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Economics of the ANFLOW Process for Municipal Sewage Treatment

W. L. Griffith

OAK RIDGE NATIONAL LABORATORY
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ECONOMICS OF THE ANFLOW PROCESS FOR MUNICIPAL SEWAGE TREATMENT

W L Griffith

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ECONOMICS OF THE ANFLOW PROCESS FOR MUNICIPAL SEWAGE TREATMENT

W L Griffith

ABSTRACT

The cost and energy requirements for conventional activated-sludge, trickling-filter, and ANFLOW processes were compared to assess the potential of the ANFLOW process for municipal sewage treatment Based on literature sources capital-cost estimates, operating manpower requirements, energy requirements, and combined annual costs were developed for each alternative For example, an ANFLOW treatment plant with a design flow rate of 1 million gal per day, which would serve a population of about 10,000 would cost on an annual basis about $135,000 as compared to $290,000 for the activated-sludge process and $190 000 for the trickling-filter process, using $10/ft^3 for the ANFLOW media Energy requirements for the ANFLOW alternative were 11/ of the activated-sludge process requirements and 23/ of the trickling-filter requirements When microscreening was added as an effluent polishing step to the ANFLOW process, the annual cost of the ANFLOW process was increased to $160 000 and the energy requirements of the ANFLOW process were increased to 23/ of the activated-sludge process and 50/ of the trickling-filter process

1 INTRODUCTION

The ANFLOW process is a relatively new method that has promise for use in wastewater treatment It was developed in order to provide an economic energy-conserving wastewater treatment process equivalent to conventional secondary processes, including activated sludge This comparative economic study was undertaken in order to determine the process potential and to define those areas where significant process-economic and energy-conserving improvements could be made

Capital-cost estimates for major process alternatives were considered on a unit operation or process basis The capital costs were based on an Engineering News Record (ENR) index of 2700, which approximates current construction conditions As construction costs change the capital costs can be adjusted using appropriate ENR index figures

Operation and maintenance labor costs were also examined since these areas can represent major continuing costs to the user of a wastewater treatment plant This is particularly important in the consideration of polishing processes, which provide effluent quality improvement Many polishing processes require large amounts of labor for proper operation In some cases, labor is equivalent to a substantial amount of the debt service on capital costs and should be considered in the evaluation of process economics

Energy requirements are a major concern in the development of new wastewater treatment processes As the cost of energy increases and energy becomes more difficult to obtain conservation of energy resources is becoming increasingly more important It is desirable to find a wastewater treatment process method that provides adequate effluent quality with limited energy usage

It is hoped that a comparison of current state-of-the-art processes and the developmental ANFLOW process will provide information indicating a promising direction for future efforts

2 SEWAGE PROCESS ALTERNATIVES

The cost and energy requirements for three different wastewater treatment processes were compared All three process alternatives considered are capable of providing secondary wastewater treatment meeting the standards of PL 92-500 Effluent polishing alternatives were also considered since they may be required to meet state and local standards

2 1 Activated Sludge

Activated sludge is the standard biological process for wastewater treatment Although a wide variety of alternative process configurations are practiced, the process scheme shown in Fig 1 predominates Influent waste entering the activated sludge process proceeds through a headworks, which usually has either a bar screen or a comminutor These devices reduce large solids in the flow to a manageable size or provide for the removal of the solids Grit (usually a coarse sandy material) is removed during this step This prevents downstream damage to pumps and other mechanical equipment The flow is also measured at this time, using a flume

From the headworks, the flow proceeds through a primary sedimentation basin In this basin, small solids are removed from the water by settling The material that is removed, called primary sludge, is taken from the bottom of the basin for further treatment

The activated-sludge basin follows primary sedimentation Microorganisms are added to the wastewater, and the mixture is aerated for a period of several hours in the activated-sludge basin During this time, the microorganisms oxidize wastewater organic materials, including dissolved, suspended, and colloidal materials The wastewater organic materials are converted to oxides, including nitrates and carbon dioxide, and to microorganism mass After the activated-sludge basin, the flow proceeds to the secondary sedimentation basin where the biological sludge is recycled back to the activated-sludge basin and for further sludge processing

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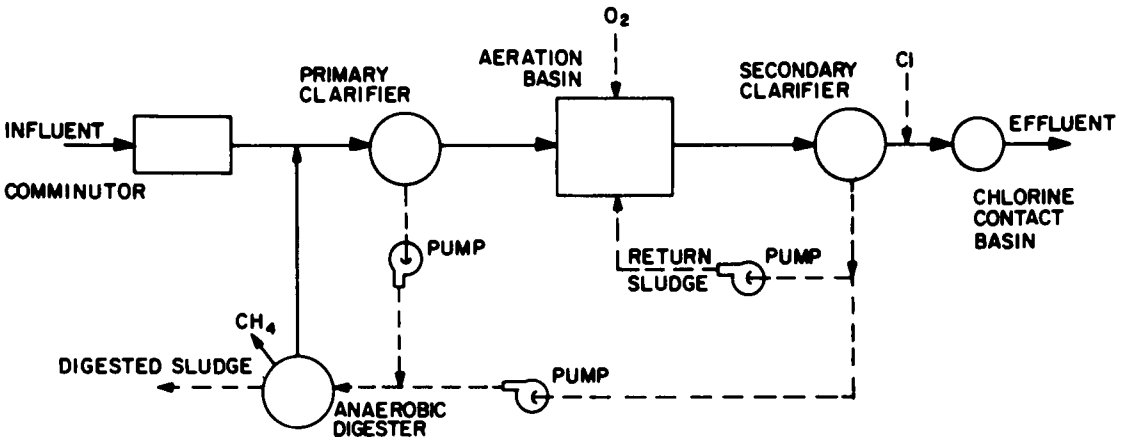
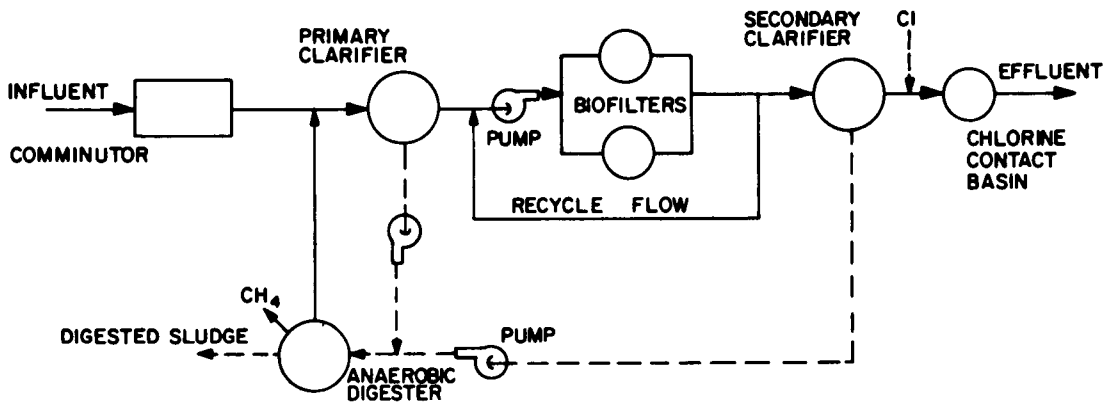
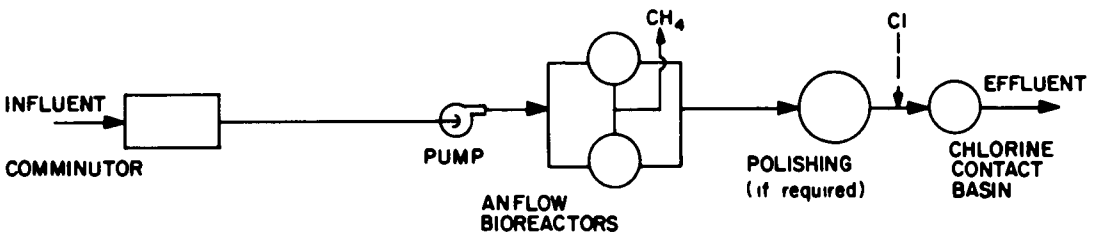


FLOWSHEET FOR ALTERNATIVE 1 ACTIVATED SLUDGE



FLOWSHEET FOR ALTERNATIVE 2 TRICKLING FILTER



FLOWSHEET FOR ALTERNATIVE 3 ANFLOW

Fig 1 Process alternatives

Effluent from the secondary sedimentation basin is treated with a disinfectant usually chlorine and discharged to a receiving water The sludge produced by the primary and secondary sedimentation basins is further treated in an anaerobic digester The digester removed about half of the organic material in the waste sludge and substantially reduces the sludge volume It is a process designed to condition the sludge so that it can be buried without deleterious environmental effects After anaerobic digestion the sludge is dewatered on sand beds and is then buried in a landfill, usually with solid waste

2 2 Trickling Filters

The trickling-filter process is an aerobic biological process that uses a fixed film of microorganisms on a packed bed for waste treatment The flow diagrams for the activated-sludge and trickling-filter processes are similar However, in general, the activated-sludge system has higher operating and energy costs than does the trickling-filter process This may cause a gradual trend toward the use of trickling filters

Like the activated-sludge process, the trickling-filter process has a preliminary treatment step designed to remove grit with parts consisting of a bar screen or a comminutor and a flow-measuring flume These processes are designed to prevent damage to downstream equipment by keeping coarse or abrasive solids out of the downstream end of the plant

A primary clarifier follows preliminary treatment This unit operation provides for the settling of small solids from the wastewater Sludge is removed from the bottom of the primary sedimentation tank for further processing

Biofilters follow the primary sedimentation basin The biofilters are high-rate trickling filters composed of process towers filled with plastic media on which a film of microorganisms attaches The wastewater is passed over the attached film of microorganisms, and the dissolved suspended and colloidal materials in the wastewater are oxidized Recycle of part of the flow to provide efficient mass transfer may be practiced

A secondary sedimentation basin follows the trickling-filter process As with activated sludge, the sedimentation basin removes the biomass that has grown on wastewater organic materials in the biological process step However because the trickling filter is a fixed-film system, biomass recycle is not necessary Waste sludge from the secondary sedimentation basin is treated prior to landfill

Effluent from the secondary sedimentation basin is disinfected by contacting the effluent with chlorine gas for about 0 5 hr After disinfection, the effluent is discharged to a receiving water

Both primary and secondary sludge are treated prior to ultimate disposal They are generally digested for reduction of their organic content, dried on sandbeds and disposed to a landfill

2 3 ANFLOW

The process flow arrangement for the ANFLOW process is different from the other two aerobic biological process arrangements in that anaerobic processes have much lower sludge production than do aerobic processes

Influent to the process enters a preliminary treatment that is similar to that used in the aerobic biological processes A comminutor or bar screen removes coarse solids The wastewater flows through a flume that is used for the measurement of waste volume After the flume the wastewater proceeds to a grit chamber where coarse solids are removed This step is used to protect mechanical equipment downstream

From the headworks, the wastewater flows directly into an ANFLOW fixed-film process tower At this point microorganisms attached to the packing reduce the organic molecules in the waste Methane and carbon dioxide are the major gaseous effluents from this process Sludge recycle is not necessary since this is a fixed-film process The process operates in an aqueous continuous-upflow mode

After the ANFLOW biological process the wastewater proceeds through a polishing step to remove the remaining finely divided solids and then is disinfected with chlorine

3 UNIT PROCESSES

Capital-cost estimates operating manpower requirements and energy requirements were developed for each unit process based on the literature sources available It should be emphasized that the estimates presented should not be used to predict costs for a particular site since construction costs differ in various sections of the United States In addition operating requirements vary with regulatory requirements and "modi operandi "

The cost estimates have been escalated to an ENR Cost Construction Index of 2700 which reflects current conditions The labor requirements have been presented as annual man-days (man-days/year) of effort to eliminate the varying cost of labor Similarly the energy requirements are presented in kilowatt hours per year (kWhr/year)

3 1 Preliminary Treatment

Preliminary treatment methods remove coarse solids from raw wastewaters The methods used often include the following screening which removes very large solids, grit removal which is performed to prevent damage to downstream machinery flow measurement and any required grease removal pre-process aeration, or flocculation Process wastes include solid materials that require disposal Collectively the group of process equipment used is often referred to as the headworks

Preliminary treatment removes 5 to 10/ of the whole sewage plant's biological oxygen demand (BOD) and ∿5 to 15/ of the sewage plant's suspended solids Additionally preliminary treatment removes ∿80 to 90/ of the grit and 80/ of the grease This capability contributes to the operation of the plant as a whole by decreasing required pump maintenance and increasing aerator oxygen transfer Preliminary treatment can produce 0 5 to 5 ft^3 of grit (av 2 ft^3) per million gallons treated

Preliminary treatment is required in most plants in order to protect downstream equipment However, the particular type of preliminary treatment used can vary considerably depending on the wastewater composition, the fluctuations in flow and the relevant standards Design criteria for the preliminary treatment processes are generally dependent upon the flow treated and the variations in the flow In the case of grit chambers the design is generally based on the simple and rapid sedimentation of coarse, high-density particles from a laminar-flow stream Flow controllers are used to provide a relatively constant process retention time The design of units to remove the grease is often based on the testing of the wastewater, since these units involve the flotation of grease particles with air or entrained gases

The capital cost of preliminary treatment for a conventional wastewater treatment plant is shown in Fig 2, adapted from Metcalf and Eddy (1975) The highest estimate of this cost is that made by Smith (1968), based on the work of Logan, Hatfield Russel, and Lynn (1962) This cost projection agrees fairly well with the estimate by Metcalf and Eddy (1975) indicated by the heavy line The lowest estimate of preliminary treatment cost was made by Dorr-Oliver, Inc (1968) Preliminary treatment for a 1-million-gal-per-day(10^6-gpd) plant was estimated to cost $35 000, based on the estimates in Fig 2

Figure 3 shows the manpower required for the operation and maintenance of preliminary treatment processes For a 10^6-gpd plant operation requirements are ∿68 man-days/year, maintenance accounts for 42 man-days/year However the amount of manpower can vary markedly with the processes used for preliminary treatment

Figure 4 indicates the manpower required for the operation of preliminary treatment processes The amount of power required is shown as constant below the 10^6-gpd design flow This results from the limited availability of smaller equipment Preliminary wastewater treatment equipment consumes 16,000 kWhr/year in an average 10^6-gpd plant

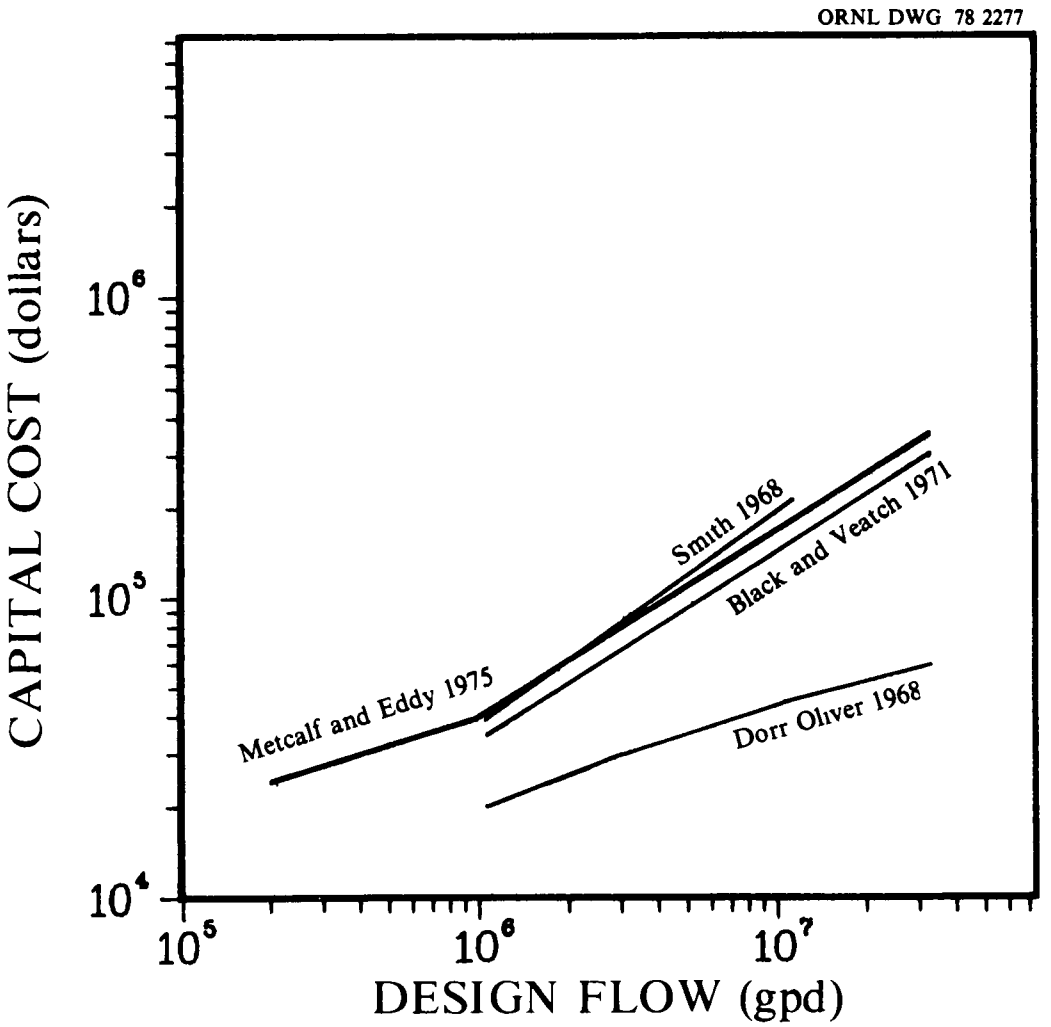


Fig 2 Capital costs of preliminary treatment

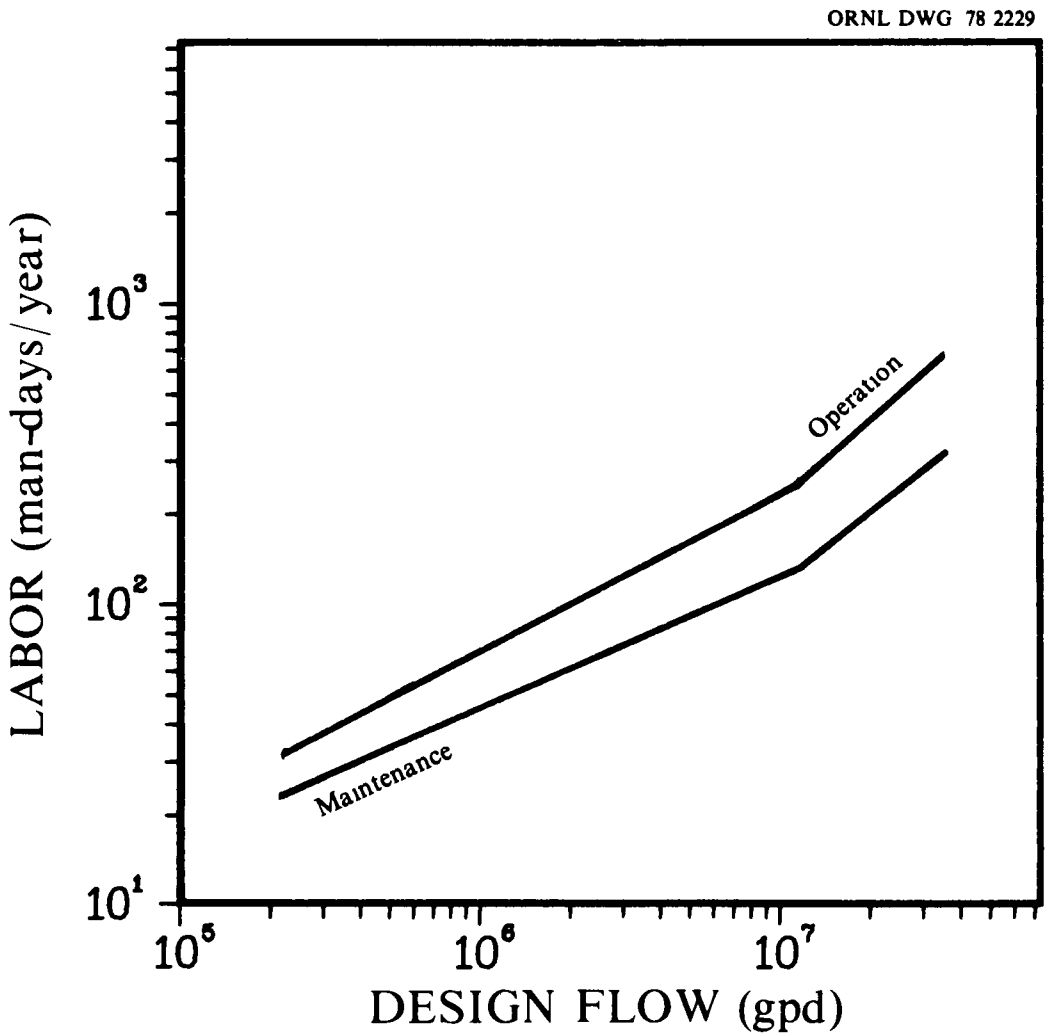


Fig 3 Labor requirements for preliminary treatment

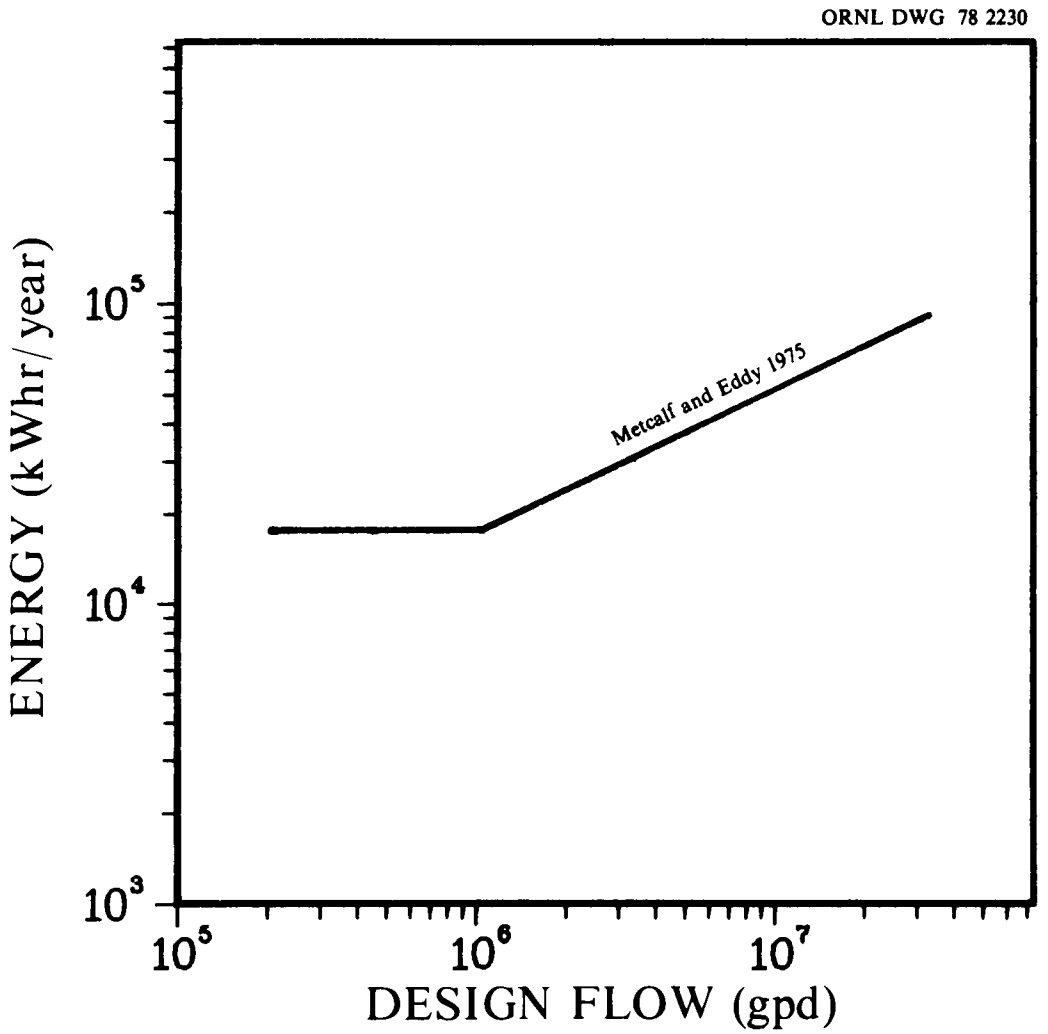


Fig 4 Energy requirements for preliminary treatment

3 2 Primary Sedimentation

Primary sedimentation is used for the removal of small solid materials from waste water This is accomplished by simple settling for periods of several hours in conditions where the water is quiet Settling of particles is sometimes enhanced by the addition of chemicals which increase either the size or the density of the particles that are being settled However chemical additions increase the amount of sludge produced About 1000 lb of dry solids are collected per one million gallons of sewage treated without chemical addition Several times as much sludge is obtained when lime alum, or ferric chloride is added

Sedimentation basins can be either rectangular or round The theoretical settling time in a basin is directly related to the ratio of the flow rate to the surface area of the basin top, which is called the overflow rate Design of sedimentation basins is generally determined by the area required to avoid exceeding a prescribed overflow rate and to provide the minimum depth needed for sludge accumulation and operating flexibility Normal liquid depths of 7 to 12 ft, when combined with appropriate overflow rates, will provide the necessary detention time The construction cost per unit of top surface area decreases with increasing size however, it is considered good design practice to provide the total required basin surface area in at least two basins that can be operated independently to attain greater flexibility of operation

The capital cost of primary sedimentation systems as a function of flow rate is presented in Fig 5 The costs calculated from the Metcalf and Eddy curve agree closely with the costs presented by Black and Veatch (1971) represented by the curved line The costs compiled by Black and Veatch were based on the experience acquired from the construction of 62 sewage systems Similar costs were also presented by Culp, Wesner, and Culp (1975) For a 10^6-gpd plant, the estimated capital cost for the primary sedimentation basins is $250 000 This cost includes piping and structures located within the physical limits of the sedimentation basin but excludes the cost of the piping that is found outside of the basin structure

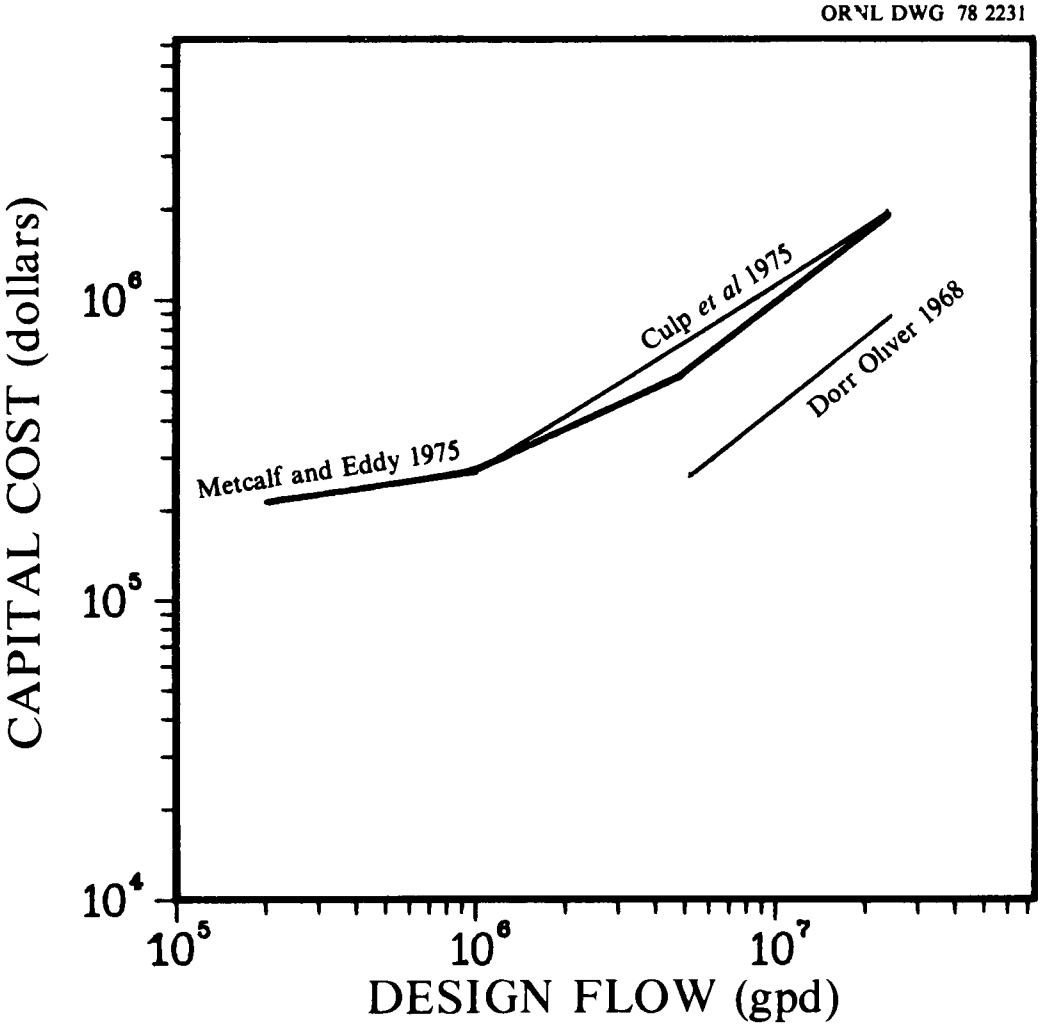


Fig 5 Capital costs for primary sedimentation

The operation and maintenance manpower requirements for primary sedimentation basins are presented in Fig 6 Operation of a primary sedimentation basin for a 10^6-gpd capacity plant requires 50 man-days/year, maintenance requires 30 man-days/year

