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Electrical Power Consumption For Municipal Wastewater Treatment

National Environmental Research Center
Office Of Rearch And Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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ELECTRICAL POWER CONSUMPTION FOR MUNICIPAL WASTEWATER TREATMENT

By

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ABSTRACT

Electrical power consumption by most conventional and advanced processes for treating municipal wastewater has been estimated on a unit process basis. Electrical power for complete plants has been estimated by adding power consumption for individual processes and plant utilities. Electrical power consumption for wastewater treatment has been compared to other consumptive uses of electrical power.

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CONCLUSIONS

Electrical power consumed in municipal wastewater treatment is about 1% of the average residential consumption of electrical power when the distribution of treatment schemes given in the 1968 Inventory of Municipal Waste Facilities is used as a basis. If all communities were served by activated sludge plants, the electrical power used will be about twice this amount. This is equivalent to about 15 watts per household. Thus, for complete secondary treatment, the power consumed is about equivalent to 24 hour operation of one desk lamp per household. The power consumed by tertiary treatment depends on the processes used, but for the Lake Tahoe system of tertiary treatment, the power consumed is about 40-50% greater than the power consumed in conventional activated sludge treatment.

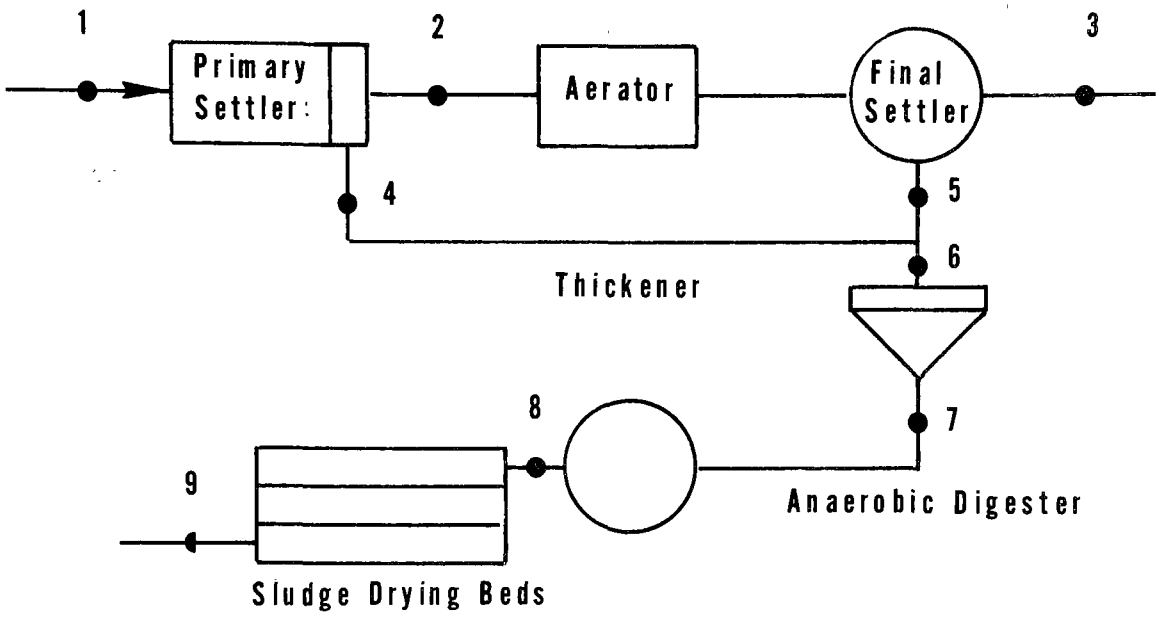
INTRODUCTION

This report contains estimates of electrical power consumption for most of the conventional and advanced processes used to treat municipal wastewater. Much of the information was taken from literature available from equipment manufacturers and some information was available from reports on EPA-sponsored research projects. The assistance of applications engineers representing the equipment manufacturers has been invaluable in clarifying important points and in the contribution of technical information not available in the open literature. This report could not have been completed without their generous contributions. The detailed cost estimates reported from the South Lake Tahoe Public Utility District in California[1] have been most useful.

The first part of the report is devoted to detailed calculations of electrical power consumption for individual conventional processes. These estimates are then summed for primary, trickling filter, activated sludge plants and the sludge handling schemes selected are shown in Figure 1. Estimates of mechanical and electrical energy available from the use of anaerobic digester off-gas are made and these are compared to the energy expended in operation of the plant. The cost of electrical power was taken from the report "Typical Electric Bills 1970" by the Federal Power Commission.[2] A detailed rate schedule currently used by the Cincinnati Gas and Electric Company was used to convert the estimated power consumption values to expenditure for electrical power.

The second part of the report presents detailed computations of electrical power consumption for the advanced or tertiary processes to be used downstream of secondary processes. Estimates of electrical power usage made at Lake Tahoe were the principal source of this information. Electrical power consumption estimates were then summed for various alternative tertiary treatment trains.

Finally, the electrical power used in treatment plants is related to other consumptive uses such as the typical residental use of electrical power. In this way the use of electrical power in treatment of wastewater is put into perspective with the national scene.



SLUDGE HANDLING SCHEME I

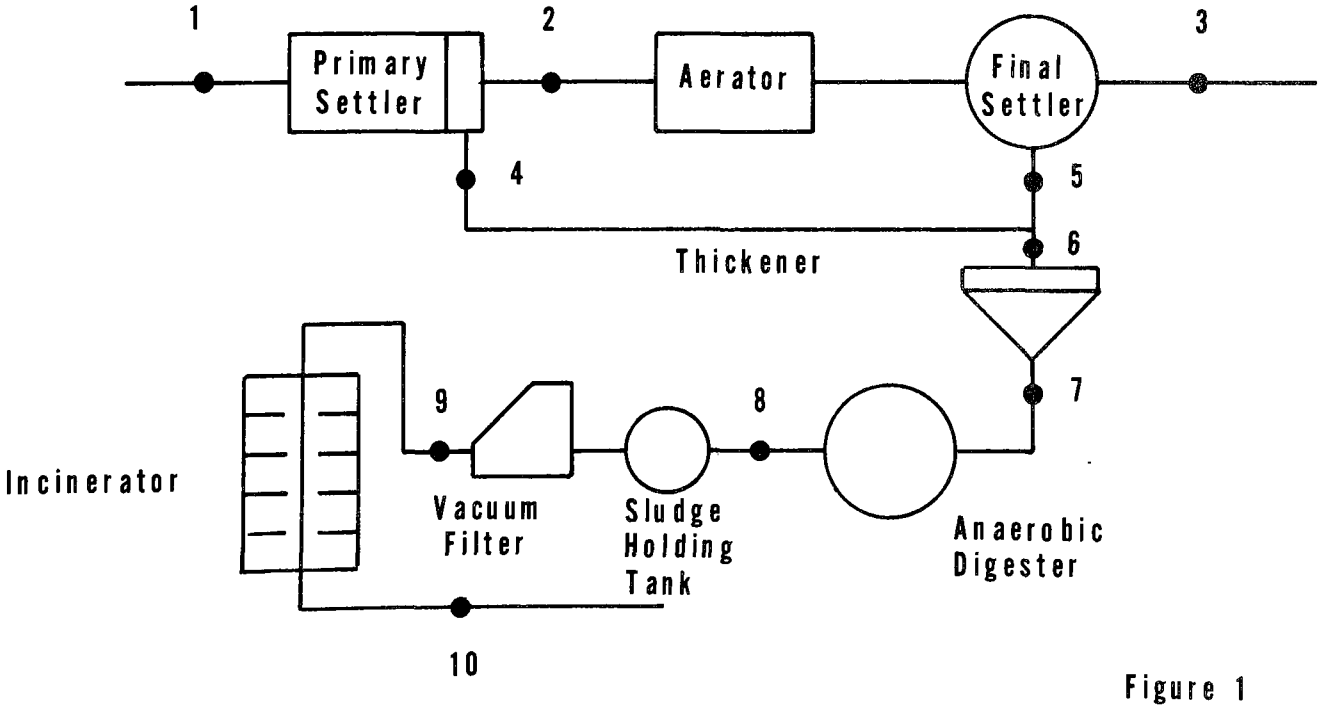


Figure 1

SLUDGE HANDLING SCHEME II

SLUDGE HANDLING SCHEME III

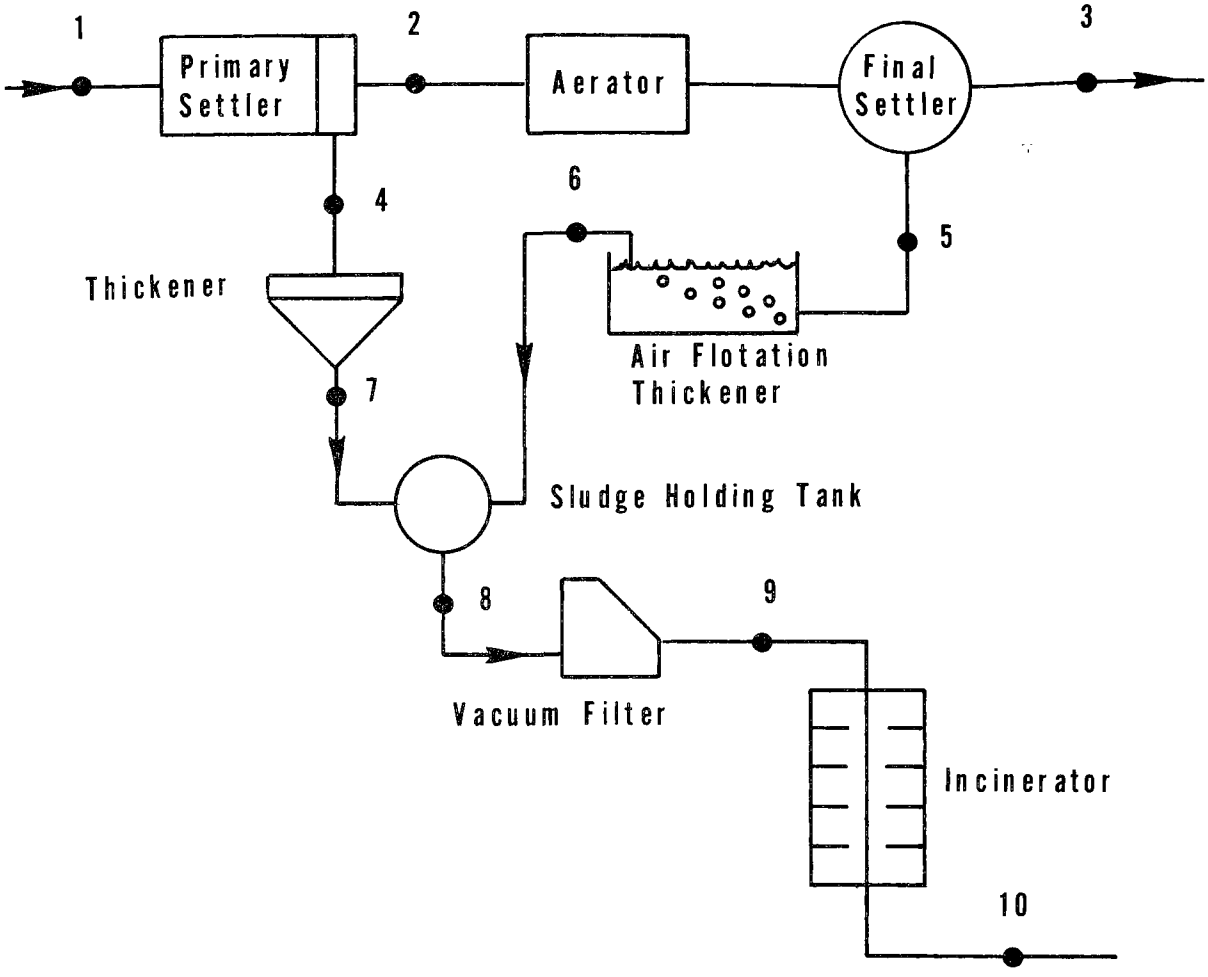


Figure 1 (Cont'd.)

PRELIMINARY TREATMENT

Preliminary treatment is a generic term which includes processes such as bar screens, comminutors, grit removal, and flow measurement. The electrical power consumption for these processes is comparatively small.

Bar screens are recommended for installation upstream of the influent pumps to remove debris which would interfere with the operation of the pumps. An average of about 5 cu. ft. of debris per million gallons is removed. The bar screen is cleaned of debris by a rake which travels about 7.5 ft/sec and operates for a maximum of about 6 minutes an hour. The channel which serves the bar screen is sized for a velocity of about 2 ft/sec at average flow. According to manufacturer's literature[3] the minimum size motor to drive the rakes is ½ horsepower and a bar screen with sufficient capacity to serve a 15 mgd plant can be powered by either a ½ or 3/4 horsepower electric motor. It will be assumed here that all bar screens up to 15 mgd will be powered by a 3/4 hp motor and for each additional 15 mgd increment an additional 3/4 hp motor will be required.

The electrical efficiency of electrical motors will be taken as 0.877 as recommended by one of the principal suppliers of electrical motors. The electrical power in kilowatts is then expressed as follows:

$$\text{Kilowatts} = 0.85 \times \text{Horsepower} \qquad (1)$$

Bar screen power consumption for all plants up to 15 mgd is, therefore 1.53 kwh/day. This estimate will apply to the 1 and 10 mgd plants. The corresponding power consumption for the 100 mgd plant will be 10.7 kwh/day.

Manufacturers' literature[3] for comminutors which are used to grind and shred floating debris gives the size of the installed motor

on each size comminutor. Several typical sizes are shown below: ::

Average Flow Range	
.25 - 1.82 mgd	0.75 horsepower motor
.97 - 5.10 mgd	1.50 horsepower motor
1.0 - 9.40 mgd	1.5 horsepower motor
1.30 - 20. mgd	2.0 horsepower motor

Thus, for the 1 mgd plant size the smallest size unit would be sufficient. The electrical power consumption, since the communitor will operate 24 hr/day, will be 15.3 kwh/day. At the 10 mgd size a conservative estimate would be two of the 1.5 horsepower sizes and the electrical power consumption would be 61 kwh/day. At the 100 mgd size five of the larger size should handle the flow and the power consumed would be 204 kwh/day.

Equipment for grit removal, according to one manufacturer[3], comes in sizes capable of handling 5 mgd. The installed electric motor is ½ horsepower. Thus, one horsepower per 10 mgd will be assumed. The grit is removed usually during the high flow period in the morning hours between 8-12 a.m. Therefore, at the 1 mgd size electrical power consumption is estimated as 1.7 kwh/day. At the 10 mgd size the power consumption can be estimated as 3.4 kwh/day and at the 100 mgd size as 34 kwh/day.

Flow measurement is accomplished by a Parshall flume in the smaller plants and by a Venturi or magnetic flow meter in the larger sizes. The power consumption for these flow sensing devices is negligible.

INFLUENT PUMPING

A major part of the electrical power consumption at a wastewater treatment plant is attributable to pumping the main stream from one level to a higher level. The total pumping head to bring the wastewater from the interceptor to the plant level varies somewhat with the plant, but about 30 ft. is commonly observed. The horsepower consumed in pumping water is given by the following relationship:

$$\text{Pumping Horsepower} = \frac{\text{MGD} \times 10^6 \times H}{1440 \times 3960 \times e_h} \qquad (2)$$

MGD = volume of water pumped, millions of gallons per day
H = total dynamic head, ft. of water
e_h = hydraulic efficiency

This relationship can be simplified as follows:

$$\text{Pumping Horsepower} = \text{MGD} \times 0.1754 \times H/e_h \qquad (3)$$

The hydraulic efficiency of water pumps depends on the volume of water pumped as well as the total dynamic head delivered. Since most water pumps are driven by induction motors, the speed of the pump is almost fixed. If the duty cycle for a pump is known, the hydraulic efficiency can be accurately determined from the pump map. For estimates of the kind made here, this is not possible. Therefore, rough averages for hydraulic efficiency will be used. One principal supplier of water pumps recommended the following values which will be used in this report:

up to 1000 gpm	70% hydraulic efficiency
1000 - 7000 gpm	74% hydraulic efficiency
over 7000 gpm	83% hydraulic efficiency

Assuming a total dynamic head of 30 ft. for influent pumping, the power consumption at the 1 mgd plant is computed as 133 kwh/day. For the 10 mgd the corresponding value is 1451 kwh/day. For the 100 mgd size the value is 12,933 kwh/day.

In this report, other pumping requirements such as recirculation pumping for activated sludge process or trickling filters or pumping of the main stream through such processes as carbon adsorption, filtration, reverse osmosis, etc. will be handled in a similar way.

SEDIMENTATION

Settlers for removal of suspended solids from raw wastewater and secondary settlers, used with the activated sludge process, can be constructed in either a circular or a rectangular shape. In this report only rectangular settlers will be considered. Rectangular settlers are normally constructed with common walls and the number of individual settlers needed, assuming an overflow rate of 800 gpd/sq ft, as a function of plant size is given below:

MGD	Number of Individual Settlers	Length, feet
1	3	37
2	4	50
3	5	56
4	6	60
5	6	74
10	8	106
20	11	149
30	14	172
40	16	198
50	17	232
60	19	248
70	20	274
80	22	283
90	23	304
100	24	323

According to manufacturer's literature[3], the installed electrical horsepower to drive the flights depends primarily on the length of the settler as shown in Figure 2. The installed horsepower, as a function of average flow, can, therefore be determined as shown in Figure 3. Since settlers normally operate 24 hr/day, we can compute the power consumption at the 1 mgd size as 30.6 kwh/day. The corresponding values for 10 mgd and 100 mgd sizes are 122 kwh/day and 734 kwh/day.

