Final Programme

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Clarification of colloidal suspension by adding composite flocculants in powder form, T. Tanaka*, H. Kadooka, M. Iwata, Osaka Prefecture University, Japan

The removal of humic acid from peat water using chitosan as a low cost adsorbent, M. A. Zulfikar, Institute of Technology Bandung, Indonesia

Comparative assessment of filter media for arsenic removal from drinking water: Commercially available and perspective hybrid sorbents, Z. Maletskyi*, T. Mitchenko, H. Shevchuk, P. Stender, Y. Kolomiyets, National Technical University of Ukraine, Ukraine

This Poster Session is followed by a poster discussion in front of the posters from 12:00-12:45

Membrane Separation I — PM1
10:45-12:00 h

Stimuli responsiveness of block copolymer membranes, S. Rangou*, A. Jung, M. Gallei, K. Buhr, P. Merten, V. Filiz, S. Bolmer, C. Abetz, V. Abetz, Helmholtz-Zentrum Geesthacht, Germany

Assembling wormlike micelles into mesoporous membranes, C. Stegelmeier*, A. Exner, S. Förster, University of Bayreuth, J. Perlich, HASYLAB/DESY, Germany

Use of raft polymerization for the synthesis of high molecular weight diblock copolymers, C. Efe, M. Rikkou-Kalourkoti, C.S. Patrickios*, University of Cyprus, Cyprus

Recovery of antioxidants from by-products of the food industry with membrane processes, B. Feketeföldi*, A. Dunkl, M. Suppan, V. Ribitsch, Joanneum Research Forschungsgesellschaft mbH, Austria

Metallic microfilters with pore size down to 0.2 micrometer, O. van Donselaar*, A. Harbiye, H. Knol, Stork Veco BV, Netherlands

Combined electrically-enhanced aqueous extraction and membrane filtration to recover oil from oil meals, J.-L. Lanoisellé, L. Ding, L. Li, D. Clausse, E. Vorobiev*, University of Compiègne, France

Study on treatment and reuse of petrochemical wastewater with high salinity by membrane distillation technology, X. Zhang*, Z. Hou, Z. Li, J. Luan, Y. Yang, Environmental Protection Research Institute - SINOPEC, China

Features of ultrafiltration applying low doses of coagulant, O. Svetleishaya, T. Mitchenko*, P. Stender, Z. Maletskyi, National Technical University of Ukraine, Ukraine

This Poster Session is followed by a poster discussion in front of the posters from 12:00-12:45

Membrane Separation II — PM2
10:45-12:00 h

A Study on the characterization of zeta potential of tubular membrane, Y.-P. Fang, K.-W. Lai, C.-J. Chuang*, Chung Yuan University, Taiwan

Total removal of microalgae in seawater by submerged microfiltration, J.-B. Castaing, S. Plantier, A. Masse, N. Sabiri, P. Jaouen, M. Pontié*, Laboratory GEPEA; J. Haure, IFREMER, Lab. Conchylicole des Pays de la Loire, France

Energy efficient concentration of clarified thin sugar juice through multistage-NF/RO membrane technology, M. Harasek*, S. Gul, Vienna University of Technology, Austria

Modeling microfiltration of baker's yeast suspensions by neural networks, A. Jokic*, B. Ikonic, J. Grahovac, S. Dodic, S. Popov, Z. Šereš, University of Novi Sad, Serbia

Olefin metathesis in a nanofiltration membrane reactor in toluene, G. Nasser, D. Delaunay, T. Renouard, M. Rabiller-Baudry*, University Rennes, France

On electrostatic interactions during nanofiltration of iron/phosphate chelates in 5.9 mol.L[-1] phosphoric acid medium, M. Rabiller-Baudry*, H. Diallo, K. Khaless, B. Chaufer, University Rennes, France

Efficient filtration via chaotic advection in a tubular membrane module, T. G. Kang*, Korea Aerospace University; G.T. Park, S.W. Kim, Boo-Kang Tech Co., Ltd., Sang-Kyu Choi, Korea Institute of Machinery and Materials, Korea (ROK)

Effect of different pretreatments on permeate flux for passion fruit microfiltration, R.C.C. Domingues, S.B. Faria Junior, R.B. Silva, G.O. Prado, V.L. Cardoso, M.H.M. Reis*, Federal University of Uberlândia, Brazil

This Poster Session is followed by a poster discussion in front of the posters from 12:00-12:45

Cleanable Dust Filtration II — G10
10:45-12:00 h

Comparative characterization of cleanable dust filter media with regard to energy consumption and filtration efficiency, T. Laminger*, F. Lebl, W. Höflinger, Vienna University of Technology, Austria

