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Technologies for water and wastewater treatment

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SUMMARY - The paper first presents a review of the technologies and processes which are used for water and wastewater treatment in order to remove the various constituents of the polluting load: solids, organic carbon, nutrients, inorganic salts and metals, pathogens. A second part describes the advanced processes to reuse treated municipal effluents in agriculture and industries and the main technologies which are used for desalination.

Key-words: natural water; wastewater, treatment processes; reuse of municipal effluents; desalination processes.

RESUME *- Dans cet article est presénté un panorama des technologies et des procédés qui sont utilisés dans les traitements des eaux et des eaux résiduaires pour l'enlèvement des différentes composantes charactéristiques de la pollution: solides, carbone organique, azote, phosphore, sels inorganiques et metaux, pathogènes. La deuxième partie est dédiée à la description des procédés avancés pour la réutilisation des eaux domestiques dans l'agriculture et dans l'industrie et l'analyse des principales techniques qui sont utilisées pour la désalinisation.*

Mots-clés*: eaux; eaux résiduaires, procédés de traitement; réutilisation des eaux domestiques; procédés de désalinisation.*

INTRODUCTION

In the industrialised countries the first water treatment techniques involved processes of a purely physical and mechanical nature to reduce the solid content. The limitations of both the results and the applicability of these processes later led to the use of treatments of a chemical nature. At the beginning of the 20th century water hygiene problems were overcome by adding chlorine. At the same time other types of treatment were introduced, with specific objectives, such as rendering the water softer or reducing the iron content.

There has been a gradual progression from the haphazard treatment of sewage water by dilution in large tanks to the use of spreading areas and to creation of centralised systems. Originally the initial stage in these systems aimed at reducing substances in suspension by using chemo-physical methods. As a result of findings in England during the last twenty years of the 19th century, which led to the activated sludge process, a second stage in the process was introduced by which organic matter was stabilised by aeration.

As a consequence, the technological evolution of these processes has led to widespread mechanisation of the systems, especially in the initial treatment stage. So far as the secondary treatment stage is concerned, trickling filters, rotating biological disks, different versions of activated sludge processes and rapid filtration systems have been introduced and perfected.

The quality of water supplies has gradually declined, largely because of high and often excessive consumption of natural water and the abuse of the ground soil as a recipient of wastewater. Pollution has also contributed to this effect. The situation is so bad that it is now necessary to process water for certain uses for which in the past no processing was ever considered necessary. Therefore, highly advanced processes have been introduced to reclaim urban effluent for agricultural and industrial purposes.

Fundamental studies in the fields of chemistry and microbiology and findings from research into process techniques provide the foundations on which new methodologies for planning and laying out wastewater treatment systems are currently built. Today these technologies conform with environmental politics which for the near future foresees the integration of systems and devices for reducing the impact of anthropic processes on the environment.

The various water treatment processes have the following objectives:

- to confer and preserve the inherent physical chemical and biological qualities of water of different origins which make it suitable for specific uses such as water for drinking and for use in productive processes;
- to permit wastewater treatment which will protect the public from health risks without causing any damage to the environment;
- to confer and preserve those characteristics of water in its natural environment which are necessary for the conservation and development of ichthyo fauna and aquatic vegetation, and for provision of drinking water for cattle and wild animals or for recreational and aesthetic purposes.

Since the reclaiming of wastewater and the introduction of processes for purifying and rendering water potable generally complement the original objective of safeguarding the environment the various processes are considered as belonging to the same field.

This study does not deal with current technology for the treatment of urban and industrial sludges. This aspect is important when analysing water treatment processes involving complex problems closely connected with disposal methods. Reference should be made to specific literature in this field for further details.

CHARACTERISATION OF NATURAL WATERS AND WASTEWATERS

Natural Water

Natural water can be divided into two categories: surface water, such as rivers, torrents, natural lakes, reservoirs, and subterranean water such as springs and ground water.

The composition of natural water is determined by a sequence of physical chemical and bio-chemical processes which occur during different stages in the hydrologic cycle. Atmospheric agents play an active role in these processes. For this reason the quality of natural water is greatly influenced by atmospheric conditions and seasonal variations in temperature, as, for example, the water in basins with a low replenishment rate.

There are numerous chemical species present in water. Concentrations vary from a few mg/l to a few g/l. In particular, the solid content of natural water can be extremely variable. This is substantially the consequence of the geomorphologic and hydraulic characteristics of the environment in which the water collects and of the manner in which it is withdrawn. Colloids are particularly important in the treatment of natural water. Roughly speaking, their dimensions vary between 10^{-3} µm and 1 µm. Colloids of smaller dimensions influence the colour of the water, and those of larger dimensions between 0.1 and 1 µm its turbidity. ***Table 1*** shows the compositions of samples of natural water collected in Italy.

Table 1 *- Typical composition of natural waters (Berbenni, 1991).*

parameter	unit	spring	groundwater			lakes	reservoirs
		Canzo (1988)	Pavia (1972)	San Zenone Po (1982)	Milano	Maggiore (1987)	Camastra (1987)
solids (at 180 °C)	mg/l	197	230	455	630	—	—
pH		8	7.1	7.3	7.3	7.2	8.4
electrical conductivity	µS/cm	315	330	645	850	136	315
organic matter	mgO$_2$/l	< 0.10	0.79	—	0.40	—	3.22
total hardness	°F	18.1	17.6	36.2	42.7	6.8	19.1
calcium	mgCa^{2+}/l	57.2	52	104	135	21	60.3
magnesium	mgMg^{2+}/l	9.4	11	25	21.8	3.8	13.48
sodium	mgNa^{+}/l	1.3	8.1	16.2	19.3	2.1	—
potassium	mgK^{+}/l	0.4	1.1	0.9	2.4	1.5	–
ammonia nitrogen	mgNH$_4^{+}$/l	—	< 0.01	< 0.01	< 0.01	< 0.01	traces
sulfate	mgSO$_4^{2-}$/l	14.1	17	62	127	29	158.3
nitrate	mgNO$_3^{-}$/l	—	1	11	18	3.7	2.0
chloride	mgCl^{-}/l	6.2	6	10	31	1.7	15
bicarbonate	mgHCO$_3^{-}$/l	197	207	378	335	45	—
silica	mgSiO$_2$/l	10	14	24	—	1.30 (as Si)	3.89 (as Si)

Organic compounds are normally composed of a combination of carbon, hydrogen and oxygen, together with nitrogen in some cases. Humic compounds, tannin, lignin, phenols, amino acids and hydrocarbons, are main products of decomposition of vegetable matter. It is interesting to note that humic substances have a precursory role in the formation of halogenated aliphatic compounds, following the colouring of water, and these are considered carcinogenic.

The abuse of land both for agricultural and industrial purposes, combined with environmental abuse and the lack of any strict controls, has led, in some cases, to an intolerable degeneration of groundwater and surface water. A series of organic and inorganic compounds exists, referred to as micro-pollutants, which even in small quantities are dangerous to man's health. The concentration of these substances is such that their removal requires specific treatment.

Inorganic micropolluting substances include ammonia, nitrites, sulphides and heavy metals. Organic micropollutants can be identified by their origins: those of industrial origin include coloured solvents, aromatics and nitrogen compounds, phenol, polychlorodiphenol, PCT and aromatic polynuclear compounds; those of agricultural origin are herbicides and pesticides which contain a large variety of chemical compounds.

The use of fertilisers may also cause metal pollution. However, the emission of metals into the water system may arise for other reasons such as atmospheric erosion of minerals, industrial extraction and processing of minerals, use of metals and their derivatives or from household waste.

Another potential source of pollution, in both surface and groundwater waters, is leakage from refuse containers.

Pathogenic micro-organisms, bacteria and viruses are usually absent in natural water, but they can normally be detected wherever waste is discharged.

Unpleasant odours are usually due to the presence of very small quantities of secretions given off by microscopic algae, and chiefly by actinomycetes which develop on surface waters and on the beds of lakes and rivers under certain conditions of temperature and chemical composition of the waters. This process is often associated with the degree of organic pollution of the water, agricultural activities and the seasons. Some malodorous products may also be formed by the decomposition of vegetable or organic matter in the soil, and from certain kinds of fish spawn or industrial waste (*Metcalf and Eddy, 1987*).

Further consideration should be given to waters with a high salt content, such as sea water and brackish water. These are non-conventional water supplies which can be used, after desalination, as drinking water, for irrigation and for industrial purposes.

Most sources of natural water contain salt in various concentrations. Besides natural water there is also industrially produced salt water which cannot be used directly for other purposes. ***Table 2*** shows the salt content, as chloride concentration, in common waters (*Heitmann, 1990*).

Table 2 *- Salt contents of common types of waters (Heitmann, 1990).*

Type of salt water	Salt content (g/l)
brackish water	up to 10
water from industrial processes	up to 50
water discharged from cooling towers	up to 5
concentrates from water-processing plants	up to 250
landfill leachate	up to 40

WASTEWATERS

For technical purposes wastewaters can be divided into urban and industrial wastewaters. The composition of the former usually conforms to a general typology. **Table 3** shows the principal values of parameters of pollution found in urban wastewaters in industrialised countries (*Metcalf and Eddy, 1987; Derjicke and Verstraete, 1986; Barbose and Sant Anna Jr., 1989*).

Most industrial processes emit wastewater during one or more stages of production. The composition of this type of water can vary dramatically as it is determined both by the products themselves and processes of production.

***Table 3** - Composition of urban sewage in industrialised countries (Metcalf and Eddy, 1987; Derjicke and Verstraete, 1986; Barbose and Sant Anna Jr., 1989).*

parameter	unit	value
temperature	°C	4-20
dry matter	mg/l	700-800
suspended solids	mg/l	200-300
COD_t	mgO_2/l	500
$bCOD_t$	mgO_2/l	330
COD_s	mgO_2/l	250
BOD^{20}_5	mgO_2/l	220
volatile acids	$mgCH_3COOH/$	40
Kjeldhal nitrogen	mgN/l l	50
ammonia nitrogen	$mgNH^+_4/l$	25-40
nitrites and nitrates	$mg(NO_2, NO_3)$	≈ 0
phosphates	$mgPO^{3-}_4/l$	10
sulphates	$mgSO^{2-}_4/l$	75
pH		7.0-7.5
alkalinity	$mgCaCO_3/l$	2-15
fats and substances extracted in ethane	mg/l	up to 100

The principal physical, chemical and biological characteristics of the pollution load of wastewater are temperature, solid content, organic matter, inorganic compounds and metals, gases and volatile compounds, taste and odour, colour and pathogenic organisms.

The solids content of an urban wastewater may be physically classified approximately as shown in Fig. 1 (*Metcalf and Eddy, 1987*).

