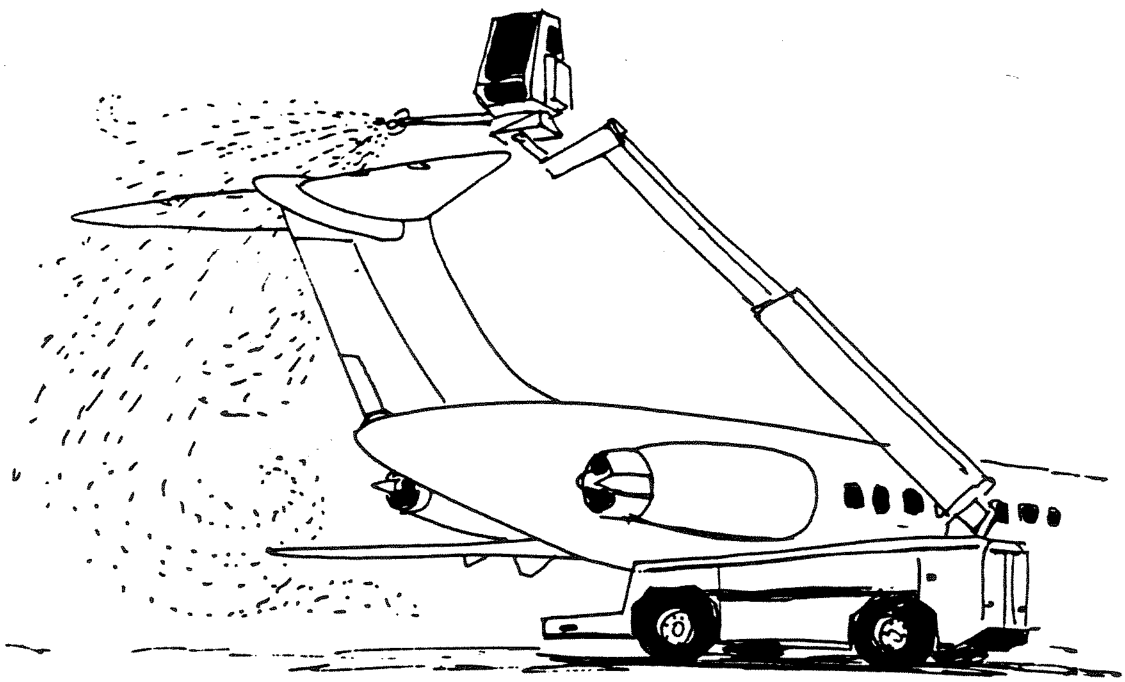
NEW OSLO AIRPORT GARDERMOEN

Biological Treatment of de-icing Fluids

O-92036



CIVIL AVIATION
ADMINISTRATION, NORWAY

Norwegian Institute for Water Research NIVA

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Abstract:

During the winter planes and runways have to be sprayed with special chemicals to prevent forming of ice. "Kilfrost" (planes) and "Clearway" (runways) are the most common de-icing fluids in Norway. They both have a large content of organic matter, and treatment is needed before outlet to recipient.

Based on system analysis and laboratory tests biological treatment; "activated sludge" has been studied. A combined treatment of both the sewage from the airport and the polluted surface water is recommended. Voluminous aeration tanks are needed due to extremely high organic load. Large flow variations necessitates retention basin.

The report gives qualitative recommendations for biological treatment based on activated sludge. Further investigations in a large scale (pilot scale) is needed to define design criteria.

4 keywords, Norwegian

1. Biologisk rensing av avløpsvann
2. Aktiv slam
3. Avisningsvæske
4. Lufthavner

4 keywords, English

1. Biological treatment of wastewater
2. Activated sludge
3. De-icing
4. Airports

Project leader

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For the Administration

Bjørn Olav Rosseland

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PREFACE

The Norwegian Institute for Water Research (NIVA) has been engaged by the Civil Aviation Administration, Norway to evaluate treatment of the de-icing fluids "Kilfrost" and "Clearway" in a low loaded biological process based on activated sludge. The project forms a part of the project for planning of a new airport for the Oslo-region in Norway (New Oslo Airport Gardermoen).

Knut Solnørdal has been project leader at the Civil Aviation Administration, Norway.

The project team at NIVA consisted of the following people:

- Research Manager Gunnar Fr. Aasgaard (Project Leader)
- Research Manager Morten Laake (responsible for the laboratory tests)
- Research Scientist Kristin Mørkved (responsible for the system analysis)
- Research Scientist Harry Efraimsen (performing the laboratory tests)
- Research Assistant Liv Bente Skancke (assisting at the laboratory tests)
- Secretary Lise Tveiten
- Secretary Liv Aaserud
- Secretary Sidsel Jensen

We extend our sincer thanks to the Civil Aviation Administration, Norway for good cooperation during the project. Many thanks also to Harald Damhaug, Taugbøl & Øverland A.S. for useful assistance.

Oslo, 9. October 1992

Gunnar Fr. Aasgaard

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SUMMARY

The de-icing fluids Kilfrost (planes) and Clearway (runways) both have a very high content of organic matter. The nutrient concentration, however, is negligible. This unbalance in concentration necessitates an external supply of nitrogen and phosphorus. The nutrient demand can alternatively be taken care of through combined treatment of polluted surface water and sewage from the airport.

Laboratory tests have been carried out to investigate the ability of activated sludge treatment of Kilfrost and Clearway. The main parameters taken into consideration were the composition of the wastewater (Kilfrost/Clearway/sewage), concentration of nitrogen, temperature and retention time.

Satisfactory treatment efficiency was obtained for wastewater temperatures down to 2°C and a retention time of 16 hours. Based on these results it is conclude that activated sludge is a viable treatment process for de-icing fluids.

The conclusion from the system analysis is that ***combined*** treatment of polluted surface water and sewage from the airport seems to represent the most favourable technological and economic solution. Large flow variations however, necessitates a separate equalisation volume for the polluted surface water. Based on the expected loads, the volumes needed for flood equalisation, biological treatment and sludge separation will be considerable. The numbers presented in the report must however be verified or adjusted through tests in larger scale (pilot scale), before design criteria can be defined.

1. PROBLEM APPROACH

During the winter, planes and runways have to be sprayed with a special chemical to prevent ice formation. Kilfrost (planes) and Clearway (runways) are the most common de-icing fluids in Norway. Kilfrost is used on separate de-icing platforms, particularly dedicated for this purpose. Accumulated surface run-off is directed, depending on concentration, partly to a recovery unit and partly to the municipal sewer system. Some of the de-icing fluids from the runways (Clearway) will also be directed to this collection system for polluted surface water.