Advantages and possible applications of a novel pulsless filtration system, S.D. Sharma*, K. McLennan, M. Dolan, A. Ilyushechkin, CSIRO Energy Technology, Australia

Developing back-pressure cleaning of nanofiber filters, W.-F. Leung*, C.-H. Hung, The Hong Kong Polytechnic University, China

Solid Gas Separation I — PG1
10:45-12:00 h

Experimental study on the collection efficiency of nanoparticles of TiO_2 by fibrous cellulose filter, J.V.M. Zoccal, F.O. Arouca, J.R. Coury, J.A.S. Gonçalves*, Federal University of São Carlos; F.O. Arouca, Federal University of Uberlândia, Brazil

Deposition of charged aerosol nanoparticles on wire screens, M. Alonso*, F.J. Alguacil, National Center for Metallurgical Research CSIC; V. Gomez, Instituto de Nanociencia de Aragón INA, Spain; C.H. Huang, Yuanpei University, Taiwan

Measuring suspended particle size with high accuracy, A. Brems*, R. Dewil, University of Leuven, Belgium; Y. Brems, J. Baeyens, University of Warwick, UK

Gas capture and vapour separation by microporous materials P. Miao*, M. Naderi, J. Khoo, D.J. Burnett, Surface Measurement Systems Ltd., UK

Evaluation of the behavior of regenerated cellulose filter media during gas filtration, P.M. Barros, E.H. Tanabe, M.L. Aguiar*, Federal University of São Carlos, Brazil

Performance of polypropylene and cellulose filters in high pressure gas filtration, E.H. Tanabe, J.R. Coury, M.L. Aguiar*; Federal University of São Carlos; M.D.M. Innocentini, University of Ribeirão Preto, Brazil

Fabrication of depth-type filter media through direct growth of carbon nanotubes on quartz fibers, P. Li*, Y. Zhang, F. Wei, Tsinghua University, China

This Poster Session is followed by a poster discussion in front of the posters from 12:00-12:45

Solid Gas Separation II — PG2
10:45-12:00 h

Study of regeneration of different filter media, M.S. Rocha*, Federal University of Espírito Santo; M.L. Aguiar, Federal University of Uberlândia; A.C.M. Rodrigues, University of Sao Carlos, Brazil

Optimization of bag house filter performance by using fast detection systems, R. Herzog, R. Heidenreich*, W.-P. Frenzel, Institute for Air Handling and Refrigeration ILK, Germany

Study of the influence of the velocity of filtration in the formation and removal of the dust cake, D.M. Nunes, F.O. Arouca*, J.J.R. Damasceno, Federal University of Uberlândia, Brazil

Performance of an aerosol generator for preparation of nanoparticles by atomization, F.O. Arouca*, Federal University of Uberlândia; N.R. Feitosa; J.R. Coury, Federal University of São Carlos, Brazil

Experimental investigation of sintered metal fiber hot gas filter, Z. Ji*, L. Yang, Q. Xu, China University of Petroleum, China

Effect of the bag arrangement on the dust removal performance of the bag filter, F. Qian*, Z. Chen, Anhui University of Technology; Y. Ye, X. Zhang, Anhui FLT Liquid-Filtering Equipment Ltd, China

Simulating permeability of 3-D fibrous media, H.-M. Fu*, Y.-Y. Li, Y.-F. Diao, Donghua University, P.R. China

This Poster Session is followed by a poster discussion in front of the posters from 12:00-12:45 h

Key-Note 3
14:00-15:15 h

Separation challenges for the biotechnology: SMART is one answer, Dr. Karsten Keller - Solae/Dupont, USA

New Membranes & Materials III — M7
14:00-15:15 h

Structure formation of block copolymer membranes, V. Abetz*, Helmholtz-Zentrum Geesthacht, Germany

Room-temperature and cryogenic-temperature electron microscopy characterization of self-assembled block-copolymer nanoporous membranes, L. Oss-Ronen*, J. Schmidt, Y. Cohen, Y. Talmon, Technion-Israel Institute of Technology, Israel

Theoretical basics of transport through the block copolymer self-assembled membranes: structure, permeability, convection instability, I. Erukhimovich*, Institute of Organoelement Compounds RAS; Y. Kriksin, Institute for Mathematical Modeling RAS, Russian Federation

Water Treatment II — M8
14:00-15:15 h

Membrane reuse: First step to cradle to cradle (C2C) approach, M. Pontié*, Laboratory GEPEA; Q. Trong Nguyen, Rouen University, France

Membrane technology in water treatment applications, W.M. Samhaber*, Johannes Kepler University, Austria

Experience with MBR-systems for cleaning highly loaded organic waste water, B.S. Mayr*, EnviCare Engineering GmbH, Austria

