The Kaldnes Moving Bed™ biofilm process
- an innovative solution to biological waste water treatment

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Introduction

Kaldnes Miljøteknologi AS is a Norwegian company that has specialised in biological treatment of municipal and industrial wastewater. The company was established in 1989. The company is owned by and co-operates closely with the Swedish company Anox AB.

The Kaldnes Moving Bed™ biofilm process is a patented process and is based on the biofilm principle with an active biofilm growing on small specially designed plastic elements that are suspended in the reactors.

Kaldnes Miljøteknologi AS is today one of the worlds leading companies in compact and advanced processes for biological treatment of wastewater. The Kaldnes Moving Bed™ biofilm process is also a very well documented biological process with over 50 published technical papers and even more internal documentation.

The flexibility of the Kaldnes Moving Bed™ biofilm process has given us more than 300 satisfied customers in over 20 countries. The process is excellent for BOD/COD removal and nitrification/denitrification in all types of wastewaters.

History of Kaldnes Miljøteknologi AS and the Development of the Kaldnes Moving Bed™ biofilm process

Todays major discoveries tend not to be sudden strokes. They are usually the result of hard work, financial investments and targeted research within successful partnerships. There also has to be a need for improvement.

The development of the Kaldnes Moving Bed™ biofilm process is an example of such a fruitful partnership between a university research group - represented by the water treatment research group at NTNU/SINTEF (NTNU - Norwegian university of Science and Technology, SINTEF - the Foundation for Scientific and Industrial research) and industry (the Norwegian company Kaldnes Miljøteknologi AS).

Kaldnes was originally one of a number of large shipyards in Norway. The bottom fell out of this market in the 1970s and restructuring became necessary. Following successes in the fields of steel structures and pipework, Kaldnes began to accumulate experience of

building large process modules for petroleum activities in the North Sea. At the same time, key Kaldnes personnel began to investigate the opportunities for development within the field of biological wastewater treatment.

The research group at SINTEF/NTNU had at this stage already started to look for new and improved techniques for biological treatment for the Norwegian market. The combination of a biological process followed by chemical treatment had been used in Norway for the last decade with good results. But at that stage there had been reported problems with the existing rotating biological contactors (RBCs) and submerged fixed biofilters.

The idea was to develop a biological treatment process which utilised the advantages of activated sludge and biofilter systems without being restrained by their disadvantages. The process also had to be compact as most wastewater treatment plants in Norway normally are covered, either by industrial-like buildings or by placing them inside a rock cavern. This makes compactness of the plants an important issue, both from an investment (less rock blasting) and an operational (less heating and ventilation) point of view.

Based on the development of a new bioreactor, the Moving Bed™ biofilm reactor (MBBR™), the company Kaldnes Miljøteknologi AS was formed.

A development project between SINTEF/NTNU and Kaldnes Miljøteknologi AS was started, with a reactor in which the biofilm carrier was suspended in the reactor, and movement caused by the agitation set up by aeration or mixers. The Norwegian Research Council (NRF) also funded the development work. The process that was developed, as a result of this research was to become the core of Kaldnes Miljøteknologi AS, and was patented as the Kaldnes Moving Bed™ biofilm process (Eur. Pat. No. 0575314, US pat. No. 5,458,779).

This was also at the time (1988/89) when agreements were made among the North Sea states to reduce nutrient discharges into the North Sea coastal waters. Consequently, a Norwegian research programme, financed by NRF and the Norwegian State Pollution Control Agency (SFT), was initiated. The funding institutions supported the idea that the experimental research of the programme was to be focused on the proposed Moving Bed™ biofilm process and chemical treatment. The development of the Moving Bed™ biofilm process had a considerable national support, therefore, both from the research funding bodies (NFR), the authorities (SFT), the industry (Kaldnes Miljøteknologi AS) and the research institutions (SINTEF/NTNU).

Although the technology was developed with specific aim of the Norwegian municipal market, it has spread rapidly to new markets. It is today used for many different purposed, both for municipal and industrial wastewater treatment, for removal of organic matter, nitrification and denitrification. It is particularly favourable where space is limited or for upgrading of old treatment plants. The technology has also been

tested for colour removal in drinking water treatment, and for biological phosphorous removal in wastewater treatment.

The technology is today sold around the world through a network of licensees. The notion invented by SINTEF/NTNU and Kaldnes Miljøteknologi AS for the process, namely Moving Bed™ Biological Reactor (MBBR™) is widely used in wastewater treatment literature, which for us is an indication of the success of the process. Also the fact that the technology has been copied by a number of companies around the world is proof that we have developed a technology that is successful.