Figure 7 shows the annual energy consumption of primary sedimentation basins for wastewater treatment plants processing 10^4 to 10^9 gpd For a typical 10^6-gpd plant, the annual energy consumption required for primary sedimentation is 7000 kWhr However, sludge pumping, which is a substantial part of the overall energy cost for primary sedimentation, is considered separately

3 3 Biological Processes

Biological processes use microorganisms to convert finely divided and dissolved organic materials into small molecules, such as carbon dioxide or methane, which can be used or discharged The processes can be aerobic (conducted in the presence of oxygen) or anaerobic (performed without air) Treatment plants that employ these processes are generally referred to as secondary treatment plants

3 3 1 Activated sludge

In the activated-sludge process suspended microorganisms are used to oxidize dissolved and colloidal organic materials in wastewater The organisms are mixed with the wastewater in continuous-flow aeration tanks Waste organic materials are removed by oxidation, by conversion to microorganism cells, and by sorption on microbial cell masses To provide rapid treatment, microbial cells are removed from the wastewater in a secondary sedimentation basin and recycled back to the head of the aeration tank Part of the organisms are wasted, rather than recycled These organisms, called "sludge," are treated anaerobically About 1 ton of sludge solids is produced in the primary step and the activated-sludge step for each million gallons of raw sewage treated Waste sludge is treated to reduce its volume and increase its density It is then usually disposed by landfill or burial The operation of the process requires the presence of an excess of air This is usually provided by diffusers or by mechanical aerators

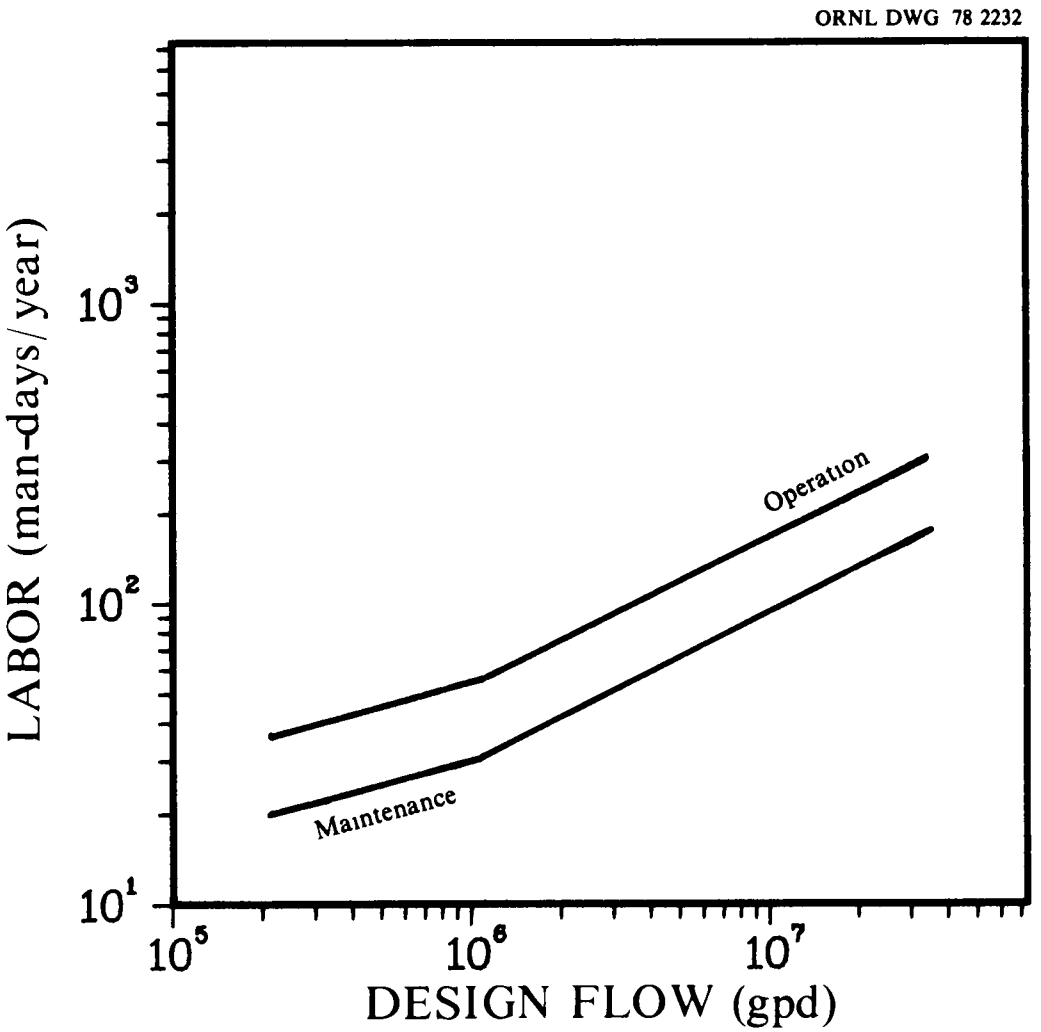


Fig 6 Labor requirements for primary sedimentation

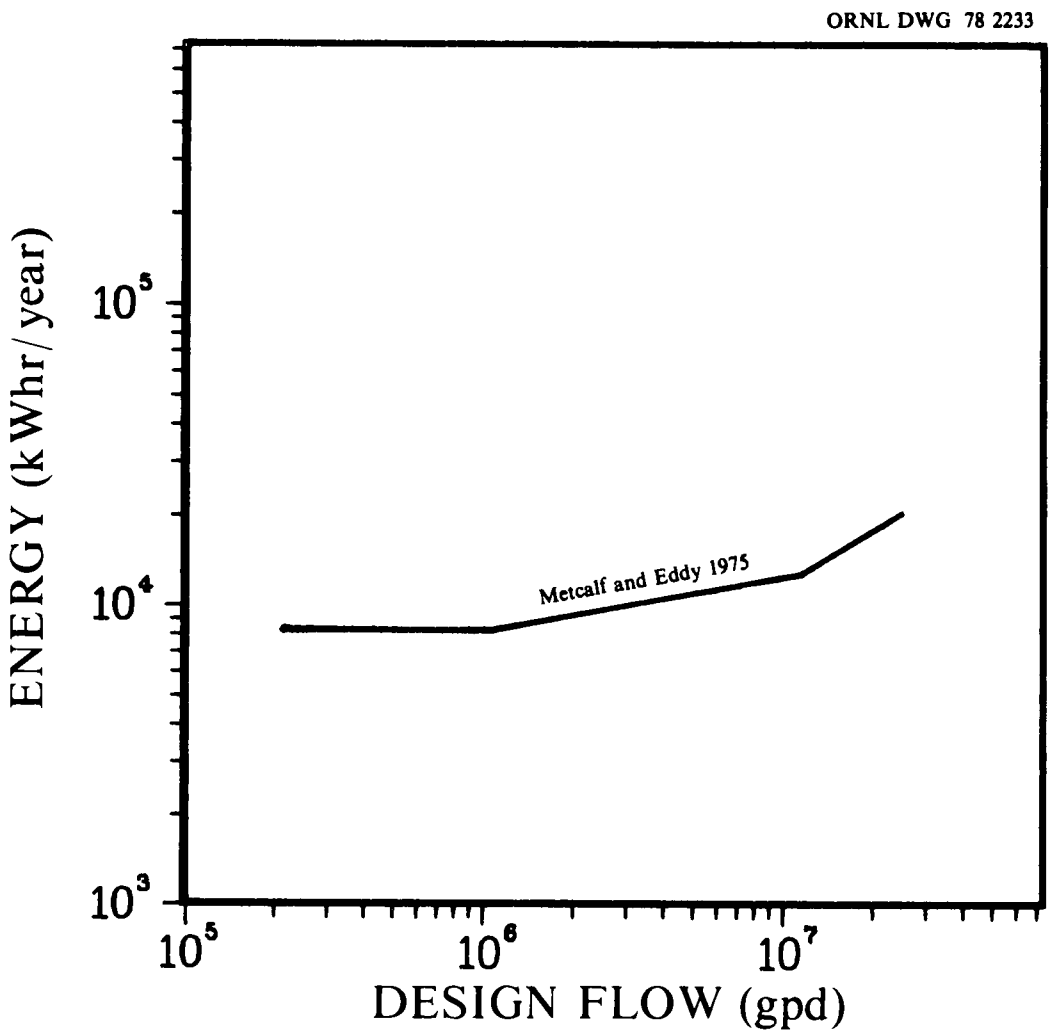


Fig 7 Energy requirements for primary sedimentation

System design is generally based on the application of a volumetric loading ratio or on a relationship between the amount of applied organic materials and the microorganisms in the system measured as organic material Volumetric loading ratios used range between 20 to 40 lb BOD_5 per day per ft^3 The ratio of applied organic materials to cells is generally between 0 2 to 0 4 lb BOD_5 per day per lb of suspended solids in the aeration tank Where a diffused air system is used for aeration, 9 to 15 times as much air as is required is generally applied This is a substantial process energy cost

The presence of heavy metals and toxic materials may require changes in design The process is not generally efficient at wastewater concentrations of <100 mg/liter BOD_5

Capital costs for an activated-sludge system are shown in Fig 8 These costs were derived from studies by the following Metcalf and Eddy (1975) Black and Veatch (1971), Battelle-Pacific Northwest Laboratories (1974), Culp, Wesner, and Culp (1975), and Brown and Caldwell (1974) The data all show general agreement for activated-sludge plants in the range of 1 to 10 x 10^6 gpd Using the heavy line that represents the Metcalf and Eddy data as a base, the estimated cost of a 10^6-gpd activated-sludge tank would be $900 000

Activated-sludge process operation and maintenance costs are shown in Fig 9 These figures are taken from Metcalf and Eddy (1975) Based on this data a 10^6-gpd activated-sludge plant would require 200 man-days of operating labor and 160 man-days of maintenance labor per year

The activated-sludge process is a major consumer of energy in an activated-sludge plant Figure 10 shows the consumption of energy by this process for plants ranging between 10^4 and 10^9 gpd The major consumer of energy in this process is aeration Based on this data from Metcalf and Eddy annual operation of a 10^6-gpd activated-sludge tank would require 250,000 kWhr

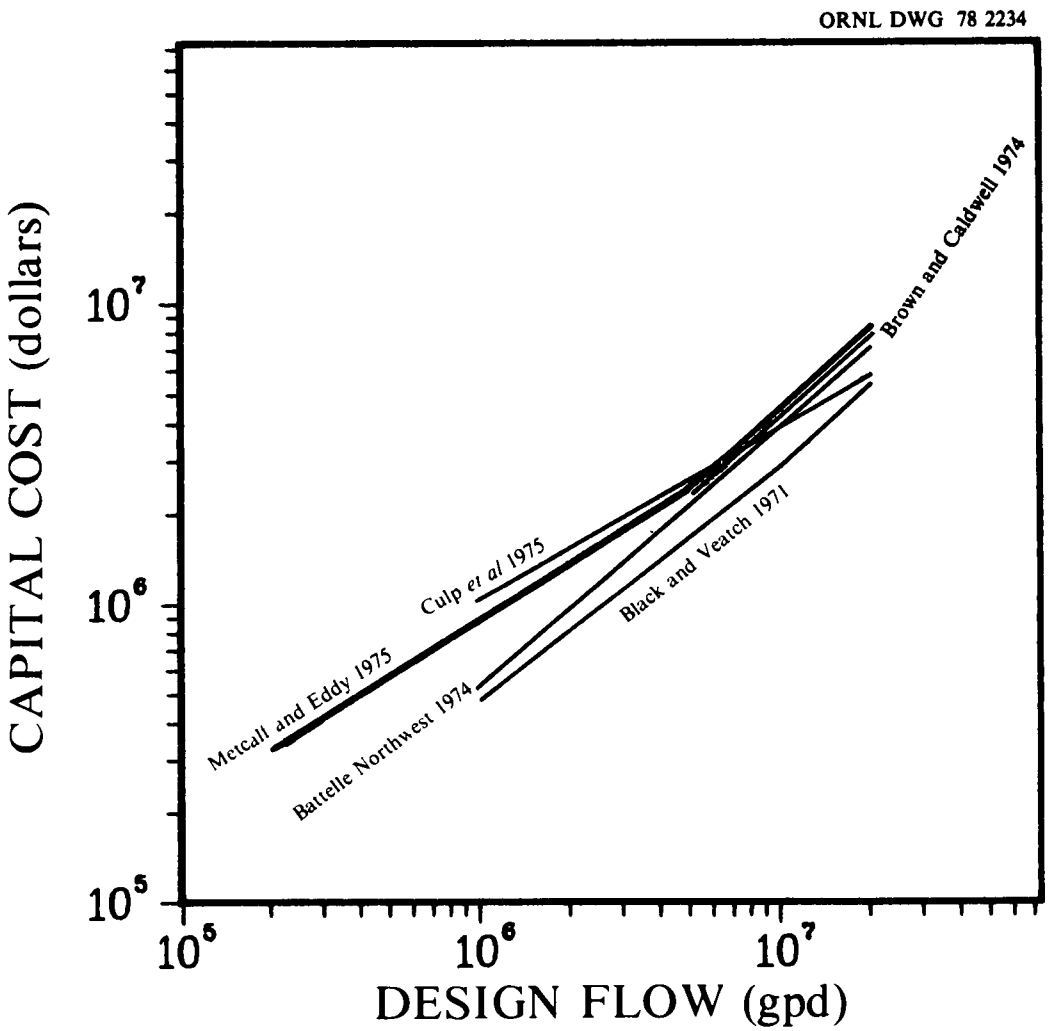


Fig 8 Capital costs for activated sludge

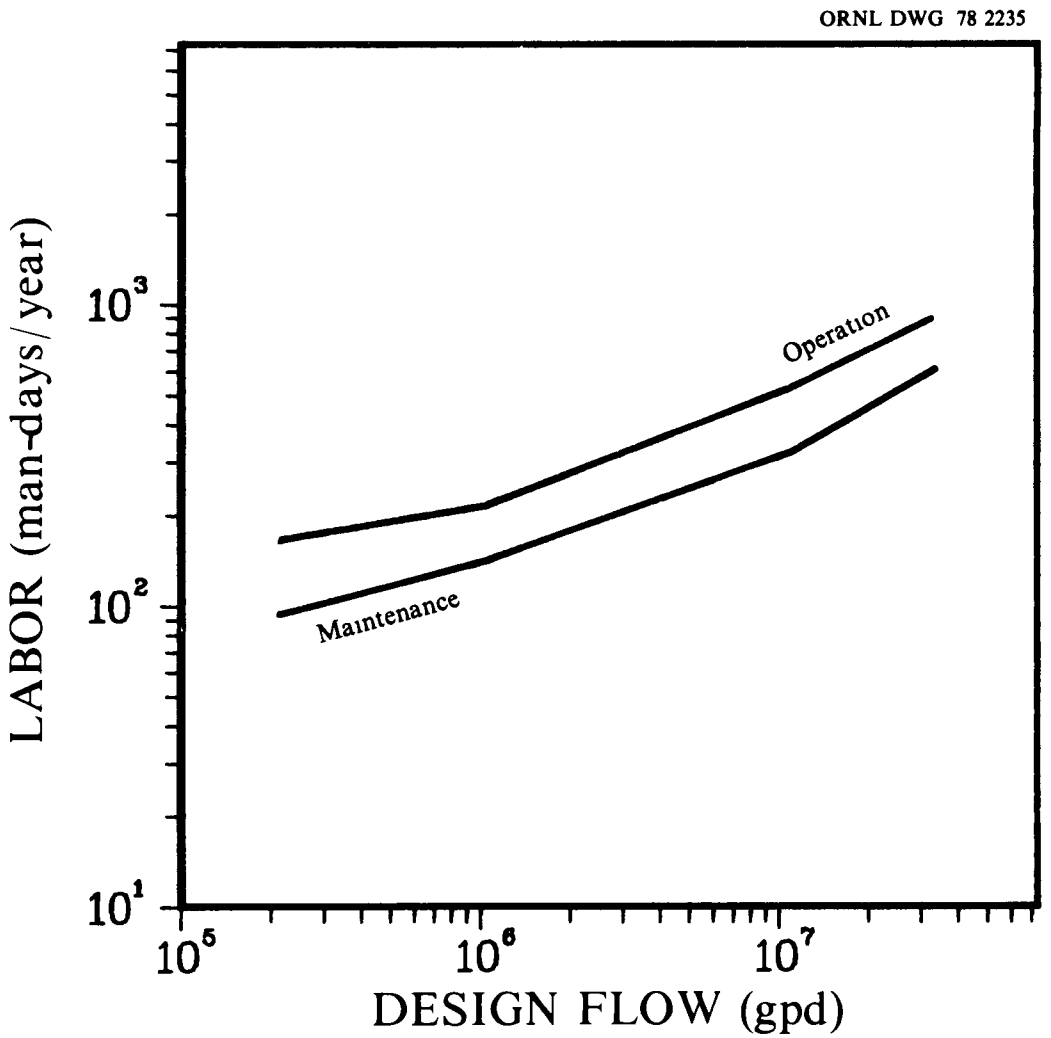


Fig 9 Labor requirements for activated sludge

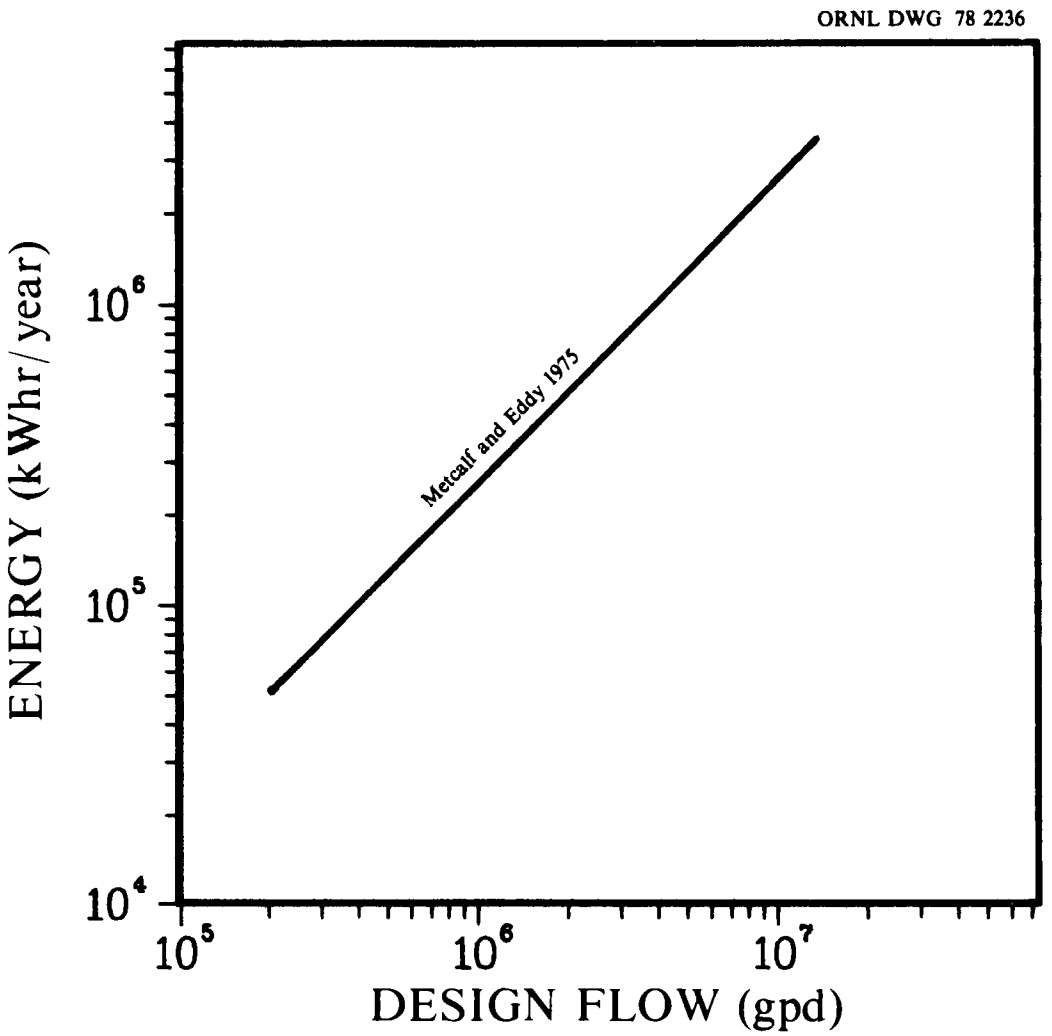


Fig 10 Energy requirements for activated sludge

3 3 2 High-rate trickling filters

A trickling filter is an aerobic biological reactor that provides a surface on which a thin layer of microorganisms can grow Wastewater flows down over this surface, and waste organics are sorbed and treated by the attached microorganisms Oxygen for the process is transferred from air flowing up through the filter packing In most cases, the reactor is operated in an air-continuous mode This device is used for the treatment of domestic wastewaters and for other applications, including the primary treatment of high-strength industrial wastewaters and the nitrification of domestic wastewaters In some cases it is also used in addition to an activated-sludge system for the treatment of seasonal wastes, such as cannery wastewaters

Conventional high-rate trickling filters are designed on the basis of volumetric loading rates and on the basis of hydraulic loadings to the upper-level packing surface area In general the cross-sectional area of trickling filters for the treatment of domestic wastewaters is designed to apply 10^7 to 4×10^7 gpd of overall hydraulic loading per acre of filter-top surface area An organic loading of 30 to 60 lb BOD_5 per 10^3 ft^3 per day is generally used Recirculation of the wastewater so that it passes through the filter several times is generally used Synthetic media depths of 15 to 30 ft or rock depths of 3 to 6 ft are common In some cases, multiple-filter stages are used

This system is the least complex and potentially most stable of the secondary wastewater treatment processes A major part of the successful design is however, the design of the secondary clarifier, which follows the biological process Shock-flow loadings may not permit the settling of the effluent from biological materials from the filter As with most biological processes the filter is affected by heavy metals or toxic materials in the wastewater

The capital costs of high-rate trickling filters are shown in Fig 11 This figure incorporates costs from several different authors The heavy line indicates costs from Metcalf and Eddy (1975) The lower light line indicates data from a Black and Veatch study (1971) and reflects the

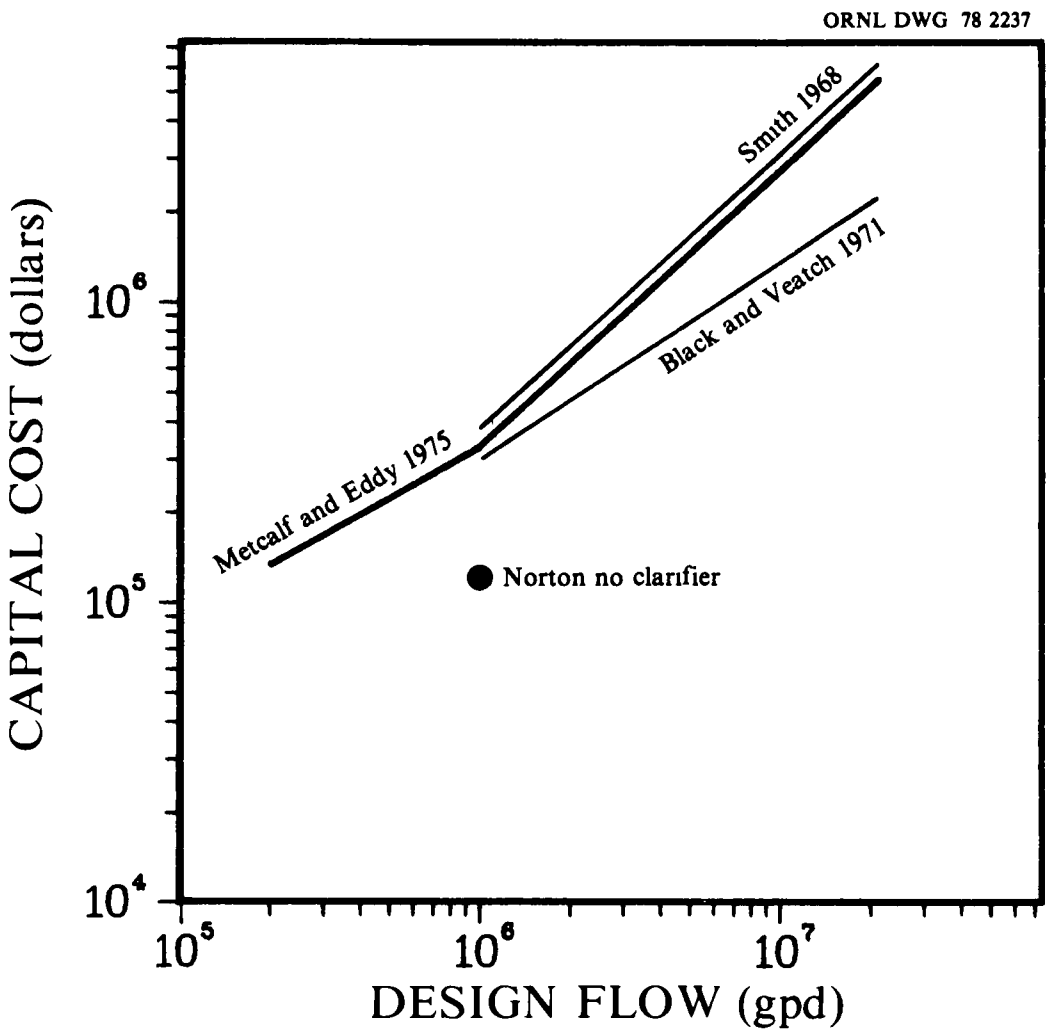


Fig 11 Capital costs for trickling filters

costs of actual construction and operation for 30 trickling-filter installations Some of these installations however used rock media rather than the newer synthetic types of media These costs reflect experienced construction costs of high-rate trickling-filter plants These costs do not include the expense of a secondary sedimentation basin The costs by Smith (1968) represent the Environmental Protection Agency (EPA) figures for the construction of trickling-filter systems These data are the highest costs cited Based on these data, the cost for a trickling-filter unit process for the treatment of 10^6 gpd would be $360,000 The single point in Fig 11 is a cost estimate for a high-rate trickling-filter plant for the treatment of 10^6 gpd of wastewater supplied by the Norton Corporation These units are supplied on a package basis Their estimated cost for such an installation is about $100,000

The high-rate trickling filter is one of the simplest biological unit processes to operate The operation and maintenance requirements for this process, in terms of man-days/year, are shown in Fig 12 For a 10^6-gpd plant operation demands 17 man-days, maintenance, 13 man-days This is substantially less than operation and maintenance for the activated-sludge process that was considered earlier