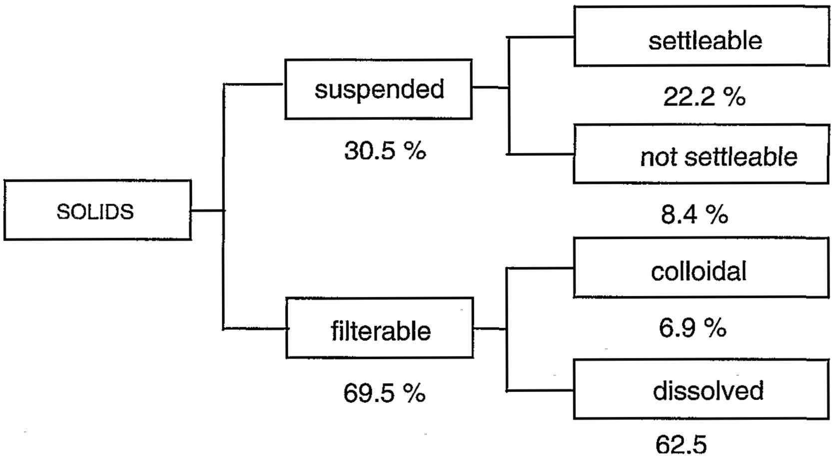


***Fig. 1** - Classification of solids found in urban wastewater (Metcalf and Eddy, 1987).*

In a typical urban wastewater, about 75 percent of the suspended solids and more than 50 percent of the filterable solids are organic in nature. These solids are derived from both the animal and plant kingdoms and the activities of these as related to the synthesis of organic compounds.

The principal groups of organic substances found in wastewater are proteins, 40 to 60 percent, carbohydrates, 25 to 50 percent; fats and oils, 10 percent (*Metcalf and Eddy, 1987*). Organic compounds are normally constituted of a combination of carbon, hydrogen and oxygen, together with nitrogen in some cases. Other important elements, such as sulphur, phosphorus and iron, may also be present.

Beyond these substances, wastewater contains small quantities of a large number of different synthetic organic molecules. Surfactants, phenols and pesticides are typical compounds.

The composition of the inorganic fraction which either dissolves in the liquid stage or clings to suspended or colloidal solids can be traced back chiefly to the metal contents of salts in general and to the content of substances such as nitrate, phosphorus, sulphur, chlorine and their compounds.

The presence of quantities of nitrate and phosphorus in domestic sewage is due to human metabolic processes, and, for phosphorus in particular, to the use of detergents. The different chemical formulae result partly from the breaking down by oxygen to which the original forms are subjected and to the length of time the sewage remains in the sewer.

Fig. 2 shows the different forms of nitrates found in urban sewage. The inorganic ammoniacal fraction is quickly and totally biodegradable, while the organic fraction is approximately only 15% so.

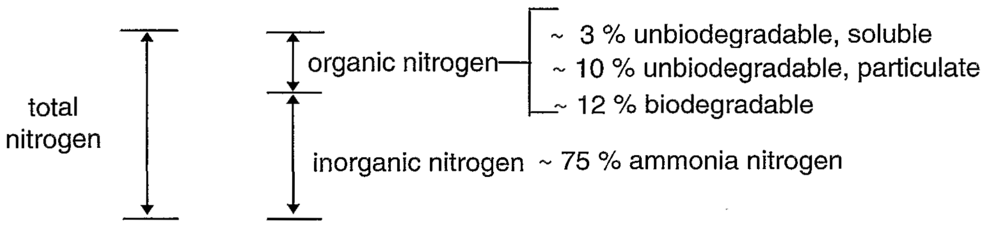


***Fig. 2** - Various forms of nitrogen in urban wastewater (Ekama et al., 1984).*

In general urban sewage contains all forms of phosphorus, while after biological treatment normally only ortho-phosphates are detectable.

Odours and tastes are associated characteristics. Industrial waste generally has a strong odour. The substances responsible for causing odour and taste are phenol compounds, sulphur compounds, iron, manganese, sodium chloride, calcium chloride, magnesium salts, acids, hydrocarbons, often present in wastes from gas and wood industries, refineries and various chemical industries (*Mendia, 1962*).

The colour of industrial waste is often a significant characteristic, especially in the textile industry, the paper industry and the food and clothing industries.

The colouring of industrial waste is caused by metallic ions: yellow and green colours are typical of chrome in its reduced form, blue of copper, green of nickel, yellow and brown of iron. Industrial dyes used in the textile, paper and leather industries produce very intense colours which linger even after repeated dilution. The colouring of wastewater can also be caused by suspensions of colloidal and oily substances, fats and lubricants. In other cases, the colour may develop in the water because of the effect of mixing different types of waste.

If sewage is to be reclaimed and used again it is important to analyse for the presence of pathogenic organisms. The enteric organisms present in sewage include viruses, bacteria, protozoa and helminths.

WATER AND WASTEWATER TREATMENT SYSTEMS

Natural water treatment systems

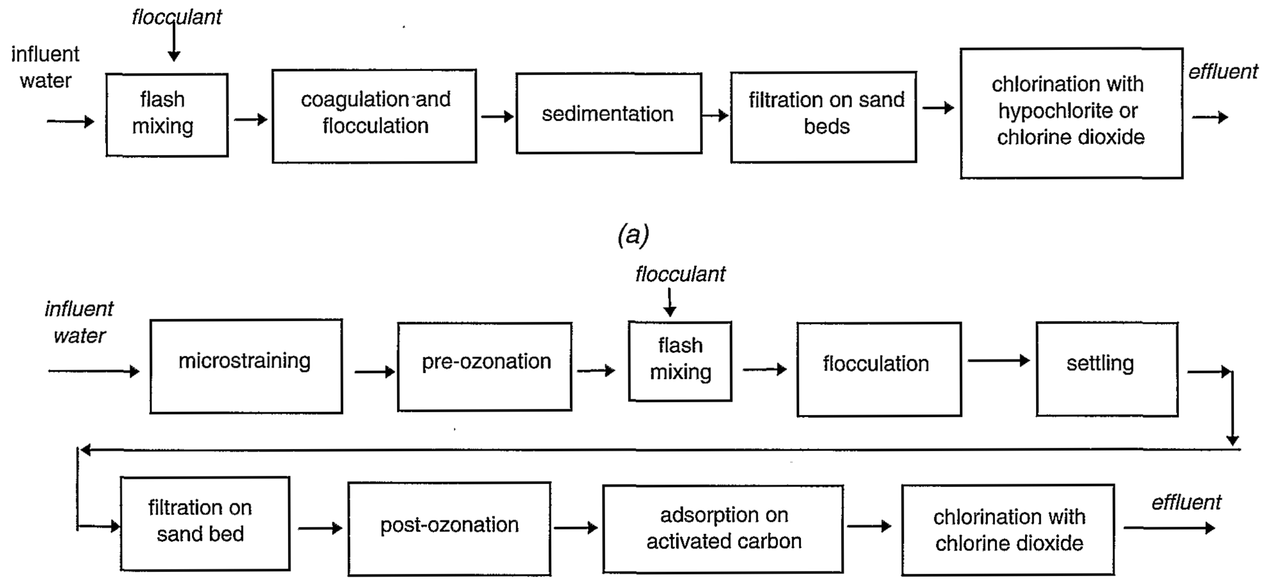
Continental natural waters are the classical source for supplies of drinking water. Spring water is the best drinking water because of the natural conditions which guarantee hygiene standards and generally preclude any specific treatment.

Also groundwater usually has good chemo-physical characteristics, because bacteria and viruses are eliminated by filtration with the movement of the water as are other polluting substances.

It is impossible to specify a precise method for treating surface waters because of the various qualities of waters that exist. Nevertheless, a series of conventional processes can be identified; such as screening, straining, oxidation, clariflocculation and filtration. These can be followed by specific stages for the removal of particular pollutants.

One of the most common and efficient methods for removing micropollutants is the process of absorption on activated carbon. This is often combined with an ozonization process. Stripping processes are used to remove volatile micro-pollutants such as solvents, chloride, ammonia and sulphide.

Natural lakes can be an excellent source of drinking water supplies if the chemical, physical and biological treatment systems naturally formed in the water mass keep the water clean. This depends on the hydraulic and geomorphologic characteristics of the catchment-basin (nature of the soil, the conveyance of solids etc.); on the type of vegetation and fauna composing the ecosystem of the basin and its surroundings; and finally - a point not to be overlooked - on the anthropic activity which exists in the basin. The treatment used for waters of good quality is generally that illustrated in Fig. 3a



(a)

(b)

Fig. 3 - Systems for treatment of lake and reservoir waters (Masotti, 1991).

Waters collected in natural lakes or artificial reservoirs where eutrophic processes take place are characterised by low quality. Under these conditions organic material is suspended in high concentrations, and the growth of certain species of algae, which thrive in particular conditions, obstructs the process of rendering the water potable. The sediment at the bottom provides conditions in which iron and manganese are readily made soluble. If intervention to clean the waters of the lake does not have a lasting effect a more complex treatment system must be designed, such as that illustrated in Fig. 3b.

Rivers provide a natural drainage system of the ground that they cross. In most cases, specially for the larger rivers, the great part of banks are densely urbanized and highly industrialized areas so that the surface water bodies are often the depository for polluting substances coming from the towns, industries, agriculture and cattle farming. Such a river water is difficult to treat because of the variability of the quality of the water, which is frequently turbid, and the considerable level of pollution (*Masotti, 1991*). The cost of treatment raises up, setting up plants for specific processes is expensive and the operating costs increase because of the large quantities of chemicals and products needed. So, the river water is often used for irrigation and industrial purposes utilizing more simpler systems..

Urban wastewater treatment systems

Solids and organic carbon removal

Systems commonly used for treatment of urban wastewater are constituted of primary treatment by settling, a biological second stage, and a tertiary treatment by disinfection, in some cases following a filtration process.

Primary sedimentation is most efficient in removing coarse solids. Biological processes are used to convert the finely dissolved organic matter in wastewater into flocculant settleable solids that can be removed in sedimentation tanks. These processes are employed in conjuction with physical and chemical processes and they are most efficient in removing organic substances that are either soluble or in the colloidal size range. Disinfection is generally operated by chlorination with Cl_2 or NaOCl.

The main systems for removal of solids, organic matter and pathogens are the activated sludge process, trickling filters, aerated lagoons, high-rate oxidation ponds, stabilization ponds. Stabilization ponds or aerated lagoons are most often used for small installations. Fig. 4 shows the lay-out of these processes.

The activated sludge process, or one of its many modifications, is most often used for larger installations. In some cases trickling filters are applied. Fig.5 shows the most common used treatment system.