Description of the Moving Bed™ biofilm reactor (MBBR™)

The idea behind the Moving Bed™ biofilm process was as mentioned previously to develop a technology that possessed the advantages of both activated sludge and biofilter processes without being restrained by their disadvantages. The aerated Moving Bed™ biofilm reactors use, as the activated sludge process, the whole volume of an open tank. It is a biofilm process because the biomass is growing on carriers that move freely within the reactor volume and that are kept inside the reactors by a sieve arrangement at the reactor outlet. Since no sludge recirculation takes place, only the surplus biomass has to be separated, as in other biofilm processes, which is a considerable advantage over the activated sludge process that is dominating today. The reactor may be used for aerobic and anoxic processes. The following figure is a schematic of the principle of the Moving Bed™ biofilm reactor.

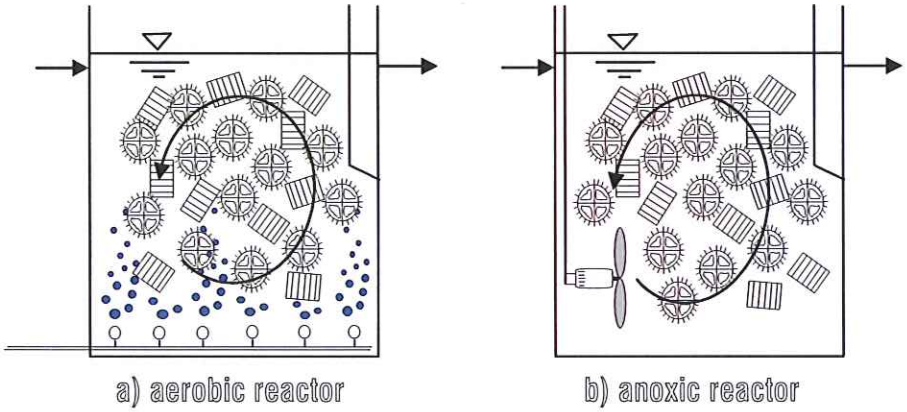

Figure 1. *Schematic showing the principle of the Moving Bed™ biofilm reactor.*

In aerobic processes biofilm carrier movements is caused by the agitation made by air from coarse bubble aeration diffusers, while in anoxic processes a mixer provides the

energy to keep the carriers in movement. Kaldnes Miljøteknologi AS has designed the aeration system especially for the MBBR™ reactor. The carriers are kept within the reactor by an outlet sieve. Most plants are designed with vertically mounted, rectangular sieves, but in some later plants cylindrically shaped sieves, vertically or horizontally mounted, have been implemented successfully.

Kaldnes Miljøteknologi AS still spends both time and money on continuous development of the mechanical design. The sieves, aeration system and mixing of anoxic reactors are areas which can all improve the effectiveness of the process even further.

The carrier elements

The core of the process is the biofilm carrier elements. The elements are designed to provide a large protected surface area for the biofilm and optimal conditions for the bacteria culture when the elements are suspended in water.

Kaldnes Miljøteknologi AS has developed carriers with different shape and size. This gives us the flexibility to use the best suitable carrier depending on wastewater characteristics, pre-treatment, discharge standards and available volumes. Currently we have three different types of media: K1, K2 and Natrix (these are shown in the picture below) which are made of high density polyethylene. The first carrier was the K1 which is shaped as a small cylinder with a cross on the inside of the cylinder and "fins" on the outside.

K1:
- Made of polyethylene
- Approximately 10 mm diameter and 7 mm long
- Protected surface area is 500m^2/m^3 in bulk

K2:
- Made of polyethylene
- Approximately 15 mm diameter and 15 mm long
- Protected surface area is 350 m^2/m^3 in bulk

K3:
- Made of polyethylene
- Approximately 25 mm diameter and 10 mm long
- Protected surface area is 350 m^2/m^3 in bulk

Natrix-media:
- Made of polyethylene
- Approximately 60 mm diameter and 50 mm long
- Protected surface area is 310 m2/m^3 in bulk

Biofilm Chip M:
- Made of polyethylene
- Approximately 45 mm diameter and 3 mm long
- Protected surface area is 900 m2/m^3 in bulk

All the carriers normally have a density slightly below that of water. However, they can all be made with varying densities if this is favourable.
One important advantage of the process is that the filling fraction of carriers in the reactor may be subject to preference. To be able to move the carrier suspension freely it is recommended that the maximum filling fraction should be below 67%. One may, however, use as much as needed below this, which is convenient, especially when it comes to upgrading plants - for instance from activated sludge to moving bed reactors.