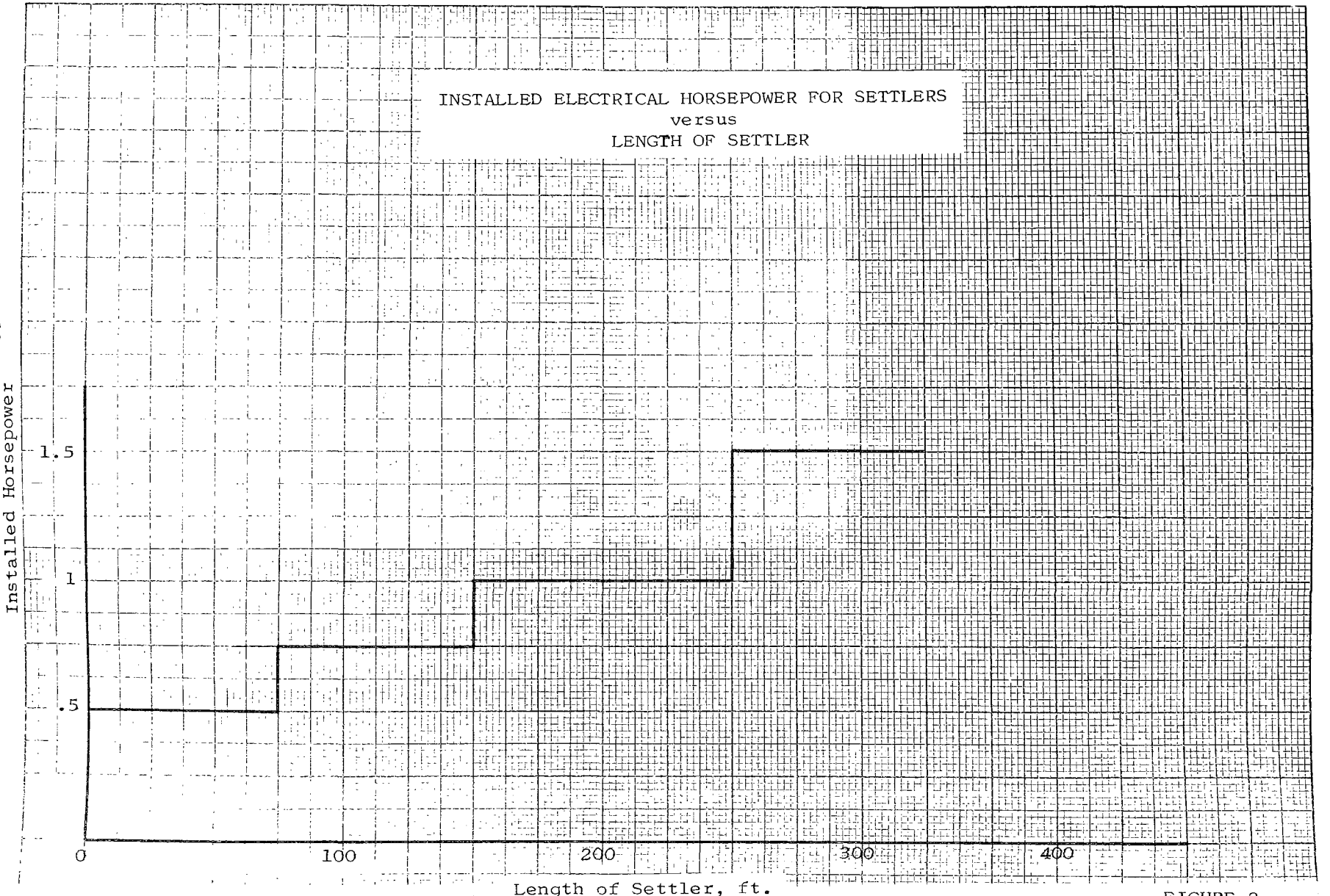

INSTALLED ELECTRICAL HORSEPOWER FOR SETTLERS
versus
LENGTH OF SETTLER
Installed Horsepower
1.5
1
.5
0
100
200
300
400
Length of Settler, ft.

FIGURE 2

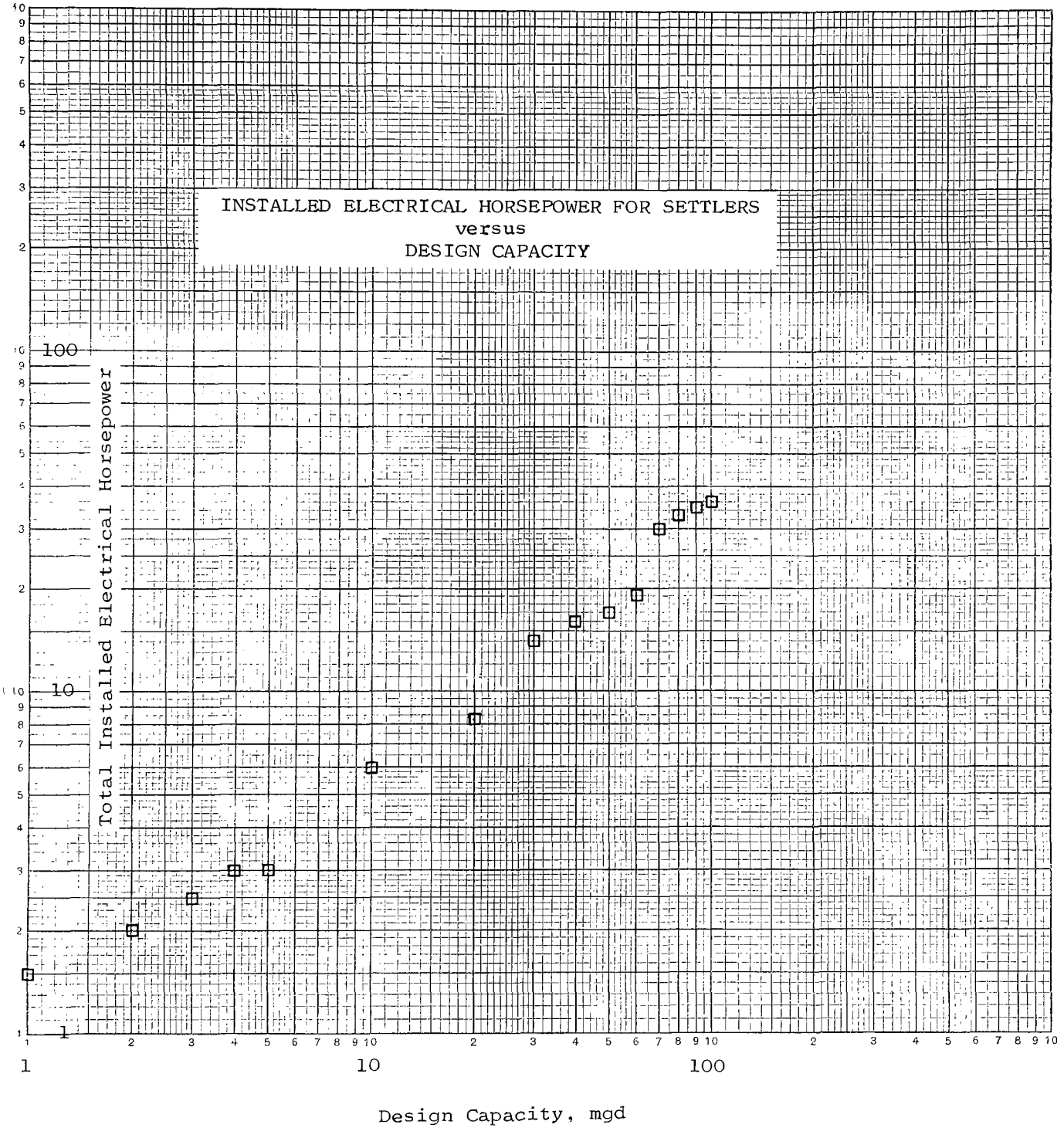

INSTALLED ELECTRICAL HORSEPOWER FOR SETTLERS
versus
DESIGN CAPACITY
Total Installed Electrical Horsepower
100
10
1
1
10
100
Design Capacity, mgd

FIGURE 3

TRICKLING FILTERS

Trickling filters can be designed in many configurations and the pumping power consumed will depend on the configuration. The loading in mgd/acre roughly divides filters into standard and high rate. Filters with loadings in the range of 1.1-4.4 mgd/acre are called standard filters while filters with loadings in the range 8.7-44 mgd/acre are known as high rate. Recycle of the main stream is commonly employed with high rate filters while standard rate filters usually have no provision for recycle.

The depth of rock media in all filters is about 6 feet. The distributor is normally about 1 foot above the top of the rock media and a head loss of about 2 feet occurs in the underdrains. The head loss across the distributor is about 3 feet. Thus, the head loss through a one stage trickling filter is about 12 feet. The electrical power consumed in driving the main stream through the filters is therefore, 61 kwh/day for the 1 mgd size, 580 kwh/day for the 10 mgd size, and 5173 kwh/day for the 100 mgd size.

The recirculation ratio (volume of recycled stream/volume of main stream) varies from 0.5 to 3 in most cases. A recycle ratio of 2.0 will be assumed here. When recycle is used, the power consumption can be estimated by multiplying the estimates given above by the recirculation ratio plus one.

For trickling filters without recycle, the power consumption is only about one-tenth that required for supplying air to the activated sludge process.

Sludge production in high-rate trickling filters has been found to be 35-50% of the BOD plus suspended solids load entering the filter. If the primary settler removes 50% of the suspended solids and 35% of the BOD, the sludge production is about 700-900 lb/mg, which is approximately the same as the conventional activated sludge process.

ACTIVATED SLUDGE PROCESS

Supplying oxygen to the activated sludge process is one of the principal needs for electrical energy. The diffused air system is most commonly used and the amount of air needed depends on the strength of the primary effluent, the detention time in the aerator, the concentration of mixed liquor suspended solids used, and whether or not nitrification occurs. For normal conditions, such as 130 mg/l 5-day BOD into the aerator and a mixed liquor suspended solids concentration of 2000 mg/l, the oxygen requirement is about 728 lb. O_2 per million gallons treated. If we take the aeration efficiency (oxygen dissolved/oxygen supplied) as a nominal 5%, the amount of air required is about 0.92 scf/gal. To supply this air, positive displacement or centrifugal compressors can be used. The pressure to be supplied by the compressor is about 8.1 psig. The power needed to compress the air, assuming isentropic compression, is given by the following relationship:

$$\text{Work of Compression, BTU/lb} = c_p T_1 \left[(P_2/P_1)^{\frac{n-1}{n}} - 1 \right] \qquad (4)$$

c_p = specific heat of air at constant pressure = .24 BTU/lb/^oF

T_1 = temperature of inlet air = 70° F = 530^oR

P_2 = outlet pressure, psia

P_1 = inlet pressure, psia

n = ratio of specific heats = 1.40

Substituting into equation 4, the work required to compress atmospheric air to 8.1 psig is 17 BTU/lb. Using the assumed value of 1 scf/gal and an air density of 0.075, 3125 lb. of air per hour must be delivered at the 1 mgd plant site. Since 2545 BTU/hr is equivalent to one horsepower, the adiabatic horsepower associated

with the air delivered is 20.87 at the 1 mgd plant size. If we take the adiabatic efficiency of the blower as 0.8, the horsepower needed to drive the blower is 26.1 horsepower for the 1 mgd size. Since the blower operates 24 hr/day, the power consumption at the 1 mgd size will be 532 kwh/day.

Literature from suppliers of mechanical aerators quote a transfer efficiency of 3.5 lb. O_2 per bhp-hr in clean water and ideal conditions. After the various correction factors are applied, the effective transfer efficiency is about 2.17 lb. O_2/bhp-hr. Since we had assumed 1 scf/gallon for the diffused air system which is equivalent to about 791 lb. O_2/mg, the amount of power needed to transfer this amount of oxygen, using mechanical aerators, is 365 bhp-hr/mg or 15.2 HP at the 1 mgd size.

Thus, based on this analysis, it would appear that mechanical aeration is significantly less expensive than diffused air. The five percent efficiency assumed for diffused air is conservative and in tests made at the Milwaukee Wastewater Treatment Plant, efficiencies as high as 15-17% have been observed for the ridge and furrow type of diffused air system.

Recirculation of activated sludge requires electrical power. The installed pump capacity recommended is 100% of the main stream, but on the average, only about 50% of the main stream is returned. From discussions with consulting engineers and pump manufacturers, the pumping head for recirculation was estimated to be 15-20 ft. of water. Thus, the electrical power consumption is 45 kwh/day at the 1 mgd size, 423 kwh/day at the 10 mgd size and 3131 kwh/day for the 100 mgd size.

Power requirements for final sedimentation will be taken as equal to those already estimated for primary sedimentation.

The Linde Division of Union Carbide Corporation[4] has estimated the power requirements for generation of pure oxygen and dissolving it in the aerator water at 25 hp for the 1 mgd size, 142 hp for the 6 mgd size, 700 hp for the 30 mgd size and 1960 hp for the 100 mgd size. An aerator with 2 hours detention time was assumed in making these estimates.

Energy for pumping sludges from the primary settler and the activated sludge process is difficult to estimate, but the head to be pumped against will be at least the 25-35 ft. required to pump the sludge into the digester. Under average conditions, the sludge volume in the primary plant will be about 0.00125 mgd/mgd of influent wastewater. For the activated sludge process, this ratio is 0.0052 mgd/mgd of plant influent. If we take the total head to be 100 ft., the power consumed in the 1 mgd primary plant is only 0.64 kwh/day. The power consumed for the 10 mgd and 100 mgd primary plants would be multiples of this value. For the 1 mgd activated sludge plant the power consumed for sludge pumping would be 2.66 kwh/day and for 10 mgd and 100 mgd the values would be 26.6 and 266 kwh/day.

The electrical power for operating gravity thickeners is based on the drag forces on the sludge scraper. These are in the range of 8-12 lb/ft of radius. The torque on the scraper and pickets, if they are provided, equals the load in pounds per foot times the radius in feet squared. The tip speed of the scraper is set at 1 ft. per minute. Horsepower is computed as torque (ft-lb) times 2π times the turning speed in rpm divided by 33,000. This relationship can be reduced to the loading in lb/ft times the radius in feet divided by 33,000. This is clearly a negligible amount of power. Since it is policy to install at least ½ horsepower motors, the power can be estimated as ½ horsepower per gravity thickener.

Primary plants are sometimes not equipped with gravity sludge thickeners. However, if a thickener is used, the normal loading rate is 16 lb/day/sq ft. Since a 1 mgd primary plant will produce about 833 lb/day of organic sludge, one 8 ft. dia. thickener should be sufficient. At the 10 mgd size, two 18 ft. dia. thickeners should be adequate. At the 100 mgd size, three 48 ft. dia. thickeners are needed. Thus, the power consumed can be estimated as 10.2 kwh/day at 1 mgd, 20.4 kwh/day at 10 mgd and 30.6 kwh/day at 100 mgd.

The recommended loading rate for activated sludge plants is 8 lb/day/sq ft. Since the activated sludge plant produces about 1726 lb. of combined primary and waste activated sludge per million gallons, the area needed at the 1 mgd size is 216 sq. ft. Thus, one 18 ft. dia. thickener will be sufficient for the 1 mgd size. For the 10 mgd size, two 38 ft. dia. thickeners will be adequate. At the 100 mgd size, four 82 ft. dia. thickeners will be sufficient. The installed horsepower is, therefore, 0.5 at the 1 mgd size, 1.0 at the 10 mgd size and 2.0 at the 100 mgd size. This is equivalent to 10.2 kwh/day for 1 mgd, 20.4 kwh/day at 10 mgd and 40.8 kwh/day at the 100 mgd size.

Installed horsepower for flotation thickening of waste activated sludge is a log-log function of the surface area of the thickener. For example, at 100 sq. ft. the installed horsepower is 14.5, at 1000 sq. ft. the installed horsepower is 115 and at 6000 sq. ft. the installed horsepower is 570. The recommended loading rate with chemical addition is 2 lb/hr/sq ft. The loading rate, when no chemicals are used, is about 0.5 lb/hr/sq ft. The amount of waste activated sludge produced is about 900 lb/mg. Thus, at a 1 mgd plant where the flotation thickener is operated 40 hr/week and chemicals are used, about 80 sq. ft. of surface area would be required. The next largest standard size is 100 sq. ft. This unit requires about 14.5 horsepower. The consumption of electrical power will be 70 kwh/day. Similarly, at the 10 mgd size (assumed to operate 100 hr/wk) the unit selected would be 400 sq. ft. and the installed horsepower is 50 horsepower. Operating an average of 14.3 hr/day the power consumption will be 608 kwh/day. At the 100 mgd size which operates 24 hr/day, the size of installation will be two 1000 sq. ft. units having 115 horsepower each for a total of 230 hp. The power consumption will be 4692 kwh/day. If no chemicals are used the power consumption at 1 mgd will be 242 kwh/day, at 10 mgd 1800 kwh/day, and at 100 mgd 18,800 kwh/day. The use of flotation thickeners for thickening of activated sludge can be expensive in terms of electrical power consumption.

Electrical energy is consumed in the anaerobic digestion process for two principal reasons; first, for mixing the contents of the primary digester (gas recirculation) and second, for heating the incoming sludge and holding the contents of the digester at the optimum temperature, usually about 95°F.

Anaerobic digesters range in size from 25 ft. in diameter to a maximum of about 110 ft. The depth is generally about 20 ft. at the 25 ft. size and about 35 ft. at the maximum size. The points on Figure 4 show the number of anaerobic digesters in installations[5] with various total volumes.

The solid lines on the right and left of the data points represent limits corresponding to 25 ft. diameter and 20 ft. deep digesters on the left bound and 110 ft. diameter and 35 ft. deep on the right bound.

An interesting and important problem is to find the number of digesters which will minimize the cost of the installation when one extra digester is provided (over and above the minimum requirements) for cleaning and maintenance. This problem can be solved in a crude way by assuming that the cost of the digester is directly proportional to the volume of concrete involved.

Clearly, if no duplication of digesters were needed, the minimum cost would be represented by building one large digester in every case up to the maximum size of 110 feet. Thus, the optimum sizes would be represented by a horizontal line at N = 1 terminating in the right hand bound and then following the right hand bound. Clearly, this principal is not always followed.

