CEWIC - Center of Expertise in the Water Industry Cluster – Eco Forum, Oulu

An analysis of global water purification trends –

Future water treatment technologies and methods

scandinavian environmental technology a.s.

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Foreword

Eco Forum, Oulu has engaged SET AS (prof. Hallvard Ødegaard) to make a proposal or structure of an environmental research unit as part of the top-level research network included in CEWIC (Centre of Expertise in the Water Industry Cluster).

The task is described in the quality offer from Hallvard Ødegaard to Eco Forum dated 22.06.2006 including 3 elements:

1. To identify the global water purification technology trends and themes that are relevant to industrial and public sector needs and have good business potential, as well as future purification technologies and methods

2. To determine the strategic themes and concepts for water research. Special emphasis should be placed on local opportunities and strengths in the Oulu region and any necessary global partners (companies and research organizations) to complement the innovation system, and on the financing options for such systems.

   Any synergy benefits that can be achieved through cooperation with leading international water purification research units and local operators (e.g. University of Oulu, Oulu Polytechnic and the Technical Research Centre of Finland VTT) should be taken into consideration

3. Make recommendations for creating the research unit organization: description of the network, the roles of different parties, enterpriser resource planning and any proposals for the post of research professor

This report is the response on the first of these tasks.

It has been found useful to give an overview of the different markets with respect to region first and thereafter to go through the technologies mostly used for the different application markets (drinking water, municipal wastewater, industrial process water etc) as well as the technology trends of these markets. Finally it is summarized which technologies that may be expected to be dominating in the future. This is then used as a basis for recommendations with respect to which technologies that one should prioritize to focus on.

It is emphasized that the views expressed in this report are those of the author. It has not been the intention to bring a balanced view based on sources from elsewhere. Therefore literature references are not used.

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Content

Summary and recommendations

This report gives an overview of the trends with respect to the development of different markets in need of water treatment as well as the water treatment technology trends in these markets.

Based on this an evaluation is carried out and some recommendations are given with respect to what areas of research that a water treatment research unit under CEWIC should focus on. These are:

1. Oxidation and disinfection processes because they are increasingly being taken into use for both drinking water, municipal wastewater, reclaimed wastewater for reuse, industrial water and even for sludge treatment:
    - for disinfection purposes
    - for oxidation of organic micro pollutants (drinking water, municipal wastewater, reclaimed water for reuse)
    - for pre-treatment of water containing heavily biodegradable organic matter before biological treatment
    - for sludge production minimization

2. Membrane filtration processes because they are becoming increasingly important for all applications which makes membrane filtration a method for the future both for:
    - particle (including pathogen) removal – micro- and ultrafiltration
    - large organic molecules (like NOM) removal – nanofiltration
    - desalination – reverse osmosis

3. Anaerobic biological processes because :
    - minimization of energy consumption will play a decisive role in the future wastewater treatment plants and processes that can produce energy instead of consuming it will be favoured
    - new reactor designs are needed in order to be able to capture methane and make use of the energy is needed, especially for reactors used for municipal wastewater treatment
    - in the developing countries market where a vast majority of people are yet not connected to treatment plants, the wastewater concentration will be more concentrated than in the developed world and the wastewater temperature higher. In this situation the anaerobic processes have an advantage

4. Biofilm processes because they are increasingly being used for biological treatment:
    - in order to save space in municipal wastewater and industrial process water treatment
    - for anaerobic treatment, primarily has utilized suspended biomass formerly.
    - in drinking water treatment – often in combination with chemical oxidation processes

5. Instrumentation, control and automation of water treatment processes because:
    - the more advanced the treatment technologies are and the stricter the water standards are becoming, the more important it is to have optimized instrumentation and control in the treatment plants.

In a second report of this project, we shall analyse the local competences and opportunities and final recommendations will be given based on both general water treatment technology trends and local competences and opportunities in Oulu.

Introduction - The need for water treatment

The main drivers for the need of water treatment technologies are:

1. The legislation for drinking water quality (i.e. EU Drinking water directive)
2. The legislation for wastewater pollutions control (i.e. EU Wastewater directive)
3. The need for freshwater supply

Historically the need for water treatment was created in order to ensure safeguarding of drinking water of acceptable quality to people by treatment of natural water sources. Later focus came on the abatement of pollution, partly to safeguard the drinking water supply need, but in most cases to safeguard the ecology of the natural waters. Over the years, the difference between these two has diminished in many regions of the world since the water courses are used both for wastewater discharges and for abstraction of water for water supply to people, agriculture and industry. The main global driver today is hence to secure enough freshwater for the growing population of the earth.

The world's water crisis is really not a global crisis, however, but a crisis of regions and cities. Throughout the world, migration of people causes villages of some few hundreds of inhabitants to blow up to cities of hundreds of thousands. Cities transform to mega-cities at a frightening high rate. As a result, local demand of food and water sky rockets, and so does generation of wastes including wastewater. From ancient times, development and implementation of water supply and sanitation technology was triggered by growth of metropolitan areas. But never before, the rate of growth was as enormously quick as it is today. Our classical methods of water supply and sanitation are based on a relatively slow path of city growth. The current situation is different, however, and needs innovative approaches, both with respect to technology and with respect to financing, legislation and public readiness to accept unacquainted rules of conduct.

There are big differences in the water situation throughout the world and the water treatment focuser are different from one market to the other. The reports from WHO on water and sanitation give an excellent overview of the situation and we shall not go into that here.

We shall discuss water treatment technology trends for different water applications water supply (drinking water), municipal wastewater discharge and industrial process water. This is, however, closely linked to the different markets and therefore it has been useful to characterise the different markets first.

Trends in the different regional and development markets

An analysis of the markets may be done based on regions or human development or based on application of the water (i.e. drinking water, municipal wastewater and industrial process water treatment). Is has been found most useful to discuss in this report along the line of the application, but it may be convenient first to outline the markets from a human development point of view in order to emphasise some regional as well as development level differences.

It is a fact that the need for water treatment technology varies quite a bit with the regional markets that are to be served as well as the human development in these markets. It has been found useful to divide the overview in:

1. The home (Scandinavian) market
2. The European market
3. The market of the developed countries outside Europe
4. The newly industrialized countries market
5. The developing countries market

As the challenges increases when going from the "home" market to the global market, we shall start discussing the "home" market. The markets shall be discussed from the point of view of drinking water treatment, municipal wastewater treatment as well as industrial process water treatment, but in this introductory overview of the markets it will reach too far discuss all the different industries. Only short remarks to dominating industries for the different markets will be given.

It is emphasised that this author has not intended here to make an in-depth market analysis – only to give en overview from a personal viewpoint, in order to put in perspective the discussion of the water treatment technologies later in the report.

The "home" (Scandinavian) market

The "home" market, whether this is the Finnish or the broader Scandinavian market, is characterized by:

Drinking water

1. There is more than enough water available, which means that one can avoid using polluted water sources for drinking water production
2. The quality of raw water for drinking water production is more governed by natural processes (i.e. humic substances, hardness, iron and manganese etc) than by pollution
3. Ensuring hygienically safe water by creating a hygienic multi-barrier system (including disinfection) is in the forefront of attention
4. The most frequent water quality problems that create a need for treatment technologies are :
    - Humic substances (Finland, Sweden and Norway)
    - Iron and manganese
    - Turbidity
    - Microbial pollution (pathogens)

In addition there are, of course, a wide variety of local problems, in Finland for instance, arsenic and radio-nucleid problems

Municipal wastewater

1. The "driver" for wastewater treatment is primarily the standards set up by the EU Wastewater Directive which is basically oriented towards preventing pollution (sapprobiation and eutrophication) in receiving waters. Only in few cases the effluent quality aimed at is determined by other matters, such as prevention of drinking water source, bathing directive etc
2. Approximately 90 % removal of SS, BOD and Phosphorous removal is required for municipal effluent discharges all over Scandinavia (except for discharge to the Western coastline of Norway) and most of the treatment plants (except those discharging to the Norwegian coastline) have also effluent standard regarding nitrogen (ca 70 % removal). Very few plants have specific effluent standards that go beyond the normal parameters (SS, BOD/COD, P and N), for instance for hygienic parameters, heavy metals, organic micropollutants etc.
3. The level of wastewater treatment is high, both with respect to how much of the wastewater that is treated and how strict the standards are. Most of the plants have a stricter effluent standard on P than the one required by the EU wastewater directive.
4. The sludge disposal situation is quite different in the Scandinavian countries. Norway has chosen a strategy in which the sludge is to be used on land after extensive treatment, while Denmark and Sweden have forbidden the use of sludge on land and gone for incineration as the final sludge disposal solution.
5. Compared to the other markets, there are relatively many small wastewater treatment plants (< 2000 pe) in Scandinavia and because the population density is low in many parts of Scandinavia, there is a substantial markets for "mini" (on-site) treatment plants for farms, recreation houses etc. This market seems to go in two different directions :
   a. Nature based systems
   b. Technology based systems
6. Upgrading of wastewater treatment plant is becoming increasingly important since most of the treatment plants in this market were built in the 60'ies and 70'ies.
7. There is an increasing awareness of the need to treat storm water. This a "new" market that seem to go in two different directions :
   a. Nature based systems
   b. Technology based systems

Industrial process water

Dominant industries in the "home" market are:

1. <u>Pulp and paper industry</u> where the main challenge is to control discharge of organic matter as well as organic micropollutants (organic chlorine compound)
2. <u>Food industries</u> where also organic matter removal as well as nutrients are in focus when it comes to discharges. In this industry the quality of the water supply is very important and hardly other qualities than drinking water quality is used. A special case is the fish farming industry (particularly in Norway) that need treatment of relatively dilute water and where ammonium removal becomes essential in recycling plants.
3. <u>Oil and gas industry</u> that needs to remove a wide variety of hydrocarbons. A special case (also especially in Norway) is the treatment of produced water (water that comes up together with oil and gas for the seabed formation). The are new ambitions for produced water treatment from before only being related to oil separation to include

soluble organic compounds in the future – a development that require new water treatment technologies.

4. Metal surface industries are found everywhere. The small industries often discharge to the municipal sewers and represent a significant portion of the heavy metal content of the combined wastewater if not treated properly at the industrial plant
5. Chemical industries including the pharmaceutical industry are also well represented in the “home” market
6. The mining industry was a very central one in the “home” market earlier, but its importance has decreased. Nevertheless the pollution caused by this industry (mine leachate) is still a major problem many places.