Cleanable Dust Filtration III — G11
14:00-14:50 h

Filtration efficiency at high filter face velocity, B. Lohrengel*, Heilbronn University, A. Reinhardt, N. Maheswaran, Mahle Industriefiltration GmbH, Germany

Energy analysis of the hybrid filtering process on a modified VDI 3926 type 2 test apparatus, F. Lebl*, T. Laminger, W. Höflinger, Vienna University, Austria

Mist Droplet Separation I — G12
14:00-15:15 h

Temporal evolution of the saturation profile of an oil-mist filter, D. Kampa*, S. Wurster, J. Buzengeiger, J. Meyer, G. Kasper, Karlsruhe Institute of Technology (KIT), Germany; B. Mullins, Griffith University, Australia

EXPERIENCE WITH MBR-SYSTEMS FOR CLEANING HIGHLY LOADED ORGANIC WASTE WATER

Bernhard Mayr

EnviCare® Engineering GmbH, Eisteichgasse 20/36, Graz, Austria

ABSTRACT

Two large scale case studies of MBR systems for cleaning highly concentrated waste water are presented and the design approach is thoroughly presented and discussed. Also several problems during start-up are addressed.

1. Background

Membrane Bioreactor Systems are well known and established for a wide range of applications nowadays. Due to the ability to adjust and control sludge age and to decouple hydraulic and sludge residence time it is possible to reach high degradation rates even for “hard” organic compounds (expressed via parameter chemical oxygen demand - COD) which are present e.g. in landfill leachate. Anyhow the membrane separation process demands more energy than conventional sludge sedimentation. Especially if highly concentrated organic waste water is processed the energy demand becomes significant also in terms of operating costs and therefore an anaerobic pre-treatment is often considered as alternative.

2. Aim

In the paper practical experience from two projects is presented. First case describes a full scale MBR installation to treat landfill leachate with a COD concentration of 25 kg/m³ and an Ammonia concentration of 4 kg/m³. As second case a MBR plant to clean waste water from renewable fuel production and from an animal fat refining with an average COD concentration of 150 kg/m³ and poor nutrient content is presented.

3. Method

Results from theoretical design based also on simulation models and from laboratory testing stage are presented and compared to data obtained from start-up of the full scale plants.

4. Main Results

Looking at the leachate treatment installation the elimination of high Nitrogen content by a nitrification/denitrification regime asks for a sufficient supply of carbon source. Therefore an anaerobic pre-treatment was not taken into account, since it would deplete COD. It became clear already a few weeks after beginning of operation that the exergy from the biological oxidation process had been under estimated. On the other hand an ammonia effluent concentration of below 20 mg/l had to be ensured in order to prevent the process to be stalled. As positive aspect the ceramic membrane is in operation since 18 years now.

Since the highly loaded organic waste water in the second case contains only a minor ammonia concentration an anaerobic pre-treatment was thoroughly tested in pilot scale on-site. Due to insufficient nutrient supply and/or toxic ingredients in the waste water and/or improper reactor design a stable operation could not be ensured. Also the biogas would show a very high content of hydrogen-sulfide and the amount would be too low to yield significant revenue if used as fuel in an existing steam boiler. It was proven by on-site pilot tests that an aerobic MBR is much less sensitive to process fluctuations and also toxic ingredients. Consequently the large scale plant was built as aerobic MBR, taking into account the drawback of significantly higher energy costs. After adjusting nutrient supply and anti-foam measures during start-up the plant ensures now the stipulated emission limits and the cross-flow organic membrane unit is performing excellently.

KEYWORDS

Membrane Bioreactors MBR, Microfiltration, Ceramic Membranes (Scale-Up)

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ABSTRACT

In the paper practical experience from large scale case studies of MBR systems is presented.

First case describes a full scale MBR installation to treat highly loaded landfill leachate. As second case a MBR plant to clean strongly concentrated waste water from renewable fuel production and from an animal fat refining is presented.

Based on start-up and operation experience exergy from the biological oxidation process, the influence of ammonia effluent concentration, nutrient supply, foaming and the feasibility of anaerobic pre-treatment are discussed. Long term behavior of cross-flow membranes is shown as well.

KEYWORDS

Membrane Bioreactors MBR, Microfiltration, Ceramic Membranes (Scale-Up)

1 Introduction

Membrane Bioreactor Systems are well known and established for a wide range of applications nowadays. Due to the ability to adjust and control sludge age and to decouple hydraulic and sludge residence time it is possible to reach high degradation rates even for “hard” organic compounds (expressed as parameter chemical oxygen demand - COD) which are present e.g. in landfill leachate. Anyhow the cross-flow membrane separation process demands more energy than conventional sludge sedimentation.