Kilfrost (approximately pure glycol) and Clearway (potassium acetate) both have a very high content of organic matter. The nutrient concentration however, is negligible. Due to the high content of organic matter, treatment is necessary before discharge. The lack of nutrients however, limits the possible treatment schemes. A combined treatment with other wastewater from the airport might be an appropriate strategy, possibly also including municipal wastewater from the region. These cases are evaluated in the analysis and a recommendation is given in Chapter 5.

Wastewater with high content of organic matter is suitable for biological treatment. Biological processes are temperature sensitive, and the efficiency is reduced with reduced temperature. Accumulated de-icing fluids are naturally normally very cold, and the laboratory tests have been performed at the temperature levels 2-3° C, 5-6° C and 10-12°C

Some key questions in the project are schematically illustrated in Figure 1.

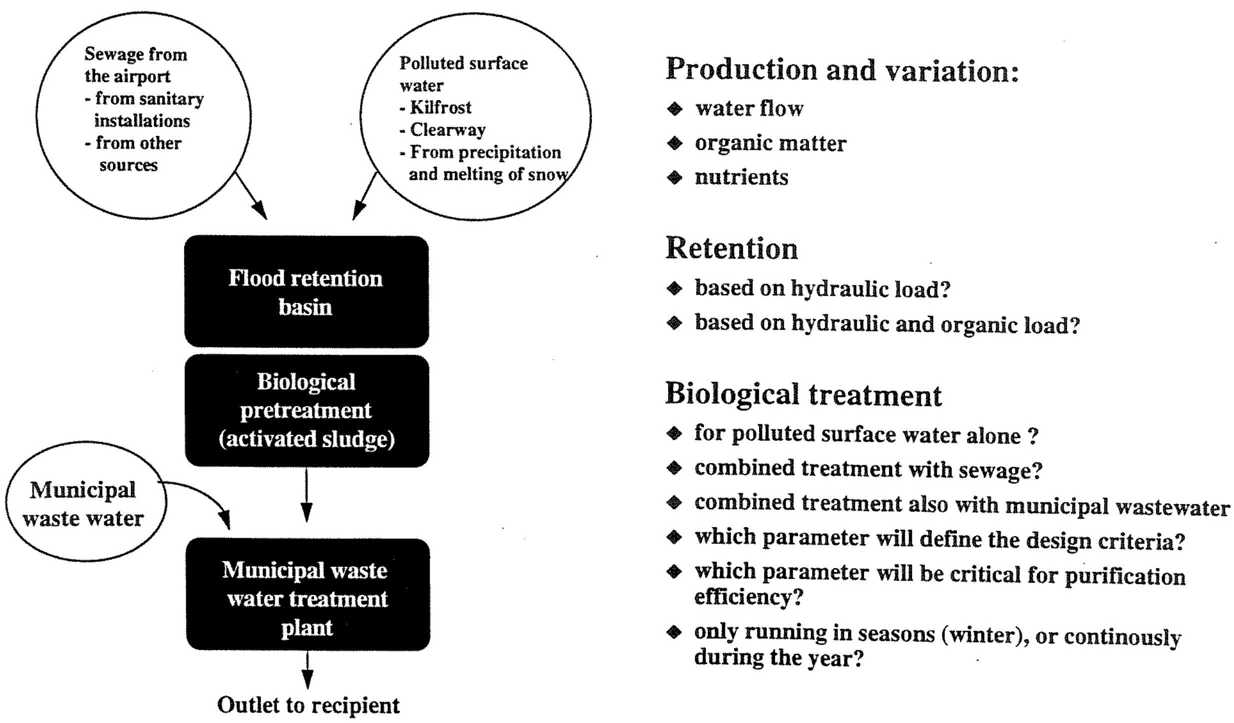

Figure 1. Schematic illustration of some key questions in the project.

2. LOADS

New Oslo Airport, Gardermoen will generate the following types of wastewater:

- sewage from the airport, offices and service areas
- sewage from lavatories in planes
- special wastewater from catering , garages etc.
- polluted surface water from de-icing platforms and runways

Evaluating of dimensioning loads are based on annual production of pollutants and their variation in time.

2.1. Pollution produced per annum

Annual production of pollutants and water flow is calculated based on information received from Avia-Plan, ANØ, Taugbøl & Øverland, and the Civil Aviation Administration, Norway.

Sewage

The calculation of annual production of sewage is based on a traffic load of 92 million passengers, each representing 0.45 pe (pe: person equivalent) (Avia-Plan, 1991). A specific production of respectively 2.1 g P, 12 g N and 22 g TOC per day (ANØ, 1991) results in the following annual production:

- Flow : 660 000 m^3 /year, based on 0.055 m^3 /passengers day (Avia-Plan, 1991)
- Phosphorus : 11 000 kg Tot-P/year
- Nitrogen : 65 000 kg Tot-N/year
- Organic matter : 120 000 kg TOC/year, equivalent to 40 000 kgCOD/year based on experienced values for TOC/COD ratio (ANØ, 1985 and Taugbøl & Øverland, 1992)

Polluted Surface Water

The calculated production of pollution in the surface water is presented in Table 1.

Table 1. Organic matter (kg/year) and flow (m^3/year) from polluted surface water generated from de-icing of planes and runways.

Source	COD kg/year	Q m^3 /year	Content of organic matter kg COD/m^3	%
Glycol (Kilfrost)				
- reject from recovery	48 000	600	80	5
- from de-icing platforms	173 000	36 300	4.8	0.3
- from runways	307 000			
Sum	528 000			
Potassium Acetate (Clearway)				
- from "glycol areas"	24 000	159 400	2.1	0.17
- from "other areas"	96 000	254 000	0.4	0.13
Sum	120 000			
Total ,Kilfrost + Clearway	648 000	450 300	1.5	0.16

2.2. Variations in time

The load from sewage , de-icing fluids and rain/snow melting is evaluated separately.

Sewage

The variation in production of sewage will probably follow characteristically variations over the year (season), week (Monday - Sunday) and day (24 hours), depending on flight schedules and possible special events. These variations however, are expected to be relatively independent of the consumption of de-icing fluid. In the following system analysis the production of sewage is therefore assumed to be constant.