The European market

Scandinavia is part of Europe and the drivers of the European markets are to a large extent similar to that of the Scandinavian market, but parts of Europe are facing a quite different situation than Scandinavia with respect to availability of freshwater.

Drinking water

1. There is an increasing area in Europe (parts of Spain, Italy, UK etc) where water stress in terms of water consumption volume divide by potentially available water volume) is becoming a serious problem.
2. The quality of raw water for drinking water production is in many cases quite bad and more governed by pollution than by natural processes than by pollution. This is the case for surface water (polluted by municipal, industrial and agricultural discharges) as well as ground water (primarily polluted by agriculture, i.e. nitrated and pesticides)
3. Ensuring hygienically safe water by creating a hygienic multi-barrier system (including disinfection) is also in Europe in the forefront of attention and focus is on persistent micro-organisms like *Cryptosporidium* and *Giardia.*
4. The type of water quality problems that are encountered throughout Europe are abundant and include the natural occurring matter (humic substances, iron and manganese, calcium and magnesium etc) as well as man-made pollutants such as pesticides, pharmaceuticals, body care products, endocrine disrupting compounds, waste of anthropogenic nanomaterials, genes (transgenics, resistant to antibiotics), prions (infectious proteins) etc.
5. In this market there is also a strong emphasis on removal of “priority pollutants” and an increasing interest in adsorption and oxidation/biofiltration for this purpose

Municipal wastewater

1. As the European market includes the “home market”, the legislation that is the main driver for municipal wastewater treatment is the same as described above (EU Wastewater Directive). It seems, however, that the different European countries comply with the wastewater directives to varying degree, and that national standards often come before the EU directive standard. The southern countries are less amenable to comply with the EU Directive but also countries like UK seem to rely mostly on national standards. As an example, discharges to the Thames estuary (the big discharges from London) do not have nutrient removal at this time.
2. The quality of the treatment plants in central Europe (UK, The Netherlands, Germany, Austria, Switzerland etc) are very good and generally on the level of that of the “home” market, while the quality of the treatment plants in the southern and eastern European countries are at a lower level. Especially in the new, eastern EU-countries

as well as other East-European countries, the wastewater treatment situation, municipal as well as industrial is very bad.

3. There are still a large number of plants in Europe that do not remove nutrients, phosphorous as well as nitrogen. Those that are complying with the EU Municipal Wastewater Directive have often less strict standard that one is used to in the "home market" as a consequence of the fact that the Scandinavian countries have stricter standards normally than the EU-directive demands.
4. The sludge disposal situation is problematic in many of the European countries. There is a clear tendency in some countries (Germany, Switzerland, The Netherlands, Austria etc) to go away from land-use of sludge and to in the direction of incineration.
5. There seem to be an increasing market for "mini" (on-site) treatment plants all over Europe, probably as a result of stricter national legislation of the discharges under 2000 pe (the lower limit for the EU wastewater directive)
6. There is an increasing focus on decentralized sanitation solution, including source separation (urine, grey water, black water) but this movement (also sometimes referred to as "ecological sanitation" seems to be on the retreat after many systems seem to have failed.
7. The upgrading of existing plants is growing very fast in this market as in the "home" market
8. There is, as in Scandinavia, an increasing awareness of the need to treat storm water.

Industrial process water

The same industries that were mentioned for the "home" market are also important on the European market. In addition we shall especially mention the leather (tanning) industry that is very important in the south of Europe (i.e. Italy, Turkey etc)

The developed countries (outside Europe) market

The situation in the global established market (the developed countries) is to a large extent similar to that of Europe. Some regional differences shall be mentioned here.

Drinking water

1. In USA there is a very strong focus on the inactivation of parasitic protozoa (*Giardia* and *Cryptosporidium*). Special new legislation targeting inactivation of Cryptosporidium is in place and this has a great impact of the technologies to be chosen for drinking water treatment in USA. It means for instance that UV-disinfection and ozone treatment will have an increased market share in disinfection technologies in USA. In Japan it seems that one is more concerned about virus and virus control is to a larger extent determining the technology development there.
2. In this market there is also a strong emphasis on removal of "priority pollutants" and an increasing interest in adsorption and oxidation/biofiltration for this purpose
3. In several countries in this market the surface water availability is not good and eutrophic lakes are often used as water source. This means that algae, algal toxins as well as taste and odour caused by algae are often representing a challenge.
4. There is an increased use of advanced particle separation technologies, like flotation and a an increasing number of membrane filtration plants are being installed
5. In some regions of this market, particularly in Australia, Eastern USA, South Africa, Middle East and some Far East countries (for instance Singapore), there is because of water shortage, an increasing interest in desalination and for producing water for supply from wastewater reclamation.

Municipal wastewater

Also with respect to municipal wastewater, the situation in this market is similar to the one in Europe. Some regional differences shall be mentioned, however.

1. It seems as if there is in many countries of this market less strict legislation, especially when discharging to seawater. In most cases only secondary treatment is required and in some cases primary treatment is accepted
2. On the other hand, the same market has several examples of water reclamation and reuse. In these cases the municipal wastewater treatment is advanced.
3. Biological treatment through activated sludge is still the dominating wastewater treatment technology and there is an increased use of biofilm systems.
4. Also in this in this market upgrading of wastewater treatment is increasingly demanded
5. Membrane bioreactors are taken into use more and more in this market, especially in those circumstances were water reclamation from wastewater has be implemented for water reuse purposes
6. There does not seem to be so strong tendency away from land use in this market as in the European. Land use of sludge is (including composting) is quite common in USA, Canada and Australia. In Japan most of the sludge is incinerated, but an increasingly larger extent the sludge is used as additives in building materials (Portland cement, expanded clay aggregates, bricks etc).

Industrial process water

All the industries mentioned above for the "home" market and the European market are also present in the developed countries (outside Europe) market.

The newly industrialized countries markets

This market includes countries like China, India, Turkey, the Gulf States, South Africa, some far East countries, Mexico and Brazil.

Many of these states are in shortage of water and need water treatment technologies in place in order to develop the society, the agriculture and the industry. Water conflicts with respect to use of water, is often encountered.

The treatment of water for supply has priority and often the extent of municipal wastewater treatment is quite low or non-existing. This leads to conflicts and poor hygienic situation. In Mexico, for instance, it is quite common to use non-treated or poorly treated municipal wastewater for irrigation.

It seems as if the industrial treatment is more advanced than the municipal one, probably because international companies often bring with them their own treatment tradition regardless of the country within which they operate. There are, of course many exceptions to this.

These countries have often a quite high level of education or competence in the water treatment area, and the reason for the low standard in wastewater treatment is more because of a lack of capital than lack of competence.

China is, of course, a very special market that should be dealt with separately. In short, the water quality situation in China(especially in the North) is very bad in many places, both because of lack of fresh water and because of negligence over several decades when it comes to municipal and industrial treatment of wastewater. As a very large portion of the water supply is based on surface water (rivers as there are relatively few lakes), the raw water for water supply is heavily influenced by wastewater discharges. It is fair to say the development of China to a very large extent depends on the countries ability to solve the water pollution challenges and hence, the market for water treatment technologies is enormous.

In India the situation is similar to that of China in many respects but the general situation seems to be less dramatic especially with regards to industrial pollution.

In the Gulf states, the challenge is mainly the availability of water which has resulted in many desalination plants being installed. Reuse of wastewater is also common and it is interesting that there are several villages/small towns where there is no wastewater system, but where the wastewater is trucked to wastewater treatment plants, treated and trucked back to the village for reuse.

The developing countries market

This market mainly consists of countries with low human development, mainly countries on the African continent. The water treatment market in these countries is low not because of lack of water quality problems but because of lack of governance and investment capital.

It is in this market, where water and sanitation has to be built up from scratch, that totally new ideas (i.e. on source separation for sanitation systems), can be implemented. The problem is only that it is difficult to get acceptance in these countries for a water and sanitation standard that is different from what is in these countries is considerer high (i.e. that of the developed world).

There is no doubt that the most important measure in order to safeguard water hygiene in the developing countries, is to ensure good sanitation systems. Sanitation is “more important” than water supply even though the developing countries are focusing far more on water supply issues.

The drinking water treatment market

The foundation for the drinking water treatment market is the needs for:

- Hygienically safe water – a water without pathogens
    - Parasites (Cryptosporidium, Giardia etc)
    - Bacteria (E.Coli, Salmonella, etc)
    - Viruses (Adenovirus, Coxackie virus, etc)
- A water without matter that can cause threat to mans health (other than pathogens)
    - Organic micropollutants (pesticides, pharmaceuticals, halogenated organic compounds, algae toxins etc)
    - Inorganic micropollutants (heavy metals, arsenic etc)
    - Other (nitrate, radon, etc)
- A water containing compounds causing problems for the use of the water
    - Salts (chlorides, sulphates, nitrates etc)
    - Metals (iron, manganese etc)
- A water that looks and tastes good – without colour, taste and odour
    - Colour (Humic substances, dyes from wastewater outlets etc)
    - Taste (MIB, Geosmin, phenols etc)
    - Odour (algae products etc)

There are several water treatment processes that can be used to deal with these challenges and below we shall first present the various unit processes mostly used and thereafter focus on the trends in the global markets.

Drinking water treatment technologies

Production of hygienically safe water
Basically the safeguarding of hygienically safe water can be done in two ways:

1. Disinfection - that inactivates pathogens in the water
2. Particle separation – that removes the pathogens from the water as particles

There is a clear trend that the water supply shall be built on the principle of "multiple hygienic barriers". This is based on the concept of risk and security, if one barrier fails there shall always be another that can cope with the situation and prevent pathogens to reach the consumer.

It is important that there has to be more than one hygienic barrier against all type of pathogens (in fact also against other health threatening compounds). The barriers can be built into the water shed through restrictions in activity here (bathing ban, grazing ban etc), or in the water treatment plant. Several incidents over that last years have, however, made one realize that the barrier created in the water shed is often of little value and therefore the multiple hygienic barriers have to be built into the water treatment system.

The principle of multiple hygienic barriers has resulted in more focus on pathogen inactivation processes and hence the market for such processes has risen considerably over the last years. While focus earlier has been mainly on bacteria, the major focus now and in the years to come is on parasites and viruses. There have been several epidemics with parasites lately. One example is the very serious Giardia-epidemic that was experienced in Bergen, Norway, in the autumn of 2004.