In a similar fashion, the high-rate trickling filter is an energy-conservative device The energy consumption for high-rate trickling-filter unit processes is shown in Fig 13 This figure was taken from Metcalf and Eddy (1975) The annual energy requirements for a 10^6-gpd high-rate trickling-filter process is 21 000 kWhr

3 3 3 ANFLOW

The ANFLOW or anaerobic upflow process is a fixed-film process in which microorganisms are allowed to grow without air in a wastewater-continuous environment A special surface is provided to encourage attachment of the microorganisms and the sorption of wastewater organic materials This process is similar to the trickling-filter process in that large masses of microorganisms are attached to the surface of the packing However, the process is operated in a water-continuous, rather than an air-continuous fashion Because the process is anaerobic, lower sludge volumes are produced

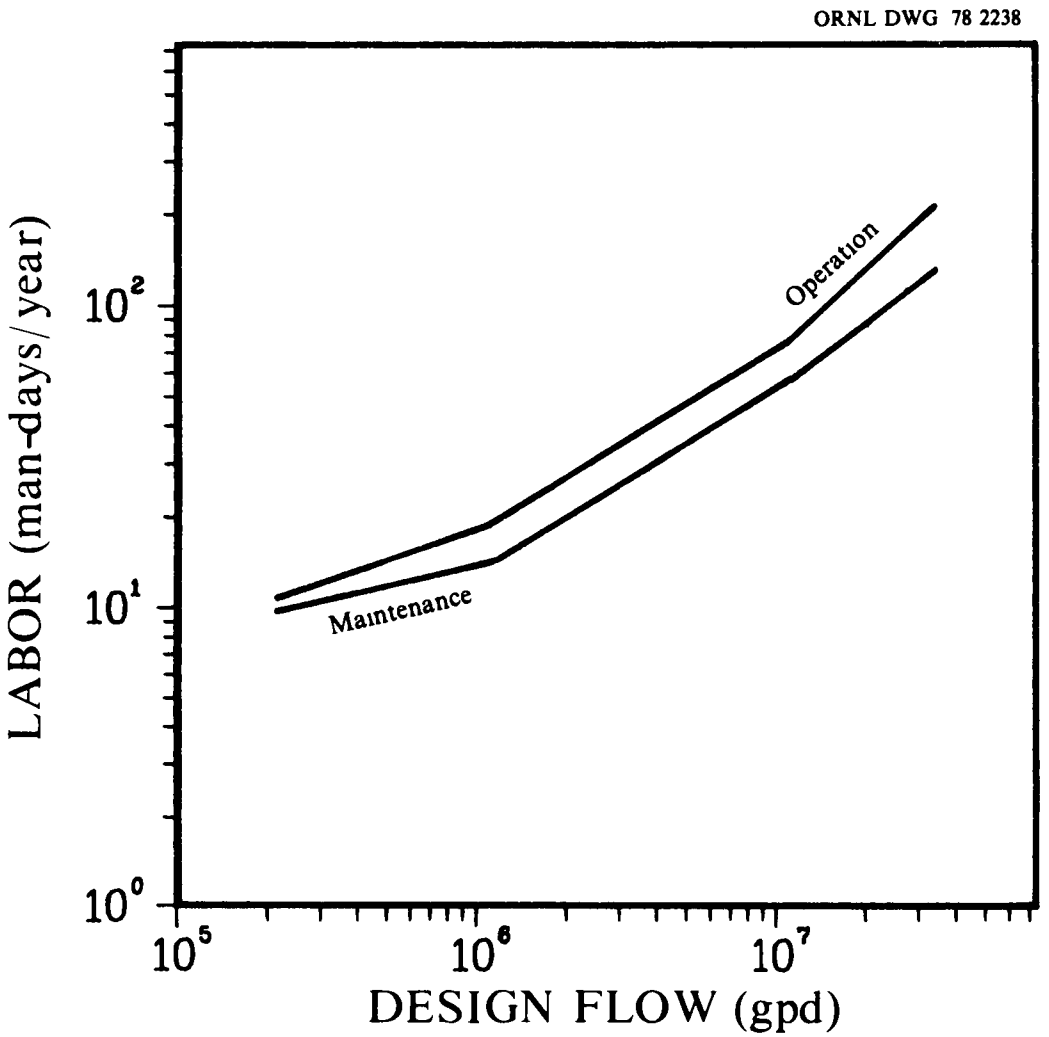


Fig 12 Labor requirements for trickling filters

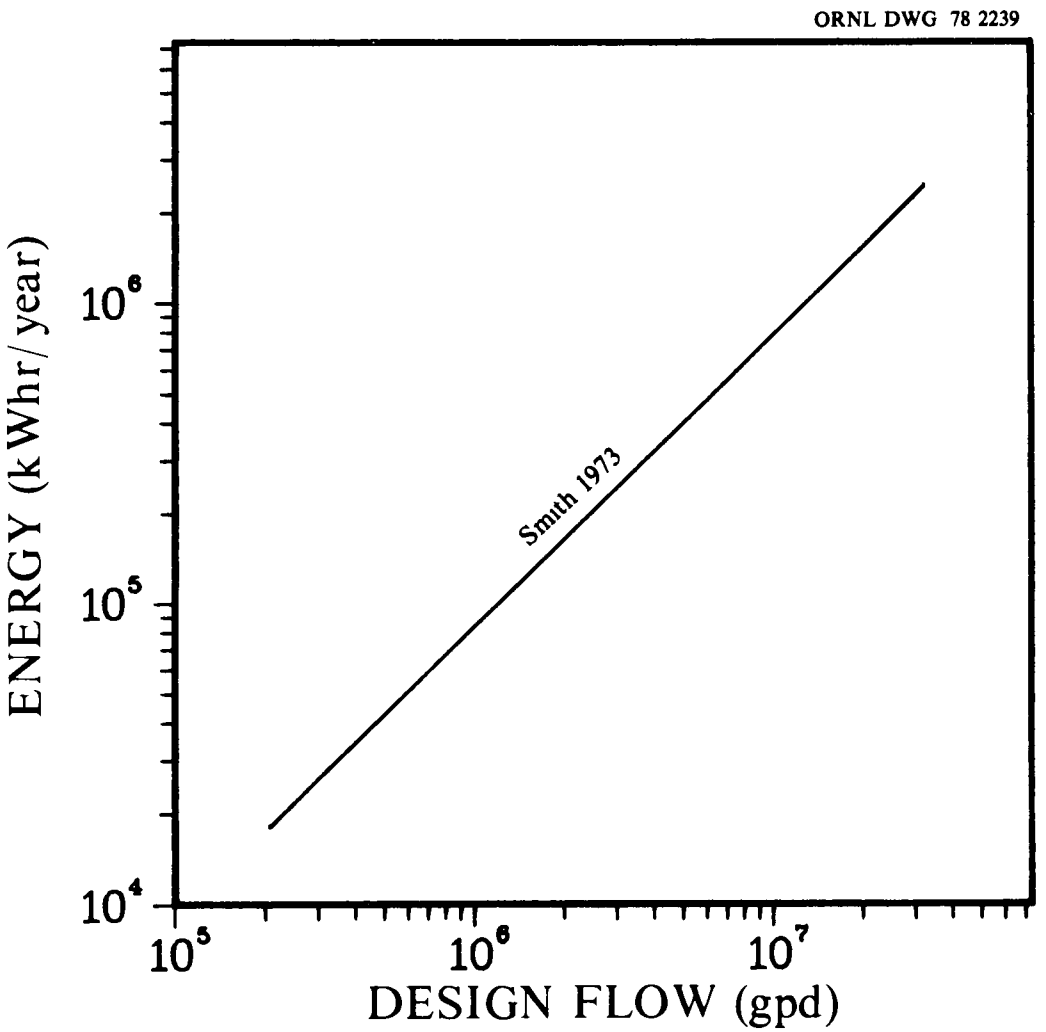


Fig 13 Energy requirements for trickling filters

Conceptual scale-up of the 5000-gpd pilot plant is shown in Fig 14 The estimates made were based on a direct scale-up of the 5000-gpd design flow rate of the pilot plant For a 10^6-gpd plant, two 50-ft-diam ANFLOW units (each with a 10-ft-deep packed bed) would be required on this basis

The process is simple to operate in that the flow is controlled by gravity and the energy requirements are minimal The process is subject to shock from toxic materials, as are aerobic biological processes However, where the toxic materials are heavy metals, they may be precipitated as insoluble sulfides during the passage through the biological treatment unit The process provides for the reduction of nitrate and nitrite to nitrogen gas but does not provide for the removal of ammonia (other than through conversion to cell biomass) Sulfate and sulfite are converted to hydrogen sulfide, which can be toxic to organisms downstream from the process at certain pH values

Capital costs for ANFLOW biological process units treating 10^5 to 10^7 gpd are shown in Fig 15 The central line reflects a media cost of $\$10/ft^3$, while the upper and lower lines represent media costs of $\$15/ft^3$ and $\$5/ft^3$ respectively Based on a media cost of $\$10/ft^3$ the capital cost of a 10^6-gpd plant would be \$900,000 A breakdown of these costs is presented in Table 1

Table 1 ANFLOW cost breakdown

Item	Cost (/)
Excavation and backfill	5
ANFLOW column	35
Flow distribution	10
Packing	50
Total	100

Operation and maintenance labor requirements for ANFLOW process units are estimated to be the same as for aerobic biofilters as presented in Fig 12 since no long term experience is available

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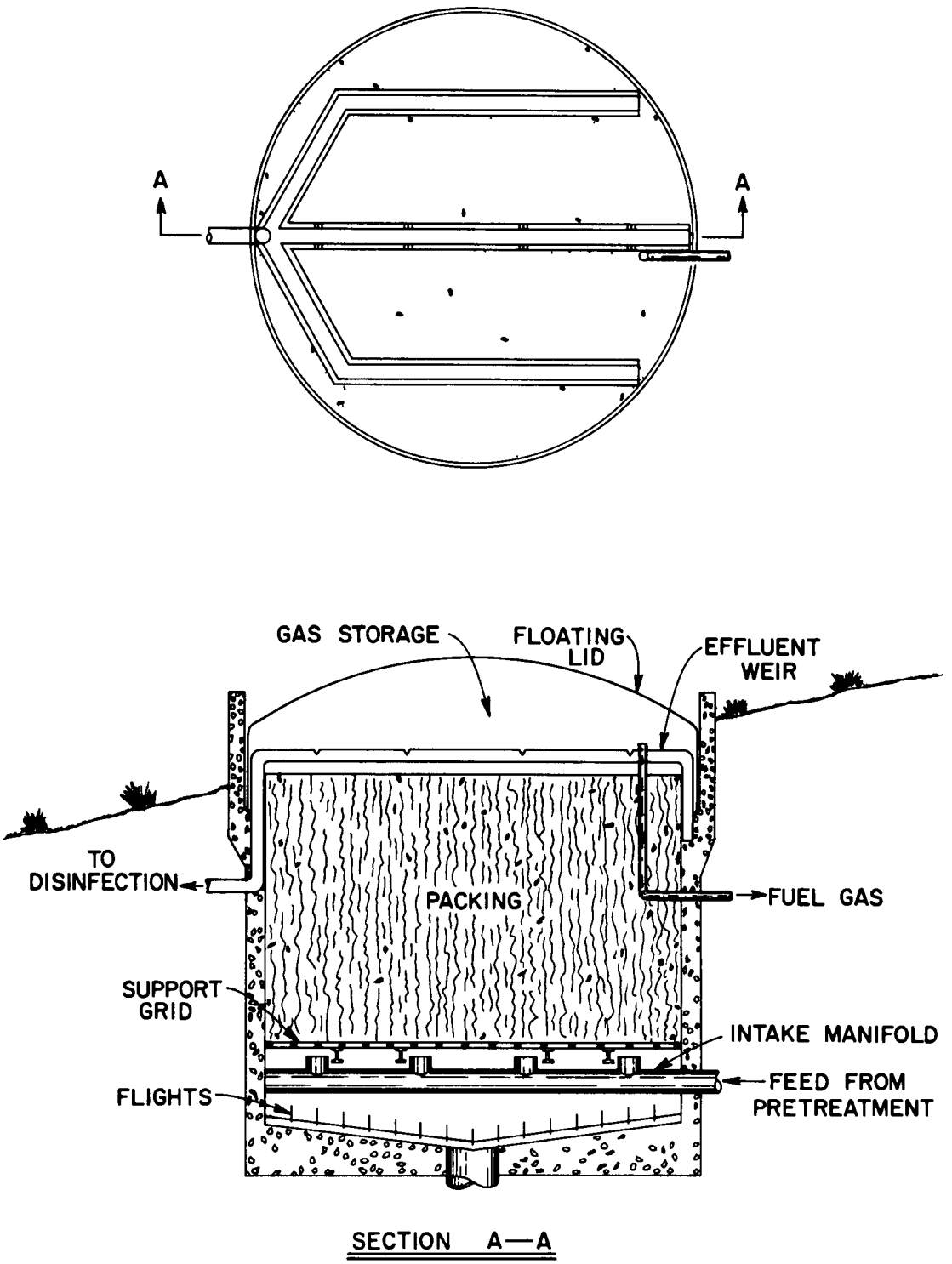

Fig 14 Conceptual ANFLOW bioreactor scale-up

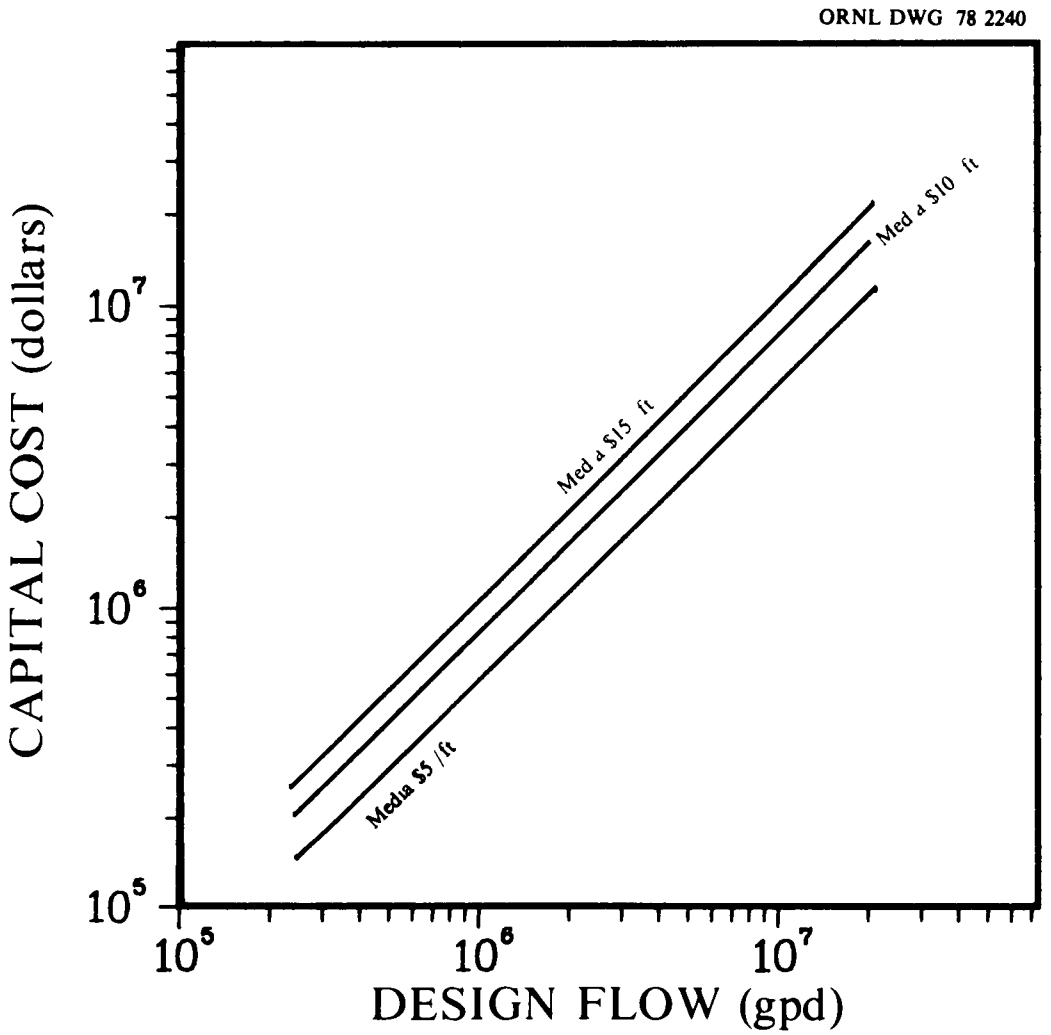

Fig 15 Capital costs for ANFLOW

3 4 Secondary Effluent Polishing Techniques

Several polishing techniques that can improve the quality of a wastewater treatment process effluent are available In general the type of effluent polishing technique that is chosen will depend to a degree on the particular type of improvement in effluent quality which is desired Sedimentation and filtration processes decrease the amount of solid material in an effluent but provide relatively little decrease in the amount of inorganic nitrogen or phosphorous compounds in the effluent These techniques can represent a cost savings over the use of a biological process design providing the same effluent quality, since the difficulty of removing materials from a wastewater increases rapidly as the concentration of material in the wastewater decreases

Effluent polishing techniques are compatible with most wastewater treatment operations As legislative requirements for effluent quality increase the use of these techniques can be expected to rise

3 4 1 Additional sedimentation

Additional sedimentation can be used for situations where the effluent requires further removal of solids Some nitrification, or conversion of reduced nitrogen compounds to oxidized nitrogen compounds, can also be expected This process can be used with most biological secondary processes In most cases, it is sufficient to provide enough sedimentation capacity to give an overflow rate of 400 gal per day per ft^2

Figure 16 shows the capital costs for sedimentation basins with an overflow rate of 400 gal per day per ft^2 The capital cost of a 10^6-gpd plant is $170 000 Operating, maintenance and energy costs can be obtained from Figs 6 and 7 Chemical requirements for simple sedimentation are nil, however the removal of some materials (such as colloidal organic compounds and phosphorous) can be enhanced through the use of coagulating or precipitating compounds, including calcium, iron, aluminum salts and organic polyelectrolytes The capital cost of equipment to add alum, ferric chloride, or polyelectrolytes is presented in Fig 17 Typical annual chemical requirements for a 10^6-gpd plant

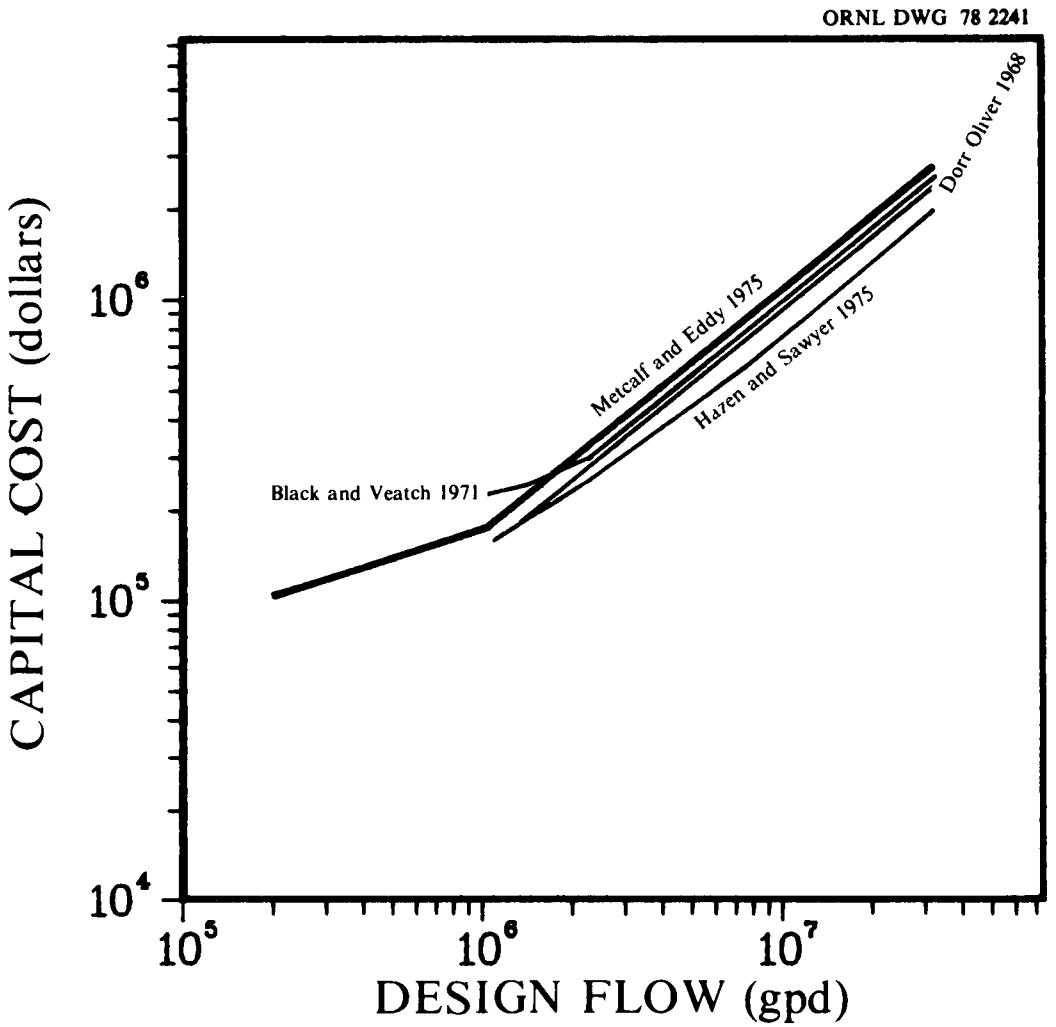

Fig 16 Capital costs for low overflow rate sedimentation

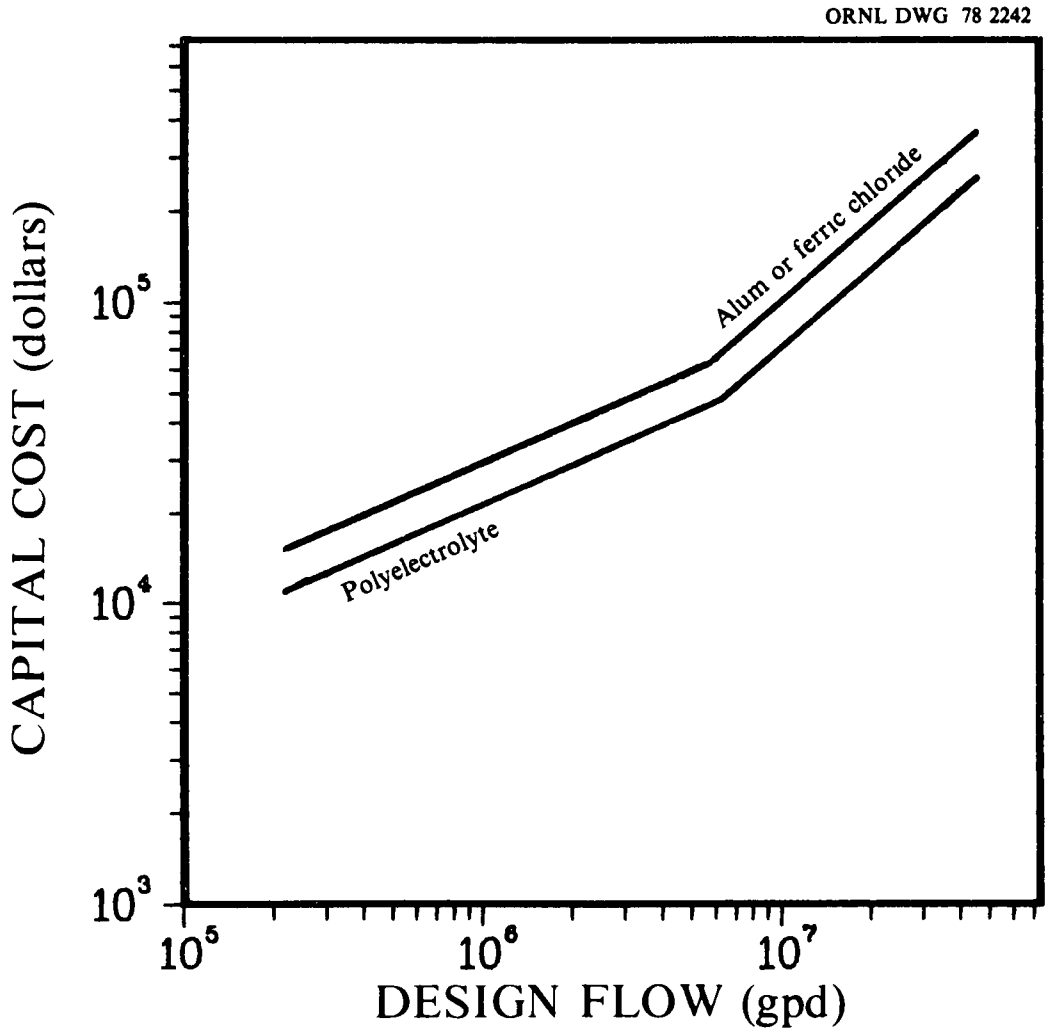

Fig 17 Capital costs for coagulant feed equipment

are the following 600 000 lb CaO 300,000 lb $FeCl_3$ or 15,000 lb polyelectrolyte The amount of sludge collected is significantly increased when chemicals are added to improve sedimentation efficiency Sludge from this process requires digestion and ultimate disposal as does the sludge from primary and secondary sedimentation processes

The process is sensitive to abrupt changes in flow These may cause bulking of the settled sludge or may result in a decreased amount of sedimentation The process is not sensitive to toxic materials in that it does not involve a biological step

3 4 2 Microscreening

Microscreening is a physical straining process used to remove solids from secondary effluents Wastewaters enter a rotating drum covered with filtration media, solids are removed as the wastewater flows out through the filtration media Solids are continuously removed from the drum by backwashing The filtration media used can be woven stainless steel or polyester cloth having apertures ranging from 15 to 60 μ The process produces a low-solids wastewater However the removed solids must be treated as sludge and disposed

Typical hydraulic loading rates for microscreens are between 5 and 10 gpm/ft^2 Head loss through a microscreen is 3 to 6 in of water The process is not sensitive to toxic materials in that it is a physical process However, variations in influent solids which might overload the system can create difficulties The microscreening process is compatible with biological secondary wastewater treatment processes

Microscreen capital costs are shown in Fig 18 adapted from Metcalf and Eddy (1975) The highest and lowest values shown in the figure come from the same author, Smith (1968 and 1969), in two separate reports The costs shown as a heavy line are best-choice values taken from a report for the EPA by Hazen and Sawyer (1975) The cost of microscreening for a 10^6-gpd plant would be $80,000 Energy requirements for the operation and maintenance of microscreens include the energy required to operate the microscreen drum, the backwash system, and the sludge pumps (See