The results of the simplified analysis of optimum number of digesters to provide one extra is shown by the squared points. The dashed stepped line is only an approximation because the number of digesters must be an integer. It appears from this analysis that at the larger sizes, say about 500,000 cu. ft., practice is not significantly different from the optimum number of digesters. At the smaller sizes,

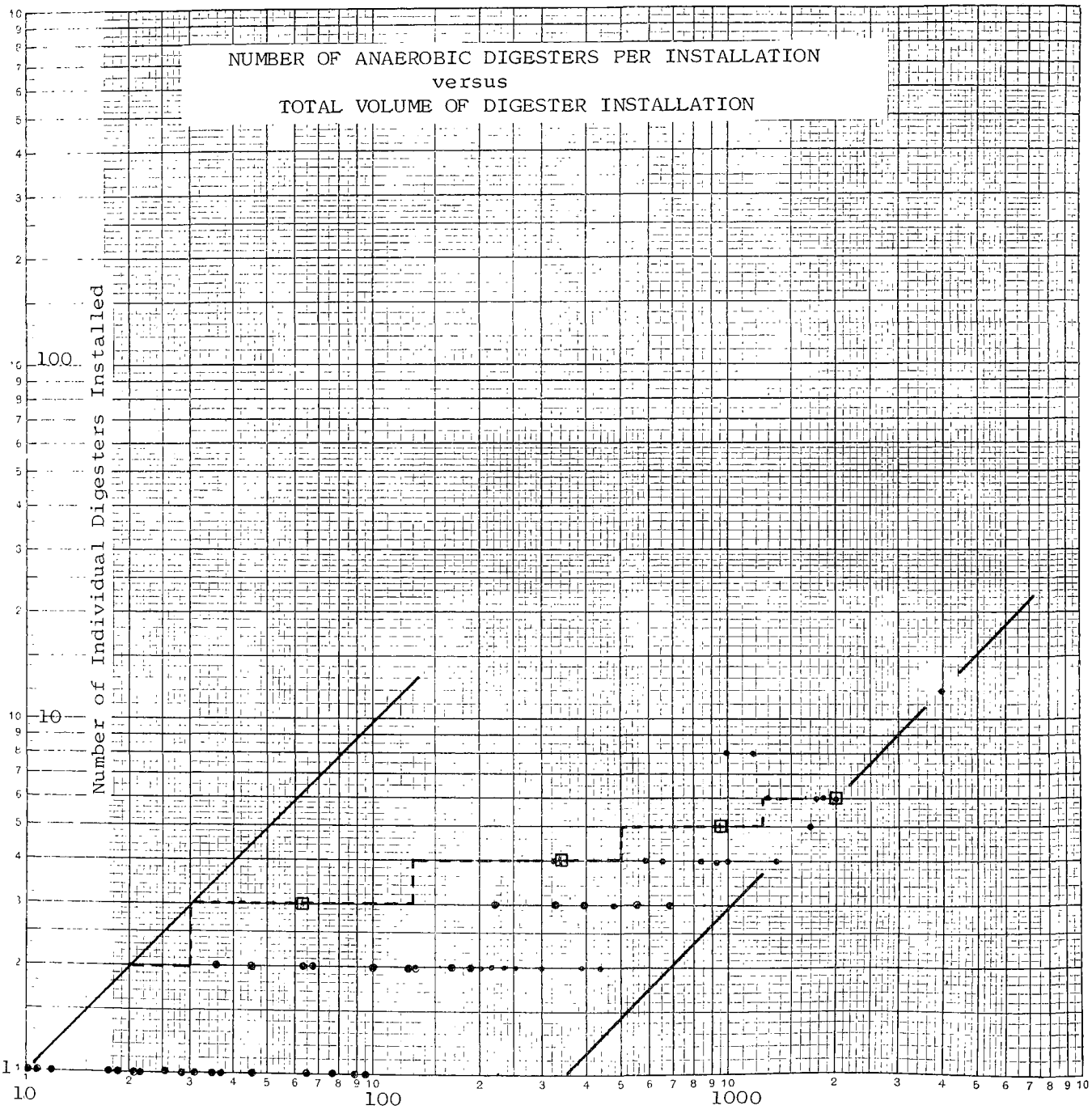

NUMBER OF ANAEROBIC DIGESTERS PER INSTALLATION
versus
TOTAL VOLUME OF DIGESTER INSTALLATION
Number of Individual Digesters Installed
100
10
1
10
100
1000
Total Digester Volume, thousands of cubic feet

FIGURE 4

however, there seems to be a tendency to not provide for duplication of digester facilities. Where duplication is shown, it appears that three digesters might have been more cost-effective than two digesters.

Electrical power is consumed in heating incoming sludge and overcoming the heat loss to the environment. The usual practice is to operate a hot water boiler and pump the sludge from the digester through the hot water heat exchanger to maintain the temperature in the digester at the 95°F level. The installed electrical horsepower for units with heating capacities in BTU/hr is shown in Figure 5. These motors do not all operate continuously, but the manufacturer estimates that power consumption would, on the average, be equivalent to operation of all motors 75% of the day. By estimating the number and size of digesters for primary and activated sludge plants of various sizes, the heat requirements can be found and from this the consumption of electrical power.

Primary plants produce about 833 lb/mg and activated sludge plants about 1726 lb/mg. In terms of volatile solids, these estimates are 650 lb/mg for the primary plant and 1275 lb/mg for the activated sludge plant.

For completely mixed digesters the recommended loading is 1000 cu. ft. of digester volume for each 80 lb. volatile solids per day. Thus, a primary completely mixed digester for a primary plant would be sized on 8,125 cu ft/mg. Similarly, for the activated sludge plant the sizing parameter would be 15,400 cu ft/mg.

If we take conventional practice as a guide, (see figure 4) we can assume that up to about 60,000 cu. ft. a single digester will be provided. Two digesters might be provided up to a volume of about 400,000 cu. ft. Three digesters might be provided up to about 850,000 cu. ft. Four digesters will be provided up to 1,350,000 cu. ft. and above this the maximum size digester with 338,000 cu. ft. might be used.

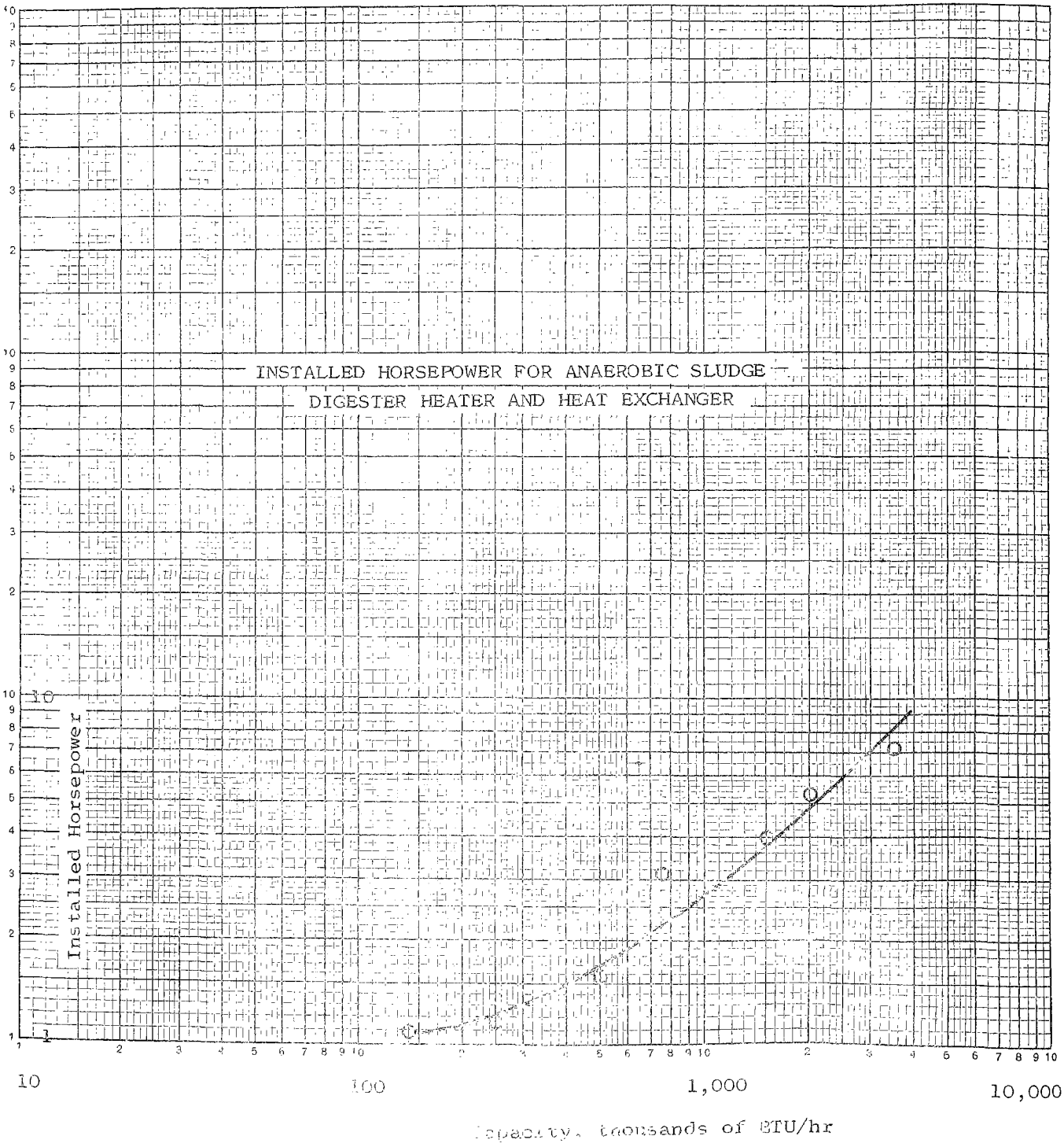

INSTALLED HORSEPOWER FOR ANAEROBIC SLUDGE
DIGESTER HEATER AND HEAT EXCHANGER
Installed Horsepower
10
100
1,000
10,000
Capacity, thousands of BTU/hr

FIGURE 5

The number and volume of primary digesters in primary and activated sludge plants can, therefore, be estimated as follows:

Primary Plants	Plant Size	Activated Sludge Plants
1 digester @ 8,125 cu ft	1 mgd	1 digester @ 15,400 cu ft
2 digesters @ 40,625 cu ft	10 mgd	2 digesters @ 77,000 cu ft
3 digesters @ 270,833 cu ft	100 mgd	5 digesters @ 308,000 cu ft

For primary plants, the heat load in BTU/hr can be computed as 9000 times the design population in thousands. The factor for activated sludge plants is 15,000. Loss of heat through the walls of the digester can also be estimated in an approximate way. For digesters with gas recirculation and exposed outside walls, the heat load can be approximated by multiplying the digester capacity in thousands of cubic feet times a factor. This factor is 4800 for a moderate climate such as that for Cincinnati, Ohio. Heat requirements for primary and activated sludge digesters can be computed as follows:

Primary Plants:

$$\text{BTU/hr} = 90{,}000 \times \text{mgd} + 4800 \times \frac{\text{Digester volume cu. ft.}}{1000}$$

Activated Sludge Plants:

$$\text{BTU/hr} = 150{,}000 \times \text{mgd} + 4800 \times \frac{\text{Digester volume cu. ft.}}{1000}$$

The capacity of sludge heating units for each size of plant can now be computed as follows:

Primary Plants	Plant Size	Activated Sludge Plants
1 @ 129,000 BTU/hr	1 mgd	1 @ 223,920 BTU/hr
2 @ 645,000 BTU/hr	10 mgd	2 @ 1,119,600 BTU/hr
3 @ 4,300,000 BTU/hr	100 mgd	5 @ 4,478,400 BTU/hr

The installed horsepower can be taken from Figure 5 to give the following estimates:

Primary Plant	Plant Size	Activated Sludge Plant
1 unit @ 1.1 hp	1 mgd	1 unit @ 1.15 hp
2 units @ 3.1 hp = 6.2 hp	10 mgd	2 units @ 4 hp = 8 hp
3 units @ 10.3 hp = 30.9 hp	100 mgd	5 units @ 10.3 hp = 51.5 hp

Assuming that these installed electric motors operate about 75% of the time, the following estimates for electrical power consumption can be computed:

Primary Plant	Plant Size	Activated Sludge Plant
16.8 kwh/day	1 mgd	17.6 kwh/day
95. kwh/day	10 mgd	122.4 kwh/day
473. kwh/day	100 mgd	788 kwh/day

These are the electrical energy requirements for the primary digester which is always heated. If the secondary digester is to be heated these values should be multiplied by two. Secondary digesters are usually not heated.

Electric motors are also used to drive the gas recirculation equipment for mixing the contents of the primary digester.

From specifications[5] of manufacturers' of gas recirculation systems for mixing of anaerobic digesters, the following operating horsepowers are shown as a function of the diameter of the digester:

25-30 ft. dia.	4.09 HP
31-40 ft. dia.	5.20 HP
41-50 ft. dia.	5.20 HP
51-80 ft. dia.	8.18 HP
81-110 ft. dia.	11.0 HP

Since the mixers normally operate 24 hr/day, the electrical power consumption can be estimated directly from the installed horsepower shown above.

Since the depth of sludge in the digester is known to vary from 20 ft. at the 25 ft. dia. size to 35 ft. at the 110 ft. dia. size, the diameter of the digesters required can be computed as follows:

Primary Plants	Plant Size	Activated Sludge Plants
1 @ 23 ft. dia.	1 mgd	1 @ 31 ft. dia.
2 @ 47 ft. dia.	10 mgd	2 @ 62 ft. dia.
3 @ 102 ft. dia.	100 mgd	5 @ 108 ft. dia.

The installed electrical horsepower for mixing is given below:

Primary Plants	Plant Size	Activated Sludge Plants
1 @ 4.09 hp	1 mgd	1 @ 5.2 hp
2 @ 5.2 hp = 10.4 hp	10 mgd	2 @ 8.18 hp = 16.36 hp
3 @ 11 hp = 33 hp	100 mgd	5 @ 11 hp = 55 hp

Power consumption in kwh/day are given below:

Primary Plants	Plant Size	Activated Sludge Plants
84 kwh/day	1 mgd	106 kwh/day
212 kwh/day	10 mgd	334 kwh/day
673 kwh/day	100 mgd	1122 kwh/day

Aerobic digestion is sometimes used to destroy suspended solids in waste activated sludge and to improve the dewatering characteristics of the remaining solids. The aerobic digester is similar to an aerator used in the activated sludge process except that settling and recycle of thickened sludge is not provided. The digester is supplied with diffused air, except during the periods when the contents of the digester are allowed to settle in order to draw off the thickened digested sludge. The detention time needed, when waste activated sludge alone is digested, is in the range 15-20 days. Since the volume of the waste activated sludge stream is about 0.018 mg/mg, a 1 mgd plant would produce about 18,000 gallons of waste activated sludge per day, requiring about 36,000 cu. ft. of digester capacity. About 25-30 cfm per 1000 cu. ft. of digester capacity is recommended to keep the sludge in suspension and supply

the oxygen demand of the microorganisms. Since about 900 scf is needed in diffused air system, the air requirements for the 1 mgd aerobic digestion process exceeds the requirements for the conventional activated sludge process by a factor of 1.3. Thus, aerobic digestion increases the electrical power consumption of activated sludge plants significantly.

The installed electrical horsepower for vacuum filters is shown in Figure 6 . The estimated amounts of sludge to be vacuum filtered, using sludge handling scheme II for primary plants and sludge handling schemes II and III for activated sludge plants. is shown below together with the size of filter likely to be installed and the operating times:

PRIMARY PLANTS SCHEME II

1 mgd	508 lb/day	60 sq. ft.	0.94 hr/day
10 mgd	5,080 lb/day	125 sq. ft.	5. hr/day
100 mgd	50,800 lb/day	250 sq. ft.	24. hr/day

ACTIVATED SLUDGE PLANTS SCHEME II

1 mgd	1,046 lb/day	60 sq. ft.	4.36 hr/day
10 mgd	10,886 lb/day	575 sq. ft.	5. hr/day
100 mgd	108,860 lb/day	2 x 575 = 1150 sq. ft.	24. hr/day

ACTIVATED SLUDGE PLANTS SCHEME III

1 mgd	1,661 lb/day	60 sq. ft.	4.6 hr/day
10 mgd	17,261 lb/day	575 sq. ft.	5. hr/day
100 mgd	172,610 lb/day	3 x 430 = 1290 sq. ft.	24. hr/day

Using these estimates and the installed electrical horsepower shown in Figure 6 , the following electrical power requirements can be calculated:

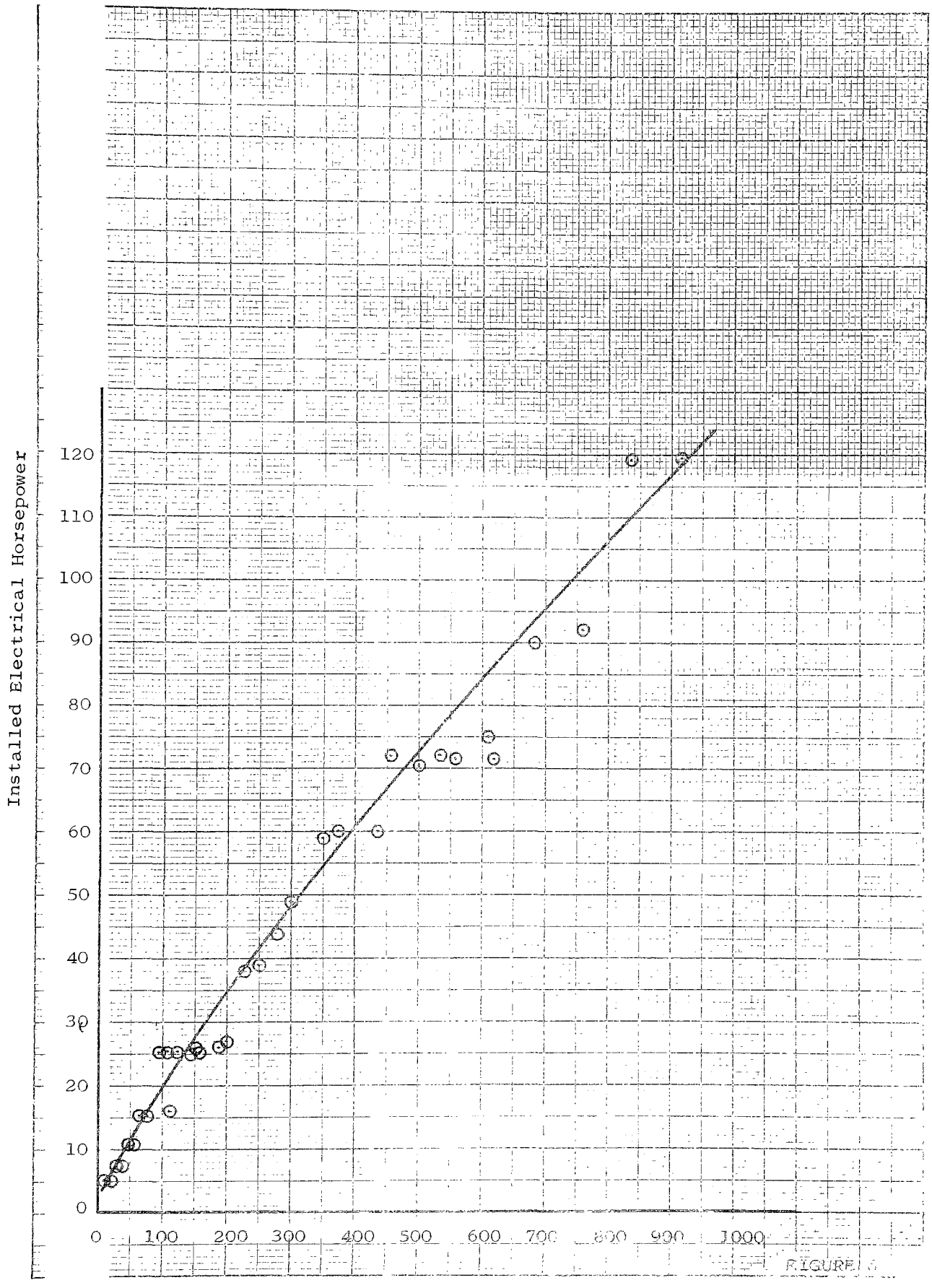
PRIMARY PLANTS SCHEME II

1 mgd	10.4 kw-hr/day
10 mgd	108 kwh/day
100 mgd	847 kwh/day

ACTIVATED SLUDGE PLANTS SCHEME II

1 mgd	57 kwh/day
10 mgd	346 kwh/day
100 mgd	3325 kwh/day

TOTAL INSTALLED ELECTRICAL HORSEPOWER FOR VACUUM FILTERS



ACTIVATED SLUDGE PLANTS SCHEME III

1 mgd	60 kwh/day
10 mgd	346 kwh/day
100 mgd	3947 kwh/day

Electrical power consumption by centrifuges used for dewatering digested organic sludge can be estimated accurately by the manufacturers of the equipment, but the computations are complex and depend on the specific application intended. The type of centrifuge considered here is the solid bowl centrifuge for dewatering digested organic sludge. Estimates of power consumed[6] are shown below for four different centrifuge sizes:

1. 0.73 - 1.6 horsepower/gpm
2. 0.8 - 1.48 horsepower/gpm
3. 0.43 - 0.81 horsepower/gpm
4. 0.41 - 0.74 horsepower/gpm

The limits of power consumption shown above correspond to 1000 g's and 2000 g's. The lower value is typical of operation where the sludge is to be disposed of by land spreading. The higher value is characteristic of a dryer sludge which might be incinerated. The range of volume handled per centrifuge is 10 gpm for the smaller size and 140 gpm for the larger size. When waste sludge is to be incinerated, it is common practice to provide a gravity thickener upstream of the centrifuge. The concentration of the thickened sludge would be about 5% solids. If we take the amounts of sludge given in the discussion on vacuum filters and convert these amounts to gpm, assuming a solids concentration of 5%, the volume of the stream to the centrifuge in the primary plants is 0.85 gpm at 1 mgd, 84.7 gpm at 10 mgd and 847. gpm at the 100 mgd size if the centrifuge is operated 24 hr/day. Thus, the power consumed in the primary plants would be 28 kwh/day at 1 mgd, 256 kwh/day at 10 mgd and 1400 kwh/day at 100 mgd. For activated sludge plants using sludge handling scheme II, the power consumed at 1 mgd would be 57 kwh/day, at 10 mgd 368 kwh/day and at 100 mgd

2740 kwh/day. For activated sludge plants using sludge handling scheme III, the corresponding values would be 90 kwh/day at 1 mgd, 435 kwh/day at 10 mgd and 4348 kwh/day at 100 mgd. Thus, the electrical power consumption for centrifugation of digested sludge is somewhat higher than that required for vacuum filters.

The amounts of sludge to be incinerated will equal the amounts vacuum filtered. Figure 7 shows the electrical power consumption[7] as a function of hearth area in terms of kwh per ton of sludge incinerated. The recommended loading is 2 lb. of sludge per hour per sq. ft. of hearth area. The size of incinerator likely to be used is shown below together with the electrical power consumption:

PRIMARY PLANTS SCHEME II

1 mgd	85 sq. ft.	28.4 kwh/day
10 mgd	510 sq. ft.	152.4 kwh/day
100 mgd	2 x 575 = 1150 sq. ft.	1148. kwh/day

ACTIVATED SLUDGE PLANTS SCHEME II

1 mgd	112 sq. ft.	54 kwh/day
10 mgd	1,117 sq. ft.	245 kwh/day
100 mgd	2,275 sq. ft.	1905 kwh/day

ACTIVATED SLUDGE PLANTS SCHEME III

1 mgd	166 sq. ft.	75 kwh/day
10 mgd	1,752 sq. ft.	328 kwh/day
100 mgd	2 x 1849 = 3698 sq. ft.	3280 kwh/day

ELECTRICAL ENERGY REQUIREMENTS FOR MULTIPLE HEARTH FURNACES

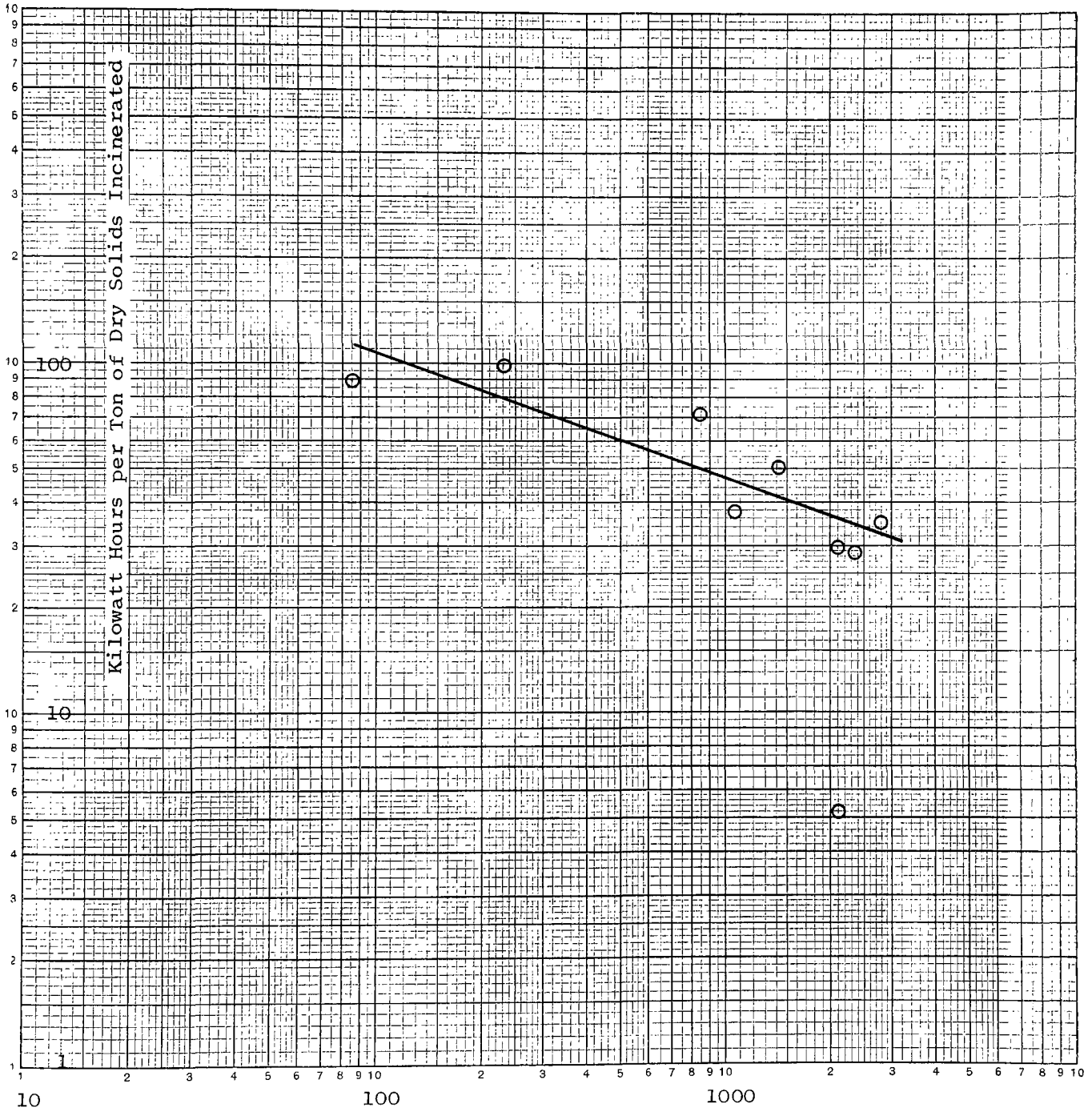


FIGURE 7

CHLORINATION

The dose of chlorine for disinfection of primary effluent is 20-25 mg/l. For activated sludge effluents the corresponding dose is 8 mg/l. Thus, the average useage of chlorine is 187 lb/mg for primary plants and 67 lb/mg for activated sludge plants. The three standard sizes of chlorinators are 400 lb/day, 2000 lb/day and 8000 lb/day. When the chlorine is removed from the storage pressure vessel as a gas, the power requirements for these chlorinators are negligible; 30 watts for the 400 and 2000 lb/day units and 75 watts for the 8000 lb/day unit.

If a large amount of chlorine is used at a plant, it is often advantageous (reduced storage) to remove the chlorine as a liquid and then evaporate the chlorine to a gas before use in the chlorinator. The kilowatt rating of a standard evaporator is 18 kilowatts. The manufacturer recommends the use of an evaporator if chlorine useage exceeds 2000 lb/day.

The actual dissipation of electrical energy can be computed from the heat of vaporization of chlorine (123.7 BTU/lb) and the heat required to raise the temperature of the gas to ambient temperature. The specific heat of chlorine is 0.115 BTU/lb and since the boiling point is -30°F, about 11.5 BTU/lb is needed to bring the gas to room temperature. The total to evaporate chlorine is 135 BTU/lb. One kilowatt-hr is equivalent to 3412 BTU.

The 2000 lb/day point is equivalent to about 10 mgd for a primary plant and 30 mgd for an activated sludge plant. The 1 mgd plant would, therefore, consume only 30 watts or 0.72 kwh/day. The 10 mgd primary plant would consume 30 watts plus 135 BTU/lb or a total of 82.4 kwh/day. The 10 mgd activated sludge plant would consume only 30 watts. The 100 mgd primary plant would consume 20,825 lb Cl_2 per day. The chlorinators would consume 225 watts and the heat to vaporize the chlorine would amount to 824 kwh/day for a total of 829 kwh/day. The corresponding value for the 100 mgd activated sludge plant is 226 kwh/day.

LIGHTS AND MISCELLANEOUS POWER

Additional electrical power is used in plants for indoor and outdoor lighting, operation of hand tools and office equipment, and other miscellaneous uses. The annual reports of the larger plants often give an estimate of this consumptive use, but in the smaller plants, an estimate must be made. The circled points in Figure 9 show values taken from the annual reports of four large plants.

Building electrical usage for lights and outlets is often estimated as 2-4 watts per square foot of floor area. In estimating the building power consumption for plants in the 1-10 mgd range, a working day of 10 hours was assumed. The floor area assumed as a function of plant size is shown in Figure 8 .

From a recent study made by Black and Veatch Consulting Engineers[8], the estimated number of outdoor lights was found to be four lights at a 1 mgd plant, 8 lights at a 5 mgd plant and 12 lights at a 10 mgd plant. The average expenditure per outdoor light was estimated as $25 per year. If we take the average cost of electrical power as 2 cents/kwh, one light would consume 342 watts, which is a good average between the conventional 400 watt street light and the 250 watt pole light often used in plants around aerators and settlers. If we assume that the outdoor lights are turned on for an average of 10 hr/day, the curve shown in Figure 9 can be constructed.

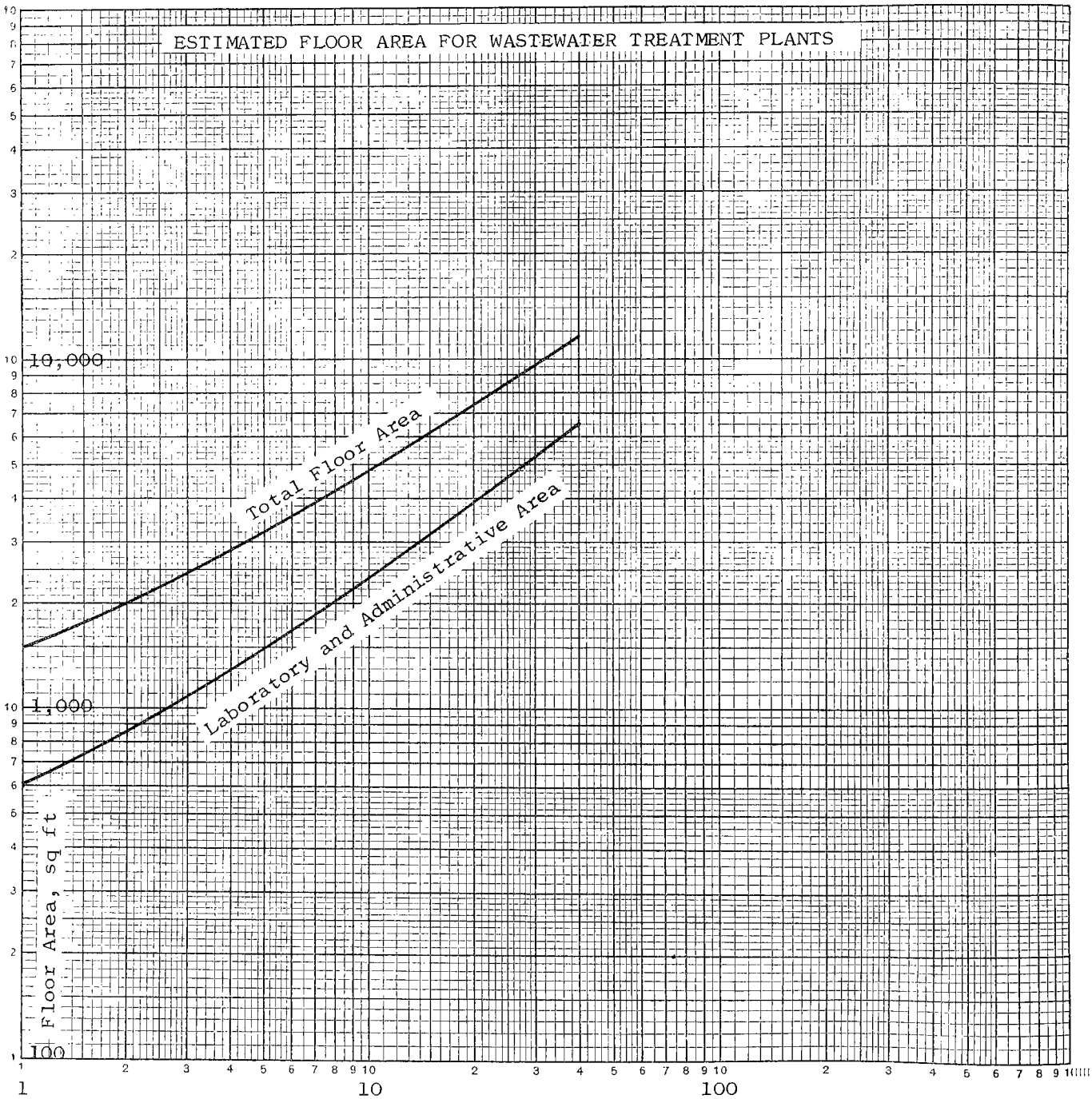

ESTIMATED FLOOR AREA FOR WASTEWATER TREATMENT PLANTS
Total Floor Area
Laboratory and Administrative Area
10,000
1,000
100
Floor Area, sq ft
1
10
100
Plant Size, mgd

FIGURE 8

ELECTRICAL ENERGY REQUIREMENTS FOR LIGHTING AND MISCELLANEOUS POWER

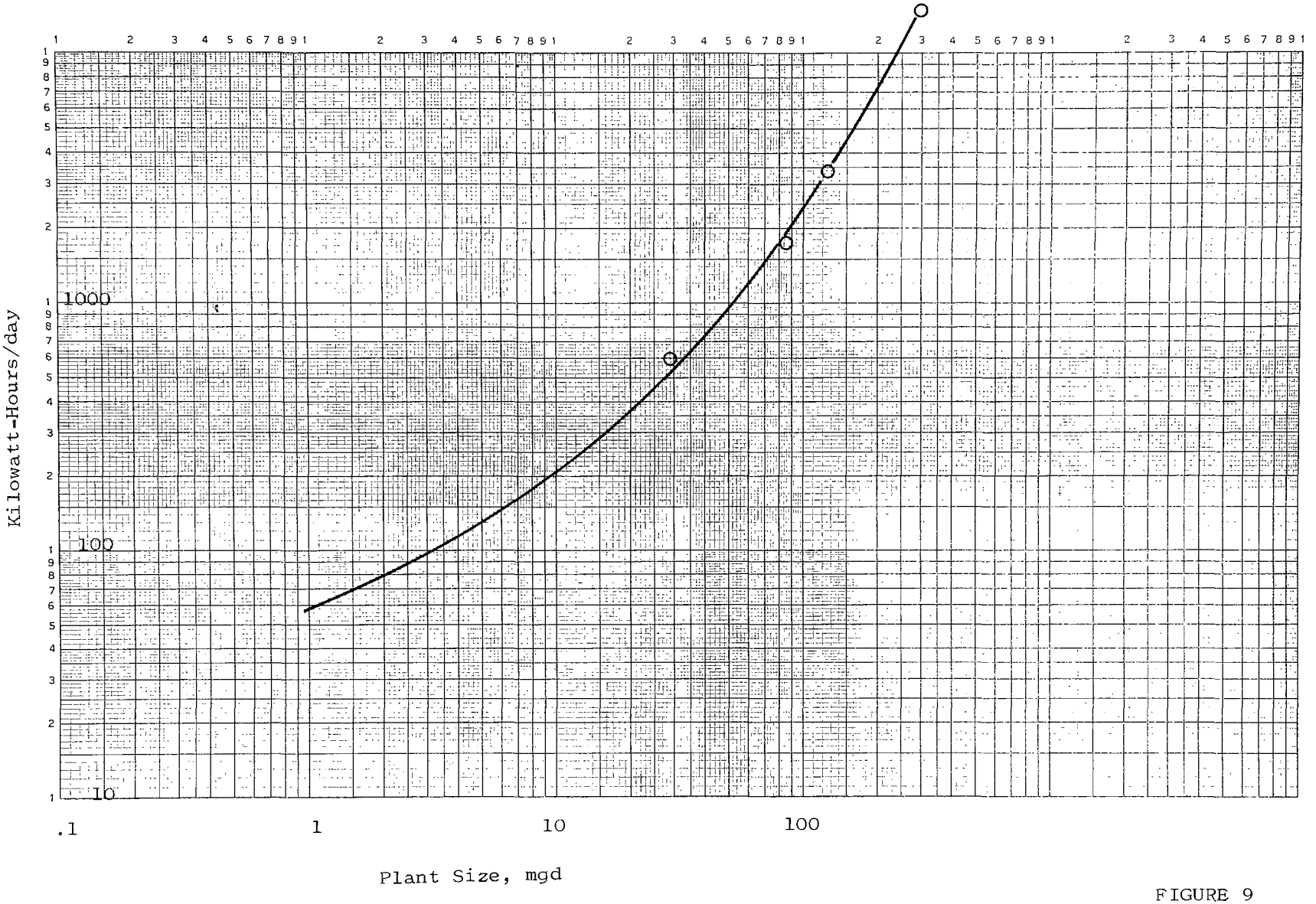


FIGURE 9

PRODUCTION OF POWER BY UTILIZATION OF SLUDGE GAS

Gas produced as a result of anaerobic digestion of organic sludge can be used to supply internal combustion engines. These IC engines can be direct coupled to air blowers or water pumps or can be used to drive electric generators. Digester gas can also be used to heat the digesters or to support combustion in the incinerator.

