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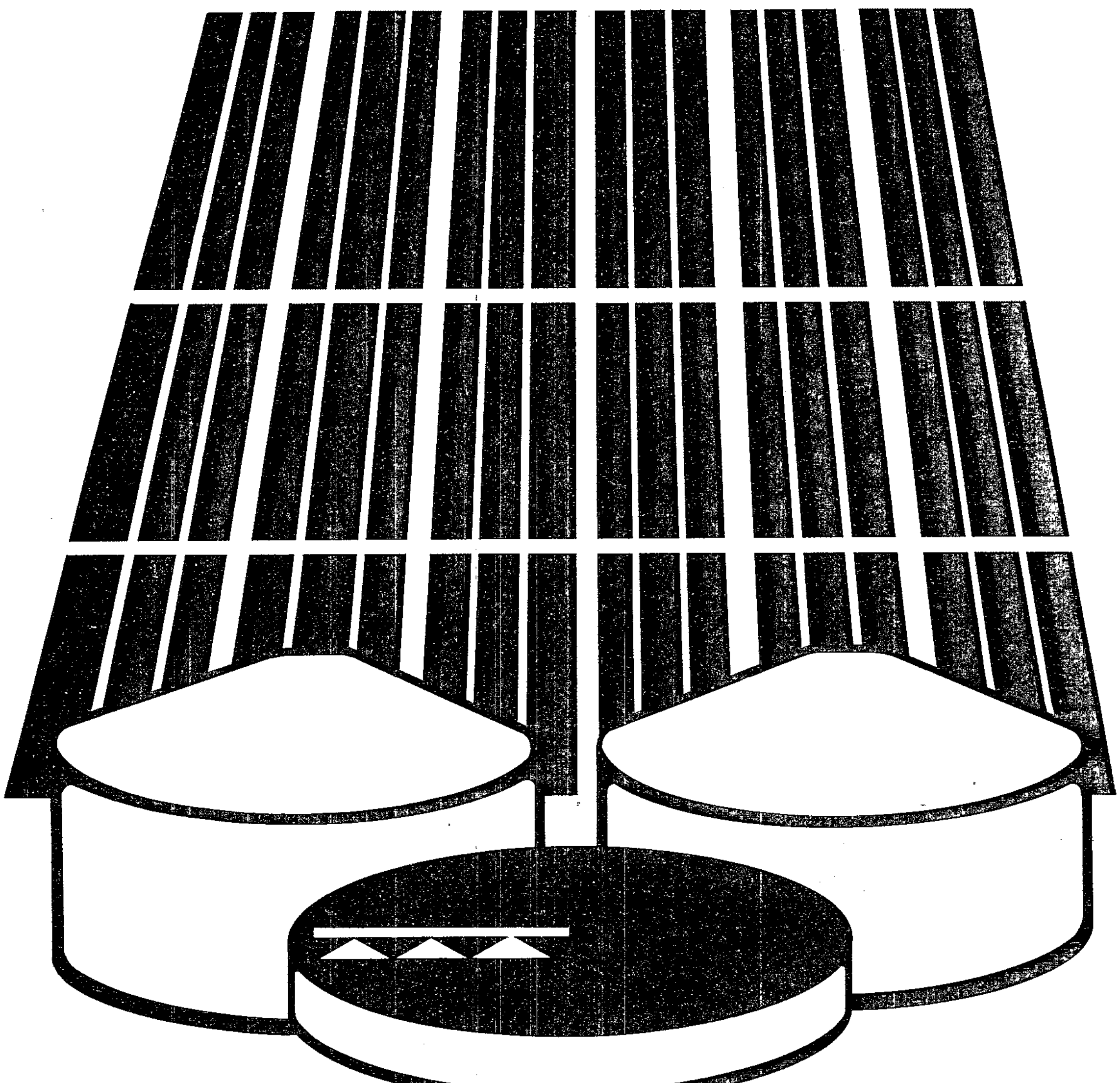
Energy Conservation in Municipal Wastewater Treatment



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TECHNICAL REPORT

ENERGY CONSERVATION IN MUNICIPAL WASTEWATER TREATMENT

BY

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Contract No. 68-03-2186, Task 9

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Office of Water Program Operations
Washington, D.C. 20460

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LIST OF ABBREVIATIONS AND SYMBOLS

ammonia/ammonium	NH_3/NH_4
average	avg
Baumé	Bé
bed volume(s)	BV
biochemical oxygen demand	BOD
British thermal unit	Btu
calcium hydroxide (hydrated lime)	$Ca(OH)_2$
calcium oxide (quick lime)	CaO
carbon dioxide	CO_2
chemical oxygen demand	COD
chlorine	Cl_2
coefficient of performance	COP
cubic foot (feet)	cu ft
cubic feet per minute	cfm
cubic yard	cu yd
degree(s)	deg
degree Celsius	°C
degree Fahrenheit	°F
diameter	diam
feet (foot)	ft
feet per second	fps
ferric chloride	$FeCl_3$
flow rate	Q
food to microorganisms ratio	F/M
gallon(s)	gal
gallons per day	gpd
gallons per day per square foot	gpd/sq ft
gallons per minute	gpm
gallons per minute per square foot	gpm/sq ft
horsepower	hp
horsepower hour(s)	hp-hr
hour(s)	hr
hydrogen sulfide	H_2S
inch(es)	in.
independent physical-chemical	IPC
internal combustion	IC
Jackson turbidity unit	JTU
kilogram(s)	kg
kilowatt	kw
kilowatt hour	kwh
mercury	Hg
methanol	CH_3OH
micron(s)	μ
miles per gallon	mpg
miles per hour	mph
milligram(s) per liter	mg/l

List of Abbreviations and Symbols (Continued)

millimeter	mm
million	mil
million gallons	mil gal
million gallons per day	mgd
minute(s)	min
mixed liquor suspended solids	MLSS
mixed liquor volatile suspended solids	MLVSS
most probable number	MPN
nitrate	NO_3
nitrogen	N
oxygen	O_2
percent	%
phosphorus	P
pound(s)	lb
pounds per square foot	psf
pounds per square inch	psi
pounds per square inch absolute	psia
pounds per square inch gage	psig
publicly owned treatment works	POTW
sodium hydroxide	NaOH
solids retention time	SRT
square foot (feet)	sq ft
suspended solids	SS
standard cubic foot (feet)	scf
standard cubic feet per minute	scfm
sulfur dioxide	SO_2
sulfuric acid	H_2SO_4
temperature change	ΔT
total dissolved solids	TDS
total dynamic head	TDH
total solids	TS
vacuum filter	VF
velocity gradient	G
volatile solids	VS
waste activated sludge	WAS
weight	wt
year(s)	yr

CHAPTER 1

INTRODUCTION

PURPOSE AND APPLICATION

This technical report provides information for primary and some secondary energy use and primary energy conservation in the EPA municipal wastewater treatment construction grants program. Primary energy is the energy used in the operation of a facility, such as the electricity used in the various processes and space heating. Secondary energy for the purposes of this report is defined as the energy required to manufacture chemicals and other consumable materials used in municipal wastewater treatment. Secondary energy requirements for treatment plant construction materials, such as concrete and steel, were not determined in this study. In addition to identifying energy utilization and conservation for a wide range of treatment alternatives available to meet the standards, the report will aid in screening alternatives for their energy reduction potential. The report should be useful to municipalities, since municipal operations including energy costs are financed by user charges.

The report is being distributed to those that have policy and decision authority impacting the design, construction, and operation of wastewater treatment plants. This will include personnel in the EPA regional offices, state and local government employees, and design consultants involved in the planning and design activities of the EPA's Construction Grants Program. This publication is not intended as a design manual but as an effective means for making preliminary energy comparisons based upon the assumptions set forth in this report. Process energy utilization and conservation should be of particular value throughout the planning project formulation, and preliminary engineering process.

BACKGROUND

Incorporation of low energy consumption concepts in municipal wastewater treatment facilities designs is a factor in the grants review process. The "Grants Regulations and Procedures, Revision of Part 40 CFR 30.420-6" (Federal Register, May 8, 1975) provides that:

> *"Grantees must participate in the National Energy Conservation Program by fostering, promoting and achieving energy conservation in their grant programs. Grantees must utilize to the maximum practical extent the most energy-efficient equipment, materials, and construction and operating procedures available."*

"Guidance for Preparing a Facility Plan" (EPA Office of Water Program Operations, May 1975 revision) requires in Part 4.2.2.e that *"energy production and consumption"* in the planning area should be described to the extent necessary to analyze alternatives and determine the environmental impacts of the proposed actions. Primary and secondary energy curves contained in this report should be useful in fulfilling this requirement for facility planning.

The economics of low energy utilization are contained in the "Cost-Effectiveness Analysis Guidelines" 40 CFR Part 35, Appendix A (Federal Register, September 10, 1973). For waste management systems, a cost-effective solution is one which will minimize total resource costs to the nation over time to meet National Pollutant Discharge Elimination System permit requirements based on best practicable waste treatment technology including Federally approved state water quality standards. Resource costs include capital (construction and land acquisition); operation, maintenance, and replacement; and social and environmental costs. Energy utilization and conservation will impact all of these resource costs.

Comparative cost information which may be useful to the reader for integrating cost and energy effectiveness may be obtained from the technical report, "A Guide to the Selection of Cost-Effective Wastewater Treatment Systems," (EPA-430/9-75-002, July 1975) in conjunction with its supplement, "An Analysis of Construction Cost Experience for Wastewater Treatment Plants," (EPA-430/9-76-002, MCD-22, February 1976). Cost information on land treatment systems may be obtained from "Costs of Wastewater Treatment by Land Application," (EPA-430/9-75-003, June 1975) and "Cost-Effective Comparison of Land Application and Advanced Wastewater Treatment" (EPA-430/9-75-016, MCD-17, November 1975).

Information contained in this report must be used in grant application within the framework of cost-effectiveness. Systems used in the design of new treatment facilities or upgrading of existing facilities which also promote energy conservation are eligible for grant funding provided that they are cost-effective. Two situations arise, however, where grant awards presently are not eligible. First, the modification of existing municipal facilites solely for the purpose of energy conservation is not grant eligible. Second, in the situation of multi-purpose projects such as co-incineration of sludge and solid waste, non-program components (e.g., solid waste) of the project are not eligible for funding despite the fact that the overall project might result in energy conservation. Cost allocation for multi-purpose projects is contained in the Municipal Construction Division Program Requirements Memorandum, "Cost Allocations for Multi-Purpose Projects." The preferred cost allocation method for multi-purpose projects is the "alternative justifiable expenditure" method, which is explained in "The Allocation of Costs of Federal Water Resource Development Projects," a report to the House Committee of Public Works from the Subcommittee to Study Civil Works, 82nd Congress, December 2, 1952.

LIMITATIONS

A basic limitation of this document is the integration of cost-effectiveness and energy effectiveness (discussed in Chapter 8). Theoretically, the two should be similar, but for a variety of reasons this may not be the case.

For instance, the regional fuel price structure is variable and will reflect the relative availability of a particular type of energy, such as fuel oil, natural gas, coal, or nuclear. Thus, a particular treatment train might be energy as well as cost-effective in one region, while only energy effective in another. Similarly, while the energy effectiveness of a particular process might be high, the cost-effectiveness might not reflect this fact if the system is labor intensive and labor costs are high for a particular project. For this reason, the current regional cost variations for various cost categories that affect treatment plant construction and operation are presented in Chapter 8. The importance of regional cost category variability in integrating energy and cost curves cannot be overstressed.

It is expected that the energy data presented in this report will be revised and updated periodically. This is necessary since waste treatment processes are modified in light of more effective energy utilization and as new energy effective techniques and methodologies are developed. As more experience is gained in practice with the existing and newer advanced wastewater treatment and sludge handling processes, more energy data will become available for analysis.

The reader should realize that the circumstances of a particular situation may alter the energy effectiveness data presented. For example, the influence of very cold weather would likely eliminate from consideration a highly temperature dependent process such as ammonia stripping and could change the energy effectiveness for other systems such as activated sludge and trickling filters. Similarly, if the percentage of industrial wastewater or inflow and infiltration is high or if the composition of the waste stream differs markedly from the "typical" influent wastewater quality assumed herein, modifications must be made in choosing energy effective systems. Adjustments will also be necessary should any of the design criteria shown on the process curves be changed.

This report attempts to ascertain all the primary energy needs of wastewater treatment processes. For secondary energy, the report provides estimates for the manufacture and transportation of the consumables used in wastewater treatment. No attempt, however, is made to estimate the energy required to manufacture the materials used in the construction of treatment plants.

CHAPTER 2

NATIONAL ENERGY REQUIREMENTS

The purpose of this chapter is to compare the energy required for various processes utilized in publicly owned treatment works (POTW's) with total national energy requirements. Data collected by EPA during the 1976 Needs Survey for publicly owned wastewater treatment facilities indicated that 13,220 POTW's are required to provide treatment for the sewered population of 158,573,000 in 1977 and 19,041 POTW's are required to provide treatment for the sewered population of 258,411,000 in 1990. Present (1977) and future (1990) energy utilization have both been estimated by integrating the data from the 1976 Needs Survey for treatment facilities with process energy utilization data in Chapter 3. Table 2-1 shows the national energy requirements for 1977 and 1990 for various processes of municipal wastewater treatment. The averages used for the different plant capacity ranges are as follows: <5 mgd, 1 mgd was used; 5 mgd < 10 mgd, 7.5 mgd was used; 10 mgd < 20 mgd, 15 mgd was used; 20 mgd < 50 mgd, 35 mgd was used; > 50 mgd, 75 mgd was used. The energy requirements per million gallons were then multiplied times the average capacity and number of plants to calculate the energy requirements for the various levels of treatment. Energy requirements for sludge treatment and disposal are included in the estimates. Energy requirements for treatment of storm flows in combined sewer systems are excluded from the estimates. It was assumed in these estimates that 40 percent of the activated sludge and trickling filter plants would dispose of sludge by incineration, 30 percent by landfill and 30 percent by land application. The energy requirements include all primary and secondary energy (except secondary energy required for construction materials) for complete wastewater treatment and sludge disposal. Because these treatment operations require both electrical energy and fuel, a breakdown is shown in Table 2-1 for various levels of treatment. Also, the total energy requirements (Btu/yr) are shown for various levels of treatment by assuming that electricity generation requires 10,500 Btu/kwh. The 1976 Needs Survey shows that 32 percent of municipal facilities have secondary treatment and it is estimated for this report that 100 percent will attain this level as a minimum by 1990. The 1976 Needs Survey also shows that 0.5 percent of municipalities are now employing nitrification, and 4 percent expect to do so in the future. Similarly, 6 percent of municipal plants now have filtration, and 26 percent expect to in the future.