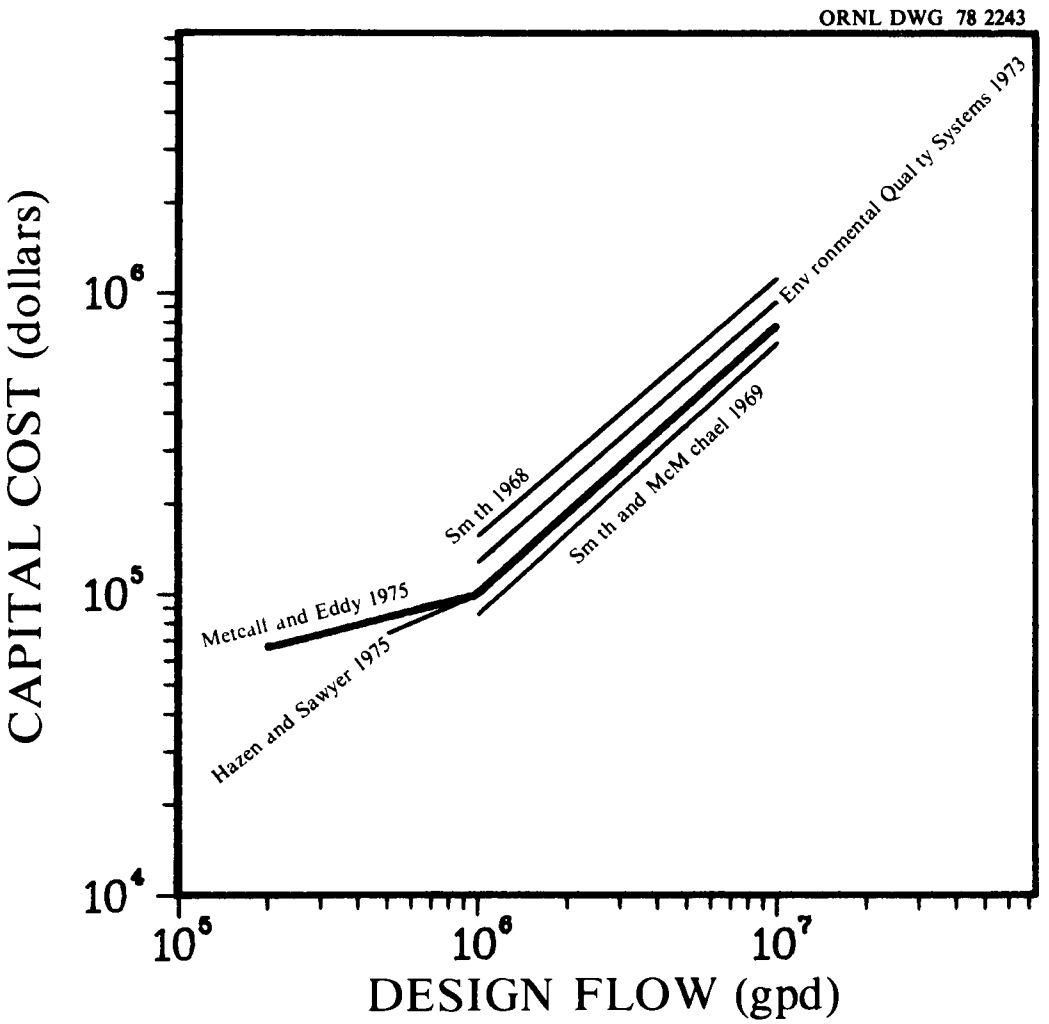

Fig 18 Capital costs for microscreening

Fig 19) Microscreening is a relatively low-energy process, using only 42,000 kWhr/year to treat 10^6 gal However, microscreening does have substantial operation and maintenance labor requirements As shown in Fig 20, the manpower requirements for microscreening in a 10^6-gpd plant are 300 man-days/year

3 4 3 Reaeration

Hydraulic aeration or cascade aeration, is used after a secondary biological treatment process to increase the dissolved oxygen content of an effluent prior to discharge to a receiving water This process can provide an effluent with an oxygen content of 5 to 8 mg/liter

A major process difficulty is the lack of a rational design method for cascade aerators The units are designed according to peak effluent flow The process is not adversely affected by the presence of toxic materials since it is a physical process However the presence of surfactant materials in the effluent can result in a decrease in process efficiency

The capital costs of hydraulic reaeration are shown in Fig 21 This cost diagram was prepared using data developed by Metcalf and Eddy (1975) Hydraulic reaeration is a very inexpensive part of an overall wastewater treatment process The capital cost for a 10^6-gpd plant is $120 000

Although hydraulic reaeration is the most common type of post-process aeration diffused aeration is also used Both porous and nonporous diffusers are utilized As with hydraulic reaeration, the process is sensitive to the presence of surfactants

Capital costs for diffused reaeration systems are shown in Fig 22 The costs for diffused reaeration systems are significantly higher than those for hydraulic reaeration systems The data on which Fig 22 is based were derived from studies by Smith (1968, 1974) and from Metcalf and Eddy (1975) The cost of a diffused reaeration system for a 10^6-gpd plant is $110,000

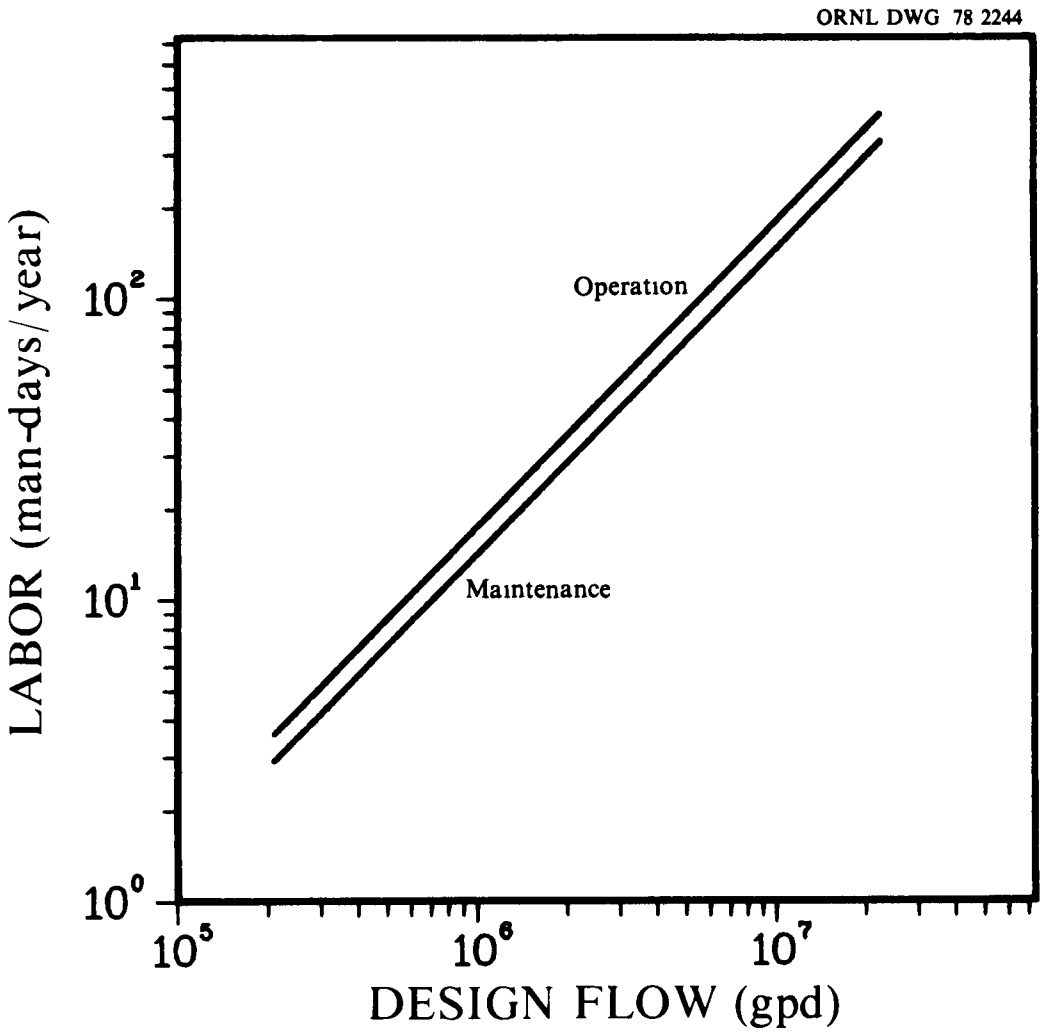

Fig 19 Labor requirements for microscreening

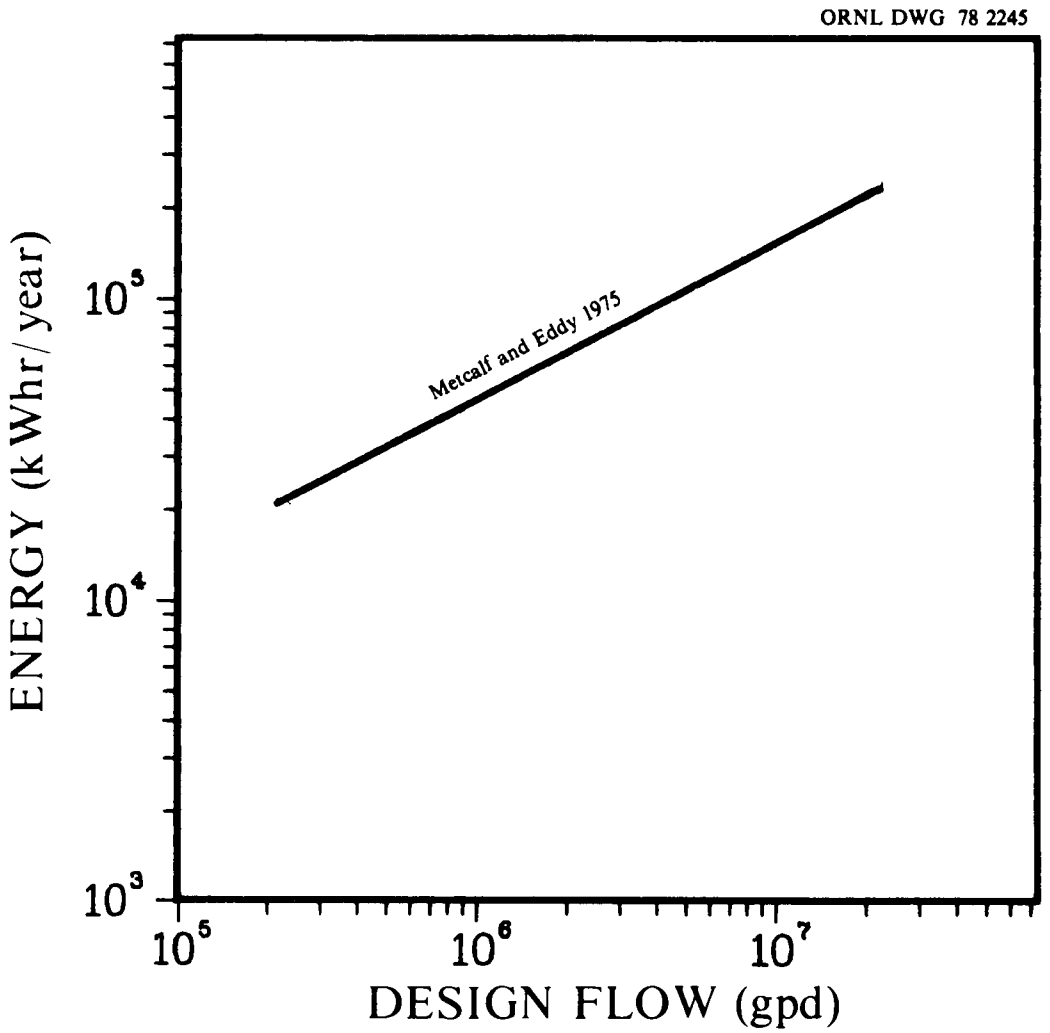

Fig 20 Energy requirements for microscreening

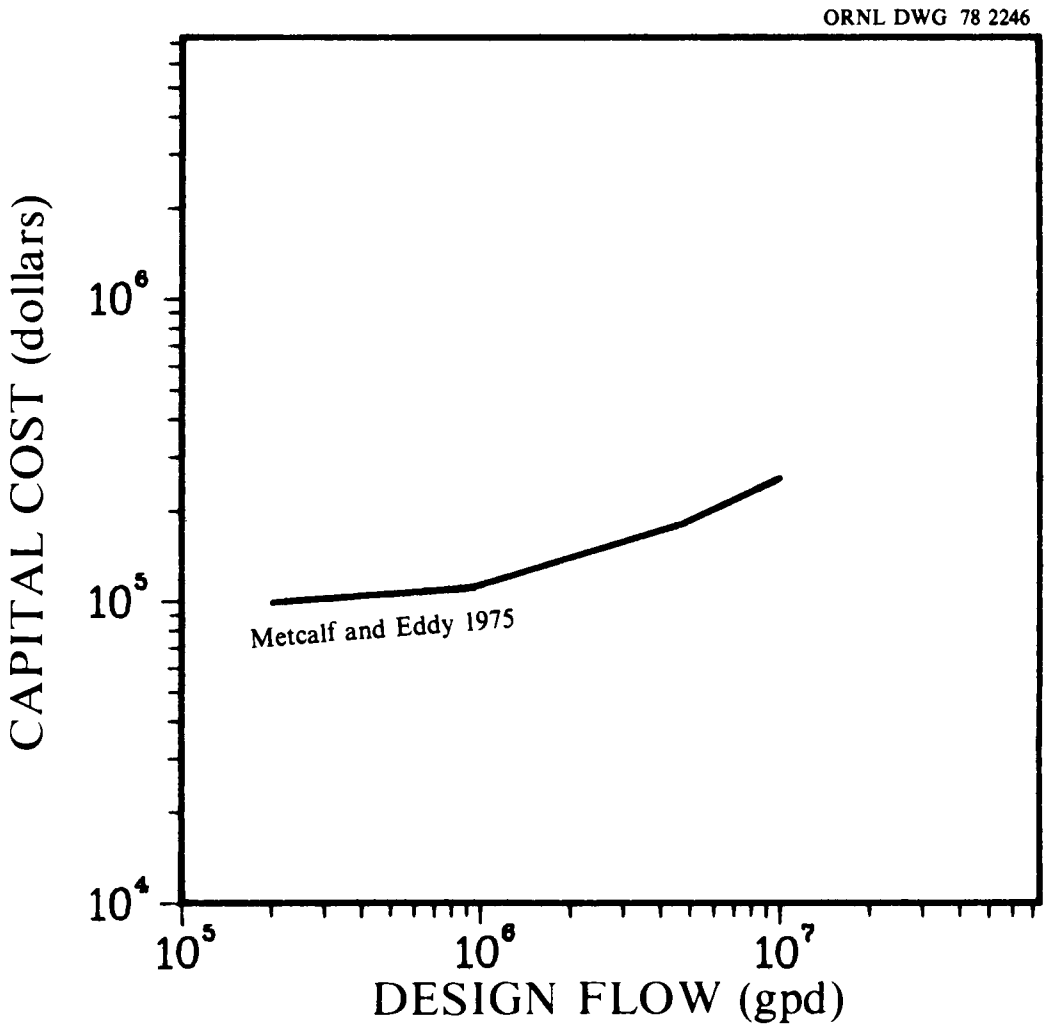

Fig 21 Capital costs for hydraulic reaeration

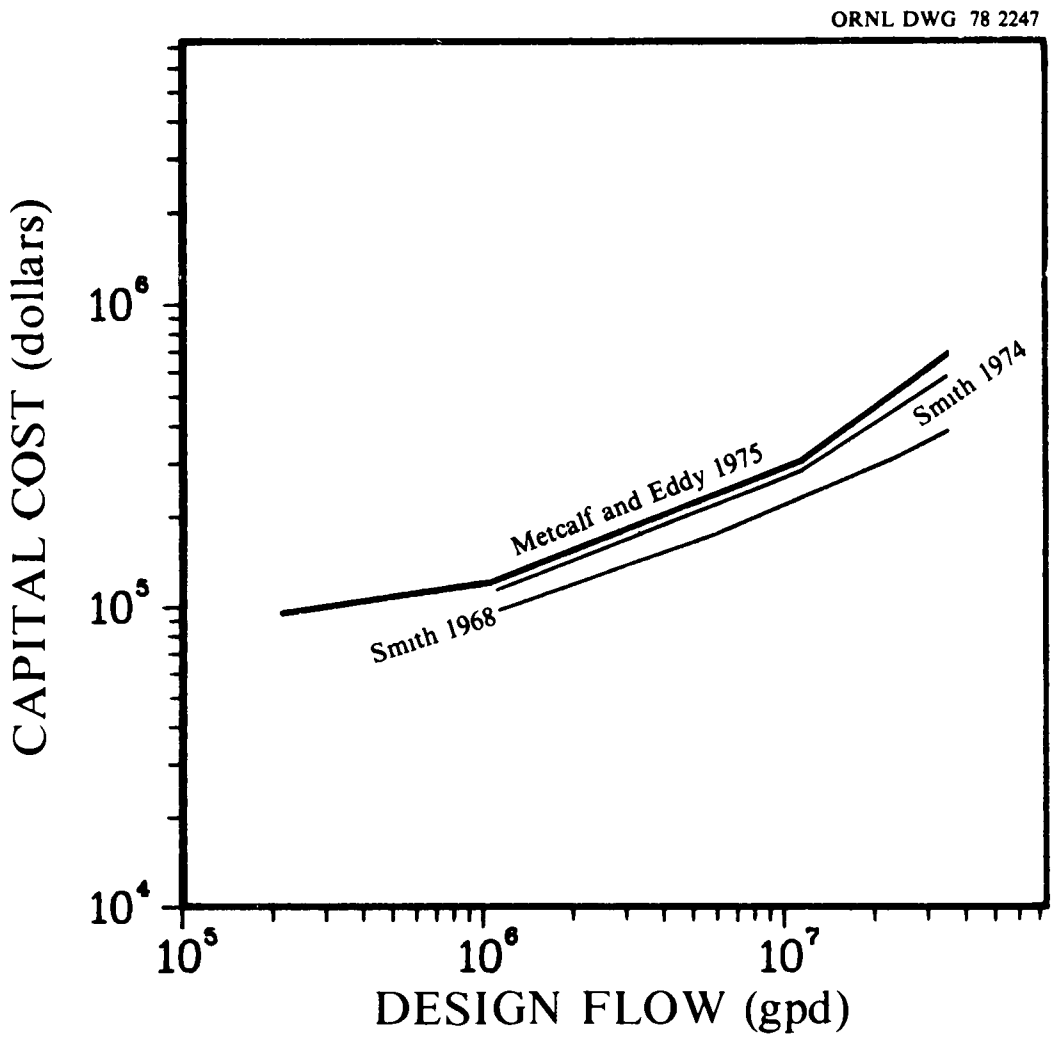

Fig 22 Capital costs for diffused reaeration

Operation and maintenance labor requirements for diffused reaeration are shown in Fig 23 For a 10^6-gpd plant, 63 man-days of operation and 20 man-days of maintenance labor are required Energy requirements for the diffused reaeration process are shown in Fig 24 Like activated-sludge aeration, diffused reaeration is energy-intensive For a 10^6-gpd plant, annual energy requirements would be 6800 kWhr (Metcalf and Eddy 1975)

3 4 4 Multimedia filtration

Filtration can be used for the removal of suspended solids from wastewaters If it is used in conjunction with appropriate chemical treatment, it can also be used to remove precipitated inorganic materials from wastewaters, including nutrient compounds such as phosphate Unless coagulating chemicals such as lime alum, or polyelectrolytes are used, the filtration process will not remove colloidal or inorganic chemicals

The process is designed on a basis of 3 to 5 gal per day per ft^2 of surface area Peak-to-average flow ratios of 1 5 are tolerated However, the process produces up to 8/ of the process flow, which must be recycled through the plant This would require additional treatment capacity and flow equalization in prior treatment steps Because this is a physical-chemical process, it is not sensitive to the presence of toxic materials However, the process is sensitive to increases in the amount of suspended solids in the water filtered An abrupt rise in the amount of wastewater solids can require a decrease in the flow rate through the filter and in the amount of time between filter backwash operations If a coagulation process is used together with the filtration process the operation and management of the process can be quite complex

Capital costs for multimedia filtration systems are shown in Fig 25, derived from Metcalf and Eddy (1975) The line representing the lowest cost was taken from a study by Hazen and Sawyer (1975) The two highest cost figures were taken from studies by Culp and Culp for Lake Tahoe (1975) and Brown and Caldwell Consulting Engineers (1974) Close agreement exists between the study by Environmental Quality Systems, Inc for the

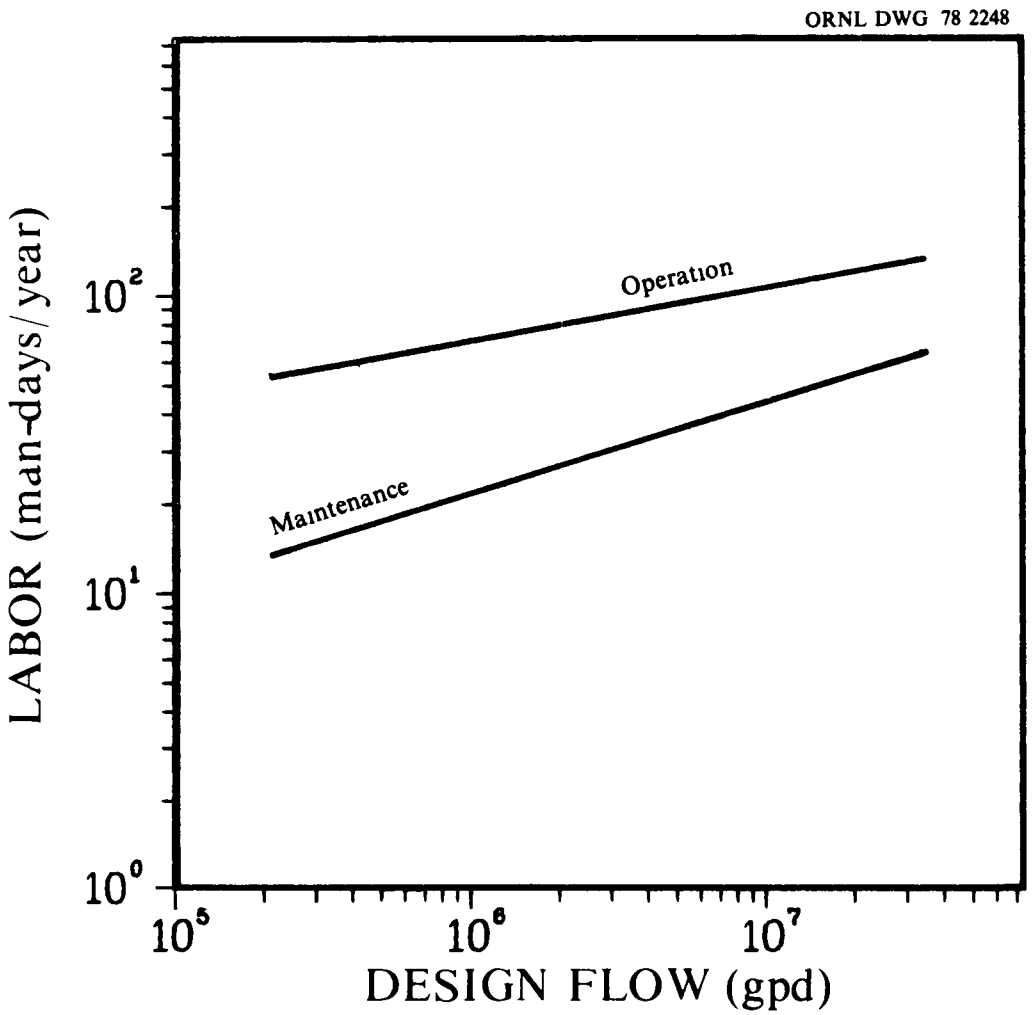

Fig 23 Labor requirements for diffused reaeration

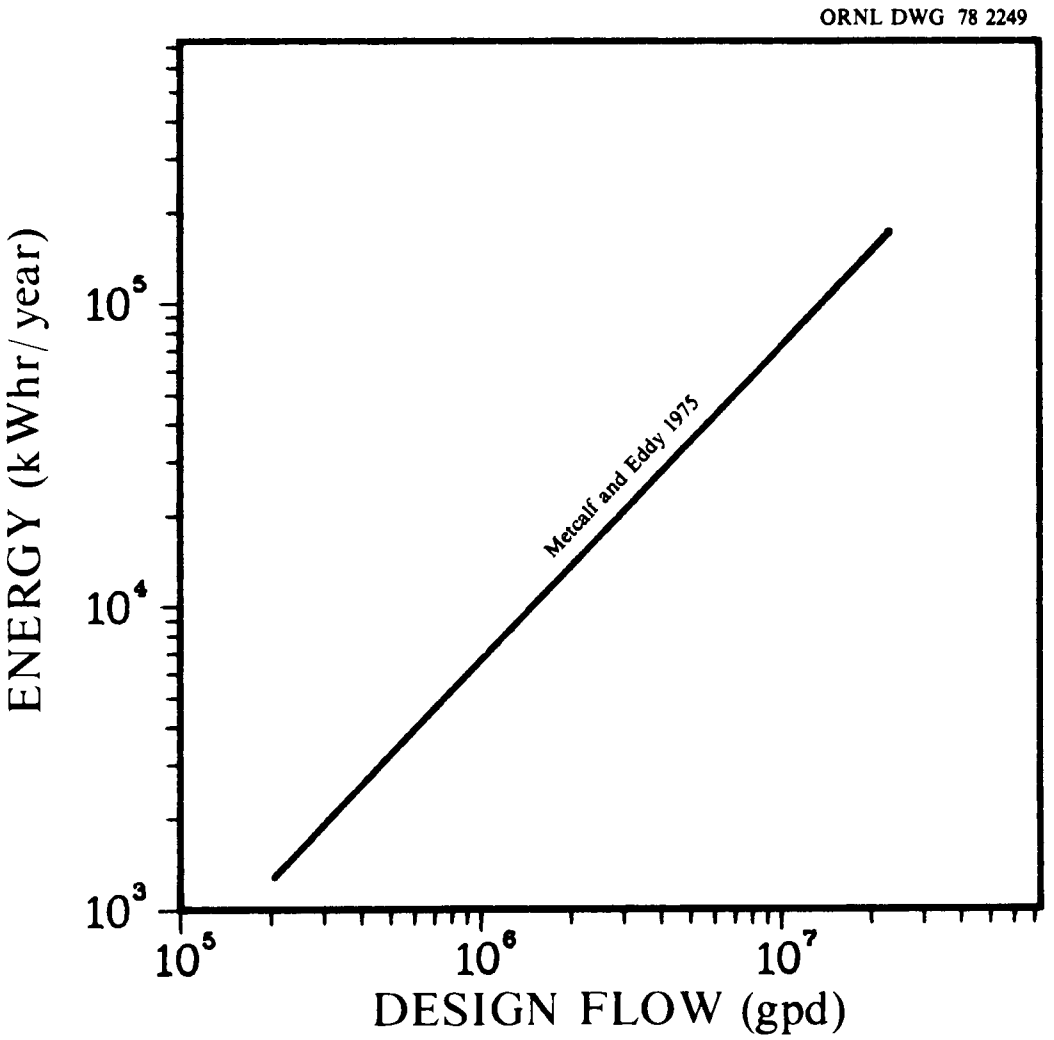

Fig 24 Energy requirements for diffused reaeration

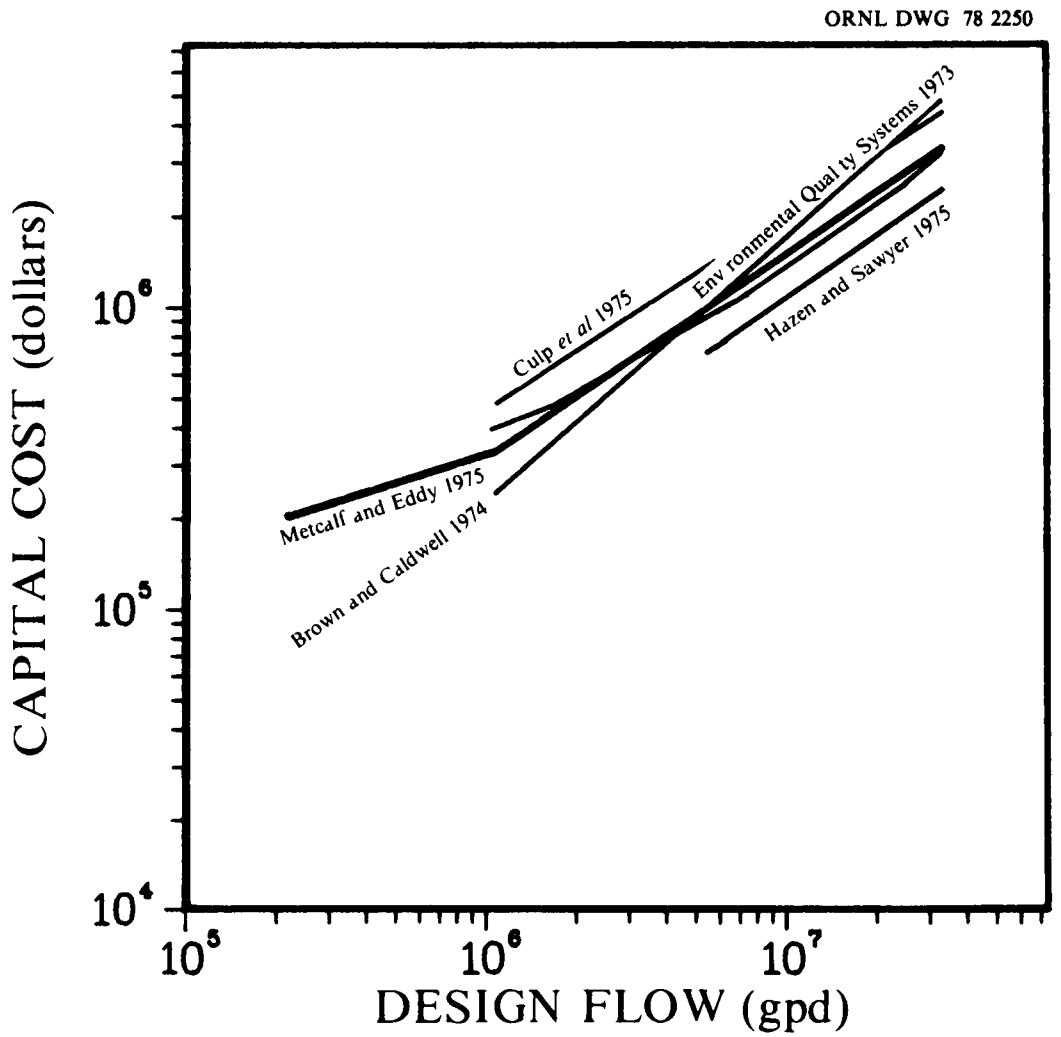

Fig 25 Capital costs for multimedia filtration

U S Army Corps of Engineers (1973) and the Metcalf and Eddy private-files data (1975) For a 10^6-gpd plant, multimedia filtration would have a capital cost of $320,000