The relative amounts of sewage and de-icing fluids will, however, be of key importance in operation of the treatment plant, refer the dependence between nitrogen and carbon cited in Chapter 4.1. The situation with low production of sewage might be particularly critical, due to the risk of nitrogen limitation and loss of potential temperature effect. To account for this minimum situation, and because the variation of sewage is not expected to be hydraulically dimensioning, the dimensioning sewage flow is calculated without a safety factor (normally a safety factor of 2 is applied). Before final plant design is done, more detailed evaluation of sewage variation must be performed.

For the system analysis the sewage contributions are calculated to:

- Flow;	$Q_{dim,sw}$	:	1 810 m^3 /day
- Phosphorus;	$P_{dim,sw}$	:	30 kgP/day
- Nitrogen;	$N_{dim,sw}$	:	178 kgN/day
- Organic matter;	$C_{dim,sw}$	:	326 kg TOC/day and 1 110 kgCOD/day

De-icing fluids

The dimensioning flow is calculated by dividing annual production equally over a 120 day period (expected to be the de-icing period), and is then applied a safety factor of 2.

Based on experience from de-icing of planes and runways in Norway, the dimensioning load is set to 20% of the annual consumption, equally divided over a 3 day period (Taugbøl & Øverland, 1992).

The contribution from glycol (Kilfrost) and potassium acetate (Clearway) will be:

- Flow;	$Q_{dim,DIC}$	=	7 500 m^3/day
- Organic matter;	$C_{dim,DIC}$	=	12 700 kgTOC/day and 43 200 kgCOD/day

The content of nutrients in the de-icing fluids are of no importance.

Rain/melting of snow

Based on received information (The Civil Aviation Administration, Norway, 1991) the dimensioning precipitation in 24 hours is set to 80 mm. A total precipitation of 100 mm as rain and 200 mm as snow is expected during the de-icing period (referring to the same report). Conferring to previous abandoned annual run-off the dimensioning load is calculated to be, $Q_{dim,P}$ = 40 400 m^3 /day.

2.3. Dimensioning load

De-icing of planes and runways will take place in cold periods, and a high consumption is expected at temperatures around 0 °C. In such periods the surface run-off will be low. Coincidence in time for high consumption of de-icing fluid and high surface run-off is not very likely. These two pollution sources will also influence the design and dimensioning of the plant in different ways:

- The consumption of de-icing fluid will be dimensioning for the *biological treatment*, due to the high content of organic matter.

- The inflow of surface water from rain/melting of snow will be dimensioning for the *sewer* and *flood equalisation basin.*

For use in the system analysis the dimensioning loads are calculated to:

- Flow; Q_{dim}:
$Q_{dim} = Q_{dim,sw} + Q_{dim,P}$ = <u>9 300 m³/day</u>

- Phosphorus; P_{dim}:
$P_{dim} = P_{dim,sw}$ = <u>30 kgTot-P/day</u>

- Organic matter; C_{dim}:
$C_{dim,TOC} = C_{dim,sw} + C_{dim,P}$ = <u>13 000 kgTOC/day</u>
$C_{dim,COD} = C_{dim,sw} + C_{dim,P}$ = <u>45 000 kgCOD/day</u>

3. LABORATORY TESTS

The following three objectives were set for the laboratory tests:

- define possible treatment efficiency for de-icing fluids
- investigate how low water temperature will influence the treatment efficiency
- investigate the need for nitrogen addition and addition of other growth inducing substances

3.1. Experimental set-up

The experiments were performed in four lab scale activated sludge units. The reactors each had a volume of approx. 900 ml and approx. 300 ml for sedimentation (Figure 2). The units were kept in an incubator with thermostat regulation, which facilitated an accurate temperature regulation (± 0.1 ° C). Each reactor receiving Kilfrost was supplied with a pH-electrode connected to a regulator that controlled a dosing of NaOH (O.1N). This fixed the pH at 7.7 ± 0.2. OECD synthetic sewage was used as sewage. This water contained approx. 10 mg DOC/l, but was modified to give a minimum of nitrogen supply. Nitrogen as ammonium chloride was then added at different concentrations depending on the test conditions.

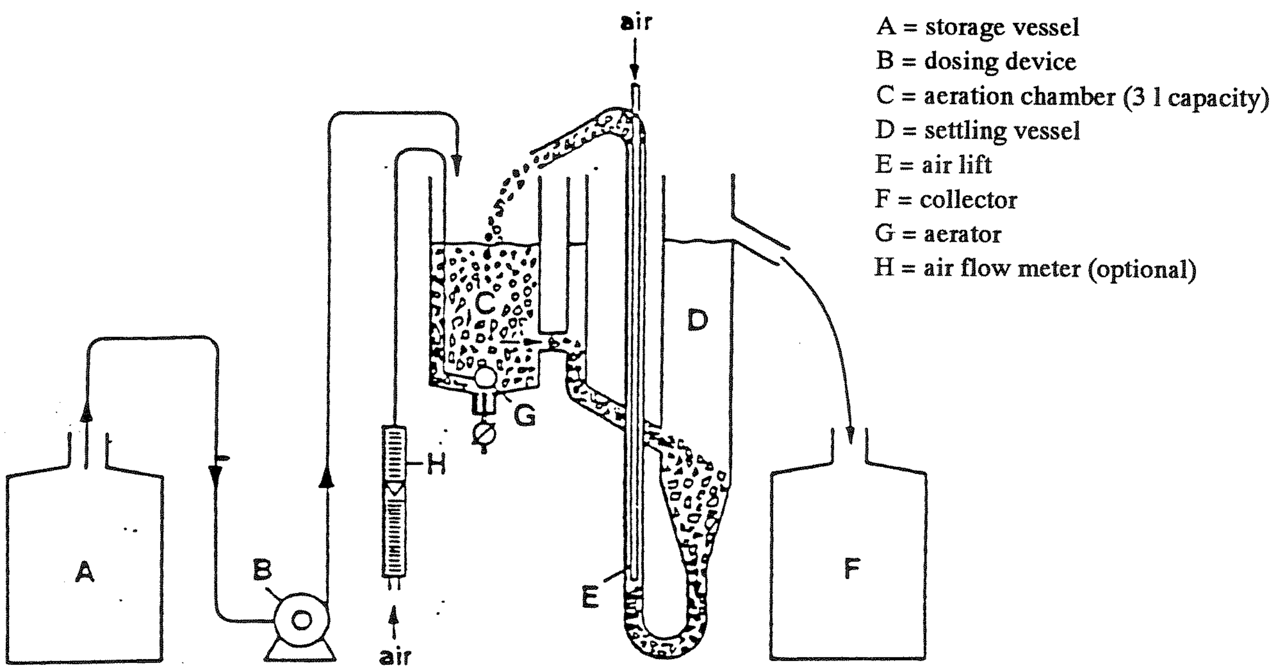

Figure 2. Sketch of lab.scale activated sludge reactors used in the test.