Based on projected effluents from the 1976 Needs Survey, approximately 200 advanced waste treatment (AWT) facilities requiring low discharge levels of BOD (< 5mg/l), suspended solids (< 5 mg/l), phosphorus (< 1 mg/l as P) and nitrogen (< 5 mg/l total N) will be constructed by 1990. The average flow of these facilities was approximately 15 mgd. In order to include these facilities in the projected energy needs, a plant consisting of secondary treatment, with separate phases for nitrification, chemical clarification and filtration and an average flow of 15 mgd was included in Table 2-1. Use of filtration and nitrification will, in many cases, be employed in these AWT facilities. As a result, some duplication in these processes occurs in Table 2-1. However, since the impact of these processes is small, the total energy requirements are not largely affected by this duplication.

For 1977, 142.87×10^{12} Btu/yr of energy use is expected, which represents 0.17 percent of the total national energy use in 1977; for 1990, 256.91×10^{12} Btu energy use is expected, which represents 0.23 percent of the total national use in 1990. (See "The Cost of Air and Water Pollution Control - 1976 thru 1985," EPA report to Congress, April 1977 Draft.) Table 2-2 presents national energy utilization estimates for present (1977) and future (1990) treatment facilities based on information from the 1976 Needs Survey applied to information contained in Table 2-1.

TABLE 2-1(a)

National Energy Requirements For Various Processes of Municipal Wastewater Treatment

SOURCE: 1976 NEEDS SURVEY FOR MUNICIPAL WASTEWATER TREATMENT

1977

PLANT CAPACITY MGD	TYPE OF TREATMENT	NUMBER OF PLANTS	KWH/YR 10^8	BTU/YR 10^{12}
Less than 4.99	T.F.*	1951	8.33	3.70
	A.S.	6925	34.99	5.82
	Filt.	471	0.14	-0-
	Nitr.	17	0.03	-0-
	Ponds	3397	11.42	-0-
5 to 9.99	T.F.	121	2.60	0.60
	A.S.	274	7.24	1.33
	Filt.	36	0.09	-0-
	Nitr.	4	0.05	-0-
	Ponds	59	1.40	-0-
10 to 19.99	T.F.	58	2.43	0.57
	A.S.	161	8.49	1.59
	Filt.	16	0.08	-0-
	Nitr.	5	0.11	-0-
	Ponds	27	1.91	-0-
	AWT	--	--	--
20 to 49.99	T.F.	34	2.91	0.73
	A.S.	116	13.28	2.50
	Filt.	9	0.11	-0-
	Nitr.	5	0.24	-0-
	Ponds	16	1.87	-0-
50 and over	T.F.	6	0.98	0.26
	A.S.	70	16.70	3.15
	Filt.	3	0.06	-0-
	Nitr.	1	0.11	-0-
	Ponds	5	1.21	-0-
	SECONDARY	13,220	115.76	20.25
	TERTIARY		1.02	--
TOTAL			116.78	20.25

	SECONDARY	141.80
	TERTIARY	1.07
TOTAL		142.87 x 10^{12} BTU/YR**

*T.F. = Trickling Filter
A.S. = Activated Sludge
Filt. = Filtration
Nitr. = Nitrification
AWT = Advanced Waste Treatment

**Assumes generation of 1 kwh requires 10,500 BTU fuel

TABLE 2-1(b)

National Energy Requirements For Various Processes of Municipal Wastewater Treatment

SOURCE: 1976 NEEDS SURVEY FOR MUNICIPAL WASTEWATER TREATMENT

1990

PLANT CAPACITY MGD	TYPE OF TREATMENT	NUMBER OF PLANTS	KWH/YR 10^8	BTU/YR 10^{12}
Less than 4.99	T.F.*	2024	8.64	3.83
	A.S.	9399	47.49	7.90
	Filt.	4543	1.38	-0-
	Nitr.	433	0.65	-0-
	Ponds	6092	20.49	-0-
5 to 9.99	T.F.	137	2.94	0.68
	A.S.	505	13.34	2.50
	Filt.	213	0.53	-0-
	Nitr.	78	0.89	-0-
	Ponds	89	2.11	-0-
10 to 19.99	T.F.	62	2.60	0.61
	A.S.	282	14.87	2.78
	Filt.	109	0.52	-0-
	Nitr.	39	0.88	-0-
	Ponds	36	2.54	-0-
	AWT	200	21.10*	7.74
20 to 49.99	T.F.	41	3.51	0.88
	A.S.	215	24.61	4.63
	Filt.	84	1.08	-0-
	Nitr.	33	1.59	-0-
	Ponds	21	2.45	-0-
50 and over	T.F.	8	1.31	0.34
	A.S.	123	29.33	5.53
	Filt.	43	0.84	-0-
	Nitr.	15	1.64	-0-
	Ponds	7	1.70	-0-
	SECONDARY	19,041	177.93	29.68
	TERTIARY		31.10	7.74
TOTAL			209.03	37.42

	SECONDARY	216.51
	TERTIARY	40.40
TOTAL		256.91 x 10^{12} BTU/YR**

*If land treatment systems replaced the 200 AWT plants, the annual electrical power would be reduced from 21.1 x 10^8 KWH/YR to 4.28 x 10^8 KWH/YR or a savings of 79%. Since solids would not be incinerated with land treatment, the BTU requirement would be 0.

TABLE 2-2

1977 and 1990 Estimated Energy Consumption
In Publicly Owned Treatment Works

TREATMENT PROCESS	1977 TOTAL ENERGY 10^{12} BTU/YR	1977 *PERCENT OF 1977 NATIONAL ENERGY UTILIZATION	1990 TOTAL ENERGY 10^{12} BTU/YR	1990 **PERCENT OF 1990 NATIONAL ENERGY UTILIZATION
Secondary	141.80	0.17	216.51	0.23
Tertiary	1.07	***	40.40	***
TOTAL	142.87	0.17	256.91	0.23

*Assumes 1977 National Energy use is 86 x 10^{15} Btu/yr
**Assumes 1990 National Energy Use is 114 x 10^{15} Btu/yr
(See "The cost of Air and water pollution control - 1976 thru 1985," EPA Report to Congress, April 1977 Draft.
***Less than 0.01 Percent

CHAPTER 3

PRIMARY ENERGY REQUIREMENTS

Primary energy requirements are presented in graphical form in Figures 3-1 through 3-118 for the municipal wastewater treatment process listed in Table 3-1. The design and operating conditions, expected influent and effluent quality and assumptions used in the determination of energy requirements are shown on the figures. The examples in Chapters 6 and 9 illustrate the use of these figures. The assumed quality of raw wastewater used in describing the unit processes is shown in Table 3-2 and assumed untreated sludge characteristics for various processes are shown in Table 3-3.

The oxygen transfer efficiency shown on the relevant biological treatment curves is "wire to water" efficiency which includes the efficiency of motors and mechanical equipment. Several of the curves are based on laboratory or pilot scale data and it is so noted below the title on these figures.

TABLE 3-1

PRIMARY ENERGY REQUIREMENTS - UNIT PROCESSES

UNIT PROCESS	FIGURE NO.
PUMPING	
Raw Sewage Pumping (Constant Speed)	3-1
Raw Sewage Pumping (Variable Speed) - TDH 5 to 30 Feet	3-2
Raw Sewage Pumping (Variable Speed) - TDH 60 to 100 Feet	3-3
Lime Sludge Pumping	3-4
Alum Sludge Pumping	3-5
Ferric Chloride Sludge Pumping	3-6
PRELIMINARY TREATMENT	
Mechanically Cleaned Screens	3-7
Comminutors	3-8
Grit Removal (Aerated)	3-9
Grit Removal (Non-Aerated)	3-10
Pre-Aeration	3-11
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Primary Sedimentation	3-12
Secondary Sedimentation	3-13
Chemical Treatment Sedimentation - Alum or Ferric Chloride	3-14
Chemical Treatment Sedimentation - Lime	3-15
BIOLOGICAL TREATMENT	
High Rate Trickling Filter (Rock Media)	3-16
Low Rate Trickling Filter (Rock Media)	3-17
High Rate Trickling Filter (Plastic Media)	3-18
Super-High Rate Trickling Filter (Plastic Media)	3-19
Rotating Biological Disk	3-20
Activated Biofilter	3-21
Brush Aeration (Oxidation Ditch)	3-22
Oxygen Activated Sludge - Open Top Reactor - Fine Bubble Diffusion	3-23
Oxygen Activated Sludge - Covered Reactor (Cryogenic)	3-24

TABLE 3-1 (continued)

TABLE 3-1 (Continued)

TABLE 3-1 (Continued)

TABLE 3-1 (Continued)

TABLE 3-2

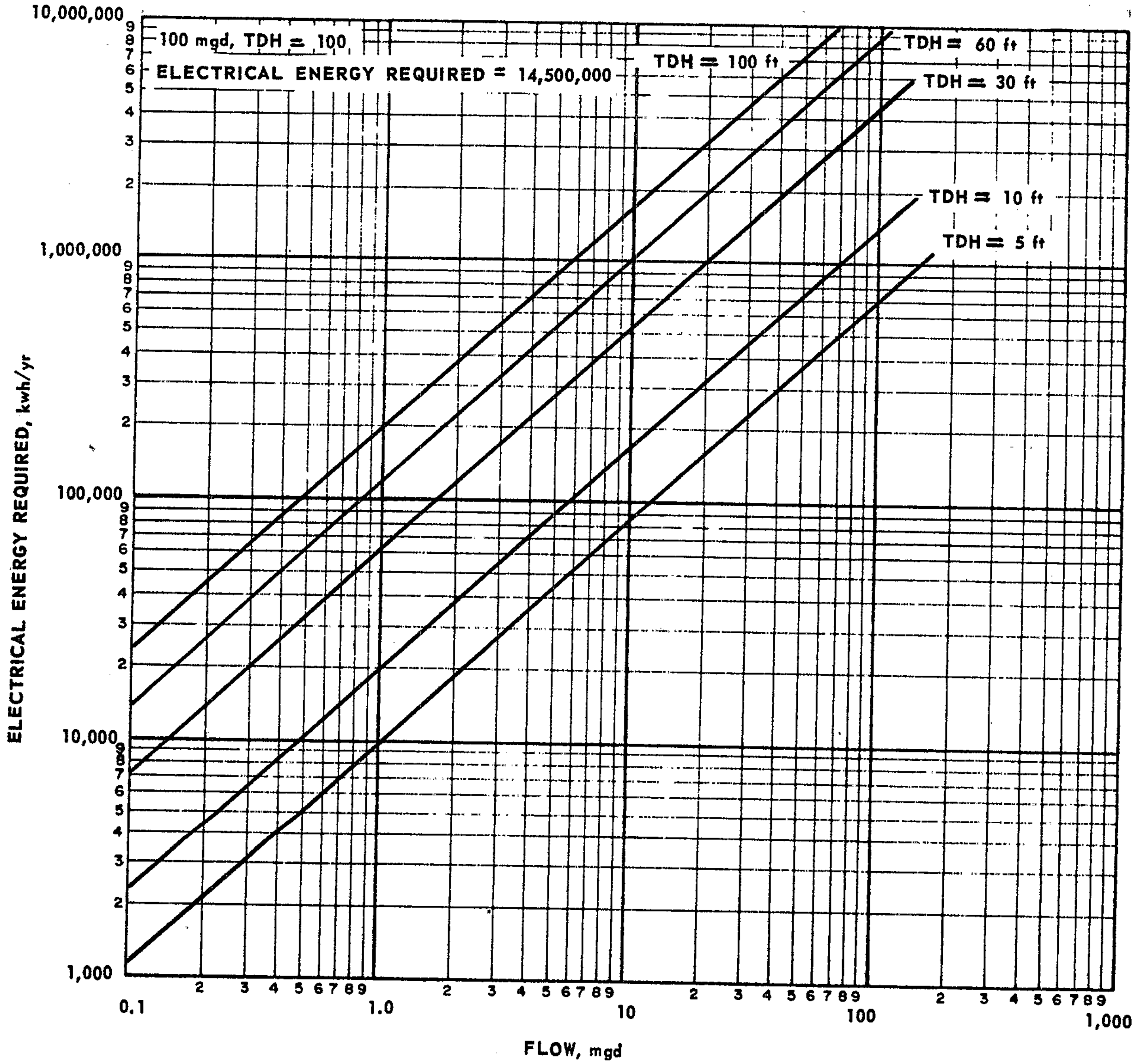
RAW WASTEWATER CHARACTERISTICS

Parameter	Concentration mg/l, except pH
Biochemical Oxygen Demand	210
Suspended Solids	230
Phosphorus, as P	11
Total Kjeldahl Nitrogen, as N	30
Nitrite plus Nitrate	0
Alkalinity, as $CaCO_3$	300
pH	7.3

TABLE 3-3

SLUDGE CHARACTERISTICS

Sludge Type	Total Solids (wt percent of sludge)	Sludge Solids (lb/mil gal) Total Solids	Sludge Solids (lb/mil gal) Volatile Solids	Volatile Solids (wt percent of total solids)	Sludge Volume (gal/mil gal)
Primary	5	1151	690	60	2,760
Primary + $FeCl_3$	2	2510	1176	47	16,500
Primary + Low Lime	5	4979	2243	45	11,940
Primary + High Lime	7.5	9807	4370	45	15,680
Primary + WAS	2	2096	1446	69	12,565
Primary + (WAS+$FeCl_3$)	1.5	2685	1443	54	21,480
(Primary+$FeCl_3$) + WAS	1.8	3144	1676	53	20,960
WAS	1.0	945	756	80	11,330
WAS+$FeCl_3$	1.0	1535	776	50	18,400
Digested Primary	8.0	806	345	43	1,210
Digested Primary+WAS	4.0	1226	576	47	3,680
Digested Primary + WAS + $FeCl_3$	4.0	1817	599	33	5,455
Tertiary Alum	1.0	700	242	35	8,390
Tertiary High Lime	4.5	8139	3219	40	21,690
Tertiary Low Lime	3.0	3311	1301	39	13,235