Operation and maintenance labor for multimedia filtration processes are shown in Fig 26 With both of these processes the labor per unit processed decreases with increasing process size For a 10^6-gpd plant, combined operation and maintenance labor to provide multimedia filtration would be 138 man-days/year

Operation and maintenance energy requirements for multimedia filtration are shown in Fig 27 Electricity is required for filter backwash operations Energy consumption for multimedia filtration in a 10^6-gpd plant is 36,000 kWhr/year

3 4 5 Granular-carbon adsorption

Dissolved and colloidal organic materials can be removed by sorption on granular activated carbon Suspended solids can also be removed if the carbon column is designed to provide filtration Design loading rates for activated carbon columns typically range between 2 and 10 gpm/ft^2 Unless a special charcoal is used, the activated carbon column will not remove polar molecules or small organic molecules

The activated carbon system is not sensitive to the presence of toxic materials because sorption is a physical-chemical process However, it is sensitive to changes in flow mass transfer efficiency is reduced at flow rates of <2 gpm/ft^2, and head loss is high at values >10 gpm/ft^2 The presence of large amounts of suspended solids can necessitate more frequent regeneration of carbon Excessively high or low pH values can decrease the sorption of various species on carbon

The process effluent is spent granular carbon This material is usually regenerated in a multiple-hearth furnace With each pass through the furnace, ∿7/ of the carbon is replaced with fresh material Spent carbon solids are equivalent to 250 lb per 10^6 gal waste with 10 mg/liter chemical oxygen demand (COD) removed

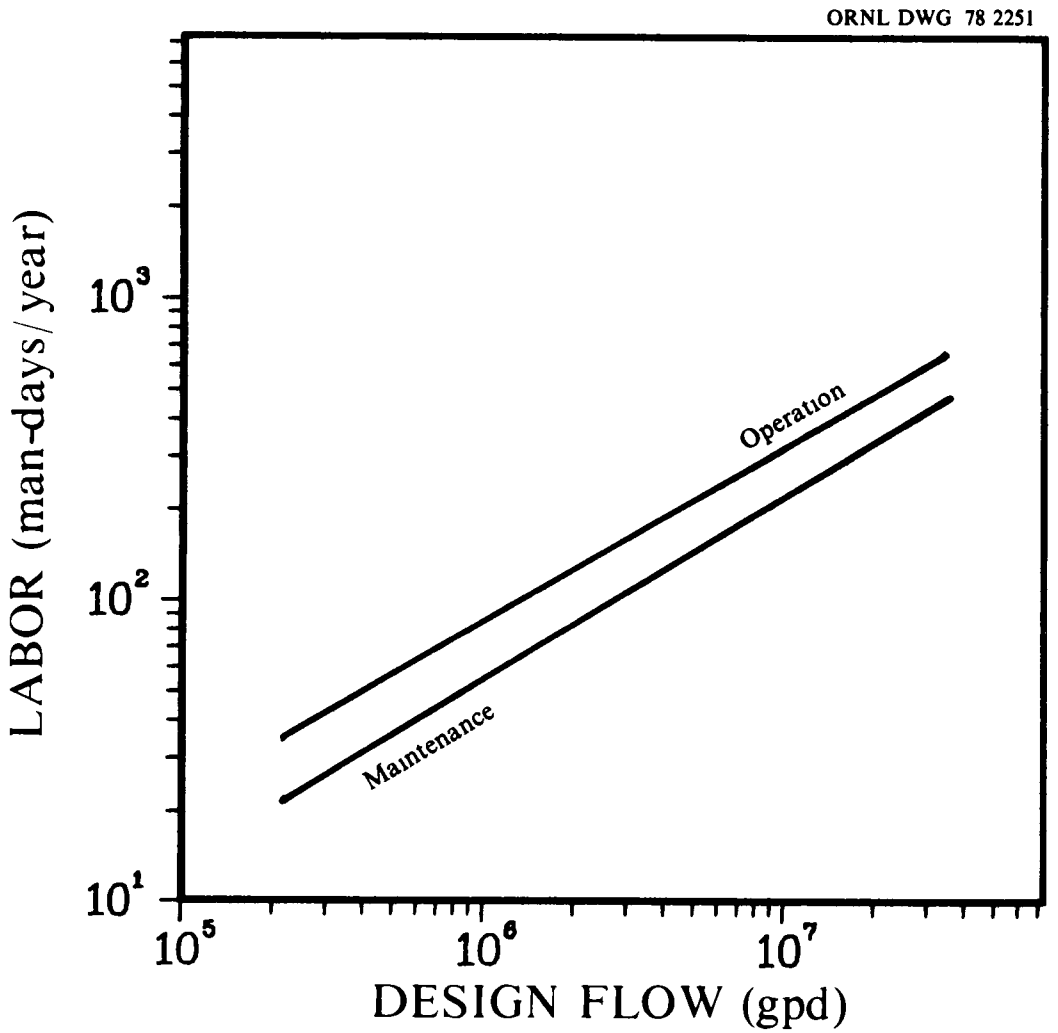

Fig 26 Labor requirements for multimedia filtration

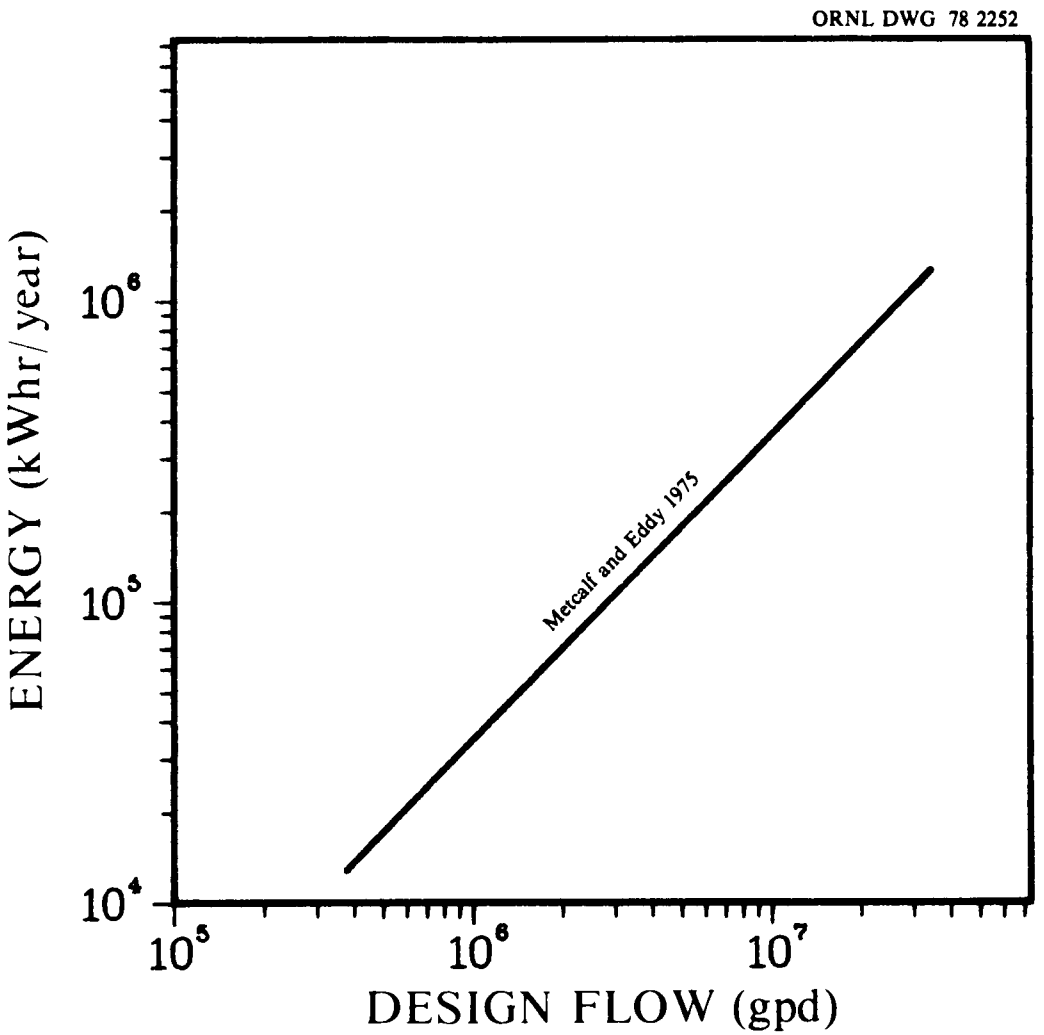

Fig 27 Energy requirements for multimedia filtration

Capital costs for a granular carbon filtration system are shown in Fig 28 For a 10^6-gpd system, the cost is $1,000,000 This amount includes the cost of a regeneration system, which provides for the regeneration of granular carbon (Metcalf and Eddy 1975)

Operation and maintenance of a granular carbon sorption unit requires a substantial commitment of manpower as shown in Fig 29 For a 10^6-gpd plant, operation demands 540 man-days/year maintenance 320 man-days/year The process has substantial energy requirements, as indicated in Fig 30 Energy demands arise from the regeneration furnace, from carbon pumping activities, and from any required backwashing Annual energy requirements for the operation of a 10^6-gpd granular carbon adsorption unit are ∿130,000 kWhr

3 4 6 Two-stage lime coagulation-filtration

After biological treatment lime is added, and the pH is raised to >11 Sufficient reaction time is provided to allow the precipitation of the phosphorous as basic calcium phosphate (apatite) The resulting calcium carbonate precipitate acts as a coagulant for the removal of suspended solids The excess dissolved calcium is removed by the addition of carbon dioxide gas until the pH is lowered to ∿10 A second addition of carbon dioxide gas is made to reduce the pH and to prevent scaling The effluent is passed through a multimedia filtration step to remove suspended solids In most instances on-site lime recovery and carbon dioxide generation is cost-effective

Since the process is a physical-chemical treatment, it is not sensitive to toxic materials in the process influent It is, however, sensitive to process flow variations in that they may affect the flow conditions in sedimentation basins If unsettled flow conditions occur, they can result in an effluent that has high levels of suspended solids The process produces a large amount of lime sludge that requires treatment or recovery This material is usually >1 5/ of the process flow The presence of soluble calcium salts in the process effluent can cause scaling on downstream structures, including the process filtration equipment

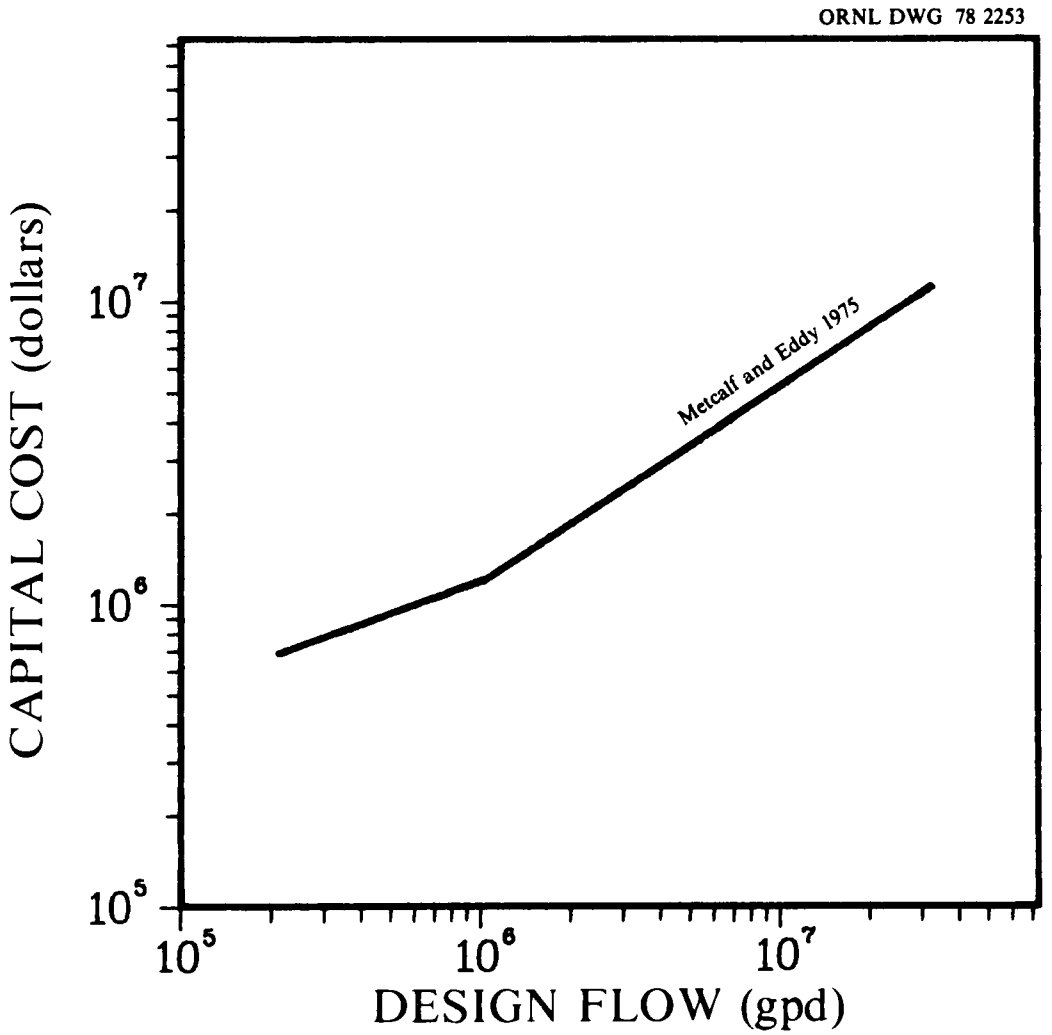

Fig 28 Capital costs for granular carbon adsorption

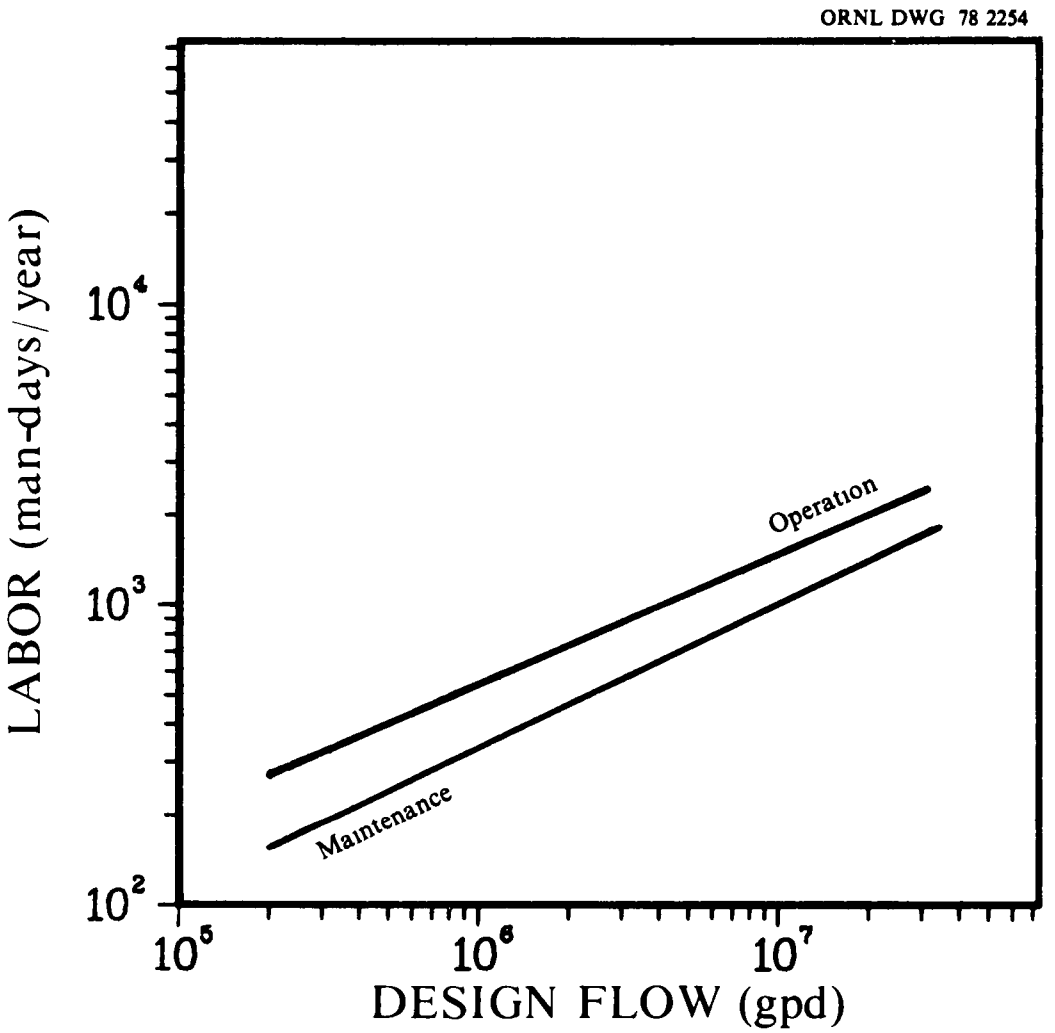

Fig 29 Labor requirements for granular carbon adsorption

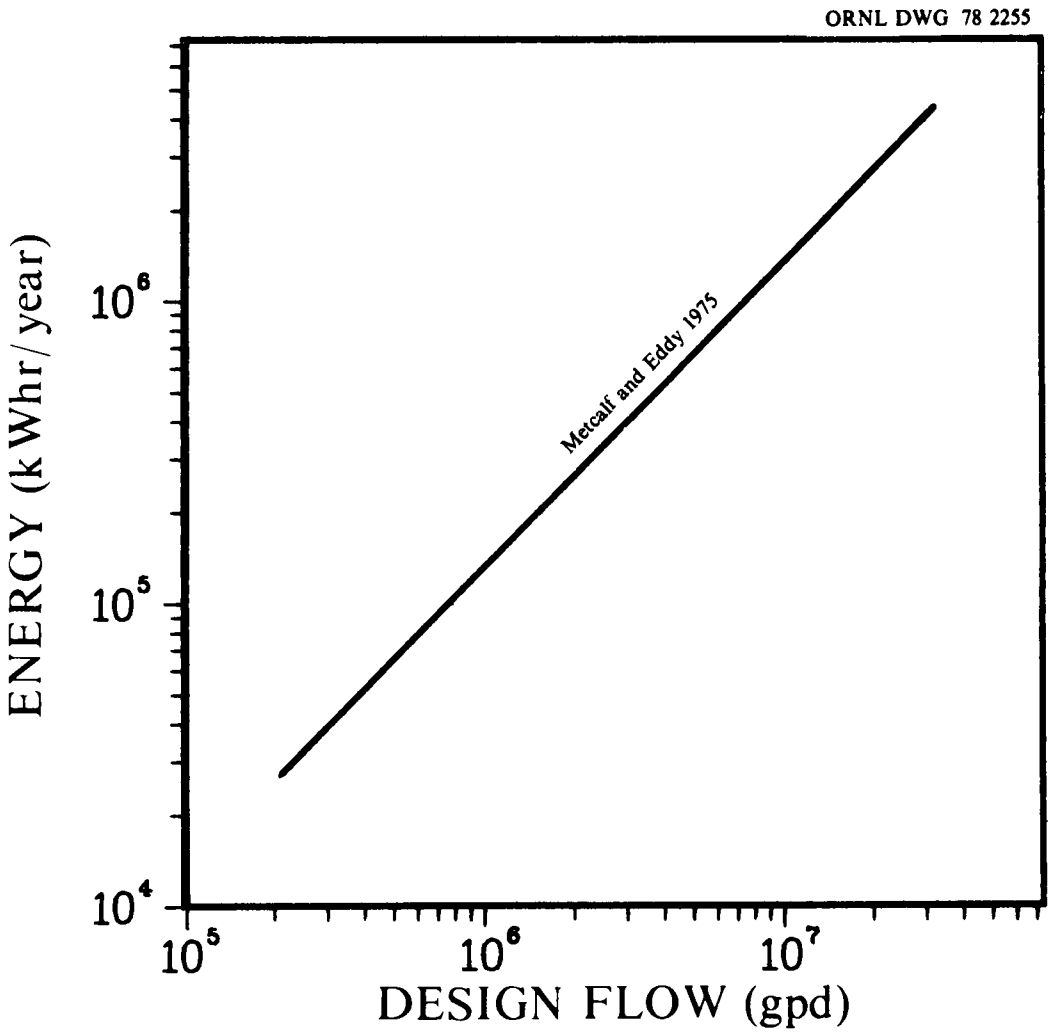

Fig 30 Energy requirements for granular carbon adsorption

Capital costs for two-stage lime coagulation-filtration equipment are shown in Fig 31 The curves from Culp, Wesner, and Culp (1975), Smith and Eilers (1970), Smith and McMichael (1969), and Convery (1970) all fall below the estimate from Metcalf and Eddy (1975), since these authors do not include filtration in their capital costs The capital cost for a 10^6-gpd lime coagulation-filtration process would be ∿$920,000

Operation and maintenance labor costs for the operation of a lime coagulation-filtration process are low in comparison to those for a granular carbon adsorption Lime coagulation-filtration operations labor for a 10^6-gpd plant is ∿140 man-days/year process maintenance labor requires 60 man-days/year, as shown in Fig 32 However, energy requirements are similar to granular carbon adsorption and involve the same energy-consuming process steps As indicated in Fig 33, two-stage lime coagulation-filtration processes for a 10^6-gpd plant would have an annual energy requirement of 130,000 kWhr

3 5 Disinfection

Disinfection is used to ensure the biological safety of discharged wastewaters by pathogen destruction Typical pathogens that might be found in wastewaters include bacteria, viruses, and protozoans Most wastewater disinfection standards are set to ensure the destruction of bacterial pathogens The destruction of virus and protozoan pathogens is not routinely measured because of the technical difficulties involved in these measurements

Many types of chemical disinfectants are available These include the following phenolic compounds, halogens and halogen compounds, ozone, hydrogen peroxide, heavy metals, quaternary ammonium compounds, and the strong acids or alkalies Although many disinfectants are available, only ozone and the halogen compounds have found much use as wastewater disinfectants Chlorine compounds are the most widely used of the halogens however, other materials such as iodine salt, are also routinely used in some applications

