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TECHNIQUES OF REDUCING POLLUTION IN WASTE DISCHARGES (CONVENTIONAL SYSTEMS, ADVANCE WASTE-TREATMENT METHODS)

by

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I INTRODUCTION

The purpose of this paper is to review the conventional methods of wastewater treatment and then to provide some insight regarding more recent methods. The latter are generally referred to as contemporary or advanced wastewater treatment.

In general, all processes of wastewater treatment may be grouped into physical, chemical or biological types of processes and one or more of these processes may be employed to achieve a desired effluent product. This classification grouping is most appropriate in the study of the individual processes, however, for design purposes, it is more common to refer to treatment as primary or secondary. Beyond secondary, tertiary or extended treatment may be provided. The discussion given below follows this design approach. The coverage here is intended to provide conceptual information rather than detailed design data.

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II CONVENTIONAL WASTEWATER TREATMENT

Primary Treatment

The basic objective of primary treatment for domestic sewage is to remove suspended solids and clarify the wastewater so as to be suitable for biological treatment. However, prior to sedimentation, it is normally necessary to provide some pre-treatment including screening, grit removal and comminution. In certain cases, pre-treatment may include grease and oil removal, pre-aeration where anaerobic conditions have developed, chlorination for odour control, pH adjustment, etc. depending on the character of the wastewater.

Primary Sedimentation

Primary sedimentation of raw sewage is generally expected to remove from 50 to 75 per cent of the total suspended solids, from 90 to 99 per cent of the settleable solids and from 30 to 35 per cent of the total organic matter.

In certain cases, chemicals may be employed to improve the degree of primary treatment. Chemical precipitation or flocculating additives, such as polyelectrolytes, generally improve the degree of suspended solids removal. However, the increased removal must be balanced against the added cost and for most domestic wastewaters, it is not economical.

Two approaches for the design of primary sedimentation are commonly employed. The most common is to size the tank on the basis of surface loading; for example, rates in the range of 600 to 1 200 gpd/sq.ft. of horizontal area are commonly used based on the average design flow.

A second approach is to size the volume required on the basis of the period of sedimentation; for example the period may be in the range of 30 minutes to perhaps two hours. The removals of course increase with the length of the period.

For both design approaches, data are available in various references for estimating the removals to be expected using various loading parameters. Perhaps the best source of design data in the USA is the manual of practice entitled "Design of Sewage Plants" available from the Water Pollution Control Federation or from the American Society of Civil Engineers. It is also advisable to carry out settling tests on a pilot plant scale or in bench tests if the settling characteristics of the wastewater are not well established.

Either a circular or rectangular tank design may be used. Both give satisfactory results if properly sized. It is important that they be of standard dimensions so that the available mechanical sludge removal and skimming equipment can be installed. Before proceeding, the design engineer should accumulate equipment drawings and design data from the companies which could be expected to provide the required mechanical and electrical equipment.

So as to minimize the concentration of suspended solids in the effluent overflow from the tank, it is best to limit the rate of flow over the effluent weir. Generally rates in the range of 10 000 to 15 000 gpd/ft. of weir are recommended.

Secondary Treatment - Biological Systems

The portion of the organic content of the wastewater which is finely suspended or dissolved and not removed in the primary process, is treated by secondary treatment. The generally accepted forms of secondary treatment now in use include trickling filters, activated sludge, waste stabilization ponds and aerated ponds. All of these systems will be recognized as employing biological processes in one form or another. Basic design considerations for trickling filters and the activated sludge process are discussed below. Waste stabilization ponds and aerated ponds are discussed in another paper of this Seminar.

Trickling Filters

In trickling filter treatment, the wastewater is applied uniformly to the surface of a filter bed. The filter bed may be of conventional media such as stone and slag or more recently manufactured plastic media have found accepted popularity. The advent of the use of manufactured plastic media has been the most significant innovation in trickling filters since their introduction in the USA in about 1908. Whereas media depths were previously limited to a maximum of about 10 ft. with stone, the plastic media are being used in towers which may be 20 feet or more in depth and at increased loading rates. Previously, it was considered that trickling filters were generally limited to populations up to perhaps 200 000 because of the area requirements, however, the tower concept now minimizes this factor. The efficiency of trickling filter plants may range from 60 to as high as 95 per cent depending on the design parameters employed.

Classification of Trickling Filter Systems

The classification of trickling filters is based on both hydraulic and organic loading rates generally as in Table 1. Table 2 provides physical data on the various types of media including the more recent units of plastic and redwood.

TABLE 1

CLASSIFICATION AND DESIGN PARAMETERS FOR TRICKLING FILTERS

Design Parameter	Classification: Low Rate	High Rate	Roughing and Synthetic Media
Hydraulic loading gpd/sq.ft.	25 - 100	200 - 700	up to 3 000 or more
Organic loading lb/BOD/1 000 cu.ft.	5 - 25	25 - 90	up to 300 or more
Depth, ft.	6 - 10	3 - 8	up to 20 or more
Recirculation	None	1 - 4	1 - 4
Hydraulic application (dosing)	Intermittent	Continuous	Continuous
Nitrification	Extensive	At low loadings	low depends on loading
BOD removal through filter only, in per cent	up to 95	up to 95	

TABLE 2

TRICKLING FILTER MEDIA PHYSICAL CHARACTERISTICS

Media	Approx. Unit Size	Bulk Unit Wt.	Void Space	Specific Surface Area
	inches	lb/cu.ft.	per cent	sq.ft./cu.ft.
Rock or stone	1 - 4	85 - 90	43 - 47	13 - 20
Slag	2 - 3	66 - 68	48 - 50	18 - 20
Vinyl Plastic	48 x 24 x 24	2 - 6	94 - 97	25 - 30
Redwood	48 x 48 x 36	10	-	14

Flow Systems

Various combinations of trickling filter flow systems are in use. The systems may be of a single stage type or a double stage type with recirculation. A number of the common flow combination are shown in Figure 1. Increased removal efficiencies may be gained through the use of the two-stage system.