Several process have been used for activated sludge. The most important are (*Metcalf and* Eddy, 1987): tapered aeration process; modified aeration process; continuous-flow stirred tank; step aeration process; contact stabilization process; extended aeration process; oxidation ditch; carrousel system; high-rate aeration process.

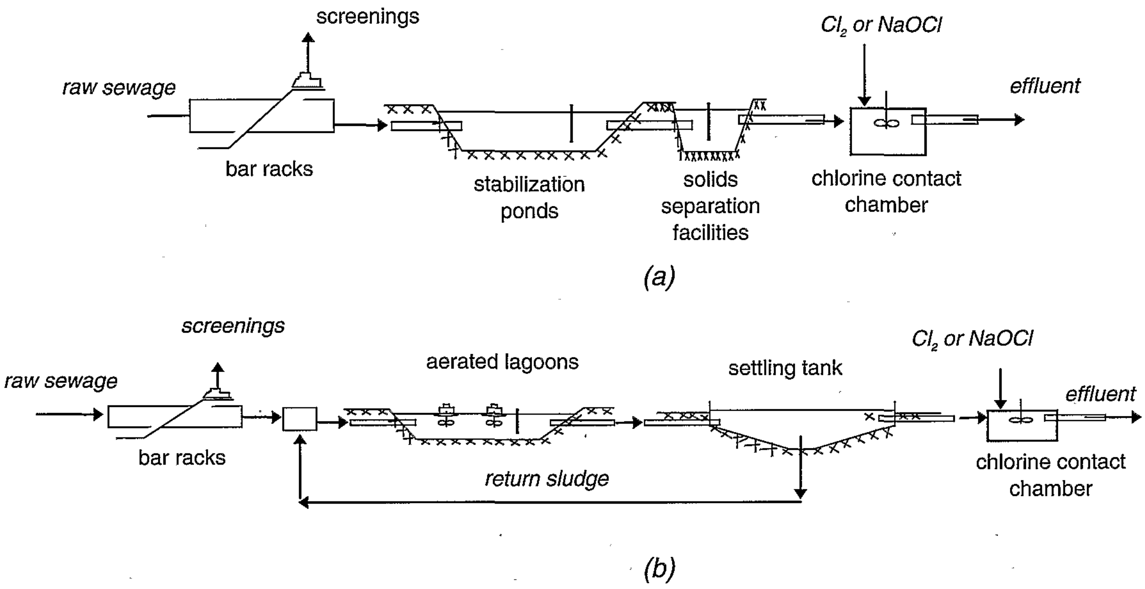


Fig. 4 - Flowsheet for stabilization pond (a) and aerated lagoon (b) processes.

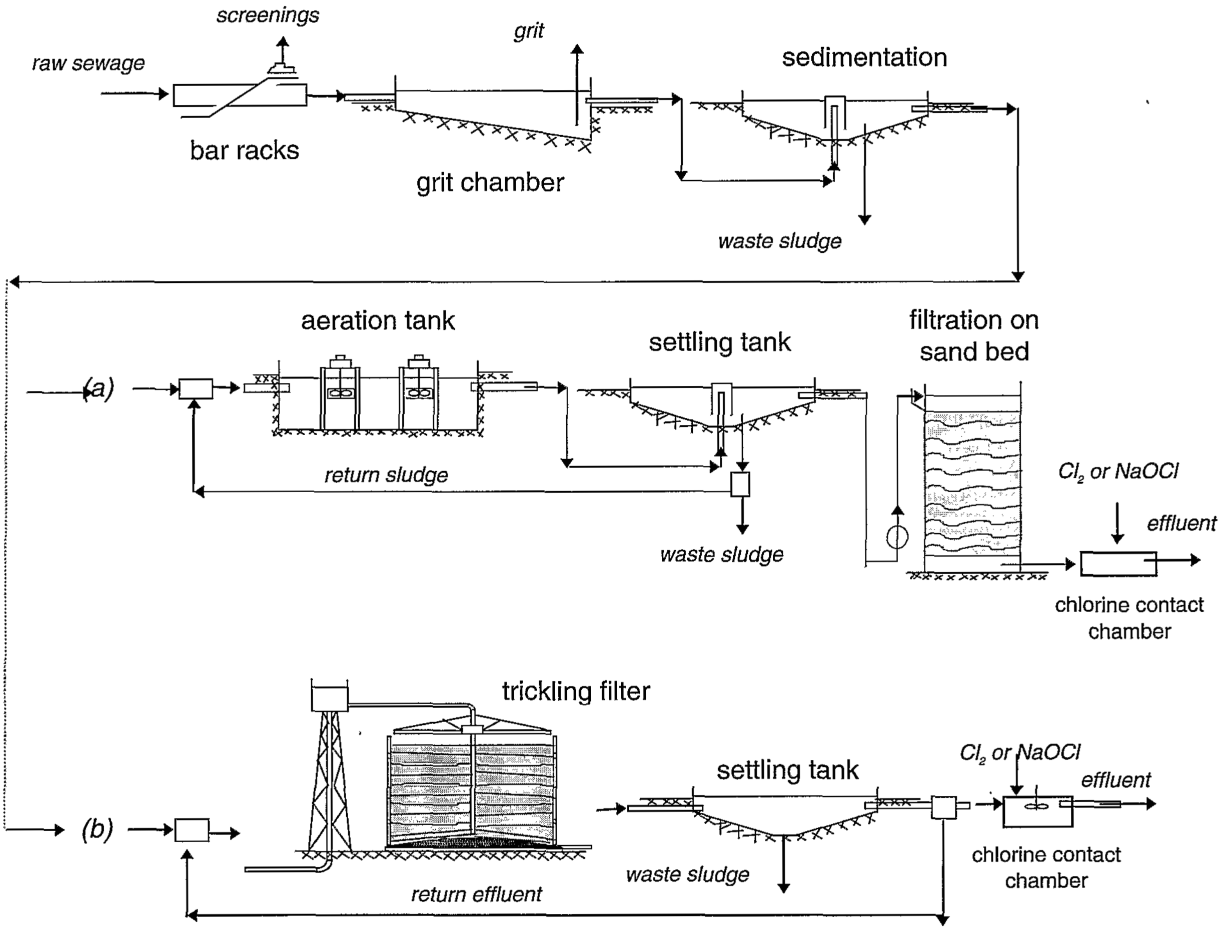


***Fig. 5** - Typical simplified flowsheets for biological processes used for urban wastewater treatment: (a) activated sludge; (b) trickling filter.*

Tapered aeration affects only the arrangement of the diffusers in the aeration tank and the amount of air consumed. It is widely used and, in a strict sense, is only a modification of the conventional process. The diffusers are spaced close together to achieve a high oxygenation rate and thus satisfy the demand. As the mixed liquor traverses the aeration tank, synthesis of new cells occurs, increasing the number of micro-organism and decreasing the concentration of available food. This results in a lower food to micro-organism ratio and a lowering of oxygen demand. The spacing of diffusers is thus increased toward the tank outlet to reduce the oxygenation rate. Two beneficial results are obtained: reduced oxygenation means that less air is required, thus reducing the size of blowers and the initial and operating costs.

The flow diagram for the *modified aeration* process is identical with that of the conventional or tapered-aeration processes. The difference in the systems is that modified aeration uses shorter aeration times, usually 1.5 to 3 h, and a high food to microorganism ratio.

The *step-aeration* process is a modification of the activated sludge process in which the settled wastewater is introduced at several points in the aeration tank to equalize the food to microorganism ratio, thus lowering the peak oxygen demand.

Flexibility of operation is one of the important features of this process.

The aeration tank is subdivided into four or more parallel channels through the use of baffles. Each channel is a separate step, and the several steps are linked together in series. A typical flowsheet for the process is shown in Fig. 6.

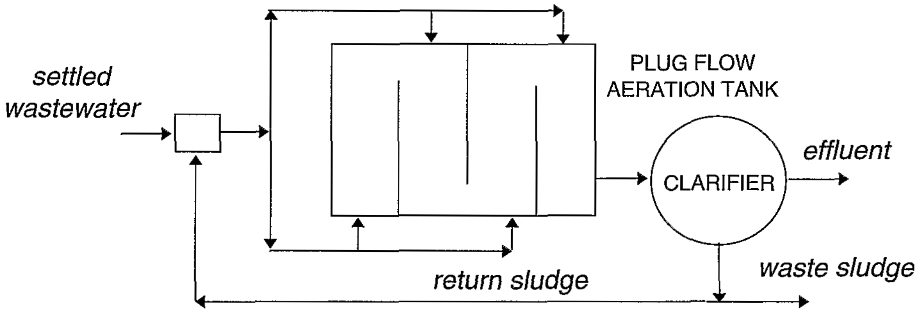


Fig. 6 - Flowsheet for step-aeration process activated sludge process.

The *contact-stabilization* process was developed to take advantage of the absorptive properties of activated sludge. It has been postulated that BOD removal occurs in two stages. The first is the absorptive phase, which requires 20 to 40 min; during this phase most of the colloidal, finely suspended, and dissolved organics are absorbed in the activated sludge. The second phase, oxidation, then occurs, and the absorbed organics are assimilated metabolically. In the contact-stabilization process, the two phases are separated and occur in different tanks.

The settled wastewater is mixed with return sludge and aerated in a contact tank for 30 to 90 minutes. The sludge is then separated from the treated effluent by sedimentation, and the returned sludge is aerated for 3 to 6 h in a sludge aeration tank. The flowsheet is shown in Fig. 7. The aeration volume requirements are approximately 50 percent of those of a conventional or tapered-aeration plant. It is thus often possible to double the plant capacity of an existing conventional plant.

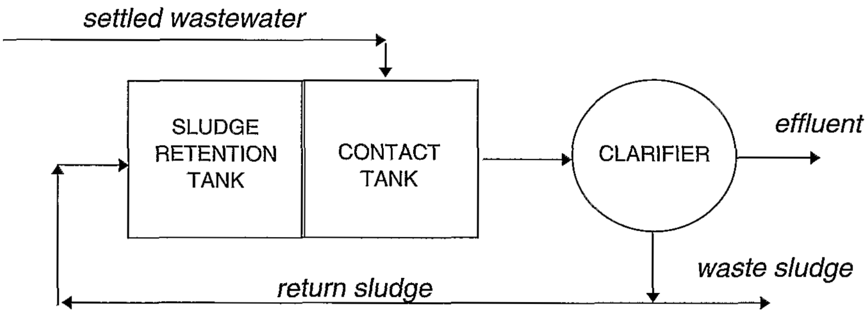


Fig. 7 - Flowsheet for contact stabilization activated sludge process.