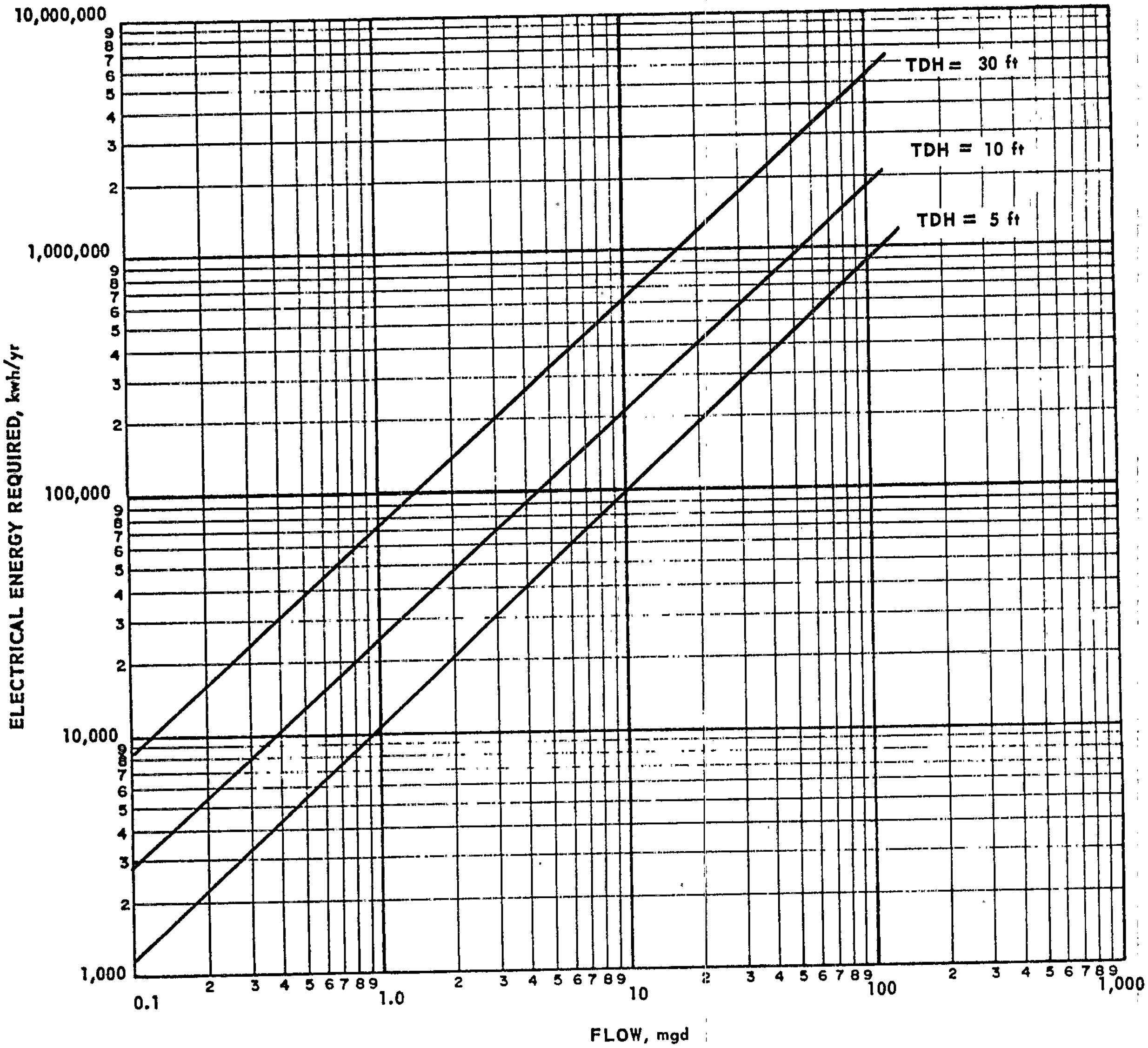
RAW SEWAGE PUMPING (CONSTANT SPEED)

Design Assumptions:

- Efficiencies for typical centrifugal pumps (varies with flow)
- Variable level wet well
- TDH is total dynamic head

Type of Energy Required: Electrical

FIGURE 3–1



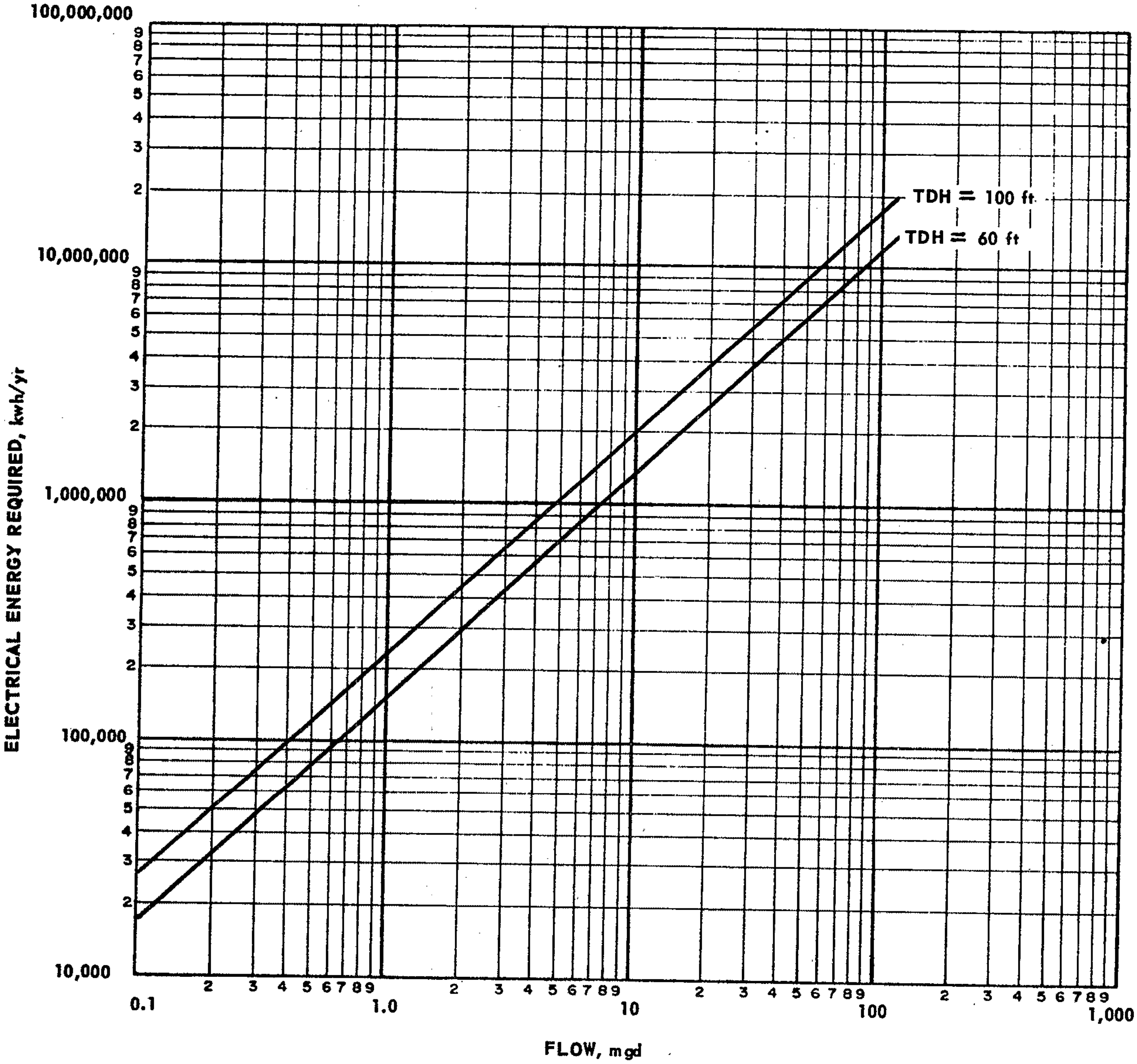
RAW SEWAGE PUMPING (VARIABLE SPEED)

(Curve 1 of 2)

Design Assumptions:
- Efficiencies for typical centrifugal pumps (varies with flow)
- Wound Rotor variable speed
- Variable level wet well

Type of Energy Required: Electrical

FIGURE 3–2



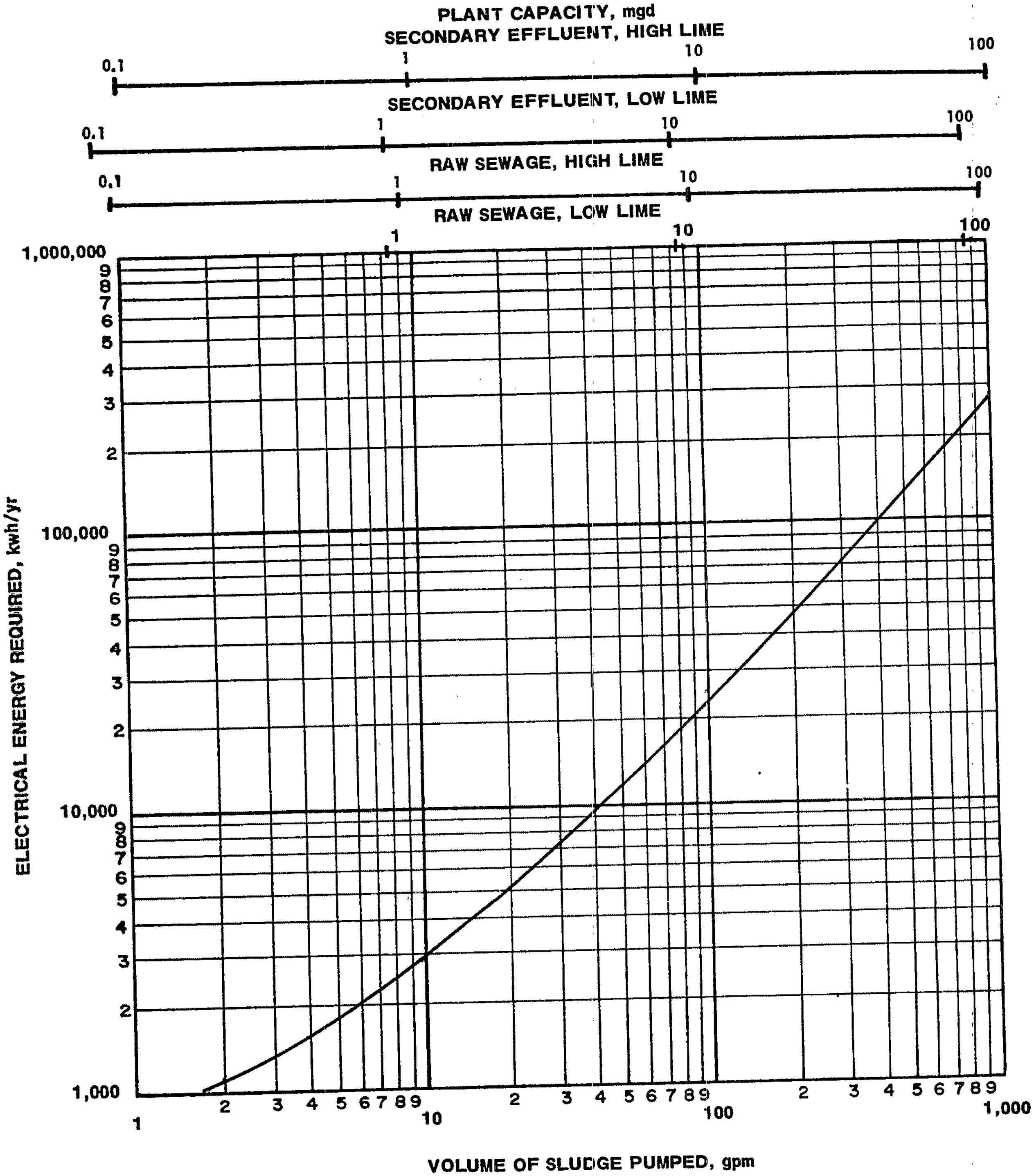
RAW SEWAGE PUMPING (VARIABLE SPEED)

(Curve 2 of 2)

Design Assumptions:
- Efficiencies for typical centrifugal pumps (varies with flow)
- Wound rotor variable speed
- Variable level wet well

Type of Energy Required: Electrical

FIGURE 3–3



LIME SLUDGE PUMPING

Design Assumptions:

TDH 25 ft

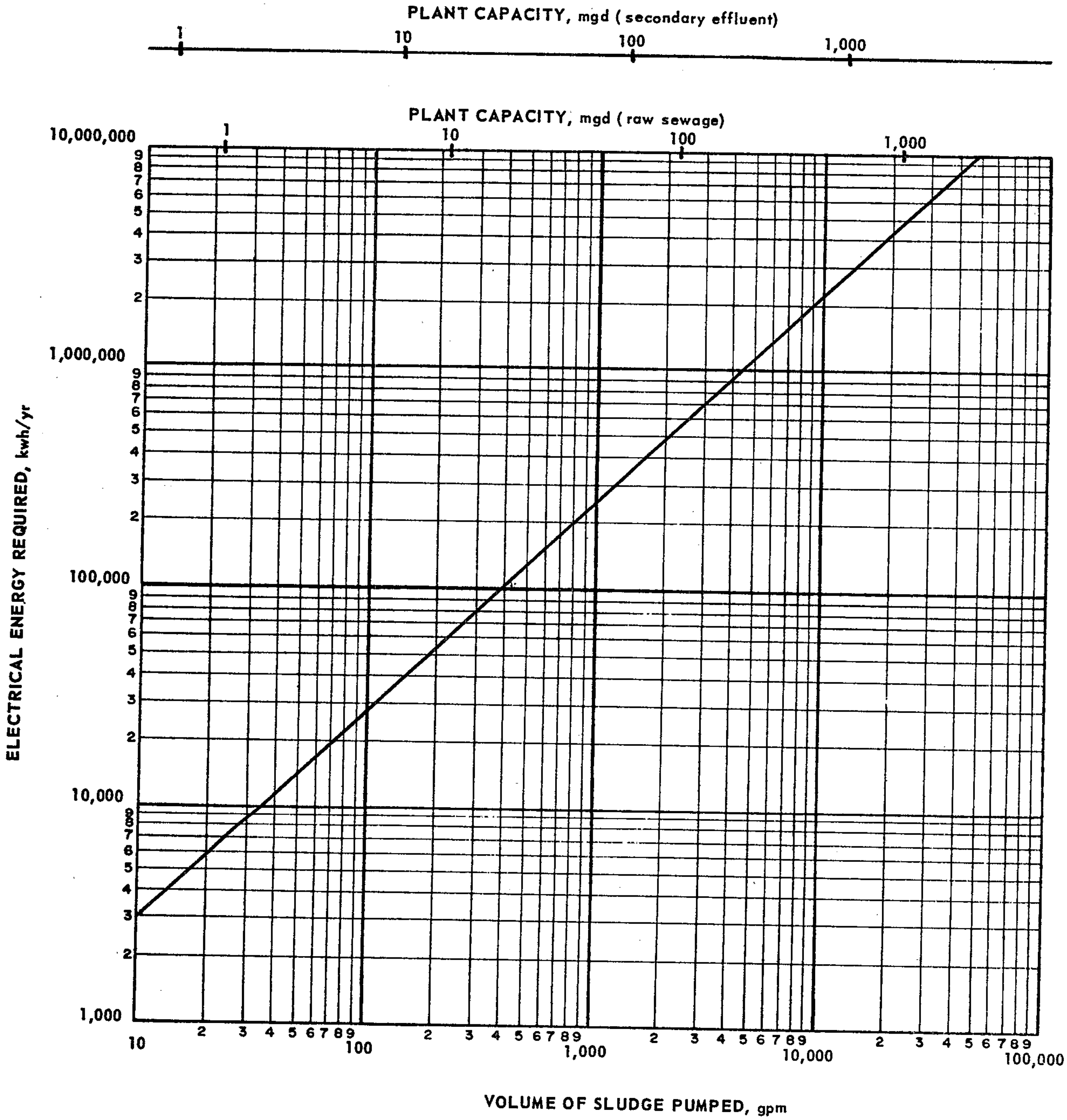
Operating Parameters:

Sludge concentrations, secondary treatment, are 5% for low lime and 7.5% for high lime

Sludge concentrations, tertiary treatment, are 3% for low lime and 4.5% for high lime

Type of Energy Required: Electrical

FIGURE 3–4



ALUM SLUDGE PUMPING

Water Quality: (Secondary)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	250	30
Phosphate as P	11.0	1.0