The parasites are much more resistant than bacteria and viruses to various form of disinfection, especially the traditional form of chlorination, and therefore new types of disinfection equipment is asked for. Parasites are, however, relatively large organisms (about 3-10 µm, against about 0,1 - 1 µm for bacteria and < 0,1 µm for viruses). This means that parasites are, relatively speaking, easier to remove by particle separation than bacteria and viruses and therefore the focus on particle separation for pathogens removal has also increased. Particle separation processes are, of course, also used for removal of other types of particles and in the following we shall discuss disinfection and particle removal separately.

Disinfection

Disinfection is becoming increasingly important because:

a) The multihygienic barrier concept has been introduced in the law rule
b) Control of growth in water systems (industry, swimming pools and spas, ships etc) is of increasing importance.

The main methods for disinfection are:

c) Chlorination
d) Ozonation
e) UV-irradiation

Chlorination. Chlorination is the dominating disinfection on the world market. It is cheap and effective against bacteria and viruses. Its popularity is declining, however, because chlorine is ineffective against parasites, especially Cryptosporidium. Chlorination has also another major disadvantage, in that health degrading (cancer producing) chlorinated organic by-products (trihalomethanes, chlorinated acetic acids etc) will be produced when chlorine is added to humic substance containing waters. When used on polluted waters, a relatively high dosage of chlorine has to be used in order to safeguard the disinfection effectiveness. This may also result in chlorine odour and taste.

Because of these shortcomings, many countries are abandoning chlorine as the preferred disinfection method, some (The Netherlands for instance) are even forbidding chlorine to be used. Chlorine is still, however, the major disinfection method in the world, even though it seems more and more to the "poor country's" method.

In Norway chlorination is still a dominant disinfection method, but there are now more disinfection plants based on UV-disinfection than on chlorination. The amount of water disinfected with chlorine is, however, larger that that disinfected by UV, even though this picture will change when Oslo and Bergen open their new treatment plants that are equipped with UV as well as chlorine in order to ensure a multiple barrier effect.

When disinfecting with chlorine in Norway, relatively low dosages (< 1 mg Cl_2/l) are used so that the drawbacks of chlorinated bi-products formation and taste and odour are not considered to be a major problem in our country.

Ozonation. Ozone is strong oxidant and therefore also a good disinfectant. It has been only moderately used in Scandinavia but it seems that this is changing, partly due to the use of ozone as an oxidant for other purposes than disinfection (humic substance removal, removal of organic micropollutants (pesticides, pharmaceuticals, endocrine disruptors etc).

The method has been used since the turn of the century was until around 20 years ago mainly used in Central Europe (France, Be-Ne-Lux, Switzerland, Germany etc). Lately its popularity has spread quickly too many parts of the world (USA, Middle East, Japan, South Korea, Kina etc). The reason for this was partly its oxidation capability, which could efficiently be used in tackling organic micropollutants like pesticides, pharmaceuticals etc (see later) and partly its disinfection capability. It was found far more efficient against viruses and parasites than chlorine.

Ozone is produced on site by an ozone generator. The ozone technology also requires an ozone injection unit, an ozone gas transfer unit (contact tank) and an ozone reaction tank. In the market there are several producers of ozone generators, less producers for equipment for the other parts of the ozone technology.

The interest in ozonation/biofiltration has increased since one in Germany realised that there was biological activity in the activated carbon filters that were placed downstream ozonation and used primarily for organic matter removal from river water. The idea has been picked up, especially in Norway, for the treatment of coloured humic water - a frequent encountered problem in Scandinavian water supplies. This method is based on the fact that ozone is able to oxidize the coloured humic substances by which the colour disappears. The oxidation products are however more biodegradable that the original humics and can cause growth in the water supply pipes. Therefore the ozonation has to be followed by biofiltration that takes out the growth potential by biodegradation. This method will be discussed later. The reason for mentioning it as a disinfection method is the fact that the ozone dose needed is relatively high, resulting in a very efficient inactivation of bacteria, viruses as well as parasites.

Ozonation does not, as chlorine, cause formation of halogenated organic bi-products that are carcinogenic, but it may, in water with high bromide concentration, form bromate that is also carcinogenic. The bromate formation is dependent on several factors concerning the characteristics of the water (calcium content, alkalinity, pH, temperature etc) and it has been demonstrated in Norwegian ozon/biofiltration plants that the bromate formation has been low and below the Norwegian bromate standard (5 µg/l) which is the strictest standard in the world while (WHO recommends 10µg/l).

UV - irradiation. UV-irradiation has been used for disinfection sine the 1930'ies, but is has, until the last 5-10 years, mostly been used in small waterworks. Norway has been a leading country in the use of this disinfection method the most and there are at this time more disinfections plants based on UV in Norway that based on chlorination.

Lately, however, UV has been taken into use also in large plants (Oslo, Stockholm, Helsinki, and also outside Scandinavia, i.e. in the US, the method is becoming popular. The reason for the popularity of UV, despite the fact that is probably is the most costly of the disinfection methods, is its effectiveness for inactivation of parasites.

UV-irradiation seems to a lesser extent to have been preferred in Asia. The Japanese, for instance, seems to be still sceptical to the efficiency for UV for virus disinfection. The fastest growing market for UV is probably USA because of their new regulations on Cryptosporidium.

Removal of colloids and particles – particle separation

Besides disinfection, the removal of colloids and particles is probably the most frequently objective of drinking water treatment plants around the world. Under colloids we may also include humic substances (or natural organic matter, NOM) that are long-chained, negatively charged organic molecules with characteristics similar to true colloids. We shall however deal with removal of NOM later.

The standard method for colloid removal has been coagulation followed by particle removal that in a conventional plant includes flocculation and floc separation through sedimentation or flotation followed by granular media (sand) filtration.

The water treatment technology elements are such a particle removal treatment scheme, which is the most common in the world, consists of: the coagulant (and possibly flocculant), the mixing of coagulant/flocculant and water, flocculation, the coarse floc separation (sedimentation or flotation) and the fine floc separation (through granular media or membrane filtration).

<u>Coagulants and flocculants</u>

Coagulants are used to destabilise colloids so that they be aggregated (flocculated) to separable flocs. Traditionally salts of aluminium or iron have been used as coagulants (aluminium- and iron sulphate or – chloride). Over the last 10-15 years more efficient polymerized aluminium and iron compounds (i.e. polyaluminiumchloride etc) has been developed and is now dominating in some markets, for instance the Scandinavian.

There is now also focus on including silica in the polymeric coagulant (i.e. polysilicate-iron/aluminium coagulants) in order to improve separability. R&D on this is particularly going on in Japan and China.

Flocculants are often used to enhance flocculation. They are normally synthetically made, organic compounds that may be made cationic, anionic or non-ionic. Because the fear that monomers of polymers may have an adverse influence on health there are restrictions with regard to which polymers that can be used in drinking water treatment and most countries have an approval system for chemicals to be used in the drinking water preparation. Nevertheless it seems that the use of flocculants in drinking water treatment is increasing, as a result of increased production of more high rate separation systems (sedimentation/flotation/filtration) being used.

In Scandinavia and Europe, the biggest producer of coagulants is Kemira with production and offices several places in Scandinavia (main offices in Helsingborg, Sweden). There are, however, a great number of flocculant producers.

<u>Coarse floc separation – sedimentation and flotation</u>

Sedimentation and flotation are very central floc separation processes in drinking water as well as wastewater treatment – maybe even more so in wastewater than in drinking water. Sedimentation tanks constitutes often a very large portion of the total area needed for a treatment plant, and since space saving is a trend driven by the struggle for cost reduction, traditional settling tanks are being used less and less – especially in the drinking water field. Lamella settlers and flotation are taking over.

Some new lamella settling and flotation technologies have emerged over the years but it is quite certain that there is more to be done in this area, and it is our estimate that the focus of enhanced capacity will boost the development of new types of coarse separators in the years to come.

Fine floc separation – filtration

The traditional technology for fine floc separation after coagulation is granular media (primarily sand) filtration. The technology of granular media filtration has developed considerably over the years and includes, multimedia filters, continuous filters, upflow- and downflow filters etc. It is not likely that granular media filtration design will develop much further, but on the other hand there is a great potential in optimising operation of coagulation/filtration systems.

One of the reasons for the "stagnation" in granular media filtration technology is the emergence of the membrane filtration technology. This will be dealt with separately later. When membrane filtration is used for particle separation, micro- and ultrafiltration membranes are normally being used.

At this time, it is not quite clear where the development of fine floc separation will go. Many designers still think that granular media filtration will be the preferred solution, while others are convinced that membrane filtration will take over and dominate also in this application area.

Nevertheless it is so that membrane filtration technology will be very central in the years to come and definitely an area that the environmental research unit under CEWIC should focus on.

Removal of natural organic matter (NOM)

Natural organic matter (NOM) or humic substances, an expression more used in Norway, represents a problem because of primarily two reasons:

1. It gives the water an unpleasant colour
2. It reacts with chlorine when added, to form halogenated organic compounds injurious to health (carcinogenic)

There are also other problems with NOM in drinking water, but these are the most serious ones.

Humic substances may be removed from water by:

- Coagulation followed by floc separation in the same manner as colloids (se above)
- Membrane separation – in which case nanofiltration membranes has to be used
- Adsorption on activated carbon – not very common because of rapid exhaustion of the carbon capacity
- Sorption on macroporous ion exchangers
- Oxidation (i.e. ozonation)/biofiltration

NOM is a very common problem in Scandinavia and in Finland in particular and all the methods mentioned above (except for adsorption on activated carbon as the sole method) are being used.

On a global basis *coagulation/floc separation* is probably the most common method for NOM removal (possibly combined with activated carbon filtration for polishing). The trend here is the same as that for colloid separation mentioned above; membrane filtration (ultra and microfiltration) seems to take over in plants were granular medium filtration have been dominating.

Nanofiltration of humic substances has become very popular in Norway (> 100 plants) because :

- the particle concentration (turbidity) is normally low when the raw water source is a lake. Otherwise the turbidity would limit the process because of membrane fouling
- the raw water sources are abundant which means that it is acceptable to waste about 30 % of the raw water treated – decisive for the economy of the method

The two points mentioned are decisive for whether or not nanofiltration is suitable in a given case. As these conditions are not so easy to find elsewhere, nanofiltation is to a very large extent "a Norwegian method" even though a few plants exist in Sweden and Finland as well as Scotland as well.

More common globally than using nanofiltration only for the removal of NOM, is the combination of coagulation and ultra-/microfiltration (see above).