Propylene glycol (Kilfrost) with and without potassium acetate (Clearway) with a total of 110 mg DOC/l was then lead to each reactor through a 4 channels hose pump. The calculation of hydraulic retention time in the reactors was based on the accumulated amount of fluids. The reactors were inoculated with aerated municipal wastewater and sludge from a laboratory scale test reactor, run on synthetic wastewater.

3.2. Test conditions

All four reactors (R1-R4) were run until steady state was achieved for each of the different test conditions. Depending on the progress, all parameters were registered 3-4 times over a period of 4-8 days. The test conditions are listed in Table 2.

Table 2. Test conditions for lab.scale activated sludge reactors.

Reactor	Retention time	De-icing fluid	Addition of nitrogen	Temperature
R1	23-25 hours	100% Kilfrost		5.6-5.7 °C
R2		-------"--------	+ 5 mg/l N	----"-----
R3		75% Kilfrost 25% Clearway		----"-----
R4		----------------"----------------	+ 5 mg/l N	----"-----
R1	23-25 hours	100% Kilfrost	+ 8 mg/l N	5.6-5.7°C
R2		-------"--------	+12 mg/l N	-----"------
R3		75% Kilfrost 25% Clearway	+ 8 mg/l N	-----"------
R4		----------------"----------------	+12 mg/l N	-----"------
R1	15-16 hours	100% Kilfrost	+ 8 mg/l N	5.6-5.7°C
R2		-------"--------	+12 mg/l N	-----"------
R3		75% Kilfrost 25% Clearway	+ 8 mg/l N	-----"------
R4		----------------"----------------	+12 mg/ll N	-----"------
R1	12-13 hours	100% Kilfrost	+ 8 mg/l N	5.6-5.7°C
R2		-------"--------	+12 mg/l N	-----"------
R3		75% Kilfrost 25% Clearway	+ 8 mg/lN	-----"------
R4		----------------"----------------	+12 mg/lN	-----"------
R1	15-16 hours	100% Kilfrost	+ 8 mg/l N	2.0-2.1°C
R2		--------"-------	+12 mg/l N	-----"------
R3		75% Kilfrost 25% Clearway	+ 8 mg/l N	-----"------
R4		------------"---------------	+12 mg/l N	-----"------

The first experiments were performed at a temperature of 10-12 °C, and approximately 100 % degradation of propylene glycol was achieved at this temperature. The temperature was then lowered to 5-6 °C which was expected to be the marginal temperature level for the process. In the last stage the temperature in the reactors were lowered to 2°C.

Calculation of the nitrogen demand is based on an admixing experiment in a respiromertric degradation test with gradually increasing concentration. The optimal addition was defined to 10 mg/l ammonium-N at a substrate level of 110 mgDOC/l (ref. next section). The addition of nitrogen to the reactors was increased from 0 to 5 mgN/l in the first series and then to respectively 8 and 12 mgN/l in the last four test series. Theoretically these amounts of nitrogen addition will result in respectively a slight (20%) shortage and a slight excess of nitrogen, compared to the amount of carbon.

3.3. Results

3.3.1. Need of Nitrogen in Respiration Tests

The experiment was carried out in a standard apparatus (ISO 9408) for respirometric determination of BOD, and the oxygen consumption was registered daily up to 5 days. As described for the reactor experiments the same mixture of synthetic sewage with addition of 75% Kilfrost and 25% Clearway was used.

The absorption of oxygen increased for an addition of nitrogen up to approx. 10 mgN/l (as ammonium chloride), ref. Figure 3. This value assumed to be representative for a balanced C/N ratio (120 :10) was used in later reactor experiments.

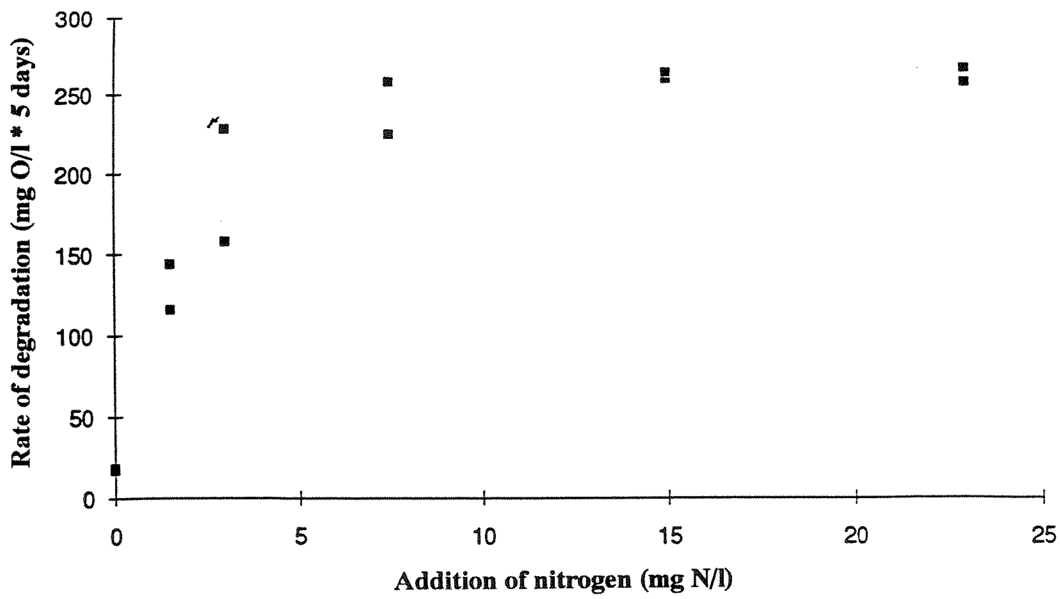

Figure 3. Degradation of de-icing fluids as a function of the nitrogen addition.

3.3.2. Treatment Efficiency in Reactor Tests

Table 3 summarises the average values for flow, retention time, treatment efficiency and sludge load for various temperatures and nitrogen addition in the 5 test series.