Design Approach

The efficiency of a trickling filter is dependent on a number of variables including type and volume of filter media, filter depth, hydraulic flow rate, influent BOD, recirculation ration, temperature of wastewater and ventilation.

Sources of design formulations and design charts have been developed by the National Research Council(1), Eckenfelder(2), Galler and Gotaas(3) and others.

Activated Sludge Process

The activated sludge process is defined as a biological sewage treatment process in which a mixture of sewage and activated sludge is subsequently separated from the treated sewage (mixed liquor) by sedimentation, and wasted or returned to the process as needed. The treated-sewage overflows the weir of the settling tanks in which separation from the sludge.

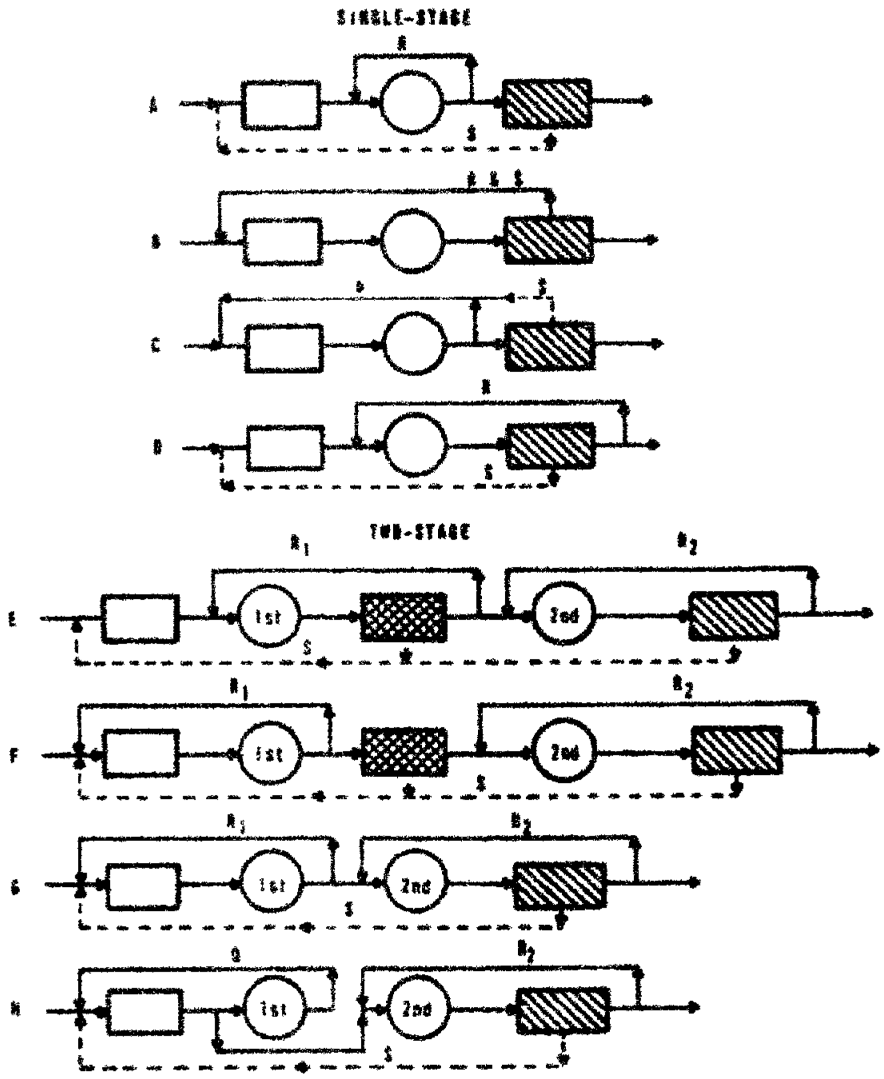
Typical flow diagrams for conventional and high rate type plants are shown in Figure 2.

The conventional process is capable of producing a 90 - 95 per cent reduction in raw BOD and results in clear sparkling effluent of very low suspended solids.

The high-rate process employs a shortened period of aeration and lower sludge concentrations which requiresless air and hence less power consumption than the conventional process, however, the degree of purification is also less. For high-rate design development, an overall BOD removal in the range of 80 to 90 per cent may be considered to apply.

FIGURE 1

COMMON FLOW DIAGRAMS FOR SINGLE AND TWO-STAGE HIGH-RATE TRICKLING FILTERS



LEGEND

- S SLUDGE RETURN
- R RECIRCULATED FLOW
- PRIMARY CLARIFIER
- TRICKLING FILTER
- INTERMEDIATE CLARIFIER
- FINAL CLARIFIER

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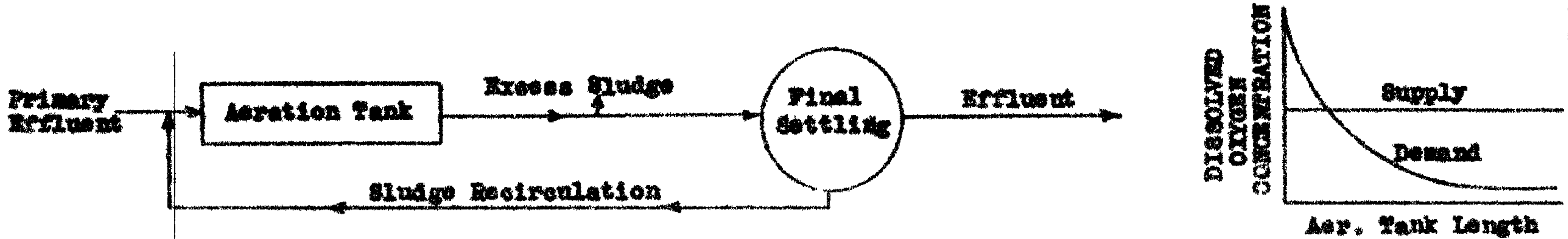
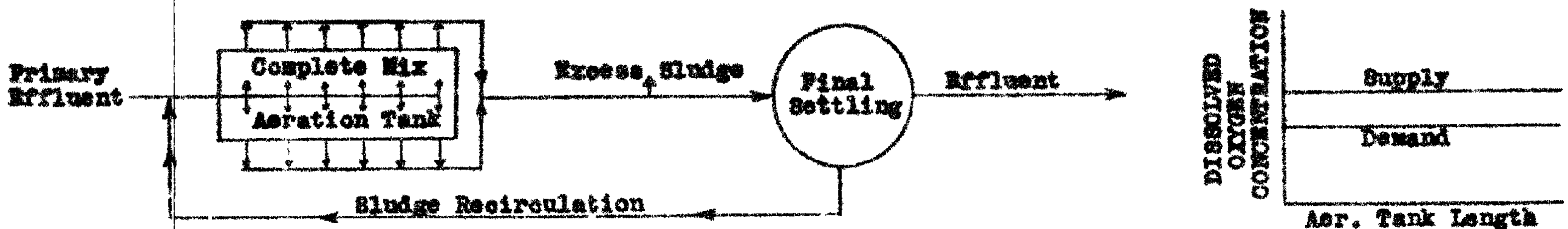
FIGURE 2