Ion exchange is only used at small plants and has severe limitations because of the need for dealing with the regenerate.

Ozonation/biofiltration has gained a lot of popularity especially in Norway. Also on the global market the interest in biological drinking water treatment is increasing for instance for removal of synthetic organic compounds)

Removal of synthetically made organic matter

The synthetically made organic compounds that can be found in natural raw waters stems from polluting discharges from cities and municipalities, from industries and from agriculture. Their origin may be pesticides, solvents, pharmaceuticals, personal care products etc and they are representing an increasing health concern.

The traditional method for separating such substances has been adsorption on activated carbon or other sorption media. The adsorbtivity vary however, from one compound to the other and other technologies are now being focused for the same purpose, especially processes based on chemical oxidation and biofiltration. This is principally the same concept as mentioned above for removal of natural organic material (NOM).

For this reason developments have been done in the area of "advanced oxidation processes" that combines various oxidation processes. At this time the most common (AOP's) are those that combines ozon with another oxidant , i.e. O_3/H_2O_2 and O_3/UV. The ozon-based processes are efficient with respect to oxidation of organic micropollutants and because of the relatively high oxidant dosage they are also very efficient disinfection processes. However, ozon-based processes have the draw back for potentially creating too high bromate concentration as an oxidation by-product in bromide containing waters. Therefore more focus has been given to hydrogen-peroxide based methods, i.e. Fe(II) /H_2O_2 (Fentons reagent) and UV/ H_2O_2.

In drinking water treatment use, it seems that the use of UV/ H_2O_2 has been developed the furthest. This process is being used at Andijk Waterworks in The Netherlands after a long and extensive research and development period.

There seems to be a particular great interest in the research community into photocatalysis. At this moment, the general opinion seems to be that photocatalysis will have to become considerably cheaper before it will be used on a large scale in water and wastewater treatment. But there seems undoubtedly to be an interesting potential in these processes.

Department of Hydraulic and Environmental Engineering at NTNU, Norway is currently carrying out a project under the EU IP project TECHNEAU in which advanced oxidation – biofiltration – membrane filtration (OBM) is being investigated for the purpose of controlling natural organic matter, synthetic organic matter as well as pathogens.

Removal of inorganic compounds
There are a large number of inorganic compounds that in actual cases need to be removed in raw water – some of which are naturally occurring compounds and some that are there as a result of pollution. We shall shortly comment on some of the most typical ones.

<u>Iron and manganese</u>
Iron and manganese are often occurring in the water as two valence ions (especially in groundwater or in anaerobic zones of lakes) that will be oxidized when coming in contact with oxygen and precipitate as iron-hydroxide and manganese-oxide. The method of removal is chemical oxidation resulting in precipitation, followed by particle separation of the precipitates.

In iron-removal air (oxygen) is often good enough as oxidant, but with manganese stronger oxidants, (i.e. ozone) is far more efficient.

<u>Arsenic</u>
Arsenic is increasingly recognised as a contaminant in groundwater resources. Severe problems are encountered in Bangladesh and other parts of the world, but many other countries have experienced problems with meeting the water quality standard after WHO in 1993 lowered the provisional guideline concentration from 50 μg/L to 10 μg/L. Arsenic can be removed from water by a range of treatment methods including chemical precipitation, sorption to a range of mineral and organic media, by membrane processes, etc. The problem with many of the actual processes is that they are too expensive for the people for which they are intended.

One of the most promising methods is to involve co-precipitation and adsorption to iron oxides. Rather small amounts of iron oxides can solve the problem and a new plant with biological iron precipitation followed by extremely good aeration by help of the creation of micro drops can solve a big part of the problem.

<u>Nitrates</u>
Too high concentrations of nitrate in drinking water may represent a health risk and nitrate needs therefore to be removed, especially in ground water polluted by nitrate rich fertilizers. Nitrate may be removed in two ways:

- By biological denitrification – mostly used in large plants
- By ion exchange – mostly used in small plants

Heavy metals

It is only in rare cases that the heavy metal concentration is so high in drinking water sources that special unit processes in the drinking water treatment plant has the be used for the removal of them. The main strategy is to prevent heavy metals to reach the raw water sources by strict wastewater treatment. If removal is needed, there are methods available, like precipitation and ion exchange.

Removal of sea salt - Desalination

As fresh water sources are becoming increasingly scarcer the use of desalination (i.e. production of fresh water from sea water) is becoming increasingly more used. This is the case in areas of the world where fresh water sources are limited.

Desalination is also used in situations where the provision of clean fresh water is very costly, like on oil platforms or islands far out at sea.

When reusing wastewater, salts also have to be removed, depending on the use of the reclaimed wastewater.

The technologies for desalination and salt removal are:

- Membrane filtration (reverse osmosis)
- Evaporation

Over the last years reverse osmosis has taken over the market for new plants more or less completely as a result of reduced costs – that are now in the order of 1 US$/$m^3$.
Very important for this is the energy use and systems with energy recovery are being favoured.

The challenges facing the reverse osmosis method are:

- Pretreatment technologies
- Brine handling technologies
- Intake facilities

In the area of pre-treatment is seems that membrane technology (in the form of micro filtration) will play an important role in the future. Regarding the brine handling problem, there is a trend that recovery of salt and other valuable resources is being considered. New plants today are often so large that the intake facilities play an important role for the total cost.

All estimates indicate that the desalination market will increase considerably (may be as much as 10-12 % per year) in the years to come.

The municipal wastewater treatment market

The foundation for the municipal wastewater treatment market is the need for:

- Preventing pollution of receiving waters in order to maintain a healthy ecology
- Preventing pollution of waters courses that are to be used for water supply

It is still so that about 50 % of the world's population does not have an acceptable sanitation situation and only about 10 % of the world population is connected to advanced wastewater treatment plants. It means that 900.000 persons have to be connected to new wastewater treatment plants every day in order to reach the UN millennium goal fore 2015 on sanitation! The global market for wastewater treatment is hence enormous.

The most important strategy for safeguarding sufficient clean freshwater in the world, is treating wastewater. This is definitely so in areas of water shortage, where reclaimed wastewater may be one of the absolute most important water sources, but also in areas of sufficient water, the same fresh water courses (rivers and lakes) that are used as water supply sources, are also used as recipients of wastewater (like Rhine, Mississippi, Yangtze, etc). The pollution of fresh water sources by wastewater is therefore the most significant one and therefore wastewater has to be treated well when discharged to fresh water sources.

Wastewater stems from municipal (cities, villages, single homes) as well as from industrial discharges from a great variety of different industries. The tradition in the municipal wastewater area is one of standardized methods based on fighting specific pollution effects (sapprobiation, eutrophication, etc) while the methods for treatment of industrial wastewater has traditionally been chosen based on the specific wastewater characteristics and the tradition of treatment in each industry.

All wastewater treatment creates wastewater sludge (or biosolids as some prefer to call it). The treatment and handling of the wastewater sludge is often as costly as treating the water itself. Therefore a lot of effort is presently devoted to developing technologies for sludge treatment and disposal.

A very important new market has emerged over the last 10-20 years, the water reclamation and reuse market. This market increases as a necessity to provide enough fresh water in areas with water scarcity. In many ways we can say that the reuse market is where the drinking water market and the wastewater market meet.

In the following we shall go through each of these markets, describe the market shortly and discuss the drivers and the trends of the markets.

Municipal wastewater treatment methods

The goal of municipal wastewater treatment has traditionally been fight against pollution that destroys the natural ecology of the water courses. This has been done by setting effluent standards on:

- Suspended solids – in order to avoid sludge deposits that cause aesthetic as well as odour and smell nuisances.
- Organic matter - in order to prevent sapprobiation (extensive growth of bacteria) and oxygen depletion in receiving water.

- Nutrients (phosphorous and nitrogen) - in order to prevent eutrophication (extensive algal growth caused by excessive fertilization) in the receiving water.

In some cases, the environmental authorities may set effluent standards on other parameter, for instance pathogens – in order to safeguard the hygienic quality of bathing waters or waters that are used for drinking water purposes. It is quite seldom that standards are set for heavy metals and organic micropollutants although these may be quite important when the receiving water is used also for water supply and when the sludge from wastewater treatment plant is to be used for agricultural purposes.

Municipal wastewater treatment has traditionally been divided in primary, secondary and tertiary treatment.

Primary treatment – removal for suspended particles, including solids (about 50 % suspended solids (SS) reduction) and suspended organic matter (about 20 % biological oxygen demand (BOD)-reduction).
Secondary treatment – removal of organic matter (BOD), suspended as well as soluble (70-90 % reduction).
Tertiary treatment – removal of nutrients (phosphorous (>90 %) and nitrogen (>70 %) as well as BOD (>95%)). Phosphorous is normally the most important nutrient to be removed in freshwater while nitrogen plays the most important role in ocean water.
Below is summarized what normally is achieved in terms of treatment efficiency with the various municipal wastewater treatment methods:

Typical treatment efficiencies achieved in municipal wastewater treatment

Method	**SS**	**BOD**	**P**	**N**	**Path.**	**HM**	**OMF**
Primary treatment							
Straining	40	20	10	5	10	10	10
Settling	50	30	15	15	25	25	20
Secondary treatment							
Chemical	90	80	90	20	99	80	80
Biological	90	90	30	20	90	60	80
Tertiary treatment							
Biol./Chem (with P-removal)	95	95	95	25	99,9	80	90
Biological (with N- and P-rem.)	95	95	80	70	99,9	80	90
Biol./Chem (with N- and P-rem.)	95	95	95	85	99,9	80	90

SS-suspended solids, BO5 - organic matter (as biological oxygen demand), P – phosphorous, N –nitrogen, Path- pathogens, HM – Heavy metals. OMF – organic micropollutants)

The effluent standards have traditionally been set for suspended solids (SS), organic matter (BOD), phosphorous (P) and nitrogen (P). In the table above, an <u>indication</u> of the removal expectancy of pathogens, heavy metals and organic micropollutants is also shown. It is demonstrated that there is a clear relationship between SS and these parameters, indicating that good removal of pathogens, heavy metals and organic micropollutants is very dependent upon good particle removal.

The reason for the high percentage removal of pathogens in secondary and tertiary treatment methods is due to the fact that the pathogens are present on extremely high numbers in wastewater, in the order of 10^6/l. After 99,9 % reduction there is still in the order of 10^3 left. In pathogens removal, therefore, it give little meaning to express percentage removals, but it is done here just as an indication that good wastewater removal also yields good pathogen removal

When discharging to receiving waters that is to be used for water supply, there is a trend therefore, that in addition to primary, secondary and tertiary treatment, the treatment plants also include treatment steps for advanced particle removal (filtration) and/or pathogen inactivation (disinfection).