Digester gas is normally about 65-70% methane by volume. The volume of gas produced per pound of volatile solids destroyed is reported as 17-18 scf/lb at the larger and better instrumented plants. Smaller plants report lesser values, sometimes as low as 6 scf/lb VSS destroyed, but these lower values are probably due to poor measurement techniques. The fuel value of methane is about 963 BTU/scf and since digester gas is about 67% methane, the fuel value of digester gas is about 645 BTU/scf.

Average values for volatile solids fed to the digesters is 650 lb/mg for primary plants and 1275 lb/mg for activated sludge plants. If we assume that about 50% of these volatile solids will be destroyed in the digester and a yield of 17.5 scf/lb destroyed, the amount of digester gas available will be 5688 scf/mg for the primary plant and 11,156 scf/mg for the activated sludge plant.

The BTU's available for power generation will be 3.669×10^6 BTU/mg for the primary plant and 7.20×10^6 BTU/mg for the activated sludge plant. If we use this gas in an internal combustion engine, the power produced, using 7000 BTU/bhp-hr, will be 524 bhp-hr/mg for the primary plant and 1029 bhp-hr/mg for the activated sludge plant. Assuming 24 hr. operation of the blowers, a direct coupled IC engine would develop about 43 horsepower per million gallons in the activated sludge plant. Thus, sufficient gas is produced to drive the blowers.

At the Cincinnati Mill Creek Primary Plant where digester gas is used

to generate electrical power, it has been reported that 17.5 scf of digester gas is used to produce one kilowatt-hour. Therefore, if all of the gas was utilized, about 325 kwh/mg could be produced in the primary plant and 627 kwh/mg could be produced in the activated sludge plant. Since primary plants use about 235 kwh/mg, it should be possible to supply all of the electrical energy requirements for primary plants by using an IC engine to drive a generator. This is, in fact, what is done at the Mill Creek Plant and a negligible amount of power is purchased. The activated sludge plants consume an average of 942 kwh/mg; this exceeds the amount of power which might be generated by utilization of digester gas. Even in activated sludge plants a maximum of 2/3 of the power needed could be generated by using sludge gas.

Since sludge gas is not produced continuously, a storage sphere is normally provided and some power is consumed in storing the gas at about 40 psig. Sludge gas is also often used for heating the digester or for operating the incinerator. Thus, the total amounts estimated above might not be available for power generation.

TOTAL ELECTRICAL POWER CONSUMPTION FOR CONVENTIONAL PLANTS

Since estimates of power consumption have been made for all of the conventional processes shown in Figure 1, these can now be summed to find the total power consumption for complete plants. These totals are shown in Tables I and II for primary plants using sludge handling schemes I and II. In Tables III and IV the totals for activated sludge plants using sludge handling schemes II and III are shown. Table V gives the totals for trickling filter plants using sludge handling scheme II. Since no electrical power is used by sand drying beds, the totals for activated sludge plants using sludge handling scheme I can be found by subtracting the consumption for vacuum filtration and incineration from totals for sludge handling scheme II. These totals are 1004 kwh/day at 1 mgd, 8218 kwh/day for 10 mgd and 75,864 kwh/day for the 100 mgd size. Similarly, the totals for trickling filter plants using drying beds would be 610 kwh/day at 1 mgd, 4215 kwh/day at 10 mgd, and 35,052 kwh/day at 100 mgd.

Total electrical power consumption for plants taken from Tables I-V are shown plotted versus plant size in Figure 10. Power consumption for activated sludge plants is almost linear with plant size because influent pumping and diffused air consumption are the major uses and these are linear with the volume of the main stream. The curves for primary and trickling filter plants show significant economy of scale.

TABLE I

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Primary SLUDGE HANDLING SCHEME I

Killowatt-hours/day

PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.7
Comminutors	15.3	61.	204.
Grit Removal	1.7	3.4	34.
INFLUENT PUMPING (30 ft TDH)	153	1,451	12,933
PRIMARY SEDIMENTATION (800 gpd/sq ft)	30.6	122.	734.
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air			
Recirculation Pumping (50%, 17.5 ft)			
Final Settlers (800 gpd/sq ft)			
CHLORINATION	0.72	82.4	829.
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	0.64	6.4	64.
Gravity Thickeners	10.2	20.4	30.6
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	84.	212.	673.
Heating	17.6	122.4	788.
Vacuum Filtration			
Multiple Hearth Incineration			
LIGHTS AND MISCELLANEOUS POWER	57.	210.	2400.
TOTAL Kilowatt-hours/day	372	2293	18,700

TABLE II

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Primary SLUDGE HANDLING SCHEME II

Killowatt-hours/day

PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.7
Comminutors	15.3	61.	204.
Grit Removal	1.7	3.4	34
INFLUENT PUMPING (30 ft TDH)	153	1451.	12,933
PRIMARY SEDIMENTATION (800 gpd/sq ft)	30.6	122.	734.
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air			
Recirculation Pumping (50%, 17.5 ft)			
Final Settlers (800 gpd/sq ft)			
CHLORINATION	0.72	82.4	824.
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	.64	6.4	64.
Gravity Thickeners	10.2	20.4	30.6
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	84.	212.	673.
Heating	17.6	122.4	788.
Vacuum Filtration	10.4	108	847.
Multiple Hearth Incineration	28.4	152.4	1448.
LIGHTS AND MISCELLANEOUS POWER	57	210	2,400
TOTAL Kilowatt-hours/day	411	2,343	21,000

TABLE III

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Activated Sludge SLUDGE HANDLING SCHEME II

Killowatt-hours/day

PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.7
Comminutors	15.3	61.	204.
Grit Removal	1.7	3.4	34.
INFLUENT PUMPING (30 ft TDH)	153	1,451	12,933
PRIMARY SEDIMENTATION (800 gpd/sq ft)	30.6	122.	734.
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air	532	5,320	53,200
Recirculation Pumping (50%, 17.5 ft)	45	423	3,131
Final Settlers (800 gpd/sq ft)	30.6	122.	734
CHLORINATION	.72	.72	266
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	2.66	26.6	266
Gravity Thickeners	10.2	20.4	40.8
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	106.	334.	1,122.
Heating	17.6	122.4	788.
Vacuum Filtration	57.	346.	3,325.
Multiple Hearth Incineration	54.	245.	1,905.
LIGHTS AND MISCELLANEOUS POWER	57	210	2,400
TOTAL Kilowatt-hours/day	1,115	8,809	81,094

TABLE IV

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Activated Sludge SLUDGE HANDLING SCHEME III

Killowatt-hours/day

PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.7
Comminutors	15.3	61.	204.
Grit Removal	1.7	3.4	34.
INFLUENT PUMPING (30 ft TDH)	153	1,451	12,933
PRIMARY SEDIMENTATION (800 gpd/sq ft)	30.6	122.	734.
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air	532	5,320	53,200
Recirculation Pumping (50%, 17.5 ft)	45	423	3,131
Final Settlers (800 gpd/sq ft)	30.6	122.	734
CHLORINATION	.72	.72	266.
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	2.66	26.6	266.
Gravity Thickeners	10.2	20.4	30.6
Air Flotation Thickeners	70.	608.	4,692.
Anaerobic Digesters			
Mixing			
Heating			
Vacuum Filtration	60.	346.	3,947.
Multiple Hearth Incineration	75.	328.	3,280
LIGHTS AND MISCELLANEOUS POWER	57.	210.	2,400.
TOTAL Kilowatt-hours/day	1,085	9,044	85,862

TABLE V

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT High Rate Trickling Filter SLUDGE HANDLING SCHEME II

Killowatt-hours/day

PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.7
Comminutors	15.3	61.	204.
Grit Removal	1.7	3.4	34.
INFLUENT PUMPING (30 ft TDH)	153	1,451	12,933
PRIMARY SEDIMENTATION (800 gpd/sq ft)	30.6	122.	734.
TRICKLING FILTERS			
Recirculation Pumping	183	1740	15,519
Final Sedimentation	30.6	122	734
ACTIVATED SLUDGE PROCESS			
Diffused Air			
Recirculation Pumping (50%, 17.5 ft)			
Final Settlers (800 gpd/sq ft)			
CHLORINATION	.72	.72	266.
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	2.66	26.6	266.
Gravity Thickeners	10.2	20.4	40.8
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	106	344	1,122
Heating	17.6	122.4	788
Vacuum Filtration	57	346	3,325
Multiple Hearth Incineration	54	245	1,905
LIGHTS AND MISCELLANEOUS POWER	57	210	2,400
TOTAL Kilowatt-hours/day	721	4,806	40,282

ELECTRICAL ENERGY CONSUMPTION BY MUNICIPAL WASTEWATER TREATMENT PLANTS
versus
PLANT SIZE

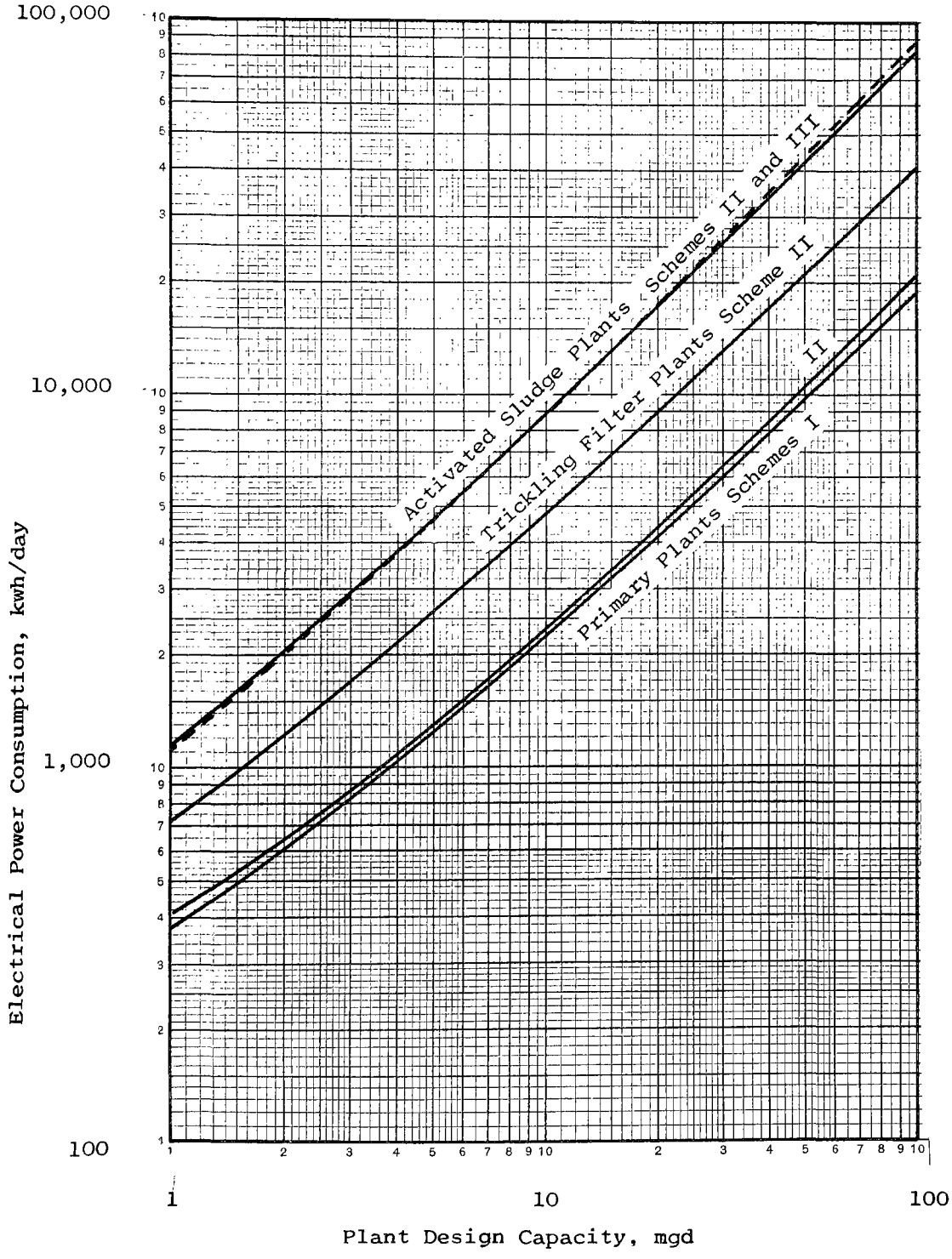


FIGURE 10

EXPENDITURE FOR ELECTRICAL POWER IN CONVENTIONAL PLANTS

The cost of electrical power depends on the peak demand for power as well as the amount of kilowatt-hours used. A schedule of charges for electrical power used by the Cincinnati Gas and Electric Co. is shown in the Appendix. The average cost of power in the United States is published yearly by the Federal Power Commission and the latest available nationwide averages are shown in the Appendix. The cost of power, based on the Cincinnati Gas and Electric schedule for the power categories used by the Federal Power Commission, is also shown in the Appendix. Notice that these exceed the 1970 national average in the 150 kw, 30,000 kwh/mo category by 8%, in the 300 kw, 60,000 kwh/mo category by 9% and the 1000 kw, 2000,000 kwh/mo category by 14%. The Cincinnati Gas and Electric schedule has been used to compute the monthly expenditure for electrical power in the five plant types shown in Tables I-V. These dollar amounts are given in Tables VI-X. These values have been converted to dollars per year and plotted in Figure 11.

In a paper by R. L. Michel[9] of EPA, published in the Water Pollution Control Federation for November 1970, the electrical power consumption in plants was reported in terms of annual dollar expenditure for electrical power. This data was gathered over the 1965-68 period. The relationships reported by Michel cover the range 0.1-10 mgd and his data for primary, high rate trickling filter, and activated sludge plants are shown as dashed lines in Figure 11. A multiplier of 1.12 was applied to Michel's data to make it consistent with the cost of electrical power, using the CG&E schedule shown in the Appendix.

The agreement between Michel's data and the estimates produced in this report is good for conventional primary plants. The agreement for activated sludge plants is not as good and this could be due to the use of sludge gas or natural gas in IC engines to power the blowers. The agreement between Michel's data on high

TABLE VI

COST OF ELECTRICAL POWER - PRIMARY - SCHEME I

TYPE OF PLANT: Primary SLUDGE HANDLING SCHEME: I						
	1 mgd		10 mgd		100 mgd	
	kwh	$/mo	kwh	$/mo	kwh	$/mo
KW Demand	31		153		1,013	
kwh/day	372		2,293		18,700	
kwh/mo	11,160		68,790		561,000	
first 6000 kwh	5,160	157.60	62,790	157.60	555,000	157.60
60 x KW Demand x 1.42¢/kwh	3,300	26.41	53,610	130.36	494,220	863.08
120 x KW Demand x 1.14¢/kwh	0		35,250	209.30	372,660	1,385.78
120 x KW Demand x 0.82¢/kwh			16,890	150.55	251,100	996.79
Additional kwh x 0.71¢/kwh				119.92		1,782.81
KW Demand minus 15	16		138		998	
First 35 KW x $2 = $70		32.	103	70.	963	70.
Second 50 KW x $1.95 = $97.50			53	97.50	913	97.50
Third 900 KW x $1.50 = $1350				79.50	13	1,350.
Additional KW Demand x $1.35						17.55
Total Monthly Bill, dollars		216.01		1,015.08		6,721.11
Cents/kwh		1.936		1.476		1.198
Cents/1000 gallons treated		.72		.338		.224

TABLE VII

COST OF ELECTRICAL POWER - PRIMARY - SCHEME II

TYPE OF PLANT: Primary SLUDGE HANDLING SCHEME: II						
	1 mgd		10 mgd		100 mgd	
	kwh	$/mo	kwh	$/mo	kwh	$/mo
KW Demand	34		156		1,138	
kwh/day	411		2,343		21,000	
kwh/mo	12,330		70,290		630,000	
first 6000 kwh	6,330	157.60	64,290	157.60	624,000	157.60
60 x KW Demand x 1.42¢/kwh	4,290	28.97	54,930	132.91	555,720	969.58
120 x KW Demand x 1.14¢/kwh	210	2.39	36,210	213.41	419,160	1,556.78
120 x KW Demand x 0.82¢/kwh			17,490	153.50	282,600	1,119.79
Additional kwh x 0.71¢/kwh				124.18		2,006.46
KW Demand minus 15	19		141		1,123	
First 35 KW x $2 = $70		38.	106	70.	1,088	70.
Second 50 KW x $1.95 = $97.50			56	97.50	1,038	97.50
Third 900 KW x $1.50 = $1350				84.00	138	1,350.
Additional KW Demand x $1.35						186.30
Total Monthly Bill, dollars		226.96		1,033.10		7,514.01
Cents/kwh		1.84		1.47		1.193
Cents/1000 gallons treated		.756		.344		.250

TABLE VIII COST OF ELECTRICAL POWER - ACTIVATED SLUDGE - SCHEME II

TYPE OF PLANT: Activated Sludge SLUDGE HANDLING SCHEME: II						
	1 mgd		10 mgd		100 mgd	
	kwh	$/mo	kwh	$/mo	kwh	$/mo
KW Demand	95.4		612		4,566	
kwh/day	1,145		9,179		84,288	
kwh/mo	34,350		275,370		2,528,640	
first 6000 kwh	28,350	157.60	269,370	157.60	2,522,640	157.60
60 x KW Demand x 1.42¢/kwh	22,626	81.28	232,650	521.42	2,248,680	3,890.23
120 x KW Demand x 1.14¢/kwh	11,178	130.51	159,210	837.22	1,700,760	6,246.29
120 x KW Demand x 0.82¢/kwh		91.67	85,770	602.21	1,152,840	4,492.94
Additional kwh x 0.71¢/kwh				608.97		8,185.16
KW Demand minus 15	80.4		596		4,551	
First 35 KW x $2 = $70	45.4	70.	562	70.	4,516	70.
Second 50 KW x $1.95 = $97.50		88.53	512	97.5	4,466	97.50
Third 900 KW x $1.50 = $1350				768.	3,566	1,350.
Additional KW Demand x $1.35						4,814.10
Total Monthly Bill, dollars		619.59		3,662.92		29,303.82
Cents/kwh		1.80		1.33		1.16
Cents/1000 gallons treated		2.07		1.22		.977