Especially if highly concentrated organic waste water is processed the energy demand for oxidizing organic compounds becomes significant also in terms of operating costs and therefore an anaerobic pre-treatment is often considered as an alternative.

In the paper practical experience from two projects is presented. First case describes a full scale MBR installation to treat landfill leachate with a COD concentration of 25 kg/m³ and an Ammonia concentration of 4 kg/m³ (2). Landfill leachates are produced as a result of the anaerobic microbial degradation and compression of solid waste on landfills (1). Landfill leachates are characterized by both high organic and high ammonium concentration. Organic compounds in waste water has been treated successfully by biological oxidation since beginning of this century in the activated sludge process. A removal of ammonium and organic nitrogen compounds by the combined aerobic and anoxic biological treatment (so called nitrification/denitrification process) was developed more recently and since then has been widely integrated in biological treatment processes (3).

Elimination of high Nitrogen content by means of a nitrification/denitrification regime asks for a sufficient supply of carbon source. Therefore an anaerobic pre-treatment was not taken into account, since it would deplete COD.

As second case a MBR plant to clean waste water from renewable fuel production and from a used fat refining plant with a average COD concentration of 150 kg/m³ and poor nutrient content is presented. Compared to data from literature (4) the concentration in the actual case study was significantly higher, probably due to the applied high yield renewable fuel production process including as well steps to recover glycerol and methanol. This process design leads to significantly lower waste water amounts from only 0.12 $m^3_{waste\ water}/m^3_{Ren.fuel}$ compared to a relation of 2 given elsewhere (4).

Two reasons were responsible to consider a MBR installation in this case. On the one hand the low emission limit for COD asked for a biological degradation process and on the other hand a straight forward approach with as less process components as possible was a pre-condition in order to keep operating costs low and process reliability high.

2 Materials and Methods

In this paper results from theoretical design based also on simulation models and from laboratory and pilot testing stage are compared to data obtained from start-up of the full scale plants.

2.1 MBR for leachate treatment

Pilot Plant

The pilot plant (Figure 1) combined biological wastewater treatment via denitrification and nitrification processes with ceramic cross-flow microfiltration (MF) to separate the purified water from the biomass.

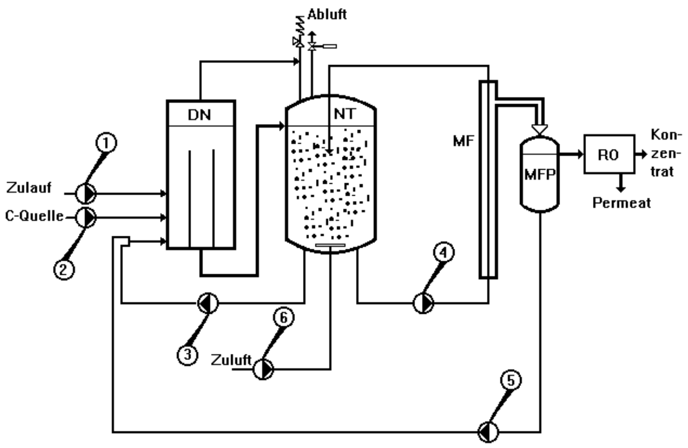

Figure 1: flow sheet of pilot plant for landfill leachate

It consisted of two separated tanks with a total capacity of 0.62 m³. 0.15 m³ was used as primary anoxic denitrification and 0.47 m³ as successive aerated nitrification. Details on design as well as on results can be found elsewhere (2).

Large Scale implementation

The design of the large scale plant was based on the results of pilot testing in respect to membrane flux and sludge load of the bioreactors.

Other parameters were taken from design guidelines like ATV A 131.

The biological leachate treatment is performed in non-pressurized bioreactors (Figure 2). Leachate is supplied to the upstream anoxic denitrification tank. Oxygen from Nitrate is used there to degrade easily degradable organic compounds while Ammonia flows through this tank largely unchanged and reaches the nitrification. Aerobic conditions are prevailing there, either for the oxidation of ammonium to nitrate or for further oxidation of the COD compounds.