Municipal wastewater treatment markets and effluent standards

Different markets require different treatment standards. In Europe, the standards are determined in the EU Wastewater directive where secondary treatment is the minimum level of treatment for urban discharges > 2000 pe to freshwater and > 10.000 pr to the ocean.

In Europe the standard is given relative to the sensitivity of the receiving waters. Generally speaking, the freshwater of the mainland Europe is defined as sensitive as well as the Baltic Sea, The North Sea and parts of the Mediterranean Ocean. Discharges to these receiving waters require normally tertiary treatment. Receiving outside this, to for instance the Atlantic Ocean and the Norwegian Ocean is defined as less sensitive and requires only secondary treatment. There is, under certain circumstances, also the possibility to give exception from the requirement of secondary treatment (which means that the standard in the exception case is primary treatment) when discharging to less sensitive waters. At this time it seems to be only Norwegian authorities that allow for this possibility of exception to be used.

The situation in Central Western Europe is such that the majority of people are connected to wastewater treatment plants, most of which operates according to the standard of the EU wastewater directive. However, the more south in Europe one goes, the lower is the wastewater treatment plant connection and especially in the Mediterranean countries (Portugal, Spain, Italy, Greece, Cyprus, Turkey) there are still a great number of treatment plants that have to be built, even in the large cities. The same is the case for Eastern Europe that has a very low standard in the wastewater treatment plant field. These countries will have to comply with the EU directive when becoming EU members and this will, of course, create a big market for “green field” plants in Eastern Europe.

In Central and Northern Europe the main market is that of rehabilitation and upgrading of existing treatment plants. This market is, however, considerable. Many of these plants were built prior to 1970 and since the life-time of machinery is around 30 years, a great number of wastewater treatment plants are being upgraded in Europe at the moment. This is also the case for Norway. In our country, there is also a market for “green field” plants that discharges to the sea, many of which will, however, apply for exception to use only primary treatment. For the rest of Europe the market for primary treatment is connected to pre-treatment in more advanced (secondary and tertiary) treatment plants.

On the American continent the rules are similar to those of Europe, tertiary treatment is required when discharging to fresh water while secondary and sometimes primary treatment is allowed when discharging to the ocean. In Japan, Australia and South Korea the situation is similar to the one in USA.

China and India have both high ambitions in the wastewater treatment field, out of necessity for the need of clean fresh water for supply. In these countries, however, large portions of the population are today not connected to wastewater treatment plants or to very low efficiency and low technology physical or biological treatment systems. The people's congress of China has, however, decided that in the present 5 year plan, wastewater treatment for small and medium-sized cities in China will have priority, which means that a very large number of treatment plants will have to be built in China in the years to come

In Africa a very low portion of the population is connected to wastewater treatment plants. At this time, it is difficult to see an immediate change in this situation even though this continent might be the one that suffers most from polluted water, because of the economical situation.

Municipal wastewater treatment technologies
The technologies used for municipal wastewater treatment naturally reflect the various treatment ambitions (primary, secondary, tertiary) that are to be complied with.

<u>Primary treatment technologies</u>
Primary treatment is carried out by the use of physical treatment methods such as:

- Strainers (light opening > 2mm)
- Sieves
    - Coarse sieves (light opening 2mm – 0,5 mm)
    - Fine sieves (mesh band filters) (light opening 0,5 mm – 0,1 mm)
    - Micro sieves (light opening < 0,1 mm)
- Sedimentation tanks

Traditionally primary sedimentation tanks are being used but there is a trend towards the use of fine sieves that can do the same job, on much less space. Salsnes Filter AS is active on this market.

<u>Secondary treatment technologies</u>
Secondary treatment has traditionally been carried out through biological (aerobic) treatment methods – normally differentiated in suspended bacterial growth processes (activated sludge processes) and fixed bacterial film processes (biofilm processes).

Secondary treatment standards (< 25 mg BOD_5/l in effluent and > 70 % removal of BOD_5) may, however, also be achieved by chemical treatment if wastewater characteristics are suitable. By chemical treatment all the suspended as well as the colloidal matter may be removed and phosphorous is precipitated as well as mentioned above. Chemical treatment has therefore been preferred in many Norwegian treatment plants.

Biological treatment methods always consist of a bioreactor step in which the biodegradation takes place and a separation step where the biomass. Similarly a chemical treatment plant consists of a reaction step (coagulation/precipitation) and a separation step (flocculation/sedimentation or flotation or filtration).

<u>Tertiary treatment technologies</u>
Both phosphorus and nitrogen may be removed biologically and chemical/physically. Chemical methods dominates, however, for P-removal (even though bio-P methods are increasing in popularity in many countries) while biological methods dominate for nitrogen removal.

Tertiary treatment involves the combination of bioreactors and particle separation reactors in a given system.

<u>Particle separation technologies</u>
Sedimentation has been the traditional particle/floc separation technology in wastewater treatment. Especially for secondary and tertiary treatment new high-rate sedimentation technologies including lamella sedimentation have taken over more and more and so has also flotation. Flotation is, for instance, the preferred method for separating biomass from the moving bed biofilm reactor (MBBR) process.

<u>Bioreactor technologies</u>
Bioreactors for municipal wastewater treatment are based either either/or on:

- Suspended biomass reactors (activated sludge reactors)
- Fixed biomass (biofilm) reactors - for instance the Kaldnes moving bed biofilm reactor (MBBR)
- Combinations of the two

Activated sludge plants are dominating for municipal wastewater treatment today. In green field (new) plants very many customers will prefer biofilm plants because they are much more compact. Almost all the tertiary treatment plants built in Norway during the last 15 years have, for instance, been based on the Kaldnes moving bed biofilm technology.

There is a very big market for upgrading of wastewater treatment plants for nutrient removal and the use of the moving bed technology has been quite successful in this market since it can easily be combined with suspended sludge processes.

<u>Membrane bioreactors</u>
Another trend is the use of membrane bioreactors based on suspended sludge (activated sludge) systems, in which the membrane separation unit is immerged in the activated sludge bioreactor making the system quite compact.

Prof. TorOve Leiknes at Department of hydraulic and environmental engineering, NTNU is coordinating the EU-project EUROMBRA and research is going at the department on the combination of moving bed bioreactors with membranes by which the membrane is placed downstream the moving bed biofilm reactor.

The increasing interest in membrane bioreactors is especially caused by the municipal wastewater reclamation and reuse market.

The municipal wastewater reclamation and reuse market
In those areas of the world were fresh water is scarce, the market of wastewater reuse is increasing rapidly. This is the case for parts of USA (i.e. California), parts of Europe (i.e. Spain), the Northern Africa countries, the Middle East countries, parts of China, several Far East countries (i.e. Singapore) and Australia. Treated wastewater is used for irrigation

purpose (golf courses, gardens etc), for cleaning purposes (car cleaning, road cleaning etc), for industrial purposes (cooling water, process water etc) and even for drinking water purposes. About 25 % of the drinking water used in Singapore comes from treated wastewater and all the wastewater in the capital of Namibia, Windhoek, is used to produce drinking water.

In wastewater treatment for reuse, the technologies for wastewater treatment and drinking water treatment meet. Such a plant will normally consist of a traditional advanced wastewater treatment plant followed by a water reclamation plant that secures pathogen control by advanced particle separation (by granular media or membrane filtration) and disinfection. The quality of the reclaimed water may be good enough for irrigation or cleaning purposes while additional treatment, for instance through chemical oxidation (for organic micropollutant removal) and reverse osmosis (for salt removal), is needed if the reclaimed water is to reused for drinking purposes. It can be expected that the market for reuse processes will increase dramatically in the future. Unit processes that will be asked for are:

- Membrane filtration processes (micro-, ultra- and nano-filtration as well as reverse osmosis
- Advanced chemical oxidation processes (ozonation, peroxide/UV-processes etc) for oxidation as well as disinfection purposes.

The wastewater sludge treatment market

Whenever wastewater is treated, wastewater sludge is created and in modern wastewater treatment plants today, the cost of sludge treatment and handling is often as high – or higher - than the cost of treating the water itself.

The sludge treatment technologies to be used are dependent upon the final disposal of sludge. In principal there are three final disposal alternatives:

1. Sludge deposits (on land or in the ocean)
2. Use of sludge on land (for fertilizing and soil conditioning purposes)
3. Extensive treatment and fractionation with the aim to recover resources from sludge

None of these alternatives exclude any of the others and it is quite common that more than one strategy is used for any particular sludge treatment plant.

Sludge deposition of sludge as such is being phased out in many areas of the world (Europe, USA, Japan etc).

Use of sludge on land is highly controversial. Most experts feel that this is the most sustainable way to deal with sludge, provided there are strict rules regarding the quality of the sludge to be spread on land, how and when the sludge may be spread and how much etc, etc. Norway is probably the country in the world that has the best system for dealing with sludge in agriculture. In Norway, for instance, correctly treated sludge of a defined quality is defined in the law rules as an organic fertilizer and not as a waste. The Norwegian rules require the sludge to be stabilized (to prevent odour), hygienized (disinfected) and dewatered before spreading.

In some countries, for instance in Denmark, Switzerland and several other European countries, there is a ban on spreading sludge on land, the argument being that accumulation of heavy metals and organic micropollutants as well as pathogens may represent a danger for food safety.

In countries that does not allow for use of sludge on land, the trend is to go for incineration of sludge. Incineration is, however, very costly and will result in an ash that has to be treated as a hazardous waste because of the concentrated content of salts and heavy metals.

The third disposal alternative that aims at recovering resources in sludge is becoming increasingly more important. The main products that can be recovered (or made from sludge) are:

- Energy
    - Biogas from anaerobic stabilization
        - Heat through burning
        - Electricity through gas motor
    - Heat from incineration
    - Oil (one full-scale plant in Australia was, however, shut down because of poor economy)
- Soil conditioner (constructed soils, compost)
- Building materials and building material additives
    - Portland cement additive
    - Expanded clay aggregates (Leca)
    - Bricks
- Coagulants (iron and aluminium)

It is quite common to produce biogas by anaerobic digestion of sludge and treatment plants with such sludge treatment are normally self-supplied with heat. Larger plants with gas motors may also be close to (depending on treatment method) being self supplied with electricity. For really large plants a surplus of electricity that can be sold on the market, is possible.

