NORWEGIAN INSTITUTE FOR WATER RESEARCH

OSLO, NORWAY

PRA 2.3   0-14/73

EUROCOP - COST 68/2/4

CHARACTERIZATION OF THE DEGREE OF STABILITY

OF WASTE WATER SLUDGES

AEROBIC STABILIZED SLUDGES

Progress Report No. 2

A Contribution to the Meeting of COST 68/2

WABOLU, Berlin, on 7th-9th October 1974

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August 20 - 1974

A B S T R A C T

During the work on "Characterization of the Degree of Stability of Waste Water Sludges", an effort was made to find possible methods for measuring the degree of stability of aerobic stabilized sludges.

At the beginning of this project it was felt that several parameters probably had to be included in order to describe sludge stability and that no single parameter would be a reliable index of sludge stability. However, as our work proceeded, it was realized that if several parameters were included in an expression for sludge stability, the practical use would be limited. An effort has therefore been made to uncover single, reliable parameters to measure sludge stability.

The information given in this progress report is largely based on pilot scale, batch experiments run at $18\ ^{\circ}C$.

The following definition of a fully aerobic stabilized sludge was given: A sludge where the Odor Intensity Index (OII) does not exceed 11 at any time prior to or during 14 days of storage at $20\ ^{\circ}C$ unless the odor can be classified as a typical "soil" odor.

It was found that aerobic digestion can produce a stable sludge that does not create odor problems during storage. The odors from the sludges during storage were generally less offensive with increasing detention time in the aerobic digester.

Strong offensive gases from raw sludges will disappear during the first stage of the stabilization period.

It was also experienced that short aeration periods (2-8 days) would make the sludges less suitable for storage since they would give a higher rise in odor intensity than raw sludges.

Three methods for measuring sludge stability were recommended. The first method used the oxygen uptake rate as an indicator of sludge stability and an expression for measuring the degree of stability was given.

The second and third methods are very simple methods designed primarily for use at small treatment plants. One method measures the content of nitrite-nitrate in the sludge. If nitrite and nitrate can be found in the sludge liquor, the sludge can be considered as a fully stabilized sludge. Only a qualitative determination is necessary.

The other method uses the flotation phenomena taking place during storage of well nitrified sludges as a method for measuring sludge stability.

PREFACE

The experimental work on "Characterization of the Degree of Stability of
Waste Water Sludges, COST 68/2/4", started in January 1974. Prior to this
date a research proposal including a litterature review, had been written.
This progress report includes all the work on stability of aerobic
stabilized sludges done at the Norwegian Institute for Water Research (NIVA)
to the end of July 1974. The conclusions and recommendations given are based
on pilot scale, batch experiments operated at 18 $^{\circ}$C although data from
continuously operated pilot scale digester previously used at NIVA have been
included when this was found neccessary.

Hopefully a field evaluation of the proposed methods for measuring stability
of aerobic stabilized sludges can be made before the end of 1974.

Oslo Aug. 20, 1974

Arild Schanke Eikum Ph.D.

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1. INTRODUCTION

Three types of stabilization processes are usually considered in sludge
treatment; anaerobic, aerobic and lime stabilization. This progress report
will only discuss our work on aerobic stabilization and methods for measur-
ing stability of aerobic stabilized sludges. When future work on
lime stabilization is completed, it will be covered in separate reports.

The overall objectives of this project are as follows:

1. To find one or several parameters that can be used as a measure of
    the degree of stability of wastewater sludges and to define in terms
    of the measured parameters what is meant by a fully stabilized sludge.

2. To develop one or several methods that are useful for determining the
    degree of stability of sludges in the daily operation of wastewater
    treatment plants. An effort will be made to find methods that are
    easy to perform with a minimum of expensive laboratory equipment.

At the beginning of this project it was felt that several parameters
probably had to be included in order to describe sludge stability and that
no single parameter would be a reliable index of sludge stability. However,
as our work proceeded, it was realized that if several parameters were
included in an expression for sludge stability, the practical use would
be limited. An effort has therefore been made to uncover single, reliable
parameters to measure sludge stability.

2. LITERATURE REVIEW

Several methods for measuring the degree of sludge stability have been proposed.

Rüffer (1966) has introduced the lead acetate test (see "Analytical Procedures") as an indicator of sludge stability. Approximately 50 ml of sludge was filled into 100 ml glass bottles and a lead acetate paperstrip was placed between the bottle and the stopper. Evolution of H_2S gas would then colour the paperstrips brown. No colouring would indicate sludge with a high degree of stability. Rüffer (1966) mentions that even though a sludge will colour the lead acetate strip after a certain incubation period, there is no certainty that the same sludge will create a nuisance problem on a drying bed.

The change in heat value of sludge during aerobic stabilization was also investigated by Rüffer. He found a decrease of heat value with increasing detention time. It might therefore be possible to use heat value as a parameter for sludge stability although this was not proposed by Rüffer.

Kehr (1966) discusses the use of volatile matter as a parameter to define the degree of stability of aerobically digested sludge. He mentions that this parameter can, under certain conditions, be used. Kehr also states that the intensity of respiration can be used as a measure of stabilization.

Okazaki et al. (1966) found that ortho-phosphate (PO_4) was released to the supernatant during aerobic digestion and therefore propose the use of PO_4 in the supernatant as a measure of sludge stability. It should be recognized, however, that anoxic conditions can induce PO_4 release to the supernatant (Shapiro et al., 1967) and therefore can be an inaccurate parameter for measuring sludge stability.

Kempa (1967) introduced a unique parameter for measuring the degree of stability. Since both the carbon (C) content and hydrogen (H) content in the sludge change during the digestion process, he proposed to use the product of C and H divided by the ash content (total solids minus volatile solids). This $C \cdot H$/ash content ratio would then decrease during the

stabilization process and a certain "break" in the curve would, according to Kempa, indicate that the sludge had been fully stabilized.

Kempa (1967) also used the expression developed by Rawn and Bant. This expression is shown below:

$$M = 100(1 - \frac{v_1 \, m_o}{v_o \, m_1})$$

M = degree of stability (%)

v_o, v_1 = organic solids content as per cent of total solids in raw and treated sludge respectively

m_o, m_1 = inorganic solids content as per cent of total solids in raw and treated sludge respectively.

This expression was originally meant to be used for anaerobic digestion. However, its use has been expanded to include aerobic digestion. The main fallacy, in the author's opinion, is that this expression will never give a fully stabilized sludge (M = 100%), and the result, therefore, can be misleading.

Muskat (Korrespondenz Abwasser, 1971) proposed the use of half-life period of the organic solids as a measure of sludge stability. The use of this parameter was based on the assumption that the reduction of organic solids followed a first or second order biochemical reaction. The expression used would be as follows:

$$\sigma = \frac{\ln 2}{K} \quad \text{(assuming first order)}$$

$$\sigma = \frac{\ln 2}{K \cdot C_o} \quad \text{(assuming second order)}$$

σ = half-life (days)

K = rate of decay constant

C_o = initial concentration of biodegradable solids.

According to Muskat, sludge with half-life equal to or higher than 5-10 days would be considered fully stabilized. This would of course depend upon the type of sludge under investigation.

Mudrack (1966) discusses several methods for measuring sludge stability:

a. Total and volatile solids determinations
b. Gas evolution during anaerobic digestion tests
c. Change in dewaterability
d. Change in oxygen uptake rate.

Mudrack stresses the importance of having a fairly constant raw sludge quality if volatile solids determination is used as a measure of sludge stability. Sludges with a low biodegradable solids concentration would show a small change in total solids concentration during the digestion process. Solids determinations would then be inaccurate as a parameter for sludge stability.

Raw sludge and partly stabilized sludge will produce gases under anaerobic decomposition. This gas-production will depend upon the amount of decomposable organic material in the sludge. By measuring the gas produced a relative measurement of sludge stability can be obtained. Mudrack used 30 days' test period at 32 $^{\circ}$C and found that the gas evolution varied from 382 l/kg VS for raw sludge to 230 l/kg VS for sludge stabilized 5 days. In a practical case detention time in excess of 5 days is usually required during aerobic stabilization. Since Mudrack only investigated detention times up to 5 days, further research is required to find the change in gas production up to at least 35 days' detention time. This test is also very time consuming and would therefore be of limited practical value.

Mudrack found that the filtration properties of sludge would improve with increasing degree of stability. It is this author's opinion that further work needs to be done before filtration properties can be directly correlated with degree of stability of sludges.

Oxygen uptake rate was measured during Mudrack's investigations. He concludes that sludge in the endogenous phase can be considered as a stable product. Oxygen uptake rate during the endogenous phase equal to or less than 0.12 kg O_2/kg VS/day indicates a stabilized sludge.

Determinations of enzyme-activity were also made by Mudrack (1966). He measured the Reductase-activity through the TTC-test (2, 3, 5, Triphenyl-tetrazoliumchloride) using a method by Bucksteeg and Thiele (1959).

A reduction of TTC-extinction with increasing detention time in the aerobic digester was found. Mudrack conludes that further work needs to be done before a certain TTC-value can be correlated with degree of stability.

Schönborn (1971) discussed the use of TTC-analyses in his work on active biomass determinations. He mentions that TTC-determinations are not accurate enough for scientific work and therefore are om limited value as a measure of active biomass.

Mudrack (1972) proposes the use of lipoid content as a measure of sludge stability. Necessary degree of stability has been reached when the lipoid content is less than 65 mg/g TS.

Pasveer (Korrespondenz Abwasser, 1971) suggests that the organic loading to a treatment plant would be a measure of the stability of the sludge produced. Organic loadings less than 0.05 kg BOD_5/kg TS.d would yield a well stabilized sludge. It is open to question whether treatment plants with the above mentioned organic loading operating during the winter period would produce a well stabilized sludge.

Müller-Neuhaus (1971) discusses sludge stabilization in detail. His approach was to measure the change in sedimentation properties, filtration properties, organic material, oxygen uptake rate, fat content and H_2S evolution during stabilization. These factors were then evaluated according to their importance. Each parameter was given a value (1 to 3) and the necessary detention time to reach a stabilized sludge was calculated. According to Müller-Neuhaus all these parameters have to be considered when discussing sludge stability. He also stresses the importance of process temperature. It is interesting to notice that Müller-Neuhaus selected the evolution of H_2S as a very important parameter for sludge stability. Parameters like reduction of organic material, oxygen uptake rate and fat content were less important, and finally the sedimentation properties were the least important.

Ahlberg et al. (1972) made an extensive field evaluation of existing aerobic digesters in Canada. They found that sludges with oxygen uptake rates between 0.5 to 1.0 mg O_2/g VSS.h were well stabilized (i.e. did not putrefy when left unaerated). At liquid temperatures less than 5 $^{\circ}$C the oxygen uptake rates mentioned would not necessarily indicate a well stabilized sludge.

Ahlberg et al. (1972) also state that the dissolved oxygen level, the oxydation-reduction potential and the nitrate concentration would indicate whether or not an aerobic digester is working satisfactorily.

3. ANALYTICAL PROCEDURES

In the following chapter only those methods that differ from the pro-
cedures set forth in Standard Methods for the Examination of Water and
Waste Water will be discussed.

3.1 Hydrogen Ion Concentration

A Radiometer, Type PHM, with a combined elctrode type GK 2311C, GK 2303C,
was used to determine pH. The pH-meter was calibrated against Radiometer
buffer solutions pH 6.50 and pH 4.65.

3.2 Dissolved Oxygen

Dissolved oxygen (D.O.) was determined with YSI-Oxygen meter, model 54.

3.3 Oxygen Uptake Rate

The oxygen uptake rate was measured with YSI-Oxygen meter, model 54.
A recorder, Leeds and Northrup, Speedomax H, was used for plotting
change of D.O. in a 200 ml test bottle vs. times. The oxygen uptake
rate was determined as the slope of the line (mg/l/min).

3.4 Total Suspended Solids

Total suspended solids was determined gravimetrically: a 40 ml volume
was centrifuged in a Sorvall Superspeed Centrifuge, type SS-1, KSB-1
for approximately 10 minutes; the clear centrate was withdrawn from the
centrifuge tube and the solids put in   aluminium foil dishes and dried
at 103 $^{\circ}$C overnight. They were then placed in a dessicator and weighed.
All tests were run in triplicate.

3.5 Volatile Suspended Solids

Samples from the total suspended solids test were placed in the muffle
furnace at 560 $^{\circ}$C for one hour. Then they were placed in a dessicator
and weighed.

3.6 Capillary Suction Time (CST)

A CST apparatus, Model 92, manufactured by Triton Electronics Ltd.,
was used for this test. The principle of the method is that filtration
is achieved by the suction applied to the sludge by the capillary action
of an absorbent filter paper of standard grade. A standard-sized cir-
cular area in the center of the filter paper is exposed to the sludge,
while the rest of the paper area is used to absorb the filtrate drawn
out by the capillary suction of the paper. The instrument records the
time the filtrate takes to travel between two concentric circles,
3.2 cm and 4.5 cm in diameters. The 1 cm diameter funnel was used for
all tests. All tests were run at room temperature (20-22 $^{\circ}$C). The
final CST value recorded was the numerical average of the three tests.

3.7 Odor Intensity Index

The method recommended in "Standard Methods" was used (identical to
ASTM D1292). Three persons participated in the panel. The method is
based on dilution with odor free water until a dilution is obtained that
has the least definitely perceptible odor.

3.8 Rüffer's Lead Acetate Test

Rüffer's Lead Acetate test is used as a measure of degree of stabilization.
100 ml bottles with glass stoppers were filled with 50 ml of sludge.
A strip of lead acetate paper was fastened between the bottle and the
stopper. The time required for the lead acetate paper to change from
white to brown due to evolution of H_2S was recorded.