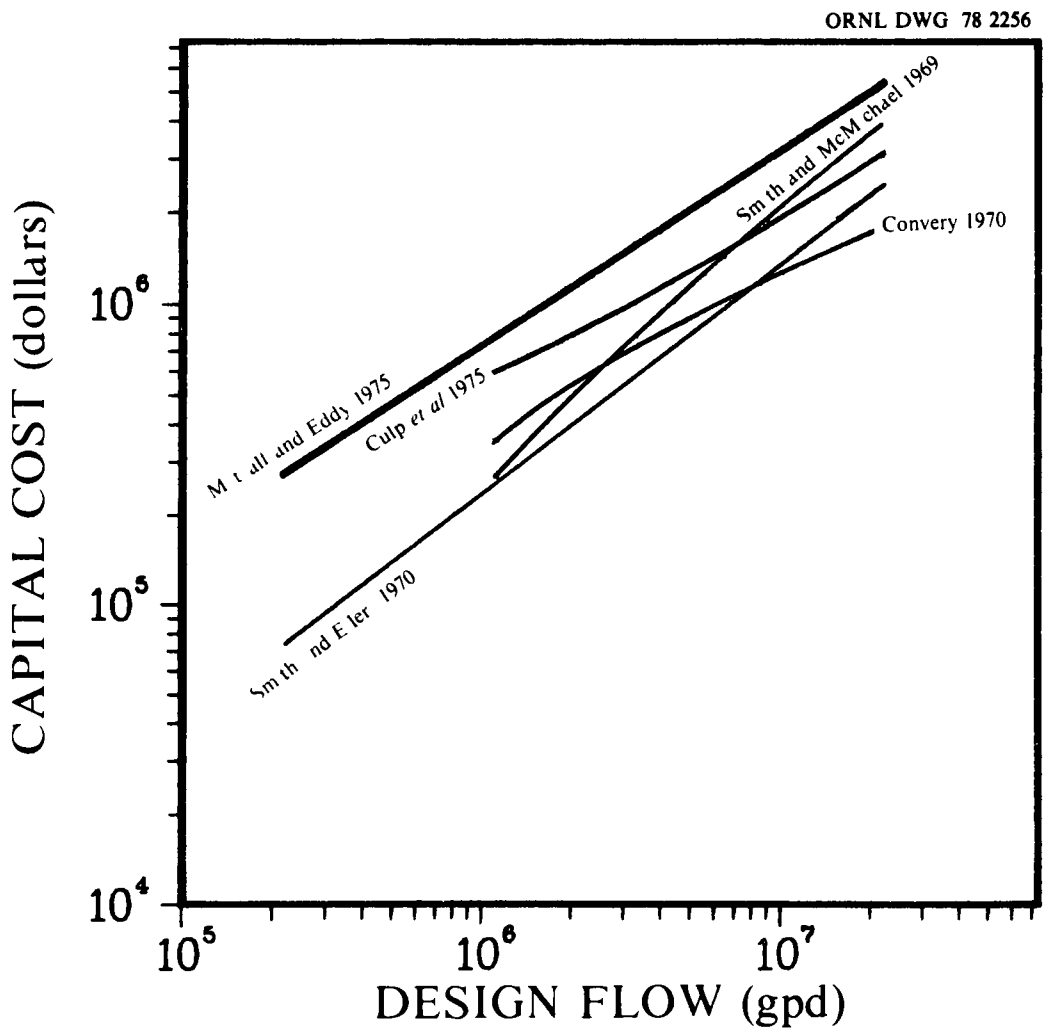

Fig 31 Capital costs for two-stage lime coagulation-filtration

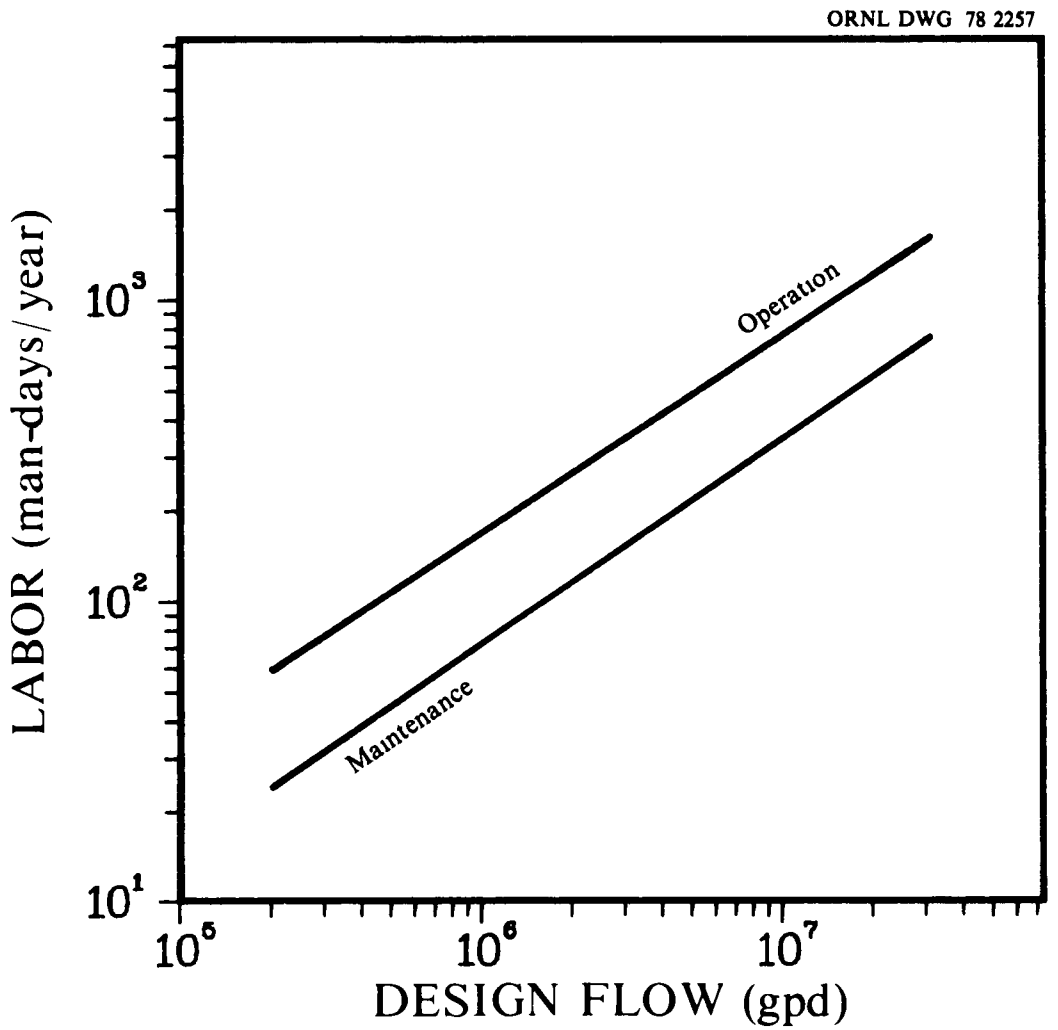

Fig 32 Labor requirements for two-stage lime coagulation-filtration

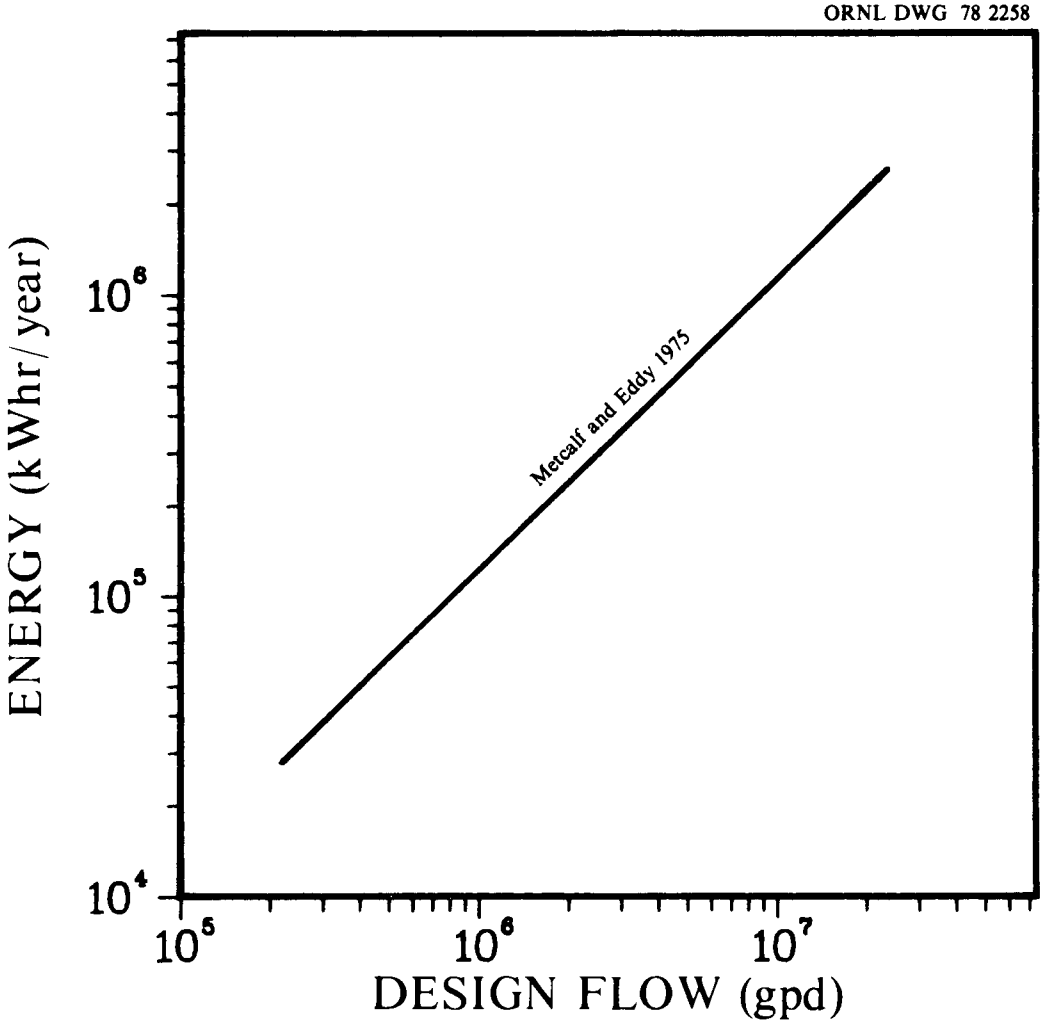

Fig 33 Energy requirements for two-stage lime coagulation-filtration

3 5 1 Chlorination

Chlorination systems include chlorine storage and handling equipment, chlorinators, mixing equipment and contact chambers, and instrumentation to measure the chlorine residual after the contact period Chlorine is purchased as liquid chlorine for larger plants, but sodium hypochlorite can be used cost-effectively in smaller plants Typical dosages of chlorine required for secondary effluents are 2 to 10 mg/liter Contact periods of 15 to 30 min are common at peak flow

Capital costs for chlorination are shown in Fig 34 Chlorination capital costs include equipment for handling dispensing and mixing chlorine gas with water For a 10^6-gpd plant, the capital cost of chlorination equipment is $100,000

Operation and maintenance labor costs are shown in Fig 35 Chlorination equipment is among the most reliable in a wastewater treatment plant, requiring only 6 man-days/year of maintenance for a 10^6-gpd plant Operation labor is higher, averaging 40 man-days/year for the same size plant

The power requirements for chlorination have not been indicated because they are very low For a 10^6-gpd plant, Smith (1973) states that chlorination power consumption is <1 MWhr for a standard chlorination system using compressed chlorine gas However the energy required for chlorine manufacture is not included in this figure

3 5 2 Ozonation

Ozone is a strong oxidizing agent that can be generated from air or oxygen As a disinfectant, it is comparable to chlorine, with the exception of residual protection in the effluent In a manner similar to chlorine it reduces residual BOD in the wastewater and decreases wastewater odors

Ozone is generated as used and is not stored on site This means that the ozone generation facility must be capable of meeting peak demands without recourse to stored material Ozone does not react with some organics in water, including ethanol Also, manganese and iron ions in solution can interfere with ozonation

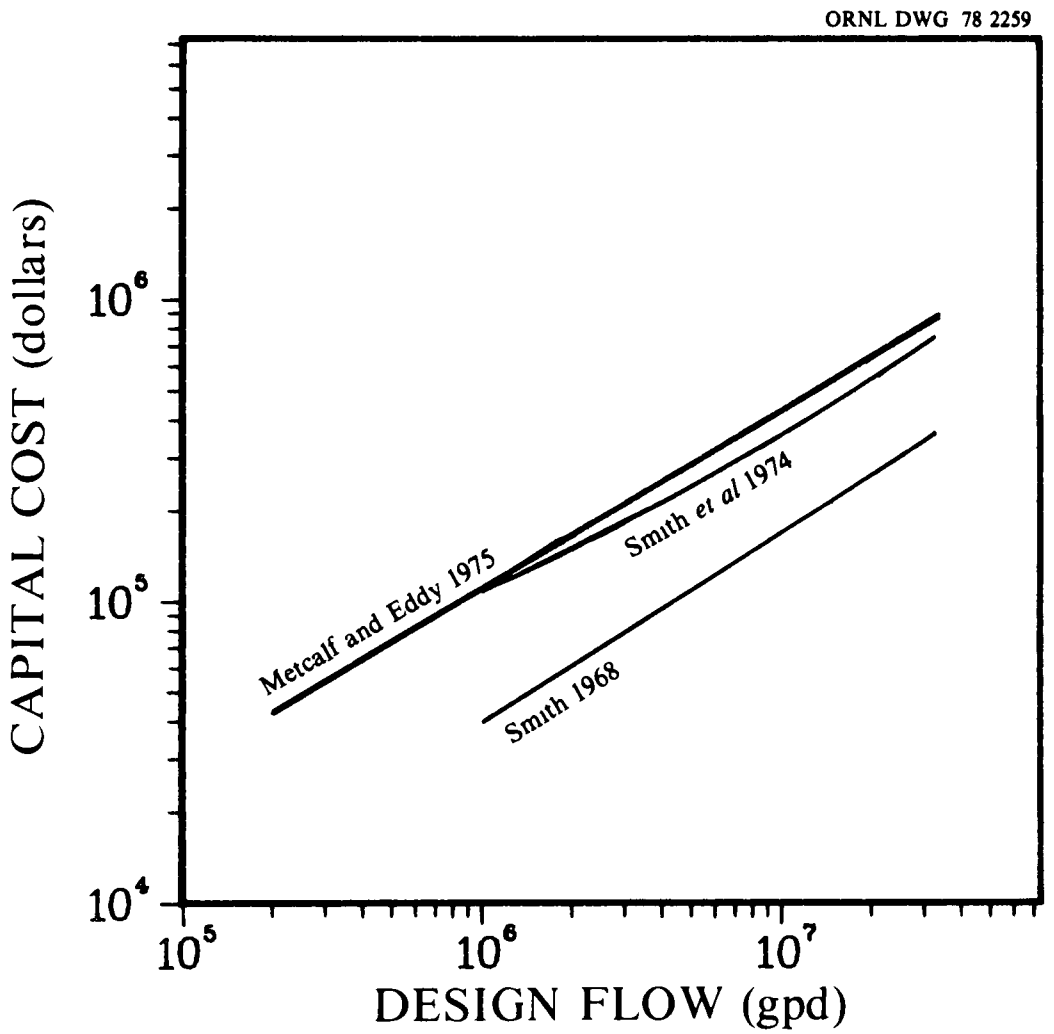

Fig 34 Capital costs for chlorination

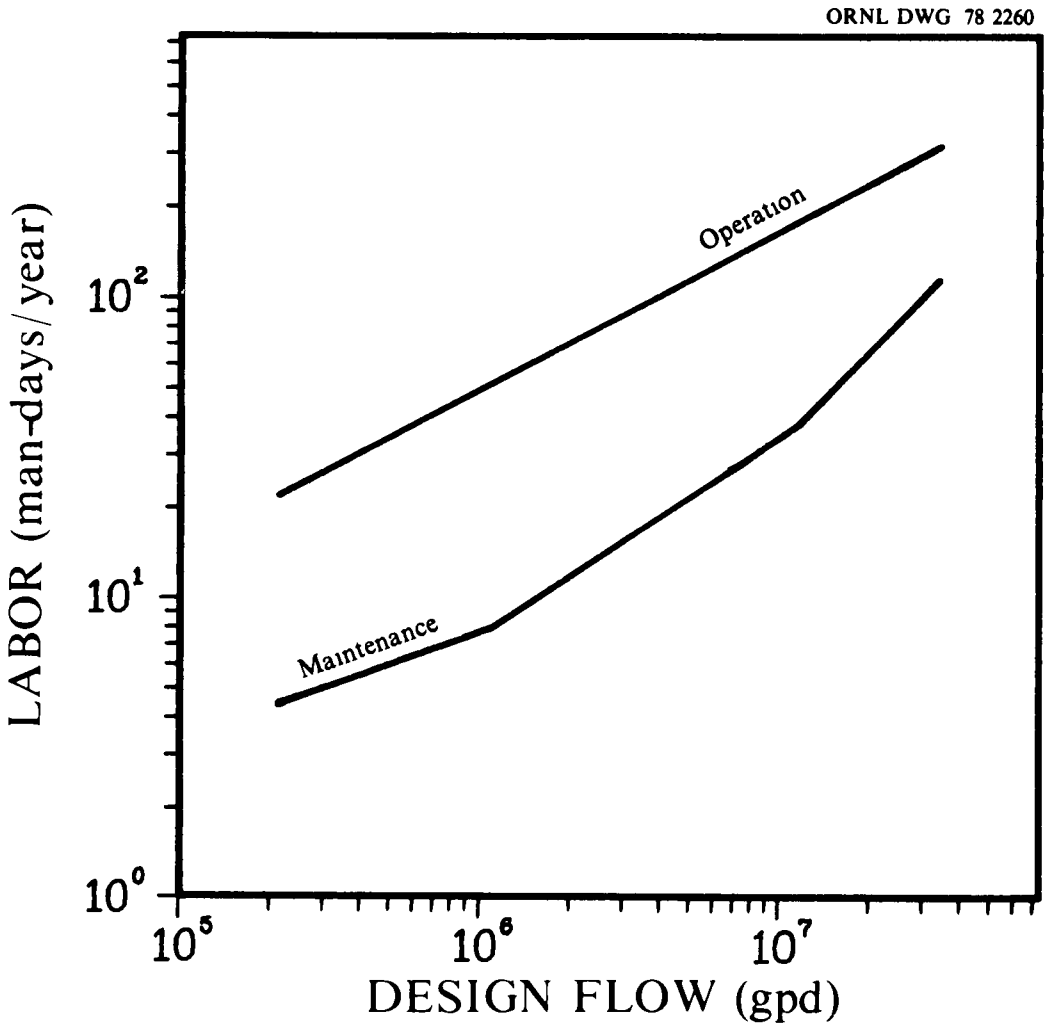

Fig 35 Labor requirements for chlorination

Capital costs for ozone generation and application are given in Fig 36 The central heavy line, taken from a study by Smith (1974) indicates that ozone capital costs for a 10^6-gpd plant may be $169,000 if air is used as a source of oxygen The lower line, also from Smith, indicates that some savings could be recognized if the plant were operated so that a pure oxygen stream was used as ozonator feed The top line represents data determined by McNabey and Wynne (1971)

Operation and maintenance costs for ozonation are given in Fig 37 These figures are slightly higher than those for chlorination Operation labor for a 10^6-gpd ozone plant is estimated to be 65 man-days/year, maintenance requires 30 man-days/year

Energy requirements are substantial for ozonation as presented in Fig 38 For a 10^6-gpd plant ∿200,000 kWhr/year are required

3 6 Surface Water Outfalls

Surface water outfalls are used to transfer effluent from disinfection to a receiving water Typically, they are fed by gravity, rather than pumped In most cases, they are simple in design, however, complicated mixing requirements may demand a sophisticated diffuser system on an outfall In some cases, an outfall is used to provide disinfectant contact time

Surface water outfall costs are shown in Fig 39 adapted from Metcalf and Eddy (1975) Also included as points on the figure are costs of individual outfalls provided by Berk (1966) The estimated cost for a 10^6-gpd plant surface water outfall is $65 000

Because of the gravity flow, operating and maintenance labor on a surface outfall is limited to periodic cleaning Additionally energy requirements are limited because the outfall is generally gravity-fed and does not require pumping

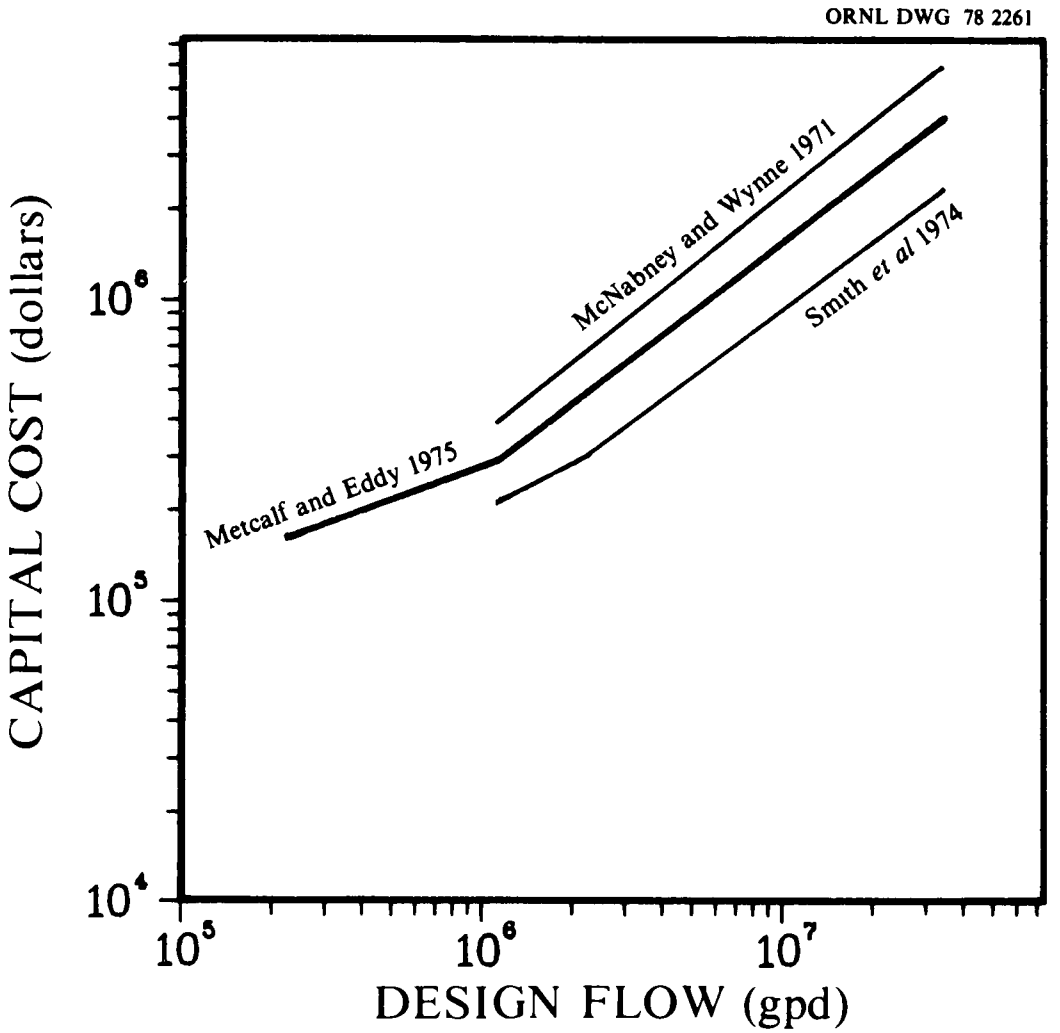

Fig 36 Capital costs for ozonation

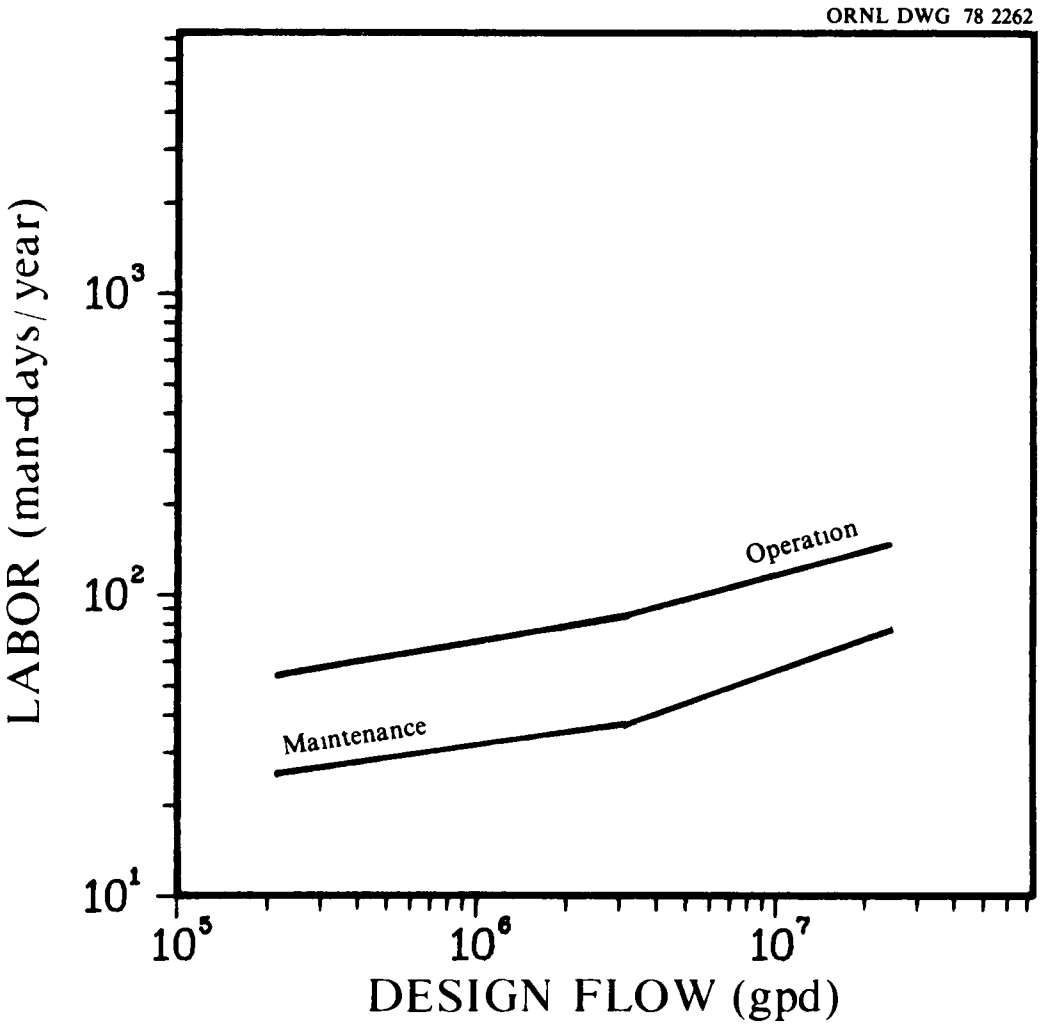

Fig 37 Labor requirements for ozonation

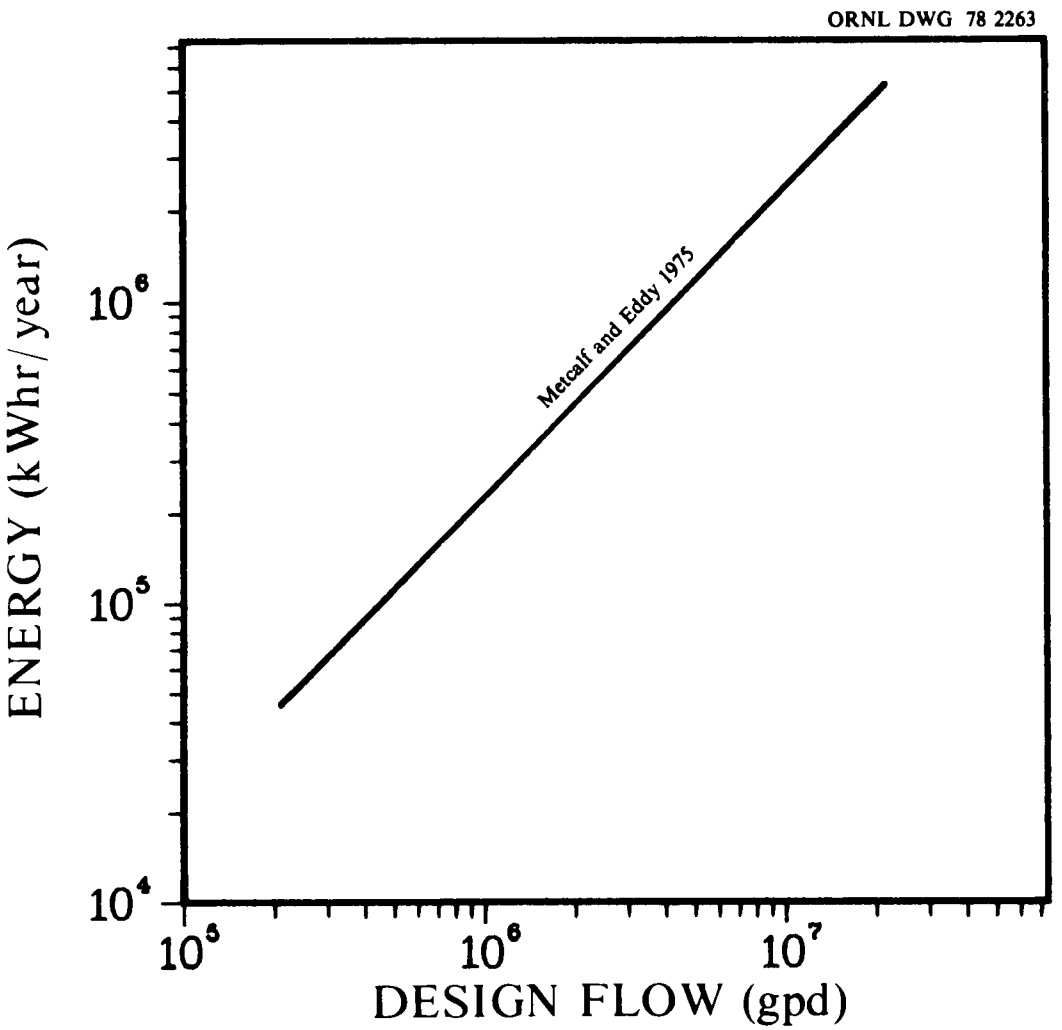

Fig 38 Energy requirements for ozonation

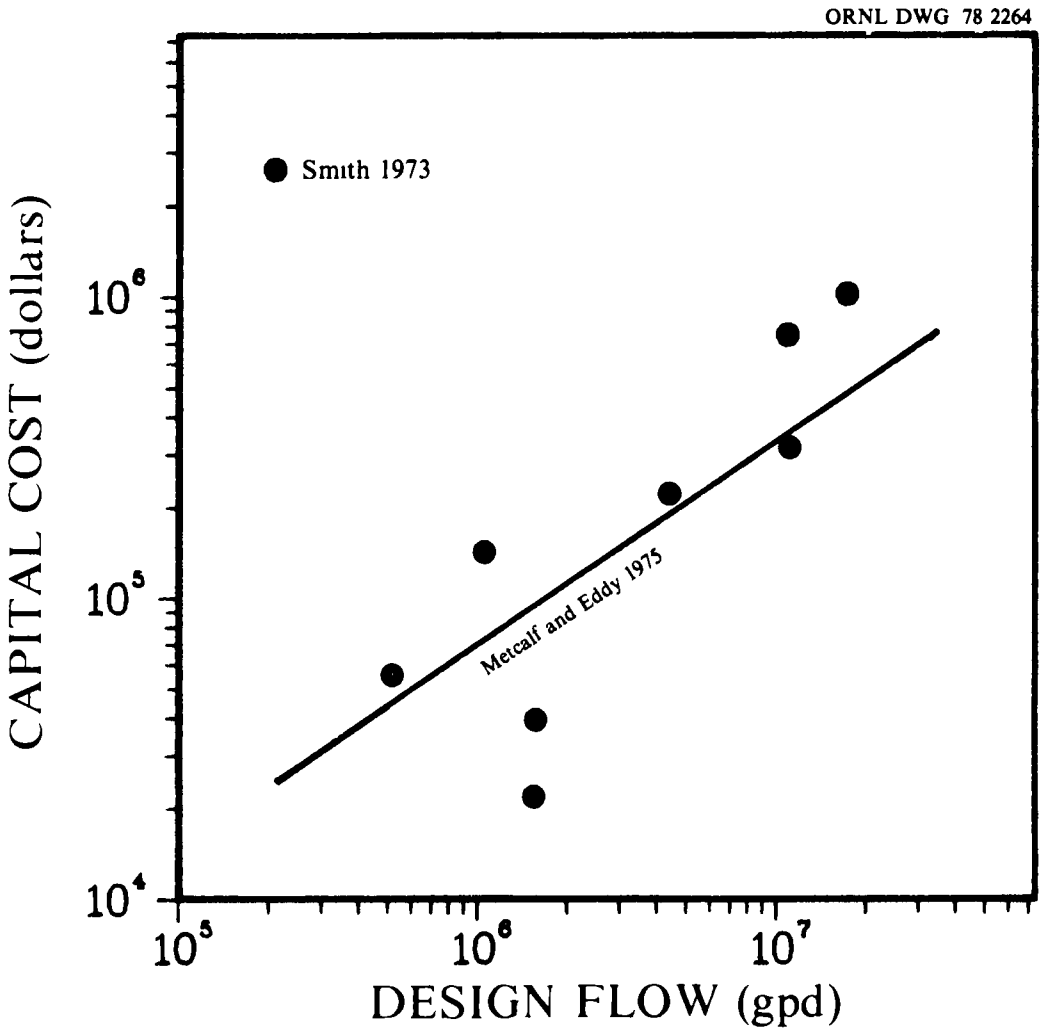

Fig 39 Capital costs for surface water outfalls

3 7 Sludge Processing

The sludge produced during sedimentation processes requires stabilization prior to disposal This is usually accomplished by anaerobic bacterial processes These processes also provide for some reduction in the organic material content of the sludge and improve its dewatering characteristics