The *extended-aeration* process operates in the endogenous respiration phase of the growth curve, which necessitates a relatively low organic loading and long aeration time. Thus it is generally applicable only to small treatment plants with capacities of less than 3800 m^3/d. This process is used extensively for prefabricated package plants that are provided for the treatment of wastes from housing subdivisions, isolated institutions, small communities and schools. Although separate sludge wasting generally is not provided, it may be added where the discharge of the excess solids is objectionable. Aerobic digestion of the excess solids, followed by dewatering on open sand beds, usually follows separate sludge wasting. Primary sedimentation is omitted to simplify the sludge treatment and disposal.

The oxidation ditch is essentially an extended aeration process. It is used in many small European towns and has found a variety of different applications in the United States. A schematic of an oxidation ditch with intermittent operation is shown in Fig.8.

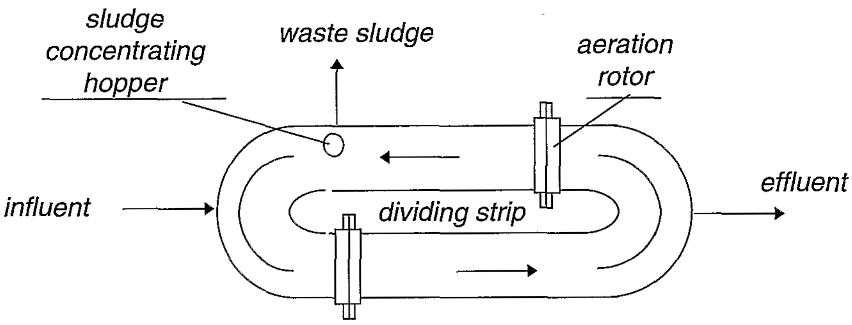


Fig. 8 - Oxidation ditch activated sludge process with intermittent operation.

It consists of a ring-shaped channel about 1 to 1.5 m deep. An aeration rotor, consisting of a modified Kessener brush, is placed across the ditch to provide aeration and recirculation. The screened wastewater enters the ditch, is aerated by the rotor, and circulates at about 0.3 to 0.6 m/s. The cycle consists of closing the inlet valve and aerating the wastewater, stopping the rotor and letting the content settle, and operating both inlet and outlet valves, thereby allowing the incoming wastewater to displace an equal volume of clarified effluent. Modifications can be made for continuous operation.

A technical modification of the original oxidation ditch concept, developed during the 1950s by Pasveer, is known as the *Carrousel* (Fig. 9). In this system, vertically mounted mechanical aerators are used to input oxygen and at the same time to provide sufficient horizontal velocity to the liquid to prevent solids from settling in the aeration channels.

For most applications, secondary settling tanks are the only major components needed in addition to the aeration channels. Settled sludge is returned from the settling tanks to the aeration channels. Excess sludge is wasted periodically. Sand bed drying is the most common method of handling the wasted excess sludge although other techniques may be used. The settling tank overflow may be disinfected and discharged into the receiving waters.

High-rate aeration is a modification in which high concentrations of mixed liquor suspended solids are combined with high volumetric loadings. This combination allows high food to micro-organism ratios (0.4 to 1.5) and long mean cell residence times with hydraulic detention times of 0.5 to 2 h. Adequate mixing in the reactor to effect oxygen transfer and to control floc size is achieved through the use of turbine mixers.

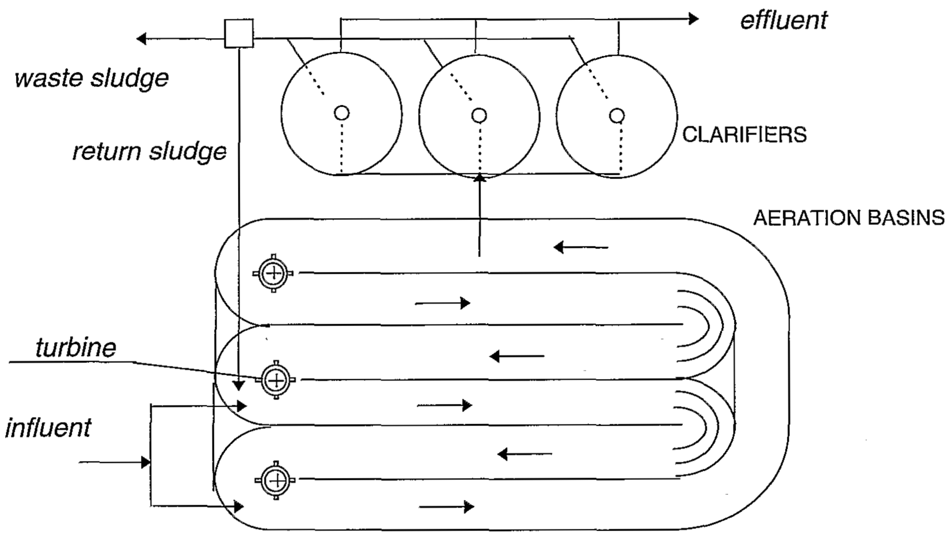


Fig. 9 - Carrousel activated sludge process.

Nutrients removal

The configuration of plants presently in use for the removal of nitrogen operate on the principle of separate and integrated biological processes, with internal and external sources of organic carbon. The plants using integrated processes with internal sources of carbon have proved to be the most economical and reliable. Other processes use an intermittent alimentation system achieving nitrification and denitrification simultaneously.

If it is not necessary to remove all the nitrogen, but merely reduced forms of it - organic and ammonia-nitrogen - then nitrification alone is sufficient. There are two fundamental operating schemes of nitrification regarding activated-sludge processes. These are illustrated in Fig.10 (*Canziani, 1990*):

a) "combined" process with oxidation of organic matter; both processes take place in the same tank;

b) "separate" process from the oxidation of organic matter; each process requires separate apparatus consisting of an aeration tank and a settler.

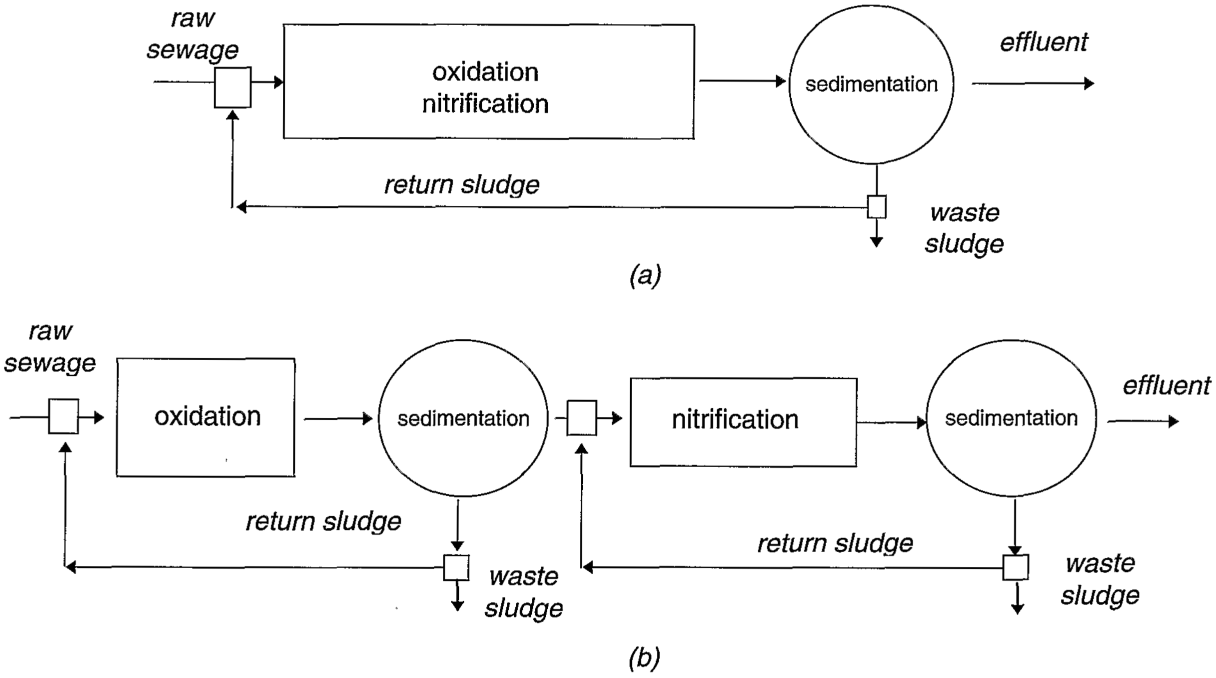


***Fig. 10** - Nitrification processes: (a) combined process; (b) separate process (Canziani, 1990).*

In the first process there is generally a bacterial mass containing a low percentage of nitrifying bacteria, because the BOD to nitrate ratio is initially high. With combined nitrification less surplus sludge is produced, there is more settled sludge, so plant and operating costs are reduced.

However, in the separate process a large portion of the organic substrate is removed in the first stage, and therefore in the nitrification stage the BOD to TKN ratio falls so that both the volatile solid nitrate portion and the speed of nitrification increase. The separate nitrification process is less responsive to variations in load as less dilution is operated; it is also less sensitive to the effects of toxic substances, which are partially neutralized by the heterotrophic biomass present in the first stage.

Both processes can achieve high levels of nitrification as long as the age of the sludge is maintained high, and the contact period between the bacterial mass undergoing aeration and ammonia-nitrogen is rather long to allow the oxidation of the latter.

- Removal of nitrogen in wastewater is operated by denitrification process, in which a specialised biomass converts nitrates in nitrogen gas.

Fig. 11 shows the lay-out of the post-denitrification process. Such process realises a first aerated stage, during which both nitrification of ammonia and oxidation of organic matter take place, and a second anoxic stage that produces denitrification of nitrates. The low efficiency of the process causes the limited interest for this configuration in full scale plants.

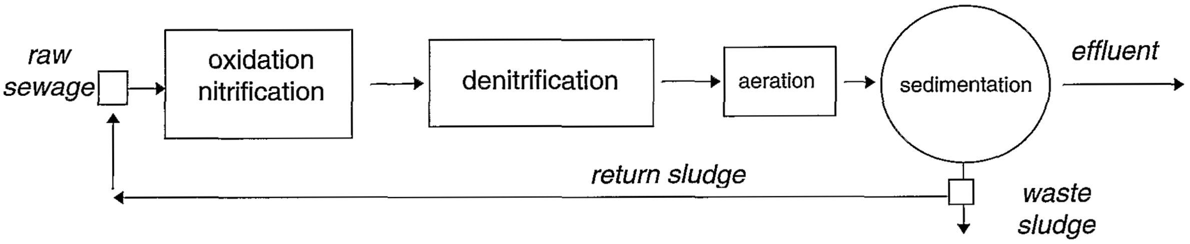


Fig. 11 - Lay-out of post-denitrification process.