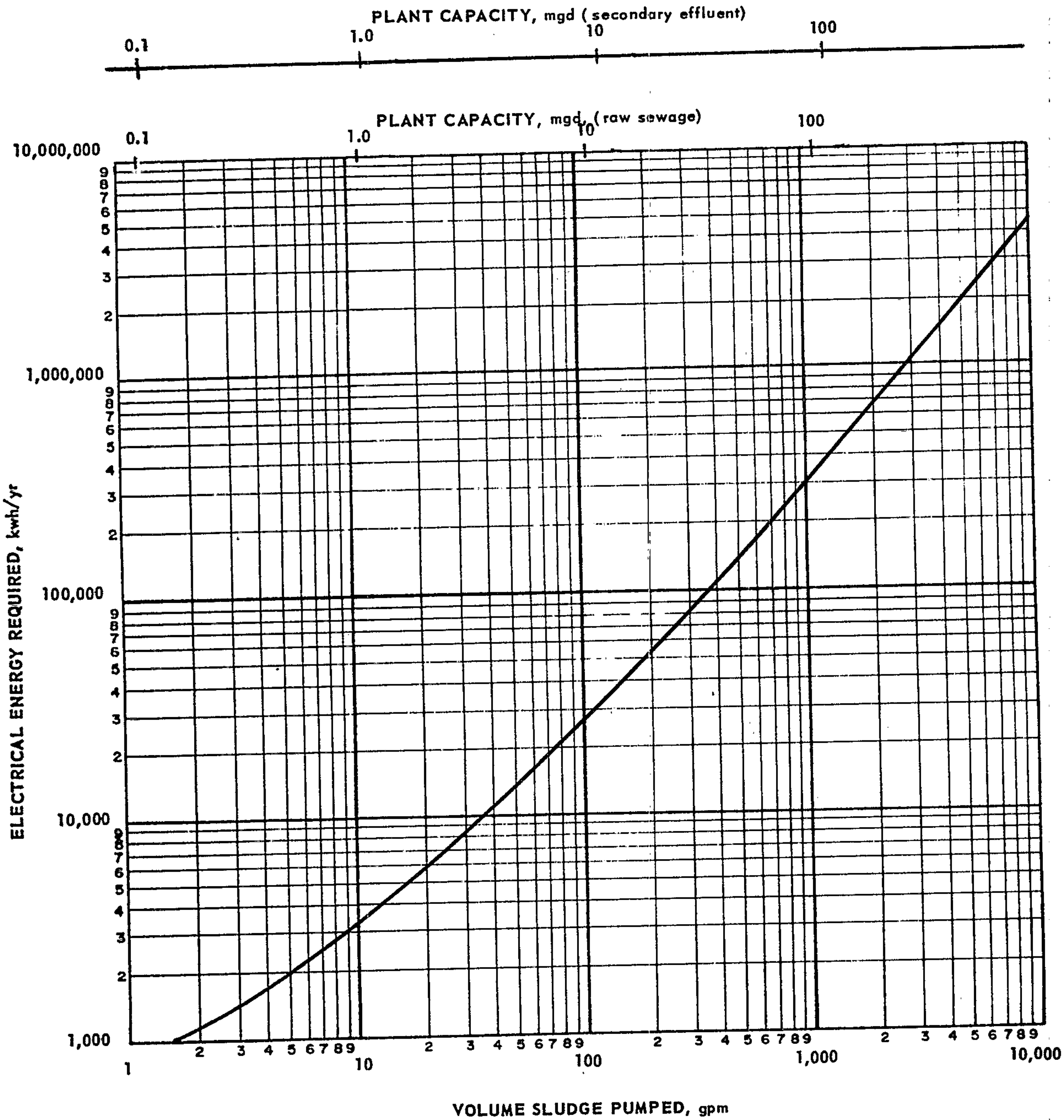
Water Quality: (Tertiary)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	30	10
Phosphate as P	11.0	1.0

Design Assumptions:
- TDH = 25 ft
- Sludge concentration (secondary) = 1%
- Sludge concentration (tertiary) ≈ 0.5%

Operating Parameter:
- Alum addition ≈ 150 mg/l

Type of Energy Required: Electrical

FIGURE 3–5



FERRIC CHLORIDE SLUDGE PUMPING

Water Quality: (Secondary)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	250	30
Phosphate as P	11.0	1.0

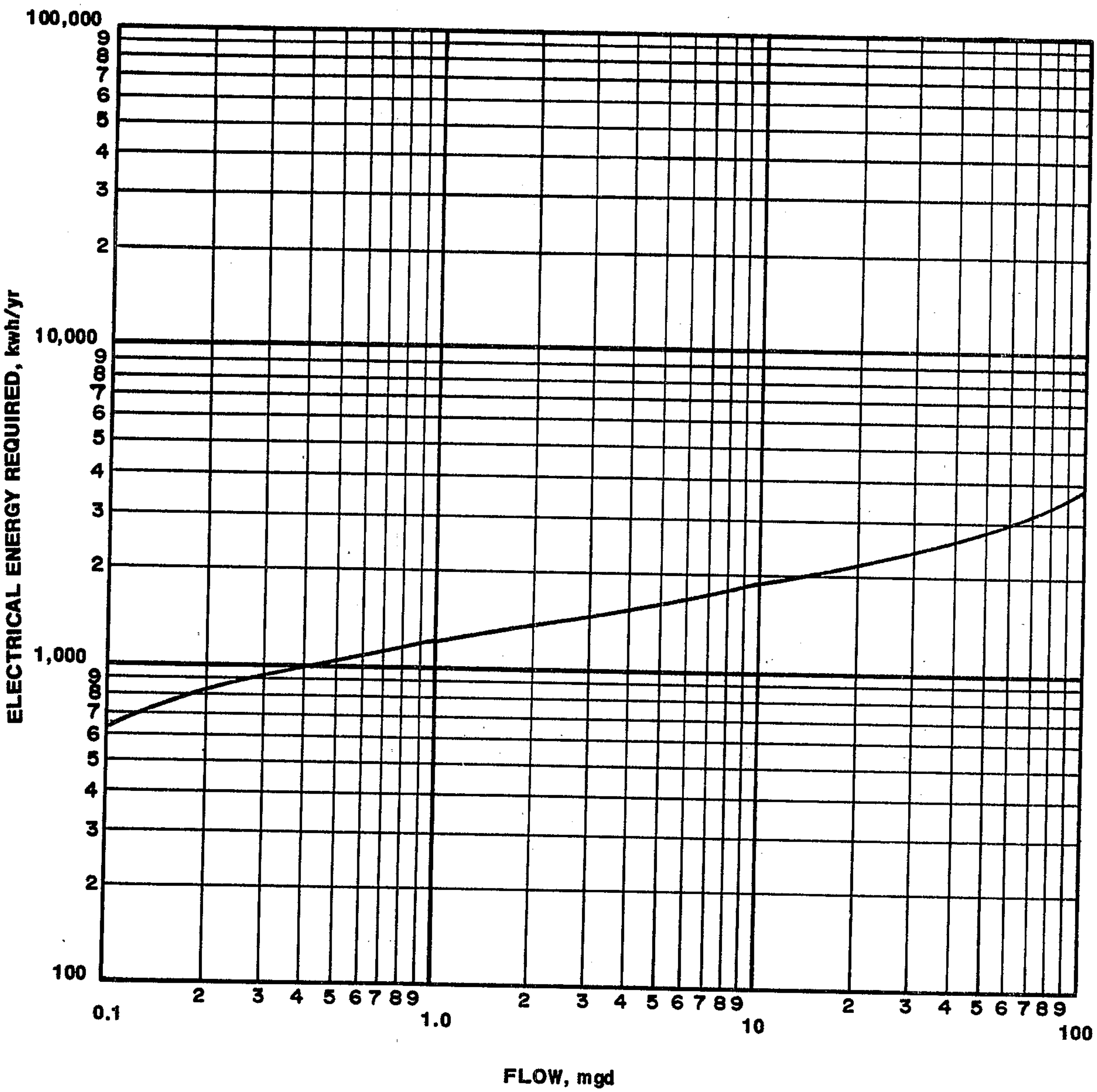
Water Quality: (Tertiary)	Influent (mg/l)	Efffuent (mg/l)
Suspended Solids	30	10
Phosphate as P	11.0	1.0

Design Assumptions:
TDH = 25 ft.
Sludge concentration (secondary) = 2%
Sludge concentration (Tertiary) = 1%

Operating Parameters:
Ferric Chloride addition = 85 mg/l

Type of Energy Required: Electrical

FIGURE 3–6



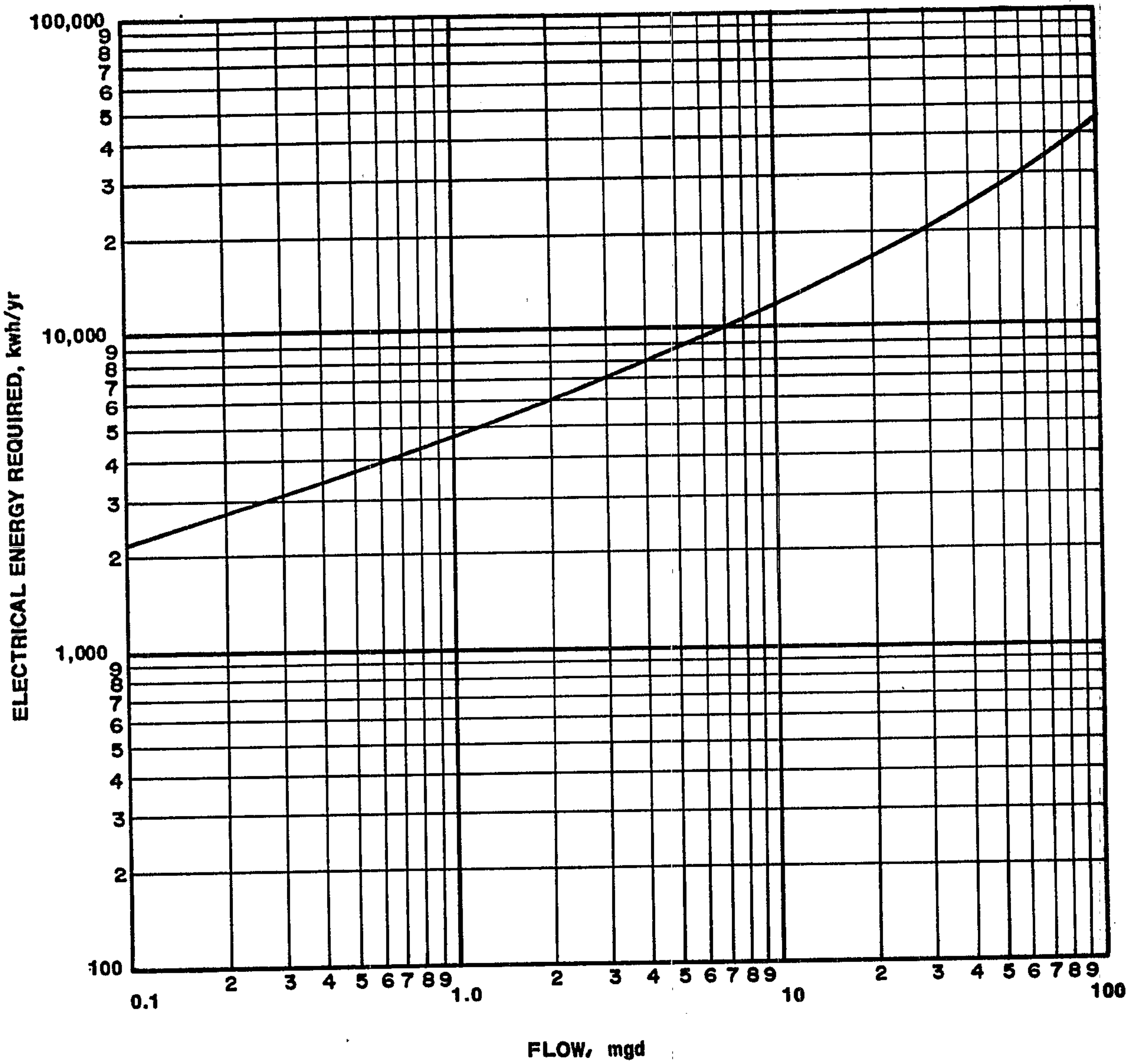
MECHANICALLY CLEANED SCREENS

Design Assumptions:

Normal run times are 10 min total time per hr except 0.1 mgd (5min) and 100 mgd (15min).
Bar Spacing is ¾ in
Worm gear drive, 50% efficiency

Type of Energy Required: Electrical

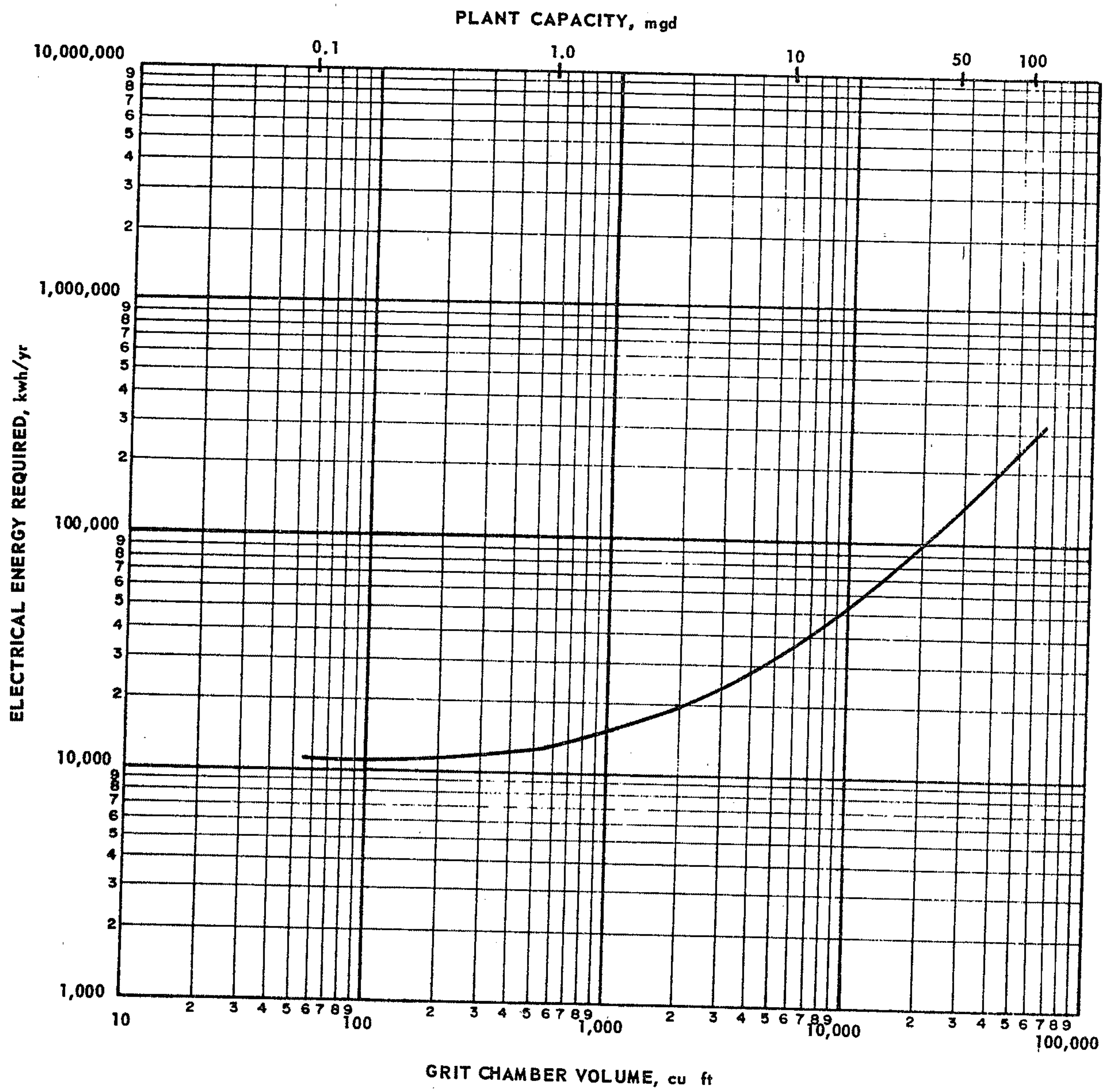
FIGURE 3–7



COMMINUTORS

Type of Energy Required: **Electrical**

FIGURE 3–8



GRIT REMOVAL (AERATED)