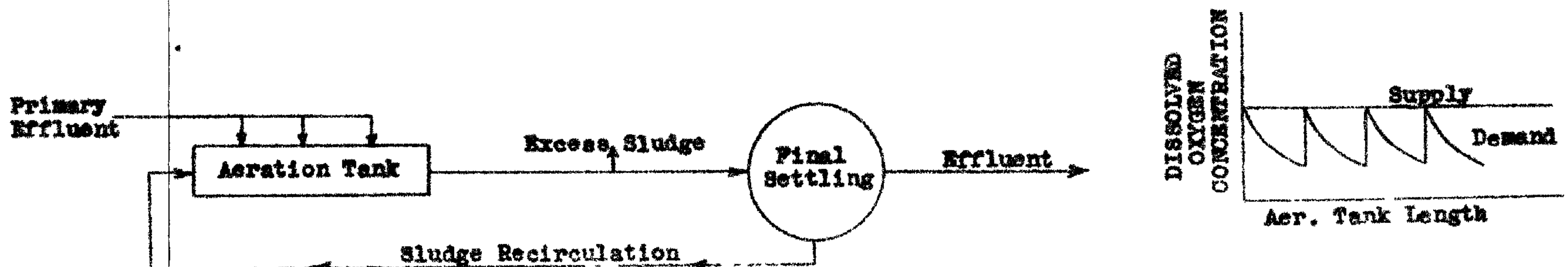
TYPICAL FLOW DIAGRAMS FOR ACTIVATED SLUDGE PROCESSES



CONVENTIONAL OR HIGH RATE SYSTEM



COMPLETE MIX SYSTEM



STEP-AERATION SYSTEM

Until recent years, the activated sludge process was largely reserved for larger populations having wastes amenable to biological treatment. Higher cost and more sensitive operations requirements, as compared with trickling filter plants, were among the main reasons for this reservation. These factors are still generally true although much has been done to apply activated sludge in various forms even for populations as small as several hundreds. The processes as mentioned above, however, are usually considered applicable for a population of about 40 000 on up. In smaller municipalities, the close operation attention and competent plant supervision is more difficult to provide.

a. Required Facilities

The required units of an activated sludge plant are:

(1) Preliminary treatment to remove grit and coarse solids.
(2) Preliminary flotation and skimming if excessive amounts of oil and grease exist, as these materials retard sludge activation.
(3) Aeration tanks with their aerating and agitating facilities.
(4) Final settling tanks with their sludge withdrawal facilities.
(5) Pumps and other devices for returning activated sludge from the settling tanks to the aeration tanks.
(6) Some provision for disposal of excess sludge.

b. Recent Advances in the Activated Sludge Process

The primary purpose of the activated sludge system is the reduction of the oxygen demand of the waste and in the process, oxygen is required to sustain the aerobic biological activity in the mixed-liquor suspension. Normally, air has been used to supply this source of oxygen by various methods of diffusion. Both fine and coarse bubble diffusers have been employed extensively as a standard practice, however, more recently various types of mechanical surface aerators have gained in popularity and apparently can show increased rates of oxygen transfer per unit of energy input.

Emphasis has been given to the reduction in the horse-power requirements per pound of oxygen actually transferred to the liquid phase. Air aeration requires a relatively high amount of energy for oxygen dissolution from the atmosphere into the aqueous mixed-liquor suspension. Substantial amounts of energy are expended in creating a large gas-liquid surface area and a high degree of interfacial turbulence to promote the mass transfer. Since air only contains approximately 19 per cent oxygen and is largely nitrogen (approximately 80 per cent), the available amount of oxygen in air is not large. Even though air is essentially free, it still has to be pumped or compressed for diffusion in the process, therefore research has been directed at the use of pure oxygen and this is perhaps the most significant recent development applicable to the activated sludge process.

Extensive investigations on the use of high purity oxygen in the conventional activated sludge process have been carried out by the Union Carbide Company[12], Albertsson, et.al.,[13], and others. The Union Carbide UNOX System has been successfully demonstrated in a number of pilot plant studies as well as in a full-scale wastewater treatment plant. In general, the apparent advantages in the use of pure oxygen or oxygen enriched air have been concluded by McKinney and Pfeffer[14] to be as follows:

1. Reduction in the power required per unit of oxygen transferred.
2. Increased rate of stabilization of organic matter.
3. Increases in organic loading where oxygen is not limiting.
4. Reduction in plant size and capital investment.
5. Increased capacity of organically overloaded plants.
6. Reduction in, or elimination of, periods of zero dissolved oxygen concentration.

The Union Carbide UNOX System employs sealed tanks and transfers the oxygen feed gas either by means of rotating spargers or with surface aerators.

Information provided by the Union Carbide Company indicates that total treatment costs can be substantially reduced as compared with a standard aeration system, however, the availability and cost of the oxygen supply are large economic factors which must not be overlooked. The current methods used for oxygen supply include liquid oxygen storage with supply provided by a specially designed truck from a central oxygen generating plant or an on-site oxygen generating plant may be constructed.