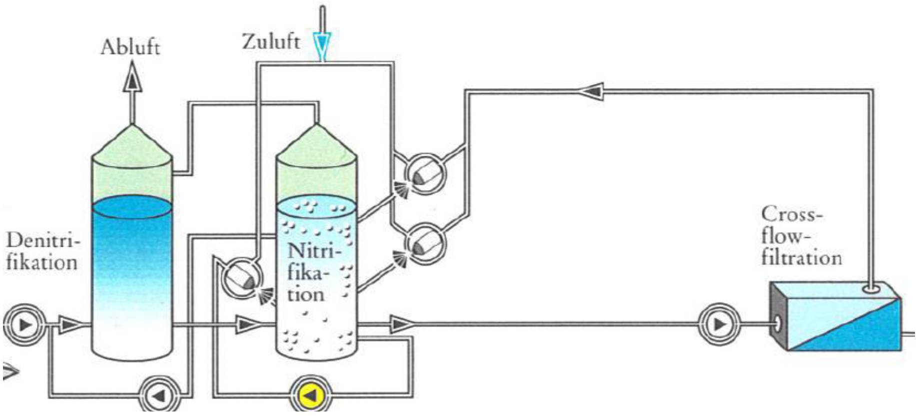

Figure 2: flow sheet of large scale installation for landfill leachate

The plant is equipped with four recirculation circuits:

- The first circuit (50 m³/h) is used for recirculation of nitrate and microorganisms from the nitrification to the denitrification;
- The second circuit (240 m³/h) connected to in the nitrification tank is used for feeding the cross-flow MF and the remaining pressure after the membrane modules is used for injector aeration. This coupling of cross-flow membrane and injector aeration causes on the one hand an increased permeate flux due to the sufficient trans-membrane pressure even at the end of the module and on the other hand an optimum energy utilization. Furthermore the active biomass stays only for one cycle in the stressful MF system and is not harmed in its biological activity;
- Other circuits are used for aeration by means of ejector. Medium is taken from the bottom of the tank and after an increase in pressure is inserted back through the injectors. In the injectors the necessary process air is sucked in and introduced in fine bubbles with an efficient utilization of oxygen into the medium. If required, some of the injectors can be switched from fresh air mode to suction of foam. The foam is then re-entered via the injectors into the medium and mechanically destroyed. A positive aspect of this aeration is a good, homogeneous and energy-saving mixing of the tank contents;
- An additional circuit (60 m³/h) was installed for cooling purposes.

For biomass removal a ceramic MF is used. The ceramic modules have a maximum pore diameter of 0.2 microns and are equipped with an automatic back-flushing device. Modules have an open channel diameter of 8 mm on the feed side.

In order to directly discharge the biologically pre-cleaned leachate to a small river a reverse osmosis system with spiral wound modules is used to eliminate ionic and non-biodegradable molecular impurities.

The main components of the large scale plant are

- Denitrification: one tank with 130 m³ operated in plug flow mode
- Nitrification: two tanks with a total volume of 260 m³ (CSTR reactor), 10 pcs of GEA Wiegand injectors
- Cross-Flow-Microfiltration: 40 m², operating transmembrane pressure 2.5 bar
- Cooling tower 200 kW
- Sludge handling with decanter press

Details on design can be found elsewhere (5).

2.2 MBR for treatment of waste water from renewable fuel production

<u>Design approaches and pilot plant tests</u>

The goal was to develop a wastewater treatment concept which enables a cost efficient reduction of the organic compounds expressed as COD from values of around 130 kg_{COD}/m^3 to <10 kg_{COD}/m^3.

Several experiments were carried out in pilot scale on site and in laboratory scale:

- Use of reverse osmosis to recover methanol and to reduce COD load
- Combination of anaerobic digestion with a conventional activated sludge process (sedimentation)
- Combination of anaerobic digestion with an aerobic MBR
- aerobic MBR as a standalone solution

For the reverse osmosis experiments a disc-tube type pilot plant was used. This unit was equipped with 172 membrane sheets with a total membrane area of 7.7 m² mounted in a 8" tube. It was possible to operate the system up to 60 bar.

Anaerobic digestion was done in a 30 m³ CSTR tank with wall heating. As an inoculum 6 m³ fermentation broth from a biogas plant was used.

The conventional activated sludge process was tested in 2 m³ aerated CSTR tank and a 0.7 m³ secondary clarifier. The effluent of the anaerobic CSTR was used as feed of the aerobic installation.

The MBR was established simply by installation of a MF cross-flow unit with a membrane area of 1.35 m² and a pore size of 0.04 µm after the secondary clarifier of the above mentioned aerobic unit.

pH Value, electric conductivity, DS and oDS, COD, gas production and quality (CH_4, CO_2, O_2, H_2S) were monitored.

In order to increase the safety of process design a process simulation on base of the ASM1 model was done as well (6), (7). The flow sheet of the model took into account that the selector will be insufficiently mixed and therefore was divided into two separated zones as shown in Figure 3.