Even if the sludge disposal is based on incineration, which growingly is the case in Europe, many plants prefer to digest sludge anaerobically before incineration, partly to get out the energy potential through biogas production and partly as a means of reducing the amount of sludge to be incinerated.

Heat treatment of sludge is being used in an increasing degree. The ultimate heat treatment method is, of course, incineration, by which the heat value of the sludge is utilized. Sludge is self-burning at a dry-solids (DS) concentration around 35 %. Dewatered sludge that has a DS-concentration of about 25-35 % will normally have to be dried before it can burn. Drying is, however, requiring heat in order to evaporate the water. Consequently the heat recovery that one may have from incinerating sludge is limited.

The production of constructed soils (compost) is becoming more and more popular. This is based on treated sludge that is mixed with some soils (clay, moor, etc) to which possibly additives (for instance potassium) is added in order to make it a very good growth media. The constructed soils are used to improve soil conditions in parks, sport arenas, golf courses, lawns, and road embankments etc, places where food is not produced. There seems to a growing market for this type of product. In Trondheim a major share of the sludge produced is taken care of by Pan LandskapAS that makes such a soil and uses it in their landscaping projects.

The use of sludge for producing building materials is especially great in Japan where a major part of the sludge produced (mainly as incineration ash but also as dewatered sludge) now is used in the production of Portland cement and expanded clay aggregates.

The industrial process water treatment market

The industry is facing an enormous variety of challenges in the water and wastewater handling. A clear trend, however, is that the highly water consuming industries (pulp and paper, steel, food and beverage, textile etc) recycle water to an increasingly higher degree, simply as a measure to lower cost through reducing water consumption and at the same time reducing discharge taxes. In these cases the wastewater treatment market has changed from being an end-of-pipe treatment market to becoming a “recycle for process water” treatment market. This creates a situation similar to that of the municipal wastewater reuse market. The treatment plant will then consist of a traditional wastewater treatment step followed by a more advanced process water treatment step. All in all this increases the needs for water treatment technologies in industry.

When it comes to smaller industries, like many food industries, many companies still prefer to discharge their wastewater to the municipal sewer and let the city take care of the waste against tax compensation. Others prefer to pre-treat the wastewater at the industrial site before discharging to the municipal sewer in order to reduce taxes.

Industrial wastewater characteristics and treatment requirements

To emphasize the importance of water for each of the major water using industrial sectors, the specific characteristics of the use of water are summarized below. Furthermore, important developments in the sector are given as far as they are relevant to water.

Pulp and paper
In the paper and pulp industry water is mainly used as “carrying/transport/dilution” medium of the fibres. The major water related processes are washing, screening, bleaching and forming. Although a lot of water is re-used in this industrial sector, the water related costs are still high.

The main pollutants from this industry are solids, COD, salts, organic chlorine compounds, sticking compounds, extractives and additives. Water treatment and energy costs as well as production and maintenance costs in relation to accumulation of detrimental substances play an important role. Further closure of the water cycle is limited by (the knowledge about) the water quality demands in relation to product and processes and by the availability of viable technologies to remove specific compounds. More knowledge is needed on dissolved and colloidal substances of organic and inorganic nature as well as micro-organisms (activity) present in the water system.

The temperature applied in paper making processes often is optimal for growth of micro-organism. This is one of the reasons why biological wastewater treatment is dominating in the treatment of wastewater from this industry

The water related costs and the saving potentials are very high in the paper sector: Fees cover some 1 – 2 % of the entire production costs, energy 3-10 %, additives 5-10 %, fibres 4-8 %. The product quality in relation to water is difficult to assess, but of course very important for the entire business.

Textile

The textile and clothing industry consist of different parts. Most water is used in the textile finishing giving the products their final physical, visual and aesthetic properties. In the textile finishing industry water is mainly used as reaction medium (dyeing, finishing), for washing/rinsing and for heating and cooling. Water quality is important to ensure process stability, product quality and occupational health. Critical compounds in the water system are dyestuff, surfactants, hardness and salts.

Improved water quality control reduces the number of products rejected. The development towards "smart textiles" requires high water quality in the future. From an environmental point of view the discharge of dyes, finishing chemicals and salts are of importance. Furthermore, thermal emissions are a point of attention.

Oxidation technologies in combination with biological wastewater treatment can be expected to play an important role in the treatment of process water from this industry.

Food

In food processing a lot of water is used in different functions: washing/rinsing, reaction medium, cleaning of equipment and heat transfer. Also water is used as raw material e.g. as part of the product.

Due to very stringent hygienic standards water quality is important to ensure product quality and safety. Much attention is given to a good quality of intake water. Until now hardly any other water quality than drinking water quality is applied. However, the European legislation is changing and that offers possibilities to use other sources than drinking water, provided that '*the competent authority is satisfied that the quality of the water cannot effect the wholesomeness of the food stuff in its finished form'* (Regulation EC 853/2004). This makes closed loop systems feasible too. A main point of attention is the microbiological constitution of the water. Other critical compounds in the water system are cleaning agents, pesticides, colouring and smelling compounds.

Biological treatment is dominantly used for wastewater treatment in this industry. Many small industries discharge their wastewater to the municipal sewer against a discharge tax, and let the wastewater be treated by the municipal wastewater treatment plant.

Leather (tanning)

The manufacture of leather follows many steps; the major steps are: curing - lime soaking – unhairing – deliming/bating – pickling – tanning- retanning /dyeing/ colouring. In these steps large quantities of water are used mainly for soaking, washing/ rinsing and dyeing.

The tanning industry is a potentially pollution-intensive industry; environmental costs – mainly on water – are estimated at about 5% of the turnover.

The wastewater streams contain high concentrations of pollutants, like:

- hide/skin materials like fleshings, hair, grease (as suspended solids)
- salt
- sulphides
- chromium (III)
- biocides

The environmental impact of the leather industry has spurred the development of cleaner technologies, such as:

- process-integrated measures:
- improved matching of water flow to the requirements of the process steps
- batch instead of running water washes; reuse of wastewater, short-float techniques
- less hazardous chemicals
- more efficient fixation of dyes
- low solvent dyeing
- separate treatment of concentrated waste streams

Also in this industry chemical oxidation processes play an important role as does also biological wastewater treatment processes.

Metal (surface treatment)
Metal surface treatment includes a variety of processes and metals. Some of the processes are not wet and therefore not relevant here. The major wet processes are:

- electroplating/anodising: covering metal surface with nickel, zinc, copper, chromium, gold, silver and other metals (salts of Ni, Co, Mn, Sn and Cu)
- phosphating: treatment of metal surfaces to achieve higher corrosion resistance and/or better adhesion of coatings (iron-, zinc-, chromate-phosphating)
- conversion coatings
- surface preparation steps, like degreasing, pickling acid etching and descaling with a great amount of specific pollutants.
- passivating of zinc, aluminium, stainless steel
- pickling of steel, brass, aluminium

All types of treatment use large quantities of water, mainly for cleaning/rinsing and as "solvent" of the metals to be precipitated on the metal surface.

The wastewater streams contain high concentrations of the metals mentioned. Other pollutants are oil, fats, dyes, pigments, corrosion inhibitors, complexing agents and cyanides.

The last decades much attention has been paid to reduce the environmental impact of the wastewater effluents. The major developments in this field are:

- separate and advanced treatment of concentrated waste streams e.g. membrane technology, anodic electrolytic oxidation, etc.
- monitoring bath quality and/or increase of bath lifetime
- reduction of drag out of bath liquids and drag out recovery
- process-integrated measures.
- alternative raw materials with less toxic components

Chemical/Pharmaceutical
The chemical industry is a very diverse business. It may be distinguished between the following main branches:

- large volume organic chemicals
- large volume inorganic chemicals
- polymers
- organic fine chemicals
- specialty inorganic chemicals

This indicates that there are plants that produce very large volumes of a few chemicals and others which produce small volumes of many different types of chemicals. Even though the total amount of different chemicals produced in the chemical industry is big, the ways to produce them are more limited. Typically the industry talks about **unit processes** and **unit operations** which are common to the industry (about 20 each). Unit processes are the principle for the chemical reaction and unit operations the principle(s) to process or to refine the product.

Water is essential in most chemical production. For a specific production, the choice of unit process(es) and unit operation(s) together with the choice of raw material and process equipment define the need and use of water. Typically the major part of water will be used in the unit operations. Here the most wastewater will be generated but it will also be generated in the unit process due to water in the raw material, produced during the reaction, or used as reaction media and/or to control the conditions for the process.

The distribution of water use and emissions to water between the unit processes and the unit operations can vary in a very wide range, depending on the chemical produced and the unit process chosen. Water is mainly used for:

- reaction medium/solvent
- product washing
- cleaning of equipment
- heat transfer (cooling, heating)

As mentioned above the contaminant concentration is not evenly distributed in the waste water streams. As a rule of thumb, 20 % of the total waste water flow contains 80 % of the contaminant load. Some examples of high concentrated waste water streams are:

- mother liquors
- condensates
- wash water first washing cycle

However, looking at the emissions from the chemical and pharmaceutical industry it is important to look not only at the concentration but also at the type of pollutants. Some are very hazardous, even at low concentrations. Critical components in chemical and pharmaceutical industry are numerous. To the already mentioned could be added: Biologically non-biodegradable organics and nutrients, microorganisms (e.g. GMO’s), dyestuff, bio-accumulative components, non-used API’s (Active Pharmaceutical Ingredients) like hormones, bio-toxic components. Especially in the pharmaceutical industry biological process water treatment based on special cultures are being used.

Cooling water

Cooling is an essential part of many industrial processes and should be seen as an important element in the overall energy management system. Where no further recovery and re-use of heat is possible cooling must be applied to release the waste heat into the environment.

Industrial cooling systems can be categorized by:

- Design: once-through systems, open-recirculation tower, closed circuits open/closed hybrid systems
- Cooling principle: water, air or combination

Water consumption varies significantly between the different types of cooling systems; once-through systems use large quantities of water as coolant. Water quality control and conditioning, to prevent scaling, corrosion and (bio)fouling ask a lot of attention.

Emissions into surface water from cooling systems, including drain, are mainly:

- cooling water additives and their reactants (anti-corrosion, anti-scaling and anti-fouling agents/biocides)
- corrosion products
- leaked process chemicals

To reduce the use of cooling water additives alternative treatments like ozone, UV, shock treatment can be applied successfully.