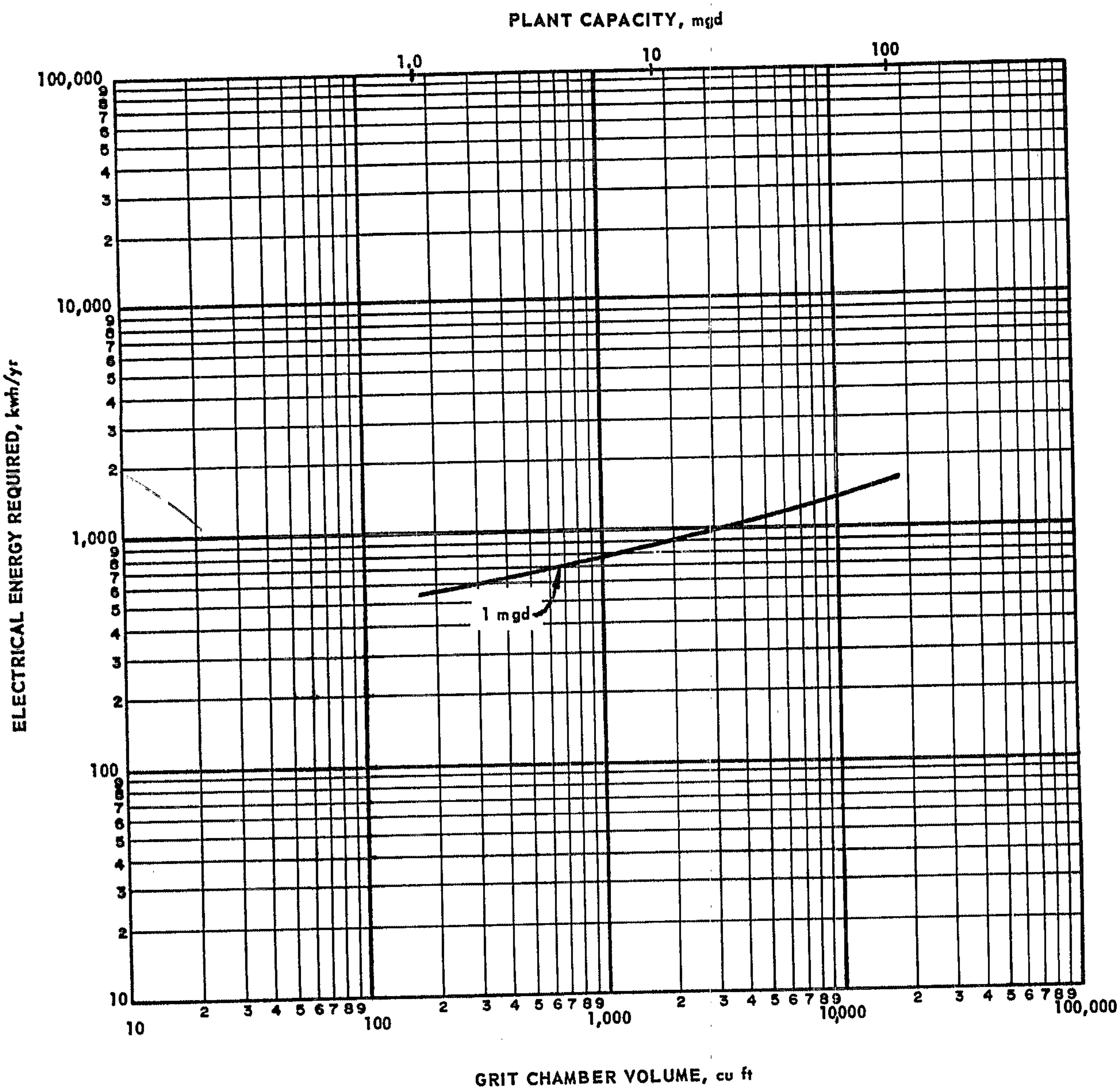
Water Quality:
Removal of 90% of material with a specific gravity of greater than 2.65

Design Assumptions:
Grit removed to a holding facility by a screw pump
Size based on a peaking factor of 2
Detention time is 3 min.
Tank design similar to that by Link-Belt, FMC Corp. or Jeffrey

Operating Parameters:
Air rate of 3 cfm per foot of length
Removal equipment

Type of Energy Required: Electrical

FIGURE 3–9



GRIT REMOVAL (NON-AERATED)

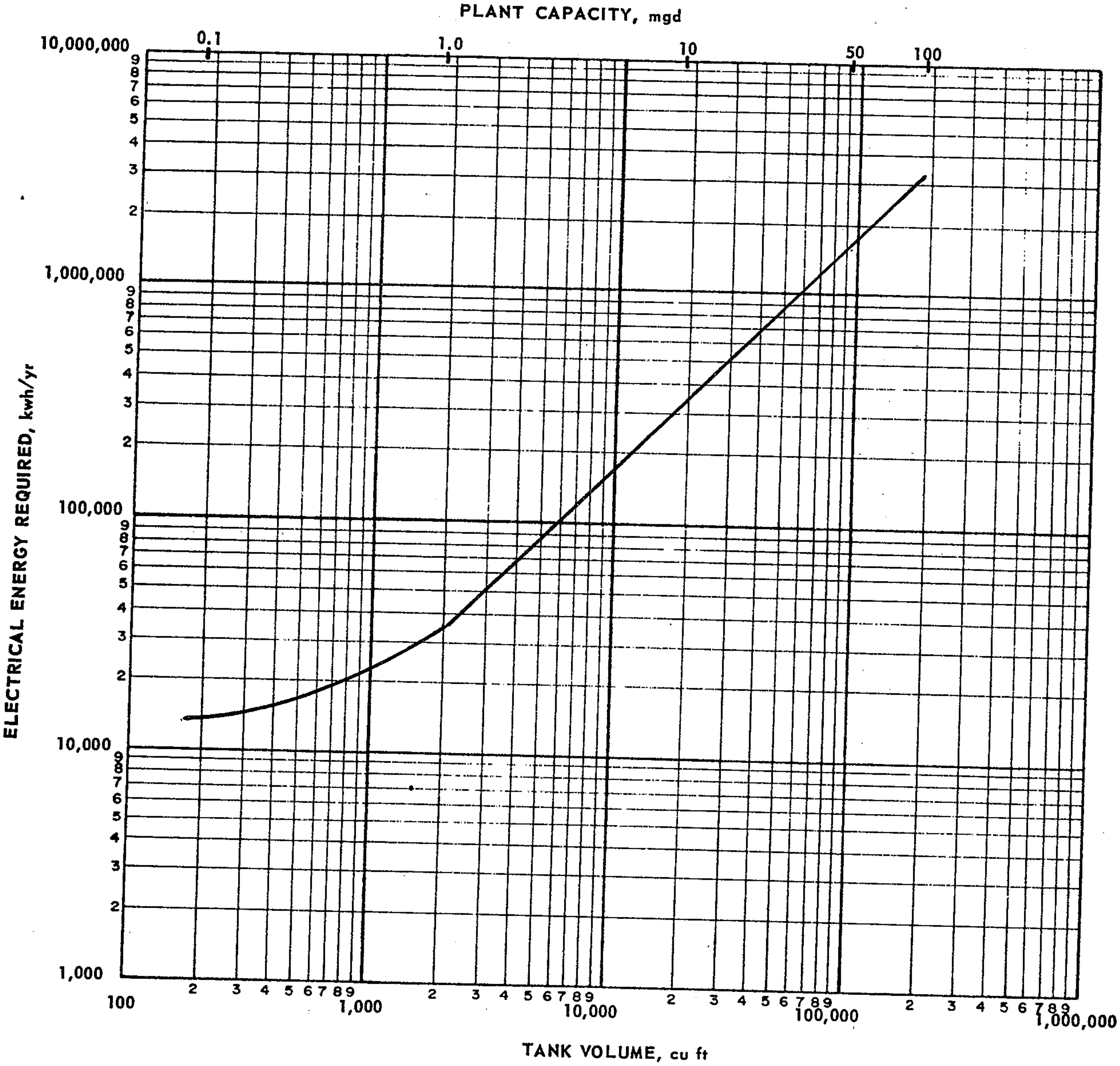
Water Quality:
Removal of 90% of material with specific gravity greater than 2.65

Design Assumptions:
Grit removed to a holding facility by screw pump
Size based on peaking factor of 2
Square tank
Smallest volume is 117 cu ft

Operating Parameter:
Velocity of 0.55 fps through square tank or 1 min detention time at average flow
Operate equipment 2 hr each day

Type of Energy Required: Electrical

FIGURE 3–10



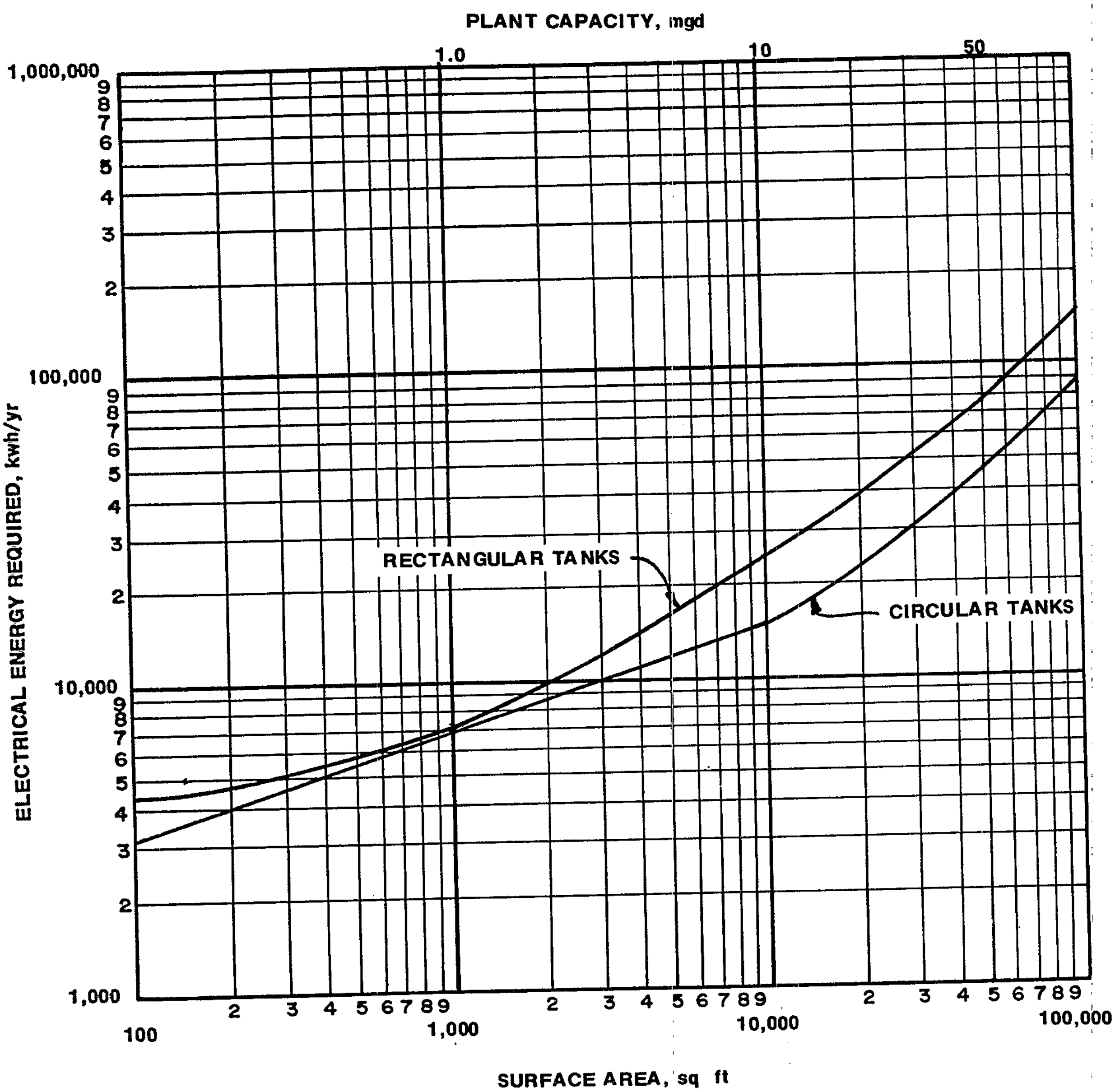
PRE – AERATION

Design Assumption:
Detention time is 20 min.