Fig. 12 reports lay-out of the pre-denitrification process. During the first anoxic stage, biomass utilises organic matter in raw sewage for reduction of nitrates. The process operates oxidation of both organic matter and ammonia-nitrogen in the second, aerated stage. The latter is converted into nitrates. Nitrates are fed by recycle flow into the anoxic tank to be reduced.

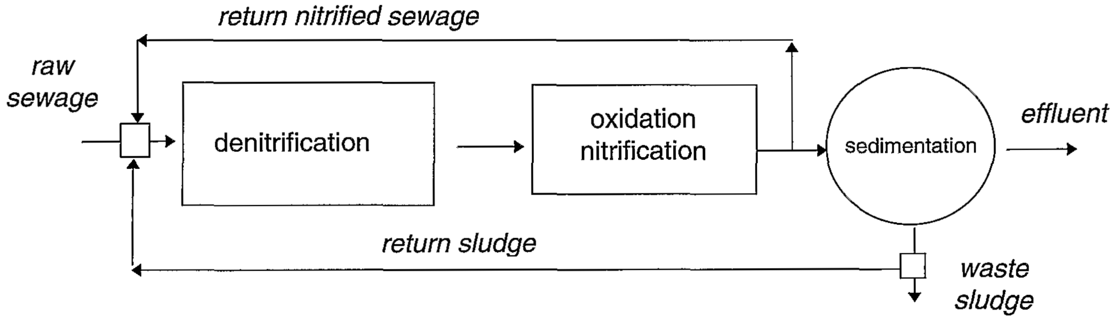


Fig. 12 - Lay-out of pre-denitrification process.

The high rate denitrification process is a combination of post and pre-denitrification processes. In such a process, both organic matter in raw sewage and endogenous carbon constitute the carbon source.

The simultaneous nitrification-denitrification process is operated with aeration and anoxic zones alternately in the activated sludge tank. Flow runs in a close pattern, and the mixed liquor is aerated and stirred in a specific point of the tank by mechanical aerators, such as rotating brushes or turbines. The process is generally operated in oxidation ditches and in Carrousel-type tanks. An important application of this type of process in full-scale was carried out in Austria, at the Vienna-Blumentat plant designed for 300,000 inhabitants. This plant, which has no primary sedimentation, includes screening and grit removal stages, two aeration tanks equipped with mechanical, rotating brushes, two end-stage settlers and a pumping station where the sludge is recycled.

There have been recent developments of techniques for the biological removal of phosphorus by means of the selection of bacterial species which accumulate this element (luxury-uptake). The operative processes can be classified in two principal categories:

- "full stream", in which the entire quantity of sewage undergoes anaerobiosis;
- "side stream", in which only part of the recycled sludge is treated.

The main "full-stream" processes are the *A/O* processes, the *Rotanox* process and discontinuous alimentation processes.

In the side-stream process quantities of sludge pass through a reactor - called a "stripper" - where they remain for some hours before being sent back to the aeration tank. Phosphorus is removed during the reactor stage. Research into the purely biological "side-stream" processes is still in its early stages.

The only side-stream process presently in operation is the *Phostrip* process. This process is not entirely biological as it uses chemicals to remove the phosphorus - lime is introduced into the final anaerobic reactor. The main advantage of this treatment compared with conventional chemical "full stream" phosphorus precipitation is that smaller quantities of lime are needed, and hence less sludge is produced.

Chemical phosphorus precipitation processes in conventional urban treatment plants, with primary sedimentation and biological oxidation with activated-sludge can be classified according to the point at which the precipitating agent is added (*Beccari et al., 1990*): pre-precipitation, when the addition occurs before the biological treatment; simultaneous precipitation, when the addition is made directly into the aeration tank or at least before the secondary sedimentation stage; post-precipitation, when the addition occurs after the biological treatment (Fig. 13).

Pre-precipitation ensures high levels of removal by using a suitable mixing recipient and adequate flocculation in the settler. The presence of different forms of ortho-phosphates mean that the removal of phosphorus is not altogether complete and therefore cannot undergo direct precipitation. Moreover, as a result of concurring reactions and variability of coagulant requirements the reactive consumption is greater than in the case of simultaneous precipitation and post-precipitation. In this process a reduction of the organic load takes place in the ensuing biological stage.

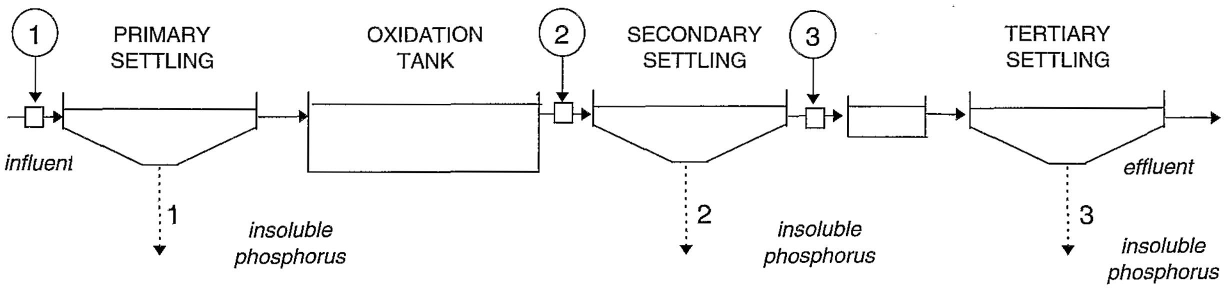


Fig. 13 *- Inlet points of chemical agents for the removal of phosphorus via chemical precipitation in a conventional plant for treatment of urban wastewater (Beccari et al 1990).*

In certain plants part of the dosage is added before the first settler and part before the second. The advantages of this operation are that it allows a more economical use of the reactive precipitants and gives considerable flexibility as the dosage can be modified.

The investment costs of post-precipitation treatment are higher because special structures have to be created. It is applied only in cases requiring extremely thorough removal.

The most frequently used procedure is probably that of adding a chemical agent directly into the aeration tank or immediately prior to the secondary settler. The simultaneous precipitation process is an efficient method of removal, superior, on average, to the process of pre-precipitation, in which the addition of mineral salts occurs, immediately after one of the entry points of the recycle flow; for example the flow of anaerobic supernatant from the sludge digester. This process seems to promote a more efficient removal of the BOD, of heavy metals and of pathogenic organisms, even though it induces an increase in the sludge volume index resulting in a higher concentration of suspended solids in the final effluent.

Reuse of municipal effluents

The most suitable use of municipal wastewater treatment plants effluents is agricultural irrigation. The accomplishment of this produces numerous advantages but requires a severe analysis of the effects on the people, soils and crops, and definition of the proper treatment process to get required quality level.

The main advantages of utilizing effluents for irrigation uses consist in the fact that many of the substances present in wastewater can be used as nutrients for crops, and would otherwise probably contaminate the water body receiver, and there is the additional advantage that less chemical fertilizers are needed.

The salinity level of wastewater and the organic and inorganic toxic compound content are usually not high enough to prevent its use for irrigation purposes. Nevertheless, it is advisable to check on the presence of these substances. Wastewater must be refined so that the concentration of suspended matter is brought down to a suitable level and its pathogenic load eliminated.

Simpler and less costly alternative systems have been tested, which eliminate clari-flocculation, but include the coagulation and flocculation stages in line.

The disinfection processes and the removal of suspended solids are especially important as many pathogenic agents are closely attached to solid particles or to colloidal agglomerates in suspension. It is essential that suspended solids are efficiently removed in order to ensure that the wastewater has been satisfactorily disinfected. The removal of phosphorus, when required, implies additional operating costs as the precipitation and disposal of chemical sludges are necessary.

The clari-flocculation stage, achieved through the processes of coagulation, flocculation and sedimentation, permits the removal of solids, principally of the organic nature, which are present in the secondary effluent. Filtration, following sedimentation or an alternative method, is an indispensable stage as it renders the wastewater limpid and therefore perfectly suitable for disinfection. Moreover, this is an essential condition for the destruction of viruses and parasites, which are extremely resistant to disinfectants. Filtration is most commonly achieved by using homogeneous, single-layered sand filters or the dual-media type filters, containing a mixture of sand and anthracite, which also permit the removal of soluble organic compounds, at moderate, rather than high, operating costs (Lopez and Liberti, 1992).

Disinfection takes on a very important role, especially with regard to the very restrictive limit values set by law concerning pathogenic loads. Disinfection is achieved through specific processes using radiation, such as UV rays, or chemical agents, including chlorine, ozone, bromine and iodine. The most frequently used disinfectant is chlorine because it is easily analyzed and economical to use.

Often the destruction of the pathogenic load is inadequate, sometimes because of the limited diffusion of disinfectants in wastewater or because of the contact time with pathogenic organisms. It is often necessary, to add high doses of chlorine in order to obtain acceptable levels. Consequently, it is necessary to operate a subsequent dechlorination stage to reduce the level of residual chlorine which could damage the crops. Different agents can be used to achieve this process. Those most commonly used are sulfur dioxide, which has the advantage that it can be administered using the same apparatus used for chlorine, and sodium sulfite, which is cheap and highly stable.

Fig. 14 shows intensive advanced treatment for secondary effluent which involves all the processes described. Both setting-up and operational costs are high, particularly those connected with the sedimentation tanks, with the use of chemical coagulants and the handling of the quantities of sludge produced.

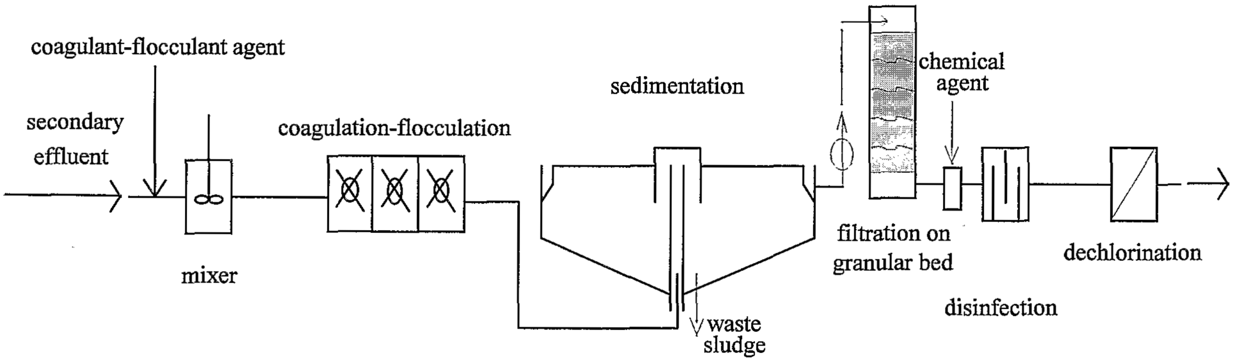


***Fig. 14** - Layout of an advanced process (Asano et al., 1992).*

Although complex systems such as that illustrated guarantee the standard of refinement, current tendencies prefer more simple systems, which may not involve the use of reactors in the coagulation-flocculation, sedimentation and dechlorination stages (*Nurizzo and Mezzanotte, 1992*).

