURCE: CEDAR HILLS

TEST RUN NO 4; ANAEROBIC FILTER, A.F.2

Duration of experiment: November 2-December 24, 1973. Temperature of operation: 22 °C

	Period of sampling (Days/Month)	Organic loading $\frac{kg\ COD}{m^3\ day}$	Gas prod. ml/day	pH	Alka-linity mg $CaCO_3$	SS mg/l	VSS mg/l	COD mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	22/11-2/12	0.73	60	7.0	7 200	1 080	270	12 400	21 800		224	35.0	1.00	0.20	0.3	0.01	0.70	1.0
	2/12-6/12	"	0	6.7	7 600	1 320	410	24 200				35.0	1.00	0.20	0.3	0.01	0.70	1.0
	6/12-12/12	"	0	6.3	8 650	1 500	410	36 800	24 540			58.0	4.70	0.81	0.5	0.02	0.18	1.2
	12/12-15/12	"	0	5.9	8 800	1 370	370	37 600				58.0	4.70	0.81	0.5	0.02	0.18	1.2
	15/12-19/12	"	0	5.9	8 700	650	200	35 600						0.71	0.7	0.03	0.87	2.1
	19/12-21/12	"	0	5.8				40 000	24 000									
	21/12-24/12	0.73	0	5.9		860		39 200										
	Influent			5.4	6 480	310	140	38 800	24 500	11.25	630	81.0	155.0	1.30	1.2	0.03	1.00	1.4

Table 71

LEACHATE SOURCE: CEDAR HILLS

TEST RUN NO 4 : ANAEROBIC FILTER, A.F.3

Duration of experiment: November 2-December 24, 1973. Temperature of operation: 22 °C

	Period of sampling (Day/Month)	Organic loading $\frac{\text{kg COD}}{\text{m}^3\ \text{day}}$	Gas prod. ml/day	pH	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	COD mg/l	COD Filt. mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	22/11-2/12	0.73	0	6.2	5700	1 040	340	23 600		18 483			36.5	9.00	0.14	0.4	0.01	0.15	
	2/12-6/12	"	0	6.2		1 110	380	25 200					36.5	9.00	0.14	0.4	0.01	0.15	
	6/12-12/12	"	0	6.1	6 660	820	300	26 800		21 513			40.5	8.75	0.23	0.6	0.03	0.80	1.1
	12/12-15/12	"	0	6.1	7 750	1 140	400	26 800		21 816			40.5	8.75	0.23	0.6	0.03	0.80	1.1
	15/12-19/12	"	0	6.1		900	300	31 200					31.5	9.00	0.16	0.6	0.04	0.65	1.0
	19/12-21/12	"	0	6.1				42 000											
	21/12-24/12	0.73	0	6.1	7 450	1 260	490	34 400											
Influent				5.4	6 480	310	140	38 800		24 500	11.25	630	81.0	155.0	1.30	1.2	0.03	1.00	1.4

Table 72

LEACHATE SOURCE: CEDAR HILLS   TEST RUN NO 5: ANAEROBIC FILTER, A.F.1

Duration of experiment: December 29-March 6 1974. Temperature of operation: 22 °C.

	Period of sampling (Day/Month)	Organic loading $\frac{kg\ COD}{m^3\ day}$	Gas prod. ml/day	pH	Alka-linity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	COD mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	14/1-19/1	0.16	385	8.1	2 390	650	283	984		22.80		65.0	1.00	0.24	0.5	0.04	0.15	1.5
	19/1-23/1	"	313	8.0	1 730	1 040	516	927		20.75		7.3	0.70	0.48	0.1	0.01	0.10	-
	23/1-29/1	"	410	7.9	2 010	540	204	840				6.0	0.50	0.40	0.4	0.01	0.10	-
	29/1-2/2	"	280	8.1	2 320	380	150	830		12.12		10.0	1.20	0.51	0.5	0.02	0.05	-
	2/2-6/2	"	280	8.0	1 790	522	347	744				10.5	1.30	0.65	0.5	0.03	0.15	1.6
	6/2-10/2	0.16	550	7.8	1 690	362	104	520	55	9.13	292	21.0	1.50	0.82	1.2	0.03	0.10	-
	10/2-14/2	0.29	588	7.8	1 660	314	168	457				8.5	1.50	0.95	0.5	0.08	0.12	1.0
	14/2-18/2	"	615	7.7	1 550	242	170	356				15.0	1.70	0.98	0.4	0.01	0.17	1.8
	18/2-21/2	"	580	7.6	1 530	267	45	371	49	9.38		13.0	0.50	0.40	0.4	0.01	0.05	-
	21/2-24/2	"	701	7.5	1 380	972	292	976				48.0	3.85	1.39	-	0.06	0.39	2.5
	24/2-28/2	"	628	7.5	1 270	431	95	433		9.25		18.5	1.40	0.54	0.1	0.02	0.05	-
	28/2-3/3	"	581	7.5	1 200	348	76	338	34	4.75	174	10.0	-	0.84	0.3	-	0.05	-
	3/3-6/3	0.29	583	7.7	1 090	652	124	505	53	14.38		31.0	3.00	0.90	1.8	0.03	0.10	2.0
Influent				5.4	2 400	320	140	9 100	5 950	5.50	172	21.5	20.3	0.45	0.35	0.03	0.65	1.1

Table 73

'LEACHATE SOURCE: CEDAR HILLS

TEST RUN NO 5 : ANAEROBIC FILTER, A.F.2

Duration of experiment: December 29-March 6, 1974. Temperature of operation: 22 °C

	Periode of sampling (Days/Month)	Organic loading $\frac{kg\ COD}{m^3\ day}$	Gas prod. ml/day	pH	Alka-linity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	COD mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	14/1-19/1	0.37	670	7.5	1 600	838	353	1 399		17.13		44.5	4.50	0.73	0.9	0.06	0.12	2.3
	19/1-23/1	"	760	7.7	1 470	334	82	684		4,33		45,0	2,55	0,37	0.3	0.01	0.05	-
	23/1-29/1	"	720	7.7	1 340	408	100	751				36.5	2,05	0.27	0.3	0.02	0.07	1.7
	29/1-2/2	"	580	7.6	1 380	650	148	895		13,38		58.0	4.05	0.52	0.4	0.03	0.10	-
	2/2-26/2	"	610	7.7	1 370	636	170	1 016				92.5	8.45	1,08	0.2	0.03	0.88	1.3
	6/2-10/2	0.37	480	7.9	1 360	435	150	632	65	9,25	204	35.0	2.90	0,22	0.1	0.03	0.20	2.0
	10/2-14/2	0.53	810	7.5	1 400	436	72	542	98			42.5	3,30	0.80	0.7	0.03	0.75	1.7
	14/2-18/2	"	970	7.7	1 270	414	74	410				32.0	1.80	0.44	0.2	0.01	0.55	-
	18/2-21/2	"	1 110	7.7	1 250	334	50	310	58	5.0		20.0	0.70	0.18	0.5	-	0.17	-
	21/2-24/2	"	420	7.6	1 270	316	57	401				39.0	1.05	0.49	0.5	0.05	0.05	-
	24/2-28/2	"	800	7.5	1 270	486	98	790		12.75		40.5	2.80	0.45	0.5	0.01	0.10	-
	28/2-3/3	"	1 040	7.4	1 300			290	56	5.55	147	25.0	0.90	0.67	0.4	0.03	-	1.0
	3/3-6/3	0.53	1 140	7.5	1 280	357	87	244	42	5.88		16.0	0.80	0.13	0.7	-	0.08	0.8
Influent				5.4	2 400	320	140	9 100	59.50	5.50	172	21.5	20.3	0.45	0.35	0.03	0.65	1.1

Table 74

LEACHATE SOURCE: CEDAR HILLS TEST RUN NO 5 : ANAEROBIC FILTER, A.F. 3

Duration of experiment: December 29-March 6 1974. Temperature of operation: 22 °C.

	Period of sampling (Days/Month)	Organic loading $\frac{kg\ COD}{m^3\ day}$	Gas prod. ml/day	pH	Alka-linity mg $CaCO_3$	SS mg/l	VSS mg/l	COD mg/l	BOD mg/l	P mg/l	N mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l
Effluent	14/1-19/1	0.36	670	7.4	1 630	430	134	730		8.88		13.0	1.50	0.305	0.2	0.02	0.08	0.8
	19/1-23/1	0.36	770	7.6	1 550	502	141	716		10.13		47.0	3.20	2.66	0.3	0.02	0.10	1.5
	23/1-29/1	0.24	720	7.8	1 240	670	168	588				-						
	29/1-2/2	"	580	7.7	1 270	412	96	694		8.75		18.0	1.20	0.75	0.2	0.03	0.10	1.6
	2/2-6/2	"	600	7.7	1 470	370	81	419				13.5	0.60	0.34	0.3	0.02	0.15	
	6/2-10/2	0.24	480	7.9	1 410	435	150	428	32[illegible]	6.63	223	20.5	0.65	0.385	0.6	0.01	0.12	0.7
	10/2-14/2	0.76	800	7.6	1 590	736	52	1 012				47.0	2.90	0.975		0.04	0.08	2.3
	14/2-18/2	"	880	7.7	1 230	718	164	1 331				51.0	3.40	1.01	0.3	0.04	0.12	1.2
	18/2-21/2	"	1 120	7.7	1 230	476	78	645	220	8.25		27.5	2.55	0.40	0.6	0.03	0.15	
	21/2-24/2	"	600	7.6	1 250	1 766	806	956				77.0	2.20	0.53	0.1	0.03	0.15	
	24/2-28/2	"	800	7.5	1 240	670	108	558		5.63		30.0	1.50	0.27	0.5	0.03	0.07	
	28/2-3/3	"	1 030	7.4	1 150	750	133	580	142	8.25	133	37.5	1.20	1.70	0.2	0.05	0.12	
	3/3-6/3	0.76	1 150	7.5	1 160	1 024	398	438	79	6.50		44.0	3.10	0.53		0.02	0.08	2.0
Influent				5.4	2 400	320	140	9 100	5 950	5.50	172	21.5	20.3	0.45	0.35	0.03	0.65	1.1

Table 75

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO I

Date of sampling (Day/Month)	pH	COD mg/1	COD Filtr. mg/1	TOC mg/1	Total nitrogen mg N/1	Alkali-nity $\frac{\text{mg CaCO}_3}{1}$	SS mg/1	VSS mg/1	Fe mg/1	Zn mg/1	Cu mg/1	Cr mg/1	Cd mg/1	Pb mg/1	Ni mg/1
22.7.- 25.7		470		146											
25.7.- 2.8	6.8	516	500	140	118.7	1 250	184	104	80.5	0.5	<0.1	<0.1	<0.1	<0.1	<0.1
2.8.- 8.8	6.7	530		150	123.8	1 450	290	162	59.0	0.4	<0.1	<0.1	<0.1	<0.1	<0.1
8.8.- 15.8		543		110	167.3	1 350			90.2	0.8	<0.1	<0.1	<0.1	<0.1	<0.1
15.8.- 23.8	6.7	500					123	32							
23.8.- 29.8	7.0	575		150	130.3		172	112							
29.8.- 9.9		501		128			156	54							
Mean	6.8	530		135	140.5	1 400	185	90							
S.dev.	0.2	31		19	23	-	73	59							
No	3	5		4	3	2	4	4							
2/8 - 9/9															

Table 76

LEACHATE SOURCE : GRØNMO TEST RUN NO I : ACTIVATED SLUDGE, A.S.1

Influent: Raw leachate. Duration of experiment: July 22 - September 9, 1974. Volume of aeration chamber: 19.1 1

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/1	COD Filt mg/1	COD-removal %	TOC mg/1	Total nitrogen mg N/1	Alkalinity $\frac{mg\ CaCO_3}{1}$	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Oxygen uptake rate $\frac{mg\ O}{1 \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Specific resistance to filtr. m/kg	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
22/7	2.1	15.0	8.0	225		53						4360	2930	920				0.0185
23	"	15.5	8.0	192	167	60						4500	2690					0.020
24	"	15.3	8.1	222		54												
25	"	15.7	8.0	241		50						4060	2710	490	5.76	2.1		0.020
26	"	16.2	8.1											450				
27	"	15.8	8.1	265	260	47												
28	"	15.7																
29	"	15.5	8.3	281		44						3650	2270	490				0.025
30	"	15.3	8.4											490				
31/7	"	15.2	8.1	323		36				65	31	4320	2470		6.00	2.4	$5.1 \cdot 10^{12}$	0.022
1/8	"		8.2											400				
2	"	15.4	8.4	332		36				132	92	4570	2690					0.021
3	"	15.0	8.2											380				
4	"	15.5																
5	"	15.7	8.3	310		40				62	30	4260	2330					0.024
6	"	16.2	8.1															
7	"	16.0		328		36				94	48	4560	2390		6.00	2.5		0.024
8	"	16.1	8.0															
9	"	15.7	8.1	336		35				51	32	3570	2040	350	5.40	2.6		0.029
10	"	15.8																
11	"																	
12	"	15.4	8.4	340		34				75	37	3370	1790		4.80	2.7		
13	"	15.3	8.4											260				
14	"	15.1	8.4	409		21								280				
15	"		8.4							61	38	3370	1870					0.030
16	"		8.4															
17	"																	
18	"	15.1																
19	"	14.8	8.5	338		32				117	52	3360	1650	320	3.0	1.3		0.032
20	"	14.3																
21	"	13.8	8.4												2.76			
22	"	14.2																
23	"	14.9	8.4	349		39				150	61	2960	1550	200	6.00	3.9		0.034
24	"	15.3																
25	"																	
26	"	16.0	8.5															
27	"	15.8		339		41	112.5	76.8	506	84	60	2690	1580	220	3.12	2.0		0.040
28	"																	
29	"	15.0		341	323	32												
30	"	16.3	8.6							128	67	2860	1510	210	3.24	2.1	$1.25 \cdot 10^{13}$	0.037
31/8	"	15.2																
1/9	"																	
2	"		8.6															
3	"																	
4	"	14.2										2680	1360	180	2.04	1.5	$1.13 \cdot 10^{13}$	0.040
5	"	14.4	8.6	248		50	85											
6	"	14.8																
7	"																	
8	"																	
9/9	"	15.1		356		29	100											
Mean		15.2	8.4	336		35.4	99			91	47	3368	1807	267	4.0	2.4	$9.6 \cdot 10^{12}$	0.033
S.dev.		0.7	0.2	38		7.4	13.8			33.9	13.6	672	350	71	1.5	0.7	$4 \cdot 10^{12}$	0.005
No.		27	17	11		11	3			9	9	10	10	9	9	8	3	8
3/8 - 9/9																		

Table 77

LEACHATE SOURCE : GRØNMO

TEST RUN NO I : ACTIVATED SLUDGE A.S 2

Influent : Raw leachate. Duration of experiment : July 22 - September 9, 1974. Volume of aeration chamber: 18.9 l

Date of sampling (Day/Month)	Feed 1/day	Temp-aeration basin °C	pH aer. basin	COD mg/l	COD Filt mg/l	COD-removal %	TOC mg/l	Total nitrogen mg N/l	Alkalinity mg $CaCO_3$/l	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate mg O/l · h	Oxygen uptake rate mg O/h mg MLVSS 10^{-3}	Specific resistance to filtr. m/kg	Organic loading kg COD/kg MLVSS day
22/7	4.3	15.0	8.3	237		51						5130	3130	920				
23	"	15.5	8.25	216	196	55						4870	2750					0.039
24	"	15.3	8.25	244		50												
25	"	15.7	8.2	290		42						4480	2830					
26	"	16.2	7.9											450	12.00	4.2		
27	"	15.8	8.0	340	305	32												
28	"	15.7																
29	"	15.5	8.2	296		41						5030	2810	480				
30	"	15.3	8.3											470				
31/7	"	15.2	8.1	298		41				140	96	5480	2970		7.80	2.6	$4.5 \cdot 10^{12}$	0.039
1/8	"		8.2											430				
2	"	15.4	8.3	323		37				111	73	5480	3020					0.039
3	"	15.0	8.1											380				
4	"	15.5																
5	"	15.7	8.2	315		40				71	35	5400	2660					0.043
6	"	16.0	8.1															
7	"	16.0		357		31				82	31	5540	2770		8.40	3.0		0.043
8	"	16.1	7.9															
9	"	15.7	7.9	355		31				55	33	8057	3340	380	3.24	0.9		
10	"	15.8																
11	"																	
12	"	15.4	8.2	344		33				78	37	3640	1580		5.52	3.3		0.076
13	"	15.3	8.3											360				
14	"	15.1		429		17								300				
15	"		8.3							49	28	4947	1840					0.061
16	"		8.15															
17	"		8.0															
18	"	15.1																
19	"	14.8	8.5	332		34				72	18	4230	2070	250	4.20	2.0		0.054
20	"	14.3																
21	"	13.7													4.56			
22	"	14.2	8.4															
23	"	14.9	8.3	335		42				82	28	3580	1820	265	6.96	3.3		0.071
24	"	15.3																
25	"																	
26	"	16.0	8.5															
27	"	15.7		320		44	107.5	80	546	78	57	3330	1880	240	5.40	2.9		0.069
28	"																	
29	"	15.0		337	329	33												
30	"	16.2	8.5							100	55	3110	1620	225	3.72	2.3	$8.8 \cdot 10^{12}$	0.070
31/8	"	15.1																
1/9	"																	
2	"																	
3	"		8.4															
4	"	14.2																
5	"	14.4		307		39	85					3200	1570	235	3.72	2.4	$7.3 \cdot 10^{12}$	0.072
6	"	14.8	8.4															
7	"																	
8	"																	
9/9	4.3	15.1		362		28	100											
Mean S.dev. No 3/8 - 9/9		15.2 0.6 27	8.2 0.2 17	345 33 11		33.8 7.5 11	97.5 11 3			74 15 9	36 12 9	4110 959 9	1978 448 9	293 64 9	5.1 1.7 9	2.6 0.9 8	$6.9 \cdot 10^{12}$ 2.2 3	0.062 0.012 9