From the aspect of safety, it must be remembered that although oxygen does not burn, it does support combustion and many substances only slightly combustible in air will burn vigorously in the presence of high purity oxygen if ignited. Therefore, certain safety precautions are required in the design and operation of the plant which ordinarily are not considered for air.

III CONTEMPORARY WASTEWATER TREATMENT

Because of increasing interest in preserving the quality of natural waters in the more developed countries of the world, effluent standards for wastewaters have become increasingly stringent. This has lead to an advanced wastewater treatment technology largely fostered by the Federal Water Pollution Control Agency at the Robert A. Taft Sanitary Engineering Centre in Cincinnati, Ohio (USA) during the early 1960's. This work in the USA is continuing under the Federal Environmental Protection Agency (USA) and much of the original theoretical work has evolved to the pilot plant stage and in a number of cases, full-scale plants are employing these more extensive methods of treatment. Other countries including West Germany, the Netherlands, Great Britain, Japan, South Africa, Switzerland, Sweden and others are also developing new methods for wastewater treatment.

In general, attention has been focused on processes for the removal of solids, organics and inorganics. Some of the constituents of concern and their effects include those listed in Table 3.

The objective concentrations shown will be noted to generally follow those prescribed for drinking water standards. Where eutrophication is a threat, such as with the discharge of nutrients, the objective concentrations are even more stringent than for drinking waters. It then becomes apparent that wastewater treatment technology is gearing to develop plants to provide effluents of basic water supply quality and which may be even directly recycled for human consumption.

A list of the various contemporary treatment methods being explored and expected removal efficiencies is given in Table 4. In most cases, it is assumed that the influent to the process is the effluent from a standard biological (secondary) treatment plant; however in several cases, it will be noted that the influent may be a primary treatment plant effluent.

TABLE 3

OBJECTIVE CONCENTRATIONS FOR VARIOUS CONSTITUENTS IN WASTEWATER EFFLUENTS FROM CONTEMPORARY (ADVANCED) WASTEWATER TREATMENT PLANTS

Constituent	Objective Concentration mg/l	Effects
	Suspended and Dissolved Solids	
Suspended Solids	5 - 15	Settle in receiving waters
Total Dissolved Solids	500 - 1 000	Degrades usability of water for domestic, industrial and irrigation uses.
	Inorganic Constituents	
Nitrate	0.3	Acts as nutrient in eutrophication; may stimulate growth of aquatic plants and biota
Ammonia	10	Methemoglobinemia in infants.
	nil	Nitrifies to nitrites and nitrates
	2.5	Toxic to fish
	nil	Increases chlorine demand in treatment
Phosphate	0.015	Acts as nutrient in eutrophication
	0.2 - 0.4	Causes problems in coagulation and softening
Chloride	250	Undesirable for drinking, industrial and irrigation
Hardness (Ca,Mg,Fe)	100	Degrades usability of water for washing
Sulfate	250	Undesirable taste and cathartic action
Sulfide	nil	Undesirable taste and odours
Mercury	0.005	Toxic to humans and aquatic life
Various other heavy metals		Toxic to humans and aquatic life
	Organic Constituents	
Surface Active Agents (detergents)	1 - 3	Causes foaming and treatment interference
Phenols	0.0005	Cause taste and odours
Petrols	0.005	Cause taste and odours
Hexachloride	0.02	Cause taste and odours
DDT	0.001	Toxic to aquatic life
Other pesticides and herbicides		May be toxic to humans, aquatic life; may cause tastes and odours

TABLE 4

VARIOUS CONTEMPORARY WASTEWATER TREATMENT PROCESSES AND APPROXIMATE REMOVAL EFFICIENCIES

Process	Influent Wastewater	Approximate Removal Efficiencies in Per Cent							
		SS	BOD	COD	NH_3	OrgN	NO_3	PO_4	TDS
Filtration·									
Sand	Secon Biol	50-80	40-70	30-60	-	20-40	-	-	-
Microstraining	Secon Biol	50-80	40-70	30-60	-	20-40	-	-	-
Multi-Media	Secon Biol	80-90	50-70	40-60	-	20-40	-	-	-
Chemical Precip.	Secon Biol	60-80	75-90	60-70	5-15	30-50	-	-	-
Ammonia Stripping	Secon Biol	-	-	-	85-98	-	-	-	-
Carbon Absorption	Secon Biol	80-90	70-90	60-75	-	50-90	-	-	-
Reverse Osmosis	Secon Biol + Filter	95-98	95-99	90-95	95-99	95-99	95-99	95-99	95-99
Electrodialysis	Secon Biol + Filter + carbon Ads.	-	-	-	30-50	-	30-50	30-50	40
Ion Exchange	Secon Biol + Filter.	-	40-60	30-50	85-98	80-95	80-90	85-98	varies w/resin
Distillation	Secon Biol + Filter.	99	98-99	95-98	-	90-98	99	99	95-99
Land Application	Secon Biol or Prelim.	95-98	90-95	80-90	60-80	80-95	5-15	60-90	-
Nitrification-Dentrification	Secon Biol	-	-	-	-	-	60-95	50	-
Harvesting of Algae	Secon Biol	-	50-75	40-60	50-90	50-90	50-90	50	-

Note: Data given above were extracted from reference (11).

Based on process research and cost studies carried out by the Advanced Waste Treatment Research Laboratory(4) at the Robert A. Taft Water Research Centre, a number of the processes listed in Table 4 are indicated to offer better possibilities for practical use than others. A list of these is given. They are not ordered according to any expected potential for practical use because of the variability of wastewaters for treatment and final product water requirements.