As in every biofilm process, the diffusion of compounds into and out of the biofilm plays a key role. Because of the importance of diffusion, the thickness of the effective biofilm (the depth of the biofilm to which the substrates have penetrated) is significant. Since this depth of full substrate penetration is normally less than 100 μm, the ideal biofilm in the Moving Bed™ biofilm process is thin and evenly distributed over the surface of the carrier. To obtain this, the turbulence in the reactor is important, both in order to transport the substrates to the biofilm and to maintain a low thickness of the biofilm by shearing forces.

Various investigations have shown that the typical biomass concentration, when calculated on reactor volume, is about 3-4 kg SS/m^3, about the same as in activated sludge reactors. Since the volumetric removal rate is several times higher in the Moving Bed™ biofilm process, this can mean only that the biomass of this process is much more viable.

The following figures show Kaldnes & Natrix carriers.

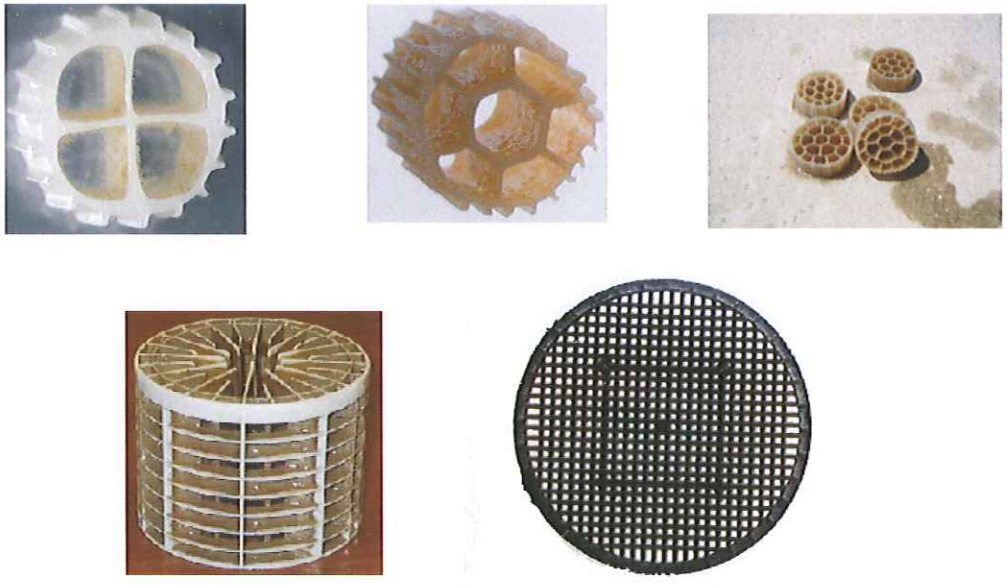

Figure 3. *K1, K2, K3, Biofilm Chip M and Natrix-O*

As shown in figure 3, less biomass is growing on the outside of the carriers than inside. This is probably caused by the erosion taking place when carriers are colliding. Because

of this phenomenon, the effective carrier area is calculated to be only about 70% of the total area.

The Kaldnes Moving Bed™ biofilm process

The process has been used for many different applications. As mentioned earlier it was developed at the time when nitrogen removal was in focus and most of the scientific data have been gathered from this application. Later, however, organic matter removal received more attention, including high-rate pre-treatment for upgrading of activated sludge plants. The process has been used both for municipal wastewater and industrial wastewater treatment.

The following figure shows some of the most common flow diagrams for different applications. This is by no means exclusive as the process is very adaptable and flexible.