The process of filtration by contact illustrated in Fig. 15*a*, and direct filtration illustrated in Fig. 15*b*, were experimented on in California.

The processes operated with dosages of alumi-nium salts in the 2-5 mg/l range and of chlorine in the 5-10 mg/l range, with 90 minutes of contact time (*Asano et al., 1992*). The results show that the simplified systems adopted by the Department of Health of California as an alternative to the intensive process are efficient. A 10 NTU turbidity value can be considered the limit indicating the economic advantage between the intensive process and the contact or direct filtration processes.

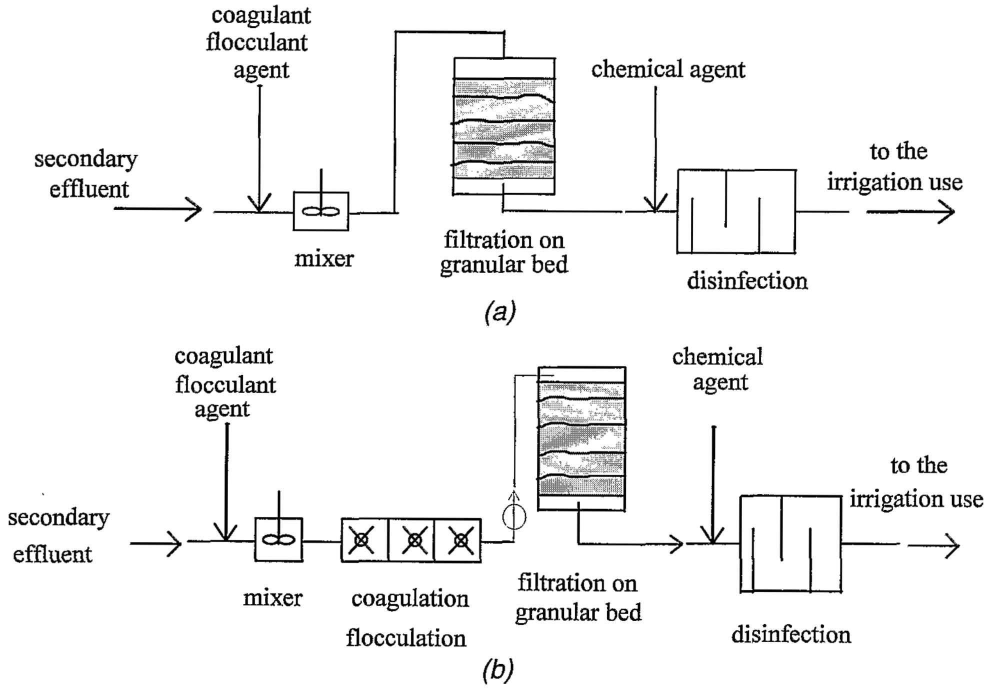


***Fig. 15** - Lay-out of advanced filtration process: (a) contact process (b) direct process (Asano et al., 1992).*

The lack of abundant water supplies could limit industrial growth and for this reason the possibility of having access to water supplies could act as an incentive to the growth of certain industrial areas.

The advantage to industry of using urban wastewater should be determined in the light of a number of fundamental aspects such as (*Mendia, 1969*): the distance between the industry and the source of the wastewater supply; any cleaning treatment at the expense of the industry; the absence of alternative water supplies; prospects of increasing productivity in the future without the possibility of having access to further supplies. Treatment required in the tertiary stage is on the whole very similar to that illustrated for reuse in agriculture.

Indirect reuse is obtained by recharging of ground water. This process prevents depletion taking place by recovering water resources that otherwise would be lost. The recharging of ground water with refined wastewater could become a reality in many arid zones. Nevertheless, the viability of its application must be analyzed in the context of each locality, which may be quite different from the localities where refining and recharging plants have already been installed; and moreover the possibility of growth from the reuse of refined sewage should be analyzed.

Recharging methods can be applied to both superficial and deep waters; natural water can be used as well as purified wastewater provided that all the necessary precautions have been taken and thorough checks carried out. If purified wastewater is used, the refining processes should focus mainly on the removal of suspended solids, the destruction of toxic solutes and on the microbiological load.

The type of tertiary treatment necessary will depend not only on the quality of the purified sewage and the selected feeding system, but also (in the case of recharging by infiltration) on the quality of the ground and of the aquifer and hence on the system's capacity for natural purification, especially where organic and inorganic micro-organisms and dissolved solids are concerned.

Full-scale plants have been in operation for several years now both in the United States and in Israel. These plants can handle a daily load of about. 350,000 m^3, used chiefly to replenish groundwater supplies and, in some cases, to provide a barrier against the intrusion of salt water.

Fig. 16 shows the refining process for purified civil waste and the recharging of groundwater in the Dan region, which involves addition by infiltration in sandy ground which is partially muddy with layers of clay (*Treweek, 1985*). The process operates using hydraulic loads for infiltration of between 10 and 160m^3/m^2 per year, on a cyclic basis, adding a load every third day. Data resulting from this plant highlights the important purifying effect of the ground, which is highly permeable.

Fig. 17 shows the Cedar Creek (United States) plant where infiltration is operated in ground consisting of a mixture of sand and gravel with clay deposits in the first layer, and diffusion is used to reach deeper layers of extremely low permeability.

Principally experimental surveys of reverse osmosis have been carried out in the study of tertiary treatment for civil wastewater (*Nusbaum et al., 1970; Cruver and Nusbaum, 1974; Lauer et al., 1984*). Given the high costs involved, the application of this process can be justified in cases where the removal of soluble substances is essential, as with the use of effluents destined for the recharging of groundwater and irrigation use. The quality of water obtained from the process of reverse osmosis is such that it can be used directly for drinking purposes. However, this process is only used in emergencies because of the rather complex and burdensome pretreatment requirements that are essential in securing reliable standards (*Boari and Mancini, 1990*).

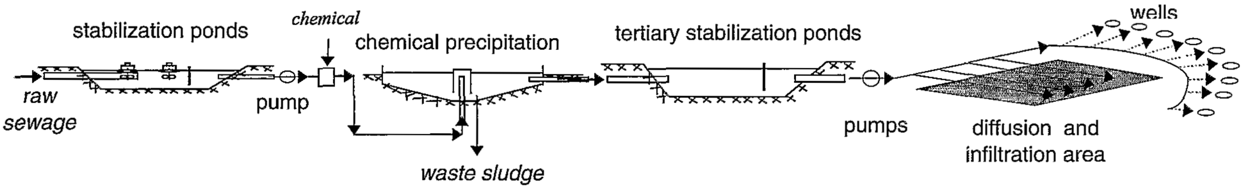


Fig. 16 - Lay-out of refining process for civil waste and recharge of groundwater at the Dan plant, in Israel (Treweek, 1985).

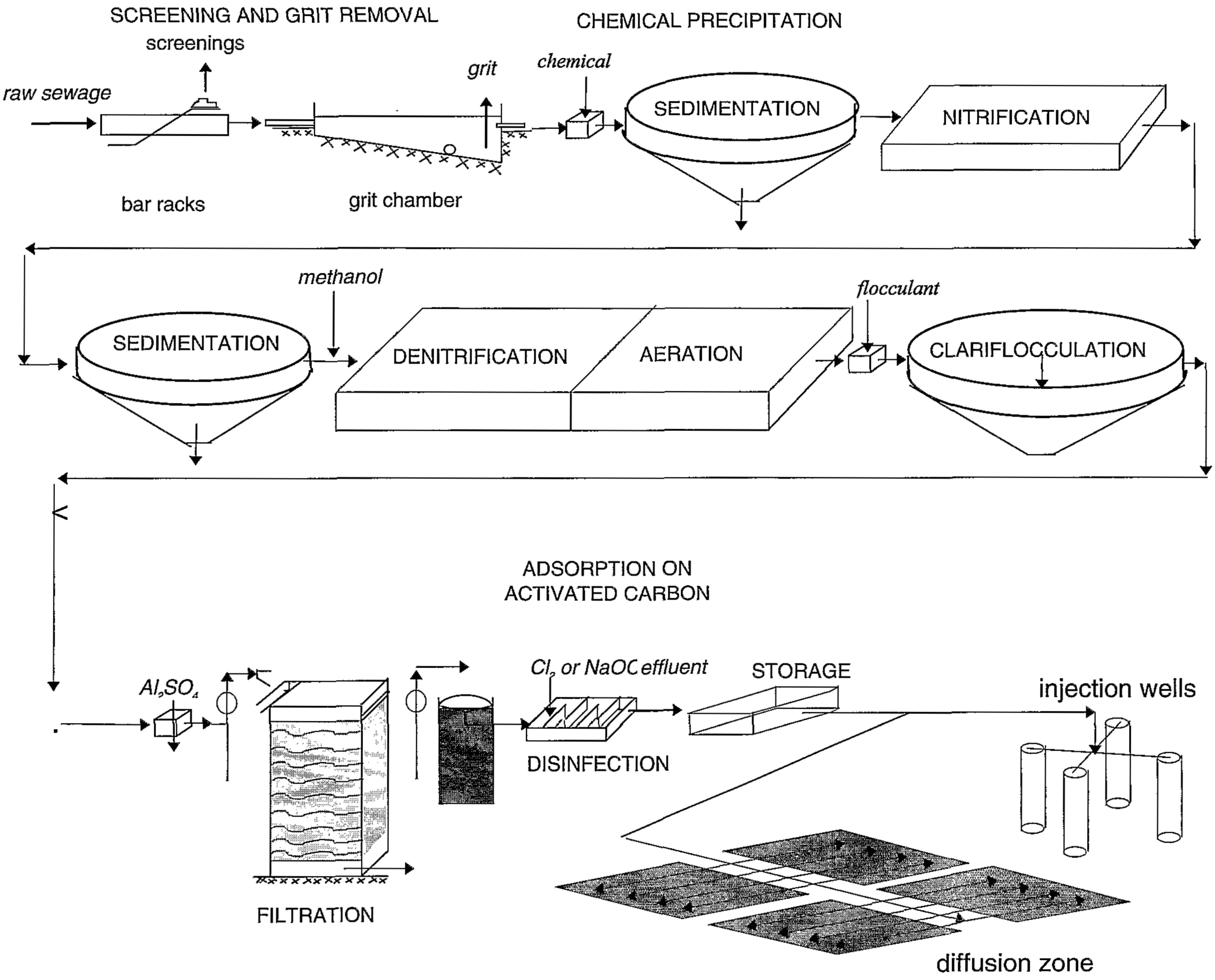


Fig. 17 - Lay-out of Cedar Creeek plant for recharge of groundwater by infiltration and aspersion of treated urban wastewater (Treweek, 1985).