Operating Parameter:
Air supply is 0.15 cu ft /gal

Type of Energy Required: Electrical

FIGURE 3–11



PRIMARY SEDIMENTATION

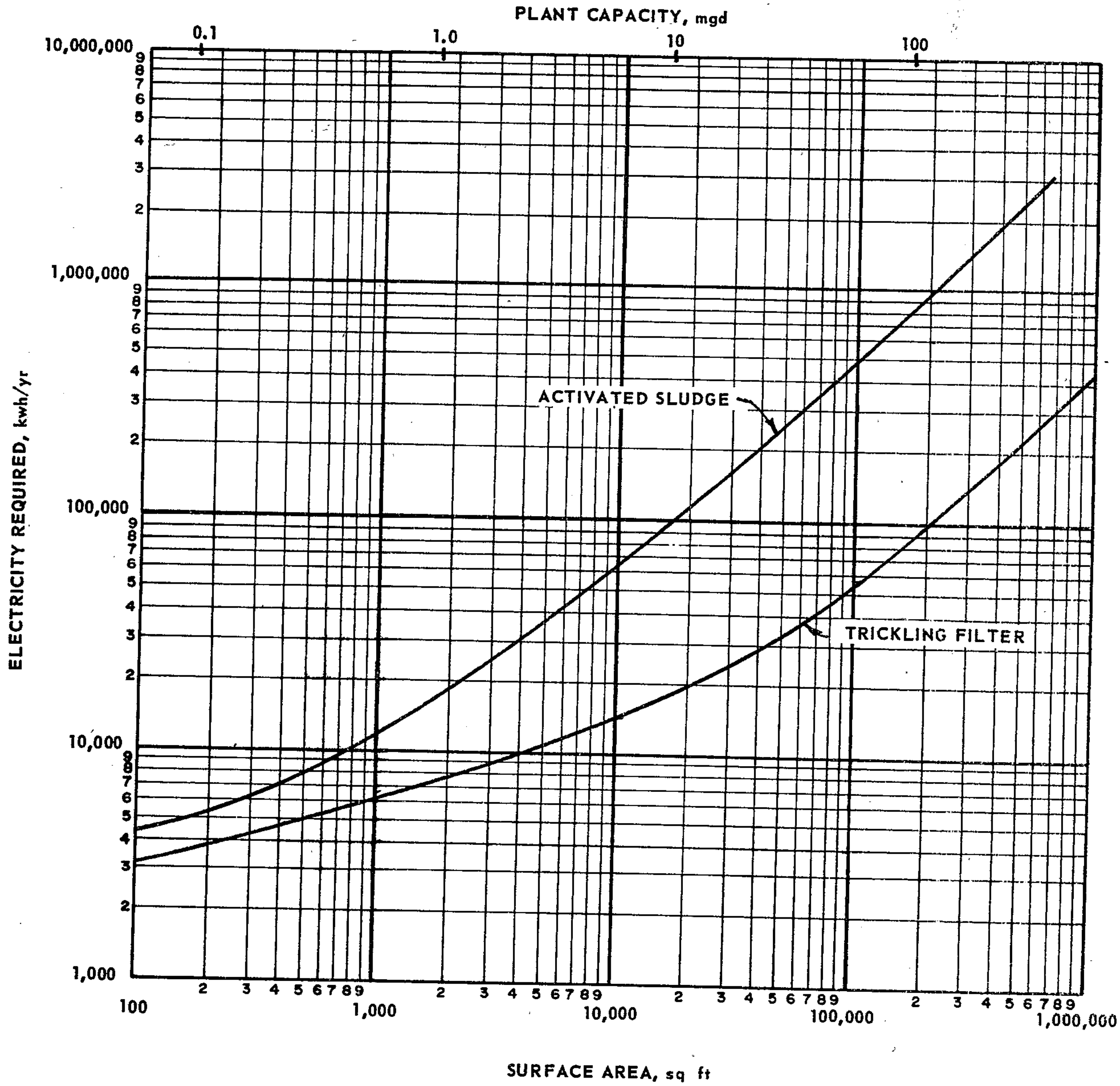
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	210	136
Suspended Solids	230	80

Design Assumptions:
- Sludge pumping included
- Scum pumped by sludge pumps
- Multiple tanks

Operating Parameters:
- Loading = 1000 gpd/sq ft
- Waste rate = 65% of influent solids, 5% concentration
- Pumps operate 10 minutes of each hr

Type of Energy Required: Electrical

FIGURE 3-12



SECONDARY SEDIMENTATION

Water Quality:	Effluent (mg/l)
BOD_5	20
Suspended Solids	20

(applicable to activated sludge system effluent quality variable for trickling filter systems)

Design Assumptions:

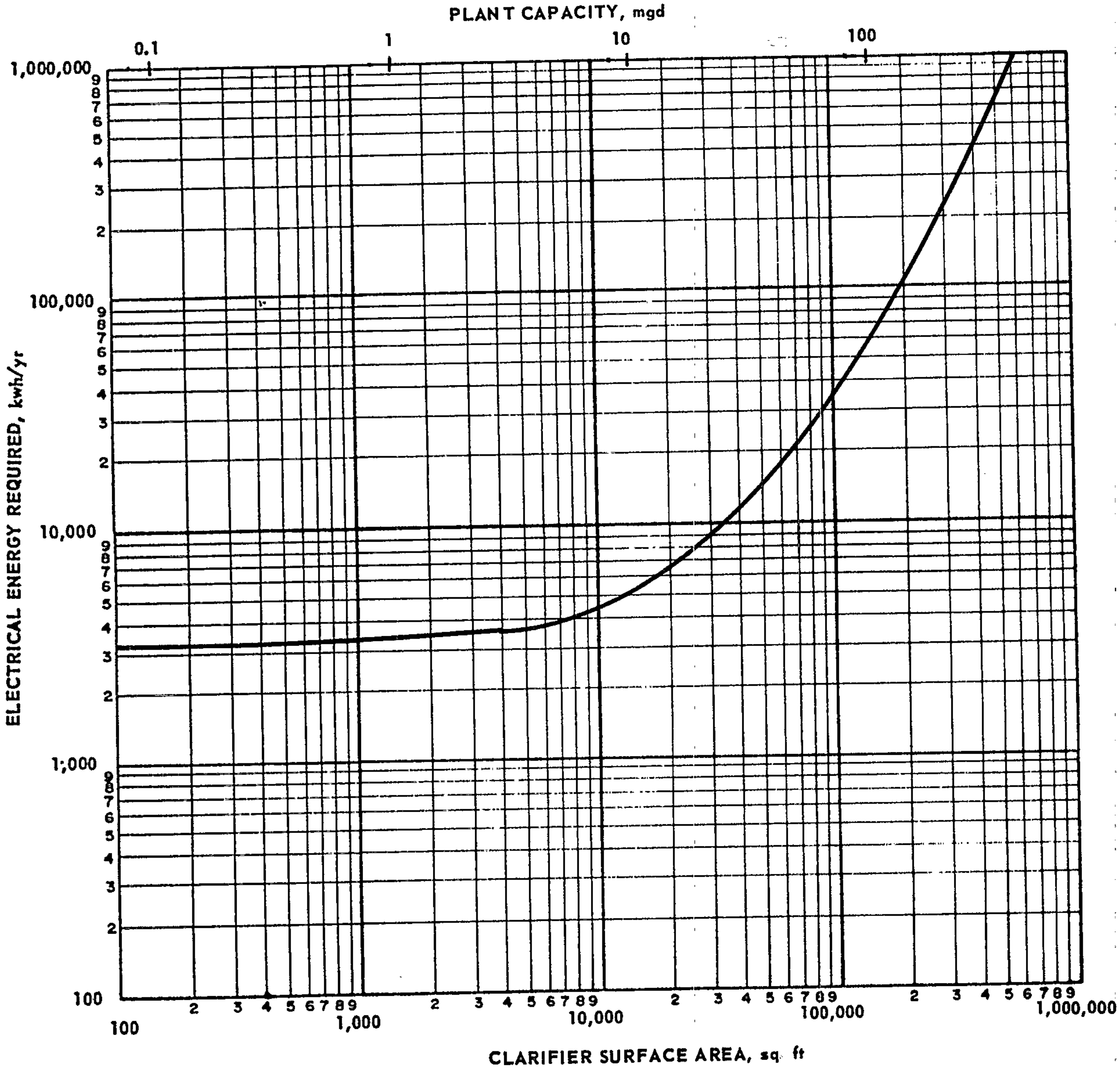
Secondary sedimentation for conventional activated sludge includes return and waste activated sludge.
Secondary sedimentation for trickling filter systems includes waste sludge pumping.
Hydraulic loading = 600 gpd/sq ft

Operating Parameters:

Waste activated sludge = 0.667 lb ss/lb BOD_5
Return activated sludge = 50% Q
Sludge concentration = 1%
Waste pumps: operated 10 minutes each hour

Type of Energy Required: Electrical

FIGURE 3-13



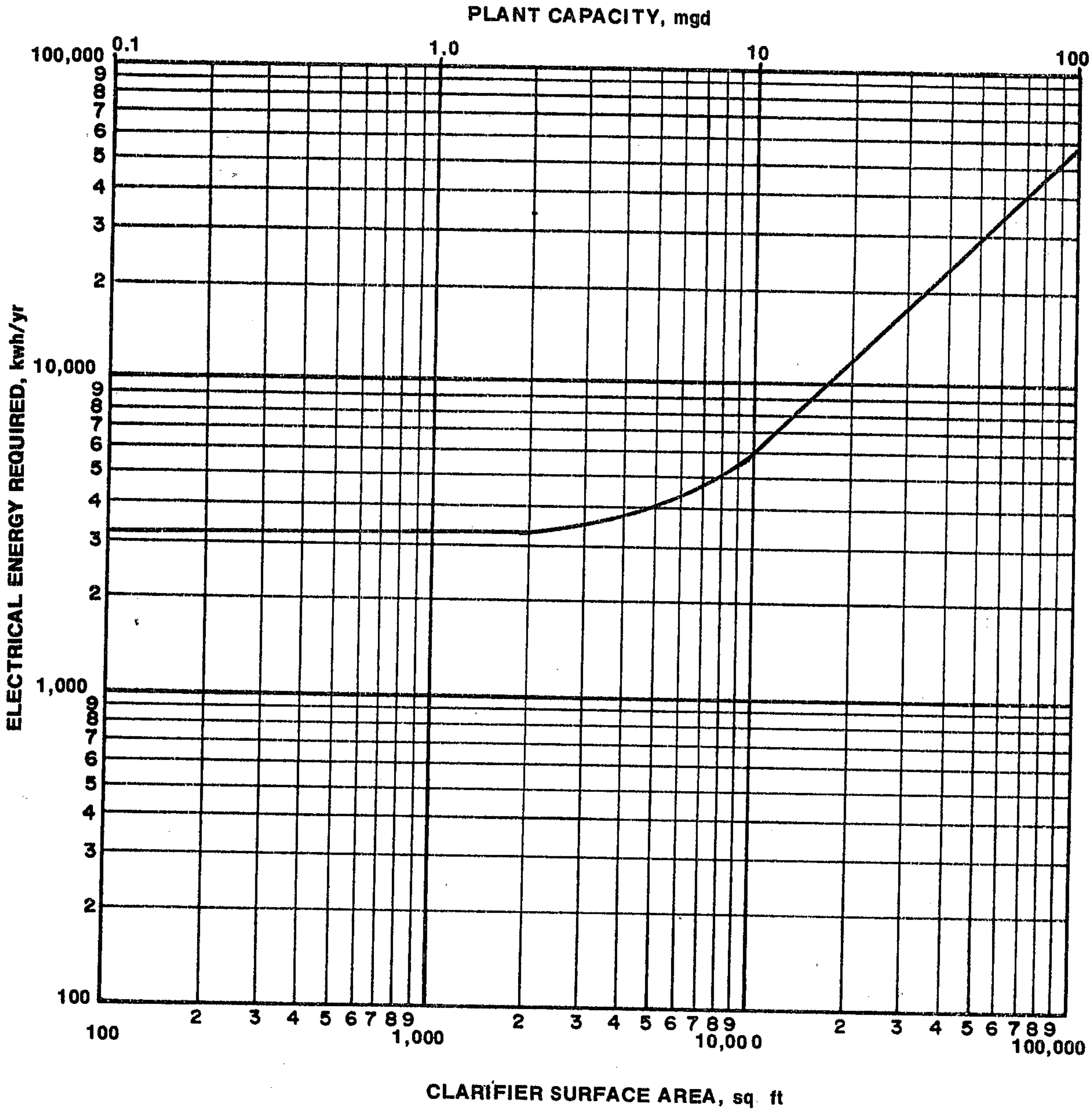
CHEMICAL TREATMENT SEDIMENTATION
ALUM OR FERRIC CHLORIDE

Design Assumptions:
Coagulant: alum or ferric chloride

Operating Parameter:
Overflow rate = 700 gpd/sq ft

Type of Energy Required: Electrical

FIGURE 3–14

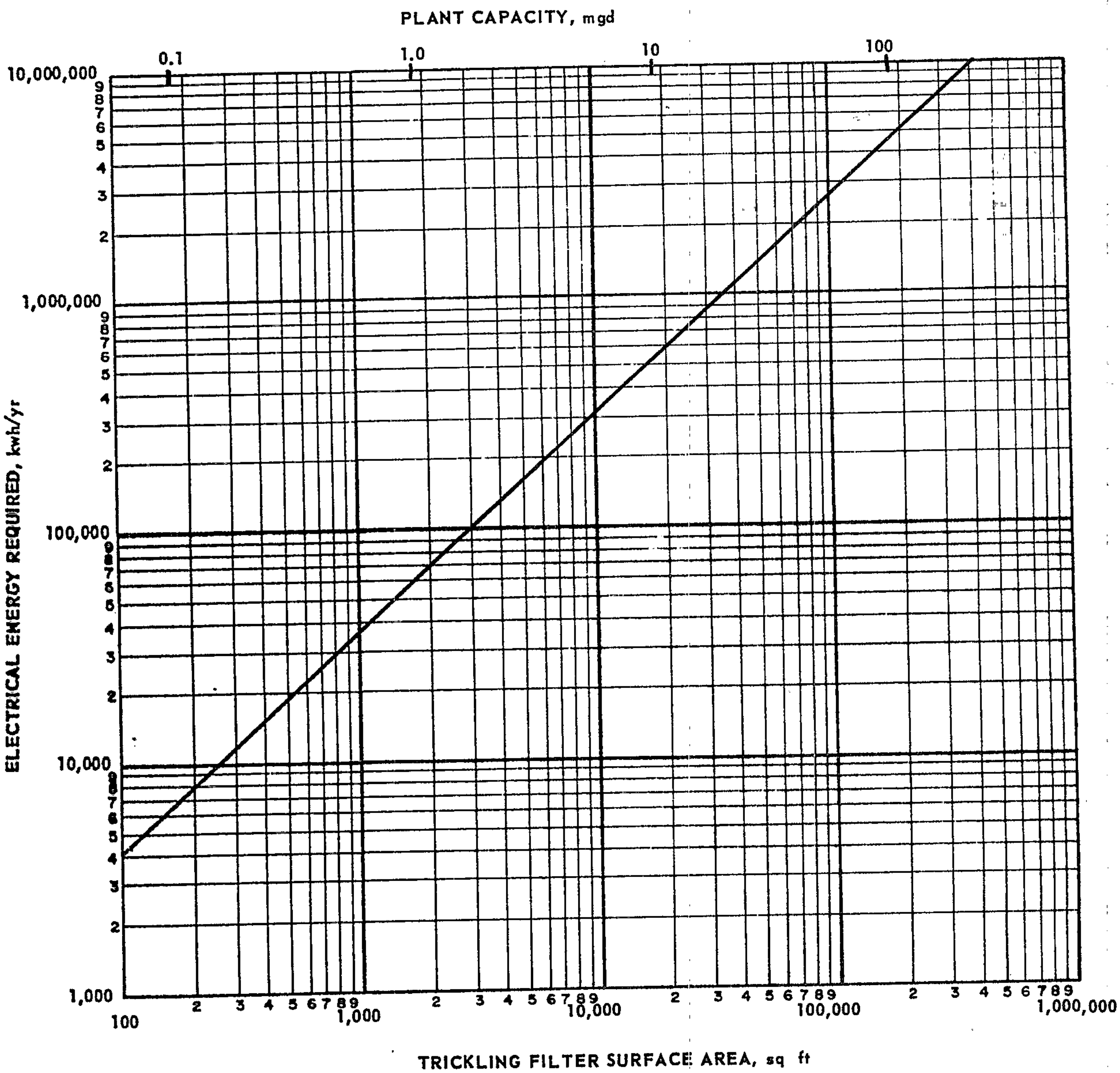


CHEMICAL TREATMENT SEDIMENTATION
LIME

Design Assumptions:
Coagulant: Lime
Overflow rate, Avg = 1,000 gpd/sq ft

Type of Energy Required: Electrical

FIGURE 3-15



HIGH RATE TRICKLING FILTER (ROCK MEDIA)