Table 78

LEACHATE SOURCE : GRØNMO

TEST RUN NO I ACTIVATED SLUDGE A.S 3

Influent : Raw leachate. Duration of experiment: July 22 - September 9, 1974. Volume of aeration chamber: 19.2 l

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filtr. mg/l	COD-removal %	TOC mg/l	Total nitrogen mg N/l	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Specific resistance to filtr. m/kg	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
22/7	7.7	15.0	8.3	177		64						5690	3160	660				0.062
23	"	15.4	8.4	226	200	53						5610	2930					0.066
24	"	15.2	8.4	306		37												
25	"	15.6	8.4	290		42						5360	3120		13.3	4.4		0.062
26	"	16.1	8.1											420				
27	"	15.7	8.0	357	312	41												
28	"	15.7																
29	"	15.0	8.1	368		27						5770	3060	480				0.067
30	"	15.1	8.6											480				
31/7	"	15.0	8.2	351		30				61	2.9	6060	3120		13.2	4.2	$4.2 \cdot 10^{12}$	0.067
1/8	"		8.2											420				
2	"	15.2	8.3	365		29				171	118	6280	3150					0.067
3	"	15.0	8.1											420				
4	"	15.3																
5	"	15.4	8.3	401		22				92	55	5620	2750					0.078
6	"	15.8	8.2															
7	"	15.9		365		29				128	58	5870	2950		8.4	2.8		0.072
8	"	16.0	8.1															
9	"	15.6	8.0	346		33				59	36	5150	2680	370	6.0	2.2		0.078
10	"	15.8																
11	"																	
12	"	15.2	8.1	392		24				56	26	6630	2890		7.2	2.5		0.074
13	"	15.1	8.1											320				
14	"	15.0	8.1	373		28								320				
15	"		8.1							62	30	3720	2040					0.10
16	"		8.0															
17	"																	
18	"	15.0																
19	"	14.4	8.3	346		31				73	23	4530	2210	300	5.76	2.6		0.091
20	"	14.2																
21	"	13.6	8.3												4.92			
22	"	13.9																
23	"	14.8	8.2	322		44				50	20	3750	1930	280	4.68	2.4		0.120
24	"	15.2																
25	"																	
26	"	15.8	8.3															
27	"	15.8		268		53	97.5	72	574	37	34	3740	2020	260	4.20	2.1		0.110
28	"																	
29	"	14.7		313	287	37												
30	"	16.0	8.4							56	30	3880	1910	280	4.56	2.4	$4.0 \cdot 10^{12}$	0.105
31/8	"	16.1																
1/9	"	15.1																
2	"		8.4															
3	"																	
4	"	14.0										3670	1770	240	4.20	2.4	$2.9 \cdot 10^{12}$	0.114
5	"	14.1	8.2	264		47	75											
6	"	14.6																
7	"																	
8	"																	
9/9	"	14.9		313		37	75											
Mean S.dev No 3/8 - 9/9		15.1 0.7 28	8.2 0.1 17	337 45 11		36.8 10.0 11	82.5 13 3			68 27 9	34.7 13 9	4656 1088 10	2315 452 10	310 56 9	5.6 1.4 9	2.4 0.2 8	$3.7 \cdot 10^{12}$ $0.7 \cdot 10^{12}$ 3	0.094 0.018 10

Table 79

LEACHATE SOURCE : GRØNMO

TEST RUN NO I : ACTIVATED SLUDGE A.S 4

Influent : Raw leachate. Duration of experiment: July 22. - September 9, 1974. Volume of aeration chamber: 19.0 l

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH acr. basin	COD mg/l	COD Filtr. mg/l	COD-removal %	TOC mg/l	Total nitrogen mg N/l	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS\ 10^{-3}}$	Specific resistance to filtr. m/kg	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
22/7	11.6	14.5	8.45	284		41						5130	2890	910				0.104
23	"	15.3	8.35	312	290	36						4940	2660					0.111
24	"	15.1	8.4	363		25												
25	"	15.3	8.4	381		24						4540	2690		8.40	3.1		0.117
26	"	16.0	8.1											370				
27	"	15.7	8.0	420	385	17												
28	"	15.4																
29	"	15.0	8.1	357		29						5650	2720	400				0.115
30	"	15.0	7.9											380				
31/7	"	14.9	7.9	378		25				130	60	5620	2830		14.40	5.1	$3.1 \cdot 10^{12}$	0.111
1/8	"		7.8											370				
2	"	15.1	8.3	338		35				140	96	5840	2880					0.110
3	"	14.9	7.8											360				
4	"	15.2																
5	"	15.3	7.9	326		37				78	35	4060	2820					0.114
6	"	15.4	7.8															
7	"	15.7		371		28				132	45	5390	2690		10.80	4.0		0.120
8	"	15.7	7.9															
9	"	15.2	7.9	367		29				51	32	4150	2080	320	4.20	2.0		0.155
10	"	15.3																
11	"																	
12	"	15.1	8.0	360		30				66	20	3470	2470		4.56	1.8		0.131
13	"	15.0	8.1											230				
14	"	14.7	8.0	355		31								260				
15	"		8.0							48	27	4630	2260					0.135
16	"		7.9															
17	"																	
18	"	14.8																
19	"	14.6	8.2	342		32				98	28	4330	2100	300	6.96	3.3		0.145
20	"	14.0																
21	"	13.5	8.1												6.60			
22	"	13.9																
23	"	14.7	8.0	322		44				40	16	4270	2080	235	5.04	2.4		0.169
24	"	15.0																
25	"																	
26	"	15.6	8.1															
27	"	13.4		351		39	97.5	59.2	589	41	28	4080	2120	250	6.96	3.3		0.166
28	"																	
29	"	14.7		354	319	30												
30	"	16.9	8.2							69	36	4830	2320	260	6.84	3.0	$1.9 \cdot 10^{12}$	0.131
31/8	"	15.0																
1/9	"																	
2	"		8.2															
3	"																	
4	"	13.8										4280	2050	240	7.44	3.6	$1.46 \cdot 10^{12}$	0.148
5	"	14.0	8.0	279		44	102.5											
6	"	14.5																
7	"																	
8	"																	
9/9	11.6	14.8		327		35	87.5											
Mean S.dev No 3/8 - 9/9		14.9 0.6 27	8.0 0.1 16	341 27 11		34.5 5.8 11				69 30 9	30 8.6	4349 513 10	2300 276 10	273 44 9	6.6 2.0 9	2.9 0.8 8	$1.7 \cdot 10^{12}$	0.14 0.02 10

Table 80

LEACHATE SOURCE : GRØNMO

TEST RUN NO I : ACTIVATED SLUDGE A.S 5

Influent : Raw leachate. Duration of experiment: July 22 - September 9, 1974. Volume of aeration chamber: 19.1 l

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filtr. mg/l	COD-removal %	TOC mg/l	Total nitrogen mg N/l	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtr. m/kg	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$
22/7	20.7	14.3	8.6	461		5						3250	2070	430				0.26
23	"	14.7	8.4	445	405	8						3030	1640					0.32
24	"	14.6	8.55	483		2												
25	"	15.0	8.5	416		17						2670	1780		5.52	3.1		0.31
26	"	15.4	8.2											230				
27	"	15.0	8.1	447	396	11												
28	"	15.0																
29	"	14.5	8.4	410		19						2920	1410	260				0.40
30	"	14.4	8.3											170				
31/7	"	14.3	8.3	439		13						4450	1800		14.40	8.0	$2.2 \cdot 10^{12}$	0.31
1/8	"		8.3											180				
2	"	14.5	8.0	382		26				150	70	5110	2020					0.28
3	"	14.4	8.1											160				
4	"	14.8																
5	"	15.0	8.2	391		24				99	38	4930	1670					0.34
6	"	15.4	8.2															
7	"	15.2		386		25				102	36	3070	2270		38.40	16.9		0.26
8	"	15.4	8.0															
9	"	15.0	8.0	394		24				75	35	4020	1430		36.00	25.0		0.40
10	"	15.1																
11	"																	
12	"	14.6	7.9	371		28				106	34	3740	1630		13.20	8.1		0.35
13	"	14.5	7.9											180				
14	"	14.5	7.9	332		36								150				
15	"		8.0							75	38	3950	1840					0.31
16	"		7.7															
17	"																	
18	"	14.3																
19	"	14.0	8.0	344		31				98	26	3830	1760	170	7.20	4.1		0.31
20	"	13.8																
21	"	13.3	7.9												8.76			
22	"	13.6																
23	"	14.2	7.9	347		40				61	19	3820	1870	175	14.40	7.7		0.33
24	"	14.5																
25	"																	
26	"	15.3	7.7															
27	"	15.2		316		46	102.5	70.4	632	66	47	3960	2050		13.20	6.4		0.30
28	"																	
29	"	14.6		358	309	26												
30	"	15.9	8.0							107	48	4160	2090	185	15.96	7.6	$1.4 \cdot 10^{12}$	0.26
31/8	"	14.8																
1	"																	
2	"		7.9															
3	"																	
4	"	13.8					140					4740	2170	180	15.60	7.2	$1.2 \cdot 10^{12}$	0.25
5	"	14.0	7.8	246		51												
6	"	14.2																
7	"																	
8	"																	
9/9	20.7	14.4		392		22	80											
Mean		14.6	8.0	353		32.1	108			88	36	4022	1878	171	18.0	10.3	$1.8\ 10^{12}$	0.3
S.dev.		0.6	0.1	44		9.8	30			18	9.1	520	265	12	11	7	$0.5\ 10^{12}$	0.05
No		27	17	11		11	3			9	9	10	10	7	9	8	3	10
3/8-9/9																		

Table 81

LEACHATE SOURCE : GRØNMO

TEST RUN NO I : ACTIVATED SLUDGE, A.S 6

Influent : Raw Leachate. Duration og experiment: July 22. - September 9, 1974. Volume of aeration chamber: 18,7 l

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt mg/l	COD-removal %	TOC mg/l	Total nitrogen mg N/l	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Specific resistance to filtr. m/kg	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
22/7	31.9	14.2	8.2	447		8							3340	260				0.25
23	"	14.7	8.3	408	372	16												
24	"	14.5	8.5	420		13												
25	"	14.9	8.5									5600	2680		12.60	4.7		0.33
26	"	15.3	8.1											310				
27	"	15.0	7.95	386	348	23												
28	"	14.8																
29	"	15.0	8.3	399		21						7050	2650	290				0.33
30	"	14.4	8.2											320				
31/7	"	14.2	8.2	424		16						8640	3250		17.40	5.3	$1.8 \cdot 10^{12}$	0.27
1/8	"		8.2											270				
2	"	14.4	8.2	365		29				120	89	9860	3380					0.27
3	"	14.3	7.9											300				
4	"	14.6																
5	"	14.9	8.0	368		29				113	35	8960	3170					0.28
6	"	15.3	7.9															
7	"	15.1		410		20				118	46	9090	3420		56.4	16.5		0.26
8	"	15.3	7.9															
9	"	15.0	7.8	290		44				74	36	0290	3410		42.0	12.3		0.27
10	"	15.1																
11	"																	
12	"	14.6	7.9	373		28				128	36	3570	2820		10.8	3.8		0.32
13	"	14.4	8.0											250				
14	"	14.5	8.0	340		34								310				
15	"		7.9							88	43	6440	3010					0.28
16	"		8.3															
17	"																	
18	"	14.2																
19	"	13.9		371						125	33	7170	3280	350	8.64	2.6		0.26
20	"	13.8	7.6			26												
21	"	13.3													12.00			
22	"	13.4	7.8															
23	"	14.1	7.8	353		39				95	62	6880	3110	330	23.04	7.4		0.32
24	"	14.3																
25	"																	
26	"	15.2																
27	"	15.1	7.7	345		40	112.5	68.8	650	89	51	7010	3400		17.00	5.0		0.29
28	"																	
29	"	14.6		412	345	18												
30	"	15.8								100	49	7110	3460		14.64	4.2	$1.17 \cdot 10^{12}$	0.25
31/8	"	14.7	7.9											390				
1/9	"																	
2	"																	
3	"		7.8															
4	"	13.6										7690	3500	350	23.04	6.6	$1.13 \cdot 10^{12}$	0.25
5	"	13.7				44	107.5											
6	"	14.1	7.8	281														
7	"																	
8	"																	
9	31.9	14.3		329		34	110.0											
Mean S.dev. No 3/8 - 9/9		14.5 0.6 27	7.9 0.1 18	352 42 11		32.4 9.0 11	110 2.5 3			103 18.6 9	43 9.5 9	7421 1820 10	3258 224 10	325 45 7	23.0 16.0 9	7.3 4.8 8	$1.15 \cdot 10^{12}$	0.23 0.02 10

Table 82

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO II

Date of sampling (Day/Month)	pH	COD mg/l	TOC mg/l	Total nitrogen mg N/l	NO_3 mg N/l	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
10.9.- 18.9	6.8	466	130	98	5.4		84	33	42	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
18.9.- 25.9	6.8	435	115	117	1.4	1 500	141	44	68	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
25.9.- 2.10	6.8	410	122.5	96	0.7		80	40	56						
2.10.-10.10	6.9	411	151	96	0.0	1 290			70						
10.10.-14.10	6.9	424	137.5	100	0.8	1 300	114	27	105	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mean S.dev. No 18/9 - 14/10	6.9 0.1 4	420 12 4	131.5 16 4	102 10 4	3.2 4.5 4	1 363 118 3	112 31 3	37 9 3	74.8 21 4						

Table 83

LEACHATE SOURCE: GRØNMO

TEST RUN NO II, ACTIVATED SLUDGE, A.S. 1

Influent: Raw leachate. Duration of experiment: September 10-October 14, 1974

Date of Sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
10/9	4.8																			
11	"																			
12	"																			
13	"		8.3	338		27									2 375	1 225	210			0.08
14	"																			
15	"																			
16	"	13.6	8.3	250		46	100	23	110	81	74									
17	"																			
18	"												58	29	3 063	1 323				0.08
19	"	13.8	8.2	264		39	77.5	33	108	74	69									
20	"	14.2	8.0												3 780	1 700				0.06
21	"																			
22	"	13.5	8.4														200			
23	"	13.6	8.4	282		35	77.5	33	120	80	67			59	3 620	1 910		3.6	1.9	0.06
24	"																			
25	"			242	240	44	67.5	41												
26	"												60	36						
27	"	14.2	8.3	278		32	75.0	39	106	75	71				3 080	1 580				0.07
28	"																			
29	"																			
30/9	"	13.1	8.4	278		32	65.0	47									180			
1/10	"																			
2	"						82.5	33												
3	"		8.3	280		32														
4	"	12.3	8.3	256		38						470	55	33	3 510	1 680	190	3.0	1.8	0.06
5	"																			
6	"																			
7	"		8.5	244		40														
8	"	12.9	8.4										61	27	3 340	1 550		1.9	1.2	0.07
9	"		8.4	232		43												3.2		
10	"		8.5	212		48	70.0	49										2.5		
11	"	12.2	8.2	250	222	41						490	71	26	3 240	1 520		1.9	1.3	0.07
12	"																			
13	"																			
14/10	4.8		8.3	275		35							37	17	3 090	1 470				0.07
Mean			8.3	258		38.2	73.5	39.2	111	76	69	480	57	32	3 340	1 466	190	2.7	1.6	0.066
S.dev.			0.1	22		5.2	6.2	6.7	7	3	2	-	11	13	272	419	10	0.7	0.3	0.007
No			14	12		12	7	7	3	3	3	2	6	7	8	8	3	6	4	8
18/9-14/10																				

Table 84

LEACHATE SOURCE: GRØNMO

TEST RUN NO II, ACTIVATED SLUDGE A,S, 2

Influent: Raw leachate. Duration of experiment: September 10-October 14, 1974

Date of Sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$
10/9	10.1																			
11	"																			
12	"																			
13	"		8.15	284		39									2 620	1 350	230			0.16
14	"																			
15	"																			
16	"	13.5	8.1	290		38	85	35	107	74	69									
17	"																			
18	"												45	22	4 000	1 870				0.13
19	"	13.6	8.3	282		35	75	35	106	71	67									
20	"	14.1	8.1												4 160	1 930				0.12
21	"																			
22	"	13.2	8.3														220			
23	"	13.2	8.15	292		33	80	30	-	80					3 800	2 000		4.4	2.2	0.12
24	"																			
25	"			256	261	35	82.5	28												
26	"																			
27	"	14.0	8.1	298		27	77.5	37	109	74	68		54	33	3 350	1 740				0.13
28	"																			
29	"																			
30/9	"	12.9	8.2	242		41	65	47									240			
1/10	"																			
2	"						102.5	16												
3	"		8.3	272		34														
4	"	12.1	8.3	268		35						500	68	26	4 830	2 190	200	4.7	2.1	0.10
5	"																			
6	"																			
7	"		8.4	278		32														
8	"	12.6	8.2										37	13	4 300	1 980		3.6	1.3	0.11
9	"		8.2	238		42												3.4		
10	"		8.4	224		45	70	49										4.6		
11	"	12.1	8.0	214	210	48						530	65	28	4 130	1 850		3.0	1.6	0.12
12	"																			
13	"																			
14/10	10.1		8.1	290		29							46	19	3 640	1 520				0.15
Mean		13.1	8.2	263		36.3	78.9	34.5	108	75	67.5	515	54	23	4 026	1 885	220	4.0	1.9	0.12
S.dev.		0.7	0.1	28		6.3	12	11	-	4.5	-	-	13	7	448	197	20	0.7	0.3	0.01
No. 13/9-14/10		9	14	12		12	7	7	2	3	2	2	5	6	8	8	3	6	4	8