Treatment efficiency of more than 90%, with regard to dissolved organic carbon (DOC), is obtained for all the tested retention times and for temperatures down to 2°C in reactors with excess of nitrogen (addition of 12 mgN/l). The treatment efficiency is reduced 2-10 % when the reactors have a slight shortage of nitrogen (addition of 8mN/l). Short retention time and reactors with propylene glycol without acetate represents the upper value of this reduction. With none addition of nitrogen the treatment efficiency is reduced to 30%.

Combined treatment of de-icing fluid and wastewater gives significantly better results than separate treatment of the fluids for all the field conditions. Combined treatment also has a positive influence on the sludge quality (ref. Ch. 3.3.3 and 3.4). This indicates that a minor amount of propylene glycol might appear in the effluent, while acetate is expected to be completely degraded.

The sludge load in the reactors was high and was influenced by the lack of nitrogen. A hydraulic retention time (HRT) of about 15 hours seems to be an optimum value (ref. Figure 4). There are no indications of system overload even for a retention time of 12 hours. On the other hand long retention time seems to result in lower sludge load than expected.

Table 3. Parameters and results from the laboratory tests .

Testing conditions	100 % Kilfrost		75% Kilfrost 25% Clearway		
Reactor	R1	R2	R3	R4	Average
Reactor volume (ml) (factor 1/V= 1.12 used as average)	915	875	875	905	892.5
T=5.6-5.7 ° C	without N	5 mg N/l	without N	5 mg N/l	
Flow (ml/day)	932	886	845	927	897.5
Retention time (days)	0.98	0.99	1.04	0.98	1.00
Treatment efficiency	29.4	48.7	32.6	75.4	
Sludge load (mgCOD/mg SS*day)	0.43	0.44	0.41	0.47	
T = 5.6-5.7°C	8 mg N/l	12 mg N/l	8 mg N/l	12 mg N/l	
Flow (ml/day)	874	938	927	844	895.75
Retention time (days)	1.05	0.93	0.94	1.07	1.00
Treatment efficiency	92.6	92.9	89	93.2	
Sludge load (mgCOD/mg SS*day)	0.57	0.58	0.63	0.61	
T = 5,6-5,7 °C	8 mg N/l	12 mg N/l	8 mg N/l	12 mg N/l	
Flow (ml/day)	1306	1247	1284	1440	1319.25
Retention time (days)	0.70	0.70	0.68	0.63	0.68
Treatment efficiency	92.9	94.9	93.7	94.1	
Sludge load (mgCOD/mg SS*day)	0.83	0.79	1.02	0.95	
T = 5,6-5,7 °C	8 mg N/l	12 mg N/l	8 mgN/l	12 mg N/l	
Flow (ml/day)	1799	1644	1605	1730	1694.5
Retention time (days)	0.51	0.53	0.55	0.52	0.53
Treatment efficiency	79.8	90.8	88.5	94.3	
Sludge load (mgCOD/mg SS*day)	1.10	0.87	0.81	0.91	
T = 2.0 - 2.1°C	8 mg N/l	12 mg N/l	8 mg N/l	12 mg N/l	
Flow (ml/day)	1310	1271	1337	1323	1310.25
Retention time (days)	0.70	0.69	0.65	0.68	0.68
Treatment efficiency	86.5	90.9	88	93.5	
Sludge load (mgCOD/mg SS*day)	0.75	0.82	0.91	0.79	

The degradation efficiency with regard to Kilfrost alone is reduced 4-5% when the temperature is lowered from 6 to 2°C (ref. Figure 4).

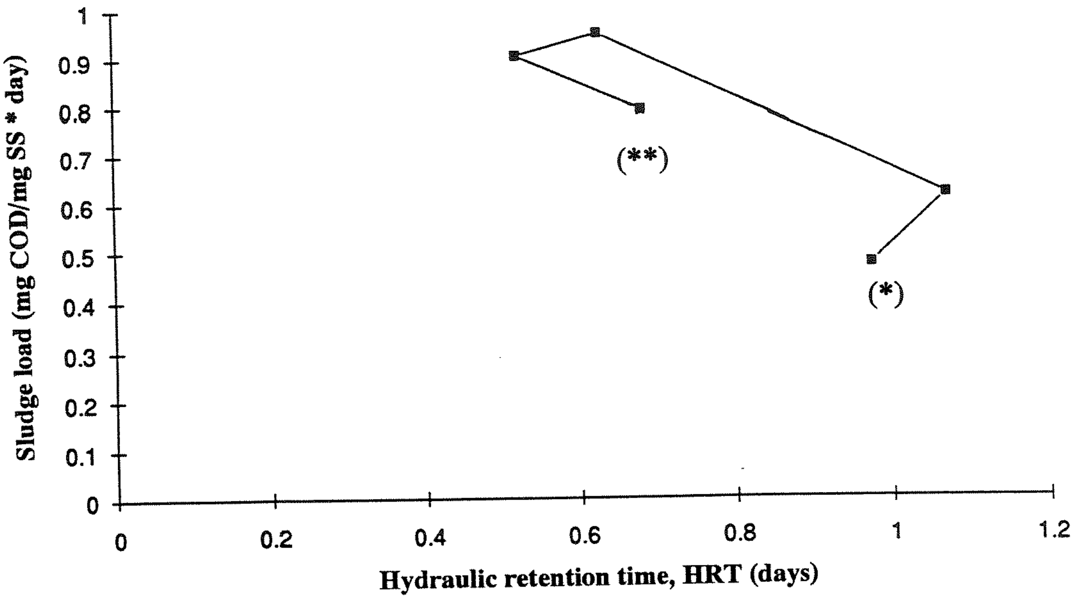

Figure 4. Sludge load as a function of retention time in the reactors when treating 75% Kilfrost + 25% Clearway with addition of 12 mgN/l at 5,6 ° C.

(*) Starting point : Addition of 5 mg N/l
(**) The temperature is lowered to 2.0°C

3.3.3. Microscopic Sludge Analysis

R1.The flocs showed a very fringed structure, with a lot of filaments bacteria, among these *Sphaerotilus natans* dominated. Observations of the inner parts of the flocs were done, but only minor amounts of bacteria forming a compact structure was observed. There was relatively a large occurrence of free swimming ciliates (bait organisms).

R2. The same structure and composition of the flocs as in R1, but the content of free swimming ciliates and prudence ciliates from the *Vortices sp* were larger.