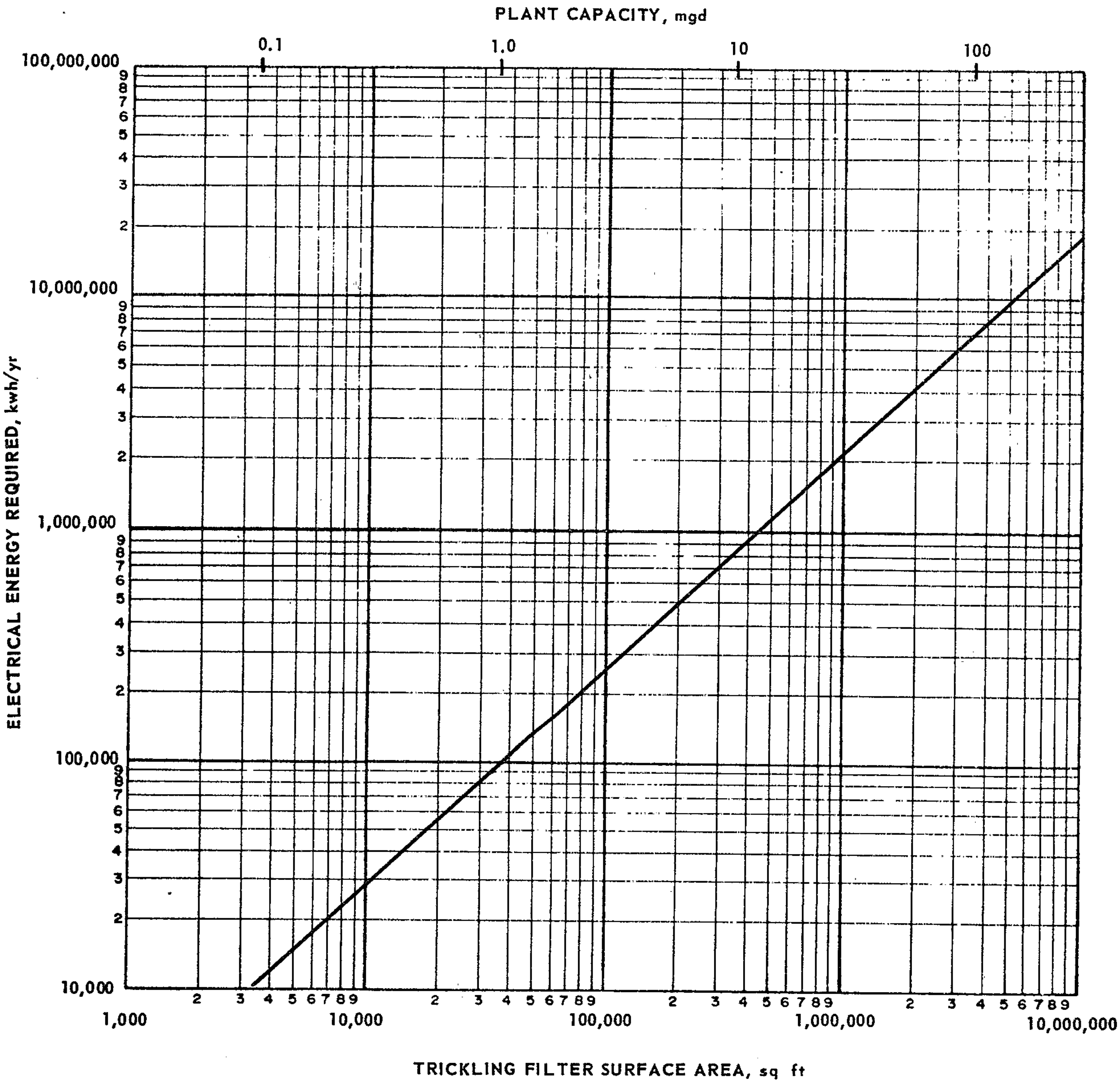
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	45
Suspended Solids	80	45

Design Assumptions:
Hydraulic loading = 0.4 gpm/sq. ft. including recirculation
TDH = 10 ft

Operating Parameter:
Recirculation Ratio = 2 : 1

Type of Energy Required: Electrical

FIGURE 3–16



LOW RATE TRICKLING FILTER (ROCK MEDIA)

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	30
Suspended Solids	80	30

Design Assumptions:

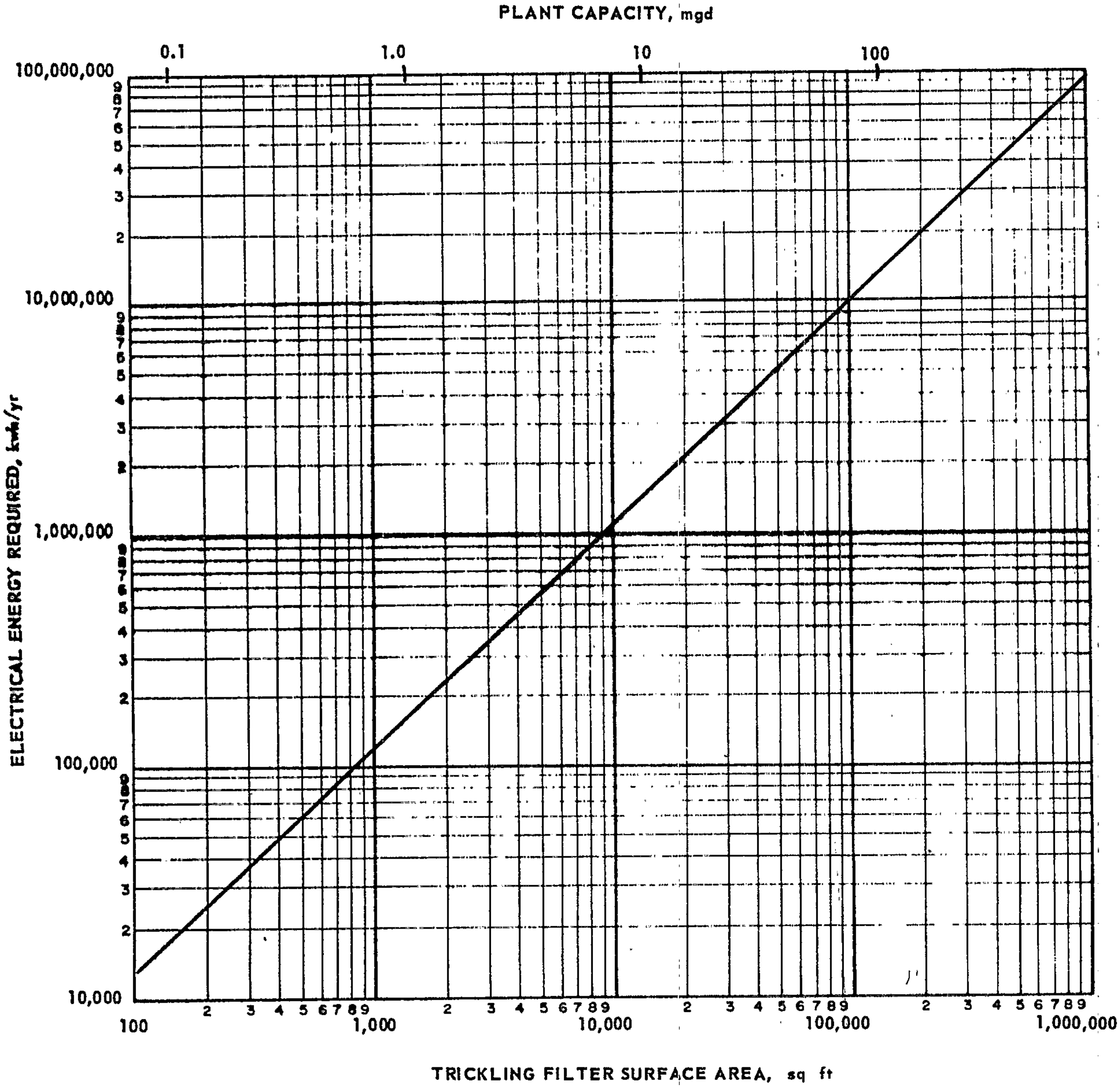
Hydraulic loading = 0.04 gpm/sq ft
TDH = 23 ft

Operating Parameter:

No recirculation

Type of Energy Required: Electrical

FIGURE 3–17



HIGH RATE TRICKLING FILTER (PLASTIC MEDIA)

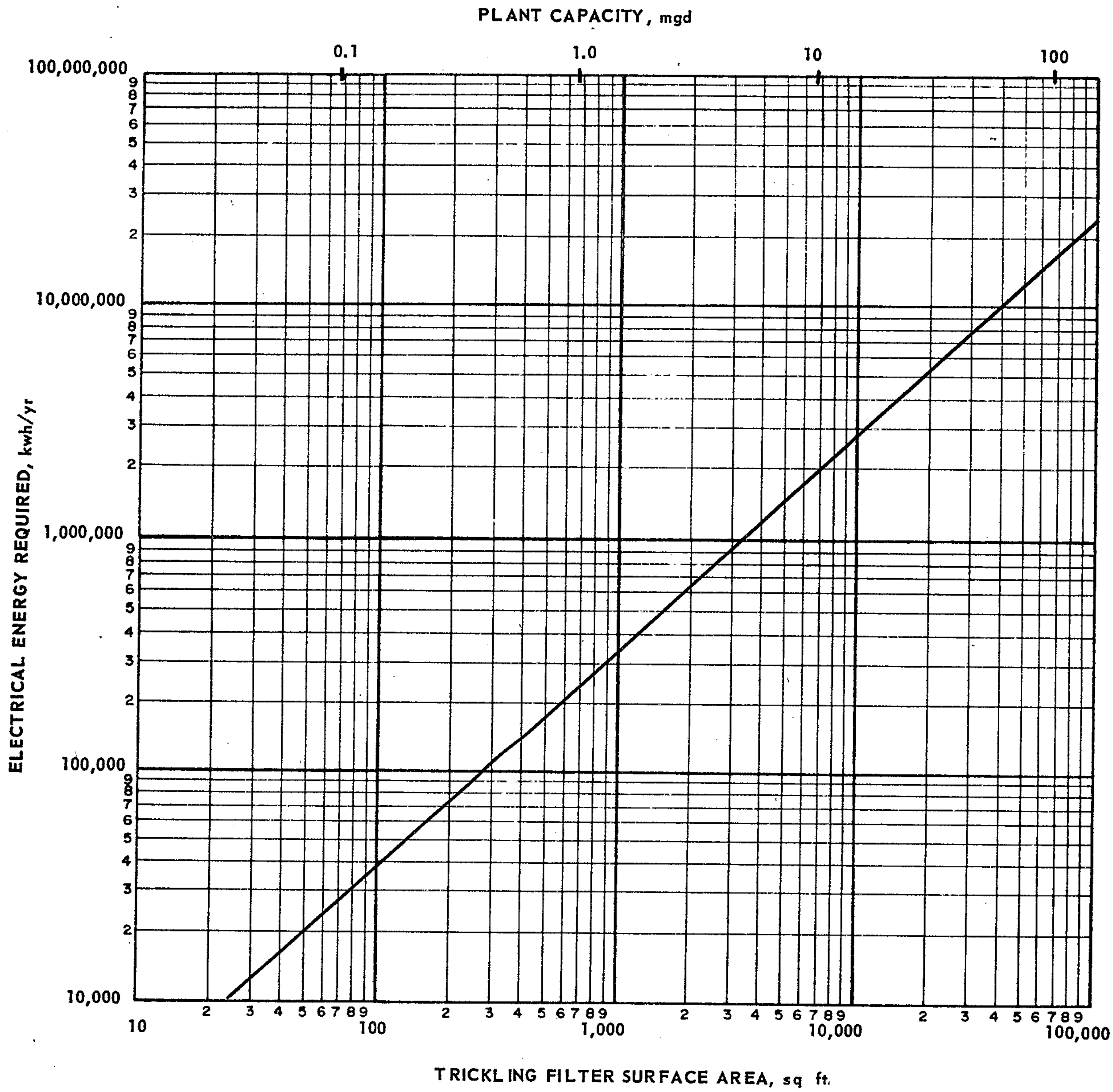
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	35-45
Suspended Solids	80	35-45

Design Assumptions:
Hydraulic loading = 1.0 gpm/sq ft including recirculation
TDH = 40 ft

Operating Parameter:
Recirculation Ratio = 5 : 1

Type of Energy Required: Electrical

FIGURE 3-18



SUPER – HIGH RATE TRICKLING FILTER (PLASTIC MEDIA)