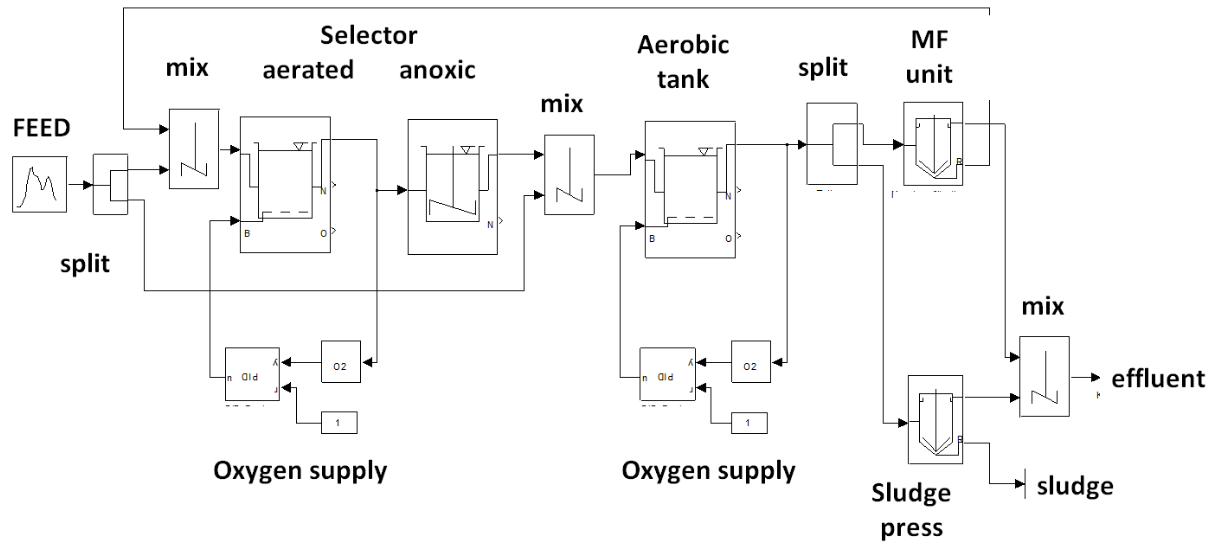

Figure 3: flow sheet of ASM1 simulation model

The following parameters were used for modeling the process:

Amount	1,05	m³/h
COD feed concentration	120	kg/m³
NH_4 feed concentration	0,05	kg/m³
NO_3 feed concentration	0	kg/m³
Excess sludge Sludge residence time	9,16 56	m³/d d
temperature	35	°C
Oxygen concentration in aerated part of selector	1	mg/l
Oxygen concentration in aerobic tank	1	mg/l

Table 1: parameters for simulation of highload organic waste water plant

Large Scale implementation

The design of the membrane unit is based on tests and measurements described above.

The design of the aerobic unit was done according to the ATV A 131 guideline with some specific adaptations.

The plant is able to process 30 m³/d of highly loaded organic waste water with a COD concentration of up to 120 kg/m³.

It consists of a slightly aerated selector with 125 m³ and a following aerated tank with 400 m³. Connected to the aerated tank are one circuit for cross-flow MF, cooler and injector areation in the selector (60 m³/h) and a second circuit for injector aeration (400 m³/h).

Special attention was given to integrate several anti-foam measures, since already during piloting foaming occurred quite frequently.

3 Results and Discussion

3.1 MBR for leachate treatment

The original concept of the large scale leachate treatment plant did not include the cooling circuit and a decanter press. At the time of start-up in 1994 this plant was quite unique in Europe because of its very high COD and Ammonia load. Therefore no operation experience from similar plants was available and the described intensive pilot test runs (2) were undertaken.

Both heat and sludge production are hard to quantify exactly under pilot conditions and therefore scale up should better be based on calculations making use of recognized guidelines, which were not available for this specific case. Because of these uncertainties cooling and sludge press was installed as soon as reliable operational data was available.

Since then the plant was able to treat the leachate to ensure direct discharge quality (COD < 50 mg/l, NH_4-N < 10 mg/l, NO_2-N < 2 mg/l, N_{tot} < 50 mg/l), even in periods of heavy rain.

The originally installed ceramic membrane modules are still in operation after 18 years with sufficient flux.

The characteristic parameters can be found in the following table:

Parameter	Pilot scale	Large scale	units
Volume tot	0,62	390	m³
Inflow	0.1	100	m³/d
pH-Wert	7.6 – 8.7	8,2	
Electric conductivity	42	36	mS/cm
COD	22 - 35	15	kg/m³
BOD_5	--	5.3	kg/m³
Ammonium	4.2 – 6.2	4.0	kg/m³
DW	25	35	kg/m³
Area MF	0,55	40	m²
B_R COD	4,60	3,85	kg/(m³.d)
B_R-NH_4	0,84	1,03	kg/(m³.d)
B_{TS} COD	0,18	0,11	kg/(kg.d)
B_{TS} NH_4	0,034	0,029	kg/(kg.d)
Biomass growth factor	0,07	0,13	kg_{TS}/kg_{COD}
Flux MF	164	104	l/(m².h)
Transmembranepressure	3,50	2,50	bar
Permeability MF	46,8	41,7	l/(m².h.bar)