Land Application
Stabilization Ponds and Harvesting of Algae
Filtration - Sand and Multi-Media
Microscreening
Reverse Osmosis
Chemical Precipitation
Nitrification - Denitrification and Nitrogen Removal
Ammonia Stripping
Activated Carbon Absorption

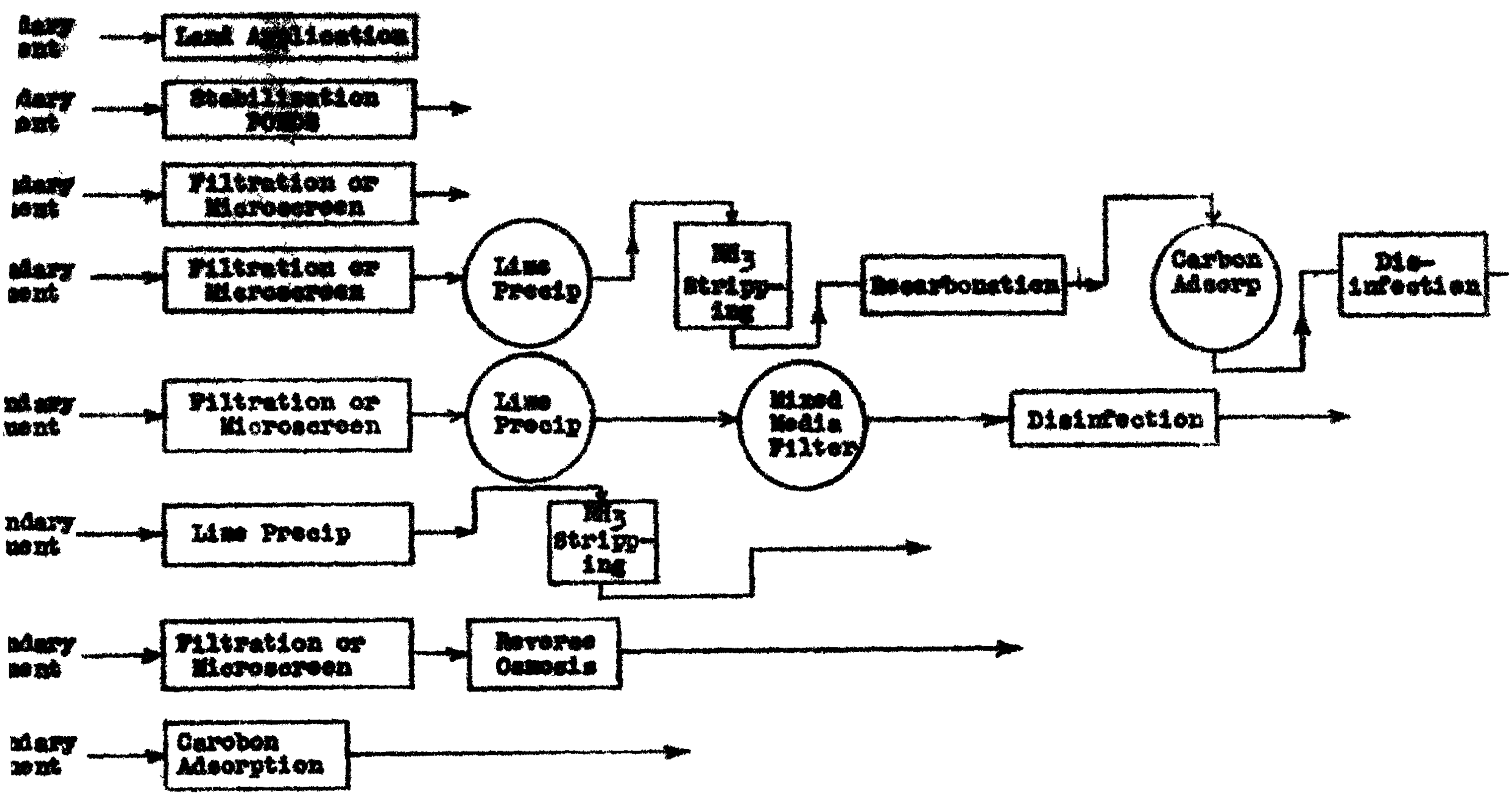
The most appropriate process for any situation must be determined on the basis of the quality of the influent to the process, the receiving water requirements, and the costs for construction as well as for operation. The various methods listed above will be discussed briefly below and are shown schematically in Figure 3.

Land Application

This process involves the distribution of the secondary effluent over a permeable land surface by sprinkling or other suitable methods of application. The soil serves as a slow sand filter and the nutrients in the wastewater may be used by appropriate vegetation such as trees and grasses. The City of Khartoum in the Sudan has established a greenbelt which successfully employs this method for the disposal of a trickling filter effluent. Nesbitt(5) has reported on the use of this method for the removal of phosphorous from municipal sewage effluents in the USA. This method is especially adaptable to arid regions where ample area is available and the effluent distribution can be carried out without serious interruptions from seasonal weather conditions. An additional benefit of this method is the replenishment of groundwater.

FIGURE 3

TYPICAL FLOW DIAGRAMS FOR CONTEMPORARY WASTEWATER TREATMENT PROCESS



However, the aspect of groundwater contamination from nitrates must be monitored. Experience in a forested area near Lake Sunapee in New Hampshire by the New Hampshire Department of Health[6] has indicated that nitrate and phosphate contamination of underground waters may be avoided if the rate of nutrient application is not in excess of that which may be utilized by the vegetation.

Filtration - Sand and Multi-Media

Filtration may be used as a roughing filter or as a polishing filter following the lime clarification process depending on the results desired.

As a roughing filter, the principal effect is the removal of suspended solids. At the Metropolitan Sanitary District of Greater Chicago, Lynam, Ettelt, and McAloon[7] in work with a roughing sand filter found an average of 75 per cent removal from a secondary effluent containing 11 mg/l suspended solids. This compares with 70 per cent for the same effluent using microscreening.

The use of mixed medias such as anthracite and sand; activated carbon and sand; resin and sand; anthracite, sand, and garnet; and others have been employed as polishing filters where the removal of turbidity is of concern for high quality waters. With the use of multimedia filters, essentially all of the suspended solids are removed.