Table 85

LEACHATE SOURCE: GRØNMO

TEST RUN NO II, ACTIVATED SLUDGE A.S. 3

Influent: Raw leachate. Duration of experiment: September 10-October 14, 1974

Date of Sampling (Day/Month)	Feed 1/day	Temp aeration basin ^oC	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
10/9	18.4																			
11	"																			
12	"																			
13	"		7.65	248		47									3 020	1 525	280			0.29
14	"																			
15	"																			
16	"	13.0	8.0	242		48	122.5	6	100	68	68									
17	"																			
18	"												46	22	5 000	2 400				0.13
19	"	13.2	8.0				77.5	33	102	69	68									
20	"	14.0	7.9												5 050	2 430				0.17
21	"																			
22	"	12.8	8.1														275			
23	"	13.0	8.0	266		39	82.5	28	117	80	68				5 870	2 780		6.0	2.2	0.15
24	"																			
25	"			270	246	34	85.0	36												
26	"																			
27	"	13.8	8.0	274		33	75.0	39	100	72	72		80	42	4 710	2 390				0.16
28	"																			
29	"																			
30/9	"	12.6	8.0	260		37	70.0	43									340			
1/10	"																			
2	"								94											
3	"		8.2	268		35														
4	"	12.0	8.1	278		32						570			5 390	2 590	290	5.3	2.0	0.15
5	"																			
6	"																			
7	"		8.2	264		36														
8	"	12.2	8.0										39	16	4 400	2 200		5.9	2.7	0.15
9	"		7.9	282		31												6.1		
10	"		8.2	230		45		45										6.4		
11	"	12.0	7.9	220	215	48						600	69	25	4 900	2 370		5.4	2.3	0.17
12	"																			
13	"																			
14/10	18.4		8.0	323		24							37	27	4 400	2 120				0.19
Mean S.dev. No 18/9-14/10		12.8 0.7 9	8.0 0.1 14	267 27 11		35.8 6.6 11	77.5 5.5 6	37.3 6.3 6	103 10 4	74 5 3	69.3 2.3 3	585 - 2	54 19 5	26 10 5	4 965 495 8	2 410 207 8	301 34 3	5.9 0.4 6	2.3 0.3 4	0.17 0.01 5

Table 86

LEACHATE SOURCE: GRØNMO

TEST RUN NO II, ACTIVATED SLUDGE, A.S. 4

Influent: Raw leachate. Duration of experiment: September 10-October 14, 1974

Date of Sampling (Day/Month)	1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{l \cdot h}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$
10/9	23.7																			
11	"																			
12	"																			
13	"		7.7	278		40									4 200	2 085	310			0.35
14	"																			
15	"																			
16	"	12.8	7.6	288		38	85.0	35	100	70	70									
17	"																			
18	"												43	18						
19	"	13.0	7.9	256		41	77.5	33	99	69	70									
20	"	13.7	7.7												6 620	3 090				0.23
21	"																			
22	"	12.2	7.9														345			
23	"	12.8	7.9	284		35	87.5	24	117	82	70				7 230	3 380		16.0	4.7	0.21
24	"																			
25	"			260	266	36	92.5	20												
26	"																			
27	"	13.2	7.6	306		34	102.5	16	104	73	70		79	40	5 440	2 800				0.22
28	"																			
29	"																			
30/9	"	12.1	7.9	308		34	65.0	47	108	71	66						320			
1/10	"																			
2	"								102	72	71									
3	"		7.9	280		32												13.8		
4	"	11.7	7.9	282		31						615	88	32	7 000	3 340	350	16.8	5.0	0.19
5	"																			
6	"																			
7	"		8.1	278		32														
8	"	12.1	8.0										37	21	5 330	2 730		12.0	4.4	0.23
9	"		7.9	272		34												12.6		
10	"		8.1	226		46	95.0	31	54	74								13.2		
11	"	11.5	7.7	245	242	42						610	74	27	4 200	2 190		15.0	6.6	0.30
12	"																			
13	"																			
14/10	23.7		8.0	352		17							31	19	3 020	1 560				0.42
Mean		12.5	7.9	280		34.5	89	31.6	106	73.4	69	613	59	26	5 548	2 727	338	14.2	5.2	0.26
S.dev.		0.7	0.1	32		7.1	13	9	7	5	2	-	24	8	1 546	657	16	1.8	1.1	0.08
No. 18/9-14/10		9	14	12		12	7	6	5	5	5	2	6	6	7	7	3	7	4	7

Table 87

LEACHATE SOURCE: GRØNMO

TEST RUN NO II, ACTIVATED SLUDGE, A.S. 5

Influent: Raw leachate. Duration of experiment: September 10-October 14, 1974

Date of Sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
10/9	36.6																			
11	"																			
12	"																			
13	"		7.9	338		27									5 555	2 410	210			0.47
14	"																			
15	"																			
16	"	12.2	7.8	236		49	185		97	70	72									
17	"																			
18	"												65	27	6 630	3 010				0.37
19	"	13.0	7.9	330		24	85.0	26	102	55	54									
20	"	13.1	7.8												6 900	3 100				0.34
21	"																			
22	"	11.8	7.9														310			
23	"	12.2	7.9	342		21	85.0	26	117	42	36				8 110	3 400		34.8	10.2	0.31
24	"																			
25	"			334		23	102.5	11												
26	"																			
27	"	12.9	7.9	326		20	72.5	41	105	58	55		103	47	6 010	2 950				0.33
28	"																			
29	"																			
30/9	"	11.8	8.0	314		23	75.0	39	96	38	39						255			
1/10	"																			
2	"						107.5	12	101	46	46									
3	"		8.1	324		21														
4	"	11.1	8.1	310		24						805	123	45	11 300	3 800	250	27.0	7.1	0.26
5	"																			
6	"																			
7	"		8.2	344		16														
8	"	11.6	8.2										56	16	8 260	3 300		27.6	6.4	0.30
9	"		8.1	322		21												21.8		
10	"		8.4	322		24	100	27										20.6		
11	"	11.0	8.0	303	262	28						880	132	47	6 890	2 760		14.4	5.2	0.37
12	"																			
13	"																			
14/10	36.6		8.2	378		11							29	9	5 660	2 270				0.45
Mean		12.1	8.1	329		22.3	90.0	26.0	104	47.8	46.0	843	85	32	7 470	3 073	271	24.3	7.7	0.34
S.dev.		0.8	0.2	19		3.0	13.8	11.7	7.8	8.5	8.5	-	40	17	1 792	455	33	7.0	2.1	0.06
No. 12/9-14/10		9	14	12		11	7	7	5	5	5	2	6	6	8	8	3	6	4	8

Table 88

LEACHATE SOURCE: GRØNMO

TEST RUN NO II, ACTIVATIED SLUDGE, A.S.6

Influent: Raw leachate. Duration of experiment: September 10-October 14, 1974

Date of Sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Organic loading $\frac{kg\ COD}{kg\ MLVSS\ day}$
10/9	63.9																			
11	"																			
12	"																			
13	"		8.0	362		22														
14	"														3 605	1 400	140			1.41
15	"																			
16	"	11.7	8.0	294		37	132.5	0	103	28	27									
17	"																			
18	"																			
19	"	12.9	8.1	322		26	92.5	20	102	41	11		89	37	7 710	1 830				1.06
20	"	12.3	7.9																	
21	"														7 830	1 940				0.96
22	"	11.3	8.1																	
23	"	11.6	8.1	364		16	100.0	13	120	10	8						190			
24	"												90	66	12 750	2 300		13.2	5.7	0.81
25	"			336	312	23	117.5	0												
26	"																			
27	"	12.2	8.0	366		10			103	7	7									
28	"												112	49	4 640	1 260				1.38
29	"																			
30/9	"	11.0	8.2	356		13			80	3	4									
1/10	"																170			
2	"								94	4	4									
3	"		8.3	316		23														
4	"	10.5	8.3	364		11														
5	"											1 040	135	47	11 350	1 720	140	10.9	6.3	1.01
6	"																			
7	"		8.5	342		17														
8	"	11.0	8.4																	
9	"		8.3	390		5							342	89	2 500	740		6.5	8.7	
10	"		8.5	380		10												6.6		
11	"			335	320	21												7.7		
12	"											1 050	216	76	15 170	1 630		4.8		1.11
13	"																			
14/10	63.9		8.4	412		3									2 520	480				
Mean		11.9	8.1	349		17.6	103	11	100	7	6.8		97	51	8 232	1 832	180	13.2	5.7	1.05
S.dev.		0.7	0.1	19		6.7	13	10	15	3	3		13	14	3 354	431	-	-	-	0.24
No. 18/9-2/10		6	6	5		5	3	3	5	5	5		3	3	4	4	2	1	1	4

Table 89

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO III

Date of sampling (Day/Month)	pH	COD mg/l	TOC mg/l	Total nitrogen mg N/l	NO_3^- mg N/l	SS mg/l	VSS mg/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$
18/7		383						
21		455						
23		435						
25		432						
27	8.7	466						
29	8.7	445						
31/7	8.6	466						
2/8	8.6	458						
5		464						
7	8.5	467				64	22	
9		469						
12	8.8	482				58	18	
15		448				46	17	
19								
22		451				21	13	
27	8.9	463				75	56	
30/8	8.4	426				59	37	
2/9	9.0	416						
6	9.2	133						
9		261	77.5					
16		362	110					
19		404	112.5	102	1.9			
23	7.2	366	102.5	113	0.1			
27	7.0	306		84	0.5	17		
30/9	7.0	346	85	68	0.8			
3/10		398	157.5			24	13	1 450
7	8.3	442	127.5					
10		464	60	125	0.1			
14		433						
18	7.0	350	120	120				
21	7.9	328	100	100				
Mean	8.2	398	105	99	0.7	46	25	
S.dev.	0.7	83.3	27	23	0.7	22	16	
No	12	23	10	5	5	8	7	
2/8-21/10								

Table 90

LEACHATE SOURCE: GRØNMO

TEST RUN NO III A.S. I

Influent: Chemically coagulated leachate. Duration of experiment: July 18-October 21, 1974. Volume of aeration chamber: 32,3 l

Date of sampling (Day/month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$
17/7	9.2																
18				156	59												
21				199	56									5 300	3 030		
23				251	42												
25				255	41									5 280	3 140		
27	6.3	16	8.2	254	45									5 130	2 940	530	0.031
29			8.2	269	40							31	20	4 495	2 600	450	0.033
31/7			8.2	296	36									5 190	2 820	480	
2/8			8.7	319	30							52	37	8 300	2 940	410	0.031
5	6.7	15.5		357	23							39	13	4 690	2 530	350	0.038
7			8.2	456	2							44	13	5 200	2 670	350	
9				361	23							33	28	4 770	2 500		0.038
12	6.7		8.45	346	28							32	19	3 550	1 820	300	
15	7.2		8.4	305	32							50	33	3 730	2 130		0.047
19		16	8.2	286								57		4 420	2 070	230	
22	6.7		8.2	353	22							43	16	4 280	2 040	245	0.045
27	6.1		8.7	288	38							22	-	4 000	2 010	240	0.043
30/8	5.6		8.4	343	19							35	24	4 080	2 050	240	0.036
2/9		17	8.8	303	27												
6	7.7		9.0	257	-											210	
9	7.7		7.6	230	11	67.5	13										
14	9.4													3 960	1 790		0.058
16	9.6	15.5		224	38	80	27										
19	9.6			212	47	65	42	112	77	69				4 190	1 900		0.063
23	9.9		7.4	236	36	70		118	84	71				4 020	2 130	190	0.053
26	9.4		7.2	256	16	72.5		112	83	74		20	-	3 980	1 890		0.047
30/9	9.4		7.4	242	30	55	35									210	
3/10	9.4			206	48	67.5	57				690	30	22	4 130	1 930		0.060
7/10	9.7		8.3	232	47	55	56							4 060	1 910	220	0.069
10				224	51	75											
14	11.2			247	43												
18	10.2			216	38	72.5	40							4 300	2 080		0.053
21	10.2		8.3	232	29	57.5	43									210	
24	10.4																
Mean	8.6	16.0	8.2	280	30.8	67.0	39.1	114	81.3	71.3		38	23	4 210	2 090	261	0.049
S.dev.	1.6	0.7	0.5	63	12.6	8.3	14.5	3.5	3.8	2.5		11.6	8.5	407	259	68	0.011
No. 2/8-21/10	19	4	16	24	22	11	8	3	3	3		12	9	16	16	13	14

Table 91

LEACHATE SOURCE: GRØNMO

TEST RUN NO III A.S II

Influent: Chemically coagulated leachate. Duration of experiment: July 18-October 21, 1974. Volume of aeration chamber: 30.8 1

Date of sampling (Day/month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/1	COD-removal %	TOC mg/1	TOC-removal %	Total nitrogen mg N/1	NO_3 mg N/1	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{1}$	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Organic loading $\frac{\text{kg COD}}{\text{kg MLVSS day}}$
18/7				253	34												
21				303	33									4 480			
23				298	31												
25				292	32									4 630	2 870		
27	12.6	16	8.1	336	28									4 498	2 668	360	0.07
29			8.1	326	27							45	23	5 110	2 805	370	0.65
31/7			8.1	357	23									4 320	2 450	320	0.077
2/8			8.7	319	30							82	48	4 620	2 740	360	0.68
5	13.6	15.5		359	23							33	26	3 940	2 150	230	0.095
7			8.1	415	11							61	31	3 990	2 180	190	0.95
9				417	11							69	52	3 600	2 030		0.10
12	13.0		8.4	377	22							67	33	4 960	2 410	170	0.08
15	25.0		8.3	407	9							52		3 120	1 960		0.18
19	13	16	8.4	344								75	26	3 010	1 400	150	
22	10.3		8.2	339	25							22		2 980	1 460	150	0.10
23												43	16				
27	9.0		8.7	320	31							15	-	2 870	1 600	140	0.85
30/8	10.4	16.5	8.4	347	18							49	35	3 030	1 600	150	0.09
2/9	11.5		8.7	301	28												
6	13.2		9.0	220	-											150	
9	12.4		7.6	170	35	57.5	26										
16	13.2	15.5		236	35	72.5	34							2 960	1 410		0.11
19	13.2			242	40	70	38	110	78	71				3 290	1 550		0.11
23	13.9		7.4	262	28	67.5		112	84	75				3 030	1 750	135	0.09
26	13.1		7.2	268	12	85		116	83	72		24	20	2 940	1 500		0.086
30/9	13.6		7.3	250	28	57.5	32									140	
3/10	10.4					67.5	57				690	29	18	2 760	1 390		0.10
7	14.9		8.4	226	49	62.5	51							2 940	1 470	140	0.14
10				272	41	70	-										
14	15.8			254	41												
18	16.5	16.0		244	30	70	42							3 350	1 790		0.10
21	16.5		8.2	260	21											160	
24/10	15.1																
Mean	13.8	15.9	8.2	297	27.0	68	40	113	81	72.7		48	30.5	3 376	1 788	159	0.102
S.dev.	3.2	0.4	0.5	68	11.0	7.9	10.9	3.0	3.2	2.1		22	12.0	642	398	78	0.026
No. 2/8-21/10	22	6	15	23	21	10	7	3	3	3		13	10	17	17	13	16

Table 92

LEACHATE SOURCE: GRØNMO

TEST RUN NO III A.S III

Influent: Chemically coagulated leachate. Duration of experiment: July 18-October 21, 1974. Volume of aeration chamber: 28.8 1

Date of sampling (Day/month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/1	COD-removal %	TOC mg/1	TOC-removal %	Total nitrogen mg N/1	NO_3 mg N/1	Nitri-fication %	Alka-linity mg $CaCO_3$/1	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Organic loading kg COD/kg MLVSS day
18/7				276	28												
21				309	32									4 120	2 510		
23				343	21												
25				341	21									4 080	2 710		
27	21.6	16	8.0	374	20									4 590	2 900	320	0.12
29			8.0	351	21							19	15	6 000	3 605	520	
31/7			8.0	361	23									5 880	3 460	640	
2/8			8.6	332	28							100	64	5 700	3 440	480	
5	25.6	15.5		357	23							36	23	4 780	2 690	300	0.15
7			8.2	373	20							92	44	5 780	3 200	430	0.13
9				349	26							38	14				
12	24.3		8.5	444	8							104	60	4 530	2 410	360	0.17
15	24.3		8.3	543	17									3 810	2 450	230	0.15
19		16	8.4	299								58		3 910	2 000		
22	19.8		8.1	418	8									3 670	1 960	220	0.16
23												38	21				
27	18.4		8.6	341	26							17		3 540	2 040	200	0.15
30/8	15.1	17	8.3	360	15							45	31	3 730	2 050	200	0.11
2/9	16.9		8.6	311	25												
6	20.4		8.9	367	-											140	
9	16.3		7.5	190	27	57.5	26										
16	21.6	15.5		240	34	75	32							3 380	1 660		0.16
19	19.2			260	36	70	38	106	75	71				3 590	1 730		0.16
23	18.9		7.4	272	26	70	32		82					3 490	2 040	160	0.12
27	19.6		7.2	270	12	77.5		117	85	73		12	-	3 400	1 870	170	0.11
30/8	25.1		7.0	232	33			109	71								
3/10	18.6			234	41	77.5	51			65	700	26	21	3 720	1 970		0.13
7	26.2		8.3	246	44	70.0	45							3 680	1 890	180	0.21
10				290	38	80.0	-	72	87								
14	24.5			280	35												
18	23.6			258	26	75	38							4 090	2 310		0.12
21	24.8		8.1	273	17	75	25									160	
Mean	21.3	16.0	8.1	314	25.7	72.7	35.8	101	80	70		51.4	34.8	4 050	2 232	248	0.145
S.dev.	3.3	0.7	0.6	79	10	6.4	9.0	19.9	6.8	4.1		32.9	19.0	761	505	110	0.027
No. 2/8-21/10	19	4	16	24	22	10	8	4	5	3		11	8	16	16	13	14