Table 2: Characteristics of the leachate plant

Particular attention in the design of the large scale installation must be laid on the following operating parameters:

Carbon source for denitrification

Because of the highly loaded and variable composition of leachate it may, as experience showed, come to a sudden shortage of easily degradable carbon for the denitrification. As a further result, a decrease of pH in biology and a massive increase in nitrate concentrations will lead to an inhibition of nitrification. For this reason, a continuous monitoring of pH and nitrate levels in biology as the base for an adequate dosage of external carbon source (acetic acid) is an essential prerequisite for trouble-free operation of the biology.

This problem never occurred during pilot tests simply because then the landfill leachate contained enough easily degradable carbon. Since less amounts of sludge were landfilled the degradable compounds deplete quickly and the addition of carbon source (acetic acid) became necessary.

Foaming

Foaming occurred already during pilot test phase, e.g. if sulfuric acid was dosed to lower the pH value. Therefore an antifoam dosing system, the already described foam suction system coupled to the injectors and 3 m of free head space over the maximum liquid level were implemented in the large scale system.

Under normal operating conditions these measures proofed to be sufficient, but depending on certain and not specifically known ingredients in the feed or due to biological problems strong foaming happened also sometimes in the non aerated denitrication tank. While at the beginning 2 – 5 l/d of antifoam was sufficient this amount increased to more than 200 l/d during half a year of operation. Obviously the biology adapted to the usually hard degradable ingredients of the anti foam agent.

As a consequence several antifoam products were tested under pilot test conditions and additional nozzles were installed to spray down the foam from the top.

Monitoring of feed characteristics to ensure flux of MF unit

Already half a year after start-up of the large scale plant it became clear that the flux of the ceramic MF unit had been overestimated during trial tests. Although the limiting fouling layers could be removed by intensive chemical cleaning these efforts exceeded the planned maintenance activities. Therefore the MF was expanded from 25 to 40 m² with an additional third module in series simply by increasing the height of the rack and using a more powerful pump.

Anyhow, due to the constantly fluctuating and not identifiable ingredients of the leachate or by their interaction with the biology repeatedly spontaneous and sometimes very massive blockages of the microfiltration occurred. This problem can be handled to a certain extent through observation and evaluation of operating conditions, by controlling the inflow system by making use of two independent leachate basins and through the use of individual purification strategies. An assignment of the causes to certain types of dumped waste is usually not possible.

Derived from Table 2 it can be concluded that volumetric load rate and the necessary oxygen uptake can be successfully scaled up from pilot scale, even if the scale-up ratio is far larger than 100.

Problems might occur in the scale-up of the membrane unit, since influences from the biological system might significantly influence the behavior of membrane operation, both flux and maintenance efforts. The same is true for foaming conditions and for the specific yield of biomass related on COD.

3.2 MBR for treatment of waste water from renewable fuel production

The above mentioned experiments with reverse osmosis showed that a major part, namely up to 80 % of the COD consists of very small organic molecules, i.e. mainly methanol. Although it is possible to restrain larger components like glycerol or propandiol in the concentrate it is not possible to ensure low COD values in permeate which would make it possible to discharge it directly to a river or to most sewer networks. Furthermore significant biofouling was observed and the membrane itself as well as the material of the spacer discs showed significant signs of wear after only some weeks of operation.

Although laboratory tests with anaerobic digestion based on addition of highload organic waste water to an Inokulum derived from a communal digestion plant were promising, the larger anaerobic CSTR pilot plant, which was started with sludge from a biogas plant, did not confirm these findings. Stable operation could not be reached and the test run had to be stopped after a collapse of the biology only after 8 weeks of operation. The reason for this unsuccessful experiment is not known for sure, but we assumed that some ingredients in the waste water have been harmful for anaerobic microorganism.

Due to a joint assessment of all involved parties an aerobic membrane bioreactor (MBR) was considered as simplest, most reliable and economically feasible solution.

Since this variant of sole aerobic treatment was not tested in pilot scale, a residual risk was remaining during scale-up. Therefore a process simulation was done.

The results of the simulation for steady state operation based on the ASM1 model show that a steady process is feasible. The applied model is appropriate and leads to reliable results.

The simulation showed that the given feed rate of COD (126 kg/h) can be oxidized to an extent higher than 95% at a biomass concentration of about 22.6 kg/m³ (= 25 $kg_{\Sigma COD}/m^3$). However, only 11 kg/m³ of which is active biomass.