3.9 ATP-Measurement

The quantitative determination of ATP by bioluminescence is dependent on:
(a) firefly luciferace enzyme being absolutely specific for ATP, (b) the
rate of the reaction being directly proportional to the concentration of
ATP, assuming that other reactants are in excess, and (c) the emission
of one photon of light for each molecule of ATP which is hydrolyzed.
The overall reaction is as follows:

$$\text{Luciferin (reduced)} + \text{ATP} + O_2 \xrightarrow[\text{Luciferace}]{\text{Mg}^{++}} \text{Luciferin (oxidized)}$$

$$+ PP_i + AMP + H_2O + h\nu$$
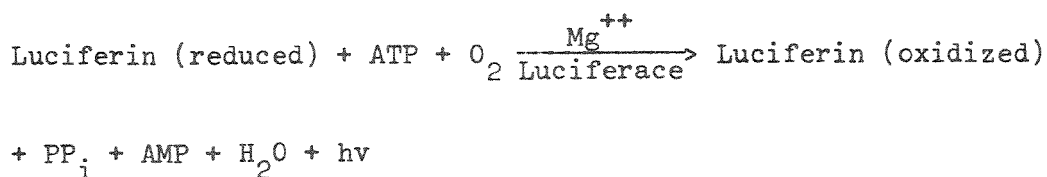
When a sample containing ATP is injected into the enzyme preparation, there is an immediate burst of light in the range of 560-580 mµ. The intensity of light declines in a semi-exponential fashion. The area under this curve is proportional to the amount of ATP in the sample.

The ATP measurements was made using a JRB-ATP Photometer from JRB Incorporated, San Diego, California, USA. According to the JRB-ATP Photometer Instruction Manual (1971), the instrument works in the following manner:

> When a sample is placed in the sample chamber after injection of ATP and the dark slide is pulled out, light strikes the photocathode of the phototube, liberating electrons which cascade through the photo-multiplier to produce a current proportional to the light intensity of the sample. This current is converted and amplified to produce a proportional voltage. This voltage is fed into a voltage-frequency converter where a pulse train is produced whose frequency is proportional to the input voltage.
>
> This pulse train is prescaled for increased accuracy and gated by a digital timer. This precision timer allows the pulse train to pass to a counter where it is accumulated for a pre-set interval. At the end of the interval the count displayed represents the integral

$$C \int_{t_1}^{t_2} I_\nu \, dt = \text{displayed counts}$$

> where C is a constant determined by a combination of the high voltage applied to the phototype (Gain) and ATTENUATOR setting, phototype sensitivity, and optical geometry.
>
> I_ν is the intensity of the light omitted from the sample, and t_1 and t_2 represent the initial and final times respectively of the integration period.

Reagents:

1. Buffer: Tris-buffer (Tris-(hydroxymethyl)-aminomethane, 0.02 M, pH 7.75) was used. After preparation, the tris-buffer was autoclaved and stored in stoppered bottles in a refrigerator. Once a flask was opened, it was used for one day.

2. Enzyme Preparation: as outlined in the JRB-ATP Photometer Instruction Manual (1971).

Sample preparation:
Approximately one litre of sludge sample was used.
This sample was homogenized in a blender and a one-millilitre sample was immersed in 20 ml of boiling (100 $^{\circ}$C) Tris-buffer. The samples were stored at - 20 $^{\circ}$C.

3.10 Protein

A colorimetric determination of protein by the Biuret test was used. The method is described by Ramanathan et al. (1968).

3.11 Carbohydrates

The Anthrone test for measuring the overall carbohydrate content was used. The method is described by Ramanathan et al. (1968).

3.12 Flotation Test

25 ml of sludge was filled in 50 ml test tubes and stored at room temperature (20 $\pm$ 2 $^{\circ}$C). The time required for the settled sludge solids to float to the top was recorded.

4. POSSIBLE METHODS FOR MEASURING SLUDGE STABILITY -
   RESULTS AND DISCUSSION

4.1 Odor Intensity of Sludges during the Stabilization Process and during Storage of Sludges

Evolution of odorous gases is one of the major problems with sludge
handling. Odorous gases are produced through biological breakdown of
organic material. The most common cause of odors is H_2S, and the con-
ditions that lead to H_2S production also favour the production of odorous
organic compounds. These compounds include mercaptans, indoles, skatoles
and other nitrogen- and sulphur-bearing compounds (Dague, 1972).

Strong offensive gases from raw sludges will disappear during the first
stage of the stabilization process. Figure 1 shows that septic tank
sludge with a strong offensive odor prior to stabilization had a rapid
decrease in odor intensity during the first 6 days of aeration. During
the following aeration period only slight changes in odor intensity would
take place. This is in agreement with practical experience since aerobic
stabilization usually does not create offensive odors at the plant.

Primary sludge and mixed primary-chemical (alum) sludge did not have a
strong offensive odor prior to stabilization. No major changes would
occur during the stabilization process. The measured Odor Intensity
Index (OII) would vary between 8 and 11. During the first 15 days of
the process the mixed primary-chemical (alum) sludge had slightly less
odor than the primary sludge alone.

Since storage of sludges quite often is necessary at small treatment
plants before the sludge is trucked to a centrally located dewatering
station or directly to a sanitary landfill, odors created during the
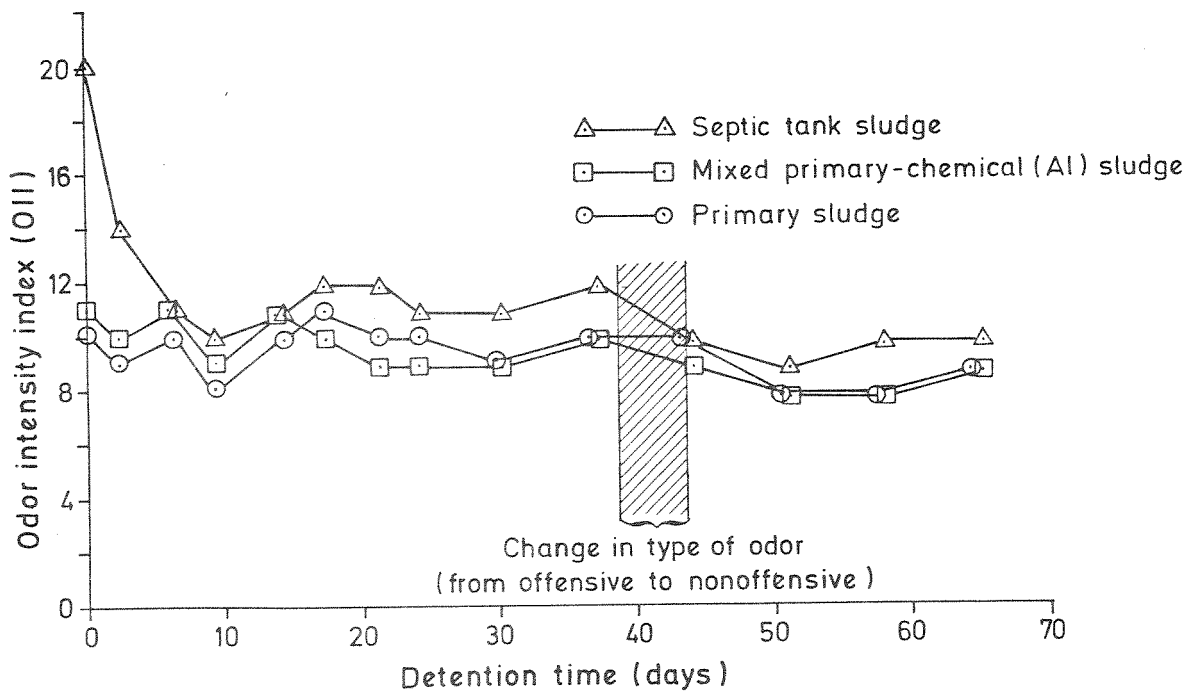storage period are of prime importance.

Figure 1. Change in Odor Intensity Index (OII) vs. Detention Time during Aerobic Stabilization at 18 °C.

Figure 2, 3 and 4 show the change in Odor Intensity Index (OII) during 14 days of storage for the three types of sludges investigated. Odor Intensity Index (OII) increased during storage for both primary sludge and mixed primary-chemical sludge. However, the amount of increase was dependent on the number of days the sludges had been aerated prior to storage. The longer the detention time in the aerobic digester, the less increase in odor intensity during storage was experienced. The same was also true for septic tank sludge, although the raw septic tank sludge decreased in odor intensity during storage rather than increased. It must be recognized, though, that the odor of this sludge was extremely offensive (OII = 20) prior to storage. Even if we had a reduction in odor intensity during storage, the odor was still quite strong throughout the storage period.

Figure 5 shows the maximum Odor Intensity Index (OII) measured through the 14 days' storage period as a function of the detention time in the aerobic digester. Generally the odors from the sludges during storage were less offensive with increasing detention time in aerobic digester. This was true for all three types of sludges investigated. However, this was not true for a detention time equal to 2-8 days. Short aeration periods (2-8 days) would not make the sludges more suitable for storage since they would give a higher rise in odor intensity during storage than the raw sludge. A possible explanation for this might be that organic material is solubilized during the early stages of the aeration process and thus more easily decomposed during anaerobic storage.

No detailed classification of the odors was made during our tests. However, during the stabilization process there was a change in type of odors although this change did not result in a great reduction in Odor Intensity Index (see Figure 1). The change was from a rotten, very offensive smell to a more earthy odor. During storage there could be a transition from the earthy odor back to the offensive odor. This was especially true for septic tank sludge.

Odor Intensity Index (OII) is not a very practical parameter to use as a measure of sludge stability. First of all it requires four persons or more to perform the test. In the author's opinion this alone makes the
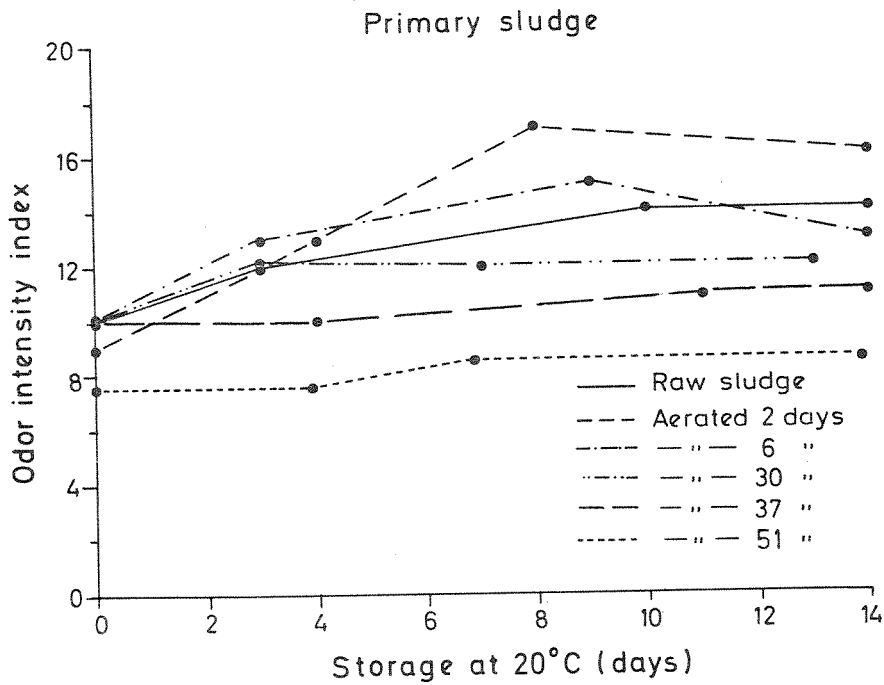
Primary sludge

Figure 2. Odor Intensity Index vs. Storage Period,
Primary Sludge.

Mixed primary - chemical (Al) sludge

Figure 3. Odor Intensity Index vs. Storage Period,
Mixed Primary-Chemical (Al) Sludge.
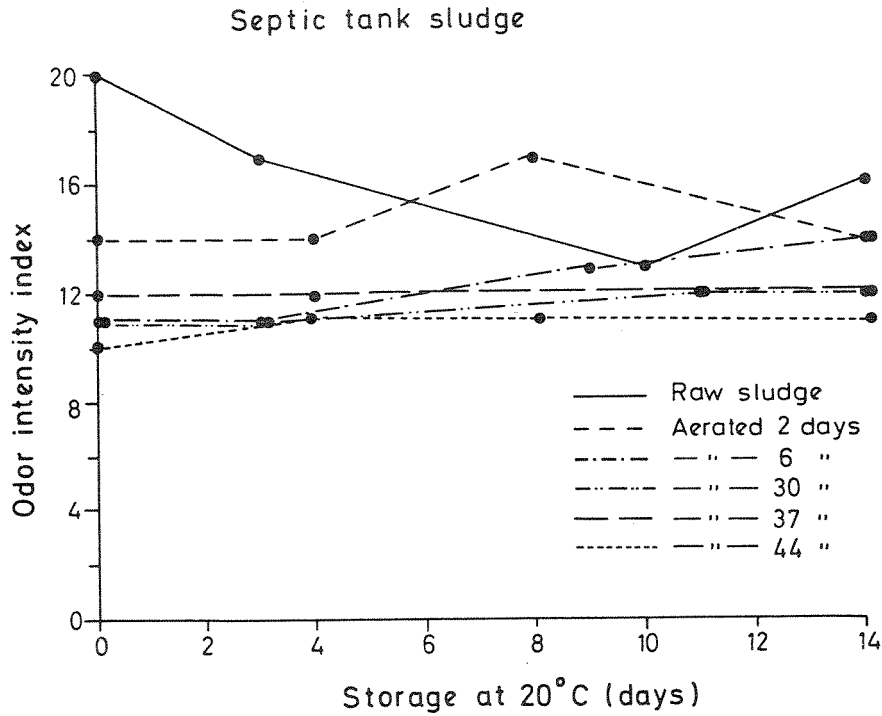
Septic tank sludge