Table 93

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO IV

Date of sampling (Day/Month)	pH	COD	TOC	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	Total nitrogen mg N/l	NH_4^+ mg N/l	NO_3 mg N/l
24/10	8.05	416					
28		462	140				
31/10	8.2	446					
4/11	8.6		170				
6		462					
7	8.5	446					
8							
11	8.2	458		1 610			
15	7.90	364					
18		404					
25	7.7	464	117.5		127.7		0.1
29/11		434	135		94.4		0
2/12	8.2	530	147.5		153.5		0.1
4		459	140		98.4		0.1
6		424	140				
9	8.4	436	155		136	140	0.5
11		554	155		153		0
15	8.6	459	155		124	132	0.1
18		460	145		134	131	0.1
20		466	122.5				
Mean	8.2	454	141		128	134	0.1
S.dev.	0.3	45	13		22	5	0.2
No 6/11-20/12	7	15	10		8	3	8

Table 94

LEACHATE SOURCE: GRØNMO TEST RUN NO IV A.S. I

Influent: Chemically coagulated leachate. Duration of experiment: October 24–December 20, 1974. Volume of aeration chamber: 32.3 l

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Ammonia mg N/l	Nitrification %	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Organic loading kg COD / kg MLVSS day
24/10	25		8.5	230	45									4 140	2 300		
28	27			220	52	62.5	55										
31/10	23		8.3	210	53									4 320	1 910		
4/11	24	16.5	8.4			85	50							3 930	2 010	160	
6	25			242	48												
7	27		8.3	238	47												
8	26																
11	25		8.2	302	34							16		4 025	1 945	132	0.18
15	25		8.2	264	27												
18	28	16.5		248	39									3 900	1 940	150	0.18
25	25		8.1	322	31	105	11	116	90		78			4 160	2 020		0.18
29/11	29	17		242	44	100	26	108	80		74	30	15				
2/12	25		8.0	470	11	107.5	40	120	56		52				2 370	140	0.17
4	25			292	36	105	25	120	93		78						
6	28			249	41	95	32										
9	26	17.5	7.9	255	41	95	39	126	86	0.3	68			4 820	2 470		0.14
11	25			325	41	102.5	34	128	94		73			4 815	2 445	155	0.18
15	28			304	34	102.5	34	126	90	0.5	71						
18	29	17	8.2	269	41	97.5	33	124	92	0.5	74						
20	25			274	41	77.5	37									120	
Mean	26.3	17	8.1	273	37.1	98.8	33.3	121	85	0.4	71	23	15	4 344	2 198	139	0.17
S.dev.	1.6	0.4	0.1	30	9.2	8.6	5.1	6.6	12	0.1	8.4	-	-	441	255	14	0.02
No. 6/11-20/12	16	4	7	14	15	10	9	8	8	3	8	2	1	5	6	5	6

Table 95

LEACHATE SOURCE: GRØNMO TEST RUN NO IV A.S. I1

Influent: Chemically coagulated leachate. Duration of experiment: October 24-December 20, 1974. Volume of aeration chamber: 30.8 1

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/1	COD-removal %	TOC mg/1	TOC-removal %	Total nitrogen mg N/1	NO_3 mg N/1	Ammonia mg N/1	Nitrification %	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Organic loading kg COD / kg MLVSS day
24/10	40	-	8.3	266	36									3 560	1 860		
28	43			228	51	67.5	52										
31/10	38		8.4	234	48									3 780	1 750		
4/11	42	16.5	8.2			90	47							3 450	1 960	170	
6	39			234	38												
7	46		8.1	248	44												
8	42											16		3 630	1 885	175	0.29
11	37		8.4	312	32												
15	41		8.2	222	39												
18	42	16.5		230	43									3 850	1 930	160	0.28
25	54		7.9	324	30			110	70		63			3 070	1 440		0.56
29/11	35	17		250	42	100	26	112	85		76	25	18				
2/12	50		7.8			102.5	45	116	92		79				2 550	190	0.34
4	61			347	24	110	21	120	92		77						
6	52			265	38	97.5	31										
9	46	17.5	8.0	271	38	102.5	34	122	85	0.5	70			5 355	3 050		
11	48			354	36	107.5	31	126	92		73			5 695	3 015	210	0.22
15	50			296	36	82.5	47	124	85	0.3	67						
18	43	16.5	8.2	271	41	92.5	36	126	93	0.5	74						
20/12	47			298	36	90	26									202	
Mean	45.8	16.8	8.1	284	36.9	98.3	33.0	119	87	0.4	72	20	18	4 320	2 311	187	0.29
S.dev.	6.7	0.5	0.2	40.7	5.4	8.7	8.6	6.2	7.7	0.1	5.4	-	-	1 143	660	20	0.05
No.	16	4	7	14	14	9	9	8	8	3	8	2	1	5	6	5	4
6/11-20/12																	

Table 96

LEACHATE SOURCE: GRØNMO

TEST RUN NO IV A.S. III

Influent: Chemically coagulated leachate. Duration of experiment: October 24-December 20, 1974. Volume of aeration chamber: 28.8 l

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	Ammonia mg N/l	Nitrification %	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Organic loading kg COD / kg MLVSS day
24/10	53		8.3	234	44									4 020	1 920		
28	58			228	51	70	50										
31/10	65		8.4	240	46									4 340	2 230		
4/11	62	16.5	8.5			90	47							4 100	2 420	200	
6	68	-		292	37												
7	69		8.3	294	34												
8	72											13		4 355	2 355	210	0.46
11	68		8.4	353	23												
15	69		8.3	246	32												
18	79	16.5		196	51									5 610	2 820	180	0.39
25	78		8.0	368	21	125	-	116	19		16			7 070	2 750		0.46
29/11	68	17		284	34	100	25	112	18		16	38	22				
2/12	74		7.9	436	18	105	29	124	16		13			10 720	3 310	170	0.41
4	90			303	34	112	20	132	13		10						
6	79			282	33	100	29										
9	72	17.5	8.1	300	31	95	39	136	12	116	9			19 455	3 485		0.32
11	86			388	30	120	23	116	8		7			13 960	3 020	150	0.54
15	80			344	25	92.5	40	113	7	112	6						
18	70	17	8.3	358	22	82.5	43	129	8	127	6						
20	73			376	19	120	2									165	
Mean	74.7	17	8.2	321	29.6	105	31.0	122	12.6	118	10.4	26	22	10 195	2 957	175	0.43
S.dev.	6.7	0.4	0.2	61	8.6	13.8	8.6	9.3	4.7	7.7	4.1	-	-	5 746	408	22	0.07
No.	16	4	7	15	15	10	9	8	8	3	8	2	1	6	6	5	6
6/11-20/12																	

Table 97

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO V

Date of sampling (Day/Month)	pH	COD mg/l	TOC mg/l	Total nitrogen mg N/l	NO_3^- mg N/l	SS mg/l	VSS mg/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$
9/8		469						
12	8.8	482				58	18	
15		448				46	17	
19								
22		451				21	13	
27	8.9	463				75	56	
30/8	8.4	426				59	37	
2/9	9.0	416						
6	9.2	133						
9		261	77.5					
16		362	110					
19		404	112.5	102	1.9			
23	7.2	366	102.5	113	0.1			
27	7.0	306		84	0.5	17		
30/9	7.0	346	85	68	0.8			
3/10		398	157.5			24	13	1 450
7	8.3	442	127.5					
10		464	60	125	0.1			
14		433						
18	7.0	350	120	120				
21	7.9	328	100					
24	8.05	416						
28		462	140					
31/10	8.2	446						
4/11	8.6		170					
6		462						
7	8.5	446						
Mean	8.1	399	114	102	0.7	42	26	
S.dev.	0.8	80	32	20	0.7	22	17	
No	15	25	12	7	5	7	6	
9/8-7/11								

Table 98

LEACHATE SOURCE : GRØNMO

TEST RUN NO V, BIODISC

Influent: Chemically coagulated leachate. Temperature og operation 17 °C. Duration of experiment: July 17-November 7, 1974

Date of sampling (Day/Month)	Feed 1/day	pH effluent	COD mg/l	COD removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Per cent nitrification	SS mg/l	VSS mg/l	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	Organic loading $\frac{\text{kg COD}}{\text{m}^2 \text{ day}}$
9/8	28.8	8.7	452	4						32	24		4.1
19	27.4	8.5	427							32	-		3.7
23	30.4	8.1	365	19						26	13		4.2
27/8	25.2	8.5	363	22						30	-		3.5
2/9	25.7		362	13									3.2
6	30	8.9	246	0									1.2
9	30.7		170	31	55	29				42	18		2.4
16	66	7.4	290	20	87	21							7.2
19	69.2		300	26	80	29	90.4	21	23				8.4
23	66.3	7.2	296	19	85	17	100	13	13				7.4
27	64.8	7.0	306	0	95		99	12	12	19	-		6.0
30/9	69.2		266	23	65	23							7.2
3/10	65.3	7.8	344	14	115	27				25	14	1 170	7.9
10	62.3		392	16	115		67	29	43				8.8
14	57.5	8.4	332	23						33	21		7.5
18	58.3		340	3	100	17							6.2
21	64.3	8.5	312	5									6.4
24	60.9		292	29									7.7
28	56.4	8.3	344	25	100	29	86	14	16				7.9
31/10	59.5		388	13									8.0
6/11	55.3	8.5	408	12	130	23							7.7
7/11	64.6		394	12									8.7
Mean	51.7	8.1	336	15.9	90	23.8	88.5	17.8	21.4	30.0	18		6.2
S.dev.	16.8	0.6	64.5	9.0	23	4.9	13.4	7.2	12.8	6.8	4.6		2.2
No 9/8-7/11	22	13	22	21	9	9	5	5	5	8	5		22

Table 99

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO VI

Date of sampling (Day/Month)	pH	COD mg/l	TOC mg/l	Total nitrogen mg N/l	NO_3^- mg N/l	SS mg/l	VSS mg/l	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$
2/9	9.0	416						
6	9.2	133						
9		261	77.5					
16		362	110					
19		404	112.5	102	1.9			
23	7.2	366	102.5	113	0.1			
27	7.0	306		84	0.5	17		
30/9	7.0	346	85	68	0.8			
3/10		398	157.5			24	13	1 450
7	8.3	442	127.5					
10		464	60	125	0.1			
14		433						
18	7.0	350	120	120				
21	7.9	328	100	100				
24	8.05	416						
28		462	140					
31/10	8.2	446						
4/11	8.6		170					
6		462						
7	8.5	446						
Mean	8.0	381	114	102	0.7			
S.dev.	0.8	83	32	20	0.7			
No 2/9-7/11	12	19	12	7	5			

Table 100

LEACHATE SOURCE : GRØNMO TEST RUN NO VI : TRICKLING FILTER

Influent: Chemically coagulated leachate. Temperature of operation 17 °C. Duration of experiment: August 5-November 7, 1974

Date of sampling (Day/Month)	Feed 1/day	pH effluent	COD mg/l	COD removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Per cent nitrification	SS mg/l	VSS mg/l	Alkalinity $\frac{mg\ CaCO_3}{l}$	Organic loading $\frac{kg\ COD}{m^3\ day}$
		8.4											
2/9	1 180	9.0	404	3									0.76
6	1 440	9.1	186	0									0.29
9	1 728		238	9	60	22				28	18		0.69
16	2 160	7.4			110	0				14	10		1.20
19	2 160		392	3	102.5	9	95	0.8	0.8				1.30
23	1 944	7.3	348	5	97.5	5	96	0.6	0.6				1.09
27	1 730	7.2	346	13	97.5		84	0.9	1,0	8			0.81
30/9	1 540		292	16	75	12							0.82
3/10	1 870	7.6	360	9	147.5	6				28	16	1 170	0.86
7	1 410		448	0	122.5	4							0.96
10	1 630		434	6	130	0	123	0.1	0.1				1.16
14	1 520	8.5	417	4						38	22		1.01
18	1 230		404	0	117.5	2							0.82
21	1 480	8.4	295	10									0.75
24	1 760		371	11									1.13
28	1 910	8.0	418	9	127.5	9	94	0.4	0.4				1.36
31/10	1 580		416	7									1.08
6/11	1 620	8.6	450	3	160	6							1.15
7	1 830		418	6									1.19
Mean	1 670	8.1	369	7.4	112	7.5	98.4	0.56	0.58	23.2	16.5		0.98
S.dev.	272	0.7	73.7	4.0	28	5.7	14.5	0.3	0.3	12.0	5.0		0.26
No 2/9-7/11	19	10	18	18	12	11	5	5	5	5	4		19

Table 101

LEACHATE SOURCE: GRØNMO

INFLUENT CHARACTERISTICS FOR TEST RUN NO VII

Date of sampling (Day/Month)	pH	COD mg/l	TOC mg/l	Total nitrogen mg N/l	NO_3 mg N/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
10.9.- 18.9	6.8	466	130	98	5.4		84	33	42	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
18.9.- 25.9	6.8	435	115	117	1.4	1 500	141	44	68	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
25.9.- 2.10	6.8	410	122.5	96	0.7		80	40	56						
2.10.-10.10	6.9	411	151	96	0.0	1 290			70						
10.10.-14.10	6.9	424	137.5	100	0.8	1 300	114	27	105	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mean	6.9	420	131.5	102	3.2	1 363	112	37	74.8						
S.dev.	0.1	12	16	10	4.5	118	31	9	21						
No 18/9 - 14/10	4	4	4	4	4	3	3	3	4						

Table 102

LEACHATE SOURCE: GRØNMO

TEST RUN NO VII, AERATED LAGOON A.L.1

Influent: Raw leachate. Duration of experiment: August 12-October 14, 1974. Volume of aeration basin: 140 l

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD removal	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	SS mg/l	VSS mg/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$
5/9	3.8	13.9	8.6	289	42								
13				298	36						15	13	
16		13.6	8.5	290	38	92	29	110	81	73			
19		13.0	8.6	316	27	82.5	28	120	81	68			
23		12.8	8.5	276	36	80	30				10		
25		12.8	8.6	249	43	92.5	20						
27		13.2	8.4	278	32	87.5	29	120	79	66			
30/9		12.2	8.5	310	24	105	14						
3/10				314	24	100	34	103	69	67			
4		12.0	8.4	282	31						22	8	450
7		12.0	8.6	268	35						9	6	
9		11.6	8.3	292	29								
10			8.6	268	37	85	38				17	8	
11		11.0	8.2	247	42								
14	3.8	11.2	8.3	362	15						22	14	470
Mean		12.4	8.5	289	32.7	90.6	27.8	113	77.5	68.8	15.8	9.8	460
S.dev.		0.9	0.1	29	7.9	8.6	7.5	8.3	5.7	3.6	5.6	3.5	
No 5/9-14/10		12	13	15	15	8	8	4	4	4	6	5	

Table 103

LEACHATE SOURCE: GRØNMO

TEST RUN NO VII, AERATED LAGOON A.L.2

Influent: Raw leachate. Duration of experiment: August 12-October 14, 1974. Volume of aeration basin: 140 l

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD removal	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	SS mg/l	VSS mg/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$
5/9	14.1	13.9	8.4	307	38								
13				356	24						30	5	
16		13.6	8.3	288	38	105	19	104	50	48			
19		13.0	8.4	276	37	87.5	24	112	43	38			
23		12.8	8.4	322	26	82.5	28	110	35	32	20	-	
25		12.8	8.5	269	38	100	13						
27		13.0	8.3	310	24	97.5	20	100	31	31			
30/9		12.0	8.4	306	25	80	35						
3/10				368	10	110	27	102					
4		11.8	8.4	274	33								800
7		11.8	8.6	328	20						20	11	
9		11.5	8.4	292	29								
10			8.6	288	32	90	35				46	22	
11		11.0	8.3	317	25								
14	14.1	11.1	8.4	371	13						23	13	840
Mean		12.3	8.4	311	27.4	94	25.1	105	39.7	37.2	27.8	12.8	820
S.dev.		1.0	0.1	33	8.8	10.7	7.7	5.2	8.5	7.8	10.9	7.0	
No 5/9-14/10		11	13	15	15	8	8	5	4	4	5	4	2

Table 104

LEACHATE SOURCE: YGGESETH

INFLUENT CHARACTERISTICS FOR TEST RUN NO VIII AND IX

Date of sampling (Day/Month)	COD mg/l	TOC mg/l	Total nitrogen mg N/l	NO_3 mg N/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
15/10 - 23/11	9425	1700	250	0.1	1 960	466	182	178	2.4	0.1	0.1	<0.1	<0.1	<0.1