Table 5 shows costs as determined by the Advanced Waste Treatment Laboratory[4] for filtration through sand or graded media at a rate of 4 gpm/sq.ft.

Microscreening

This process and roughing sand filters are both intended for the purpose of removing suspended solids and they produce approximately the same results. In general, removals in the range of 60 to 89 per cent of 10 to 30 mg/l suspended solids can be removed using microscreening. The mesh of the screen may be selected depending on the degree of removal desired. Table 5 shows costs for microscreening of a secondary effluent.

TABLE 5

COST ESTIMATES FOR VARIOUS CONTEMPORARY TREATMENT PROCESSES OF SECONDARY EFFLUENTS FOR TERTIARY TREATMENT

Design Capacity of Plant	Costs			
	Tot. Cap. Cost million dollars	Oper. & Maint. cents/1 000 gal.	Debt Service* cents/1 000 gal.	Total Treatment cents/1 000 gal.
Filtration Through Sand or Graded Media, 4 gpm/sq.ft.:				
1.0 mgd	0.1	4.5	1.85	6.3
10 mgd	0.44	1.95	0.82	2.8
100 mgd	2.1	0.85	0.37	1.2
Microscreening				
1.0 mgd	0.033	0.57	0.61	1.18
10 mgd	0.25	0.46	0.47	1.00
100 mgd	1.9	0.36	0.36	0.87
Lime Clarification Process, 2 Clarifiers, Without Chemical Costs				
1.0 mgd	0.14	7.6	2.57	11.0
10 mgd	0.72	2.7	1.33	4.1
100 mgd	4.92	1.75	0.91	2.6
Lime Recalcination Plus Make-Up Lime for Use With Lime Clarification				
1.0 mgd	0.20	5.30	3.70	9.2
10 mgd	0.63	2.45	1.80	3.6
100 mgd	2.00	1.55	0.37	1.9
Ammonia Stripping Process (May Follow Lime Clarification)				
1.0 mgd	0.10	4.80	1.75	6.7
10 mgd	0.74	2.25	1.38	3.7
100 mgd	6.00	1.65	1.10	2.75
Granular Carbon Absorption				
1.0 mgd	0.38	23.0	8.0	31.0
10 mgd	1.60	7.0	3.3	10.0
100 mgd	11.60	4.5	2.45	8.0

*Debt Service based on amortization at 4 1/2 per cent over 25 years.

Note: Cost data given in this table were extracted from reference (4).

Reverse Osmosis

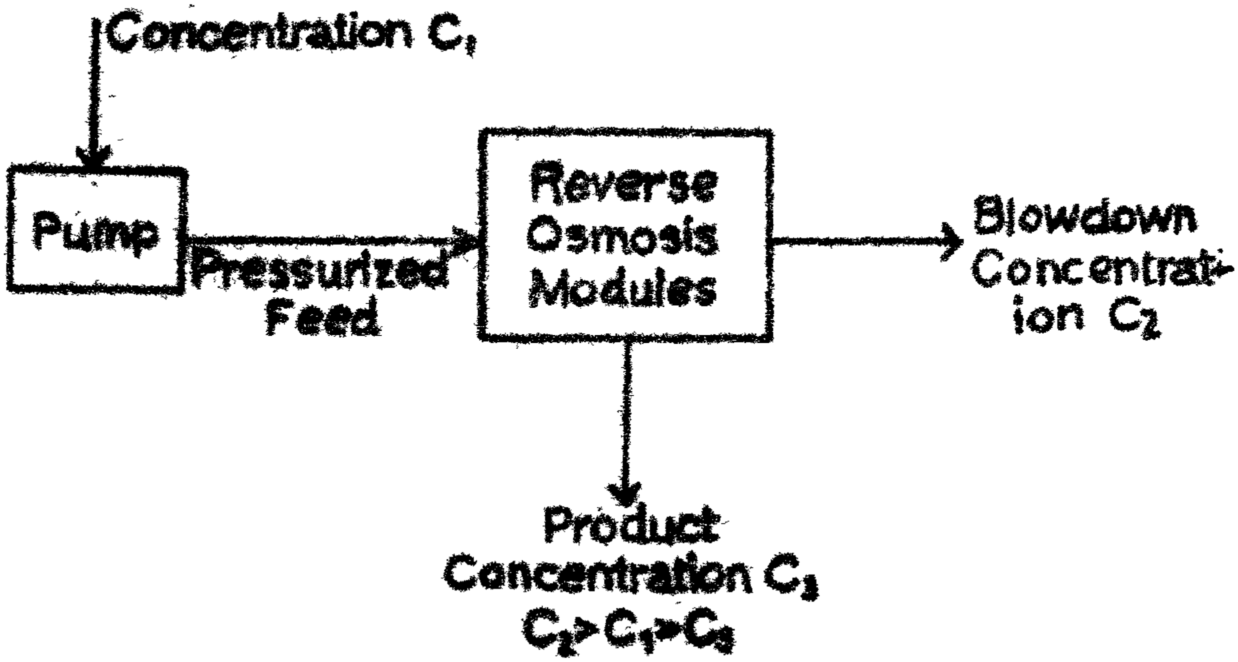
Osmosis is a natural phenomenon which occurs when a dilute liquid such as fresh water and a concentrated liquid such as salt water are separated by a suitable semi-permeable membrane. Selective membranes may be used which allow only certain types of molecules to pass. In the osmosis process, the pure water molecules will diffuse through the membrane into the adjacent more concentrated saline solution thereby decreasing the salt concentration. However, if pressure is applied to the concentrate side of the system, reverse osmosis takes place and the movement of water molecules is in the opposite direction from osmosis. Water molecules pass through the semi-permeable membrane from the concentrated solution into the fresh water leaving the salts behind. Pressures in the range of 600 to 1 500 psi are normally required to overcome the osmotic pressure of the solution and force the fluid through the membrane. The process is illustrated schematically in Figure 4.