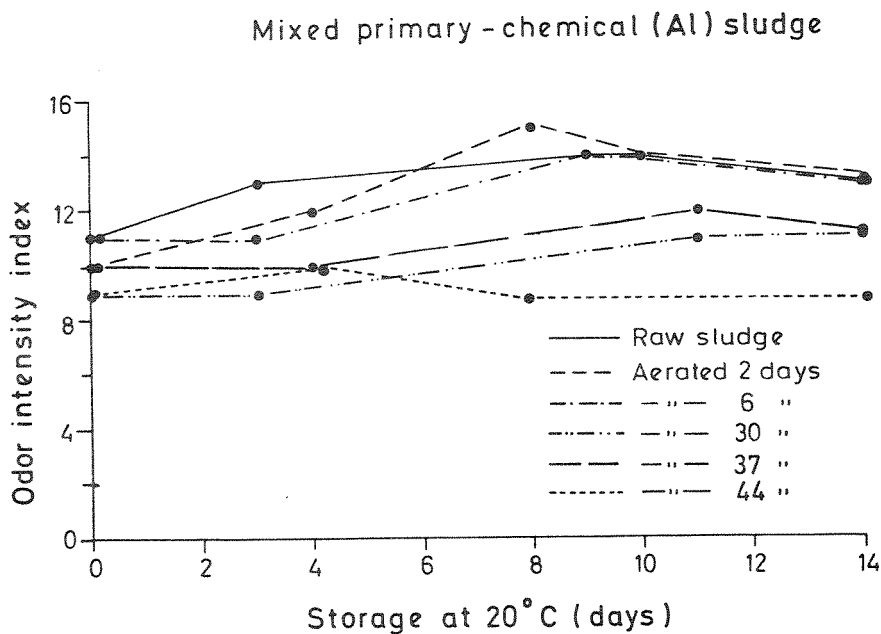Figure 4. Odor Intensity Index vs. Storage Period,
Septic Tank Sludge.
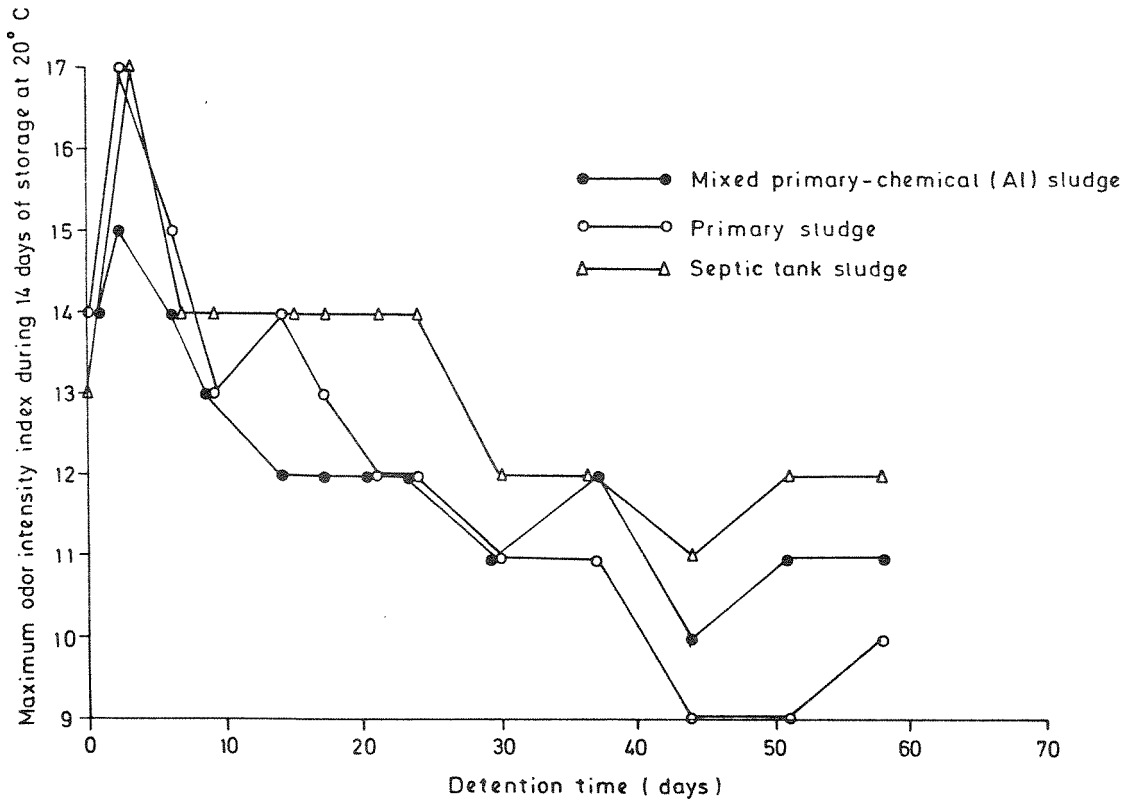
Figure 5. Maximum Odor Intensity Index Measured during 14 Days
of Storage vs. Detention Time in Aerobic Digester.

test applicable in research type work only. It is therefore important to tie parameters that can be used in practical operation of treatment plants to the odor intensity of sludges.

The difficulties in establishing limits on the odor created during storage (based on Odor Intensity Index) from sludges are recognized by the author. Not only the odor intensity is important, but also the type of odor.

If the sludge is stabilized well enough to obtain the characteristic soil odor throughout the 14 days' storage period, the intensity of the odor is of minor importance. This characteristic soil odor is not objectionable.

Based on our existing data, the following requirements regarding odor should be met before an aerobically stabilized sludge can be considered as a fully stabilized sludge:

> The Odor Intensity Index (ASTM D 1292) should not exceed 11
> at any time prior to or during 14 days of storage at 20 $^{\circ}$C, unless
> the odor can clearly be classified as a typical "soil" odor.

The three types of sludges investigated meet the requirements given above if the detention times exceed the values given in the table below (batch operation):

Table 1. Necessary Detention Time to Produce a fully
          Stabilized Sludge.

Type of sludge	Necessary detention time
Primary sludge	37 days (at 18 $^{\circ}$C)
Mixed primary-chemical (alum) sludge	40 " " " "
Septic tank sludge	44 " " " "

With these detention times established it should be possible to determine "threshold" values for other parameters that might be used to measure sludge stability.

4.2 Reduction of Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) and Chemical Oxygen Demand (COD) during Aerobic Stabilization

The content of volatile suspended solids as a percentage of total suspended solids is not a suitable method for measuring sludge stability. The overall change is usually too small. This is shown in Figure 6. Analytical inaccuracy would easily influence the result.

The overall reduction of VSS might be a usable method for measuring sludge stability (see Figure 7). Changing quality of the raw sludge fed into the aerobic digester will often make this parameter difficult to use during practical operation. The change in character of the raw sludge can be minimized by collecting information on TSS and VSS during a long period of time and then use an average value of TSS or VSS in the calculations of TSS or VSS reductions.

Most single aerobic digesters are operated in a semi-continuous fashion. In other words, they are fed with raw sludge once or twice a day. The air supply is usually shut off and supernatant is withdrawn from the unit before raw sludge is pumped into the digester. This type of operation will increase the solids concentration in the unit. In order to calculate solids reductions a complete mass balance has to be made. This is time-consuming and quite often difficult to do.

In those cases where a separate thickener separates the liquid and the solids after digestion, calculations of the TSS or VSS reductions can be made without too much difficulties.

A modified version of the expression developed by Rawn and Bant (Kempa, 1967) has previously been used to measure the degree of stability of aerobically digested sludges (Eikum, 1973). This expression is based on the reduction of organic solids.

$$M = 100 \left(1 - \frac{v_1 m_o}{v_o m_1}\right) \cdot K \qquad \text{Equation I}$$
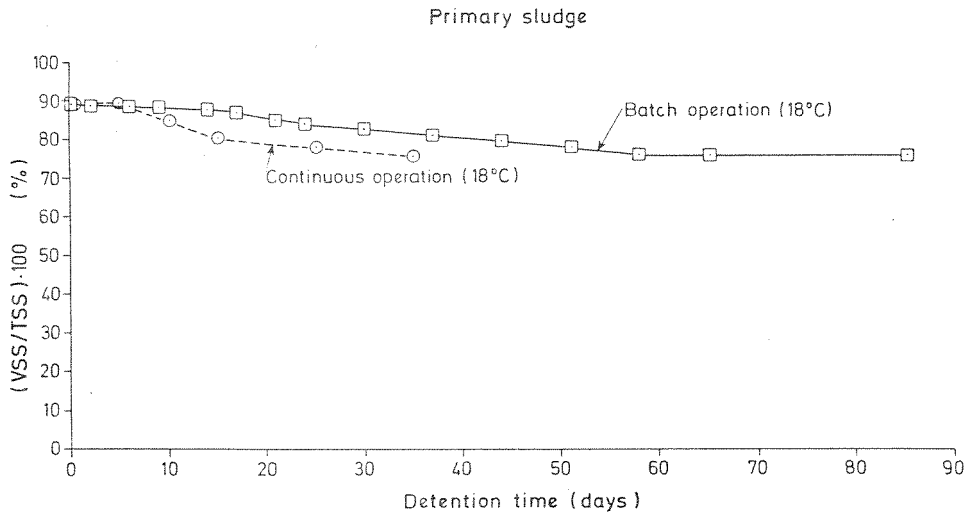
Primary sludge

Figure 6. Change in Percent Volatile Suspended Solids (VSS)
vs. Detention Time in Aerobic Digester.
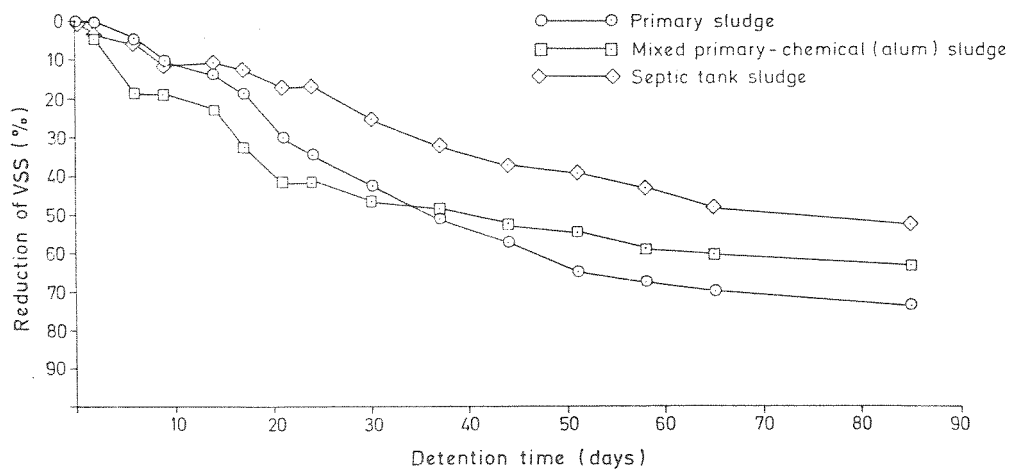
Figure 7. Reduction of Volatile Suspended Solids (VSS) vs.
Detention Time in Aerobic Digester.

M   =   degree of stability $(\%)$

v_o, v_1 =   organic solids content as per cent of total
                solids in raw and treated sludge respectively

m_o, m_1 =   inorganic solids content as per cent of total
                solids in raw and treated sludge respectively

K   =   stability constant.

The author of this progress report is of the opinion that a fully
stabilized sludge (M = 100%) has to be defined for different types of
sludges before this expression can be used. This can then be expressed
through the stability constant (K).

Since the expression given above is based on continuous operation,
the similar expression for batch operation would be:

$$M = 100 \left(1 - \frac{v_1}{v_o}\right) \cdot K \qquad\qquad \text{Equation II}$$

Using the detention times given on page 21   to determine the 100%
stability level, the following values for K can be determined (see
table 2 below):

Table 2.   <u>Stability Constant K for different Type of Sludges.</u>

Type of sludge	v_o (mg/l)	v_1 (mg/l)	K
Primary sludge	16059	7863	1.96
Mixed primary-chemical (alum) sludge	12556	6200	1.98
Septic tank sludge	26201	16513	2.70

Figure 8 indicates how the degree of stability (M) changes with the
detention time. If it is assumed that the per cent reduction of volatile
suspended solids necessary to obtain a fully stabilized sludge during
batch operation, would be the same under continuous operation, the same
value for K could be used in equation I and equation II.

Figure 8. Degree of Stability (%) vs. Detention Time
in Aerobic Digester.

Practical application of this method at a sewage treatment plant would require that the K value was determined through laboratory experiments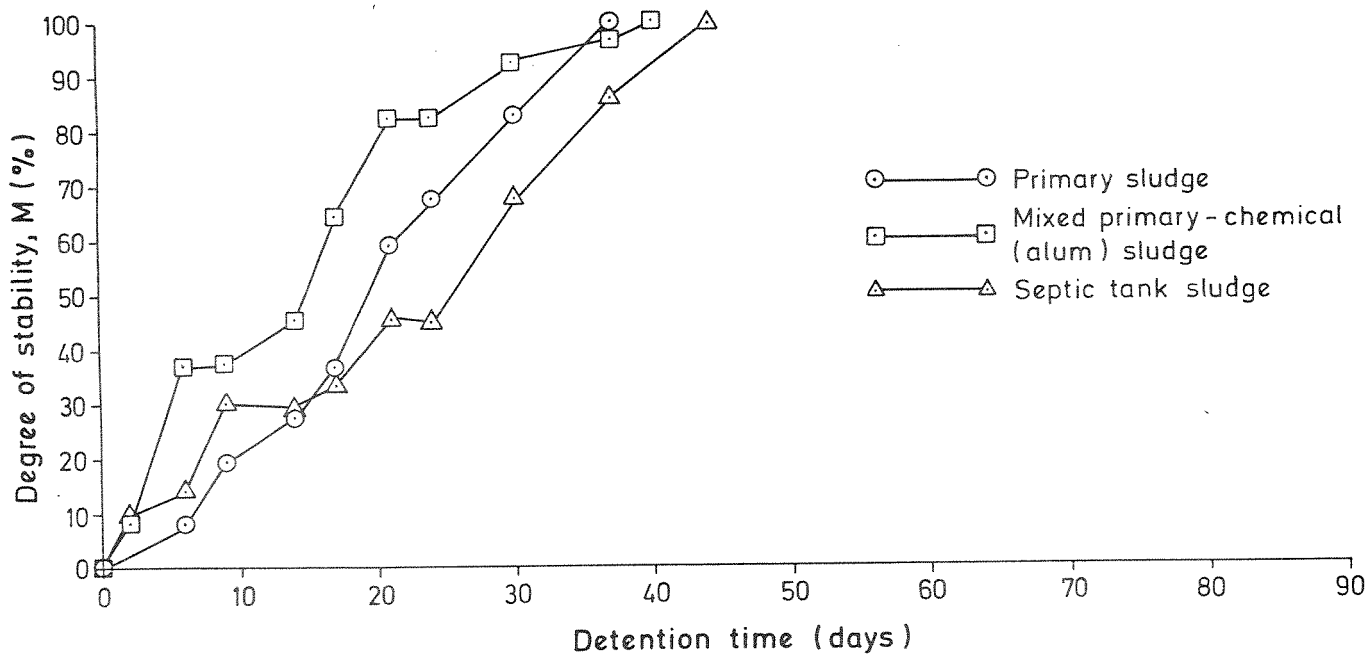. This is a major disadvantage. Very few small treatment plants have the necessary equipment and personnel to do this type of work.