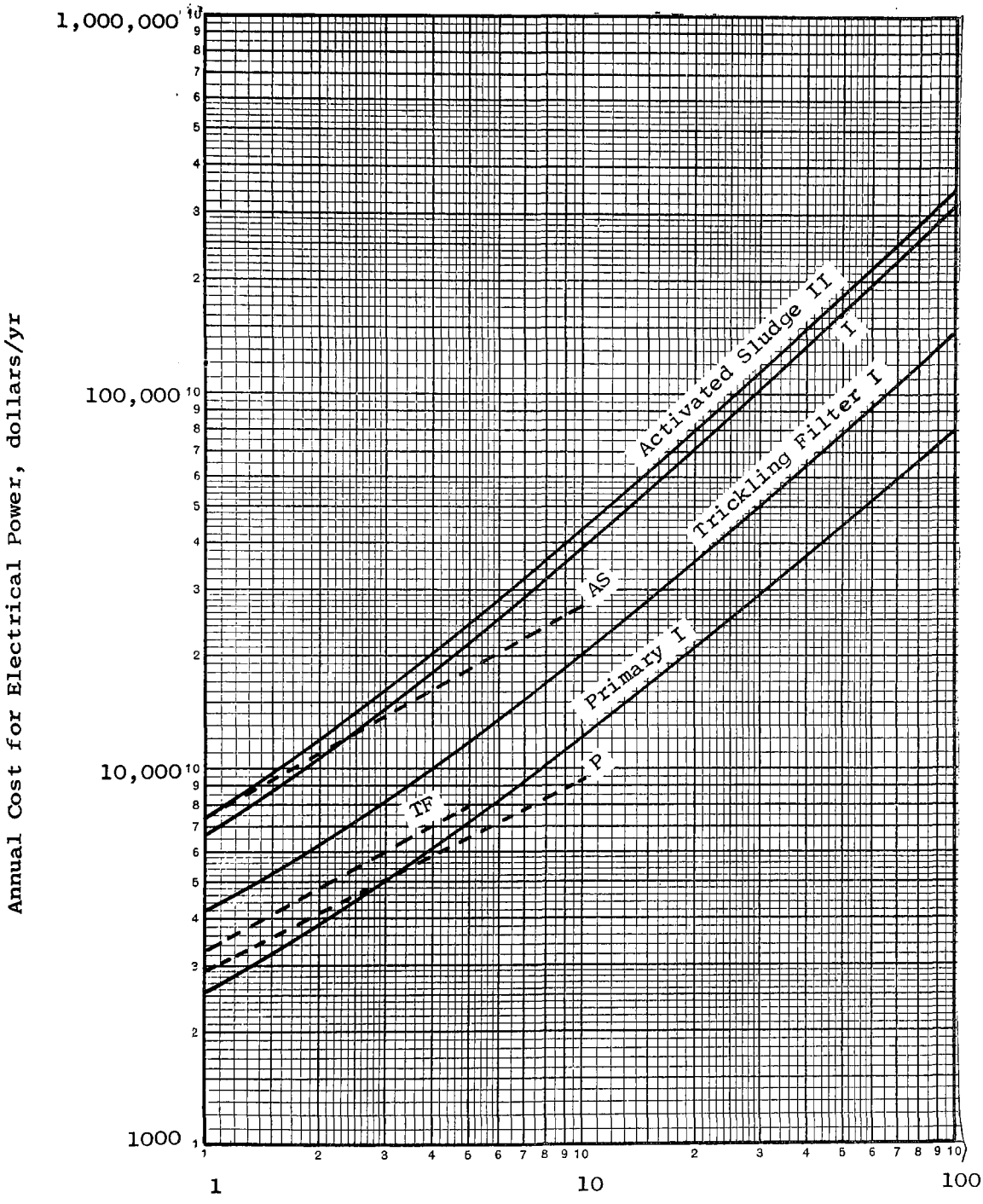
TABLE IX COST OF ELECTRICAL POWER - ACTIVATED SLUDGE - SCHEME III

TYPE OF PLANT: Activated Sludge SLUDGE HANDLING SCHEME: III						
	1 mgd		10 mgd		100 mgd	
	kwh	$/mo	kwh	$/mo	kwh	$/mo
KW Demand	93		628		4824	
kwh/day	1,115		9,414		89,056	
kwh/mo	33,450		282,420		2,671,680	
first 6000 kwh	27,450	157.60	276,420	157.60	2,665,680	157.60
60 x KW Demand x 1.42¢/kwh	21,870	79.24	238,740	535.06	2,376,240	4,110.05
120 x KW Demand x 1.14¢/kwh	10,710	127.22	163,380	859.10	1,797,360	6,599.23
120 x KW Demand x 0.82¢/kwh		87.82	88,020	617.95	1,218,480	4,746.82
Additional kwh x 0.71¢/kwh				624.94		8,651.21
KW Demand minus 15	78		613		4809	
First 35 KW x $2 = $70	43	70.	578	70.	4774	70.
Second 50 KW x $1.95 = $97.50		83.85	528	97.50	4724	97.50
Third 900 KW x $1.50 = $1350				792.	3824	1,350.
Additional KW Demand x $1.35						5,162.40
Total Monthly Bill, dollars		605.73		3,754.15		30,944.81
Cents/kwh		1.81		1.33		1.15
Cents/1000 gallons treated		2.01		1.25		1.03

TABLE X COST OF ELECTRICAL POWER - TRICKLING FILTER - SCHEME II

TYPE OF PLANT: Trickling Filter SLUDGE HANDLING SCHEME: II						
	1 mgd		10 mgd		100 mgd	
	kwh	$/mo	kwh	$/mo	kwh	$/mo
KW Demand	60		320		2,182	
kwh/day	721		4,806		40,282	
kwh/mo	21,630		144,180		1,208,460	
first 6000 kwh	15,630	157.60	138,180	157.60	1,202,460	157.60
60 x KW Demand x 1.42¢/kwh	12,030	51.12	118,980	272.64	1,071,540	1,859.06
120 x KW Demand x 1.14¢/kwh	4,830	82.08	80,580	437.76	809,700	2,984.98
120 x KW Demand x 0.82¢/kwh		39.61	42,180	314.88	547,860	2,147.09
Additional kwh x 0.71¢/kwh				299.48		3,889.81
KW Demand minus 15	45		305		2,167	
First 35 KW x $2 = $70	10	70.	270	70.	2,132	70.
Second 50 KW x $1.95 = $97.50		19.50	220	97.50	2,082	97.50
Third 900 KW x $1.50 = $1350				330.	1,182	1,350.
Additional KW Demand x $1.35						1,595.70
Total Monthly Bill, dollars		419.91		1,979.86		14,151.74
Cents/kwh		1.94		1.37		1.17
Cents/1000 gallons treated		1.40		.66		.472

ANNUAL EXPENDITURE FOR ELECTRICAL POWER IN CONVENTIONAL PLANTS
versus
PLANT SIZE



AS = activated sludge, TF = high rate trickling filter

P = conventional primary, I & II refer to sludge handling schemes

FIGURE 11

rate trickling filters and the estimates made here is not good. Michel's estimates for trickling filters is only slightly above his estimates for conventional primary. The explanation for this discrepancy is not known at this time. The cost of electrical power versus the amount of power used, taken from Tables is shown plotted in Figure 12.

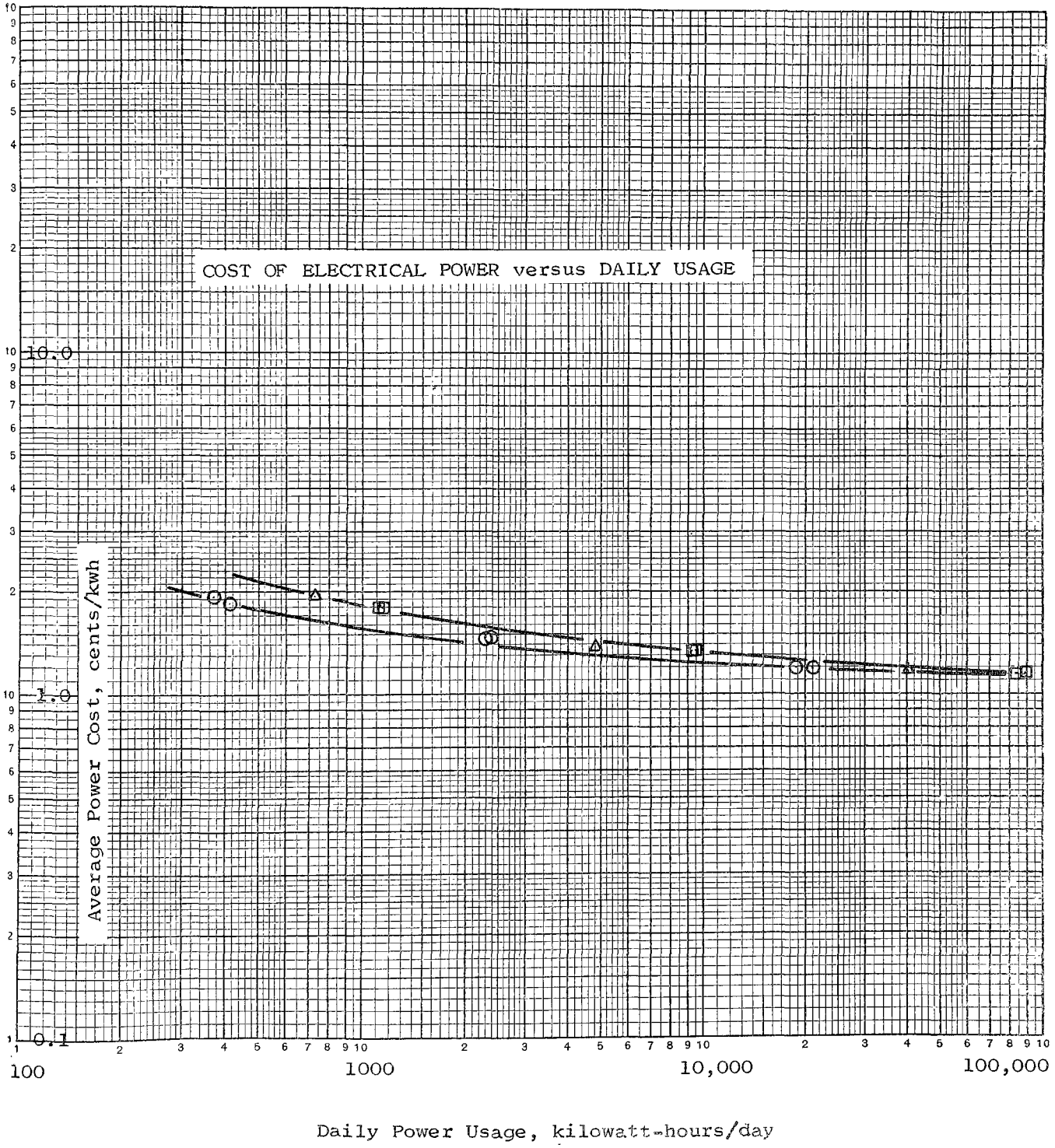

COST OF ELECTRICAL POWER versus DAILY USAGE
10.0
1.0
0.1
Average Power Cost, cents/kwh
100
1000
10,000
100,000
Daily Power Usage, kilowatt-hours/day

FIGURE 12

ELECTRICAL POWER REQUIREMENTS FOR ADVANCED PROCESSES

The first process which might be considered for use downstream of the activated sludge process is microscreening to remove suspended solids which escape over the weirs of the final clarifier. Installed electrical horsepower and average electrical power consumption for microscreening equipment is shown in Figure 13. The principal source of this information is a paper presented at the 41st Annual Meeting of the Ohio Water Pollution Control Conference by E. W. J. Diaper of Glenfield and Kennedy Inc. The triangular points are from a recent EPA report 17090 EEM 12/71. Thus, the power actually consumed is about 115 kwh/day for 1 mgd, 375 kwh/day at 10 mgd and 1200 kwh/day at 100 mgd. The economy of scale is apparently very significant.

Liquid alum can be added to the aerator to remove phosphorus with the waste activated sludge. The usual dose of aluminum is 1.5 moles of aluminum per mole of phosphorus in the main stream. If we take the influent phosphorus concentration as 10 mg/l, the aluminum dose would be 13.05 mg/l or 144 mg/l of dry alum. Since one gallon of liquid alum contains 5.4 lb. of dry alum, the amount of liquid alum used would be 222 gallons/mg treated. This is equivalent to 9.25 gph/mgd. It is customary to install a one-third horsepower motor on all feeders up to 60 gph. A second pump might be needed to deliver the liquid alum to a head tank and a one-third horsepower motor would also be adequate for this purpose. The actual horsepower consumed in raising the liquid 50 ft. would only be 0.3 horsepower at the 100 mgd size. The total power consumption for feeding liquid alum will, therefore, be taken as 10 kwh/day at the 1 mgd size, 15 kwh/day at the 10 mgd size, and 110 kwh/day at the 100 mgd size.

The addition of alum to the aerator will result in extra sludge production and extra electrical power consumption. Addition of

ELECTRICAL ENERGY REQUIREMENTS FOR MICROSCREENS

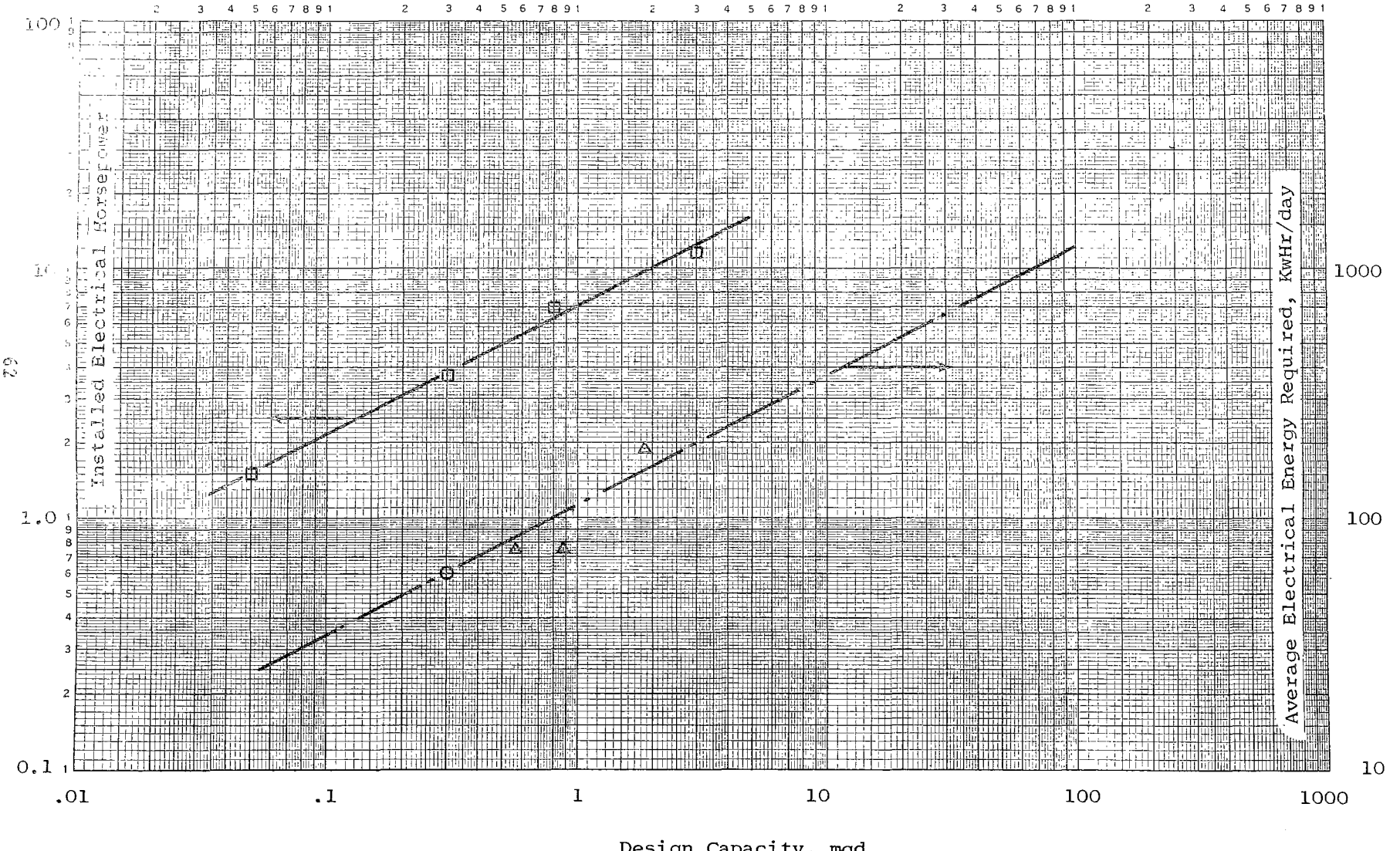


FIGURE 13

alum to the aerator will result in an increase of about 40% in sludge production. The increased power consumption for mixing and heating of anaerobic digesters will be about 25 kwh/day at 1 mgd, 90 kwh/day at 10 mgd, and 400 kwh/day at the 100 mgd level. Increased power for vacuum filtration will be 42 kwh/day at 1 mgd, 87 kwh/day at 10 mgd, and 964 kwh/day at 100 mgd. Additional power for incineration of the extra sludge will amount to 24 kwh/day at 1 mgd, 141 kwh/day at 10 mgd, and 1044 kwh/day at 100 mgd. Thus, if we select sludge handling scheme II for use with alum addition to the aerator, the total additional power consumption will be 101 kwh/day at 1 mgd, 333 kwh/day at 10 mgd, and 2518 kwh/day at 100 mgd.

For lime clarification, Lake Tahoe estimates power consumption as 431 kwh/day for clarification, 637 kwh/day for dewatering of lime mud, and 550 kwh/day for recalcining of lime sludge for a total of 1618 kwh/day at the 7.5 mgd size. Lake Tahoe uses two stage lime clarification with the ammonia stripping tower built over the second clarifier. The EPA report on lime clarification, TWRC-14[10], gives the installed horsepower per densator as 14/11 times the flow in mgd for sizes of 11 mgd and less and 14 + 0.06 (mgd - 11) for sizes greater than 11 mgd. Thus, the installed horsepower for a two stage lime clarification at the 7.5 mgd size would be estimated as 10 horsepower per clarifier which would consume an average of 408 kwh/day which is close to the Lake Tahoe value. Using the estimates from TWRC-14 we can estimate the power consumption for lime clarification at the 1 mgd size as 52 kwh/day, at the 10 mgd as 611 kwh/day and at the 100 mgd size as 2958 kwh/day. The largest densator will handle 20 mgd so the power requirements for this size was multiplied by five to find the estimated power requirements for the 100 mgd size.