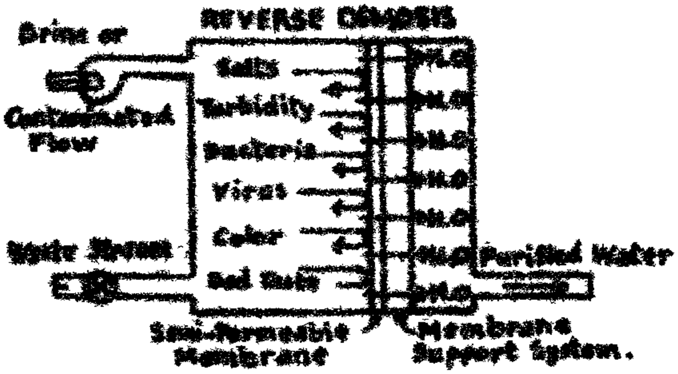
Practical units for wastewater effluent applications are currently available from commercial companies in the USA, however, they are most applicable where the influent waters are essentially free of all suspended and organic materials, otherwise the membranes become fouled and high head losses result in the membrane passage.

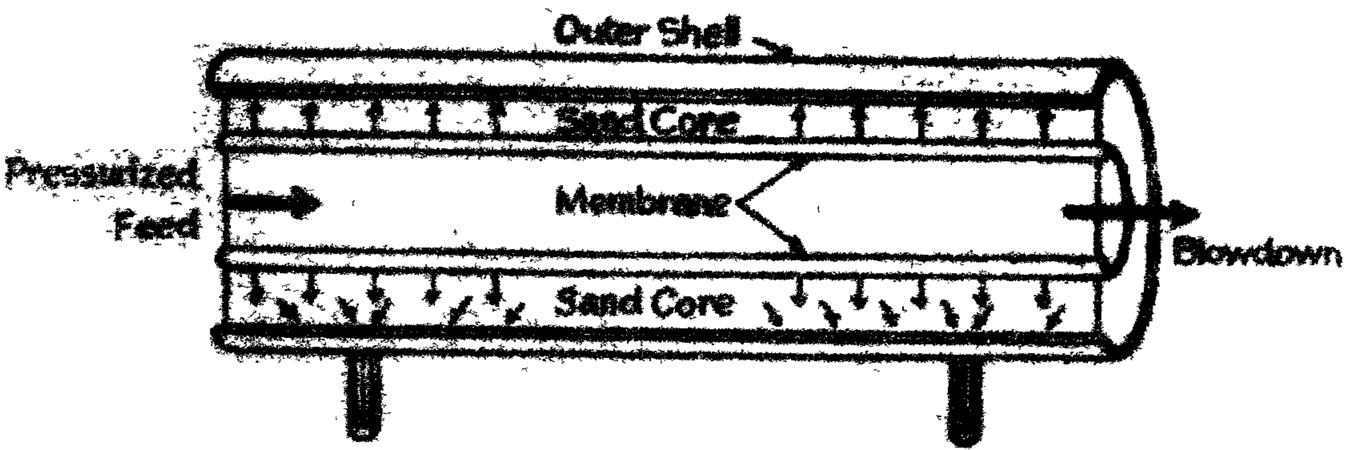
Chemical Precipitation

Phosphorous and suspended organic matter may be removed by chemical precipitation using lime, alum, iron salts or polyelectrolytes. An additional benefit with the use of lime is the increased pH which makes ammonia nitrogen available for removal by air stripping. Experimental lime clarification plants operated by the Environmental Protection Agency[(4)] have employed upflow clarifiers in series with an ammonia stripping tower and recarbonation. At the Lebanon, Ohio pilot plant[(4)], influent phosphate concentration averaging 30 mg/l were reduced to an average of 2.2 mg/l. The BOD removal averaged 86 per cent and the removals of TOC and COD averaged 58 per cent. Costs for a two clarifier lime clarification process without chemical costs are shown in Table 5.

FIG. 4: OSMOSIS SYSTEMS







Nitrogen Removal: Nitrification - Denitrification and Ammonia Stripping

Nitrogen is considered undesirable in wastewater effluents where it may cause excessive algal blooms and other aquatic plant growths in the receiving water.

In raw domestic sewage, the nitrogen is usually largely in the form of ammonia or organic nitrogen. Depending on the method used, the secondary treatment process usually provides some degree of nitrification. For example, the effluent from a low-rate trickling filter can be expected to be fully nitrified, that is fully converted to nitrates, whereas in high rate filters, nitrification occurs at low loadings. In the activated sludge process, a portion of the influent nitrogen is oxidized to nitrate and the remainder is converted into cellular material. For essentially a completely nitrified effluent, a mean cell residence time of at least ten days has been found(8) to be required. This is much longer than the normal residence time in an activated sludge system. Considerable attention has been given to a nitrification-denitrification process and a flow diagram for such a plant has been developed from bench test studies by Barth, et.al.(9).

For the removal of nitrogen in the form of ammonia, ammonia stripping towers may be employed. In wastewaters, ammonia is found to exist with ammoniations according to the following equilibrium:

$$NH_3 + H_2O \rightleftharpoons NH^+_4 + OH^-$$

The percentage of ammonia in the wastewater increases as the pH is increased above 7 and the concentration of ammoniumions decreases. Therefore, by controlling the pH, the nitrogen can be stripped by passing it through an aerating tower. Because of the lowering of the pH in lime clarification precipitation, ammonia stripping fits well following this process and this appears to be the most promising process for removal of ammonia nitrogen from a wastewater. In a pilot plant ammonia stripping tower at Lake Tahoe in California, Culp(10) found that more than 90 per cent of the ammonia nitrogen could be removed during summer conditions. However, during cooler temperature conditions in the winter, this degree of removal was reduced.

Costs developed by the Advanced Waste Treatment Lab are shown in Table 5.

Activated Carbon Absorption

Absorption using activated carbon has been found to be an effective method for polishing secondary effluents. Using downflow pressure contacters containing granular carbon and a high quality secondary effluent, the Federal Water Quality Administration[4] in pilot plant studies at Pomona, California, found that approximately 80 per cent of the organic species (COD, TOC) could be removed and the product stream was normally less than 1 mg/l in suspended solids. However, in this process, nitrogen and phosphorous are largely not removed.