The reduction of chemical oxygen demand (COD) was measured during the stabilization process. The result is shown in Figure 9.
There are no obvious reasons why COD could not be used to measure sludge stability in the same way as has been suggested for VSS. However, the overall change in COD during the aerobic stabilization process is usually less than the change in VSS. The analytical work involved in measuring COD is also more complicated than measuring VSS. The author therefore feels that the use of COD as a parameter for measuring sludge stability cannot be recommended.

4.3 Change in Oxygen Uptake Rate during Aerobic Stabilization

Oxygen uptake rate has been proposed by several researchers as a parameter for measuring sludge stability. Data obtained in this study is shown in Figure 10. During batch operation an increase will occur during the first few days of aeration and then a gradual decrease will take place.

Several factors influence the oxygen uptake rate measured during aerobic stabilization. The most important ones are:

    A. Type of sludge
    B. Temperature during the process
    C. Operation of the aerobic digester
    D. Microbial composition of the sludge
    E. Procedure used when measuring oxygen uptake rate.

An effort was made to find the correlation between the maximum odor intensity during storage and the oxygen uptake rate. This is shown in Figure 11. High oxygen uptake rates during the stabilization process are usually associated with high Odor Intensity Index during storage.
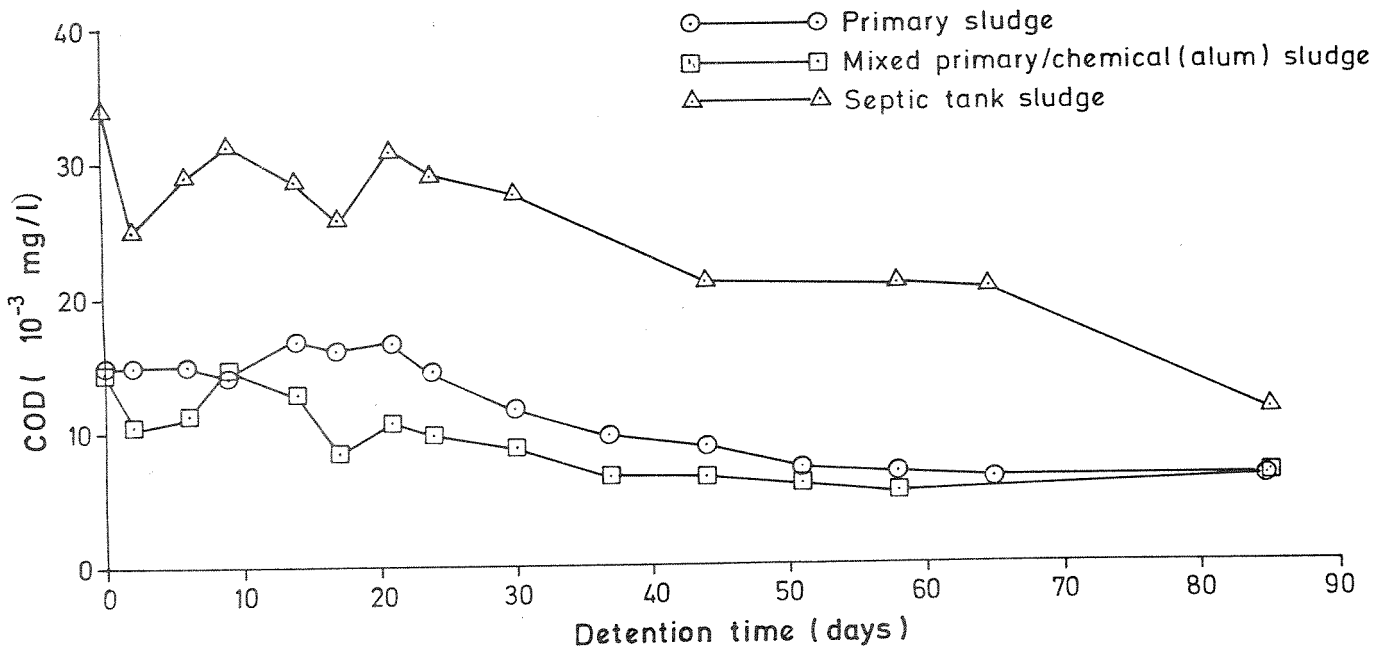
Figure 9. Chemical Oxygen Demand (COD) vs. Detention Time
in Aerobic Digester.
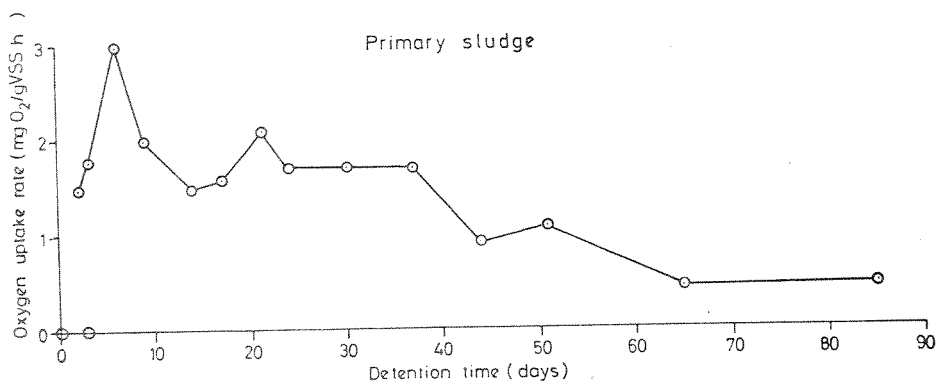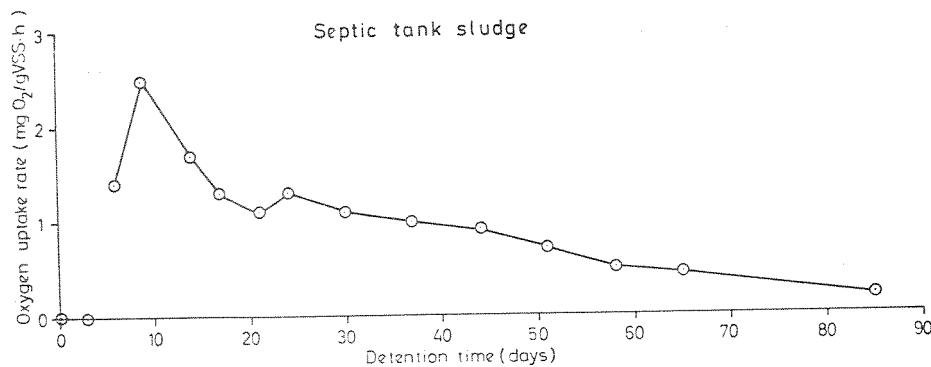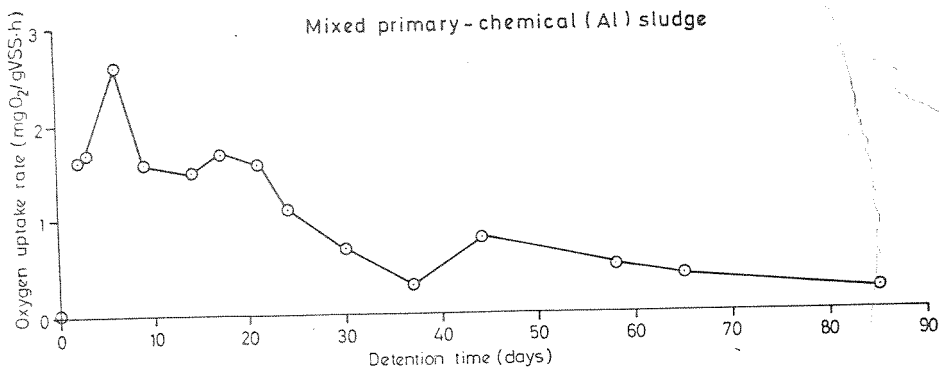
Figure 10.   Oxygen Uptake Rate vs. Detention Time
             in Aerobic Digester.

Primary sludge

Mixed primary-chemical (alum) sludge

Septic tank sludge
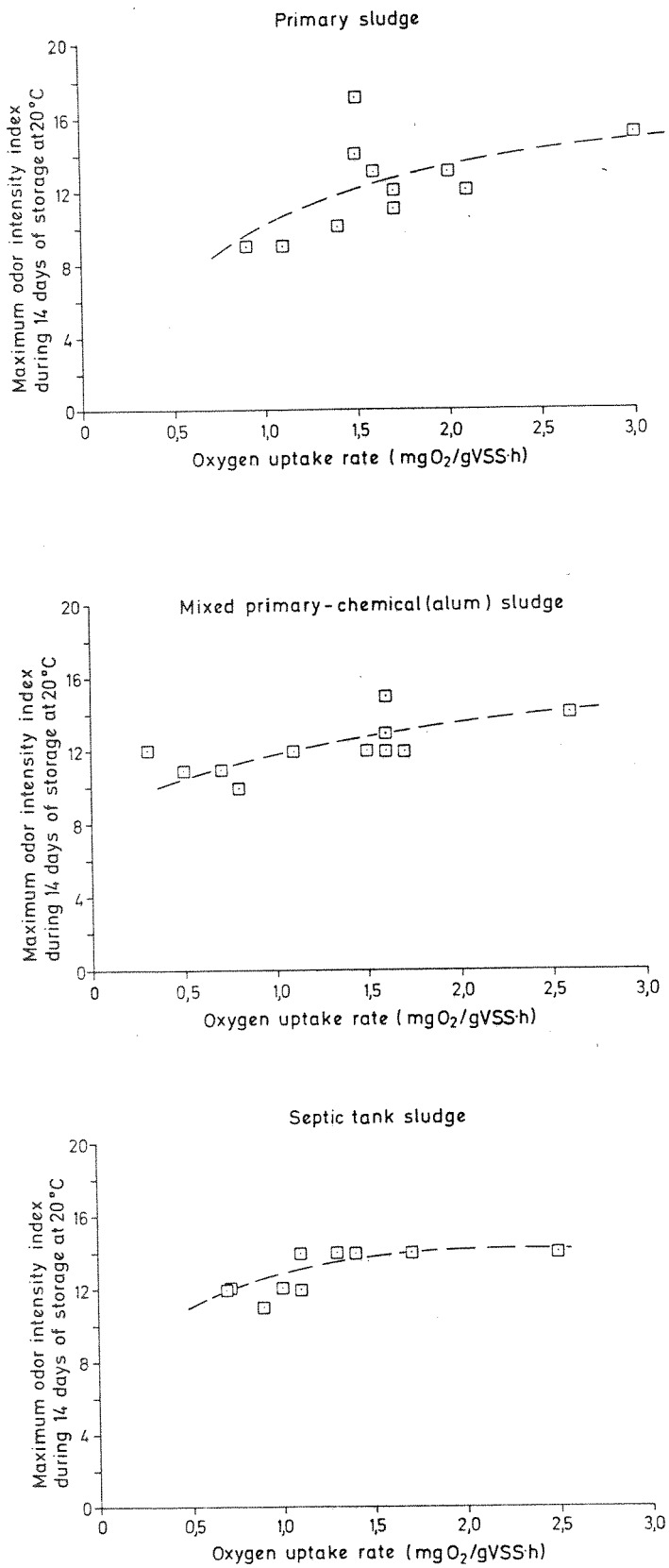
Figure 11. Maximum Odor Intensity Index during 14 Days
of Storage at 20 °C vs. Oxygen Uptake Rate.

Based on our previous definition of a fully stabilized sludge (see page 21)
the oxygen uptake rate for completely stabilized sludges has to be less
than the values given in Table 3 below:

Table 3. Maximum Oxygen Uptake Rate for fully Aerobic
          Stabilized Sludges at 18 $^{\circ}$C.

Type of sludge	Max. oxygen uptake rate at 18 $^{\circ}$C (mg O_2/g VSS.h)
Primary sludge	1.2
Mixed primary-chemical (alum) sludge	0.7
Septic tank sludge	0.7

The values for oxygen uptake rate have to be adjusted for different
temperatures. Higher temperatures during the stabilizing process would
normally mean higher biological activity and thus higher oxygen uptake
rate. This is illustrated in Figure 12. The process temperature was
not controlled during this batch operation. If we assume that the tem-
perature will change the oxygen uptake rate in the same manner as the
rate of decay constant for the reduction of VSS (Jaworski et al., 1963),
we can calculate the following "threshold" values for the oxygen uptake
rate:

$$\frac{OUR_{T_1}}{OUR_{T_2}} = \theta^{(T_1-T_2)} \qquad\qquad \text{Equation III}$$

OUR = oxygen uptake rate

θ = the Streeter-Phelps temperature sensitivity coefficient

T = temperature.
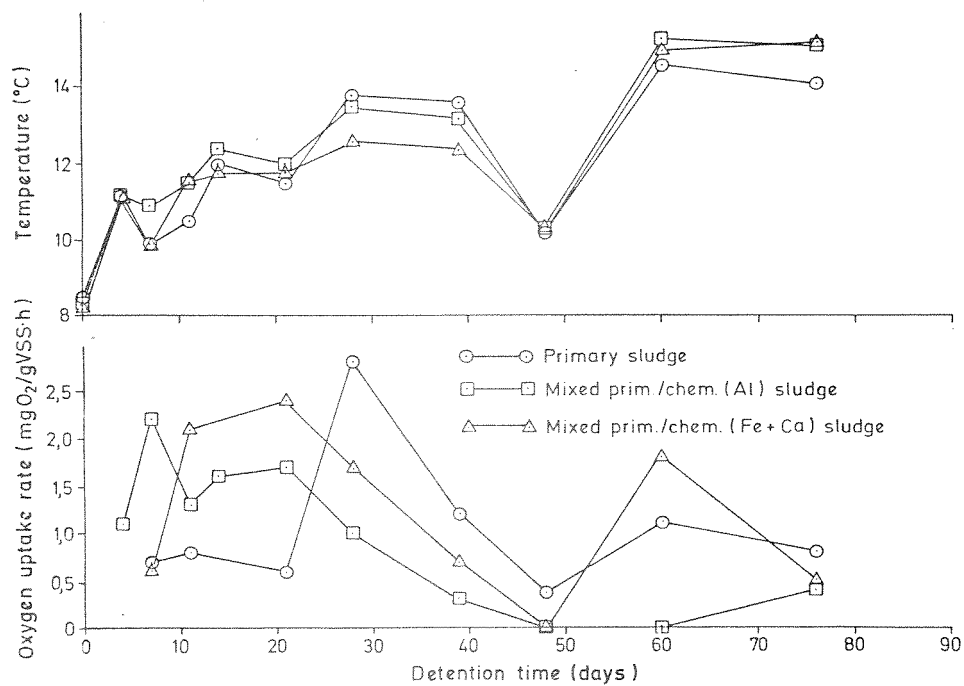
Figure 12. Temperature and Oxygen Uptake Rate vs. Detention
Time during Aerobic Stabilization.