Table 105

LEACHATE SOURCE : YGGESETH

TEST RUN NO VIII activated sludge, A.S 1

Influent : Raw leachate. Organic loading : 0.08 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$ Duration of experience : October 15. - November 23. 1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS	Specific resistance to filtration m/kg
15/10	0.72	8	8.5																						
16	"		8.5																						
21	"	12	8.6																						
22	"		8.4												2000	1010									
23	"	12.3															140								
24	"	11.8	8.4	136		98.6									3020	1390		6	4.7						
25	"	12.1	8.5	142		98.5									2490	1280	140	12.5	9.8						
28	"	12.0	8.4	176		98.1									2810	1660		7.9	4.7						
29	"	12.7	8.4												3140	1830		12.6	6.8						
30	"		8.4	132	130	98.6	40	97.6	52	34	65		8.0	8	2940	1720		15.0	8.7						
31/10	"		8.4	132		98.6									2750	1650									
1/11	"		8.3												2980	1590		9.0	5.7						
3	"														3080	1880									
4	"	11.7	8.5	172		98.2							16	16	2930	1810	308	6.0	3.3						
5	"	9.9	8.4									410			3700	2280		8.8	3.9						$2.2 \cdot 10^{12}$
6	"		8.2												3400	1990									
7	"		8.3	198	188	97.9							19	19	3700	2150	250								
8	"		8.2												3730	2200									
9	"	13.8		146		98.5	35	97.9	14.4	5.5	38				3600	2270	270								$1.2 \cdot 10^{12}$
10	"	13													3350	2020	260								$1.3 \cdot 10^{12}$
11	"		8.5	150		98.4							13	9	4500	2770									
12	"		8.4									500			4680	2700									
13	"		8.5	140		98.5									4510	2680		12	4.5						
14	"	13.0	8.6										8	6	4550	2700	430	12.6	4.7						$1.2 \cdot 10^{12}$
15	"		8.3	186		98.0	45	97.4	11.8	4.6	39				4910	2990		12.1	4.0	1.0	4910	4910	2990	2990	
16	"																								
18	"		8.3	132		98.6							14		4760	2830		16.8	5.9						
19	"		8.6										9	9	4880	2980	550	16.2	5.4	1.4	5368	10278	4172	7162	$1.4 \cdot 10^{12}$
20	"	13.1													4750	2830									
21	"		8.4	124		98.7	36	97.9	16.8	8.5	53	485	26	21	4630	2630		8.8	3.3						
22	"														5030	3040		10.0	3.3						
23	0.72		8.4	134		98.6									5090	3030		9.6	3.2						
Mean		12.4	8.4	153		98.4	39	97.7	14.3	6.2	43	465	15	13	4261	2573	345	11.3	4.2						$1.38 \cdot 10^{12}$
S.dev.		1.4	0.1	25		0.3	5.5	0.3	2.5	2.0	8.4	48	6	6	676	413	120	3.4	0.9						$0.5 \cdot 10^{12}$
No		6	14	9		9	3	3	3	3	3	3	7	6	18	18	6	10	10						5
4/11-23/11																									

Table 106

TEST RUN NO VIII ACTIVATED SLUDGE, A.S 2

LEACHATE SOURCE : YGGESETH

Influent : Raw leachate. Organic loading : 0.16 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$ Duration of experiment : October 15. - November 23.1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/1	COD Filt. mg/1	COD-removal %	TOC mg/1	TOC removal %	Total nitrogen mg N/1	NO$_3$ mg N/1	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{1}$	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Oxygen uptake rate $\frac{\text{mg O}}{1 \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal 1	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS	Specific resistance to filtration m/kg
15/10	1.56		8.5																						
16	"		8.5																						
21	"	12	8.5																						
22	"		8.4												3290	1630									
23	"	12.3															200								
24	"	11.8	8.4	146		98.5									4620	2150		16.4	7.6						
25	"	12.1	8.4	142		98.5									4250	2110	240	24.0	11.4						
28	"	12.0	8.3	184		98.0									7630	3370		27.0	8.0						
29	"	12.7	8.3												5610	3340		23	6.9						
30	"		8.3	184	156	98.0	42.5	97.5	61.6	40	65		13	13	5480	3390		18.0	5.3	4.2	20538	20538	14238	14238	
31	"		8.3	160		98.3									4920	3000				2.0	9840	30378	6000	20238	
1/11	"		8.2												4770	2710		12.7	4.7	1.0	4920	35298	2710	22948	
3	"														5050	3140				2.5	12625	47923	7850	30798	
4	"	12.0	8.4	192		97.9							31	30	4420	2800	328	10.8	3.9						
5	"	10.0	8.4									520			4970	3290		13.0	4.0	3.0	14910	62833	9870	40668	$2.3 \cdot 10^{12}$
6	"		8.2												4240	2640									
7	"		8.2	250	240	97.3							16	16	4720	3010	345			1.5	7080	69913	4515	45183	
8	"		8.2												4220	2680									
9	"	14.1		228		97.6	55	96.8	21.6	2.9	13				4330	2980	310			2.0	8660	78573	5960	51143	$1.9 \cdot 10^{12}$
10	"	13.0													4230	2700	270			1.0	4230	82803	2700	53843	$2.4 \cdot 10^{12}$
11	"		8.6	224		97.6							18	17	4160	2880				0.5	2080	84883	4420	58263	
12	"		8.3									585			4500	2970				1.0	4500	89383	2970	61233	
13	"		8.4	214		97.7									4390	2840		16.8	5.9	1.0	4390	93773	2840	64073	
14	"	13.2	8.5										7	5	4700	3120	370	15.2	4.9	2.0	9400	103173	6240	70313	$1.9 \cdot 10^{12}$
15	"		8.2	280		97.0	82.5	95.1	23.0	1.0	4				4980	3150		15.8	5.0	2.0	11840	115013	6300	76613	
16	"																			2.0	9600	124613	6100	82713	
18	"		8.3	232		97.5							28	10	4660	3010		15.4	5.1	2.0	9320	133933	6020	88733	
19	"		8.6												4630	3030	410	14.4	4.7	1.5	6945	140878	4545	93278	
20	"	13.0													4370	2910				1.0	4370	145248	2910	96188	$2.6 \cdot 10^{12}$
21	"		8.3	264		97.2	92.5	94.6	42.4	0.8	2	620	74	61	4550	2920		11.0	3.8	1.0	4550	149798	2920	99108	
22	"														4630	3040		13.2	4.3						
23	1.56		8.4	256		97.3									4690	3090		16.8	5.4						
Mean		12.6	8.4	238		97.5	76.7	95.5	29	1.6	63	575	29	23	4522	2948	339	14.2	4.7						$2.2 \cdot 10^{12}$
S.dev.		1.4	0.1	27		0.3	19	1.2	11	1.1	5.8	50	24	20	246	172	48	2.2	0.7						$0.3 \cdot 10^{12}$
No		6	14	9		9	3	3	3	3	3	3	6	6	18	18	6	10	10						5
4/11 - 23/11																									

Table 107

TEST RUN NO VIII , ACTIVATED SLUDGE A.S 3

LEACHATE SOURCE : YGGESETH

Influent : Raw leachate. Organic loading : 0.28 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$. Duration of experiment : October 15. - November 23. 1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS	Specific resistance to filtration m/kg
15/10	2.93		8.5																						
16	"		8.4																						
21	"	12.0	8.5																						
22	"		8.4												3750	1960									
23	"	12.3															190								
24		11.8	8.2	184		98.0									5270	2620		20.9	8.0						
25	"	12.1	8.2	304		96.7									4910	2000	270	25.1	12.5						
28		12.0	8.0	1140		87.9									8550	2940		20.6	7.0						
29		12.7	8.1												5870	3640		25.9	7.1						
30	"		8.0	1204	1672	81.9	430	74.7	78.4	6.6	8		22	22	5790	3610				4.2	24318	24318	15162	15162	
31/10	"		8.0	2160		77.0									4810	3110				2.0	9620	33938	6220	21382	
1/11	"		8.0												4550	2850		21.6	7.6	1.0	4550	38488	2850	24232	
3															6070	3930				3.0	18210	56698	11790	36022	
4	"	11.6	8.1	2320		75.4							25	25	6290	4010	445	35.8	8.9	2.0	12580	69278	8020	44042	
5	"	10.2	8.2									990			5900	3900		37.8	9.7	4.0	23600	92878	15600	59642	$5.6 \cdot 10^{12}$
6			8.0												5200	3370				3.0	15600	108478	10110	69752	
7	"		8.2	1326	1280	85.9							63	63	5330	3390	275			3.0	15990	124468	10170	79922	
8	"		8.1												3400	2210									
9	"	14.2		1216		87.1	265	84.4	92	0.1	0.1				5220	3530	270			2.0	10440	134908	7060	86982	$1.4 \cdot 10^{12}$
10	"	13.2													5130	3390	260			3.0	15390	150298	10170	97152	$6.7 \cdot 10^{12}$
11	"		8.3	1056		88.8							153	140	3570	2540									
12	"		8.2									920			4390	2930				1.0	4390	154688	2930	100082	
13	"		8.2	1296		86.2									5740	3700		40.8	11.0	2.0	11480	166168	7400	107482	
14	"	13.5	8.3										200	163	5600	3590	360	40.2	11.2	3.0	16800	182968	10770	118252	$1.6 \cdot 10^{13}$
15	"		8.2	1272		86.5	240	85.5	100	0.3	0.3				6800	4040		44.2	10.9	4.0	27200	210168	16160	134412	
16	"																			2.0	13000	223168	7800	142212	
18	"		8.2	1176		87.5							282	252	6260	3790		35.6	9.4	4.0	25040	248208	15160	157372	
19	"		8.4												5330	3360	325	38.4	11.4	3.0	16050	264258	10080	167452	$1.1 \cdot 10^{13}$
20	"	13.2													5090	3100				2.0	10180	274438	6200	173652	
21			8.5	1128		88.0	150	91.1	114.8	0.1	0.1	770	436	406	5220	3100		25.6	8.3	2.0	10440	284878	6200	179852	
22	"														4550	3010		31.2	10.4						
23	2.93		8.2	1184		87.4									4460	2910		25.2	8.7						
Mean		12.7	8.2	1206		87.2	218	87.1	102	0.2	0.2	893	193	175	5298	3390	323	35.5	10.0						$3.3 \cdot 10^{12}$
S.dev.		1.5	0.1	90		1.0	60	3.5	11.6	0.1	0.1	112	150	138	790	423	71	6.3	1.1						$2.6 \cdot 10^{12}$
No 4/11-29/11		6	14	8		8	3	3	3	3	3	3	6	6	17	17	6	10	10						5

Table 108

LEACHATE SOURCE: YGGESETH

INFLUENT CHARACTERISTICS FOR TEST RUN NO VIII AND IX

Date of sampling (Day/Month)	COD mg/1	TOC mg/1	Total nitrogen mg N/1	NO_3 mg N/1	Alkalinity $\frac{mg\ CaCO_3}{1}$	SS mg/1	VSS mg/1	Fe mg/1	Zn mg/1	Cu mg/1	Cr mg/1	Cd mg/1	Pb mg/1	Ni mg/1
15/10 - 23/11	9425	1700	250	0.1	1 960	466	182	178	2.4	0.1	0.1	<0.1	<0.1	<0.1

Table 109

LEACHATE SOURCE: YGGESETH

TEST RUN NO IX, ACTIVATED SLUDGE A.S. 1

Influent: Raw leachate

Zn addition = 0 ppm. Organic loading $\frac{0.30 \text{ kg COD}}{\text{kg MLVSS day}}$.

Duration of experiment: November 24-December 21, 1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS
25/11	1.6				570	93.9							76	60	5 610	3 680				2.5	14 025	14 025	9 200	9 200
26	"		8.2												5 090	3 270				1.0	5 090	19 115	3 270	12 470
27	"	13.1		427		95.3						740			5 090	3 300	559	(35.4)	10.7	3.0	15 270	34 385	9 900	22 370
28	"		8.6												4 500	3 050		25.2	8.3	2.0	9 000	43 385	6 100	28 470
29/11	"		8.3	356		96.2									4 530	2 980				2.0	9 060	52 445	5 960	34 430
2/12	"	13.2	8.2	518		94.5							70	–	4 920	3 210	573	17.2	5.4	3.0	14 760	67 205	9 630	44 060
3	"	12.4													4 940	3 320				4.1	20 254	87 459	13 612	57 672
4	"			463		95.1									4 300	2 860	442			1.0	4 300	91 759	2 860	60 532
5	"	13.4	8.4				135	87	0.1		0				4 730	3 100		15.0	4.8	2.0	9 460	101 219	6 200	66 732
6	"			529		94.4									4 600	2 920		12.6	4.3	4.0	18 400	119 619	11 680	78 412
9	"	13.8	8.4	601		93.6									4 680	3 000		17.2	5.7	1.5	7 020	126 639	4 500	82 912
10	"	13.7	8.3										114	44	4 250	2 870	360	18.8	6.6	2.6	11 050	137 689	7 462	90 374
11	"			616	410	93.5									4 530	2 650		14.9	5.6	1.9	8 607	146 295	5 035	95 409
12	"	13.1	8.4									880			4 600	2 720		15.7	5.8					
13	"	11.5		507		94.6									4 150	2 570		14.8	5.8	0.5	2 075	148 371	1 285	96 694
15	"		8.3																					
16	"	13.7	8.5	541		94.3	105	95	0.1	88	0				4 800	2 920	565	17.5	6.0	1.0	4 800	153 171	2 920	99 614
17	"												37	37	4 800	3 100		12.7	4.1	2.3	11 040	164 211	7 130	106 744
18	"	12.9	8.4									800			4 290	2 730				4.1	17 589	181 800	11 193	117 937
19				453		95.2	160	71	1,0	84	0				4 370	2 610		5.8	2.2					
20/12	1.6			464	334	95.1									4 680	2 720								
Mean		13.1	8.4	522		94.5							73.7		4 576	2 886	485	14.7	5.1					
S.dev.		0.7	0.1	58		0.6							38.6		252	226	102	3.5	1.2					
No		9	8	9		9							3		15	15	4	11	11					
2/12-20/12																								

Table 110

LEACHATE SOURCE: YGGESETH

TEST RUN NO IX , ACTIVATED SLUDGE A.S.2

Influent: Raw leachate

Zn addition = 10 ppm. Organic loading $\frac{0,28 \text{ kg COD}}{\text{kg MLVSS day}}$.

Duration of experiment: November 24-December 21, 1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS
25/11	1.6			432		95.4								91	69	4 730	3 040				1.2	5 676	5 676	3 648	3 648
26	"		8.3													4 660	2 840								
27	"	13.0		410		95.6										5 110	3 220	605	12.5	3.9	3.0	15 330	21 006	9 660	13 308
28	"		8.6													4 340	2 870		13.3	4.6	0.5	2 170	23 176	1 435	14 743
29/11	"		8.4	254		97.3										4 570	2 930				2.0	9 140	32 316	5 860	20 603
2/12	"	13.2	8.4	292		96.9								25		4 840	3 040	705	16.2	5.3	2.0	9 680	41 996	6 080	26 683
3	"	12.4														5 010	3 300				2.0	10 020	52 016	6 600	33 283
4	"			278		97.0										5 080	3 170	582			2.5	12 700	64 716	7 925	41 208
5	"	13.4	8.3				90	94.7 -	69	0.1		0				4 600	2 960		16.6	5.6	1.0	4 600	69 316	2 960	44 168
6	"			345		96.3										4 350	3 080		13.2	4.3	3.0	13 050	82 366	9 240	53 408
9	"	13.7	8.3	261		97.2										5 050	3 420		25.2	7.4	4.0	20 200	102 566	13 680	67 088
10	"	14.0	8.3											106	81	4 420	3 040	430	12.5	4.1	2.0	8 840	111 406	6 080	73 168
11	"			372	320	96.1										4 210	2 700		13.2	4.9					
12	"	13.1	8.4													4 300	2 870		14.4	5.0	0.5	2 150	113 556	1 435	74 603
13	"	11.5		381		96.0										3 970	2 590		10.3	4.0	0.5	1 985	115 541	1 295	75 898
15	"		8.3																						
16	"	13.7	8.5				135	920	82	0.2	84	0				4 460	2 920	475	14.2	4.9	1.0	4 460	120 001	2 920	78 818
17														79	79	4 910	3 270		15.8	4.8	3.3	16 203	136 204	10 791	89 609
18	"	12.9	8.4										780			4 030	2 660								
19	"			385		95.9	125	92.6	73	0.2	86	0				4 290	2 720		4.2	1.5					
20/12	1.6			374	304	95.9										4 750	2 920								
Mean		13.1	8.4	336		96.4	117	93.1						70		4 551	2 977	548	14.1	4.7					
S.dev.		0.8	0.1	501		0.5	24	1.4						41		370	247	122	5.0	1.4					
No 2/12-20/12		9	8	8		8	3	3						3		15	15	4	11	11					

Table 111

LEACHATE SOURCE: YGGESETH

TEST RUN NO IX , ACTIVATED SLUDGE A.S. 3

Influent: Raw leachate

Zn addition = 30 ppm. Organic loading $\frac{0,28\ \text{kg COD}}{\text{kg MLVSS day}}$.