Also a big problem in cooling water systems is Legionella. Due to the formation of biofilms, techniques like UV and ozone are not always sufficient. Also other techniques to reduce the organic pollutions without secondary pollution, like
anodic electrocatalytic oxidation, are in development.

Oil and gas

Water in oil/gas exploitation is used in drilling activities and water comes out as product water originating from the oil/gas resources. Critical compounds are drilling agents, salts from the oil/gas deposits, bio-toxic organics (PAH, BTEX), heavy metals, and some times high concentrations of biologically degradable organics.

As in future more complex oil/gas fields will be taken into production and legislation on water discharges will become more stringent the need for water treatment technologies will increase.

If the oil and gas section includes the energy sector (power stations) as well, the critical compounds should include components from the flue gas scrubber liquids (salts, nitrogen, biologically non-degradable (or slowly degradable) organics and nitrogen, heavy metals.

For all sectors counts that optimised water use only pays off if a combination of the following items is taken into account:

- less effluent discharge fees by reduced emission level
- less energy costs by energy recovery (direct re-use or by heat exchange)
- less water supply costs
- less raw material costs by recovery of raw materials and additives
- product recovery from waste water streams
- improved process stability and product quality by improved and/or more constant water quality.

Mining industry

Mineral extraction, which is usually connected with the necessity of draining a working pit, is carried out using two methods: an underground method and surface (open pit) method. To some extent the drainage water is irretrievably used for internal circle of the facility or pressed back into the geological formation. Most of the water, however, is discharged to surface waters. Working pit drainage always disturbs the natural water balance - in the area of depression sinks groundwater from several different aquifers may often be degraded. In surface watercourses the flows are changed (usually raised). Unfavourable changes include:

increased salinity with chloride and sulphate salts, contamination with heavy metals and natural radioactive elements contained in groundwater.

The techniques used so far are insufficient to remove salt from water effectively. Very often, in order to reduce the effects of salted water discharge, controlled dosage systems correlated with flow in rivers are built; their impact on water environment, however, is not well recognized. Methods for balancing costs of environmental changes and costs of constructing installations for mine drainage water management (or costs that must be incurred) are not worked out, either.

Treatment technologies used in industrial water and wastewater treatment

It is impossible here to go through all the various industries because they represent a very wide variety of treatment problems. We shall, however make a brief analysis and differentiate based on the wastewater characteristics and comment in which industry the actual characteristics are relevant.

Wastewater containing high concentration of easily biodegradable organic matter (high BOD)

Discharge of untreated wastewater from such industries will lead to high consumption of oxygen in the receiving water with oxygen deficiency (anaerobic conditions) as a possible result.

Typical industries with such kind of water are :

- Pulp and paper industry
- Food industries
- Petrochemical industries

Both the pulp and paper industry and the petrochemical industry may contain heavily biodegradable organic matter as well.

The removal of easily biodegradable organic matter is carried out through biological treatment, that may be aerobic, anaerobic or a combination of both. Aerobic treatment will consume much energy due to the need for aeration while anaerobic treatment produces energy in the form of biogas that may be used to produce heat and electricity (trough a gas motor). Anaerobic processes are, however, slower than aerobic processes and therefore the investment of aerobic processes is lower, so the choice among the two becomes very often a choice between high investment cost versus high operation cost. Because of the increasing cost of energy, the trend is to use anaerobic pre-treatment in order to take down the organic matter down considerably, but not necessarily down to the consent value, and then do aerobic post-treatment in order to reach the consent value.

When using anaerobic processes, process solutions based on suspended biomass still seems to be dominating, even though biofilm processes seem to be increasingly often being chosen.

Lamella settlers are often used for biomass separation. Because the growth of anaerobic bacteria is so slow, it is, however, of great importance to be able to retain the biomass in the reactor and there is a trend towards improved biomass separation, before recycle of biomass, by the use of membrane separation of biomass..

The so-called UASB reactor combines the benefits from suspended cultures with that of biofilm cultures, in that it is based on granulation of the biomass. The granules are suspended but they act also as biofilm carriers and improve the settleability and retention of the biomass in the reactor. The granulation technology seems to be increasingly used in many parts of the world. New insights into the anaerobic degradation of very different categories of compounds, and into process and reactor technology will lead to very promising new generations of anaerobic treatment system, such as 'Expanded Granular Sludge Bed' (EGSB) and 'Staged Multi-Phase Anaerobic' (MPSA) reactor systems. These concepts will provide a higher efficiency at higher loading rates, are applicable for extreme environmental conditions (e.g. low and high temperatures) and to inhibitory compounds. Moreover, by integrating the anaerobic process with other biological methods (sulphate reduction, micro-aerophilic organisms) and with physical-chemical methods, a complete treatment of the wastewater can be accomplished at very low costs, while at the same time valuable components can be recovered for reuse

Both suspended biomass (activated sludge) processes and biofilm processes are used for the aerobic reactors, but the trend is clearly in favour of the biofilm processes. Especially the suspended carrier or moving bed process (AnoxKaldnes) seems to be favoured by the pulp and paper industry at this time.

Wastewater containing high concentration of heavily biodegradable organic matter (high COD)
These industries will also have to reduce the organic load, partly because the high COD eventually will cause high oxygen consumption in the receiving water and partly because the organic matter may contain undesirable specific compounds.

Typical industries with such kind of water are :

- Pulp and paper industry
- Pharmaceutical industries
- Textile industry
- Leather industry
- Petrochemical industries

This kind of water may also be treated biologically, as mentioned above, but often they require specific bacterial cultures and the processes may be very slow. One way to overcome this is to chemically oxidize the heavily biodegradable organic matter prior to biological treatment, in order to make it more easily biodegradable.

The traditional chemical oxidation processes may be used, especially ozone oxidation, but to an increasing extent, advanced, combined oxidation processes are taken into use, such as:

- O_3/H_2O_2
- O_3/UV
- Fe(II)/H_2O_2 (Fentons reagent)
- UV/H_2O_2

Wastewater containing high concentration of heavy metals
Such wastewaters are toxic to aquatic organisms and the heavy metal content has to be brought down. Typical industries that have to remove heavy metals are:

- Metal surface finishing industries

- Textile industries
- Leather industries

Heavy metals are normally removed through precipitation processes in which particle separation plays an important role. There is a trend to recover the heavy metals and therefore to optimize the separation process through the use of membrane filtration for separation. Alternatively heavy metals may be removed through ion exchange

Water containing high concentrations of ammonium

Ammonium will be consuming oxygen in the receiving water through biological nitrification and will therefore have to be brought down to acceptable values. Ammonium is also toxic to aquatic organisms (toxicity dependent on pH).

Typical industries with such water are :

- The explosives industry
- The fertilizing industry

Ammonium may be removed physical/chemically, through:

- Ammonium stripping
- Magnesium-ammonium-phosphate (MAP) precipitation

or biologically, through nitrification (biological oxidation of ammonium to nitrate). In the latter case also denitrification has to be used in order to remove the nitrate. MAP-precipitation may be an option of the water also contains high concentrations of phosphate. In concentrated waters, for instance that from the fertilizing industry, ammonia stripping by the use of water vapour instead of air as stripping gas is a favoured solution.

Water containing low concentrations of ammonium – but too high

A typical case here is the aquaculture industry – especially the fingerling production phase. Ammonium is toxic to fingerlings are very low levels and has to be removed. Normally this is done biologically through (aerobic) nitrification in biofilm reactors but ion exchange can also be used.

Produced water in the oil and gas industry

When producing oil and gas of shore, the water that comes up with the oil has to be treated before discharge or reinjection. Most of the commercially available produced water treatment technologies today are for dispersed oil removal. The hydrocyclone is the most used technology on the North Sea platforms. Recent technological innovations in dispersed oil removal seem to have either concentrated on increasing the hydrocyclone removal efficiency (coalescers, CTour) or developing more compact and efficient flotation processes, for example, by combining flotation with cyclonic separation.

In connection with new standards for discharge to the ocean from the oil sector (Zero discharge concepts) better removal of dispersed oil as well as dissolved hydrocarbon treatment has to be achieved.

In dissolved hydrocarbon treatment, there seem to be no good treatment alternatives available for produced water treatment in oil platforms with large water streams. Many methods that effective for dissolved hydrocarbon removal like adsorption and MPPE are unsuitable (due to size, adsorbent disposal etc.) for treatment of large volumes of produced water in offshore applications.

Although membranes are now widely used in water and waste water treatment (and other applications), the petroleum industry seems to be sceptical for process due to problems with fouling and regeneration (cleaning) in earlier field trials.

It is a challenge to develop a process for dissolved organics removal which is also compact enough for use on offshore oil-fields. Biological treatment is judged to require too much space and oxidation is hardly mentioned in overviews.

Technology trends in the various water treatment markets

In the following we shall discuss the different markets separately and summarize based on a technology analysis – independent on the markets.

Technology trends in the drinking water treatment market

The main drivers of the new technological trends in the drinking water treatment area are:

1. The multiple hygienic barrier requirement - in order to meet what seems to be an increasing risk for epidemics, possibly as a result of globalization
    - Improved disinfection processes are asked for – especially for parasite inactivation
    - Improved particle separation processes are asked for – especially for pathogen separation
2. The increased use of :
    - used water (wastewater or water from water courses polluted with wastewater)
    - saline (ocean) water

    for drinking water production as a result of the need for more fresh water in certain areas of the world because of increased consumption caused by increased population and industrialization
3. The stricter standards on organic micropollutants like pesticides, pharmaceuticals etc require:
    - Improved oxidation processes
    - Improved adsorption processes
    - Improved biological filtration processes

These drivers call for development in :

a. Disinfection technologies
b. Oxidation technologies
c. Biofiltration technologies
d. Particle separation technologies
e. Desalination technologies

Disinfection technologies

We can see the following trends in disinfection technologies:

- There is a clear trend away from chlorine and towards alternative disinfection methods in drinking water disinfection.
- For solely disinfection purposes it seems to be a clear trend that UV-disinfection increases more that the alternatives (i.e. ozonation and chlorine dioxide) primarily because of its effectiveness regarding Cryptosporidium inactivation.
- Because of the concept of multi hygienic barriers, the use of more than one disinfection step (with different processes in each step) is increasing.
- Disinfection is asked for in the strongly increasing market of wastewater reclamation and reuse. In this market the use of particle separation(i.e. membrane filtration) is favoured for removal of parasites while a disinfectant is more often used for bacteria and virus control.
- Disinfection is playing an increasingly important role in industrial process water treatment, for instance for growth control in (i.e. Legionalla) in recycling systems or heat water systems. A special case that is creating a lot of attention at this time is

treatment of ballast water on board ships for the prevention of pathogens and foreign species over continents.