Table 4. <u>Maximum Oxygen Uptake Rate for fully Aerobic Stabilized</u>
<u>Sludges at different Temperatures.</u>

Type of sludge	Oxygen uptake rate (mg O_2/g VSS.h)				
	7 °C	12 °C	18 °C	25 °C	θ used
Primary sludge	0.4	0.6	1.2	2.6	1.114 (Eikum 1973)
Mixed primary-chemical (alum) sludge	0.2	0.4	0.7	1.8	1.090 " "
Septic tank sludge	0.2	0.4	0.7	1.8	1.100 [1]

1) Assumed value.

We assume that when the oxygen uptake rate is at its maximum during the
stabilization process, the sludge stability is at its minimum. Using the
required detention time to reduce the Odor Intensity Index below 11
during 14 days of storage as the detention time necessary to reach the maxi-
mum stability level, we can develop the following expression for the sludge
stability (S).

$$S = 100 \cdot A \left(1 - \frac{OUR_{MEAS}}{OUR_{MAX}}\right) \qquad \text{Equation IV}$$

S	=	sludge stability (%)
A	=	constant
OUR_{MEAS}	=	oxygen uptake rate measured
OUR_{MAX}	=	maximum oxygen uptake rate during batch stabilization (S = 0).

Using the equations III and IV for the sludge stability, a family of
curves showing the relationship between process temperature, oxygen uptake
rate and sludge stability can be developed (see Figure 13).

The method outlined above has to be tested out during operation of full
scale aerobic digesters. Previous work at NIVA also indicates that the
degree of nitrification will give slightly higher oxygen uptake rates
and thus signify a less stable sludge than what it actually is.
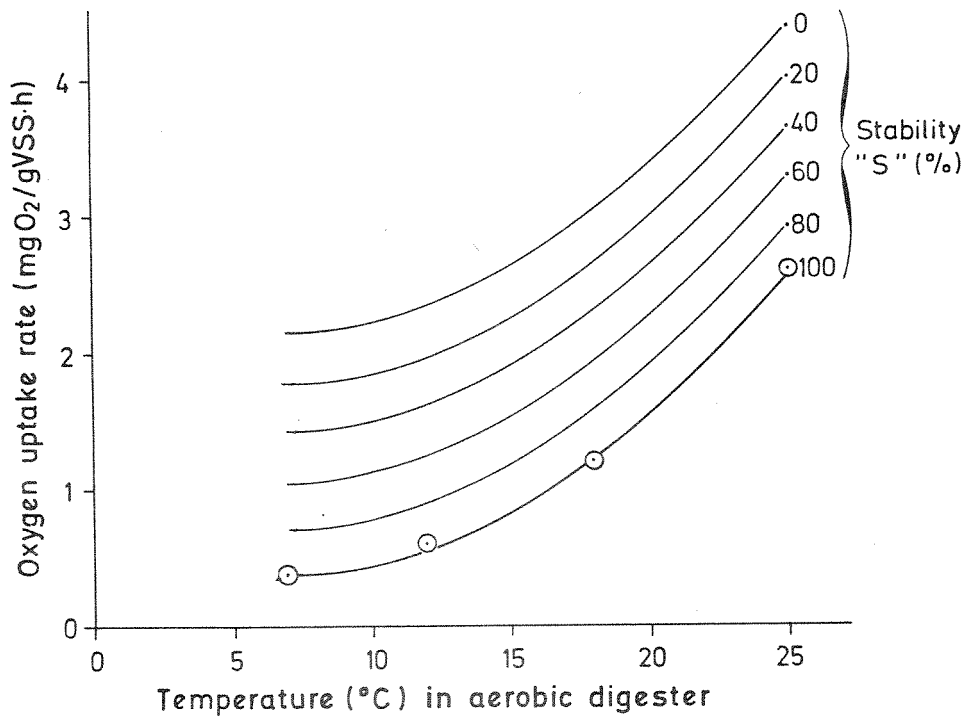
Figure 13. Oxygen Uptake Rate and Degree of Stability (%)
vs. Temperature in Aerobic Stabilization Unit,
Primary Sludge.

The difference in the predominance of species in the heterogeneous populations during aerobic stabilization will also influence the oxygen uptake rate. Higher organisms like highly mobile protozoans have been found to increase the oxygen uptake rate.

The degree of agitation during the oxygen uptake test will affect the result. The test should therefore be standardized so that the volume of test sample and the degree of agitation could be agreed upon among the participating countries.

4.4 Change in Adenosine Triphosphate (ATP) during Aerobic Stabilization

The potential of ATP measurements for providing valid approximations of sludge stability was studied during this project. Typical change in ATP during aerobic stabilization for primary sludge and septic tank sludge is shown in Figures 14 and 15.
Since ATP is found neither in dead cells nor associated with any non-living material, Figure 14 indicates that the number of living organisms decreases with an increase on detention time in the digester. Also the ratio ATP/VSS shows that the viable portion of the volatile suspended solids decreases during aerobic stabilization after the initial increase that one would expect during batch operation.

The change in total ATP content (mg/l) during aerobic digestion can be correlated with sludge stability much in the same way as has been proposed for oxygen uptake rate. However, at the present time the author of this report sees no immediate advantages in using ATP instead of more common parameters like VSS reduction, oxygen uptake rate etc. for measuring stability of aerobic digested sludges.

The ATP analysis is not particularly difficult or time consuming. However, it requires a specific type of laboratory equipment which very few laboratories have. The use of this test as a measure of the degree of stability of aerobic stabilized sludges is therefore not practical at the present time.
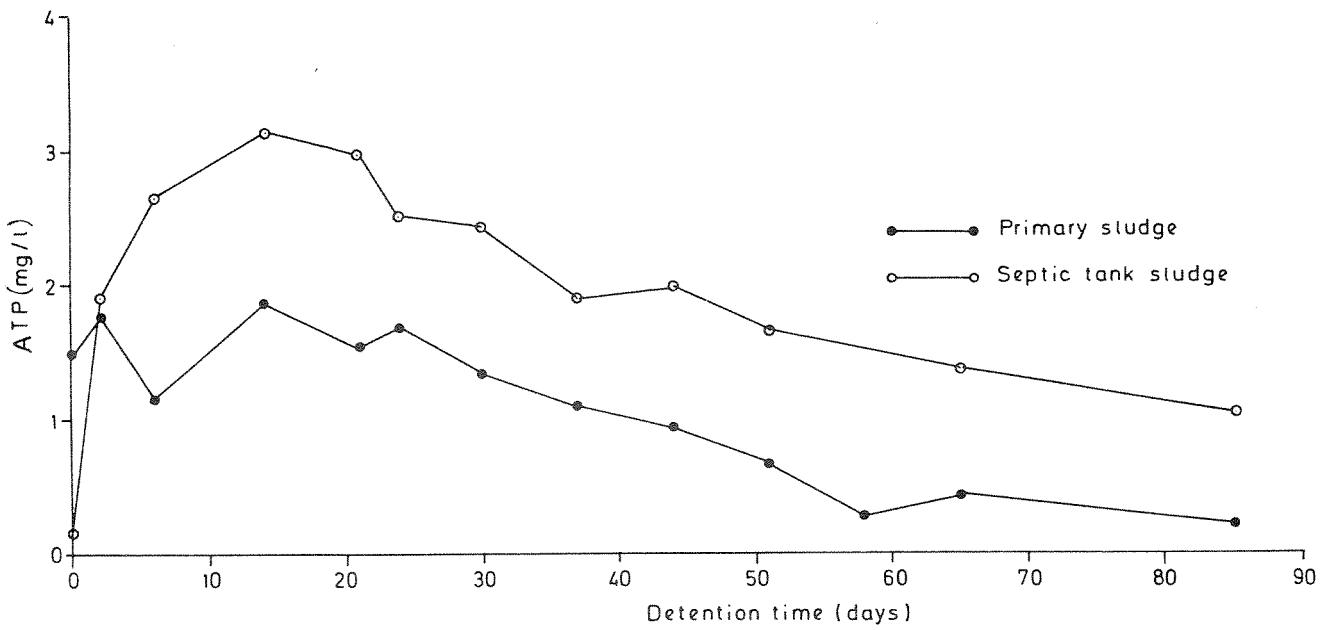
Figure 14. Adenosine Triphosphate (ATP) Content in Sludges
vs. Detention Time.
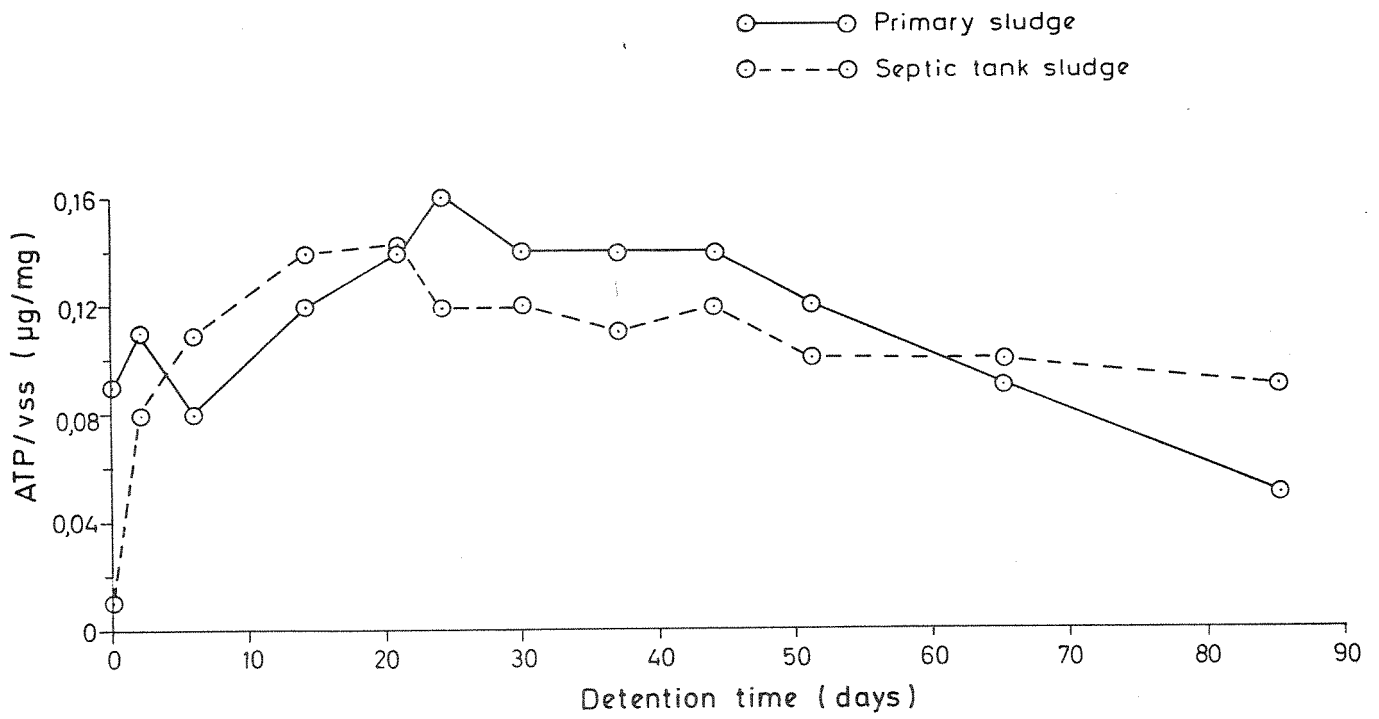
Figure 15. ATP/VSS vs. Detention Time in Aerobic Digester.

It was recognized that ATP values determined for chemical sludges (Fe or Al) were too low. Work was therefore initiated to find out how Fe or Al added to partly aerobic stabilized primary sludge would affect the ATP values. The result shows (see Figure 16) that the concentration of Al or Fe has to be less than 0.1 mg/l (as Al or Fe) to prevent interference. The result agrees with work by Patterson et al. (1970). Considering that the aluminium or iron content of chemical sludges can be 1000 mg/l (as Al or Fe) or more, a dilution of 10^4 times must be made to prevent inhibition. Since the ATP values during aerobic stabilization of sludges are quite low (see Figure 14), such a dilution would make us approach the lower detection limit of ATP.

4.5 Change in Carbohydrates and Protein Content of Sludges during Aerobic Stabilization

The change in protein and carbohydrate content during aerobic stabilization was considered as one possibility for measuring sludge stability. There was a reduction in the total carbohydrate content (mg/l) during the stabilization process of all thre three sludges investigated (see Figure 17). The total protein content would change very little during the 85 days of stabilization. This is in agreement with work by Moore (1970) and Parker (1970).