Duration of experiment: November 24-December 21, 1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3^- mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{1}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg } O}{1 \cdot h}$	Oxygen uptake rate $\frac{\text{mg } O}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS
25/11	1.6			456		95.2								103	73	5 060	3 240				2.5	12 650	12 650	8 100	8 100
26	"		8.4													4 740	2 890								
27	"	13.0		410		95.6										5 010	3 120	605	13.2	4.2	2.5	12 525	25 175	7 800	15 900
28	"		8.5													4 560	2 950		30.2	10.2	1.0	4 560	29 735	2 950	18 850
29/11	"		8.5	264		97.2										4 630	2 960				2.0	9 260	38 995	5 920	24 770
2/12	"	13.2	8.5	304		96.8								35		4 460	2 760	576	9.6	3.4					
3	"	12.7														5 270	3 400				3.0	15 810	54 805	10 200	34 970
4				280		97.0										4 780	2 970	505			1.5	7 170	61 975	4 455	39 425
5	"	13.4	8.4				85	95	70	0.2		0				5 240	3 280		16.8	5.1	3.0	15 720	77 695	9 840	49 265
6	"			301		96.8		-								4 740	2 890		13.2	4.6	3.0	14 220	91 915	8 670	57 935
9	"	13.4	8.5	217		97.7										4 930	3 240		15.4	4.8	3.0	14 790	106 705	9 720	67 655
10	"	13.9	8.4											107	85	4 410	2 880	385	10.7	3.7	0.5	2 205	108 910	1 440	69 095
11	"			310	254	96.7										4 880	2 820		12.6	4.5	0.5	2 440	111 350	1 410	70 505
12	"	13.1	8.5													5 030	2 990		14.8	4.9	1.5	7 545	118 895	4 485	74 990
13	"	11.4		285		97.0										4 380	2 630		10.3	3.9	1.0	4 380	123 275	2 630	77 620
15	"		8.3																						
16	"	13.3	8.6				85	95	77	0.1	81	0				4 850	2 900	398	13.9	4.8	1.0	4 850	128 125	2 900	80 520
17	"													38	38	4 510	2 880		12.7	4.4	0.8	3 608	131 733	2 310	82 830
18	"	12.7	8.5										720			4 780	2 900				1.0	4 780	136 513	2 900	85 730
19	"			246		97.4	85	95	71	0.8	69	0				4 700	2 780		6.8	2.4					
20/12	1.6			264	236	97.2										4 970	2 820								
Mean S.dev. No 2/12-20/12		13.0 0.7 9	8.5 0.1 8	276 32 8		97.1 0.3 8	85 0 3	95 0 3						60 40 3		4 795 276 15	2 942 210 15	466 91 4	12.4 2.9 11	4.2 0.8 11					

Table 112

LEACHATE SOURCE: BRÅNÅSDALEN

INFLUENT CHARACTERISTICS FOR TEST RUN NO X

Date of sampling (Day/Month)	pH	COD mg/l	TOC mg/l	Tot P mg p/l	Total nitrogen mg N/l	NH_4 mg N/l	NO_3 mg N/l	Alkalinity $\frac{\text{mg } CaCO_3}{1}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
18.10.- 2.11	6.9	1110	260	1.0	264	292	0.1	2 500	282	118	115.0	1.0		<0.1	<0.1	<0.1	<0.1
2.11.- 15.11	6.7	1512	380	1.0	283	278		2 700			125.0	4.2	0.3	<0.1	<0.1	<0.1	<0.1
15.11.- 12.12	6.7	1444	300	0.5	148		0	2 825	106	62	100.1	4.4	<0.1	<0.1	<0.1	<0.1	<0.1
12.12.-21.12	6.9	824		0.9	254	216	0				95.8	5.0	<0.1	0.2	<0.1	<0.1	<0.1
Mean S.dev. No 2/11 - 21/12	6.8 0.1 3	1260 379 3	313 61 3	0.9 0.1 4	228 71 3						106.9 16 3	4.5 0.4 3					

Table 113

LEACHATE SOURCE : BRÅNÅSDALEN

TEST RUN NO X : ACTIVATED SLUDGE A.S. 1

Influent : Raw leachate. Organic loading: 0.14 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$. Duration of experiment : October 15.- December 21.1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS	Specific resistance filtration m/kg
22/10	5.3	12.0	8.1												4290	2040									
23	"	12.2															210								
24	"	11.8	8.2	208											5250	2280		16.4	7.2						
25	"	12.1	8.2	228											4680	2020	260	24.0	11.9						
28	"	12.0	8.2	244											5330	3130		17.6	5.7						
29	"	12.5	8.3												5920	2660		31.0	11.6						
30	"		8.3	238	226	86.1	80	69	91	72	79.0		29	21	5780	2510									
31/10	"		8.3	248		85.6									5650	2460									
1/11	"		8.3												5590	2270		26.6	11.7						
3	"														5770	2440									
4	"	11.6	8.4	274		81.9							39	35	5950	2620	393	20.4	7.8						
5	"	9.9	8.4									1080			6680	2720		17.4	6.4						$8.7 \cdot 10^{11}$
6	"		8.4												7070	2830				1.0	7070	7070	2830	2830	
7	"		8.4	264	256	82.5									7000	2890	260			0.7	4900	11970	2023	4853	
8	"		8.3										31	23	6630	2480									
9	"	13.8		260		82.8	65	83	129	72	55.8				6580	2560	245								$7.9 \cdot 10^{11}$
10	"	12.3													6960	2670	250			1.0	6960	18930	2670	7523	$9.1 \cdot 10^{11}$
11	"		8.5	272		82.0							31	22	6410	2530									
12	"		8.4									1070			6980	2760									
13	"		8.4	256		83.1									6880	2420		24.0	9.9						
14	"	13.0	8.4										60	27	7330	2800	260	16.8	6.0	0.4	2932	21862	1120	8643	$9.7 \cdot 10^{11}$
15	"		8.3	306		78.8	87.5	71	110	80	72.7				7430	2700		16.6	6.1						
16	"																								
18	"		8.2	258		82.1							57	34	7630	2720		21.6	7.9						
19	"		8.3												7940	2950	280	14.4	4.9	1.0	7940	29802	2950	11593	$7.1 \cdot 10^{11}$
20	"	12.8		244	206	83.1									9230	3060				2.0	18460	48262	6120	17713	
21	"		8.0	238		83.5	55	82	146	135	92.4	300	84	66	8270	2770		12.3	4.6						
22	"														8640	2950		18.0	6.1						
23	"														8570	2940		25.2	8.5	1.0	8570	56832	2940	20653	
24	"		8.2	238		83.5																			
25	"	13.4	8.2	186		87.1							54	36	8200	2930		9.4	3.2	1.0	8200	65032	2930	23583	
26	"		8.1												8130	2750				1.0	8130	73162	2750	26333	
27	"	12.6		210		85.4						415			8170	2840	260	10.0	3.5	0.8	6536	79698	2272	28605	
28	"		8.5												8060	2870		21.7	7.5	0.5	4030	83728	1435	30040	
29/11	"		8.2												7990	2980				2.0	15980	99708	5960	36000	
2/12	"	12.5	8.2	176		87.1							23		7320	2560	251	7.1	2.8						
3	"	12.2													7770	2840				0.4	3108	102816	1136	37136	
4	"			188		86.9	60	80	170	139	81.7				7530	2760									
5	"	13.0	8.2												7530	2770	290	21	7.6	3.0	22590	125406	8310	45446	
6	"			161		88.8									7710	2810		22.2	7.9	2.5	19275	144681	7025	52471	
9	"	13.6	8.1	157		89.1									6890	2690		19.2	7.1						
10	"	13.6	8.2										58	33	7000	2770	315	19.7	7.1						
11	"			146	139	89.8									6940	2590									
12	"	12.8	8.2									300			7140	2730									
13	8"2	11.0		150		81.7									7060	2650		9.0	3.4	1.0	7060	151741	2650	55121	
16	"	12.9	8.0				75	71	210	140	66.7				7010	2570	235	26.2	10.2						
17	"												64	55	7220	2840		29.3	10.3	0.5	3610	155351	1420	56541	
18	"	12.2	7.9												6780	2530									
19	"			242		70.6	85	67	250	180	72.0	500			7140	2540		10.8	4.3						
20/12				252		69.4									6730	2550									
Mean		12.5	8.3	224		83.0	71.3	76	169	124	73.5	610	50	37	7383	2735	276	18.4	6.5						**$8.5 \cdot 10^{11}$**
S.dev		1.0	0.1	48		5.3	13.4	6.8	53	41	12.5	367	19	15	695	155	45	5.7	2.3						**$1.0 \cdot 10^{11}$**
No		17	25	20		20	6	6	6	6	6	6	10	9	38	38	11	21	21						**5**
4/11-20/12																									

Table 114

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO X : ACTIVATED SLUDGE A.S 2

Influent : Raw leachate : Organic loading : 0.25 $\frac{kg\ COD}{kg\ MLVSS\ day}$: Duration of experiment : October 15 - December 21, 1974.

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO_3 mg N/l	Nitrification %	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{mg\ O}{l \cdot h}$	Oxygen uptake rate $\frac{mg\ O}{h\ mg\ MLVSS}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d mg VSS	Specific resistance to filtration m/kg
22/10	10.5		8.1												4690	2190									
23	"	12.1															220								
24	"	11.7	8.1	270																					
25	"	12.0	8.2	286											6630	2650		15.6	5.9						
28	"	11.6	8.3	292											6310	2530	270	26.0	10.2						
29	"	12.2	8.3												5510	2540		21.0	8.3						
30			8.2	268	250	84.4	105	60	95.5	80	83.7				7990	3370		29.0	8.6						
31/10	"		8.2	292		83.0							72	33	8000	3460				4.2	33600	33600	14532	14532	
1/11	"		8.1												6250	2740				1.0	6250	39850	2740	17272	
3	"														6140	2500		32.9	13.2	1.0	6140	45990	2500	19772	
4	"	11.7	8.1	266		82.2									6180	2740									
5	"	9.8	8.1										228	84	6780	3180	252	32.2	10.1	1.5	10170	56160	4770	24542	
6	"		8.2									1280			6560	3190		34.0	10.7	2.5	16400	72560	7975	32517	$6.1.10^{11}$
7	"		7.9	252	244	83.3									5930	2850				1.0	5930	78490	2850	35367	
8	"		7.9												5820	2780	194								
9	"	13.8		254		83.2	675	82	154	110	71.4		32	21	6100	2940				1.0	6100	84590	2940	38307	
10	"	12.8													6270	3150	230			2.0	12540	97130	6300	44607	$2.5.10^{12}$
11	"		8.1	250		83.2									6050	3030	240			2.0	12100	109230	6060	50667	$4.8.10^{12}$
12			7.9										30	24	5430	2840				0.5	2715	111945	1420	52087	
13	"		8.6	254		83.2						890			5680	2930				1.0	5680	117625	2930	55017	
14	"	13.0	8.1												5370	2730									
15	"		8.0	284		80.3	87.5	71	140	95	75.3		30	14	5840	3020	200			1.5	8760	126385	4530	59547	$6.9.10^{11}$
16	"														5040	2610		28.7	11.0						
18	"		7.9	238		83.5														1.0	5500	131885	2800	62347	
19	"		8.1										52	34	6120	3150		22.2	7.0	2.0	12240	144125	6300	68647	
20	"	13.0		222	214	84.6									5980	3150	220	33.6	10.7	2.5	14950	159075	7875	76522	$9.0.10^{11}$
21	"		8.0	200		86.1	55	82	126	123	98.4				5590	2900				1.0	5590	164665	2900	79422	
22	"											680	56	42	5420	2770		12.8	4.6						
23	"														5390	2770		12.0	4.3						
24	"		8.1	200		86.1									6130	3210		30.0	9.3	2.0	12260	176925	6420	85842	
25	"	13.3	8.2	200		86.1																			
26	"		8.0										29	6	5620	3080		13.1	4.2	1.0	5620	182545	3080	88922	
27	"	12.6		230		84.1									5720	3040				1.5	8580	191125	4560	93482	
28	"		8.2									609			5440	2950	168			1.0-	5440	196565	2950	96432	
29/11	"		8.0												5400	2890		18.0	6.2	0.5	2700	199265	1445	97877	
2/12	"	12.8	8.0	168		88.4									5170	2890				1.0	5170	204435	2890	100767	
3	"	12.0											32	14	5060	2890	187	10.2	3.5	0.5	2530	206965	1445	102212	
4	"														5220	2940				1.0	5220	212185	2940	105152	
5	"	12.8	8.2	202		86.0	65	78	170	123	72.3				5270	2970				1.0	5270	217455	2970	108122	
6	"			184		87.3									5090	2650	180	11.4	4.3						
9	"	13.2	8.0	163		88.7									5510	3050		9.6	3.1	4.0	22040	239495	12200	120322	
10	"	13.4	8.2												4980	2870		7.8	2.7	0.5	2490	241985	1435	121757	
11	"			181	146	87.5							52	35	5050	2980	181	19.6	6.6	1.5	7575	249560	4470	126227	
12	10.5	12.8	8.2												4990	2730		9.0	3.3						
13	16.8	11.2		189		77.1						405			5110	2800		31.3	11.2						
16	"	12.4	8.0												5130	2820		27.1	9.6						
17	"						90	65	216	140	64.8				4800	2560	154	39.6	15.4	2.5	12825	262385	7050	133277	
18	"	12.0	7.3										119	88	5350	2980		36.7	12.3	1.5	8025	270410	4470	137747	
19	"			308		62.6									5220	2700									
20/12	16.8			316		61.6	105	60	250	180	72.0	450			5690	2740		6.0	2.2						
															5800	2870									
Mean		12.5	8.1	228		81.9	78	73	176	129	75.7	719	66	36	5617	2910	200	21.2	7.3						$1.9 \cdot 10^{12}$
S.dev.		1.0	0.1	45		7.4	19	9.2	48	29	11.6	325	63	28	453	166	31	11	3.8						1.7
No		17	21	20		20	6	6	6	6	6	6	10	10	38	38	11	21	21						5
4/11-20/12																									

Table 115

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO X , ACTIVATED SLUDGE A.S. 3

Influent: Raw leachate. Organic loading: 0,48 $\frac{\text{kg COD}}{\text{kg MLVSS day}}$. Duration of experiment: October 15-December 21, 1974

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC removal %	Total nitrogen mg N/l	NO$_3$ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Sludge withdrawal l	Sludge withdrawal mg SS	Cumulative sl.w.d. mg SS	Sludge withdrawal mg VSS	Cumulative sl. w.d. mg VSS	Specific resistance to filtr. m/kg
22/10	20.4		8.2																						
23	"	12.0													5 640	2 270									
24	"	11.5	8.3	382													190								
25	"	11.8	8.3	460											8 130	2 770		17.4	6.3						
28	"	11.1	8.3	530											7 580	2 630	220	24.0	9.1						
29	"	12.0	8.4												5 320	3 270		16.1	4.9						
30	"		8.4	520	480	69.8	215	18							9 400	3 170		21.5	6.8						
31/10	"		8.4	556		67.7			241	3.0	1.2		143	72	9 500	3 310		19.9	6.0						
1/11	"		8.4												7 630	2 510									
															7 410	2 180		14.9	6.8						
4	"	11.2	8.2	908		39.9									7 290	2 390									
5	"	9.3	8.3										83	73			250	14.2	6.0						
6	"		8.5									1 880			7 840	2 350		15.8	6.7						2.6 · 10^{12}
7	"		8.3	864	712	42.9									7 530	2 120									
8	"		8.3												8 920	2 460	160								
9	"	13.2		808		46.6	195	49					176	113	10 210	2 730									
10	"	12.2							176	0.3	0.2				10 910	3 080	190			1.0	10 910	10 910	3 080	3 080	3.2 · 10^{11}
11	"		8.7	768		49.2									11 060	3 060	180			2.0	22 120	33 030	6 120	9 200	3.4 · 10^{11}
12	"		8.5										107	103	10 310	2 870				0.5	5 155	38 185	1 435	10 635	
13	"		8.6	760		49.7						1 650			10 200	2 730									
14	"	12.5	8.6												10 100	2 910		26.4	9.1	1.0	10 100	48 285	2 910	13 545	
15	"		8.5	836		42.1	240	20	276				280	104	10 340	2 720	190	22.2	8.2	0.4	4 136	52 421	1 088	14 633	3.4 · 10^{12}
16	"									0.1	0				11 180	3 130				1.0	11 180	63 601	3 130	17 763	
18	"		7.9																						
19	"		8.6										183	–	12 150	3 120		19.7	6.3	2.0	24 300	87 901	6 240	24 003	
20	"	13.0		804	720	44.3									11 670	3 280	210	16.8	5.1	3.0	35 010	122 911	9 840	33 843	4.4 · 10^{12}
21	"		8.4	812		43.7	225	25	218						10 990	3 010				1.5	16 485	139 396	4 515	38 358	
22	"									0.3	0.1	1 340	175	125	10 630	3 060		13.4	4.4	2.0	21 260	160 656	6 120	44 478	
23	"																	12.0	4.3						
24	"		8.3	812		43.7									9 920	2 680									
25	"	13.3	8.2	556		61.5																			
26	"		8.4										28	10	10 920	3 310		13.1	3.9	1.0	10 920	171 576	3 310	47 788	
27	"	12.4		396		72.5									11 260	3 390				2.5	28 150	199 726	8 475	56 263	
28	"		8.2									1 285			10 190	3 060	190	19.8	6.4	2.0	20 380	220 106	6 120	62 383	
29/11	"		8.6												10 420	3 270		19.1	5.8	3.0	31 260	251 366	9 810	72 193	
2/12	"	12.6	8.6	256		82.3									9 740	3 000				2,0	19 480	270 846	6 000	78 193	
													86		10 060	3 160	260	14.2	4.5	3.0	30 180	301 026	12 480	90 673	
4	"			370		74.3									8 850	3 080				2.0	17 700	318 726	6 160	96 833	
5	"	12.8	8.4				115	62	195	0.1	0				9 200	3 220	210			2.5	23 000	341 726	8 050	104 883	
6	"	11.9		333		76.9									9 440	3 300		13.8	4.2	3.5	33 040	374 766	11 550	116 433	
9	"	13.6	8.4	361		75.0									8 690	2 940		18.0	6.1	3.0	26 070	400 836	8 820	125 253	
10	"	13.1	8.2												8 430	3 150		14.4	4.6	2.5	21 075	421 911	7 875	133 128	
11	"			324	254	77.6							348		9 070	3 390	230	8.4	2.5	4.0	36 280	458 191	13 560	146 688	
12	20.4	12.7	8.5												8 120	2 840		9.1	3.2	0.5	4 060	462 251	1 420	148 108	
13	34.1	11.0		422		48.7						1 020			8 790	3 080				2.0	17 580	479 831	6 160	154 268	
16	"	11.8	8.3												8 100	2 810		7.2	2.6	2.5	20 250	500 081	7 025	161 293	
17	"						175	33	266	0.1	0				10 370	3 220	162	8.5	2.6	3.0	31 110	531 191	9 660	170 953	
18	"	11.7	8.3										215	136	10 230	3 150		6.8	2.1	2.5	25 575	556 766	7 875	178 828	
				587		28.8									10 150	2 790									
20/12	34.1			584		28.7	190	27	260	0.1		1 820			11 220	2 910		16.1	3.4	1.0	11 220	567 986	2 910	181 738	
															10 940	2 870									
Mean		12.3	8.4	608		54	190	36	232	0.2	0.1	1 500	168	95	9 948	2 979	202	14.7	4.8						**2.2 · [illegible]**
S.dev.		1.0	0.2	223		17	44	16	41	0.1		338	97	42	1 140	284	33	5.1	1.9						**1.8 ·**
No 4/11-20/12		17	25	19		19	6	6	6	6	6	6	10	7	36	36	11	21	21						**5**