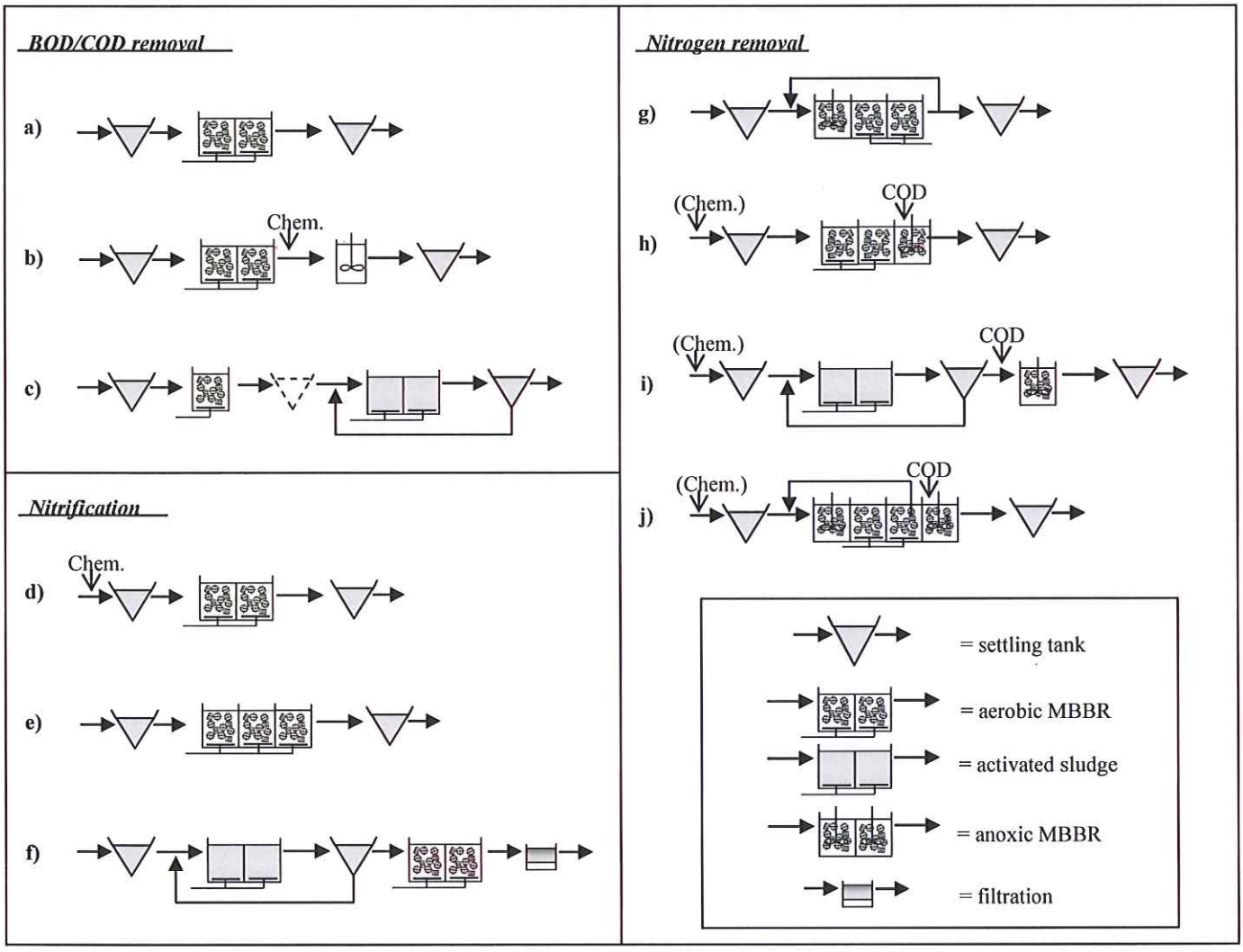

Figure 4. *Typical MBBR™ flow diagrams for different applications.*

Examples of Successful Full Scale Installations

As mentioned earlier the Kaldnes Moving Bed™ biofilm process is now installed in over 300 plants world wide. It started with small municipal plants but the big break-through came with the new advanced treatment plant for the Olympic city of Lillehammer that was opened prior to the Olympic games in 1994. As an example of an advanced municipal treatment plant shall be mentioned the Gardermoen wastewater treatment plant.

Gardermoen Wastewater Treatment plant (Norway)

In December 1994 the pollution control authorities ordered the Norwegian municipalities of Ullensaker and Nannestad to build a new wastewater treatment plant. This new treatment plant should treat all the wastewater from the new Oslo international airport, Gardermoen, as well as wastewater from the surrounding communities. The airport was already under construction and scheduled to open in October of 1998. This meant that the new treatment plant had to be in operation by September of 1998, and it gave Ullensaker municipality, who was the responsible party, limited time for planning, purchasing and construction.

The treatment plant was to be located very close to the airport. It had to be completely covered, partly because it is a tradition in Norway and provides a very good working environment for the operators (annoying odors, noise and aerosols can easily be eliminated), and partly because open basins will attract birds and create a hazard for the airplanes. The treatment plant buildings had to have the same architectural design as the new airport buildings.