The ratio of protein to carbohydrates or the percentage of protein to volatile suspended solids could probably be correlated with the odors created during storage of the sludges. However, the author of this report does not see any advantages in using neither of these two parameters as a measure of sludge stability. The analytical procedures are too laborious to justify the use of these parameters instead of more common parameters.
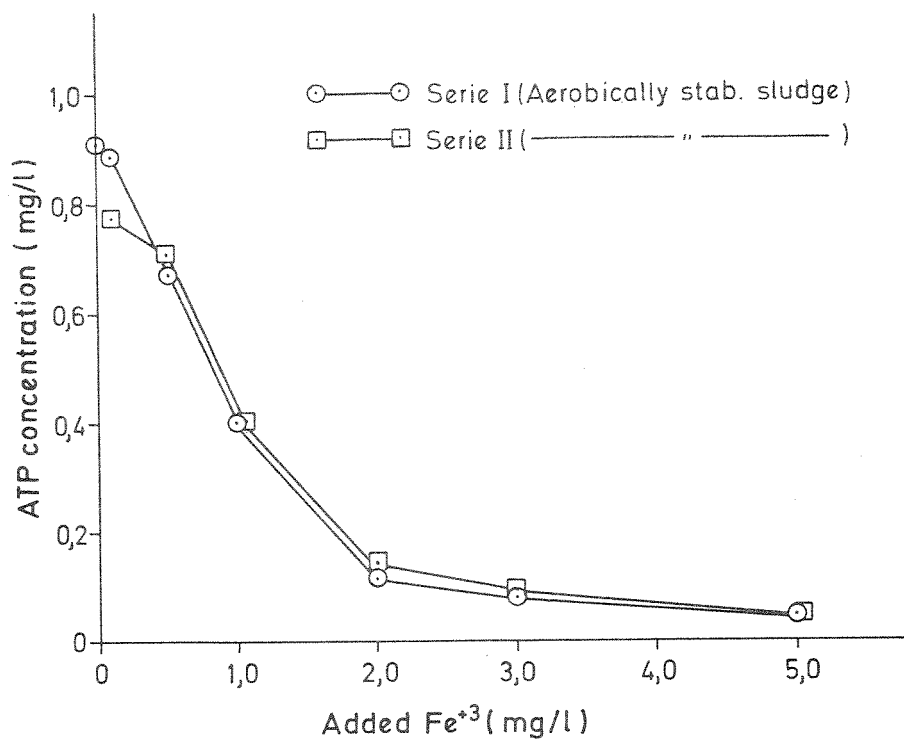
Figure 16. The Influence of Al^{+3} or Fe^{+3} on ATP Content Measured.
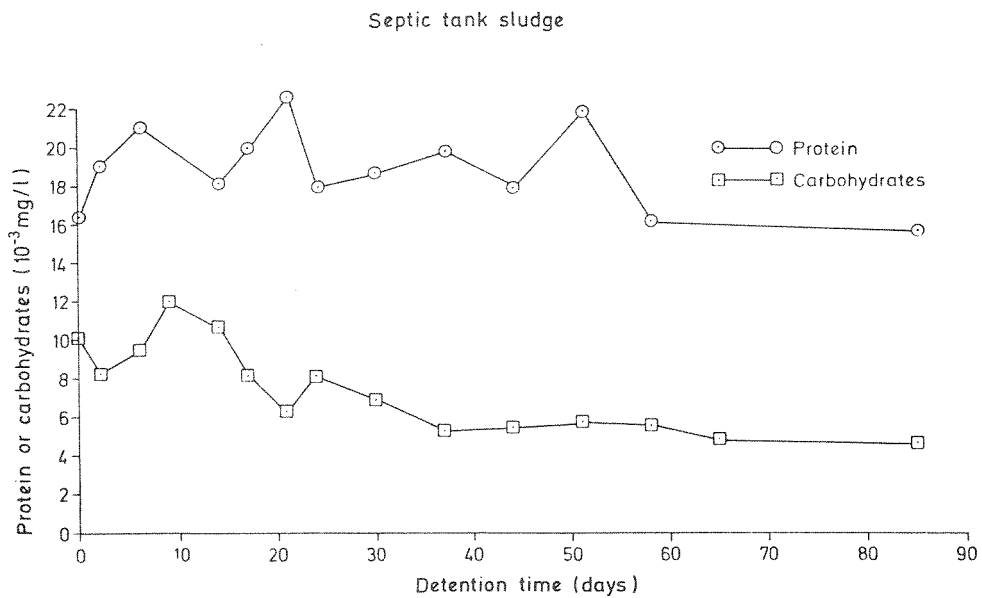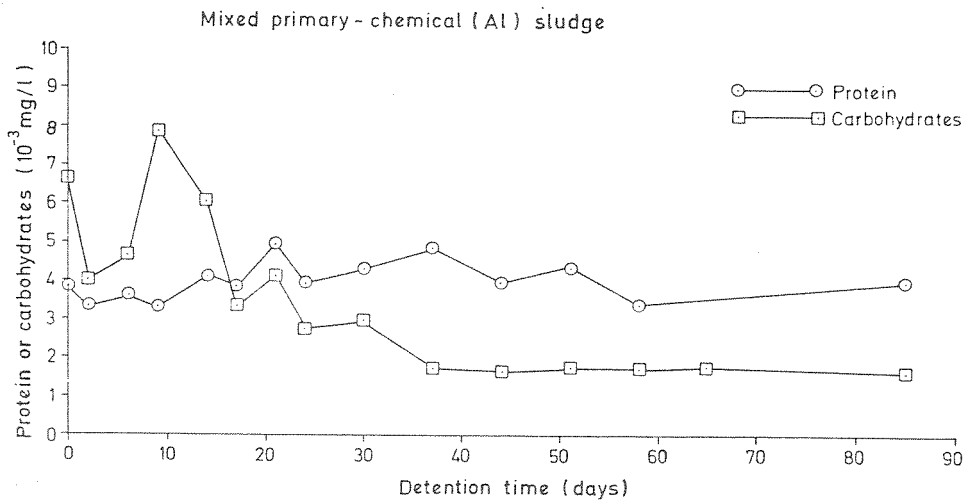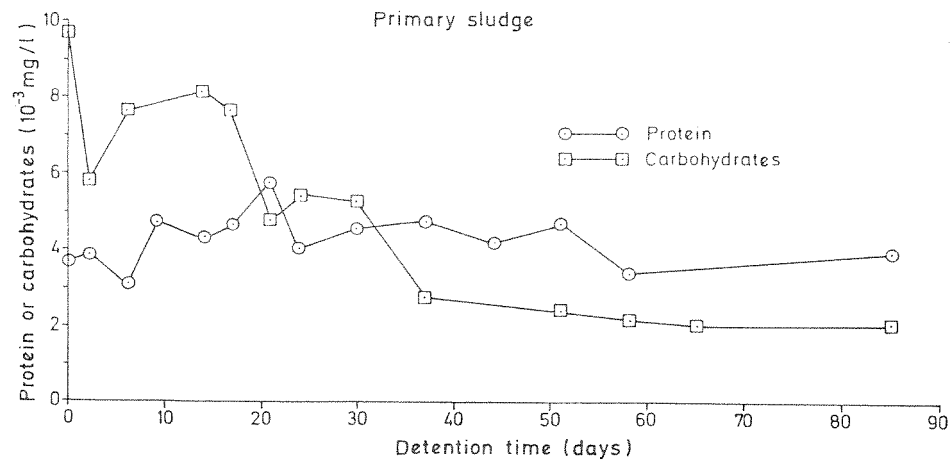
Figure 17. Protein and Carbohydrate Content of Sludges vs. Detention Time in Aerobic Digester.

4.6   Change in Filtration Properties of Sludges During Stabilization

Previous work (Eikum et al., 1974) indicates that aerobic stabilization
generally improves filtration properties of sludges. It is also stated
that one of the advantages for the stabilization process is to improve
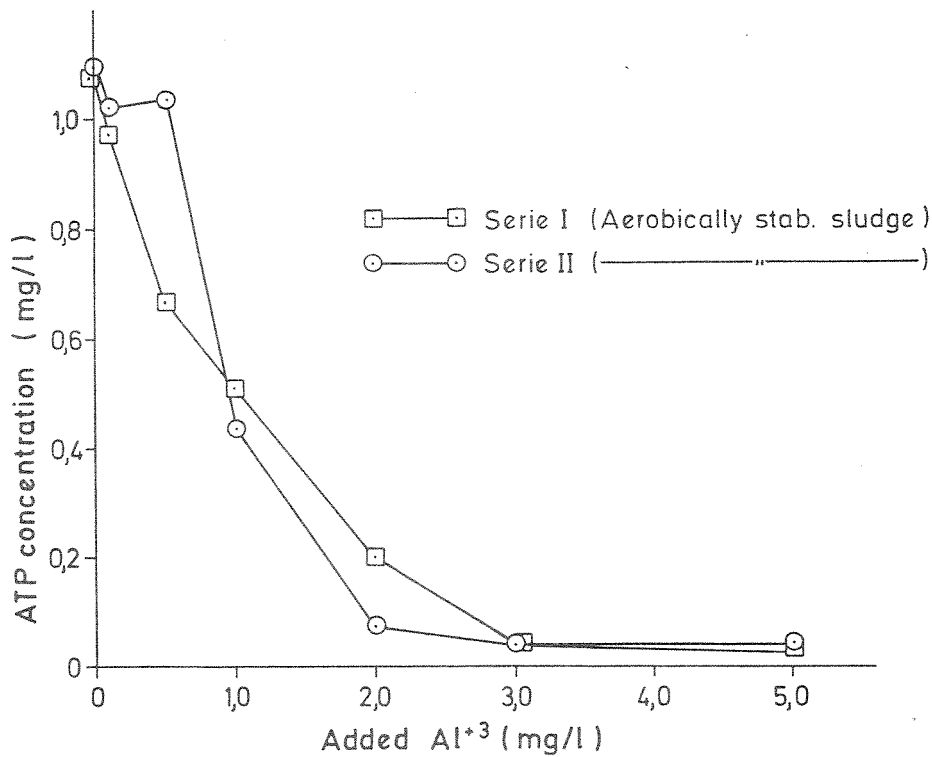the filtration properties. It must be recognized, however, that the
initial filtration properties of the raw sludge as well as the detention
time and the temperature in the aerobic stabilization unit will determine
whether or not an improvement can be achieved. The operation of the
aerobic digester will also influence the final outcome of the fil-
tration properties.

Figure 18 shows that septic tank sludge and mixed primary-chemical (alum)
sludge had an increase in CST/% SS values during the first 10-15 days
of operation during batch digestion. Then a gradual decrease would take
place. Primary sludge did not improve its filtration properties during
the stabilizing process, but showed an increase in CST/% SS values with
an increase in detention time. This is not in agreement with previous
work (Eikum et al., 1974) when a continuous process (batch fed), opera-
ting at the same temperature (18 $^{\circ}$C) was used.

Based on our work at the present time an improvement in filtration properties
cannot always be expected during aerobic stabilization. In other words,
an increase in the degree of stability is not synonymous with an improve-
ment in filtration properties. The author of this report is therefore of
the opinion that filtration properties cannot be used as a measure of
sludge stability.