At the Lake Tahoe plant, the lime sludge with a solids concentration of about 1% solids is first gravity thickened to about 4.9% solids and then dewatered with centrifuges before disposal. The estimated

lime sludge produced by the 7.5 mgd plants is 17 tons per day of dry solids. A fraction of this must be wasted to prevent build-up of phosphates in the system. The estimated amount to be recalcined is 9 tons per day at the 7.5 mgd plant. Thus, roughly one-half of the lime sludge would be combined with the organic sludges and disposed of by incineration or land fill.

The underflow stream from the lime sludge thickener at Lake Tahoe was estimated as 36 gpm with a solids concentration of 4.9%. The amount of electrical power used in the dewatering process was given as 637 kwh/day at the 7.5 mgd size and this would correspond to 31.2 horsepower for 24 hr/day or 0.324 hp/gpm. Estimates from the manufacturer for the 24" x 60" centrifuge, used at Lake Tahoe, was 0.43 - 0.81 hp/gpm. These values were for digested primary sludges and, therefore, the 0.324 hp/gpm value seems reasonable. Therefore, for lime sludge dewatering, the estimates are 84.9 kwh/day at the 1 mgd size, 849 kwh/day for the 10 mgd size and 8490 kwh/day for the 100 mgd size.

In the Lake Tahoe estimate for recalcination, only the cost of the recalcined sludge was included and the cost of burning the waste lime sludge with the organic waste sludge was included in the cost of the conventional processes. The policy used here will be to charge the cost of burning the waste lime sludge to the lime recalcination process. A loading rate of 2 lb/hr/sq. ft. will be assumed for the waste lime sludge. Since about 8 tons/day of waste lime sludge are burned at the 7.5 mgd size, the estimate of power consumption will be 100 kwh/day at 1 mgd, 450 kwh/day at 10 mgd, and 3500 kwh/day at 100 mgd for burning of the waste lime sludge.

The 14.25 ft. diameter, 6 hearth recalcination furnace used at Lake Tahoe has a hearth area of 575 sq. ft. The maximum capacity of this furnace is given as 20 tons/day or about 3 lb/hr/sq. ft. It was found at Lake Tahoe that the optimum feed rate was 1.13 lb/hr/sq. ft. to maximize the activity of the recalcined lime. This value will be used here. Using a recalcination rate of 1.29

tons/day/mgd, the size of the recalcination furnace at the 1 mgd size should be 457 sq. ft. if the furnace is operated an average of 5 hours per day.

From the electrical power consumption estimates shown in Figure 7 for incineration of organic sludge and the fact that the loading rate is 2 lb/hr/sq. ft., we can derive the following relationship for power consumption in terms of kilowatts/sq. ft.

$$\text{kilowatts/sq. ft.} = 0.636\ (\text{hearth area, sq. ft.})^{-0.37712}$$

Using this relationship, we find the power consumption for the recalcination furnace used at Lake Tahoe to be 33.3 kw. The 550 kwh/day estimated at Lake Tahoe would correspond to a loading of about 1.3 lb/hr/sq. ft.

Using the optimized loading of 1.13 lb/hr/sq. ft., the 10 mgd plant would require a hearth area of 951 sq. ft., if operation is 24 hr/day. The next standard size furnace is 988 sq. ft. The power consumption would be 46.7 kw or 1120 kwh/day. At the 100 mgd size, a hearth area of 9513 would be required. Three recalcination furnaces with hearth area of 3120 sq. ft. would be sufficient. The power consumption would be 95.5 kw per furnace or 6874 kwh/day total. Electrical power consumption for the 1 mgd plant would be 30.8 kw or 154 kwh/day. Thus, the total power consumption, including burning of waste lime sludge, would be 254 kwh/day at 1 mgd, 1570 kwh/day at 10 mgd, and 10,374 kwh/day at 100 mgd.

For recarbonation, Lake Tahoe estimates 702 kwh/day. It will be assumed here that power for recarbonation is proportional to flow. Therefore, the power consumption at 1 mgd would be 93.6 kwh/day, for 10 mgd, 936 kwh/day, and for the 100 mgd size, 9355 kwh/day.

Ammonia stripping requires a significant amount of power because the water must be pumped to the top of the tower and the volume of air required to strip the ammonia from the water is large. At Lake Tahoe the estimate was 672 kwh/day/mgd for each day the ammonia

stripping tower is in operation. In the colder climates, the ammonia stripping tower is likely to freeze in the winter months and provision must be made for this if a yearly average is computed. At Lake Tahoe it was estimated that the tower could operate about 65% of the year.

The principal consumptive use of electrical power, associated with multi-media filtration, is the energy required to pump the main stream through the filters. Additional power is required for backwashing, surface spray, and feeding of chemicals. The estimates for electrical power from Lake Tahoe are not generally applicable because of the filters and the carbon adsorption vessels are in series, and because of the peculiarities of the site. For example, the total dynamic head for the filters was given as 100 ft. of water. Actually, the filters which were sized for 5 gpm/sq. ft. were backwashed when the head across the two filters in series reached 16 ft. of water. Horsepower for pumping the main stream is given by the following relationship:

$$\text{Horsepower} = \text{mgd} \times 0.17546 \times \text{TDH/eff}$$

mgd = millions of gallons per day
TDH = total dynamic head, ft.
eff = hydraulic efficiency

Backwash pumps must deliver about 5% of the main stream against a head of about 75 ft. Surface wash pumps operate for about 15 minutes per day and are sized for about 1.42 gpm/sq. ft. at a head of about 300 ft. If we use a hydraulic efficiency of 70% for the 1 mgd size and an average pumping head of 15 ft., the power consumed by the main stream would be 77 kwh/day. For backwashing, the power consumption would be 19.2 kwh/day. For surface spray, the power consumption would be 3.3 kwh/day and the total would be 99.5 kwh/day. Since the power consumption will be proportional to flow, except for the hydraulic efficiency, the estimate for 10 mgd would be 953 kwh/day and 8743 kwh/day at the 100 mgd size.

The pressure drop through a column of granular carbon varies with the application rate and with the length of the column. When the design contact time and the hydraulic surface loading is known, the length of the column can be computed with the following relationship:

$$\text{Column Length, ft.} = \frac{\text{gpm/sq. ft. x contact time, min.}}{7.48}$$

If we assume a design contact time of 40 minutes and a hydraulic surface loading of 7 gpm/sq. ft., the length of the column required is 38 ft. The pressure drop through 38 ft. of clean granular carbon will be about 8.23 psig or 19 ft. of water. It is common practice to design the pressure contactors for a maximum working pressure of 50 psi or 116 ft. of water. The average of these two is about 68 ft. of water. Therefore, the electrical power used in pumping the main stream through the granular carbon will be about 348 kwh/day at the 1 mgd size. If variable speed pumping is used rather than a flow equalization tank, this value might be increased by about 25%. The corresponding values for 10 mgd and 100 mgd are 3287 kwh/day and 29,308 kwh/day. About 5% of the main stream will be used for backwash and the pumping head will be about 75 ft. of water. The electrical power consumed will be 19.2 kwh/day for 1 mgd, 192 kwh/day for 10 mgd and 1916 kwh/day for 100 mgd.

The surface spray will operate for about 15 minutes per day and will be sized for 1.42 gpm/sq. ft. Thus, the power consumed for surface spray will be 3.24 kwh/day at 1 mgd, 32.4 kwh/day at 10 mgd, and 324 kwh/day at 100 mgd. The total power consumption for the carbon columns will, therefore, be 371 kwh/day at 1 mgd, 3511 kwh/day at 10 mgd, and 31,548 kwh/day at 100 mgd.

The amount of granular carbon to be regenerated is about 350 lb/million gallons treated. The recommended loading rate for the regeneration furnace is 100 lb/day/sq. ft. of hearth area or 4.17 lb/hr/sq. ft. At the 1 mgd size the smallest standard size regeneration furnace (85 sq. ft.) will be capable of regenerating

the spent carbon, operating an average of one hour per day. At the 10 mgd size, a furnace with 168 sq. ft. of hearth area will be capable of regenerating the carbon, operating 5 hours per day. At the 100 mgd size, a furnace with 351 sq. ft. will be able to regenerate the carbon if it operates 24 hours per day.

At the Lake Tahoe plant a regeneration furnace with about 62 sq. ft. of hearth area was used. The maximum capacity of this furnace was 6000 lb/day or about 100 lb/day/sq. ft. The amount of power expended for carbon regeneration was 169 kwh/day. If we estimate the amount of carbon to be regenerated as 350 lb/mg, the furnace would be operated for about 10 hours per day. Using the relationship for power consumption for a multiple hearth incinerator, the power consumption for the regeneration furnace alone would be about 83 kwh/day. Thus, the total power used, which would include transport of the carbon, is about twice that used by the regeneration furnace alone. Using this information, we can estimate the power requirements for the 1 mgd plant as 20 kwh/day at the 1 mgd size, 155 kwh/day at the 10 mgd size, and 1175 kwh/day for the 100 mgd size.

The principal consumptive use of electrical power for biological nitrification is the additional air required. The amount of oxygen required to convert ammonia nitrogen to nitrate can be computed from the following chemical relationship:

$$2NH_4^+ + 4O_2 \longrightarrow 2NO_3^- + 2H_2O + 4H^+$$

The ratio of oxygen required per pound of nitrogen converted to nitrate is, therefore, 64/14 or 4.57. If we take the concentration of ammonia nitrogen as 20 mg/l, we can compute that 761 pounds of oxygen is required per million gallons treated. If diffused air is used to supply the oxygen, the amount of air needed can be calculated as follows:

$$\text{scf/day} = (\text{lb } O_2/\text{day})/.075/.21/\text{aeration efficiency}$$

If we take the aeration efficiency as a nominal 5%, the amount of air needed for nitrification is 0.967 scf/gallon treated. This is essentially the same as the amount of air assumed for the activated sludge process. An additional expenditure of electrical energy will be required to supply about 50% recycle and for final settling.

The denitrification process will require power to keep the floc in suspension and for recycle. The power needed for mixing is about one-half horsepower per mgd. Thus, the power consumed will be about 10.2 kwh/day at the 1 mgd size, 102 kwh/day at the 10 mgd size and 1020 kwh/day at the 100 mgd size. Recycle will be taken as 50% of the main stream.

Where demineralization of the water is required, electrodialysis or reverse osmosis can be used. From EPA report WP-20-AWTR-18 the cost of supplying DC power to the electrodialysis process was given as 0.85 kwh/1000 gallons. The cost of pumping the main stream through the electrodialysis stacks was estimated as 0.491 kwh per 1000 gallons. Thus, the total for reducing the TDS of the water from 850 mg/l to 500 mg/l is 1.341 kwh/1000 gallons.

For the reverse osmosis process the principal consumptive use of electrical power is for pumping the main stream through the membrane. The pressure drop through the reverse osmosis process is about 500 psig. About 10% of the feed stream is wasted with the rejected salts and a small amount of power could be recovered by using this stream to drive a turbine. This scheme, however, has not been shown to be cost/effective and it will not be considered here. At the 1 mgd size, the power consumed will be 5903 kwh/day. At the 10 mgd size, the corresponding value is 55,836 kwh/day and at the 100 mgd size, the power consumption would be 497,811 kwh/day.

ELECTRICAL POWER REQUIREMENTS FOR ADVANCED PROCESS TRAINS

Estimates of electrical power consumption for various alternative tertiary treatment trains are shown in Tables XI-XIII. Train VIII represents the set of processes used at Lake Tahoe. For the ammonia stripping process, it was assumed that the process will operate 65% of the year. Trains III and IV represent the sets of processes which are most likely to be used in the near future for control of nutrients such as nitrogen and phosphorus. Values for electrical power consumption shown in Tables XI-XIII for trains without demineralization are shown in graphical form in Figure 14.

The power requirements for treatment train III are roughly 20% less than the activated sludge plant using sludge handling scheme II. The Lake Tahoe system shown as train VII is 20-40% more expensive in terms of electrical power than the activated sludge plant.

TABLE XI

ESTIMATED ELECTRICAL POWER CONSUMPTION FOR ALTERNATIVE TERTIARY TREATMENT TRAINS AFTER SECONDARY TREATMENT

Plant Size - 1 mgd

ADVANCED PROCESSES USED	I	II	III	IV	V	VI	VII	VIII
Microscreening	115							
Alum Addition and Extra Sludge Handling		101	101					
Lime Clarification				52	52	52		52
Lime Sludge Dewatering				64	64	64		64
Lime Recalcination				254	254	254		254
Recarbonation								94
Ammonia Stripping								437
Nitrification		638	638					
Denitrification		10	10					
Multi-Media Filtration			100	100	100	100	100	100
Granular Carbon Adsorption					371	371		371
Carbon Regeneration					20	20		20
Electrodialysis								
Reverse Osmosis						1341	5503	
Total Power Consumption, kwh/day	115	749	849	470	861	2202	6003	1392

TABLE XII

ESTIMATED ELECTRICAL POWER CONSUMPTION FOR ALTERNATIVE TERTIARY TREATMENT TRAINS AFTER SECONDARY TREATMENT

Plant Size - 10 mgd

ADVANCED PROCESSES USED	I	II	III	IV	V	VI	VII	VIII
Microscreening	375							
Alum Addition and Extra Sludge Handling		333	333					
Lime Clarification				611	611	611		611
Lime Sludge Dewatering				637	637	637		637
Lime Recalcination				1570	1570	1570		1570
Recarbonation								936
Ammonia Stripping								4368
Nitrification		6235	6235					
Denitrification		102	102					
Multi-Media Filtration			953	953	953	953	953	953
Granular Carbon Adsorption					3511	3511		3511
Carbon Regeneration					155	155		155
Electrodialysis								
Reverse Osmosis						13,410	55,836	
Total Power Consumption, kwh/day	375	6670	7623	3771	7437	20,847	57,239	12,741

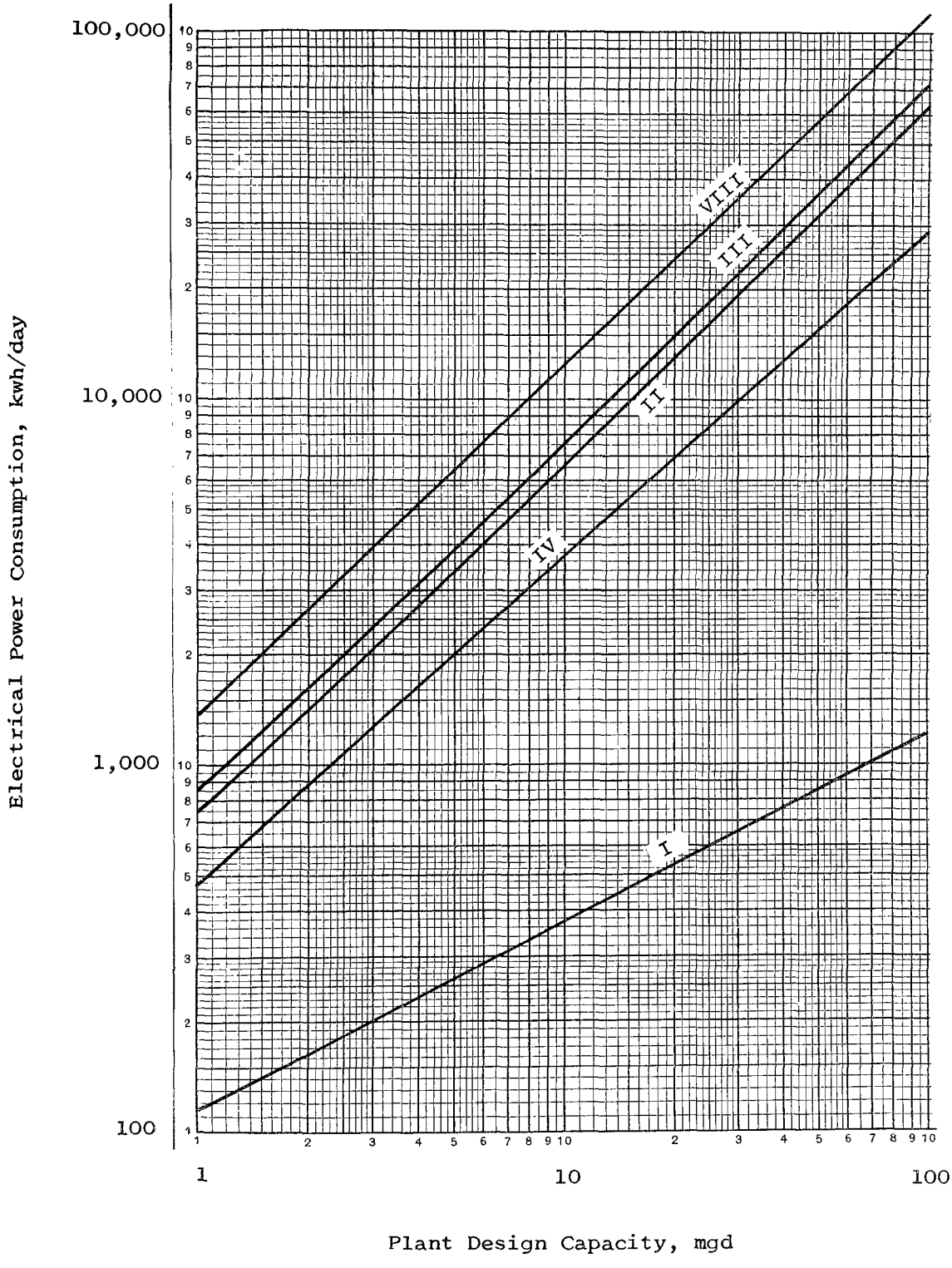
TABLE XIII

ESTIMATED ELECTRICAL POWER CONSUMPTION FOR ALTERNATIVE TERTIARY TREATMENT TRAINS AFTER SECONDARY TREATMENT

Plant Size - 100 mgd

ADVANCED PROCESSES USED	I	II	III	IV	V	VI	VII	VIII
Microscreening	1,200							
Alum Addition and Extra Sludge Handling		2,518	2,518					
Lime Clarification				2,958	2,958	2,958		2,958
Lime Sludge Dewatering				6,370	6,370	6,370		6,370
Lime Recalcination				10,374	10,374	10,374		10,374
Recarbonation								9,355
Ammonia Stripping								43,680
Nitrification		60,259	60,259					
Denitrification		1,020	1,020					
Multi-Media Filtration			8,743	8,743	8,743	8,743	8,743	8,743
Granular Carbon Adsorption					31,548	31,548		31,548
Carbon Regeneration					1,175	1,175		1,175
Electrodialysis								
Reverse Osmosis						134,100	497,811	
Total Power Consumption, kwh/day	1,200	63,797	72,540	28,445	61,168	195,268	506,554	114,203

ELECTRICAL ENERGY CONSUMPTION FOR TERTIARY WASTEWATER TREATMENT TRAINS
versus
PLANT SIZE



Note: I, II, III, IV, & VIII refer to specific treatment trains

FIGURE 14

COMPARISON WITH OTHER CONSUMPTIVE USES

The total production of electrical power in the United States in 1969 has been estimated by the Department of Commerce as 1,522,229 million kwh. The total for 1971 was 1,717,520 million kwh. Residential sales of electrical power totaled 407,922 million kwh in 1969. In 1969 the average residential consumption of electrical power was 5,943 kwh per year and the average population per household was 3.2 persons. Thus, the per capita residential use of power was about 5.09 kwh/day.