R3. The basic floc structure was formed by filaments bacteria from *Sph. natans* bacillus producing a slimy substance covering this basic structure (zoogleic structure of growth). This growth type resulted in a more compact floc structure, particularly in the central parts of the flocs Peripherally there was a growth of *Sph.natans*. In R3 there was obviously less occurence of filamentous bacteria than in R1 and R 2, but essentially larger content of *Vorticella sp.*, both spread in the floc structure and in the periphery of the floc. The large occurence of several species bait organisms indicated that the sludge was in good condition.

R4. The floc structure was more compact than in R3 and the content of filamentous bacteria was noticeable smaller. Visually this reactor had the largest spreading of prudence ciliates from *Vorticella sp.* R 4 had the widest plurality of species of bait organisms, and the consistence and structure of the sludge indicated very good condition and activity.

3.4. Discussion of the Results

The results from the lab.scale reactors cannot automatically be transferred to a large scale plant. This is among other factors due to hydraulic conditions, design of the sedimentation unit and process control. In a full scale plant measures can be taken for instance to prevent sludge loss and thereby loss of activity.

The test results do not indicate any loss of biomass at a retention time as low as 12 hours . On the contrary, the amount of sludge was increasing. This might explain why the treatment efficiency remains high and why the sludge load is hardly influenced at high hydraulic load.

The results indicate that a significantly less part of the biomass is active at long retention times, thus causing lower sludge load. The reason might be an increase in the need of nitrogen to maintain the basic metabolism, and that the biomass even with high nitrogen addition, suffered due to lack of nitrogen at HRT of 23- 24 hours. Therefore, a larger addition of nitrogen would have been desirable in the reactors R2 and R4, e.g. 15 mg N/l.

The microscopic evaluation of the sludge indicates a positive effect both from addition of nitrogen and from combined treatment of propylene glycol and acetate. Visually this was confirmed by observing that R4 maintained a sludge with better settling characteristics, and had a clear effluent with less content of bacteria than the other reactors. As a rule, the effluent from the other reactors was turbid. Propylene glycol alone showed a tendency toward a growth of filaments bacteria, which in a large plant might cause problems due to sludge flotation (bulking).

4. SYSTEM ANALYSIS

4.1. Frame Conditions

Based on evaluation of the design data and the performed laboratory tests, the following conditions are set for the system analysis:

- Treatment efficiency:
  - 90% removal of organic matter from the total airport wastewater flow before inlet to municipal wastewater treatment plant
  - In the municipal wastewater treatment plant:
    - 90 % removal of organic matter
    - 95 % phosphorus removal
    - 15 % nitrogen removal

- The hydraulic load will be dimensioning for the flood equalisation basin. Detailed analysis of the intensity/duration of both precipitation and snow melting must be done to define design criteria. This is not a subject of this project.

- Dimensioning organic load, C_{dim} :

  $C_{dim,TOC}$ = 13 000 kg TOC/day
  $C_{dim,COD}$ = 45 000 kg COD/day

  The specific nutrient demand is investigated in laboratory batch tests. These investigations indicated a nitrogen demand of about 12 mg N/l. Theoretical calculations and results from previous experiments indicate a N/P ratio of 10-12 : 1

- Temperature/retention time:
  The temperature in the sewage from the airport will be higher than in the polluted surface water. The temperature in the influent to the biological pretreatment will therefore depend on the mixing of different wastewaters. The treatment efficiency is expected to be reduced with falling wastewater temperature due to lower specific growth and turnover of micro-organisms.

  Two strategies are possible to obtain sufficient treatment efficiency at low temperature:
  - increase of the retention time at constant load
  - reduction of the load at constant retention time

  These parameters are not easy to manipulate in a running plant, and this must be considered in the design phase. These relationships are illustrated in the laboratory tests, and Table 4 presents a comparison between treatment efficiency and load for two parallel tests at 5.6° C and 2 °C.

Table 4. Comparison of tests at two different temperatures.

Temperature (°C)	5.6	2.0
Hydraulic retention time (hours)	17	17
N-concentration (mgN/l)	12	12
Treatment efficiency (%)	94	93.5
Sludge load (kg COD/kg SS * day)	0.95	0.8

- Sludge Load:
  Sludge load (kg COD/kg SS*day) is defined as the turnover of organic matter per quantity of

activated sludge (active micro-organisms). This will be the dimensioning parameter for the volume of the biological stage. (Note: In lab.test the whole sludge population was considered to be active and therefore no distinction between SS and VSS was done).

Normally the treatment efficiency in activated sludge plant will decrease when the sludge load increases. Our laboratory tests do not unambigously confirm this relationship. A possible explanation might be that results from such small scale reactors are relatively unstable due to small volume margins.

Because most of the tests have been done just above (12 mg N/l) or just below (8 mg N/l) the assumed nitrogen equilibrium, it might be possible that the effect of the nitrogen has been more dominating than the sludge load itself (ref. Ch. 3.4). It was therefore decided to use the values (results) from the lowest temperature (2° C) and multiply these with a safety factor of 1.5.

An indicative sludge load is then:

0.8/1.5 = 0.5 kg COD/kg SS*day

The authors emphases that this sludge load indicates a correct starting level for pilot tests, and must not be understood as a design criteria.

4.2. Separate Treatment of Polluted Surface Water

It is not considered relevant to build two separate treatment plants at the new airport. Separate treatment of polluted surface water therefore requires that the sewage is lead directly to the municipal wastewater treatment plant.

A flow scheme for such an alternative is presented in Figure 5.

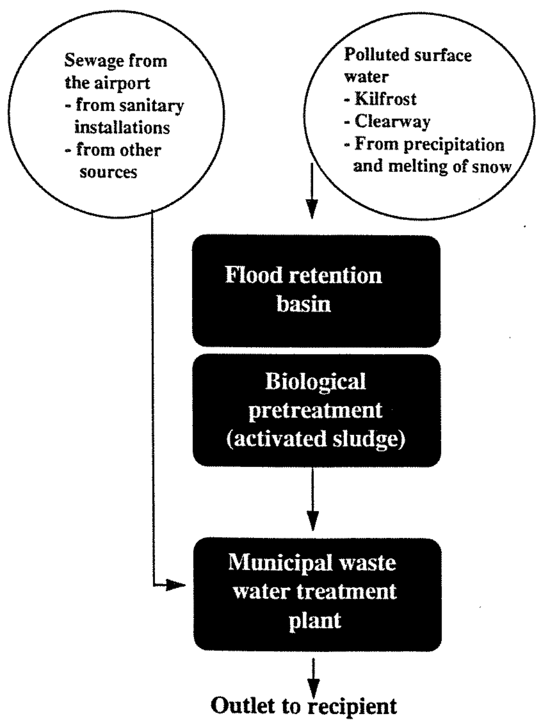

Figure 5. Flow scheme for separate treatment of polluted surface water

The effects of such a solution will be:

- The demand of 90% removal of organic matter from all the wastewater generated at the airport must be taken care of through treatment of polluted surface water alone. This means that the treatment efficiency for this surface wastewater must be increased from 90% to approx. 93%.