Industrial wastewater treatment

Treatment of wastewater produced by an industry takes place in a plant purposely built in the area of production, or after transport in the sewage system by purpose-built structures within the urban waste treatment plant. Moreover, treatment carried out within the area of production can confer those characteristics on the industrial waste that allow it to be deposited directly into the final receiver, or even used again, either completely or partially, in the productive cycle, hence giving the wastewater the necessary qualities for its discharge into the public sewage system.

The treatment of industrial wastewater involves the same processes as those used in the treatment of civil water. However, because of specific compositions, the systems tend to vary.

The chemo-physical type processes are especially important for the removal of inorganic matter. The basic processes used are (*Mendia, 1962*):

- neutralization
- the reduction and oxidation of inorganic compounds (such as chromic salt, chromates or cyanate, to cyanide) and also of organics, with ion or radical substitutents;
- the precipitation of cations and anions in the form of insoluble compounds, such as the precipitation of metals, as hydroxides, and chromates (for example barium chromate) and cyanides (such as ferrocyanide).

The simplest plant system for neutralization is that in which the wastewater comes into contact with a considerable amount of reagent. All that remains is to determine the length of time that the wastewater is detained in the tank, where falling sludge is collected on the hopper bottom.

Lime in the form of milk of lime is the chief agent used in the neutralization process. In some cases it is better to use carbonate or sodium hydroxide to prevent the precipitation of calcium sulfate.

When treating corrosive waste it is advisable to add a neutralizing reactant during the first stage, so reducing the quantity of non-corrosive apparatus and tubing required.

The efficiency of urban wastewater treatment can be adversely affected by highly acid or basic waste containing toxic compounds with an elevated solid, fat or emulsion content, inflammable material, clay sand or abrasive particles, not treated previously.

In some industries the treatment of waste is limited to the primary stages of screening, grit removal, flotation, degassing, sedimentation and neutralization in order to reach the standards necessary for discharge into an urban sewer system.

Treatment of industrial wastewater which by nature is substantially organic can be carried out according to the treatment systems generally used for the purification of domestic sewage in appropriately designed plants.

Industrial wastewater with a high content of organic matter, characterized by average concentrations of COD higher than about 3 g/l, can be treated using systems involving anaerobic processes in the central stages, conducted in traditional digestors or advanced reactors *(Lettinga et al., 1980, 1989; Lettinga and Hulshoff Pol, 1986*). Compared with aerobic processes, these processes produce less biomass - the availability of substrate being equal - because of the different ways in which micro-organisms use energy, and therefore, a smaller quantity of biological sludge. Toxic substances can cause more damage than in processes where aerobic biomass is used. Anaerobic bacteria, especially obligatory anaerobic groups such as methanogens, are sensitive to environmental variations and are more affected by toxic substances.

Treatment of high-organic wastewater in anaerobic advanced reactors, such as UASB and fluidized bed reactors, could be considered, along with urban wastewater. In this case, the low organic load of wastewater should be increased. The nutrient content of the latter could increase the low nutrient content of industrial wastewaters. Research has been carried out on combined anaerobic biological processes for urban sewage and high organic wastewater, such that deriving from agro-industries such as olive oil mills and cheese production (*Boari et al., 1984, Carrieri et al., 1988, 1993; Boari and Mancini, 1990*). Researches on olive oil mill effluent anaerobic codigestion with urban sludge have shown very promising results, but successful operation needs to be confirmed on full-scale plants (*Carrieri et al., 1986, 1993; Boari et al., 1993*).

Co-digestion processes are based on the principle that the limiting stage in the stabilization of surplus sludge is hydrolysis of organic material in particulate form. This is dissolved and converted by groups of hydrolytic *bacteria (De Baer et al., 1981, 1982*). By adding organic material in soluble form the volumetric load of mixed digestors can be increased, without overcharging the hydrolytic biomass but at the same time promoting greater activity of acidifying bacteria and of methanogen bacteria. Fig. 18 illustrates this process.

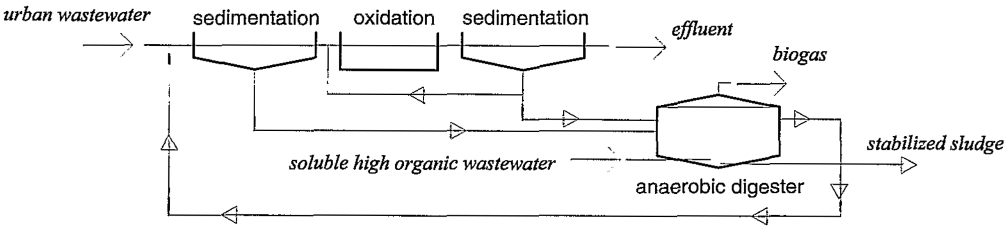


***Fig. 18** - Combined anaerobic digestion process for urban sludge and dissolved high organic wastewater.*

Yet, for operation of an advanced anaerobic reactor, a separation pre-treatment has generally to be provided, to decrease the suspended solids contents of the anaerobic influent (*Boari et al., 1993; Mancini et al., 1994*). Such processes could be chemo-physical, as clariflocculation, but this requires too much land area; more suitable are processes mechanical, as microstraining or centrifugation. Fig. 19 shows the lay-out of a processes with an advanced anaerobic reactor.

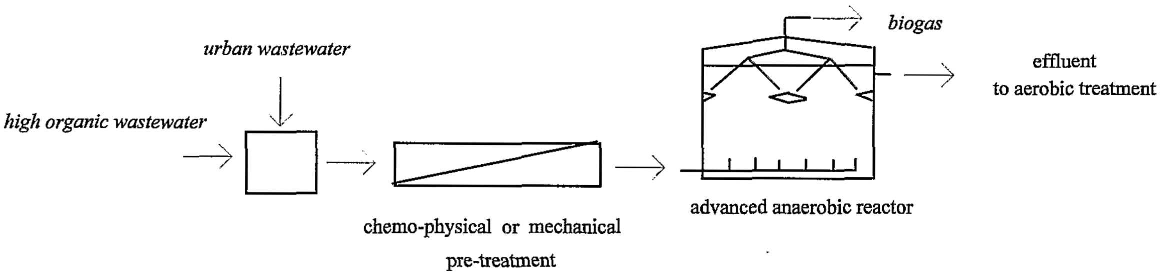


***Fig. 19** - Anaerobic digestion process for high-organic wastewater and urban wastewater.*

Desalination of salt water

The growing increase in demand for water in the 60s led to the idea of using seawater as a last resource. Consequently suitable desalination processes have been tested, with the aim of producing water with a low salt content using seawater or brackish water as the raw material. The first plants were built in the United States, Russia, Israel and Kuwait. All the desalination plants now in operation have been built during the last forty years.

Sea water and brackish water cannot be used directly. Therefore, desalination processes must guarantee the removal of the salt content in accordance with concentration values indicated by common practice. ***Table 4*** indicates values of chloride concentration for common use.

Table 4 *- Values of chlorides concentration for uses of water (Heitmann, 1990).*

use	chloride concentration (g/l)
potable	0.20 - 0,60
industrial	0.02 - 0.75
irrigation (according to type of soil and crops)	0.15 - 3.00

The widespread use of desalination as a primary water source has not come about because of the increased costs of raw material, personnel and, above all, of energy, which have brought about considerable increases in the costs of producing desalinated water. Today, the cost of desalinated water is much higher than that of waters from conventional sources.

The most widespread processes of desalination adopt the principle of evaporation and inverse osmosis. These processes, which are not widely applied in the European Community, assume great importance in the Middle East, where 60 % of the world desalination capacity is located. There are three main processes used to desalinate seawater by evaporation:

- multiple-effect long-tube distillation;
- multistage flash-distillation;
- vapour compression distillation.

These processes are based on the principle that the boiling temperature of water decreases with diminution in pressure. The first two make use mainly of heat energy and the third of mechanical energy.

Multiple-effect plants (Fig. 20) consist of a series of reactors of gradually decreasing pressure. Inside each of these there are a series of long, vertical, tubes which divide the reactor into two zones: a condensation zone into which vapour for heating is admitted, and an evaporation zone into which the saline solution passes.

Vapour for heating produced in a special boiler is sent into the first reactor; as the vapour condenses it produces heat energy which brings the sea water around the tubes to boiling point.

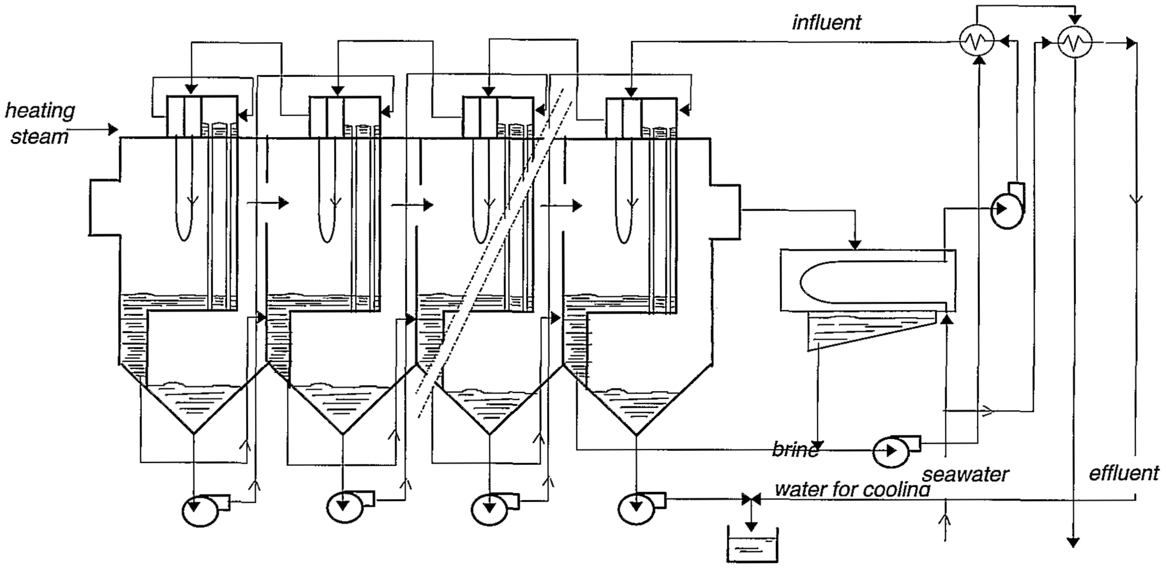


Fig. 20 *- Multiple-effect long-tube distillation (Chiappa et al., 1970).*

Vapour produced during the boiling stage is used for heating purposes in the following stage. During the last phase, in which waste brine is extracted, vapour is condensed by incoming seawater, which in turn is heated.