Table 116

LEACHATE SOURCE: BRÅNÅSDALEN

INFLUENT CHARACTERISTICS FOR TEST RUN NO XI

Date of sampling (Day/Month)	pH	COD mg/l	COD Filtr. mg/l	TOC mg/l	Total nitrogen mg N/l	NH_4 mg N/l	NO_3 mg N/l	Alkalinity $\frac{\text{mg } CaCO_3}{1}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
3.1.- 10.1	6.8	618	600														
10.1.- 22.1	6.9	838			350	344					73.0	0.9					
22.1.- 30.1	6.9	688		180	200	238	0.7				68.0	4.0	<0.1	0.1	<0.1	<0.1	<0.1
30.1.- 12.2	6.9	762		215	238	244	0.1		271	105	72.9	7.7	<0.1	0.1	<0.1	<0.1	<0.1
12.2.- 25.2	6.8	743		205	254	304	0	1 210			86.2	8.6	0.1	0.2	<0.1	<0.1	<0.1
Mean	6.9	731		200	231	262	0.3				75.7	6.7					
S.dev.	0.1	38		18	28	36	0.4				9	2.4					
No 22/1 - 25/2	3	3		3	3	3	3				3	3					

Table 117

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XI, EFFECTS OF TEMPERATURE A.S.1

Temperature of operation: 5 °C. Organic loading $\frac{0.16 \text{ kg COD}}{\text{kg MLVSS Day}}$. Duration of experiment: January 3-March 17, 1975

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/1	COD Filt. mg/1	COD-removal %	TOC mg/1	TOC-removal mg/1	Total nitrogen mg N/1	NO_3 mg N/1	NH_4^+ mg N/1	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{1}$	SS mg/1	VSS mg/1	MLSS mg/1	MLVSS mg/1	SV ml/1	Oxygen uptake rate $\frac{\text{mg O}}{1 \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal 1
15/1	10.0															6 130	1 600					
17	"	5.0	8.6	592	472	29																
20	"			590		29										10 690	3 310					
21	"	4.9								filt.												6.0
22	"	5.7	8.8	536		26	120	33	280	21	244	8				7 120	2 220		4.2	1.9		
23	"																		6.0			
24	"	4.9		450		34										7 500	2 380		4.4	1.8		
27	"			394		43	125	32	218	11	204	5		245	127	7 730	2 380		5.2	2.2		1.0
29	"	5.0	8.6	388		44										7 150	2 160	130	4.6	2.1		2.0
30	"	5.3	8.7				115	46	210	8	214	4							5.6			
31/1	"	5.0	8.6	396		48										7 550	2 140		5.2	2.4		
2/2	"	5.4		394		48																
3	"	5.0	8.7											150	52	8 170	2 170	130	4.0	1.8		
4	"			408		46	125	42	234	6	229	3							4.4			
5	"																		5.8			
6	"		8.9	412		46													5.2			
7	"		8.8						268	5	244	2				8 400	2 580		4.0	1.5	3.1 · 10^{12}	
8	"	4.2		410		46																
9																						
10	"	5	8.8	432		43	180	16		2	244			236	74	8 890	2 260	110	5.0	2.2	1.3·10^{12}	1.0
11	"		8.6																5.8			
12	"	4.2	8.6	448		40										8 540	2 210		5.2	2.3		
13	"		8.6				145	29	236	1	234	0.5		375	150				5.4	2.1		
14	"	8.6														8 780	2 580					
15	"	5.0		496		33							900									
16	"																					
17/2	10.0	4.7	8.7	490		34	155	28	252	1		0.5							5.4			
Mean		4.9	8.7	427		42	140	32	236	5	228	2.5		252	101	8 079	2 318	123	5.1	2.0		
S.dev.		0.4	0.1	37		5	24	10	21	3.8	16	1.8		93	45	620	173	12	0.6	0.3		
No		11	12	12		12	6	6	6	7	6	6		4	4	9	9	3	15	9		
23/1-17/2																						

Table 118

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XI, EFFECTS OF TEMPERATURE A.S. 2

Temperature of operation: 10 °C. Organic loading: $\frac{0.19 \text{ kg COD}}{\text{kg MLVSS day}}$. Duration of experiment: January 3-March 17, 1975

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal mg/l	Total nitrogen mg N/l	NO$_3$ mg N/l	NH$_4^+$ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal l
15/1	10.0	10.0													6 150	2 250					0.3
17	"	"	8.2	354	58										6 820	2 420					2.0
20	"	"		504											7 510	2 640					
21	"	"																			4.0
22	"	"		602		155		260	66	206	25				6 180	2 100					
23	"	"																			
24	"	"		702											6 490	2 150					
27	"	"	8.2	338	60	80	56	200	106	114	53		192	115	5 840	2 050		15.6	7.6		
29	"	"	8.3	338	60										5 070	1 860	150	13.6	7.3		
30	"	"	8.3			115	47	212	96		45							12.4			
31/1	"	"	8.3	342	55										5 160	1 750		12.0	6.9		
2/2	"	"		330	57																
3	"	"	8.4										107	48	5 590	1 750	13.0	11.6	6.6		0.3
4	"	"		342	55	105	51	288	64	173	22							0.4			
5	"	"	8.5															10.6			
6	"	"	8.4	352	54													10.0			
7	"	"	8.5					240	69	180	29		88	63	5 900	2 280		8.0	3.5	$5.2 \cdot 10^{12}$	
8	"	"		340	55																
	"	"																			
10	"	"	8.5	300	60	115	47	240	63	199	26				6 470	2 050	130	10.4	5.0	$2.9 \cdot 10^{12}$	1.0
11	"	"	8.4															10.4			
12	"	"	8.4	364	51										7 630	2 130		10.8	5.0		
13	"	"	8.4			125	39	250	57	180	23		226	114				12.2			
14	"	"	8.3												6 850	2 240		13.0	5.8		
15	"	"		368	50							7 200									
16	"	"																			
17	"	"	8.5	366	51	125	42	240	51		21							13.4			
	"	"																			
25/2	10.0	10.0				100	53	240		12											
Mean			8.4	344	55.3	111	47	239	72	169	31		153	85	6 111	2 029	136	11.6	6.0		
S.dev.			0.1	19	3.7	17	6.1	28	21	32	12.6		66	35	829	199	11	1.8	1.4		
No			12	11	11	6	6	7	7	5	7		4	4	9	9	3	15	8		
23/1-17/2																					

Table 119

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XI, EFFECTS OF TEMPERATURE A.S.3

Temperature of operation: 10-14 °C. Organic loading $\frac{0.16 \text{ kg COD}}{\text{kg MLVSS day}}$. Duration of experiment: January 3-March 17, 1975

Date of sampling (Day/Month)	Feed	Temp aeration basin	pH aer. basin	COD	COD-removal	TOC	TOC-removal	Total nitrogen	NO_3	NH_4^+	Nitrification	SS	VSS	MLSS	MLVSS	SV	Oxygen uptake rate	Oxygen uptake rate	Specific resistance to filtration	Sludge withdrawal
	l/day	°C		mg/l	%	mg/l	mg/l	mg N/l	mg N/l	mg N/l	%	mg/l	mg/l	mg/l	mg/l	ml/l	$\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	$\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	m/kg	l
15/1	10.0													6 470	2 380					0.5
17	"	12.0	8.2	342	59									7 020	2 280					0.5
20	"	13.5		390	53									7 640	2 480					2.5
22	"	14.0	8.2	320	53	75	58	220	130	88	59			7 140	2 520		14.8	5.8		3.0
23	"	14.0															24.2	10.3		
24	"	13.3		274	60									5 870	2 160		22.0	10.2		1.5
27	"	12.5	7.9	262	62	80	56	214	200		93	128	75	6 240	2 290		21.6	9.4		1.0
29	"	14.5	7.8	254	63									5 870	2 210	180	25.6	11.5		
30	"	14.3	7.8			80	63	216	180		83						24.0	10.4		
31/1	"	14.0	7.9	244	68									6 630	2 370		26.0	10.9		1.5
2/2	"	13.1		266	65															
3	"	12.7	8.0									55	28	6 440	2 150	150	23.6	10.9		0.3
4	"	12.4		280	63	95	56	236	220		93						28.0	11.5		
5	"	11.5	8.1														26.8	11.4		
6	"	12.0	8.0	292	62			226	200		88	40	27				23.6	10.0		
7	"	11.0	8.1											7 030	3 450		17.6	-	1.3 · 10^{12}	
8	"	10.5		290	62															
10	"	10.5	8.2	316	58	105	51	226	160		71	172	58	7 710	2 530	150	23.8	9.4	1.9 · 10^{12}	1.0
11	"	10.0	8.2														21.3	8.4		
12	"	10.2	8.2	312	58									8 310	2 530		14.4	5.7		
13	"	12.0	8.1	342	54	110	46	240	123		51	150	52				26.4	10.0		
14	"	12.0	8.1	336	55									8 230	2 780		25.9	9.3		
15	"	12.0																		
16	"			342	54															
17/2	10.0			338	55	105	51	238	132		56						25.4	9.1		
Mean S.dev. No 23/1-17/2		12.2 1.4 19	8.0 0.1 12	296 35 14	59.9 4.4 14	93.8 14 6	53.8 5.8 6	228 10 7	173 37 7		74 17 8	109 58 5	48 20 5	6 925 953 9	2 378 221 8	160 17 3	23.5 3.4 17	9.7 1.8 17		

Table 120

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XI, EFFECTS OF TEMPERATURE A.S. 4

Temperature of operation: 18.0 °C. Organic loading $\frac{0.16 \text{ kg COD}}{\text{kg MLVSS day}}$. Duration of experiment: January 3-March 17, 1975

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal mg/l	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal l
15/1	10.0	18.0														6 070	2 320					0.5
17	"	"	7.9	310		63										6 380	2 340					1.5
20	"	"		466	e.m.																	
21	"	"																				
22	"	"	8.1	318		54	75	58	280	190		68				6 670	2 480		23.4	9.4		2.5
23	"	"																	43.2			
24	"	"		280		59										5 720	2 180		41.2	18.9		1.5
27	"	"	7.9	234		66	85	53	240	240		100		96	38	5 950	2 260		41.6	18.4		0.5
29	"	"	7.9	232		66										5 840	2 280	140	45.6	20.0		1.0
30	"	"	7.9				75	65	220	210		95							37.2			
31/1	"	"	7.8																27.2			
2/2	"	"		236		69																
3	"	"	7.9											81	47	6 350	2 180	110	38.4	17.6		1.0
4	"	"	7.9	242		68	85	60	296	234		79							36.8			
5	"	"	7.9																40.8			
6	"	"		240		69			272	280		100		41	17				36.8			
7	"	"	7.8													6 130	3 170		36.8	11.6	$1.0 \cdot 10^{12}$	
8	"	"		246		68																
10	"	"	7.8	242		68	85	60	244	290		100				6 750	2 480	110	32.0	12.9	$1.2 \cdot 10^{12}$	1.0
11	"	"	7.8																31.2			
12	"	"	7.8	280		62													28.0			
13	"	"	7.9				100	51	268	260		97		108	42				34.8			
14	"	"	7.9													7 020	2 700		30.0	11.1		
15	"	"		302		59							260									
16	"	"																				
17	"	"	7.9	288		61	105	51	272	250		92							29.4			
25/2	10.0	18.0							312	300	12	96										
Mean S.dev. No 23/1-17/2			7.9 0.1 14	257 25 11		65.0 4 11	89 11 6	56.7 5.8 6	262 25 8	244 34 8		95 7 8		82 29 4	36 13 4	6 251 484 7	2 464 363 7	120 17 3	35.9 5.6 17	15.8 3.8 7		

Table 121

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XI, EFFECTS OF TEMPERATURE A.S. 5

Temperature of operation: 25 °C. Organic loading $\frac{0.17\ \text{kg COD}}{\text{kg MLVSS day}}$. Duration of experiment: January 3-March 17, 1975

Date of sampling (Day/Month)	Feed 1/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal mg/l	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{l \cdot h}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal l
15/1	10.0	25.0													6 320	2 420					0.6
17	"	"	7.9	300	64										6 350	2 430					2.0
20	"	"		340	59										5 900	2 340					1.5
21																					
22	"	"	8.0	272	60	60	67	300	200		67				5 970	2 430		33.0			2.5
23																		64			
24	"	"		242	65										5 130	2 080		54.4	26		1.0
27	"	"	7.8			60	67	230	230		100		93	36	5 640	2 240		52.0	23		0.5
29	"	"	7.8	206	70										5 460	2 180	100	64.0	29		
30	"	"	7.8			70	67	230	200		87							48.0			
31/1	"	"	7.9	222	71										6 140	2 220		54.4	25		
2/2				214	72																
3	"	"	7.9										48	22	6 520	2 210	100	64.0	29		1.0
4	"	"		208	73	65	70	258	250	-	97							52.0			
5	"	"	8.0															56.0			
6	"	"		228	70			274	270		98		52	26				57.6			
7	"	"	7.9												6 460	2 390		73.6	31	1.6 · 10^{11}	
8	"	"		228	70																
9	"	"																			
10	"	"	7.9	228	70	60	72	250	290		100		138	55	7 000	2 610	97	83.2	32	1.2 · 10^{11}	2.0
11	"	"	7.9															82.5			
12	"	"	7.9	232	69										6 930	2 420		78.4	32		
13	"	"	7.9			80	61	272	260		96		59	24				47.6			
14	"	"	8.2															56			
15	"	"		236	68							190									
16	"	"																			
17	"	"	7.8	238	68			274	270		99							82.4			
25/2	10.0	25.0				72	67	352	350	13	99										
Mean			7.9	225	67.7	67.8	68.1	268	265		97		78	33	6 160	2 293	99	63	28		
S.dev.			0.1	12	4.2	7.7	4.2	38	44		4.3		38	14	690	169	1.7	12	3.3		
No			13	11	11	6	6	8	8		8		5	5	8	8	3	17	8		
23/1-17/2																					

Table 122

LEACHATE SOURCE: BRÅNÄSDALEN

INFLUENT CHARACTERISTICS FOR TEST RUN NO XII

Date of sampling (Day/Month)	pH	COD mg/l	COD Filtr. mg/l	TOC mg/l	Total nitrogen mg N/l	NH_4 mg N/l	NO_3 mg N/l	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
10.1.- 22.1	6.9	838			350	344					73.0	0.9					
22.1.- 30.1	6.9	688		180	200	238	0.7				68.0	4.0	<0.1	0.1	<0.1	<0.1	<0.1
30.1.- 12.2	6.9	762		215	238	244	0.1		271	105	72.9	7.7	<0.1	0.1	<0.1	<0.1	<0.1
12.2.- 25.2	6.8	743		205	254	304	0	1 210			86.2	8.6	0.1	0.2	<0.1	<0.1	<0.1
Mean S.dev. No 22/1 - 25/2	6.9 0.1 3	731 38 3		200 18 3	231 28 3	262 36 3	0.3 0.4 3				75.7 9 3	6.7 2.4 3					

Table 123

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XII, HEAVY METAL TOXICITY A.S. 1

January 30-February 10 Zn = 10 ppm. February 12-February 19 Cu = 25 ppm. Organic loading $\frac{0.17 \text{ kg COD}}{\text{kg MLVSS day}}$.

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD Filt. mg/l	COD-removal %	TOC mg/l	TOC-removal mg/l	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg } O}{l \cdot h}$	Oxygen uptake rate $\frac{\text{mg } O}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal l
15/1	10.0															6 700	2 250					0.3
17				342		59										7 480	2 460					2.0
20	"	13.5		392		53										7 340	2 280					1.0
22	"	14.0	8.2	344		50	70	61	220	140		63				7 380	2 460		15.0	6.1		2.5
23	"	13.6														6 050	2 170		32	14.7		1.5
24	"			306		56													24.4	11.3		
27	"	12.5	8.1	258		63	85	53	216	180		83							20.8	9.7		
29	"	13.9	8.0	246		64										6 290	2 150	230	25.6	11.9		
30	"	14.3	8.0																28.6	13.6		
31/1	"	13.5	8.1	238		69										5 980	.2 000		24.0	12.0		
2/2	"	13.1		264		65																
3	"	12.7	8.2											86	33	6 400	1 950	185	24.0	12.3		0.3
4	"	12.2		270		64	90	58	238	130		55							16.4	8.2		
5	"	12.0	8.3																16.0	7.2		
6	"	12.0	8.2	282		63			220	130		59							22.2	9.4		
7	"	11 .0	8.3													7 040	2 650		17.6	6.6	1.9 · 10^{12}	
8	"	10.5		280		63																
10	"	10.5	8.3	272		64	100	53	214	100		47				7 520	2 260	155	18.4	8.2	2.4 · 10^{12}	1.0
11	"	10.0	8.2																18.0	8.0		
12	"	10.2	8.3	338		54													14.6	6.2		
13	"	12.0	8.4	414		44	120	41	240	81	174	33		444	162				18.8	7.5		
14	"	12.0	8.2	466		37													16.0	6.0		
15	"			512		31							6.900			9 000	2 660					
16	"																					
17	"	12.0		538		28	180	16	246	69		28							16.0	6.1		
19/2	10.0			542																		

Table 124

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XII, HEAVY METAL TOXICITY A.S. 2

January 30-February 10: Zn = 25 ppm. February 12-February 19: Cu 10 ppm. Organic loading $\frac{0.13 \text{ kg COD}}{\text{kg MLVSS day}}$.