Many configurations are possible for a sludge processing system--all must provide for sludge pumping, delivery to a digestion process, digestion, dewatering, and ultimate disposal The process configuration selected consists of pumping, digestion, dewatering on open drying beds and ultimate disposal in a sanitary landfill The digester sizing is generally performed on a volumetric loading basis and is usually 2 to 4 ft^3 per capita for activated sludge

Because the digestion process is biological it is sensitive to a variety of toxic materials, including heavy metals and toxic aromatic compounds However, since it deals with a concentrated process effluent, flow variations will probably not cause a serious process upset

The capital costs for sludge processing according to the above process scheme are shown in Fig 40 From this figure, capital costs for processing sludge from a 10^6-gpd plant would be $830,000

The operation and maintenance manpower is shown in Fig 41 Sludge disposal is the most labor-intensive process of the secondary biological wastewater treatment plants Operation labor is estimated at 285 man-days/year maintenance, at 149 man-days/year

Energy requirements for sludge processing operations are shown in Fig 42 As noted in the figure, the annual energy requirement for processing sludge from a 10^6-gpd activated-sludge plant is 50,000 kWhr, provided that process gas is used for heating If additional heating is required, the energy cost may be substantially higher

3 8 Structures and Site Work

As a part of the construction of a wastewater treatment plant, administrative buildings, laboratory facilities, landscaping, parking

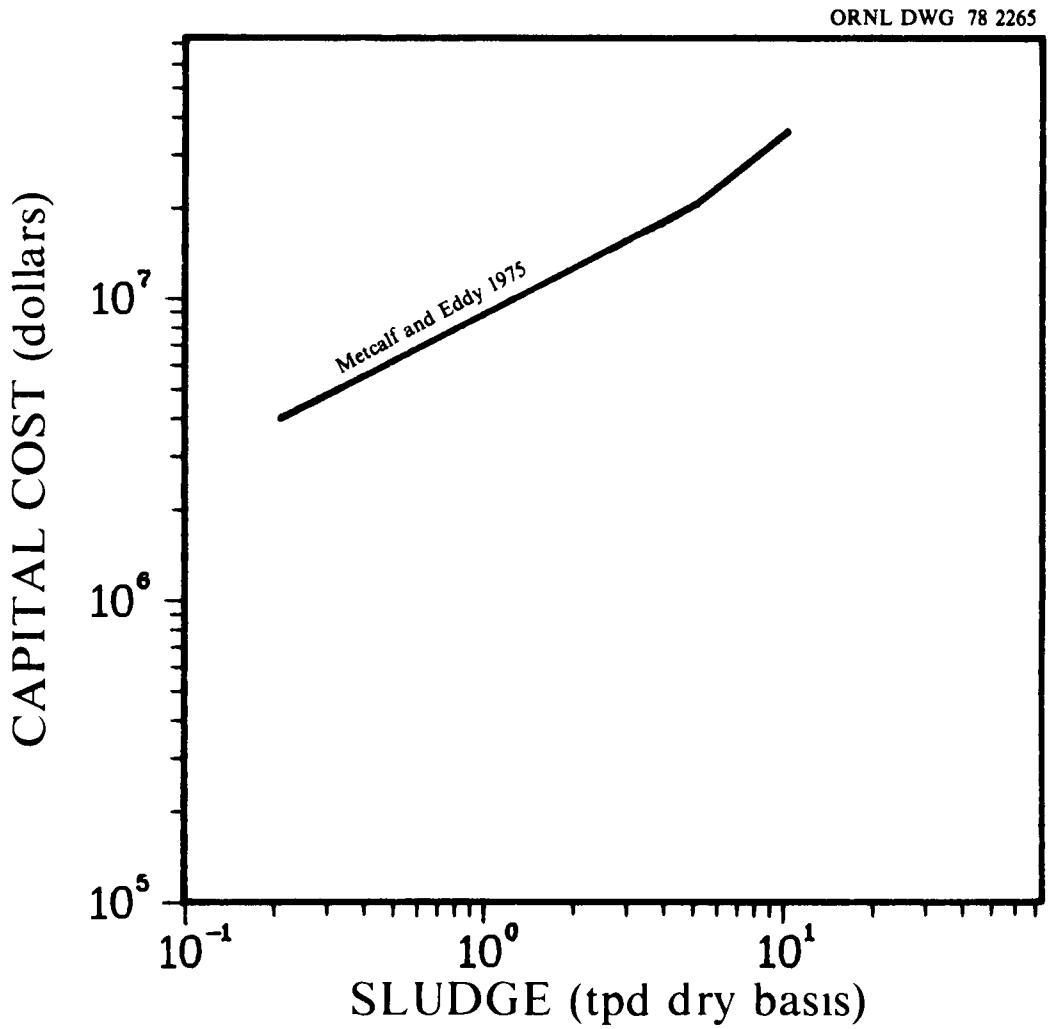

Fig 40 Capital costs for sludge processing

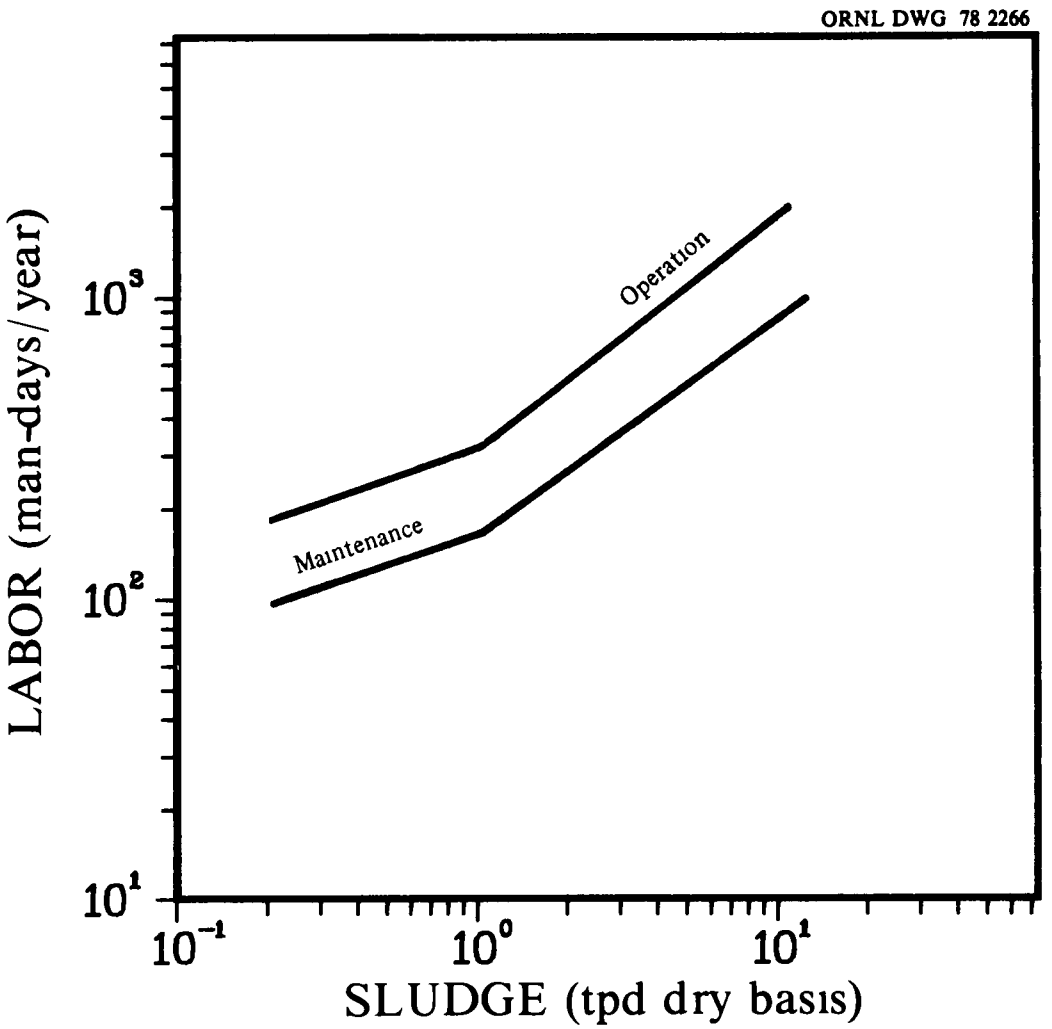

Fig 41 Labor requirements for sludge processing

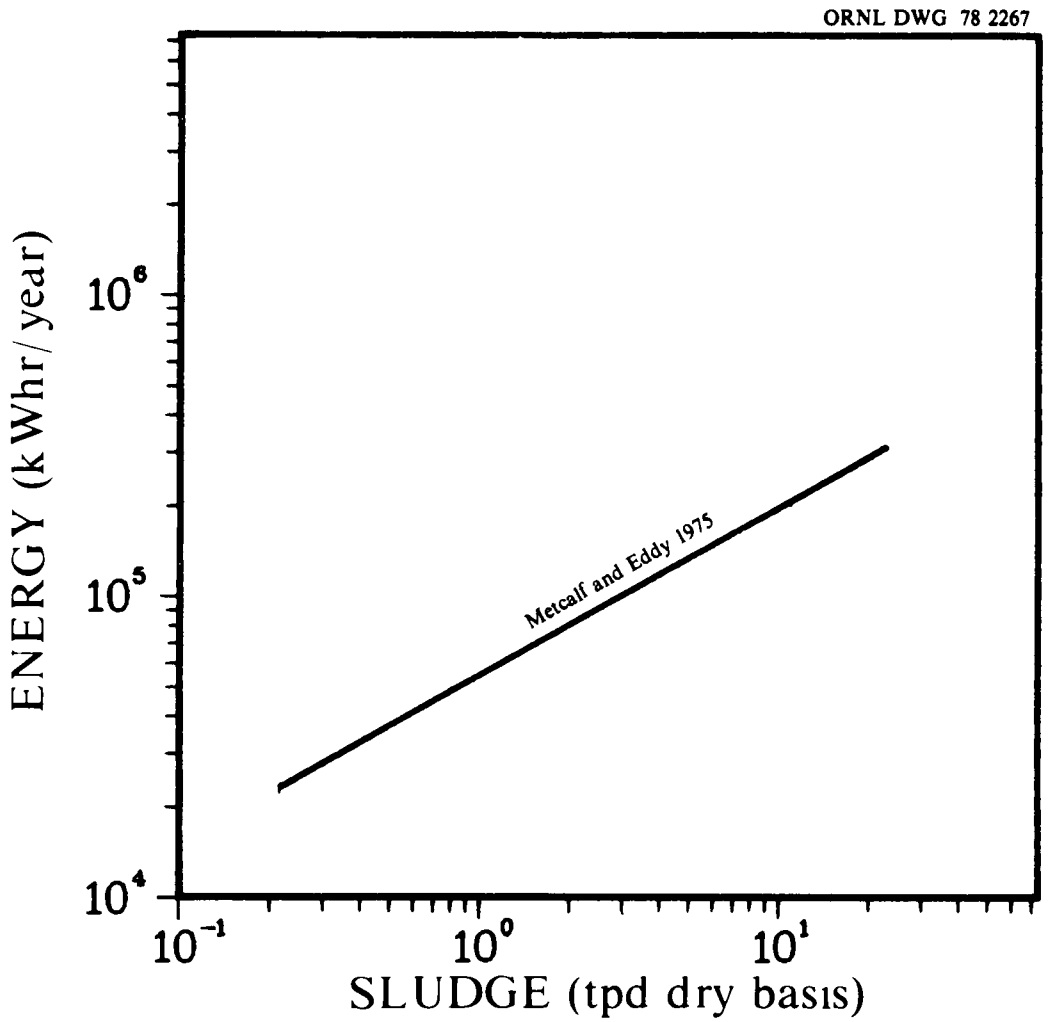

Fig 42 Energy requirements for sludge processing

and storage facilities are required These facilities are not included in the cost for unit processes surveyed earlier However, they are a required part of every wastewater treatment plant

Estimates in Fig 43 include data from Metcalf and Eddy (1975) and from Black and Veatch (1971) The cost of facilities is roughly proportional to the size of the plant It can be expected that the cost of facilities will increase with the increase in legal requirements and the sophistication of control and metering equipment

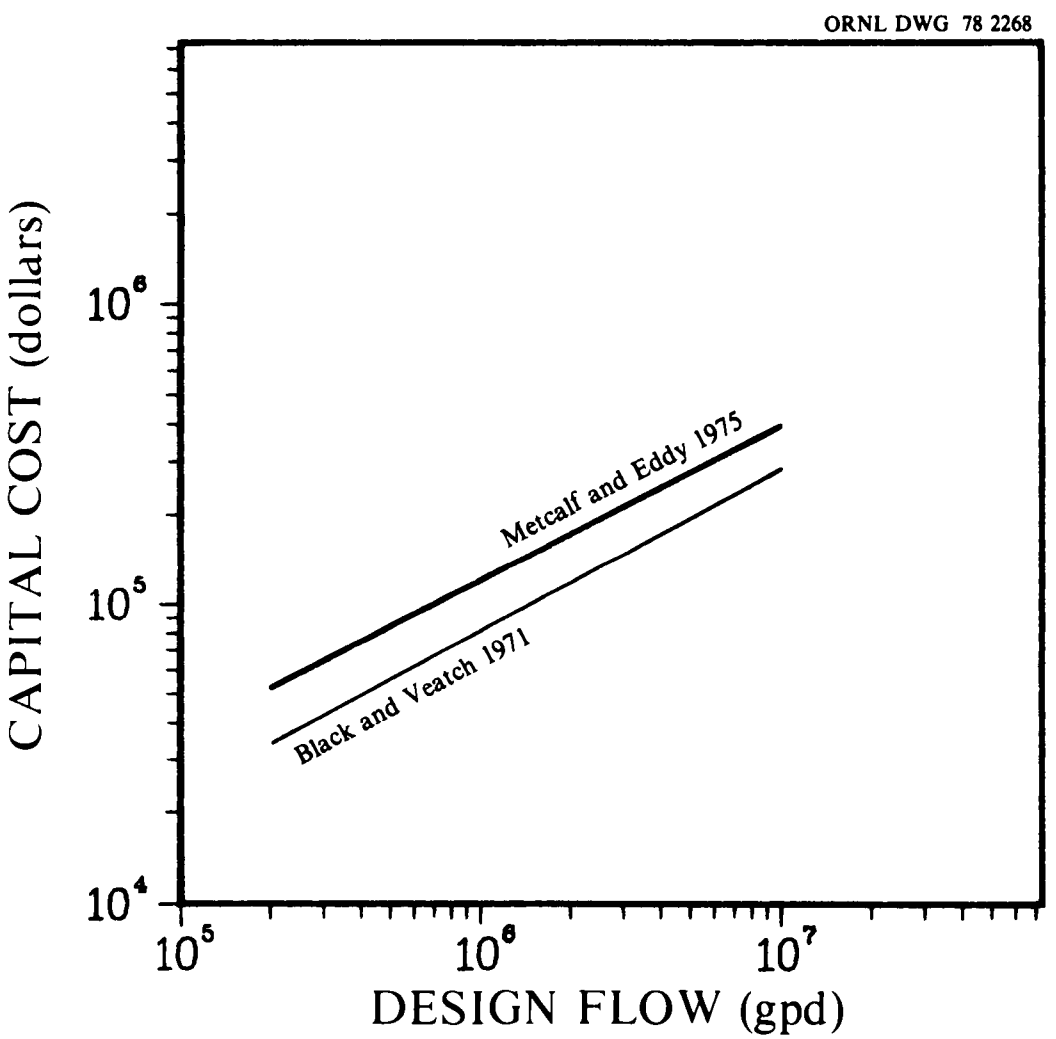

Fig 43 Capital costs for structures and site work

4 EVALUATION OF ALTERNATIVES

In order to determine the ANFLOW process potential and to define those areas where process- or energy-conserving improvements can be made, comparative estimates reflecting the capital cost, labor requirements, energy consumption, and combined annual cost for the activated-sludge, trickling-filter, and ANFLOW processes were made for the alternatives shown in Fig 1 These estimates were developed from the requirements for each unit process presented in Sect 3 Although all of the estimates of the requirements for each process presented were considered, the estimates by Metcalf and Eddy were generally used since they were available for most processes on a consistent basis Capital labor, and energy requirements for a 10^6-gpd plant for alternative processes are detailed in Tables 1-3 For example, an ANFLOW treatment plant with a design flow rate of 10^6 gpd, which would serve a population of about 10,000 would cost on an annual basis ∿$135 000, as compared to $290 000 for the activated-sludge process and $190 000 for the trickling-filter process, using $10/ft^3 for the ANFLOW media Energy requirements for the ANFLOW alternative were 11/ of the activated-sludge process requirements and 23/ of the trickling-filter requirements

Table 1 Capital costs for a 10^6-gpd plant[a]

Operation	Activated sludge	Trickling filter	ANFLOW
Preliminary	$ 35,000	$ 35,000	$ 35,000
Primary	250 000	250 000	
Aerator blowers	900,000		
Biofilter		360,000	900,000
Disinfection	100,000	100 000	100 000
Sludge handling	830,000	570,000	
Outfall	65,000	65 000	65 000
Site controls	120,000	120,000	120,000
TOTAL	$2,300,000	$1,500 000	$1,220,000

[a]In 1978 dollars

Table 2 Labor requirements for a 10^6-gpd plant[a]

Operation	Activated sludge	Trickling filter	ANFLOW
Preliminary	110	110	110
Primary	80	80	
Aerator blowers	360		
Biofilter		30	30
Disinfection	46	46	46
Sludge handling	434	360	
TOTAL	1030	626	186

[a]In man-days/year

Table 3 Energy requirements for a 10^6-gpd plant[a]

Operation	Activated sludge	Trickling filter	ANFLOW
Preliminary	16	16	16
Primary	7	7	
Aerator blowers	250		
Biofilter		77	
Sludge handling	50	40	
Site controls	22	22	22
TOTAL	345	162	38

[a]In MWhr/year

Capital costs for the three alternatives are presented in Fig 44 for design flows ranging from 2 x 10^5 to 10^7 gpd No effluent polishing was included for the ANFLOW process A media cost of \$10/ft^3 for the ANFLOW process was used Conventional activated sludge was more expensive than trickling filters for all design flows considered At a design flow of 10^6 gpd the cost of ANFLOW was \$1,100,000 less than the activated-sludge process and \$280,000 less than the trickling-filter process At low to moderate flow rates, the cost of the ANFLOW process was estimated to remain less than either of the other two processes A break-even point for the ANFLOW and trickling-filter processes was calculated at a flow of 3 x 10^6 gpd and a break-even point for the ANFLOW and conventional activated-sludge processes was calculated at a flow of 10^7 gpd With reference to Fig 14, a media cost of \$5/ft^3 would reduce the ANFLOW process estimate so that the ANFLOW alternative would be less than either activated sludge or trickling filters over the entire range of design flows considered

Labor requirements for the three alternatives are presented in Fig 45 The trickling-filter process required less labor than the activated-sludge process, and the labor requirements for the ANFLOW process was much less than either of the other two alternatives At a design flow rate of 10^6 gpd, the annual labor requirements were ∿1000 man-days for the activated-sludge process, ∿630 man-days for the trickling-filter process, and ∿190 man-days for the ANFLOW process

Energy requirements are presented in Fig 46 for the three alternatives The trickling-filter process required less energy than the activated-sludge process, and the ANFLOW process required much less energy than either the activated-sludge or the trickling-filter process At a design flow rate of 10^6 gpd the annual energy requirements were ∿350 MWhr for activated sludge, ∿160 MWhr for trickling filters, and 38 MWhr for ANFLOW The relative advantage for the ANFLOW process increased percentage-wise with increasing design flow, as indicated in Fig 46

Thus for design flows less than 3 x 10^6 gpd, the ANFLOW process appears most advantageous for an ANFLOW media cost of \$10/ft^3 If a

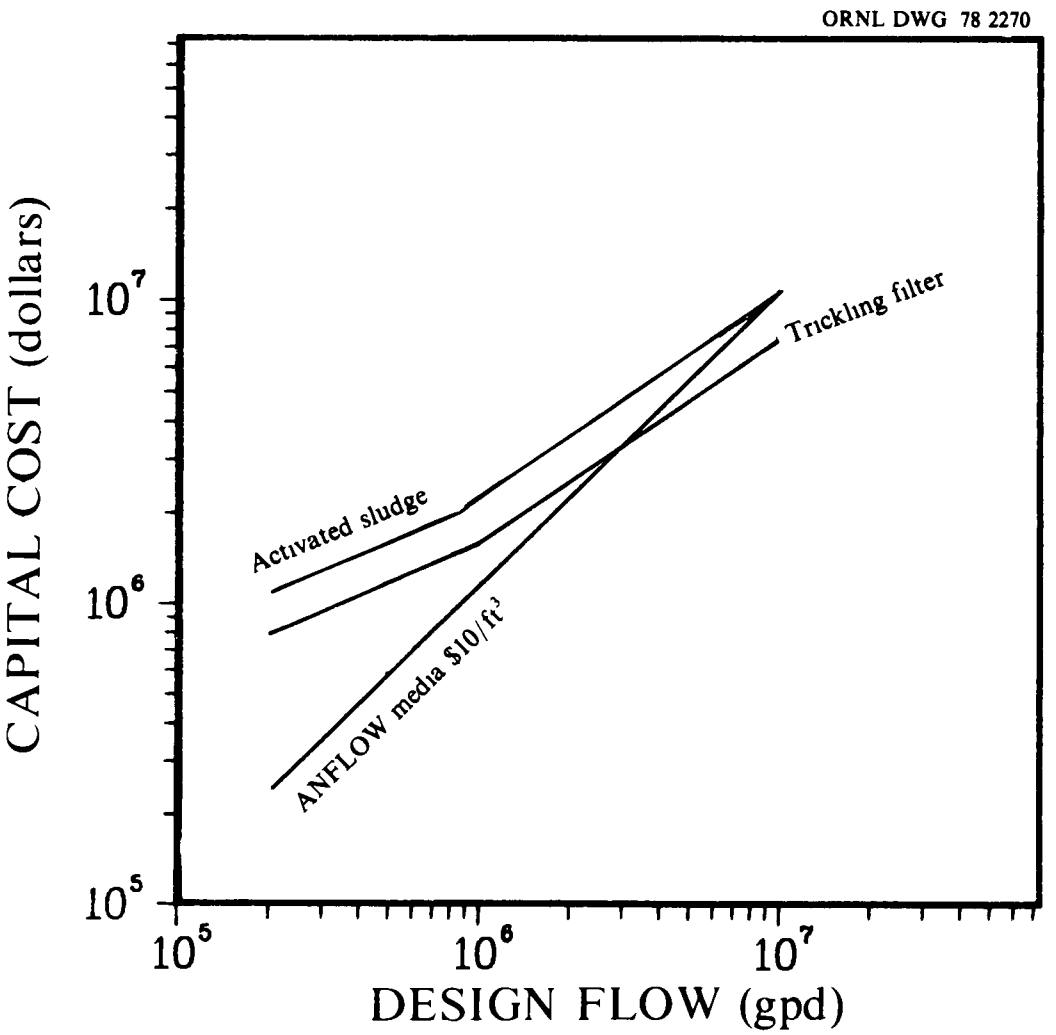

Fig 44 Capital costs for process alternatives

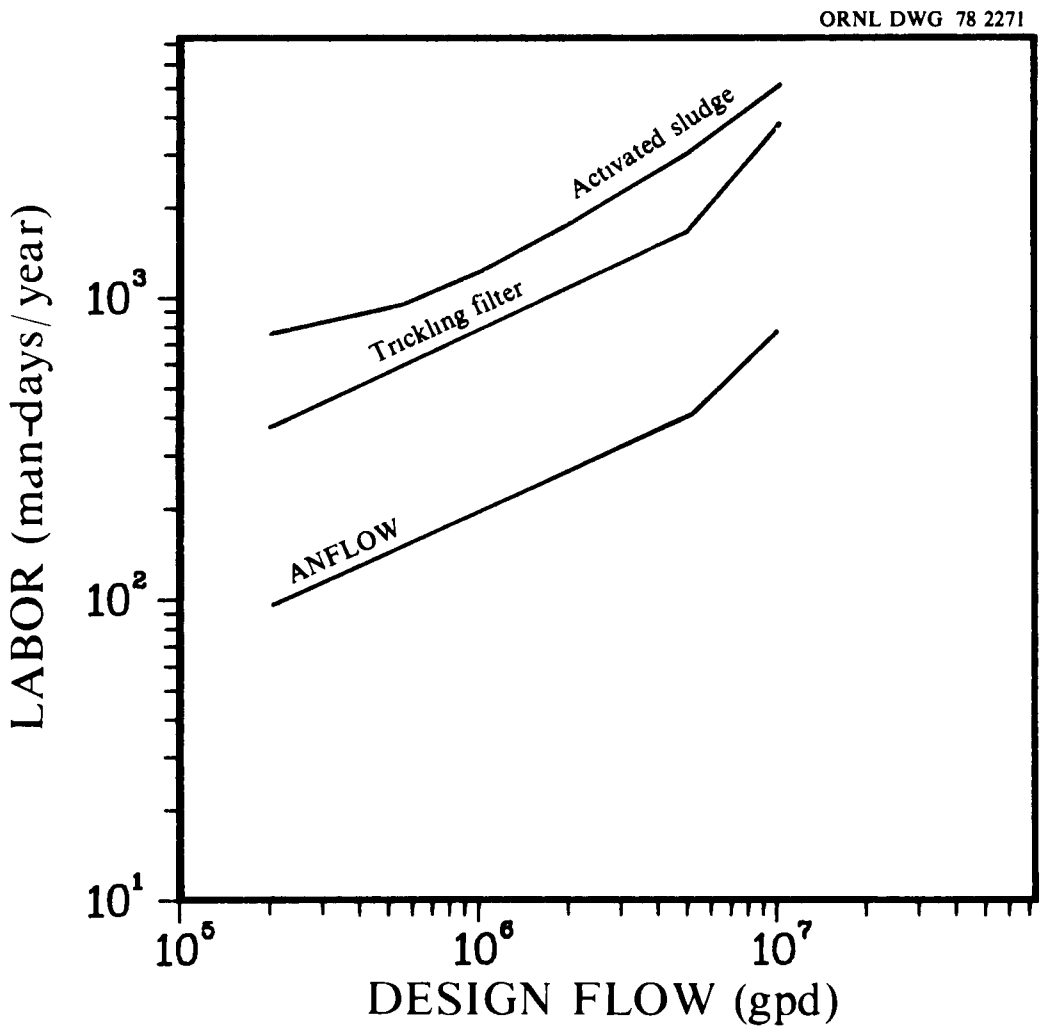

Fig 45 Labor requirements for process alternatives

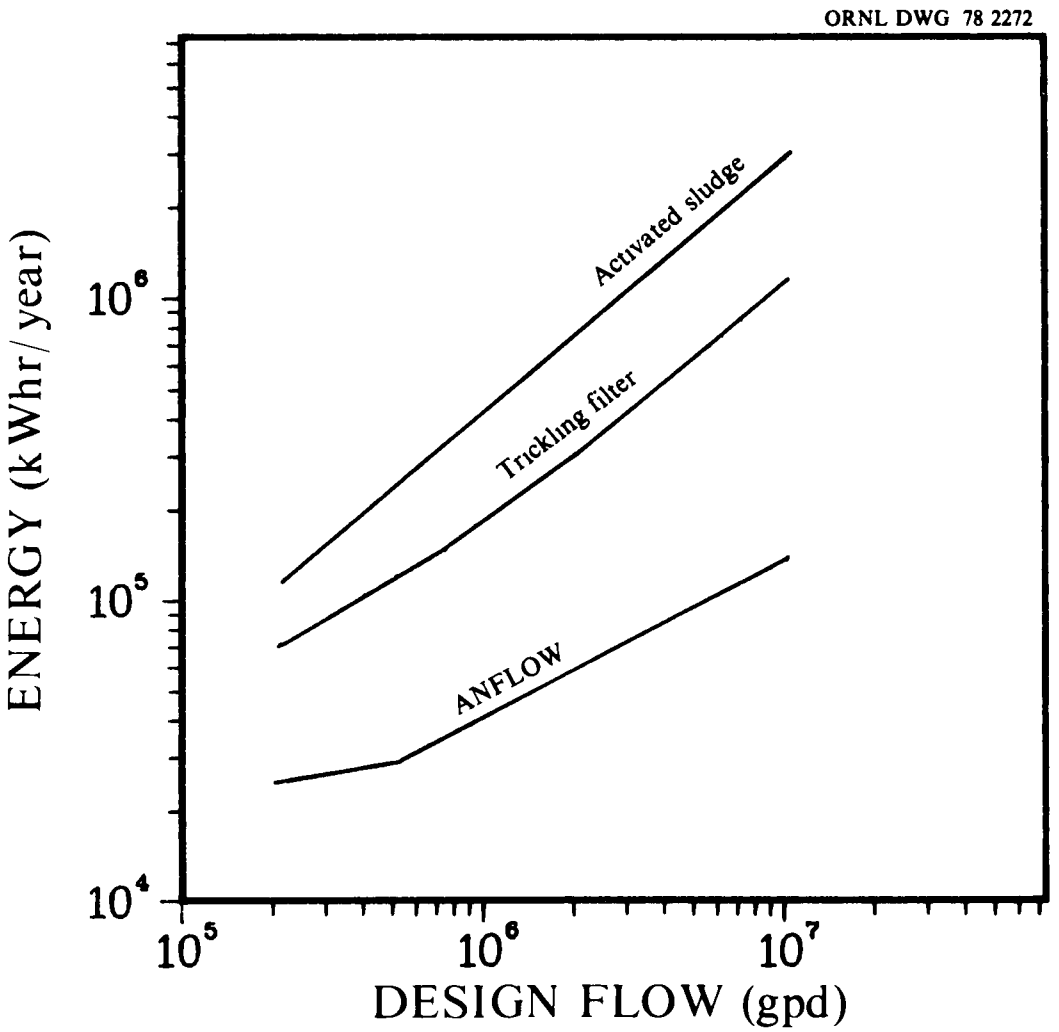

Fig 46 Energy requirements for process alternatives

media cost of $5/ft^3 can be attained, the ANFLOW process will be less expensive for all of the design flows considered when an effluent polishing step is not required