- Addition of external nitrogen and phosphorus will be necessary due to the nutrient demand. Potential sources for external nutrients might be:

  - commercially available products, e.g. fertiliser
  - by-product from chemical industry e.g. dust/waste
  - waste products, e.g. concentrated runoff with high content of nutrients.

  When evaluating external nutrient sources it is essential to take care that they do not represent any additional organic load, and that no inhibition or toxic effects occur.

  Addition of nutrients will increase the operational costs, both for procurement and for handling of the product.

- A positive temperature effect from the sewage will not be used.

4.3. Combined Treatment of Polluted Surface Water and Sewage Water from the Airport

Addition of external nitrogen and phosphorus will not be necessary if combined treatment of polluted surface water and sewage from the airport is applied. Due to the large flow variations, however, the surface water must be lead to a flood equalisation basin before mixing with sewage in the biological aeration tank. A flow scheme is presented in Figure 6.

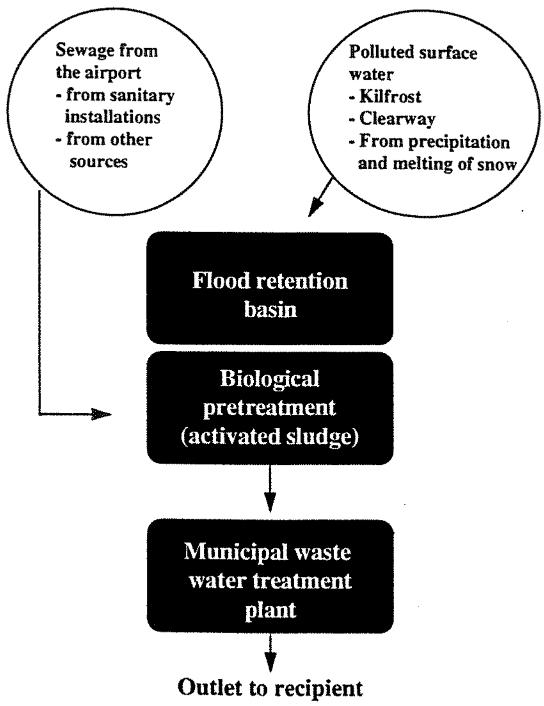

Figure 6. Flow scheme for combined treatment of polluted surface water and sewage from the airport.

The effects of such a solution will be:

- The content of nitrogen and phosphorus in the sewage will be sufficient for the activated sludge process:
  - Nitrogen in the sewage : 178 kg N/day
  - Calculated nitrogen demand : 115 kg N/day
  - Phosphorus in the sewage : 30 kg P/day
  - Calculated phosphorus demand : 10 kg P/day

  The margins seem to be sufficient to conclude that there will be no need for addition of nutrients even if part of the nitrogen or phosphorus should be unavailable due to unfavourable binding- or mixing conditions, or major flow variations should occur.

- The mixed wastewater will represent substrate with greater compositional complexity than the surface water alone. The laboratory tests clearly indicate the positive effect of this phenomenon on the treatment efficiency.

- The demand for trace nutrients (growth inducing substances) is also expected to be covered by the complex sewage.

- The temperature will be low in the polluted surface water, consisting partly of melted snow. An uncovered aerated equalisation tank might also cause a low temperature in the water.

- At the coldest, surface water coming from melted snow will be close to 0°C. This is considered to be an extreme situation, and 2° C is a more realistic dimensioning temperature for the polluted surface water. The sewage temperature, however, is expected to be considerably higher, with a realistic range of 10-15 °C, due to the following reasons:

  - The sewer system will be built as a duplicate system, meaning that the sewage will not be mixed with the (cold) surface water.
  - A new sewer system is expected to have only marginal infiltration.
  - Some of the sewage originates from kitchens and other sources with hot water.

Variations of the temperature in the inlet to the aeration tank, depending on the temperature in respectively the surface water and the sewage is presented in Table 5.

Table 5. Inlet temperature to the aeration tank.

Surface water (°C)	Sewage (°C)	Inlet aeration tank (°C)
0	10	1.9
0	15	2.9
2	10	3.6
2	15	4.5
4	10	5.4
4	15	6.3

As shown in Table 5 the temperature at the inlet to the aeration tank is expected to be 2 - 6°C. The performed laboratory tests cover this temperature span.

4.4. Combined Treatment of Polluted Surface Water, Sewage from the Airport and Municipal Wastewater

Combined treatment of all three types of wastewater mentioned above implies that wastewater from the airport is lead to the municipal wastewater treatment plant in the region. A flow scheme is presented in Figure 7.