Multistage flash-distillation plants (Fig. 21) also consist of a series of chambers of decreasing pressure. The seawater is usually brought to a temperature of between 100 and 200°C.

In both the multistage flash-distillation process and the multiple-effect long-tube vertical distillation process the greater the number of stages the higher the quantity of distilled water produced per unit of heat energy provided by the boiler. On the other hand, the higher the number of stages the greater the cost of setting up the plant. The number of stages necessary for each plant is determined on the basis of a techno-economic analysis. Multistage flash-distillation processes usually involve a sequence of 10-12 reactors while multiple-effect long-tube vertical distillation processes involve a series of 30-40 chambers. These plants produce 10-12 kg of distilled water for every kg of vapour supplied by the boiler.

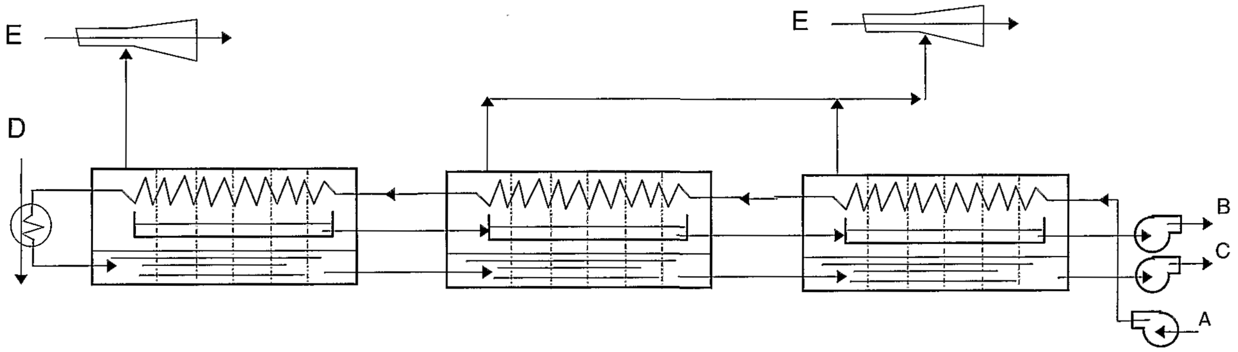


***Fig. 21** - Multistage flash-distillation plant (Chiappa et al., 1970).*
A, influent; B, end product; C, brine; D, heating vapour; E, medium pressure vapour.

A cost evaluation on the relative plant costs of multistage flash-distillation type processes referred to the situation in Italy (*Di Pinto, 1988*) suggests 3.3 to 4.4 US$/m^3 costs, inclusive of operating costs (combustibles, personnel and other costs) but depending on the capacity of plant.

Plants using the vapour compression distillation process, illustrated in Fig. 22, consist essentially of a reactor in which sea water is kept at boiling point. The vapour produced is removed and compressed, generally in a centrifugal compressor.

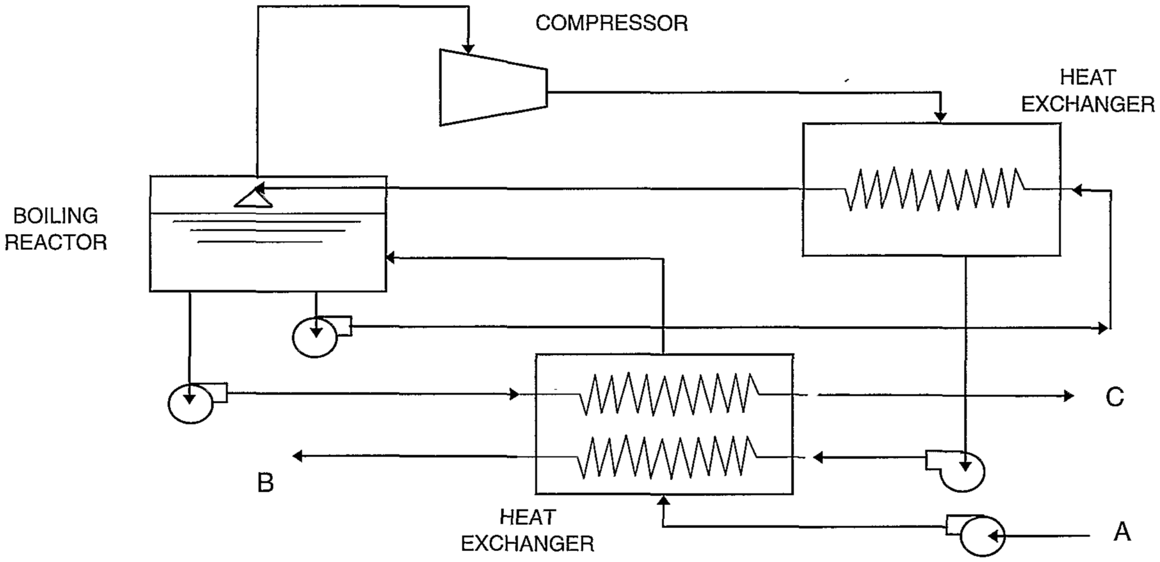


***Fig.** 22 - Diagram of a vapour-compression distillation plant (Chiappa et al., 1970). A, influent; B, end product; C, brine.*

Usually, if the distilled product is to be used for drinking purposes it must undergo secondary treatment. In some cases, secondary treatment is also necessary for products derived from reverse osmosis plants. Although distillate can be mixed with seawater to give it the qualities of drinking water, water produced in this way has a very bland taste. A more efficient method is that of hardening the water by adding calcium carbonate and magnesium.

Membrane processes are used on a large scale to desalinate brackish water and also - by reverse osmosis - seawater. Problems caused by membrane soiling due to the precipitation of barely-soluble matter or by biological processes have considerable influence on the operating process and the water may require suitable pre-treatment. Semi-permeable membranes are used in reverse osmosis processes, and pressure acts as a driving force. In processes involving electrodialysis electrically charged membranes are used, and the driving force is electrical energy.

Reverse osmosis processes (Fig. 23) depend on the properties of certain types of membrane which allow water to pass through them, but retain a high quantity of the salts dissolved in the water. Both these and the cellulose acetate membranes are called "semipermeable". This process has been in use for a long time for the desalination of brackish water, of low salt content, for which relatively low pressure operations can be used.

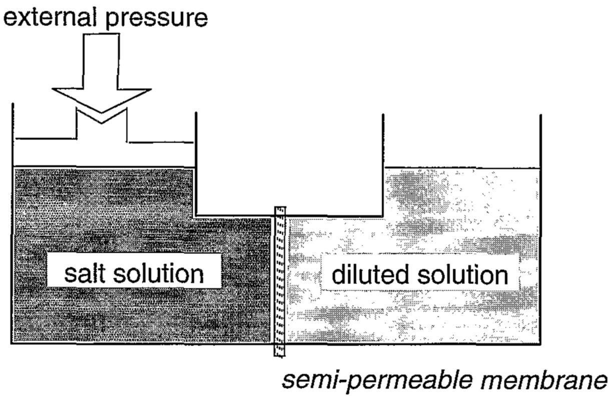


***Fig.** 23 - Principles of the reverse osmosis process (Heitmann, 1990).*

Electrodialysis plants consist of a series of cells, located one next to the other. Their walls are made of electrically charged membranes and are alternately permeable to anions and cations (Fig.24). When the cell pack is subjected to a field of continuous current the ions migrate towards the opposite electrodes. As the membranes are alternately permeable to anions and to cations there is an accumulation of ions in one cell and a reduction of ions in the next cell. When water is then extracted from the cells two flows are produced: one with a high salt content, which constitutes the brine waste and the other having a low salt content constitutes the product.

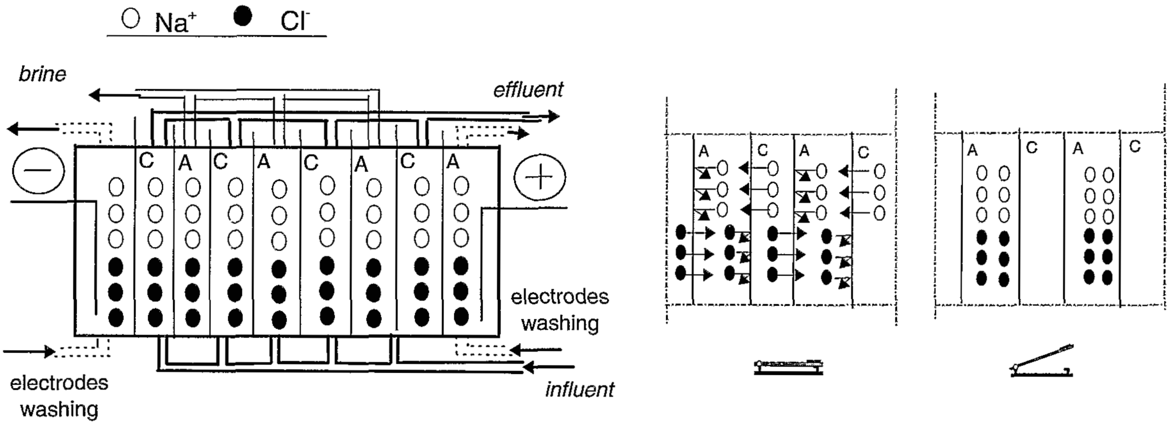


Fig. 24 - Principles of water purification by electrodialysis (Boari and Mancini, 1990).

Particular attention must be paid to the problems of scaling and plant corrosion. If suitable materials are used corrosion can be reduced.

Calcium sulfate scaling is especially common in evaporation plants. The solubility of this compound has a limiting effect on the maximum concentrations that can be achieved and on the evaporation temperature. Precipitation of calcium sulfate can only be avoided by preventive elimination of calcium ions and of sulfate ions. If these ions are not in solution, a greater concentration in the residue can be obtained by using higher evaporation temperatures. These ions can be removed by precipitation or ion exchange.

By preventing the formation of deposits the best possible exchange of heat across the surfaces can be guaranteed, as well as a rise in the maximum operating temperatures and maximum cycle efficiency.

Ion exchange processes are used for the desalination of water with a low salt content. Plants consist of a series of columns for anionic and cationic exchange. When water passes through the columns, the ions in the salt contained in the water are exchanged with the hydroxyls and with the hydrogen ions. When the exchange resins have been used they are regenerated using alkaline and acid solutions.

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