According to the Federal Power Commission[2], the average consumption of electrical power varied significantly with the area of the country from a high of 19,636 kwh/yr/household in Eugene, Oregon to a low of 2,275 kwh/yr/household in Bronx, New York.

Commercial and industrial power were combined and divided into small light and power and large light and power. Power usage for small light and power was estimated by the Department of Commerce as 286,686 million kwh in 1969 and 557,222 million kwh for large light and power for a total of 843,908 kwh/yr for industrial and commercial. Thus, commercial and industrial power represented about 55% of the total power generated while residential power represented only 27%.

The Edison Electric Institute[11] conducted a survey of 127 companies to determine the percentage usage of electrical power among various industries. The results of the survey is shown in Table IX. The principal users of electrical power are primary metals and chemicals and allied products. The aluminum industry alone used 51,894 million kwh in 1970.

The estimated power consumption for plants, included in the 1968 Inventory of Municipal Waste Facilities[12] is shown in Table X. The average usage was 0.0573 kwh/day/capita. This amount of power

TABLE XIV

PERCENTAGE DISTRIBUTION OF MINING AND MANUFACTURING KWHRS BY MAJOR GROUPS OF SIC FOR THE INVESTOR-OWNED ELECTRIC UTILITIES OF THE TOTAL U.S.*

		1971 %		1970 %		1969 %	
Mining							
10	Metal Mining		1.2		1.3		1.3
11	Anthracite Mining		0.1		0.1		0.1
12	Bituminous & Lignite		1.4		1.5		1.5
13	Crude Petroleum & Natural Gas		2.6		2.5		2.4
14	Nonmetallic except Fuels		1.2		1.2		1.2
	Mining Total		6.5		6.6		6.5
Manufacturing							
19	Ordnance & Accessories		0.5		0.6		0.7
20	Food & Kindred Products		5.1		5.1		4.9
21	Tobacco Manufactures		0.2		0.2		0.2
22	Textile Mill Products		6.0		6.0		6.0
23	Apparel & Other From Fabrics, etc.		0.6		0.5		0.5
24	Lumber & Wood Products, except Furniture		1.5		1.4		1.3
25	Furniture & Fixtures		0.5		0.5		0.5
26	Paper & Allied Products		6.2		6.0		6.0
27	Printing and Publishing		1.1		1.0		1.0
2812	Alkalies and Chlorine	1.1		1.2		1.3	
2818	Industrial Organic Chemicals	1.6		1.7		1.6	
2819	Industrial Inorganic Chemicals	4.2		3.4		3.3	
2821	Plastic Materials	0.8		0.7		0.8	
28 +	Chemicals & Allied Products		19.3		18.7		18.1
29	Petroleum Refining & Related Industries		5.1		4.9		4.6
30	Rubber & Misc. Plastic Products		2.8		2.8		2.8
31	Leather & Leather Products		0.2		0.2		0.2
32	Stone, Clay & Glass Products		5.2		5.3		5.4
3334	Primary Aluminum Production	2.0		2.1		2.1	
33 +	Primary Metal Industries		18.9		19.8		20.3
34	Fabricated Metal Products, except Ordnance, Machinery & Trans Equip		3.1		3.2		3.2
35	Machinery, except Electrical		3.7		3.8		3.9
36	Electrical Machinery, Equip & Supplies		4.8		5.0		4.9
37	Transportation Equipment		7.2		7.0		7.6
38	Professional, Scientific, and Controlling Instruments; Photographic & Optical Goods; Watches & Clocks		0.7		0.7		0.7
39	Miscellaneous Manufacturing Industries		0.8		0.7		0.7
	Manufacturing Total		93.5		93.4		93.5
TOTAL REPORTED SIC KWHRS (Millions)			354,211		337,354		329,390
TOTAL INVESTOR-OWNED MONTHLY INDUSTRIAL KWHR SALES (Millions)			468,512		447,665		433,421
Percentage Relationship of Reported SIC Kwhrs to Total Investor-Owned Monthly Industrial Kwhr Sales			75.6%		75.4%		76.0%

* Data based on SIC questionnaires returned to EEI representing 127 companies.

\+ For 3 digit data see Supplement A.

TABLE XV

CONSUMPTION OF ELECTRICAL ENERGY BASED ON THE 1968 INVENTORY OF MUNICIPAL WASTE FACILITIES

	Population Served	gpd/capita	kwh/day/capita	kwh/day
Minor Treatment	1,360,870	122	.0185	25,176
Primary Treatment	36,947,397	122	.0286	1,056,696
Intermediate Treatment	5,857,690	122	.0286	167,530
Activated Sludge	41,264,036	123	.113	4,662,836
Trickling Filters	29,617,136	89	.043	1,273,537
Ponds	6,123,078	89	.0135	82,662
Other and Unknown	8,636,514	89	.0135	116,593
Tertiary Treatment	325,530	123	.226	73,570
Totals	130,132,251			7,458,600

Average kwh/day/capita = 0.0573

consumed in wastewater treatment is about 1% of the average residential consumption of electrical power. This amount of power is about equivalent to one 8 watt bulb in each household, burning 24 hours per day. If all of the population was served by activated sludge plants, the power consumption would be about 0.113 kwh/day/capita which is equivalent to a 15 watt light bulb, burning in each household 24 hours per day. A desk lamp is normally equipped with two 15 watt fluorescent lamps.

Power consumption for tertiary treatment is highly dependent on the train of processes selected. For train V the power consumption is roughly equivalent to the activated sludge process. For the Lake Tahoe system, shown as train VIII, the power consumption is roughly 40-50% greater than activated sludge. Thus, if we assume train III or train V, the consumption of power per household would be roughly equivalent to a 30 watt desk lamp burning for 24 hr/day.

In terms of cost per capita for activated sludge plants, the usage would be about 0.54 cents/day/household, taking the cost of electrical power as 1.5 cents/kwh. If tertiary trains III or V are provided, an additional cost of about 0.44 cents per household day would be incurred, making a total of roughly 1 cent/household per day.

ACKNOWLEDGMENTS

This study was made possible through the help and support of various equipment manufacturers such as Westinghouse Electric Corp., Pacific Flush Tank Division of Rex Chainbelt, Inc., Dorr-Oliver, Inc., Bird Machine Co., Wallace and Tiernan, Environmental Control Group, Rex Chainbelt, Inc., Allis Chalmers and others. The Rex Chainbelt and PFT Engineering Manuals were particularly valuable. Valuable information on plant utilities was supplied by Black and Veatch Engineers of Kansas City and by the Cincinnati Gas and Electric Co.

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11. Edison Electric Institute Publication, July 21, 1972, "Tabulations of Industrial KWHR Sales by Investor-Owned Companies for 1971"

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A P P E N D I X

GENERAL SERVICE - LARGE

AVAILABILITY
Available in localities indicated on Sheets No. 2, 2-A of this schedule, where facilities of suitable voltage and adequate capacity are adjacent to the premises to be served.

APPLICABILITY
Applicable to electric service required for any purpose by an individual customer on one premise, when supplied at one point of delivery, except breakdown, standby or supplemental service, or resale service not in conformity with Company's service regulations. When both single and three phase service is required by a customer the monthly usage shall be the arithmetical sum for three phase and for single phase service.

The account shall never be billed as one single phase account and one three phase account on this rate. When customer's demand for single phase service has not exceeded 5 kilowatts in every month of twelve consecutive months, customers will be billed for single phase service on Rate General Service Small, if available.

TYPE OF SERVICE - Alternating current 60 Hz, single or three phase at Company's standard voltage.

NET MONTHLY BILL Computed in accordance with the following charges:.

A. Secondary voltage service: where Company furnishes standard rating primary voltage transformers and appurtenances and supplies service from its overhead or underground systems at standard secondary voltage. Company may meter at primary or secondary voltage as circumstances warrant.

Demand Charge:

First 15 kilowatts of Demand or less	$0.00
Next 35 kilowatts of Demand	at $2.00 per kilowatt
Next 50 kilowatts of Demand	at $1.95 per kilowatt
Next 900 kilowatts of Demand	at $1.50 per kilowatt
Additional kilowatts of Demand	at $1.35 per kilowatt

Energy Charge:

First 500 kilowatt hours	at 5.12¢ per kilowatt hour
Next 1,500 kilowatt hours	at 3.12¢ per kilowatt hour
Next 4,000 kilowatt hours	at 2.13¢ per kilowatt hour
Next 60 kilowatt hours per kilowatt of Demand	at 1.42¢ per kilowatt hour
Next 120 kilowatt hours per kilowatt of Demand	at 1.14¢ per kilowatt hour
Next 120 kilowatt hours per kilowatt of Demand	at .82¢ per kilowatt hour
Additional kilowatt hours	at .71¢ per kilowatt hour

Plus or minus an adjustment per kilowatt hour determined in accordance with "Tax Adjustment" set forth in Sheet No. 60 of this tariff.

Plus or minus 0.0055¢ per kilowatt hour for each 0.5¢ per million Btu by which the average cost of fuel burned during the next preceding month is above or below 20.5¢ per million Btu. The average cost of fuel burned shall be that recorded on Company's books,exclusive of charges for unloading from the shipping medium.

A three phase customer whose demand does not exceed 15 kW will be charged an additional surcharge of $4.00 per month for the three phase service.

Minimum: The Demand Charge for the Billing Demand but not less than $5.00.

B. Primary voltage service: where customer furnishes primary voltage transformers and appurtenances and takes service from Company's overhead or underground system at standard primary nominal voltage of 13 kV or higher. Billing at rate in paragraph A above subject to the following additional provisions:

	13 kV	33 kV	66 kV	138 kV
Monthly discount per kW billing demand	$0.15	$0.25	$0.35	$0.45

Under this paragraph B, if Company elects to meter at primary voltage the kilowatt hours registered on Company's meter will be reduced 1-1/2% for billing purposes.

Minimum: - The Demand Charge for the billing Demand but for not less than 300 kW.

GENERAL SERVICE - LARGE

DEMAND

1. The Demand shall be the kilowatts derived from the Company's demand meter for the fifteen minute period of customer's greatest use during the month adjusted for power factor, as provided herein. At Company's option a demand meter may not be installed if the nature of the load clearly indicates the load will have a constant demand, in which case the demand will be the calculated demand. The Company may install a demand meter when the consumption exceeds 2500 kilowatt hours for two consecutive months or when the Company has reason to believe the demand exceeds 15 kilowatts.

2. When both three phase service and single phase service are supplied each shall be metered separately, and the Demand for billing shall be the arithmetical sum of the demand for three phase service and for single phase service.

In no event will the billing Demand be taken as less than the higher of the following:

A. 70% of the highest kilowatts similarly established during the preceding 11 months.
b. 300 kilowatts for primary voltage service.

Power Factor Adjustment:

This rate is based on a maintained power factor of not less than 90% lagging and if the Company determines Customer's power factor to be less than 90%, the billing demand will be the number of kilowatts equal to the kilovolt amperes multiplied by 0.90.

Power Factor may be determined by continous measurement or by tests at Company's option; if by continuous measurement, power factor determined during the interval in which the kilowatt maximum demand is established, will be used for billing purposes; if by tests, power factor determined during a period in which Customer's KW demand as measured is not less than 90% of the measured kilowatt maximum demand in the next preceding billing period, will be used for billing purposes until superseded by a power factor determined by subsequent test made at the direction of Company or request of Customer.

PAYMENT
The Net Monthly Bill is payable within fourteen (14) days from date. When not so paid, the Gross Monthly Bill, which is the Net Monthly Bill plus 5%, is due and payable.

TERM OF SERVICE - One (1) year for Secondary voltage service, and three (3) years for Primary voltage service.

SERVICE REGULATIONS
The supplying of, and billing for, service and all conditions applying thereto, are subject to the jurisdiction of The Public Utilities Commission of Ohio, and to Company's Service Regulations currently effective, as filed with The Public Utilities Commission of Ohio, as provided by law.

Effective October 30, 1970

Issued by B. John Yeager, President
Cincinnati, Ohio

TABLE 8.—NATIONAL WEIGHTED AVERAGE BILLS FOR INDUSTRIAL SERVICE, 1935–1970

[Large cities only]

Date	Average bill			Average charge per kWh			Index of average bill (1967=100)		
	150 kW 30,000 kWh	300 kW 60,000 kWh	1,000 kW 200,000 kWh	150 kW 30,000 kWh	300 kW 60,000 kWh	1,000 kW 200,000 kWh	150 kW 30,000 kWh	300 kW 60,000 kWh	1,000 kW 200,000 kWh
Jan. 1, 1970	$648	$1,183	$3,492	2.16	1.97	1.75	102.4	102.1	102.0
Jan. 1, 1969	636	1,163	3,436	2.12	1.94	1.72	100.5	100.3	100.4
Jan. 1, 1968	634	1,160	3,428	2.11	1.93	1.71	100.2	100.1	100.2
Jan. 1, 1967	633	1,159	3,422	2.11	1.93	1.71	100.0	100.0	100.0
Jan. 1, 1966	631	1,154	3,407	2.10	1.92	1.70	99.7	99.6	99.6
Jan. 1, 1965	634	1,160	3,423	2.11	1.93	1.71	100.2	100.1	100.0
Jan. 1, 1964	634	1,159	3,414	2.11	1.93	1.71	100.2	100.0	99.8
Jan. 1, 1963	638	1,167	3,442	2.13	1.95	1.72	100.8	100.7	100.6
Jan. 1, 1962	628	1,140	3,351	2.09	1.90	1.68	99.2	98.4	97.9
Jan. 1, 1961	624	1,136	3,337	2.08	1.89	1.67	98.6	98.0	97.5
Jan. 1, 1960	627	1,134	3,309	2.09	1.89	1.65	99.1	97.8	96.7
Jan. 1, 1959	622	1,124	3,283	2.07	1.87	1.64	98.3	97.0	95.9
Jan. 1, 1958	621	1,123	3,279	2.07	1.87	1.64	98.1	96.9	95.8
Jan. 1, 1957	616	1,111	3,235	2.05	1.85	1.62	97.3	95.9	94.5
Jan. 1, 1956	612	1,103	3,204	2.04	1.84	1.60	96.7	95.2	93.6
Jan. 1, 1955	606	1,091	3,168	2.02	1.82	1.58	95.7	94.1	92.6
Jan. 1, 1954	605	1,089	3,162	2.02	1.82	1.58	95.6	94.0	92.4
Jan. 1, 1953	601	1,086	3,154	2.00	1.81	1.58	94.9	93.7	92.2
Jan. 1, 1952	583	1,046	3,042	1.94	1.74	1.52	92.1	90.3	88.9
Jan. 1, 1951	578	1,036	3,011	1.93	1.73	1.51	91.3	89.4	88.0
Jan. 1, 1950	580	1,043	3,024	1.93	1.74	1.51	91.6	90.0	88.4
Jan. 1, 1945	565	1,002	2,863	1.88	1.67	1.43	89.3	86.5	83.7
Jan. 1, 1940	565	995	2,828	1.88	1.66	1.41	89.3	85.8	82.6
Jan. 1, 1935	612	1,085	3,081	2.04	1.81	1.54	96.7	93.6	90.0

Source: Federal Power Commission Report FPC R-76 "Typical Electric Bills 1970" Federal Power Commission, Washington, D. C.

Comparison Between Federal Power Commission Power Categories and CG&E Schedule						
	1 mgd		10 mgd		100 mgd	
	kwh	$/mo	kwh	$/mo	kwh	$/mo
KW Demand	150		300		1,000	
kwh/day						
kwh/mo	30,000		60,000		200,000	
first 6000 kwh	24,000	157.60	54,000	157.60	194,000	157.60
60 x KW Demand x 1.42¢/kwh	15,000	127.80	36,000	255.60	134,000	852.
120 x KW Demand x 1.14¢/kwh		171.	0	410.40	14,000	1,368.
120 x KW Demand x 0.82¢/kwh						114.80
Additional kwh x 0.71¢/kwh						
KW Demand minus 15	135		285		985	
First 35 KW x $2 = $70	100	70.	250	70.	950	70.
Second 50 KW x $1.95 = $97.50	50	97.50	200	97.50	900	97.50
Third 900 KW x $1.50 = $1350		75.		300.		1,350.
Additional KW Demand x $1.35						
Total Monthly Bill, dollars		698.90		1,291.1		4,009.90
Cents/kwh		2.33		2.15		2.00
Cents/1000 gallons treated						

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No.

2.

3. Accession No.

W

4. Title

ELECTRICAL POWER CONSUMPTION FOR MUNICIPAL WASTEWATER TREATMENT

5. Report Date Aug. 1972

6.

8. Performing Organization Report No.

7. Author(s)

Robert Smith

10. Project No.

9. Organization

Environmental Protection Agency
National Environmental Research Center
Advanced Waste Treatment Research Laboratory
Cincinnati, Ohio 45268

11. Contract/Grant No.

13. Type of Report and Period Covered

12. Sponsoring Organization

15. Supplementary Notes

Environmental Protection Agency report number, EPA-R2-73-281, July 1973.

16. Abstract

Electrical power consumption by most conventional and advanced processes for treating municipal wastewater has been estimated on a unit process basis. Electrical power for complete plants has been estimated by adding power consumption for individual processes and plant utilities. Electrical power consumption for wastewater treatment has been compared to other consumptive uses of electrical power.

17a. Descriptors

*Waste Water Treatment, *Electrical Power Demand, *Electric Power Costs, Sewage Treatment Plants, Sewage Works

17b. Identifiers

Wastewater Treatment Processes, Electrical Power Consumption

17c. COWRR Field & Group

18. Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

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