Cost information on this process is given in Table 5.

IV SUMMARY AND CONCLUSIONS

In this paper, a general review of conventional wastewater treatment methods has been given and this has been followed by a discussion of contemporary wastewater treatment methods.

In general, the basic methods of secondary treatment employing trickling filtration and activated sludge still are practical. Some recent innovations in these methods may be employed to increase removal efficiencies and reduce overall costs. For example, the most significant recent innovation in trickling filter design is the advent of plastic media which allows deeper filters and reduces area requirements.

Activated sludge systems continue to be used extensively and may be of a standard rate or high rate type depending on effluent requirements. Recent research and innovations in this process have centered around improvements in oxygen transfer. The most notable advancement has been the application of pure oxygen as an oxidizing medium rather than ordinary aeration. However, the overall benefits and associated costs connected with pure oxygenation have yet to be clearly established. Indications are that the pure oxygenation process can only be justified in certain situations.

Much emphasis has been given to advanced waste treatment in the USA and a number of contemporary wastewater treatment methods have been discussed in this paper. In general, these methods may be divided into physical-chemical and biological. It is intended that these processes will provide a further treatment for secondary effluents where high quality effluents are required. The technology for accomplishing this further treatment has been largely established, however, the additional expense is considerable and must be considered in justification of the benefits. A substantial portion of the advanced treatment research has dealt with the physical-chemical methods in the hope that such processes may completely replace conventional plants employing biological secondary methods. A drawback of biological plants is the delicate balance of biological life which must be maintained in the plant operation.

However, a number of the biological methods for further treatment offer distinct cost advantages over some of the physical-chemical treatment methods and must not be overlooked, particularly where economics are of primary concern. Waste stabilization ponds and land surface spreading of effluents are examples of low cost methods for extended treatment of secondary effluents.

V FUTURE CONSIDERATIONS FOR WASTE TREATMENT

In the foregoing, conventional and contemporary wastewater treatment processes have been discussed. Now let us take an overall view of the status of our technology and future directions.

First, let us question: "How practical are the conventional and contemporary methods of wastewater treatment?"

The conventional methods of course have been in practice for many years and the more recent contemporary methods discussed in this paper have all been at least proven to operate in pilot plant systems. But the operational and economic aspects seem difficult to accept.

As it stands, the operation of a conventional treatment plant (trickling filters and activated sludge) is extremely difficult and complicated. Adding tertiary treatment to this (such as physical-chemical or another biological process) will add to this complication and cost. The decision must be made as to how much we are willing to pay for treatment of these waters or more realistically, an analysis must be made of costs versus benefits.

Such an analysis should be called an "environmental analysis" because in addition to the directly assessable benefits, certain intangibles must be considered which in general affect the environment. Examples of such benefits are: health, prevention of disease, stimulation of the economy, employment, comfort, better living conditions for more people, esthetics, fishing, boating, water sporting, recreation, etc. Once the "environmental analysis" report has been developed, it then should be fitted into the priorities of the economy, naturally, these priorities will vary with the country and its government. In the USA, legislation requires tertiary treatment for all plants on all streams flowing into Lake Michigan, but this may not be appropriate at this time for a lake or stream in different circumstances such as in an African country.

Seemingly, the plant technology is becoming overly complicated and costly. The processes developed will do what we want them to do, but how can these extenuating factors of mechanical complication and cost be reduced?

A suggestion may be to look at a completely new approach to wastewater treatment. An immediate thought might be to completely re-develop the system concept. Currently, we collect the wastewater in a toruous underground piping system and discharge it at a central plant for treatment and ultimate disposal of the effluent in a water course. The cost of the piping and transportation of the wastewater constitutes perhaps 3/4 of this cost. A new concept might be to eliminate this vast collection system and treat all wastes (water and solids) at the source such as in the home or industry. Such an innovation would require reducing these wastes to an inoffensive residue which could be collected at intervals and returned to the earth, or a home owner might even use it as a soil builder in his own garden. Nice? Yes, but how can it be done? To do this will require energy and individual units which will be more economical than the community collection system. This seems to point to a unit which can evaporate and incinerate and properly dispose of the undesirable products including residues, combustion gases, and heat. Since we also want to avoid polluting the atmosphere, we must either discharge these products into the ground or into outer space. Research is needed to develop such an idea, but perhaps this will be the way of the future!!

What is the way of the more immediate future in wastewater treatment for developing countries?

Because of competition with other economic priorities, the methods must be low cost. Fortunately, the climate in most of these countries is adaptable to low cost methods of treatment. Methods such as waste stabilization ponds, irrigation, ground spreading, oxidation ponds, aerated ponds, algae harvesting, and other low-cost biological methods are indicated to offer the best possibilities. Since freezing is not a problem, some pipe collection systems might even be laid on the surface of the ground to reduce costs. Pipe sizes could be reduced in some cases by using pressure systems rather than gravity systems. Where new areas are developed, consideration should be given to combining utilities in a single shallow utility conduit or tunnel adjacent to streets. These utility conduits might include pressurized sewers, water lines, gas lines, electrical lines, and communication lines. Combining these utilities into a single conduit certainly would offer many advantages over the present individually constructed systems. Although, the combination of sewer and water lines in the same conduit may at first appear to be undesirable, certainly pressurized piping systems can be designed to avoid any possible contamination.

In conclusion, it is recommended that a developing country not try to follow waste treatment practices being employed in more advanced countries, but that it use this experience and adapt it to local needs. In most cases, this points in the direction of simplified processes which can be constructed and operated with a minimum of foreign reliance.

By all means, the engineers in developing countries must look to imaginative schemes based on innovative thinking. This process starts in the planning and preliminary design, therefore, it is most important that considerable emphasis be placed on these phases as well as on the final design. It is also wise to engage the consultation of "outside" engineers to avoid the pitfall of "ingrown" ideas.

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