4 1 ANFLOW Effluent Polishing

In order to evaluate the cost of adding an effluent polishing step to the ANFLOW process (which may be necessary for some applications), the capital costs and the labor and energy requirements for the ANFLOW process were calculated for the following low overflow-rate sedimentation, microscreening, reaeration, multimedia filtration, granular carbon adsorption, and two-stage lime coagulation filtration The capital costs are presented in Fig 47 For reasons of comparison, the costs for activated sludge and trickling filters appear as dotted lines The capital estimates for the ANFLOW process based on a media cost of $10/ft^3 with effluent polishing steps (i e , reaeration, microscreening, sedimentation, and multimedia filtration) were equal to the capital estimates for the trickling-filter process for design flows of 2 0, 2 0, 1 5, and 1 0 x 10^6 gpd respectively The ANFLOW process with coagulation filtration as an effluent polishing step was more expensive than the trickling filters above design flows of 0 5 x 10^6 gpd Granular carbon adsorption increased the cost for ANFLOW so that it exceeded the cost of trickling filters over the design range considered The capital estimates for the ANFLOW process, based on a media cost of $10/ft^3 with effluent polishing steps (i e reaeration, microscreening, sedimentation, multimedia filtration, coagulation filtration, and granular carbon adsorption) were equal to the capital estimate for the activated-sludge process for design flows of 6 0 4 0 4 0, 3 5, 1 4 and 1 2 x 10^6 gpd respectively

A comparison of the labor requirements for the ANFLOW process with alternative effluent polishing steps is presented in Fig 48 The labor requirements for the activated-sludge and trickling-filter alternatives are shown as dashed lines The labor requirements for ANFLOW with sedimentation, multimedia filtration, or coagulation require much less labor than either activated sludge or trickling filters without effluent polishing Reaeration was assumed to require no additional labor as an

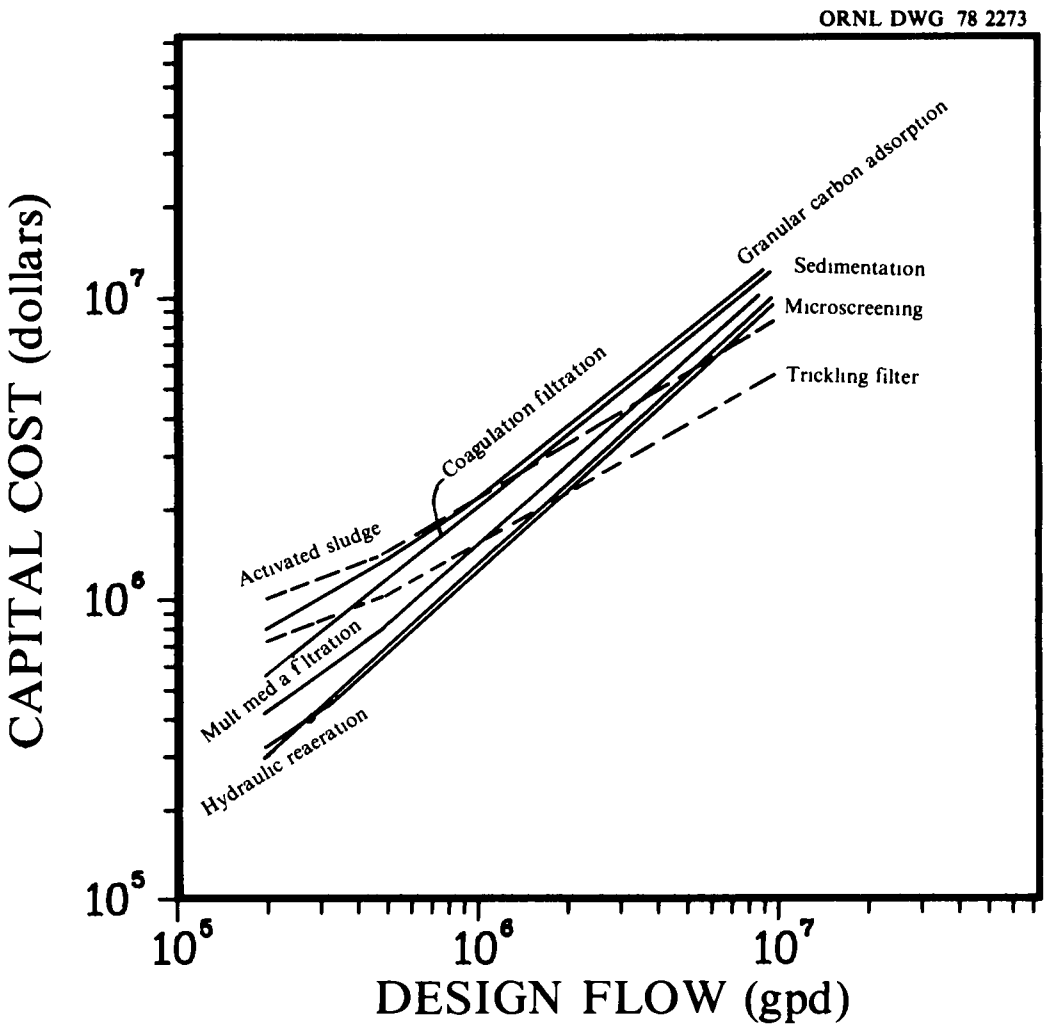

Fig 47 Capital costs for ANFLOW with effluent polishing

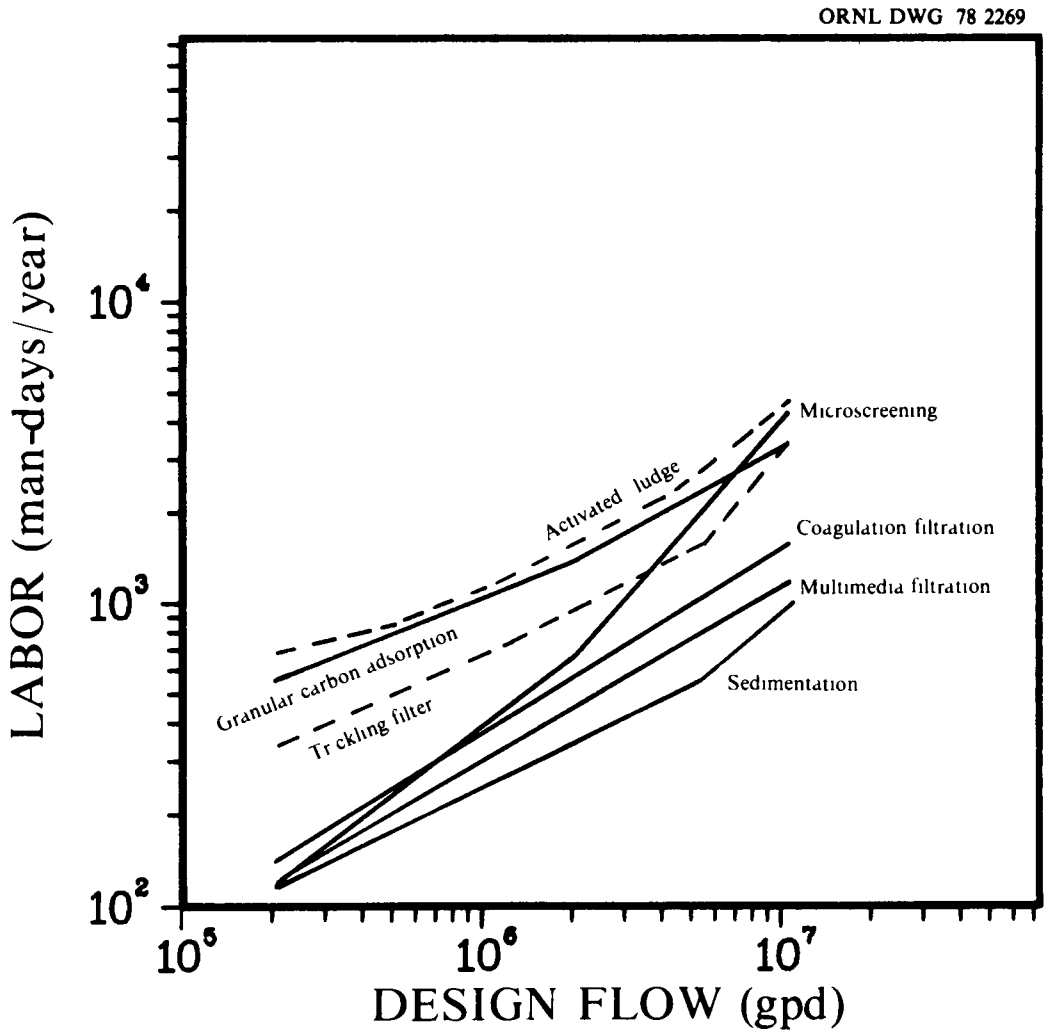

Fig 48 Labor requirements for ANFLOW with effluent polishing

effluent polishing step and the labor requirements for ANFLOW with reaeration would be the same as shown for ANFLOW in Fig 45 The labor requirements for ANFLOW with microscreening equaled the requirements for trickling filters without effluent polishing at a design flow of 3 7 x 10^6 gpd ANFLOW with granular carbon adsorption exceeded the labor requirements for trickling filters over the design range considered, however, ANFLOW with either microscreening or granular carbon adsorption required less labor than activated sludge over the entire design range considered

The estimated energy consumption for ANFLOW with effluent polishing steps is presented in Fig 49 The estimated energy requirements for trickling-filter and activated-sludge alternatives are presented as dashed lines The energy requirements for ANFLOW with effluent polishing was much less than activated sludge for all polishing alternatives considered Only ANFLOW with granular carbon adsorption or coagulation-filtration exceed the trickling-filter alternative, and then only at design flows higher than 6 x 10^6 gpd

In order to assess the overall combined advantage of the three alternatives, annual costs for each alternative were computed using an annual capital recovery factor of 0 10185 based on 8/ for 20 years, labor charges of $50/man-day to include miscellaneous materials and energy charges of $20/MWhr The results of this analysis are summarized in Fig 50 for activated sludge trickling filter and ANFLOW without effluent polishing alternatives A break-even cost for ANFLOW and the trickling-filter alternative was obtained at a design flow of 5 5 x 10^6 gpd The ANFLOW process was less expensive than the activated-sludge process over the entire design range considered

The relative annual costs of the ANFLOW process with selected effluent polishing steps are presented in Fig 51 The comparative annual costs of the activated-sludge and the trickling-filter alternatives are shown as dashed lines The break-even points between the ANFLOW process and the trickling-filter process for ANFLOW effluent polishing steps (i e , reaeration sedimentation, and microscreening) were 5 0, 2 6, and

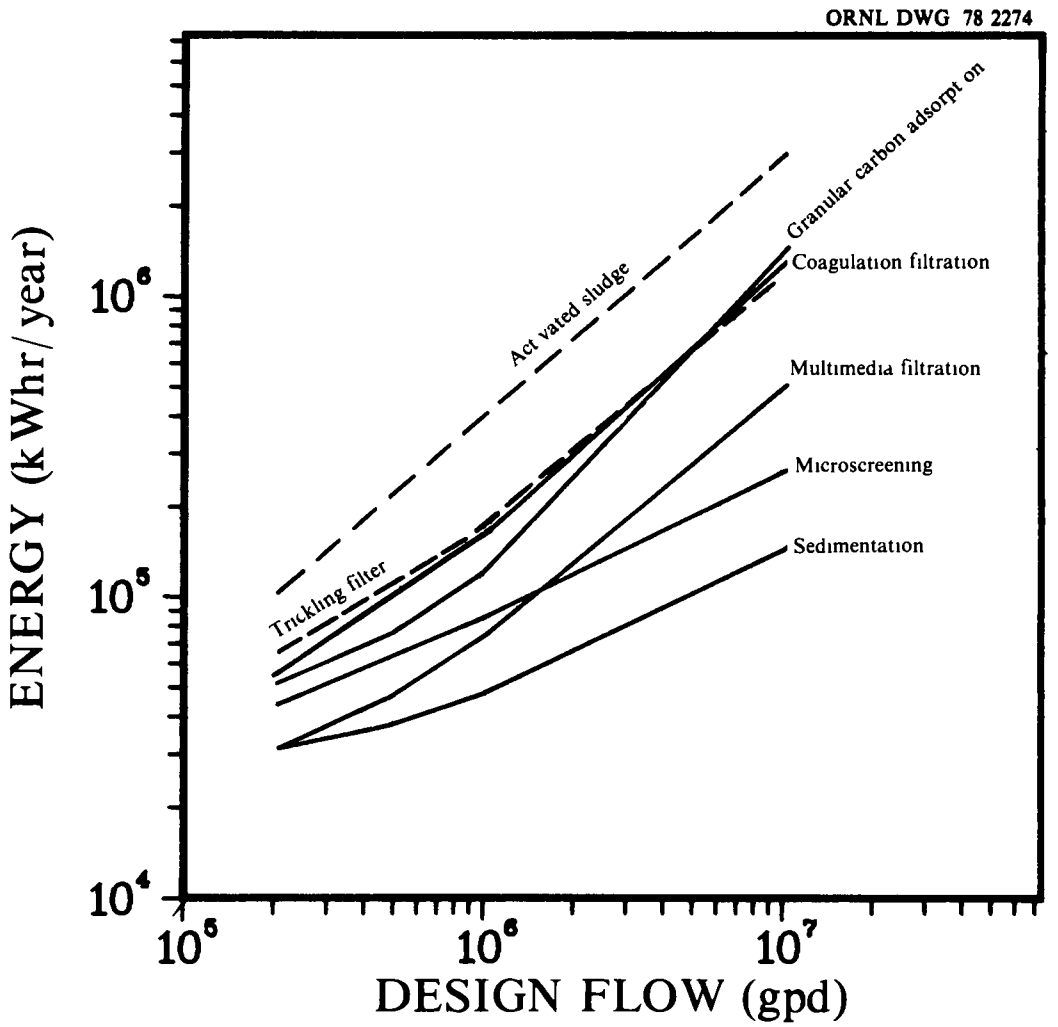

Fig 49 Energy requirements for ANFLOW with effluent polishing

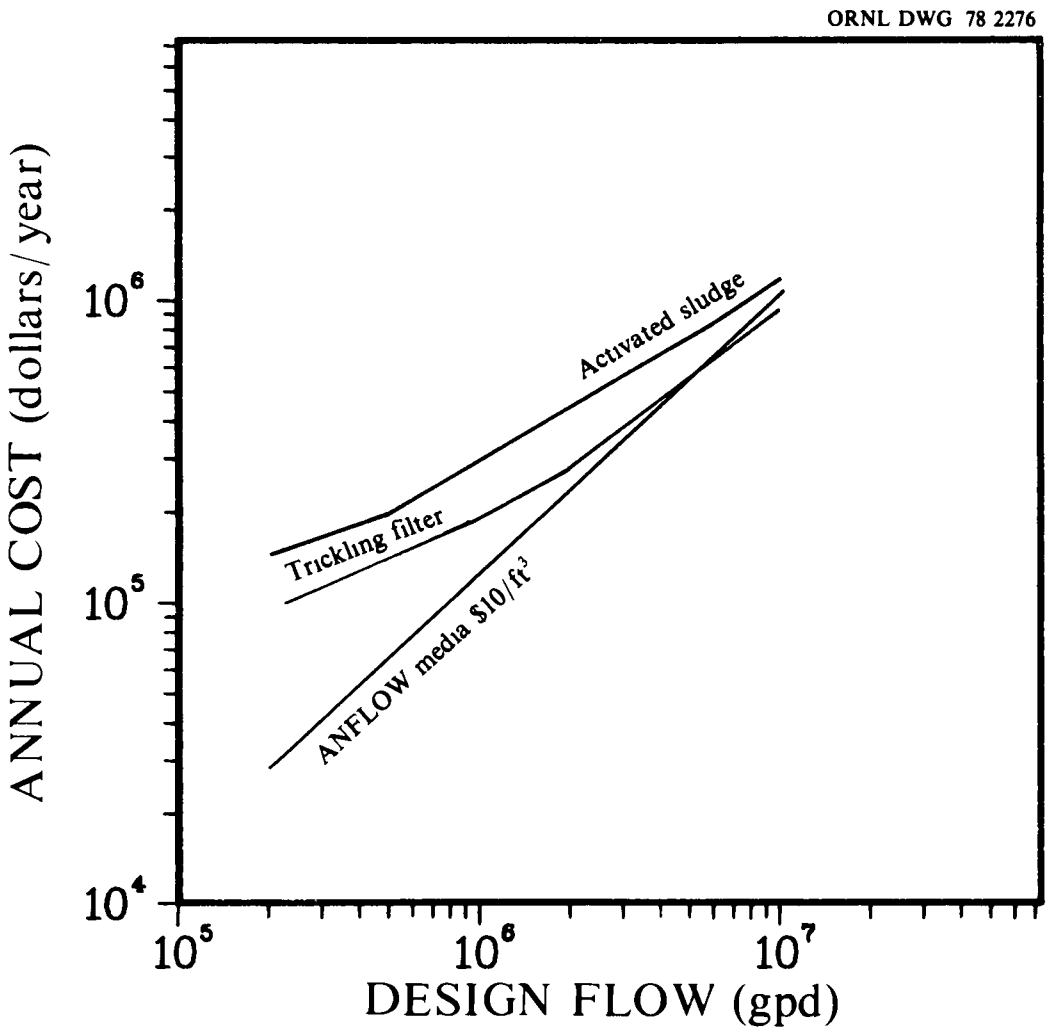

Fig 50 Annual costs for ANFLOW process without effluent polishing

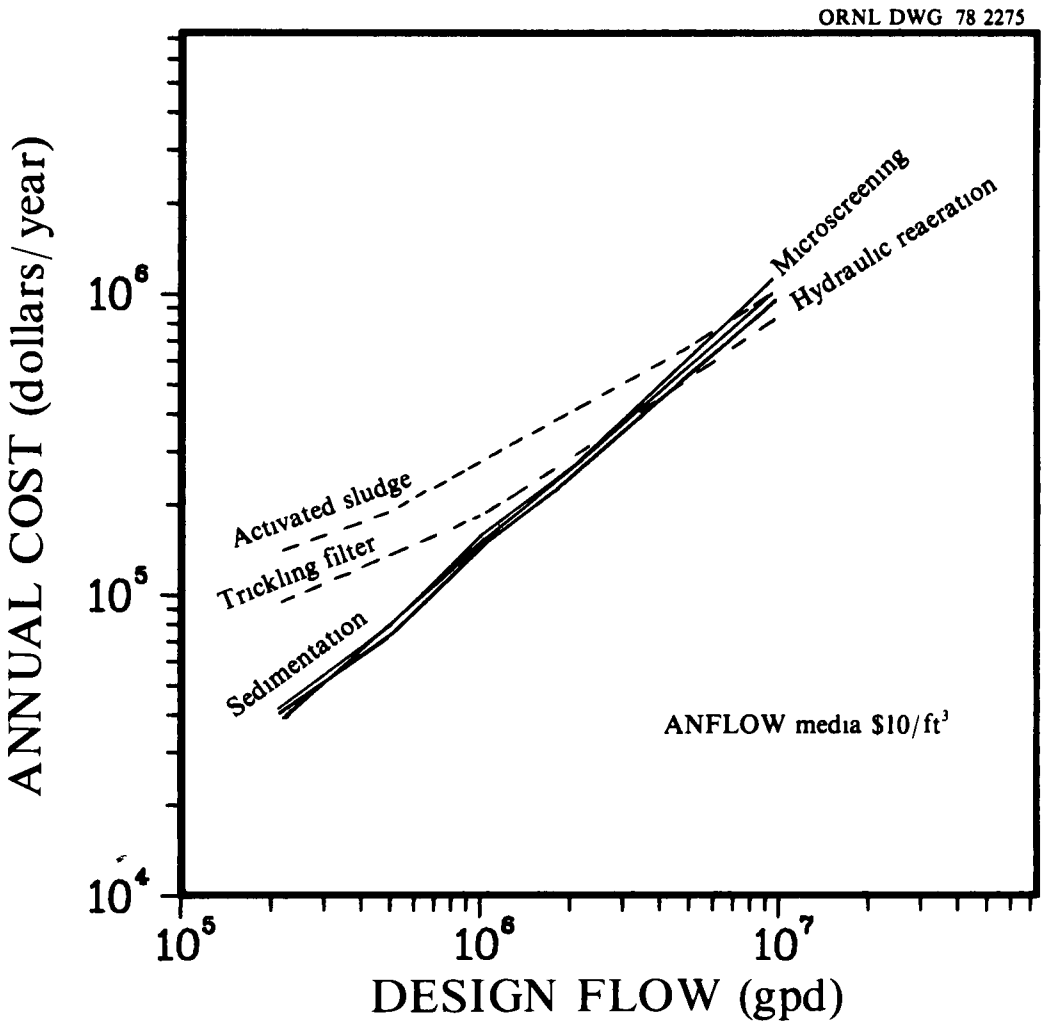

Fig 51 Annual costs of wastewater treatment alternatives

2 5 x 10^6 gpd respectively The break-even points between the ANFLOW process and the activated-sludge process for ANFLOW polishing steps--reaeration, sedimentation, and microscreening--were 10 0, 9 0, and 7 5 x 10^6 gpd respectively

5 SUMMARY

The cost and energy requirements for conventional activated-sludge, trickling-filter, and ANFLOW processes were compared to assess the potential of the ANFLOW process for municipal sewage treatment Capital-cost estimates operating manpower requirements and energy requirements were developed for each unit process based on literature sources available The costs estimated were escalated to an ENR Construction Cost Index of 2700, which reflects current conditions It should be emphasized that the comparative estimates prepared should not be used to estimate costs for any particular site since construction costs vary in various sections of the United States In addition, operating requirements and costs vary with regulatory requirements and "modi operandi " Except for the computation of annual costs, labor requirements were presented as annual man-days, and energy requirements were presented as annual kilowatt hours to facilitate estimates on other bases if needed

Based on an ANFLOW media cost of \$10/ft^3, break-even capital costs were calculated for the trickling-filter and the ANFLOW processes at a design flow rate of 3 x 10^6 gpd Break-even points for the conventional activated-sludge process and the ANFLOW process were estimated to be at a design flow rate of 10^7 gpd The labor requirements for the trickling-filter process were less than the activated-sludge process, and the labor requirements for the ANFLOW process were much less than either of the other processes Similarly, the energy requirements for the trickling-filter process were less than the activated-sludge process and the energy requirements for the ANFLOW process were much less than for either of the other processes When all of these factors were considered on an annual cost basis, the break-even cost between the ANFLOW process and the trickling-filter process was a design flow rate of 5 5 x 10^6 gpd The

ANFLOW process was less expensive than the activated-sludge process over the entire design flow rate range considered

As expected, the increased cost to provide an effluent polishing step to the ANFLOW process reduced the design flow rates where break-even capital costs were estimated Based on an ANFLOW media cost of $10/ft^3$, the capital estimates for the trickling-filter process were equal to the capital estimates for the ANFLOW process with sedimentation microscreening and reaeration at design flow rates of 1 5, 2 0 and 2 0 x 10^6 gpd respectively The break-even capital-cost design flow rates for the activated-sludge process and ANFLOW with these effluent polishing steps were 4 0, 4 0, and 6 0 x 10^6 gpd respectively Labor requirements for ANFLOW with these effluent polishing steps (except microscreening) were estimated to be much less than either of the other processes The design flow rates where ANFLOW with microscreening as an effluent polishing step equaled the labor requirements for the trickling-filter and activated-sludge processes were 3 7 and 6 0 x 10^6 gpd Energy requirements were much less than either the trickling-filter process or the activated-sludge processes for all of these effluent polishing alternatives When these factors were combined as an annual cost, the break-even design flow rates for the trickling-filter process and ANFLOW with microscreening sedimentation, and reaeration as effluent polishing steps were 2 5, 2 6, and 5 0 x 10^6 gpd respectively When the estimates were based on an ANFLOW media cost of $5/ft^3$ much higher break-even design flows were obtained It is noteworthy that the current cost of trickling-filter media is about $2 50/ft^3$ and as the ANFLOW process is developed it is believed that low-media costs can be attained The break-even design flow rates for the activated-sludge and ANFLOW processes with $10/ft^3$ media and microscreening, sedimentation and reaeration for effluent polishing were 7 5 9 0 and 10 x 10^6 gpd respectively

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