Oxidation technologies

There is an increasing interest in the use of advanced chemical oxidation technologies in drinking water treatment. We can see the following trends and developments in oxidation technologies:

- The use of ozone for oxidation purposes (and also for disinfection) is increasing. The negative element with ozone use is the formation of bromate in bromide containing water. Alternatives to ozone are being looked for as a consequence of this.
- Therefore it is reason to believe that advanced oxidation processes (AOP's) will play a more important role in the future drinking water treatment because of the need to degrade organic priority pollutants (pesticides, pharmaceuticals, solvents etc) in the raw water. The new EU Water Frame Directive will probably push the development in this direction since priority pollutants are strongly focused on in this directive.

Biofiltration technologies

There is also an increased interest in using biological treatment methods (here called biofiltration) for treating drinking water. Traditionally this was done by slow sand filtration that has been used for several decades by many of the major European cities. Slow sand filters are very area demanding and are now longer built except for developing countries and for in-situ groundwater or river-bank infiltration systems.

The renewed interest in biological treatment systems is coupled with the interest in advanced oxidation techniques by which heavily biodegradable organic micro-pollutants can be made more easily biodegradable and removed in biofilters. Modern biofilters are much more compact than slow sand filters as they use the total surface area of the filter carriers as growth area for the biomass. There is reason to believe that one will see a considerable advancement in drinking water biofiltration technologies in the years to come.

Particle separation technologies

The clearest trend in particle separation technologies is that membrane filtration is taking more and more over for granular media filtration. New membrane systems are being developed at a high pace.

The development in the production of the membrane itself is faster than the development in membrane modules, i.e. the technology around the membranes. This is, therefore, clearly an area that could be focused on in the research unit under CEWIC..

Desalination technologies

It is estimated that the desalination market will increase considerably, may be as much as 10-12 % per year, in the years to come. This market will probably increase at a higher rate than the other water treatment technology markets.

The challenges facing the reverse osmosis desalination market are:

- Pre-treatment technologies
- Brine handling technologies

In the area of pre-treatment is seems that membrane micro filtration may play an important role in the future. Regarding the brine handling problem, there is a trend that recovery of salt and other valuable resources is being considered.

Technology trends in the municipal wastewater treatment market

The main drivers of the new technological trends in municipal wastewater treatment are :

- Energy price is increasing – low energy processes are asked for
- Space (building area) costs are increasing – compact processes are asked for
- Stricter effluent standards have to be met
  - Better particle separation processes are asked for
  - More efficient biological processes are asked for
  - Chemical oxidation processes are taken into use
- Epidemics are more frequently being encountered – resulting in more focus on pathogen removal also in wastewater treatment
- Scarcity of freshwater results in increasing reuse of wastewater
- Sludge handling is becoming an increasing greater problem
- Upgrading of existing municipal wastewater treatment is needed

These "drivers" has resulted and/or will result in the following technology trends in the municipal wastewater treatment market :

- More efficient nutrient removal technologies will be asked for.
  - More energy efficient biological nutrient removal processes
  - More efficient physical/chemical treatment
- Anaerobic treatment will be used more
  - In some areas of the world, where water consumption is low (resulting in high strength wastewater) and water temperature is high (.i.e. Brazil, India, etc) anaerobic treatment methods will increasingly be taken into consideration, at least as pre-treatment before aerobic methods
- Compact treatment reactors will be asked for, for instance:
  - Bioreactors
    - the moving bed biofilm reactor (the Kaldnes process, developed in Norway)
    - the membrane bioreactor
    - the fluidized bed reactor
  - Particle separation reactors
    - fine sieves for primary treatment (for instance Salsnes Filter)
    - flotation reactor
    - high rate settling (lamella) reactors
    - membrane filtration (micro- and ultrafiltration)
- Improved sludge handling technologies will be asked for

Nutrient removal technologies

Even though both phosphorous and nitrogen may be removed both biologically and chemically, it is so that biological treatment is dominating for N-removal while chemical treatment is dominating for P-removal. There is a very strong interest in biological P-removal, however, as it is considered cheaper especially when activated sludge plants are used. Many bio-P plants have, however, to add chemicals as well in order to meet the effluent standards. These standards are likely to be sharpened and therefore there will still be a large global market for P-precipitating chemicals.

In the biological nutrient removal area there are a whole group of new processes emerging (the Anammox process, the Sharon process, the Canon process and the Oland-process etc) from various research groups. It seems, however, that many of these processes are so difficult to control that they have not come to extensive practical use at this time.

In the area of nitrogen removal the use of biological methods will dominate also in the future, but the stricter effluent standard will cause a need for adding an external carbon source in many plants. In this situation, biofilm reactor will probably be favoured over activated sludge reactors and there is reason to believe that the market for upgrading activated sludge plants for improved nutrient removal is strongly increasing which opens the door for the hybrid (combined suspended/fixed biomass) systems. The Kaldnes moving bed biofilm process is particularly suitable for this.

Anaerobic biological treatment technologies

The reason for the renewed interest in anaerobic wastewater treatment systems is the benefit on the energy side. Anaerobic processes have the potential of producing energy through utilisation of the biogas, while aerobic processes consume energy (aeration).

Anaerobic processes are slow though and investment cost for them are higher than for aerobic processes. The market for anaerobic processes lies therefore in the countries that have concentrated wastewater with high temperature, which is the case for many developing countries.

Compact treatment methods

Compact treatment reactors are needed both among bioreactors and separation reactors. This is the main reason for the development we have seen in new biofilm reactors (for instance the Kaldnes moving bed biofilm reactor) and the membrane bioreactors.

Wastewater sludge treatment technologies

The following areas within sludge treatment technologies seem to be gaining momentum:

- Sludge minimization technologies
    - Physical, chemical and thermal technologies
- Advanced thermal oxidation technologies
    - Thermal hydrolysis
    - Supercritical water oxidation
- Enhanced anaerobic digestion for extended biogas production
    - Combined aerobic/anaerobic digestion
    - Thermophilic anaerobic
- Disinfection (hygienization) technologies
    - Biological/thermal
    - Thermal
    - Chemical
- Drying and incineration

Technology trends in the municipal wastewater reuse market

The main driver of the reuse market is the need for fresh water in areas with water scarcity. Most of this reused water is used for irrigation or for industrial purposes.

The new increasing market of wastewater reuse asks for advanced municipal wastewater treatment, i.e. tertiary treatment followed by improved particle separation, improved soluble organic matter removal and pathogen removal (partly achieved by advanced particle separation).

Because of this, membrane bioreactors are especially targeting the reuse market since several of the objectives are reached with such reactors. However, reuse plants normally also includes reactors for adsorption on activated carbon (for improved soluble organic matter removal possibly preceded by chemical oxidation technologies) as well as disinfection technologies (ozon or UV),

Technology trends in the industrial process water treatment market

The main drivers of the new technological trends in industrial water treatment are:

- Energy price is increasing – low energy processes are asked for
- Space (building area) costs are increasing – compact processes are asked for
- More extensive treatment is required partly because:
    - Treated water is to be reused as process water
    - Stricter effluent standards have to be met
        - More efficient biological processes are asked for
        - Better particle separation processes are asked for
        - Chemical oxidation processes are taken into use – especially in industrial WWTP
- Scarcity of freshwater results in increasing reuse of municipal wastewater for industrial purposes

There seems to be three principal trends in the industrial wastewater market:

1. The first trend wastewater treatment market is that of water recycle. Industries want to reduce costs through reducing the water supply bill as well as discharge taxes
2. The second trend is that of stricter effluent standards for those industries that have their own effluent discharge (typically large industries – pulp and paper, steel, petrochemical etc)
3. The third trend is that those industries that discharge the wastewater to municipal sewers (typical for food industries and smaller metal surface finishing industries), to an increasing extent is pre-treating their wastewater before discharge in order to reduce discharge taxes that are normally connected to pollution load

Water treatment technologies to focus on for the environmental research unit under CEWIC

Based on the previous chapters that are giving an overview of the trends regarding water treatment technologies for the various markets, we shall summarise and make some recommendations based on the market trends with regard to which of the water and wastewater treatment technologies the environmental research unit under CEWIC could focus on.

When going through the technology trends in the various markets, it is interesting to note that some of the treatment technologies are emerging in all markets of water treatment, such as:

1. Physical/chemical oxidation processes are increasingly being taken into use for both drinking water, municipal wastewater, reclaimed wastewater for reuse, industrial water and even for sludge treatment
    - For disinfection purposes
    - For oxidation of organic micropollutants (drinking water, municipal wastewater, reclaimed water for reuse)
    - For pre-treatment of water containing heavily biodegradable organic matter before biological treatment
    - For sludge production minimization

2. Membrane filtration processes is becoming increasingly important for all applications which makes membrane filtration a method for the future both for:
    - Particle (including pathogen) removal – micro- and ultrafiltration
    - Large organic molecules (like NOM) removal – nanofiltration
    - Desalination – reverse osmosis

3. Anaerobic biological processes for municipal as well as industrial wastewater treatment:
    - Minimization of energy consumption will play a decisive role in the future wastewater treatment plants and processes that can produce energy instead of consuming it will be favoured
    - New reactor designs are needed in order to be able to capture methane and make use of the energy is needed, especially for reactors used for municipal wastewater treatment
    - In the developing countries market where a vast majority of people are yet not connected to treatment plants, the wastewater concentration will be more concentrated than in the developed world and the wastewater temperature higher. In this situation the anaerobic processes have an advantage

4. Biofilm processes are increasingly being used for biological treatment:
    - In order to save space in municipal wastewater and industrial process water treatment
    - For anaerobic treatment, primarily has utilized suspended biomass formerly.
    - In drinking water treatment – often in combination with chemical oxidation processes

These are areas of treatment technologies that we recommend the research unit under CEWIC to focus on in the competence build-up since they have in them great potentials for industrial development.

Another area that is not mentioned in this report as it is not a water treatment technology as such, but that is of utmost importance, is the area of instrumentation, control and automation. The more advanced the treatment technologies are and the stricter the water standards are becoming, the more important it is to have optimized instrumentation and control in the treatment plants in order to:

- be able to operate the processes in the best and most economical manner
- be able to document to the environmental protection authorities that the water quality standards are being met.