For the survival of the biomass, however, a much higher content of ammonium in the inflow is necessary: 5 kg/m³, since ammonium is a major limiting factor for biomass growth. Even with an ammonium addition of 5 kg/m³ a limiting effect might still occur.

The simulation further predicts that an aeration with 196 kg_{O2}/h will be adequate.

During simulation the following parameters have proven to be particularly critical system parameters:

- COD load

- supply of NH_4, P_2O_5, K_2O and other nutrients
- oxygen uptake rate

All three parameters are limiting for the growth of biomass and must be supplied in sufficient quantities and in a suitable ratio to each other.

When the temperature is lowered from 30° C to 20 ° C the amount of active biomass in Selector and Aerobic tank increases due to a slower death rate.

The model predicts that less active biomass in the system will lead to lower concentrations in the effluent after MF and decanter. Simulation results further show that COD reduction degree is to be expected between 96.8% (at 35 ° C) and 94.4% (at 20 ° C).

Oxygen demand increases with temperature due to the increased biomass growth and lower solubility.

The waste water derived mainly from distillation processes requires the addition of nutrients in long-term operation and the quantity and quality could not be defined in the experiments, because the aerobic pilot tests were done by using the nutrient rich effluent of the anaerobic pilot test run which itself was started with a nutrient containing sludge from a biogas plant.

<u>Operation of the large scale plant</u> was started in 2009.

Ever since plant operation was commenced the intended emission values for the discharge of permeate of the microfiltration unit into the communal sewer network had been fulfilled.

The degradation rate of COD is higher than 95 %, thus ensuring emission limits of lower than 5.000 mg/l.

The biological process is robust and no toxic inhibitions have been recognized so far. The membranes of the organic cross-flow microfiltration had to be changed once after some fibers and other debris harmed the surface during start-up. Since then the membranes are operating at design flux and regular chemical cleanings are done according to standard operating procedures.

The following operation and scale-up experience was learned:

<u>Cooling system</u>

Based on the experience from the highly loaded leachate the cooling capacity of the large scale plant was designed taking into account the power demand for aeration and microfiltration and a certain surplus was provided for heat derived from oxidizing organic compounds. This estimation proved to be sufficient, but problems occurred because fibres in the Inokulum blocked the plate heat exchanger as well as the microfiltration inlet several times. After an additional and time-consuming filtering this problem could be solved.

<u>Sludge withdrawal and decanter press</u>

Again a decanter press was installed only after the process was already fully established and the supplier of the press had the chance to run laboratory tests with the sludge of the plant in order to define the best flocculant. This approach prohibits any fail or improper design and is possible due to the fact that biomass growth rate is low and the biomass content in the bioreactors can be adjusted and also increased up to 50 kg/m³.

The amount of surplus sludge is in the range of 0.12 kg_{DW}/kg_{COD} and higher than predicted by the simulation model.

<u>Nutrient supply</u>

The mainly carbon based waste water with high amounts of methanol, glycerol and fats makes it necessary to provide a wide range of nutrients. Therefore as base supply a agricultural fertilizer is dosed and Nitrogen, phosphorus and potassium among others is monitored by regular offline analysis.

<u>Foaming</u>

Although several measures to prevent or fight foaming were already included in the installation like a foam overflow and destruction, free head space, anti foam dosing and a sufficient nutrient supply still foaming caused several problems.

Obviously incomplete mixing of the selector contributed as well and since the liquid level was significantly lowered the problem was successfully solved.

4 Summary

Nowadays highly loaded organic waste water should be treated by anaerobic means simply because biogas and consequently energy can be derived from the process. Two case studies are presented in this paper where an aerobic MBR installation was realized in contrary to this statement.

The reasons for this design approach are differing, in the case of landfill leachate biological degradation of ammonia needs carbon source and in contrast to this need an anaerobic treatment would increase an expensive external carbon supply and is therefore not economically or ecologically viable.

In the second case an anaerobic process could not be successfully implemented due to insufficient nutrient supply and/or toxic ingredients in the waste water. Also the biogas would show a very high content of hydrogen-sulfide and the amount would be too low to yield significant revenue if used as fuel in an steam boiler or cogeneration-unit.

It was proven that aerobic MBRs are much less sensitive to process fluctuations and also toxic ingredients. Consequently the large scale plants were built as aerobic MBR, taking into account the drawback of significantly higher energy costs. After adjusting nutrient supply and anti-foam measures during start-up both plant ensure now the stipulated emission limits and the cross-flow organic membrane units are performing excellently.

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6 Abbreviations

COD	chemical oxygen demand
CSTR	continuous stirred tank reactor
DS	dry solids (105 °C)
oDS	organic dry solids (550 °C)
MBR	membrane bioreactor
MF	microfiltration