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal mg/l	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal l
15/1	12.2														6 290	2 280					0.4
17	"	11.9	7.8	356	58										6 740	2 550					3.5
20	"														6 270	2 290					1.0
21	"	13.3																			
22	"	13.9	7.7	320	53	70	61	240	170		71				6 890	2 680		14.6	5.4		5.5
23	"	13.3																12.4	5.2		
24	"	12.9		290	58										5 340	2 180		-			2.0
27	"	12.2	7.7	284	59	85	53	228	180		79				5 660	2 310		12.0	5.2		1.5
29	"	13.5	7.8	258	63										5 110	2 210	140	16.0	7.2		
30	"	14.0	7.7															16.8	7.6		
31/1	"	13.8	7.7	240	69										5 300	2 160		17.6	8.1		
2/2	"	12.8		238	69																
3	"	12.2	7.9	264	65								74	30	5 430	2 110	140	12.0	5.7		
4	"	12.0		270	65	90	58	230	130		56							14.8	6.7		
5	"	12.0	8.1															14.4	6.4		
6	"	12.0	8.1	276	64			224	100		45							13.6	5.9		
7	"	11.0	8.1												6 040	3 070		12.2	4.0	$1.2 \cdot 10^{12}$	
8	"	9.8		272	64																
9	"																				
10	"	10.0	8.2	316	59	100	53	212	90		42				6 820	2 490	140	13.2	5.3	$3.1 \cdot 10^{12}$	1.0
11	"	10.0	8.2															12.0	4.7		
12	"	8.5	8.2	302	59										7 920	2 570		9.8	3.8		
13	"	12.0	8.1	324	56	105	49	232	84	165	36		143	55				18.0	6.5		
14	"	12.0	7.9	366	51										7 670	2 870		16.4	5.7		
15	"			354	52							570									
16	"			355	52																
17	"	12.0	8.1	370	50	135	37	236	113		48							22.4	7.8		
19/2	12.2			366																	

Table 125

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XII, METAL TOXICITY A.S. 3

-January 30-February 19: Zn = 50 ppm. Organic loading $\frac{0.12\ \text{kg COD}}{\text{kg MLVSS day}}$.

Date of sampling	Feed	Temp aeration basin	pH aer. basin	COD	COD Filt.	COD-removal	TOC	TOC-removal	Total nitrogen	NO_3	NH_4^+	Nitrification	Alkalinity	SS	VSS	MLSS	MLVSS	SV	Oxygen uptake rate	Oxygen uptake rate	Specific resistance to filtration	Sludge withdrawal
Day/Month	l/day	°C		mg/l	mg/l	%	mg/l	mg/l	mg N/l	mg N/l	mg N/l	%	$\frac{\text{mg CaCO}_3}{\text{l}}$	mg/l	mg/l	mg/l	mg/l	ml/l	$\frac{\text{mg O}}{\text{l} \cdot \text{h}}$	$\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	m/kg	l
15/1	12.0															5 950	2 330					0.5
17	"	12.1	8.0	330		61										6 940	2 510					3.5
20	"															6 460	2 340					1.5
21	"	13.3																				
22	"	13.9		296		57	65	64	220	150	76	68				6 730	2 630					5.0
23	"	13.3																	28.0	12.1		
24	"	13.0		288		58										5 640	2 260		26.0	11.5		3.0
27	"	12.2	7.7	252		63	75	58	226	190		84				5 440	2 280		20.4	8.9		1.0
29	"	13.5	7.6	255		63										5 030	2 160	140	26.8	12.4		
30	"	14.0	7.6																24.4	11.5		
31	"	13.8	7.8	216		72										5 020	2 090		16.4	7.8		
2/2	"	12.8		238		69																
3	"	12.2	8.0	288		62								96	42	5 820	2 220	145	14.4	6.4		1.0
4	"	12.0		296		61	95	56	230	80		35							16.4	7.1		
5	"	12.0	8.2																14.4	6.2		
6	"	12.0	8.1	304		60			220	70	157	32							14.6	6.0		
7	"	11.0	8.2													7 110	3 210		11.2	4.5	$1.3 \cdot 10^{12}$	
8	"	9.8		332		56																
9	"																					
10	"	10.0	8.4	392		48	125	42	202	49		24				7 960	2 730	140	9.6	3.5	$1.3 \cdot 10^{12}$	2.0
11	"	10.0	8.4																9.6			
12	"	8.5	8.3	414		44										8 380	2 610		8.2	3.1		
13	"	12.0	8.3	420		43	135	34	220	43	191	20		250	76				14.0	5.1		
14	"	12	8.0	440		41										8 440	2 890		10.0	3.4		
15	"	12.3		408		45							700									
16	"			406		45																
17	12.0	12.2	8.4	388		48	145	33	246	55		22							11.8	4.0		

Table 126

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XII, HEAVY METAL TOXICITY A.S. 4

February 12-February 19: Cu = 50 ppm. Organic loading $\frac{0.14\ \text{kg COD}}{\text{kg MLVSS day}}$.

Date of sampling (Day/Month)	Feed l/day	Temp aeration basin °C	pH aer. basin	COD mg/l	COD-removal %	TOC mg/l	TOC-removal mg/l	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Nitrification %	Alkalinity $\frac{\text{mg } CaCO_3}{l}$	SS mg/l	VSS mg/l	MLSS mg/l	MLVSS mg/l	SV ml/l	Oxygen uptake rate $\frac{\text{mg O}}{l \cdot h}$	Oxygen uptake rate $\frac{\text{mg O}}{\text{h mg MLVSS}}$ 10^{-3}	Specific resistance to filtration m/kg	Sludge withdrawal l
15/1	13.0														5 160	2 130					0.2
17	"	12.0	7.7	304	64										6 620	2 570					3.5
20	"														5 780	2 330					1.5
21	"	13.3																			
22	"	13.9	7.8	292	58	75	58	240	180		75				5 810	2 520		13.2	5.2		4.0
23	"	13.3																18.6	11.5		
24	"	12.2		290	58										5 090	2 310		23.0	9.9		3.0
27	"	12.2	7.9	270	61	85	53	226	160		71				5 700	2 360		19.0	8.0		2.0
29	"	13.5	7.9	334	51	69	62								5 450	2 270	140	19.2	8.5		1.0
30	"	14.0	7.9															22.0	10.0		
31/1	"	13.8	8.0	232	70										5 390	2 120		18.8	8.9		
2/2	"	12.8		238	69																
3	"	12.2	8.0	216	72								26	20	6 100	2 130	130	19.0	8.9		
4	"	12.0		232	70	75	65	238	190		80							21.6	9.8		
5	"	12.0	8.1															21.0	9.1		
6	"	12.0	8.0	236	69			230	160		70							18.2	7.6		
7	"	11.0	8.0												6 960	3 640		14.4	4.0	9.3 · 10^{11}	
8	"	9.8		242	68																
9	"																				
10	"	10.0	8.1	270	65	85	60	224	160		71				7 800	2 680	145	19.0	7.1	5.2 · 10^{11}	2.0
11	"	10.0	8.1															18.4	7.0		
12	"	8.5	8.2	272	63										8 030	2 490		12.0	4.3		
13	"	12.0	8.2	334	55	100	51	234	134	106	57		193	84				20.4	7.8		
14	"	12.0	8.2	416	44										8 250	2 830		16.4	5.8		
15				514	30							660									
16				584	21																
17	"	12.0	8.3	608	18	200	7	236	73		31							15.5	5.5		
19	13.0			594																	

Table 127

LEACHATE SOURCE: BRÅNÅSDALEN

INFLUENT CHARACTERISTICS FOR TEST RUN NO XIII

Date of sampling (Day/Month)	pH	COD mg/l	COD Filtr. mg/l	TOC mg/l	Total nitrogen mg N/l	NH_4 mg N/l	NO_3 mg N/l	Alkalinity $\frac{mg\ CaCO_3}{l}$	SS mg/l	VSS mg/l	Fe mg/l	Zn mg/l	Cu mg/l	Cr mg/l	Cd mg/l	Pb mg/l	Ni mg/l
3.1.- 10.1	6.8	618	600														
10.1.- 22.1	6.9	838			350	344					73.0	0.9					
22.1.- 30.1	6.9	688		180	200	238	0.7				68.0	4.0	<0.1	0.1	<0.1	<0.1	<0.1
30.1.- 12.2	6.9	762		215	238	244	0.1		271	105	72.9	7.7	<0.1	0.1	<0.1	<0.1	<0.1
12.2.- 25.2	6.8	743		205	254	304	0	1 210			86.2	8.6	0.1	0.2	<0.1	<0.1	<0.1
Mean	6.9	731		200	231	262	0.3				75.7	6.7					
S.dev.	0.1	38		18	28	36	0.4				9	2.4					
No	3	3		3	3	3	3				3	3					
22/1 - 25/2																	

Table 128

LEACHATE SOURCE: BRÅNÅSDALEN

TEST RUN NO XIII, BIODISC

Duration of experiment : January 3. - February 17, 1975. Organic loading : 1.8 $\frac{\text{g COD}}{\text{day m}^2}$

Date of sampling (Day/Month)	Feed l/day	Temp. effluent °C	pH effluent -	COD mg/l	COD-removal %	TOC mg/l	TOC-removal %	Total nitrogen mg N/l	NO_3 mg N/l	NH_4^+ mg N/l	Alkalinity $\frac{\text{mg CaCO}_3}{\text{l}}$	SS mg/l	VSS mg/l
22/1	8.0		8.6	496	41	90	50	120	0.2				
23/1	"	10.3											
27	"	11.3	8.7	384	44								
29	"	13.0	8.5	362	47								
30	"	13.3	8.3										
31/1	"	13.1	8.0	376	47								
2/2	"	12.5		392	49								
3	"	12.0	8.4										
4	"	11.3		368	52	100	53	124	0.3	76			
5	"	11.2	8.3										
6	"	11.8	8.1	368	52								
7	"	10.8	8.0										
8	"	10.0		382	50								
9	"												
10	"	10.1	8.0	402	47	110	49	136	0.4	133			
11	"	10.1	8.2										
12	"	10.0	8.3	388	49								
13	"	12.0	8.3			130	37	146	0.3	134		58	14
14	"	12.0	8.5								715		
15	"	12.2											
16	"												
17/2	8.0	12.1	8.6	444	40	150	30	124	0.5				
Mean		11.5	8.3	397	47.1	116	43.8	130	0.3	114			
S.dev		1.1	0.2	40	4.0	24	9.8	10.8	0.1	33			
No 22/1 - 17/2		19	15	11	11	5	5	5	5	3			

APPENDIX C

Table 129.

CHEMICAL TREATMENT OF RAW LEACHATE **ADDED HEAVY METALS** - TEST SERIES NO 4

Precipitant	pH	COD mg/1	COD red. %	TOC mg/1	TOC red. %	Colour mg/1	Turb. JTU	Fe mg/1	Zn mg/1	Cu mg/1	Cr mg/1	Cd mg/1	Pb mg/1	Ni mg/1
Raw leachate	7.3	426		160				72.7	39.8	47.6	23.0	41.2	4.4	36.5
NaOH	8	367	13.8	135	15.6	385	84	2.90	5.11	4.54	1.78	12.2	1.15	25.5
NaOH	9	380	10.7	135	15.6	580	117	0.66	0.44	2.45	0.29	1.20	0.26	11.27
Ferric chloride 150	9	411	3.6	125	21.8	284	28	1.08	0.24	1.51	0.41	0.41	<0.1	4.35
" " 250	9	403	5.4	135	15.6	472	105	0.88	0.44	2.76	0.45	0.66	0.54	6.88
" " 400	9	372	12.6	125	21.8	268	54	0.98	0.15	1.08	0.30	0.20	0.12	2.12
Alum 150	6	399	6.3	115	28.1	538	64	3.06	38.00	9.16	2.45	19.60	1.33	30.72
" 250	6	378	11.3	115	28.1	525	102	3.25	30.80	7.75	2.23	19.50	1.38	31.12
" 400	6	390	8.5	115	28.1	509	79	2.78	24.0	7.39	1.94	19.50	1.32	31.60
Lime	9	372	12.6	140	12.5	497	142	1.21	0.74	2.58	0.64	1.68	0.60	12.74
"	10	376	11.7	120	25.0	201	35	0.55	0.11	1.50	0.30	0.16	0.15	0.60
"	11	351	17.6	127	20.3	93	74	0.22	<0.1	0.56	<0.1	<0.1	<0.1	0.12
Lime	12	347	18.5	120	25.0	173	68	0.44	0.13	0.75	0.26	0.20	0.19	0.44

Alum as $Al_2(SO_4)_3 \cdot 18H_2O$

Ferric chloride as $FeCl_3 \cdot 6H_2O$

Doses in mg/1

APPENDIX D

Table 130 and 131.

Adsorption isotherm data - Source no 1 (Grønmo).

Raw leachate: TOC = 152.5 , COD = 508.

Influent: Chemically precipitated leachate.

	TOC basis			COD basis		
Carbon dosage M g/l	Residual TOC C mg/l	X = Co-C	$q_e = \frac{X}{M}$	Residual COD C mg/l	X = Co-C	$q_e = \frac{X}{M}$
0	152.5 = Co			508 = Co		
0.4	112	40.5	101.3	408	100	250
0.75	90	62.5	83,3			
1.5	62.5	90	60	282	226	151
3.0	40	112.5	37.5	247	261	87
7.5	23.8	128.7	17.2	218	290	39
15	20	132.5	8.8	156	352	23

Influent: Biologically treated and chemically coagulated leachate.

	TOC basis			COD basis		
Carbon dosage M g/l	Residual TOC C mg/l	X = Co-C	$q_e = \frac{X}{M}$	Residual COD C mg/l	X = Co-C	$q_e = \frac{X}{M}$
0	97,5 = Co			344 = Co		
0.2	70	27.5	137.5	296	48	240
0.4	61.25	36.25	91	249	95	237.5
0.8	47.5	50.0	62.5	222	122	152.5
1.5	36.25	61.25	40.8	196	148	99
4.0	21.25	76.25	19.1	176	168	42
8.0	17.50	80	10	134	210	26

Table 132.

Adsorption isotherm data - Source no 3 (Yggeseth).

Raw leachate: TOC = 62.5
COD = 232

Influent: Biologically treated and chemically coagulated leachate.

	TOC basis			COD basis		
Carbon dosage M g/l	Residual TOC C mg/l	$X = Co - C$	$q_e = \frac{X}{M}$	Residual COD C mg/l	$X = Co - C$	$q_e = \frac{X}{M}$
0	62.5 = Co			232 = Co		
0.2	46.3	16.2	81	206	26	130
0.4	41.3	21.2	53	196	36	90
0.8	33.5	29	36			
1.5	31.5	31	21	146	86	57
4.0	20	42.5	10.6	108	124	31
8.0	12.5	50	6	102	130	16

Table 133 and 134.

Adsorption isotherm data - Source no 2 (Brånosdalen).

Influent: Chemically precipitated leachate.

Carbon dosage M g/l	Residual TOC C mg/l	X = Co-C	$q_e = \frac{X}{M}$	Residual COD C mg/l	X = Co-C	$q_e = \frac{X}{M}$
0	160 = Co			594 = Co		
0.3	132.5	27.5	92	470	124	413
0.8	107.5	52.5	66	446	148	185
1.5	87.5	72.5	48	388	206	137
3	75	85	28	352	242	81
6	62.5	97.5	16	342	252	42
15	40	120	8	272	322	21
30	30	130	4.3	234	360	12

Influent: Biologically treated and chemically coagulated leachate.

	TOC basis			COD basis		
Carbon dosage M g/l	Residual TOC C mg/l	X = Co-C	$q_e = \frac{X}{M}$	Residual COD C mg/l	X = Co-C	$q_e = \frac{X}{M}$
0	65 = Co			192 = Co		
0.2	47.5	17.5	87.5	155	37	185
0.4	37.5	27.5	69	142	50	125
0.8	30	35	44	128	64	80
1.5	22.5	42.5	28			
4	15	50	12.5	116	76	19
8	10	55	6.8	104	88	11

APPENDIX E

Table 135.

RESULTS FROM ADDITIONS OF LEACHATES TO MUNICIPAL PRIMARY CHEMICAL TREATMENT PROCESSES

		COD mg/l	TOC mg/l	Tot P mg/l	Ort P mg/l	Spec. conductance µS/cm	Turbidity JTU	Color mg Pt/l
D=domestic wastewater	$Al_2(SO_4)_3 \cdot 18H_2O$ 175 mg/l. pH 6.0	58	14.5	0.17	0.018	630	12	130
98% D + 2% Gr		60	22	0.38	0,16	390	12	110
95" " + 5" "		65	22.5	0.40	0.40	580	7	85
90" " +10" "		85	22.5	0.36	0.041	840	12	130
80% D +20% Gr		116	42.5	0.35	0.035	1020	20	180
98% D + 2% Br		66	26.5	0.16	0.007	370	5	60
95" " + 5" "		104	30	0.24	0.003	470	9	100
90" " +10" "		166	62.5	0,11	0.035	1220	6	70
80% D +20% Br		273	112.5	0.13	0,009	1000	16	145
99% D + 1% Yg		146	20	0.36	0.006	370	8	100
98" " + 2" "		225	92.5	0,27	0.035	420	7	80
95" " + 5" "		510	160	0.18	0.037	560	16	160
90% D +10% Yg		910	180	0.18	0.023	780	22	240
D=domestic wastewater	Lime pH 11.3	85	23	1.7	0.85	480	43	530
98% D + 2% Gr		109	-	1.6	0.60	580	46	560
95" " + 5" "		112	30	1.2	0.31	660	27	300
90" " +10" "		120	35	0,8	0.15	740	28	290
30% D +20% Gr		-	40	0.12	0.02	910	16	130
98% D + 2% Br		116	37.5	0.7	0,49	890	17	190
95" " + 5" "		159	52.5	0,26	0.02	1160	11	130
90" " +10" "		217	57.5	0.13	0,043	1900	5	70
80% D +20% Br		344	102.5	0,06	0.019	3300	2	30
99% D + 1% Yg		204	65	2.2	1.1	360	48	730
98" " + 2" "		290	92.5	1.9	0.6	450	36	420
95" " + 5" "		525	145	1.0	0,3	570	18	190
90% D +10% Yg		925	155	0.6	0.098	850	12	130

Gr = Grønmo   Br = Brånåsdalen   Yg = Yggeseth