4.7 Change in pH of Sludges During Storage

During this study the change of pH during storage of sludges was proposed
as one possibility for measuring sludge stability. Information on this
particular subject had been collected during earlier work at NIVA (see
Figure 19). The change in pH during storage of aerobic digested primary
sludge clearly showed that an increase in the detention time in the aerobic
digester (higher degree of stability) was followed by a lesser change in pH
during storage. Mixed primary-chemical (alum) sludges, however, did not show
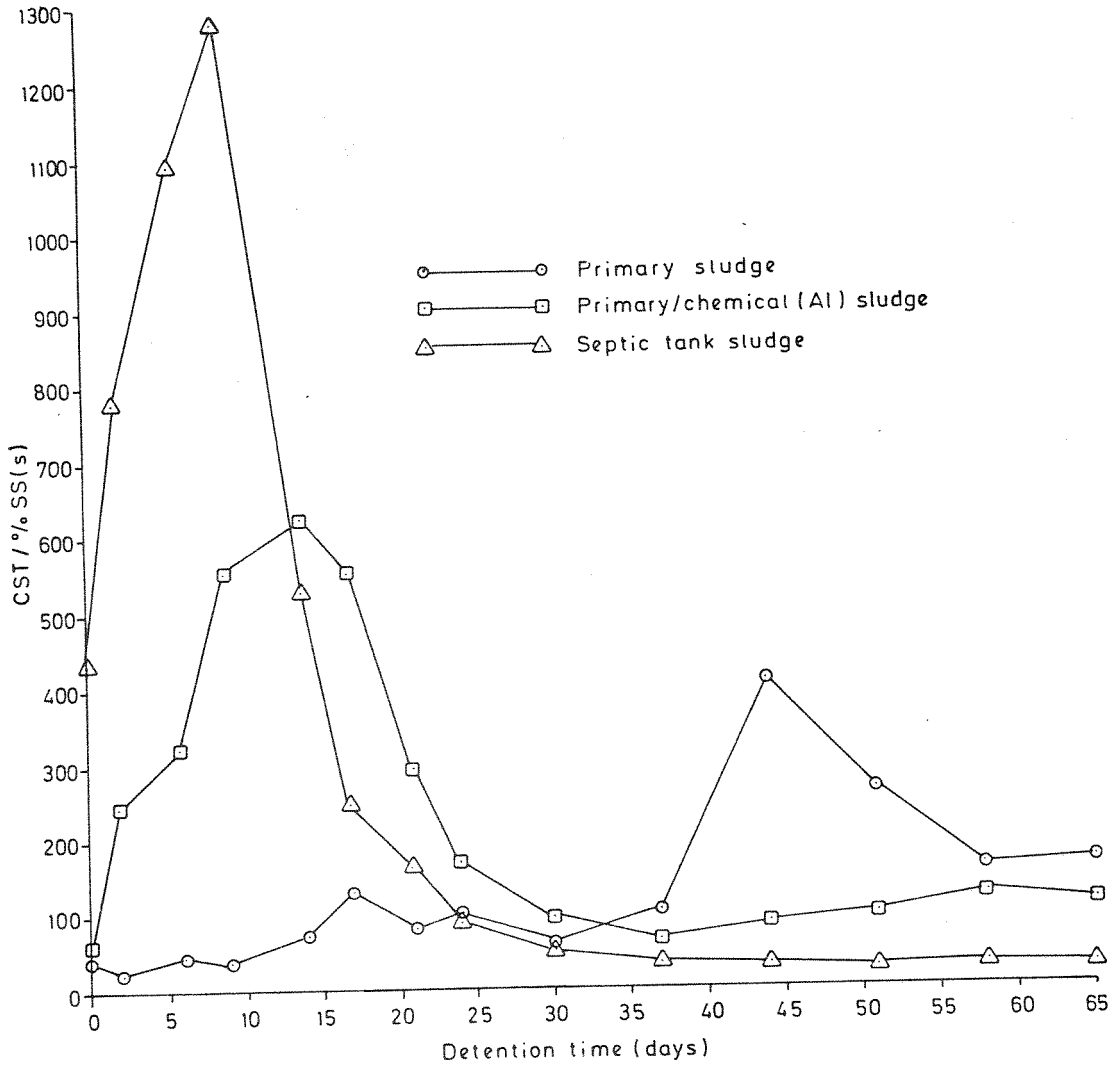
Figure 18. Change in CST/% SS vs. Detention Time in Aerobic Digester.
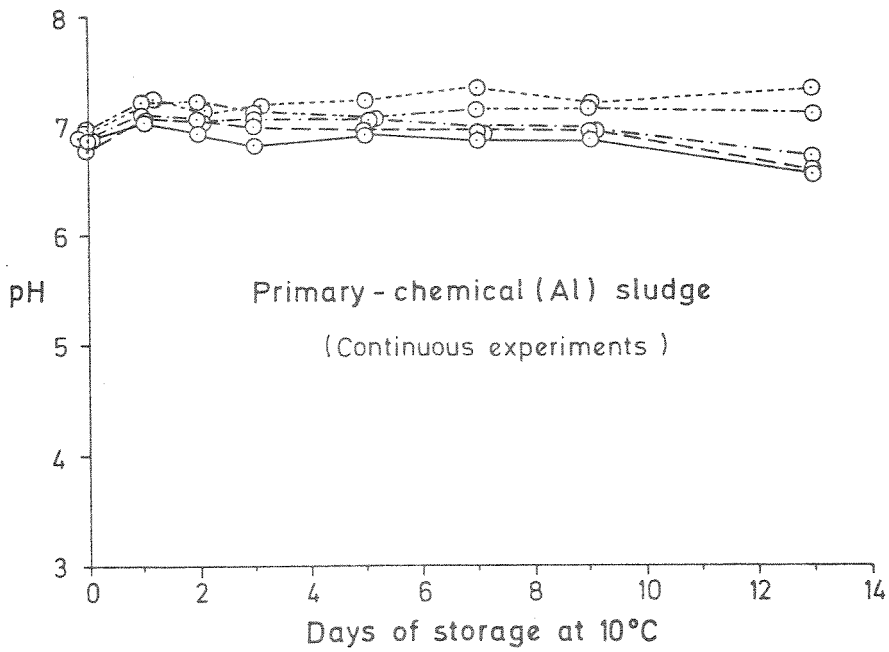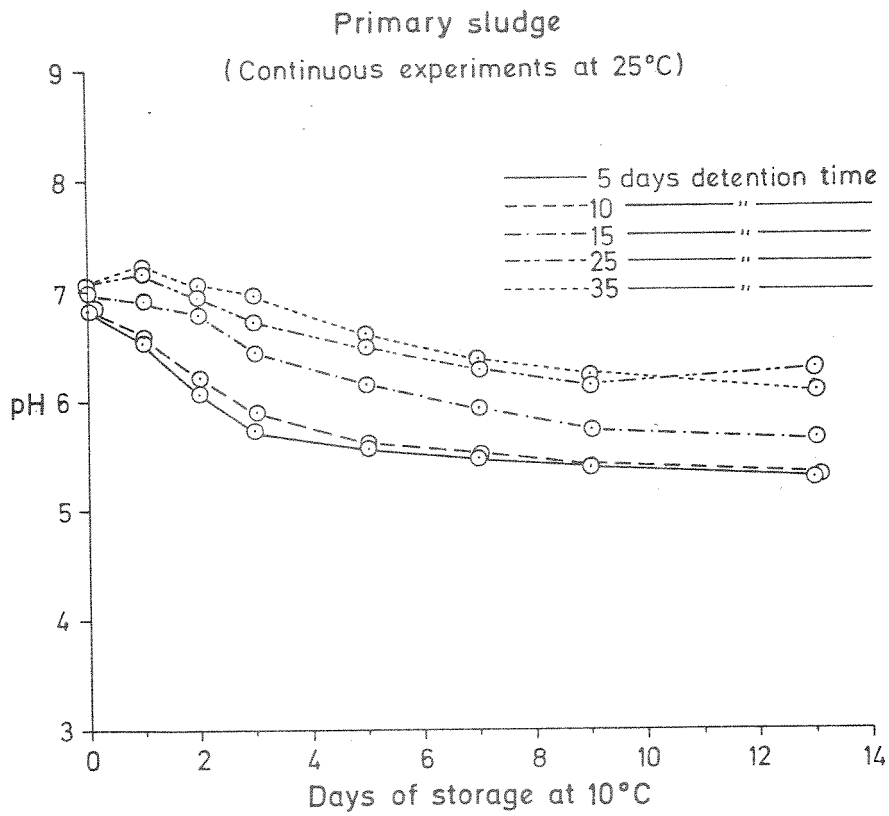
Figure 19. Change in pH during Storage of Aerobic
Digested Sludges at 25 °C.

the same relationship. Very little change in pH would take place during storage at 10 $^\circ$C regardless of the degree of stability. The possibility of using the change of pH during storage as a method for measuring sludge stability will therefore not be pursued any further.

4.8 Rüffer's Lead Acetate Test

The use of Rüffer's lead acetate test as a measure of stability of aerobic digested sludges was investigated during this project. The method is described under "Analytical Procedures".

The result obtained during the test series completed in June 1974 is given in Table 5. Only raw sludges gave a colour change of the lead acetate paper strip within 20 days. All other test bottles during this series gave a negative result.

Table 5. Rüffer's Lead Acetate Test for
Aerobic Digested Sludges at 18 $^\circ$C.

Stabilization period (days)	Period before colour appears (days)		
	Primary	Prim + Chem(Al)	Prim + Chem(Ca/Fe)
0	2	2	N.C.
4	N.C.[x]	N.C.	N.C.
7	N.C.	N.C.	N.C.
11	N.C.	N.C.	N.C.
14	N.C.	N.C.	N.C.
21	N.C.	N.C.	N.C.
28	N.C.	N.C.	N.C.
39	N.C.	N.C.	N.C.
48	N.C.	N.C.	N.C.

x) N.C. indicates no colour in 20 days.

Table 6 below shows results obtained during previous work at NIVA (Eikum, 1973). During these experiments the raw primary sludge coloured the paper strip within 10 minutes, while the raw mixed primary-chemical (alum) sludge used 3 hours before the paper strip was coloured brown.

Primary sludge stabilized at 12 $^{\circ}$C used from 3 to 5 days before colour change appeared. The same sludge stabilized at 18 $^{\circ}$C would, in the case of 5 and 10 days' detention time, use 4 days to colour the strips. Detention times in excess of 10 days showed no indication of H$_2$S evolution during the 20 days of testing.

Mixed primary-chemical sludge stabilized at 12 $^{\circ}$C showed a colour change if the detention time was below 25 days. The same sludge stabilized at 18 $^{\circ}$C gave no indication of H$_2$S evolution during the test period regardless of the detention time.

Table 6. Rüffer's Lead Acetate Test for Aerobic
Digested Sludges at 12 $^{\circ}$C and 18 $^{\circ}$C (Eikum, 1973).

Stabilization period (days)	Period before colour appears (days)			
	Primary (at 12 $^{\circ}$C)	Primary (at 18 $^{\circ}$C)	Prim + Chem(Al) (at 12 $^{\circ}$C)	Prim + Chem(Al) (at 18 $^{\circ}$C)
0	–	10 minutes	–	3 hrs.
5	3	4	2	N.C.
10	3	4	3	N.C.
15	4	N.C.	15	N.C.
25	4	N.C.	N.C.	N.C.
35	5	N.C.	N.C.	N.C.

The lead acetate test had previously been tried on untreated septic tank sludges in Norway (Løken, 1973). The goal of this work was primarily to find out if there was a wide variation in the stability of septic tank sludges. In this case the method gave positive result (brown colour) for 36 out of 41 samples (31 of 41 samples gave a colour change within 2 days).

The method was tested out at existing treatment plants using aerobic stabilization. The result is given in Table 7 below.

Table 7. Rüffer's Lead Acetate Test for Raw and Aerobic
Digested Sludges at Existing Treatment Plants.

Treatment plant	Period before colour appears (days)					
	Primary raw	Chemical raw	Biol. raw	Prim+chem +biol.(stab)	Primary (stab)	Biol. (stab)
Storfors, Sweden	N.C.	N.C.	N.C.	N.C.	-	-
Mariefred, "	-	17	-	-	N.C.	-
Säffle, "	-	-	N.C.	-	-	N.C.
Hagfors, "	1	N.C.	N.C.	N.C.	-	-
Hällefors, "	-	N.C.	N.C.	--	-	N.C.

The work done on the lead acetate test indicates that it is not a reliable
method for measuring stability of aerobic digested sludges. Evidently
not enough H_2S was produced during storage of partly stabilized sludges
to give the colour change.

4.9 Flotation Test

Gas evolution during storage of sludges has a tendency to make the settled
sludge solids to float. During our previous work on sludge stabilization
it had been noticed that the time at which flotation occurred, was a function
of the sludge stability. A very simple flotation test was therefore in-
cluded in this study to find out if sludge flotation during storage was
a possible way for measuring sludge stability. In this test a 50 ml test
tube was filled with 25 ml of sludge. The sludge solids would settle
during the first few hours of storage and a clear interface between the
solids and the supernatant would normally be obtained. The number of days
before the flotation of the sludge solids occurred was then recorded.

It was recognized that nitrification taking place during aerobic stabili-
zation would subsequently cause denitrification with the result of N_2 gas
production during storage. The N_2 gas would cause flotation to happen in
the same way as gases produced during anaerobic decomposition of organic
material. Since decomposition of organic material would normally take
place in raw or partly stabilized sludges while denitrification would occur
in well stabilized sludge, an effort was made to inhibit the denitrification
step during the test. The inhibitor used, however, should not inhibit the
anaerobic decomposition. Otherwise no gas would be produced at all.

During pure culture studies it was determined that 0.1 mg/l Na-azid would inhibit the denitrification step, but not the anaerobic decomposition of the organic material. It was then decided to use 0, 0.25, 1.25 and 2.50 mg/l Na-azid during the flotation test to determine if the result obtained during the pure culture studies would be applicable when using actual sludges. Results obtained using three different types of sludges showed that even a concentration of 2.50 mg/l Na-azid would not inhibit denitrification during the flotation test (see Table 8 below).

Table 8. Results from Flotation Test of Aerobic Digested Primary + Chemical (Ca/Fe) Sludge.

| No. of days stabilized | Days before flotation occurs (flotation period) | | | |
| | Inhibitor mg/l Na-azid | | | |
	0	0.25	1.25	2.50
0	21	8	8	21
4	10	24	24	10
7	8	10	10	10
11	25	9	10	25
14	14	14	14	14
21	18	19	19	18
28	4	–	12	4
39	1	1	1	1
48	2	2	2	2
60	2	2	2	2

The overall result from this test shows that long detention times in the aerobic digester (high degree of stability) are associated with a rapid flotation (1-2 days) of the sludge solids (see Figure 20). It is of interest to notice that the drop in the number of days it takes to make the sludge float in the test tube happens approximately at the same time the nitrification occurs (see Table 9). This is expected since the reason for the rapid flotation is denitrification.

The limited amount of work done on the flotation test indicates that the N_2-gas evolution normally taking place during storage of a well stabilized sludge would cause the solids to float within 1-2 days. Short flotation periods (1-2 days) would therefore indicate a fully stabilized sludge while longer flotation periods indicate raw or partly stabilized sludges.
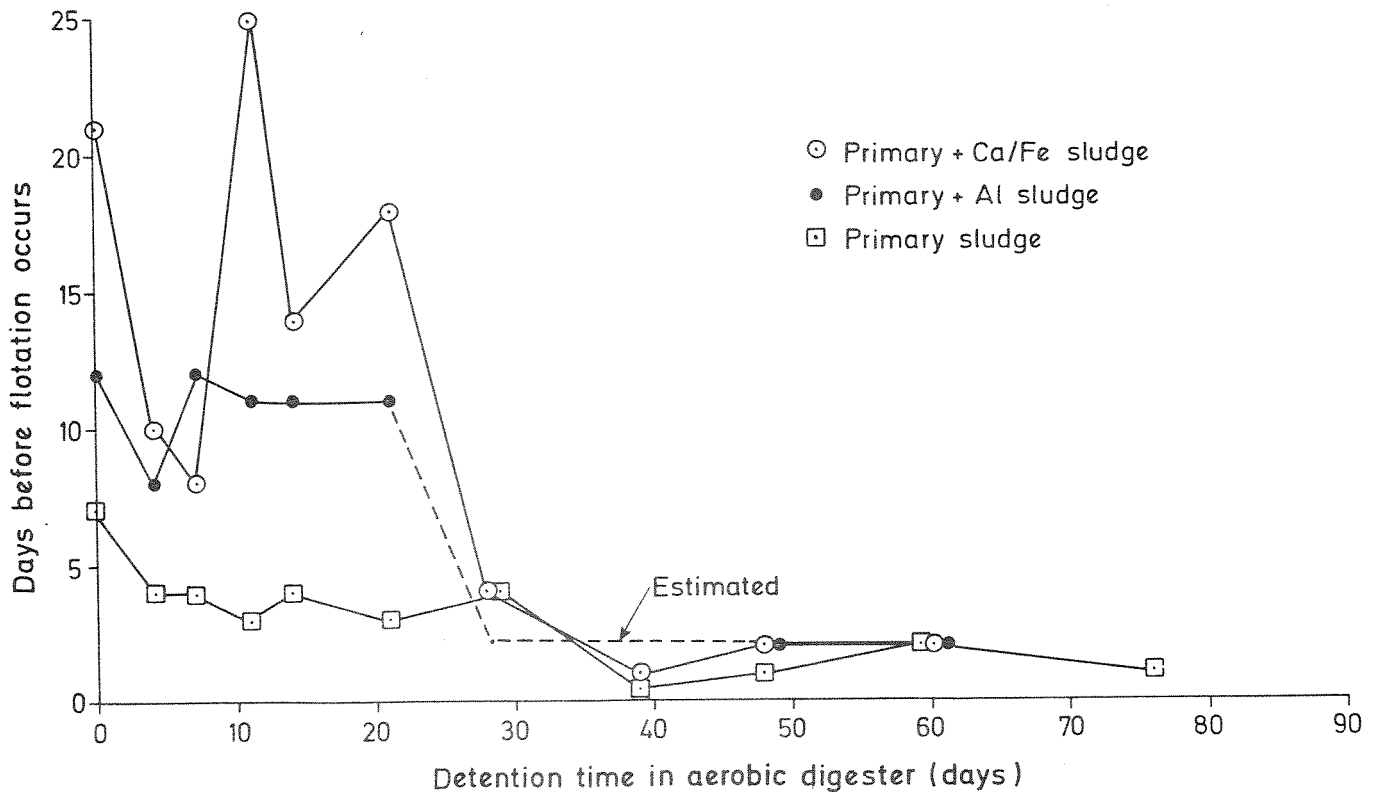
Figure 20. Days before Flotation occurs vs. Detention Time
in Aerobic Digester.