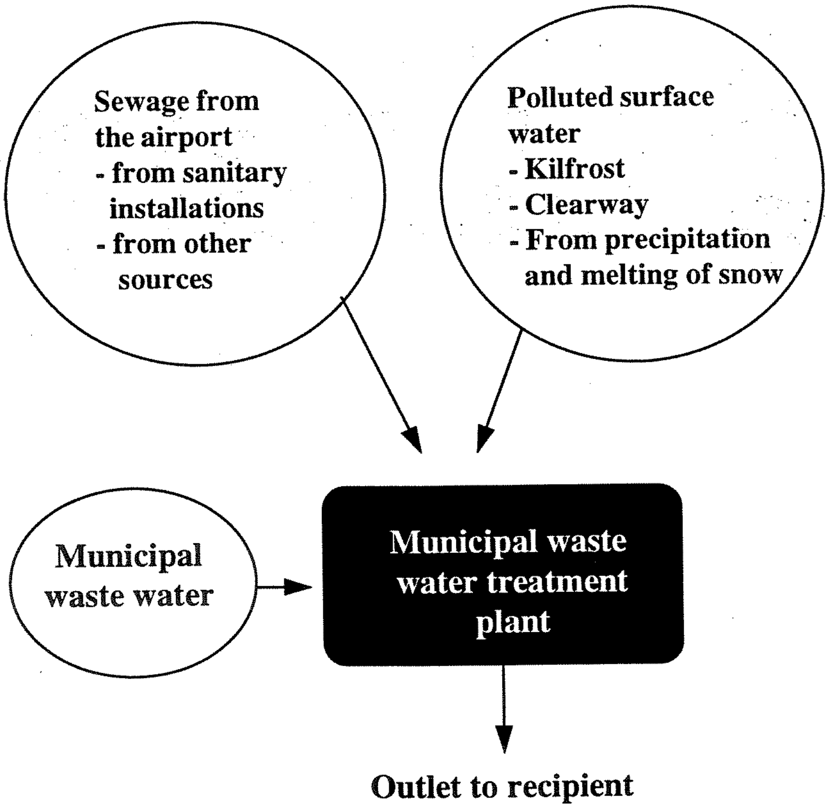

Figure 7. Flow scheme for combined treatment of polluted surface water, sewage from the airport and municipal wastewater.

When planning a new municipal wastewater treatment plant for the Gardermoen region, combined treatment with the sewage from the new airport should be evaluated. The composition of the sewage will, for such a solution, be essentially different than provided in this project. The indicative design criteria presented in this report might therefore not be relevant. Some concerns for further planning are listed below:

- Building and operation of one combined treatment plant will probably be more cost-effective than two separate plants.
- If nitrogen removal should be necessary for a new municipal treatment plant, the polluted surface water may represent a potential carbon source for improving the denitrification process. (Denitrification is the latter of two stages in biological nitrogen removal from wastewater.
- There will be an excess of nutrients for biological treatment of the wastewater from the airport.

- Current requirements demand 90% removal of organic matter in the treatment plant at the airport, and then further 90% reduction of organic matter in the municipal wastewater treatment plant.

  The future amount of municipal wastewater is not known, and requirements for a combined treatment plant can not be calculated. It seems obvious, however, that treatment efficiency above 90% will be required. Detailed design and economical analysis must be performed in order to comply with such requirements.

- The large variations in hydraulic load from the polluted surface water indicates the need for a flood equalisation basin integrated into the municipal treatment plant located at the airport. Alternatively retention might be obtained by using large dimensioned sewers for the surface water.

5. SELECTION OF PROCESS

Based on the laboratory tests and the system analysis, combined treatment of polluted surface water and sewage in a separate biological stage (ref. Chapter 4.3) seems to be the most appropriate solution for the wastewater from the airport.

5.1. Flood equalisation

The polluted surface water is expected to be produced over a period of 120 days during the winter. Large variations in production and run-off might occur depending on climatic conditions. Hydraulic retention of the surface water is therefore necessary to ensure stable operation of the biological stage. The definition of equalisation volume capable of limiting the inflow to the biological stage to Q_{dim} =7500 m^3 /day must be based on knowledge of the precipitation (rain and snow). Such evaluations are not included in this project.

To prevent anaerobic conditions in the equalisation basin, aeration is recommended. Anaerobic conditions might cause operational problems such as gas production (smell) and inhibition of activity in later stages.

Aeration will also have a mixing effect, resulting in a more homogenous wastewater and reduced sedimentation in the equalisation basin.

An equalisation basin should be covered due to temperature loss and to prevent operational problems at the airport (birds, mist). A cost/benefit evaluation of these factors must be done when the design criteria are defined. This also applies for evaluation of type of equalisation basin. A pond with canvas seal and conventional concrete basin are two possible alternatives. The primary objective is to prevent leakage.

5.2. Biological treatment

The project definition stated that an activated sludge process should be tested and evaluated. Other biological processes have therefore not been evaluated. In the activated sludge process active micro-organisms are held in suspension in an aeration tank. The microorganisms (the activated sludge) transform the pollutants into new cell material (more sludge) and other end products (e.g. CO_2, H_2O).

The sludge/water suspension is separated in a sedimentation unit. Treated water is discharged, part of the sludge is resirculated back to the aeration tank to ensure a stable concentration of activated sludge, and excess sludge is drawn off for separate treatment and disposal.

A calculation of the biological stage based on the preliminary dimensioning values indicated from the laboratory tests is as follows:

- Conditions:

-Sludge load	: 0.5 kg COD/kg SS*day
-Sludge concentration	: 2 500 mgSS/l =2.5 kg SS/m^3 reactor volume (based on experiences from conventional activated sludge plants, must be verified in larger scale tests).
⇒ System load	:1.25 kg COD/m^3 reactor volume

- Indicative volume need:

  - Based on COD-load:
    - 45 000 kg COD/day
    - 1.25 kg COD/m^3 reactor volume

  ⇒ Volume needed: 36 400 m^3

  - Control of retention time:
    - 36 400 m^3 /day ⇒ 3.9 days

  ⇒The pollution load will be dimensioning, not the retention time.

Separation of excess sludge will be done in a sedimentation tank. The settling characteristics of the sludge will define design and volume of the sedimentation unit. Laboratory tests do not sufficient basis for evaluation of sludge characteristics and experiments in larger scale must be performed.

5.3. Operational Comments

Supply of polluted surface water follow the seasons (120 days/year). Each autumn it will be necessary to establish a culture of micro-organisms (biomass), that can handle a wastewater with wastewater with high content of carbon. A start-up period of 1-2 months may be necessary.

Both from construction and operation viewpoint it might be desirable to divide the reactor volume into several parallel tanks. On this basis there are three possible strategies for dealing the seasonal variations:

a. Outside the de-icing period, only the volume needed for sewage treatment is kept in operation. The other aeration tanks are closed (emitted) and must be re-started each autumn. Under start up biomass from the sewage treatment is used.

b. In the beginning of a new de-icing period, a quicker establishment of appropriate sludge culture will be possible A limit sludge culture is kept artificially alive in a separate tank during the summer.

c. Outside the de-icing period the whole treatment plant is closed and the sewage is lead to the municipal wastewater treatment plant.

The last alternative will cause an extra load on the municipal treatment plant, and must be evaluated in cooperation with the municipality.

The laboratory tests performed in this project indicated a relatively quick establishment of appropriate biomass. It must however, be pointed out that small reactors in a laboratory provide an unrealistic control and optimisation of surrounding conditions. Pilot-tests are therefore recommended as basis for a choice between the strategies alternatives a and b.

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