Spent aircraft de-icing fluid is a major pollution problem at airports operating in areas with a severe winter climate. Currently monopropylene glycol (MPG) is used for de-icing, and during the planning process tests showed that it would be feasible to use runoff from the de-icing platforms at the airport as an external carbon source for denitrification at the new wastewater treatment plant (Rusten et al., 1996).

By January 1996, Ullensaker municipality asked for competitive turnkey bids for the new wastewater treatment plant. Separate bids for respectively a liquid treatment process and a sludge treatment process were required. Based on the bids, Ullensaker municipality selected a process package for liquid treatment offered by Kaldnes Miljøteknologi.

Industrial Plants

Due to the good results the Moving Bed™ biofilm process achieved removing BOD from high strength wastewater the process has been tested and implemented in many different industries. One of the first areas we started to work with was the Pulp &

Paper Industry. We did see that untreated wastewater from this industry caused serious pollution problems at several locations.

Conventional suspended growth systems needed large volumes and were hampered by sludge bulking problems. By using the Moving Bed™ biofilm technology the volumes became significantly smaller and washout of the reactor biomass did not occur.

Today Kaldnes have experience of treating wastewater from several types of industry and it has proven to be a very good technology for industrial plants as it is stable and easy to operate.

Further development of the process and the future

Kaldnes Miljøteknologi AS has over the last 10 - 15 years been able to take what was an idea, develop it and last but not least been able to turn it into a commercial success. It has been a rapid development, but we can by now means rest on the laurels of success. We will continue to develop the technology to make it even more competitive in the market.

The process has proven to work in municipal wastewater treatment as well as almost all kinds of different types of industries. It is very well suited for upgrades of existing treatment plants that needs to expand or to meet new standards. The process can replace existing processes or be used in combination with existing processes. It has also proven to be very well positioned for treatment of water within fish farming, one of the fastest growing industries in many parts of the world.

Even though wastewater treatment plants have been built all over the world, the demand for wastewater treatment will increase dramatically for the following reasons:

- There are still major areas of the world where wastewater treatment is not fully (or even partially) implemented. This is mainly in underdeveloped (for instance in Africa) and in developing countries (for instance China, South East Asia, South America). In order to develop and prevent epidemics, these countries will have a need to treat wastewater in the future.

- There are many large cities around the world, located at the ocean front, that discharge their wastewater untreated or only primary treated directly to the sea. These cities that represents an enormous amount of wastewater, will have to treat their wastewater better because of local pollution as well as international declarations on pollution prevention of the oceans.

- In many developed countries (for instance in Eastern Europe and South America) implementation of wastewater treatment has began, but it is still not up to the

standards set by the authorities. Nutrient removal will still have to be implemented many places.

- There is a growing focus on "sustainable urban water systems". Many are pointing at more decentralised solutions as being more "sustainable". This will require small treatment plants with high removal efficiencies.

- In many countries there is a scarcity of water for different uses. This is even the case for some European countries. Many areas will be dependent on water reuse in order to balance the water needs. Water reuse is the key to maintaining progress for humanity in many areas of the world and wastewater treatment is a key element in wastewater reuse.

- Wastewater is a resource. It contains the water itself (for irrigation), the heat of the water (for heating purposes), carbon (that can be used for energy production via biogas or heat recovery from incineration) and nutrients (for fertilising purposes). Some of the resources of wastewater are more important in some areas than others, but eventually all of them might have to be recycled in the future. Wastewater treatment is the process by which the resources will be separated from each other and could be utilised again.

- Sludge handling is one of the biggest challenges that we face in the area of wastewater treatment. One may look at wastewater sludge as a waste that must be disposed of, or as a raw material from which valuable resources may be recycled. Whatever attitude is taken, the handling of sludge from wastewater treatment plants will require new ideas and technical solutions.

Kaldnes Miljøteknologi AS will continue to further develop the principles of the Kaldnes Moving Bed™ biofilm process to be even more compact and robust and to expand its use into new areas and markets. In this way we will also be very well positioned to meet those areas of concern that can be expected to be most influential on the development of wastewater treatment for the future.

Although the process have been used with success world-wide for years already we still feel that the need for further research is as important as it was 10 years ago. We are competing in a competitive market and the process is being copied. The only way we can stay ahead of competition is by being the best on the market when it comes to this technology.

Kaldnes Miljøteknologi AS will continue to base its efforts of returning water safely back to nature on natures own premises.