Table 9. Nitrite and Nitrate Concentrations during Aerobic
          Stabilization.

Detention time (days)	$NO_2 + NO_3$ (mg/l-N)		
	Primary sludge	Prim + Chem(Al)-sludge	Prim + Chem(Fe/Ca)-sludge
0	–	–	–
21	0.04	13.2	2.1
28	0.09	50.0	49.0
39	58.0	61.0	–
48	60.0	60.0	80.0
60	60.0	60.0	80.0

The method discussed in this chapter has one major advantage; it is very
simple to do. However, more work needs to be done in the field to find
out how reliable the method is.

4.10 Reduction of COD and BOD, and the Content of PO_4-P in Sludge Liquor during Aerobic Stabilization

The BOD of the sludge liquor was investigated as one possibility for
measuring sludge stability. The information given on this subject has
been obtained from previous work at NIVA (Eikum, 1973). This data is
based on a continuous flow system, operated at 7 $^{\circ}$C and 25 $^{\circ}$C. The
sludge liquor was in this case obtained by filtering the sludge through
10 cm of fine sand. The sludge liquor would probably contain more col-
loidal material than if it had been filtered through GF/C filters.

Table 10 and 11 show a sharp drop in BOD_7 between 0 and 5 days' detention
time and then a more moderate reduction or a nearly constant value with
detention times in excess of 5 days. This is in agreement with work by
Kehr (1966). It is apparent that the BOD_7 values in the sludge liquor
are reduced much faster than the necessary time required to produce a
well stabilized sludge. For this reason the BOD_7 values of the sludge
liquor would not be a good parameter for measuring sludge stability.

Table 10. Quality of Filtrate - Primary Sludge.

Det. time (days)	Temp. °C	COD mg/l		BOD$_7$ mg/l		PO$_4$-P mg/l		Turbidity JTU	
		1 series	2 series	1 series	2 series	1 series	2 series	1 series	2 series
0	25	1362	1879	470	830	19.00	36.00	324	227
5	25	125	293	10	42	2.10	3.80	15	34
10	25	144	257	13	14	1.30	1.40	14	17
15	25	196	182	9	9	0.18	3.00	16	7
25	25	144	170	0	13	0.07	2.90	7	6
35	25	175	165	12	4	0.30	2.90	9	4
0	7	1735	1800	1365	1350	35.00	32.00	340	460
5	7	430	642	110	135	0.90	11.00	67	88
10	7	304	553	46	220	0.13	0.50	32	33
15	7	290	382	25	155	0.13	0.05	33	37
25	7	309	308	65	54	0.05	0.04	29	22
35	7	310	260	26	24	0.18	1.30	51	34

Table 11. Quality of Filtrate - Mixed Primary-Chemical Sludge.

Det. time (days)	Temp. °C	COD mg/l		BOD$_7$ mg/l		PO$_4$-P mg/l		Turbidity JTU	
		1 series	2 series	1 series	2 series	1 series	2 series	1 series	2 series
0	25	468	693	350	646	0.09	0.18	22	25
5	25	161	132	23	17	0.50	0.33	25	16
10	25	69	94	6	10	0.27	0.09	15	7
15	25	74	106	5	8	0.34	0.14	17	8
25	25	61	54	3	6	0.43	0.12	16	6
35	25	70	47	8	4	0.60	0.04	23	4
0	7	809	817	630	700	2.40	0.25	88	40
5	7	306	347	44	67	2.80	0.70	81	32
10	7	120	189	16	16	0.41	0.33	17	18
15	7	-	72	17	-	0.17	0.04	17	3
25	7	115	49	18	-	0.06	0.09	14	3
35	7	85	39	17	-	0.13	0.04	14	2

The change of COD in the sludge liquor is more gradual than BOD, but again the reduction beyond 5 days' detention time is relatively small. The use of COD in the sludge liquor will therefore not be pursued any further.

The content of soluble ortho-phosphate in the sludge liquor has previously been suggested as an index of sludge stability (Sekikawa et al., 1966). Based on the result in Table 10 and 11 this seems to be a possibility for primary sludge, but certainly not for mixed primary-chemical (alum) sludge. Since the chemical sludges (Al and Fe) are very common in Scandinavia, the author of this report feels that the methods investigated must be applicable for the chemical sludges as well.

4.11 Nitrification during Aerobic Stabilization

A large portion of the nitrogen in the raw sludge is in the form of organic nitrogen and ammonium. Only minute quantities of nitrite and nitrate are usually present in the raw sludge.

Several biological processes that change the nitrogen forms will take place simultaneously during aerobic digestion. Ammonification will liberate ammonia from the organic material. This ammonia serves as the starting point for nitrification.

During our previous work on aerobic stabilization it had been noticed that nitrification would not take place during the early stages of the digestion process. Figure 21 illustrates this for three different types of sludges during batch operation. The reasons for this will not be discussed in this progress report since the subject of nitrification has been covered quite extensively by others (Wuhrmann, 1964, Downing, 1964, Rüffer, 1964). Also work by others on aerobic stabilization indicates that nitrification would only take place in fairly well stabilized sludges (see Table 12). The time periods before nitrification occurs varies from 15 to 39 days. A certain variation would be expected since several factors like oxygen concentration, temperature, pH etc. would influence the degree of nitrification.
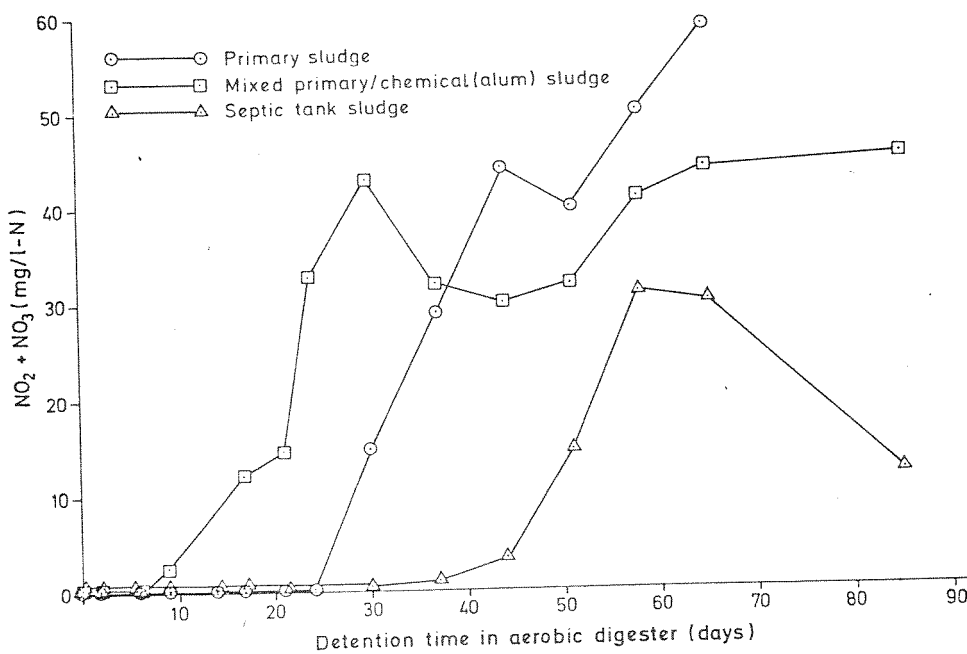
Figure 21. Nitrite and Nitrate Concentration vs. Detention Time during Aerobic Stabilization.

Table 12. Days before Nitrification occurs during Aerobic Stabilization.

Type of sludges	Process temp. $^{\circ}C$	Days before nitrification occurs	Reference	Comments
Primary + activated	20	15 - 20	Jaworski et al.(1963)	Continuous digestion, lab.units
Activated	20	approx.10	Moore (1970	Batch operation
Primary	17-19	19	Rüffer (1966)	Batch operation
Primary	25	15 - 25	Eikum (1973)	Continuous operation
Primary	7	25 - 35	" "	"
Primary	18	28 - 39	NIVA (unpubl.)	Batch operation
Prim + Chem (Al)	18	21 - 28	" "	" "
Prim + Chem (Ca/Fe)	18	28 - 39	" "	" "

If high concentrations of nitrite and nitrate would normally occur at a high sludge age, it seems possible to use a qualitative $NO_2 + NO_3$ analysis as an indicator of sludge stability. The test would give a "yes or no" answer on whether or not a particular stabilization unit would produce a stable sludge.

Analytical work involved in determining $NO_2 + NO_3$ present could be mini-mized by using prepackaged reagents (HACH or equivalent). This would enable treatment plant operators to do the test with a minimum of training and expensive laboratory equipment.

9. Aluminium and iron content of sludges in excess of 0.1 mg/l (Al or Fe) will affect the ATP determination.

10. The analytical procedures in determining protein and carbohydrates are too laborious to justify their use for sludge stability measurements.

11. Filtration properties cannot be used to measure sludge stability.

12. Change in pH during storage of sludges is not a usable method for measuring sludge stability.

13. Our research indicates that Rüffer's Lead Acetate test is not a reliable method for measuring stability of aerobic digested sludges. Evidently not enough H_2S was produced during storage of partly stabilized sludges to give a colour change.

14. The flotation test seems to have possibilities as a practical test for determining sludge stability. Short flotation periods (1-2 days) indicate a fully stabilized sludge while longer flotation periods are associated with raw or partly stabilized sludges.

15. The reduction of BOD_7 and COD in the sludge liquor cannot be used to measure sludge stability.

16. The content of soluble ortho-phosphate in the sludge liquor might be a possible method for measuring stability of aerobic stabilized primary and biological sludges, but not chemical sludges.

17. A qualitative determination of $NO_2 + NO_3$ might be used as an indicator of sludge stability.

6. RECOMMENDATIONS

6.1 Definition of Stability

It is recommended that a stable sludge from an aerobic stabilization unit
is defined as:

> A sludge where the Odor Intensity Index (OII) does not exceed 11
> at any time prior to or during 14 days of storage at 20 $^\circ$C unless
> the odor can be classified as a typical "soil" odor.

6.2 Methods for Measuring Sludge Stability

The following three methods are recommended for the measurement of sludge
stability. Method A is recommended for larger plants where plant personnel
have the necessary training and laboratory equipment to do the test ade-
quately. Method B and C are recommended for small treatment plants where
a minimum of laboratory equipment is available. Method B and C will only
give a "yes" or "no" answer to the question of whether or not a stable sludge
is produced at the plant.

A. Oxygen uptake rate. The oxygen uptake rate should be measured in a
200 ml Erlenmeyer flask placed on a magnetic stirrer. An oxygen probe
should enter the flask through a rubber stopper. The change in dissolved
oxygen content vs. time should be recorded. Since the oxygen uptake rate
is dependant on the solids concentration, the volatile suspended solids
(VSS) must be measured. The oxygen uptake rate should then be recorded
as mg O_2/g VSS.h. The digester temperature should also be recorded.
The following equation is used to determine the degree of stability (S):

$$S = 100 \cdot A \left(1 - \frac{OUR_{MEAS}}{OUR_{MAX}}\right) \qquad \text{Equation IV}$$

The following constants can be used for the three types of sludges
investigated.

Table 13. <u>Sludge Stability Constants</u>.

Type of sludge	A	OUR_{MAX} at 18 ^{o}C
Primary sludge	1.67	3.0 mg O_2/g VSS.h
Mixed primary-chemical (Al) sludge	1.37	2.6 " " "
Septic tank sludge	1.39	2.5 " " "

For different types of sludges the A and the OUR_{MAX} must be determined
through batch experiments.

The oxygen uptake rate measured must be adjusted to 18 ^{o}C, using
equation III, given on page 30 , before the constants in Table 13 are
used to calculate degree of sludge stability (S).

B. <u>Flotation test</u>. The test should be done according to the description
given under "Analytical Procedures", page 15 . Flotation periods less
than 2 days indicate a fully stabilized sludge.

C. <u>Nitrite and nitrate determination</u>. If nitrite and nitrate can be
found in the sludge liquor, the sludge can be considered as a fully sta-
bilized sludge. Only a qualitative determination is necessary. Prepackaged
reagents can be used to minimize the laboratory work.

7. CONTINUATION OF THE RESEARCH PROJECT

During the COST 68 period, ending in December 1974, the group working
on sludge stability will strive for a field evaluation of the methods
recommended in this progress report. It is our opinion that
only through a field study can an objective evaluation of the methods
be given.

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