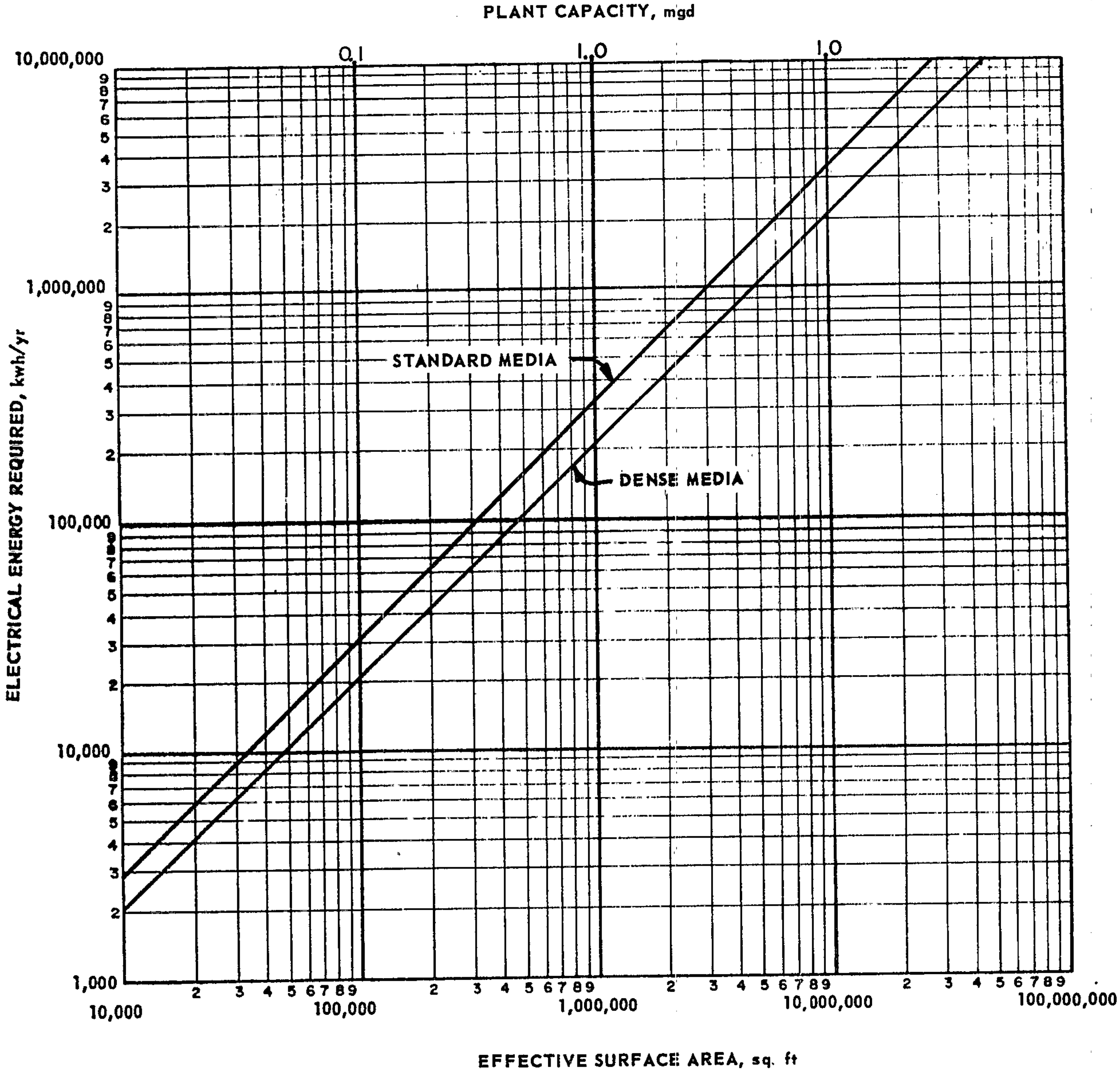
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	82
Suspended Solids	80	48

Design Assumptions:
Hydraulic loading = 3 gpm/sq ft. including recirculation
TDH = 40 ft

Operating Parameter:
Recirculation ratio = 2:1

Type of Energy Required: Electrical

FIGURE 3–19



ROTATING BIOLOGICAL DISK

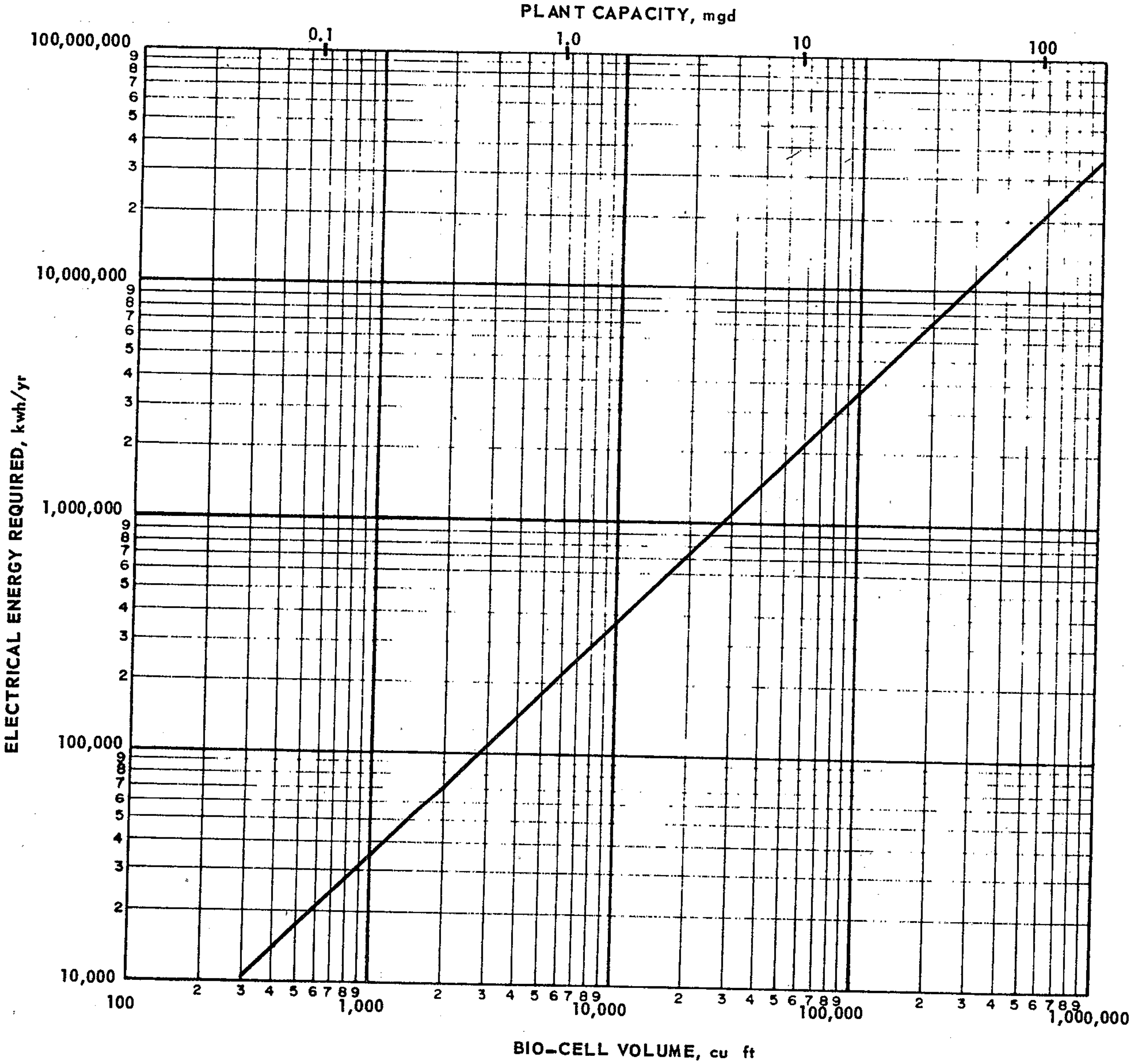
Water Quality:

	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	30
Suspended Solids	80	30

Design Assumptions:
Hydraulic loading = 1 gpd/ sq ft
Standard media = 100,000 sq. ft per unit
Dense media = 150,000 sq ft per unit

Type of Energy Required: Electrical

FIGURE 3–20



ACTIVATED BIOFILTER

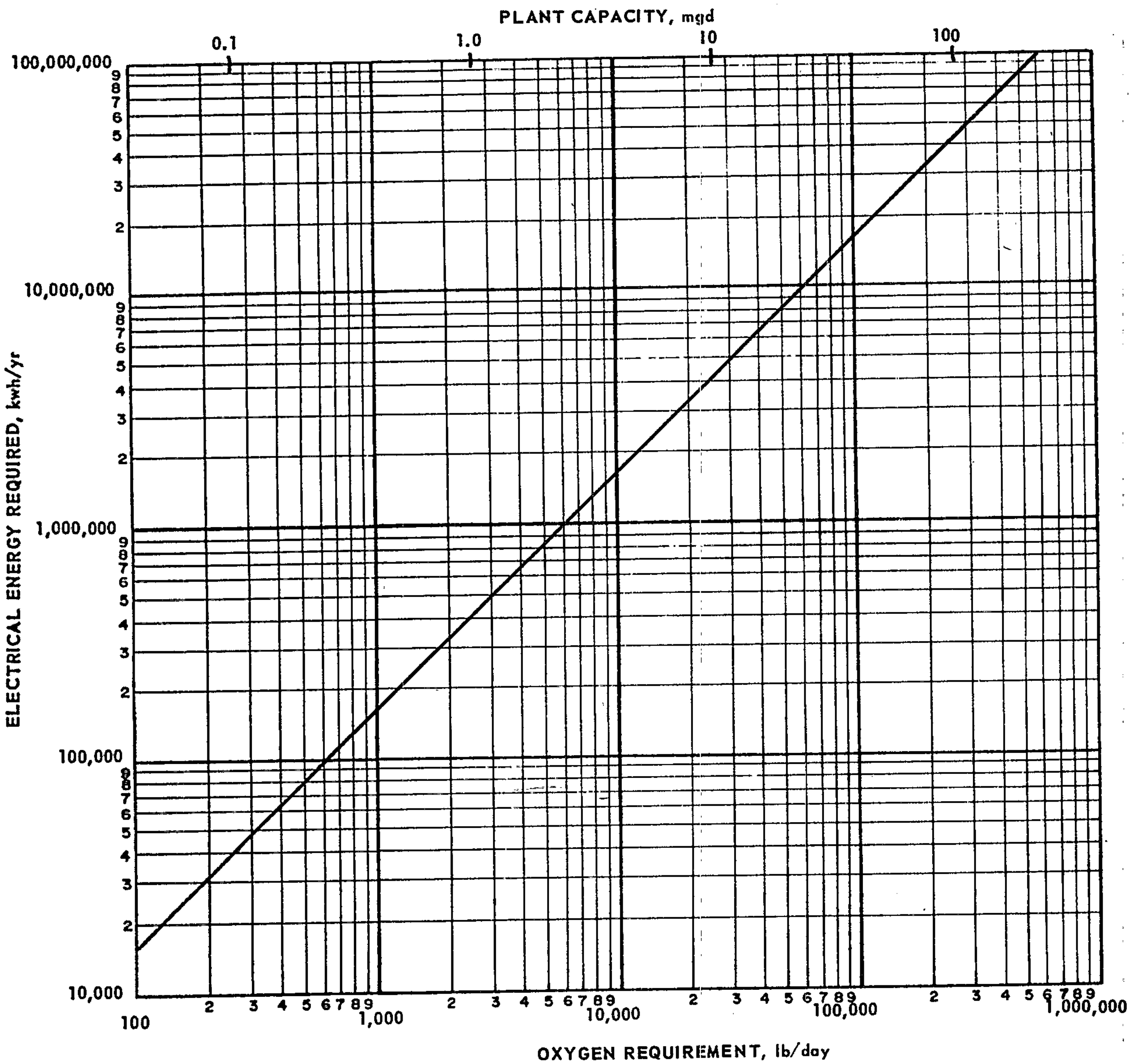
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:
Bio-cell loading = 200 lb BOD_5/1000 cu ft
Aeration = 1 lb O_2/lb BOD_5
Oxygen transfer efficiency in wastewater (mechanical aeration) = 1.8 lb O_2/hp-hr

Operating Parameters:
Recirculation = 0.9:1
Recycle sludge = 50%

Type of Energy Required: Electrical

FIGURE 3-21



BRUSH AERATION (OXIDATION DITCH)

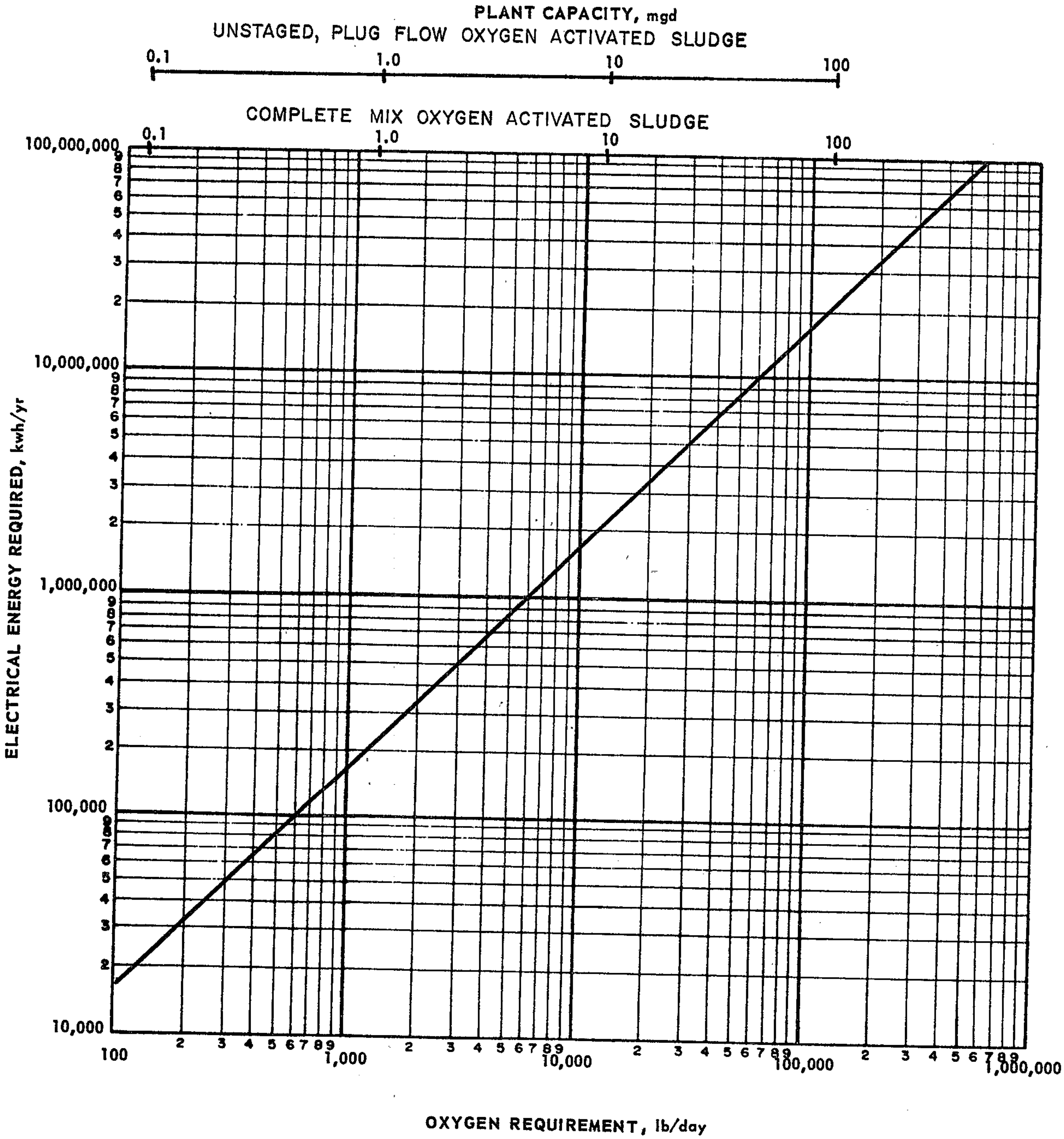
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:
Oxygen transfer efficiency = 1.8 lb O_2/hp-hr (wire to water)

Operating Parameter:
Oxygen requirement = 1.5 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in reactor feed) oxidized

Type of Energy Required: Electrical

FIGURE 3–22



OXYGEN ACTIVATED SLUDGE – UNCOVERED REACTOR WITH CRYOGENIC OXYGEN GENERATION

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:

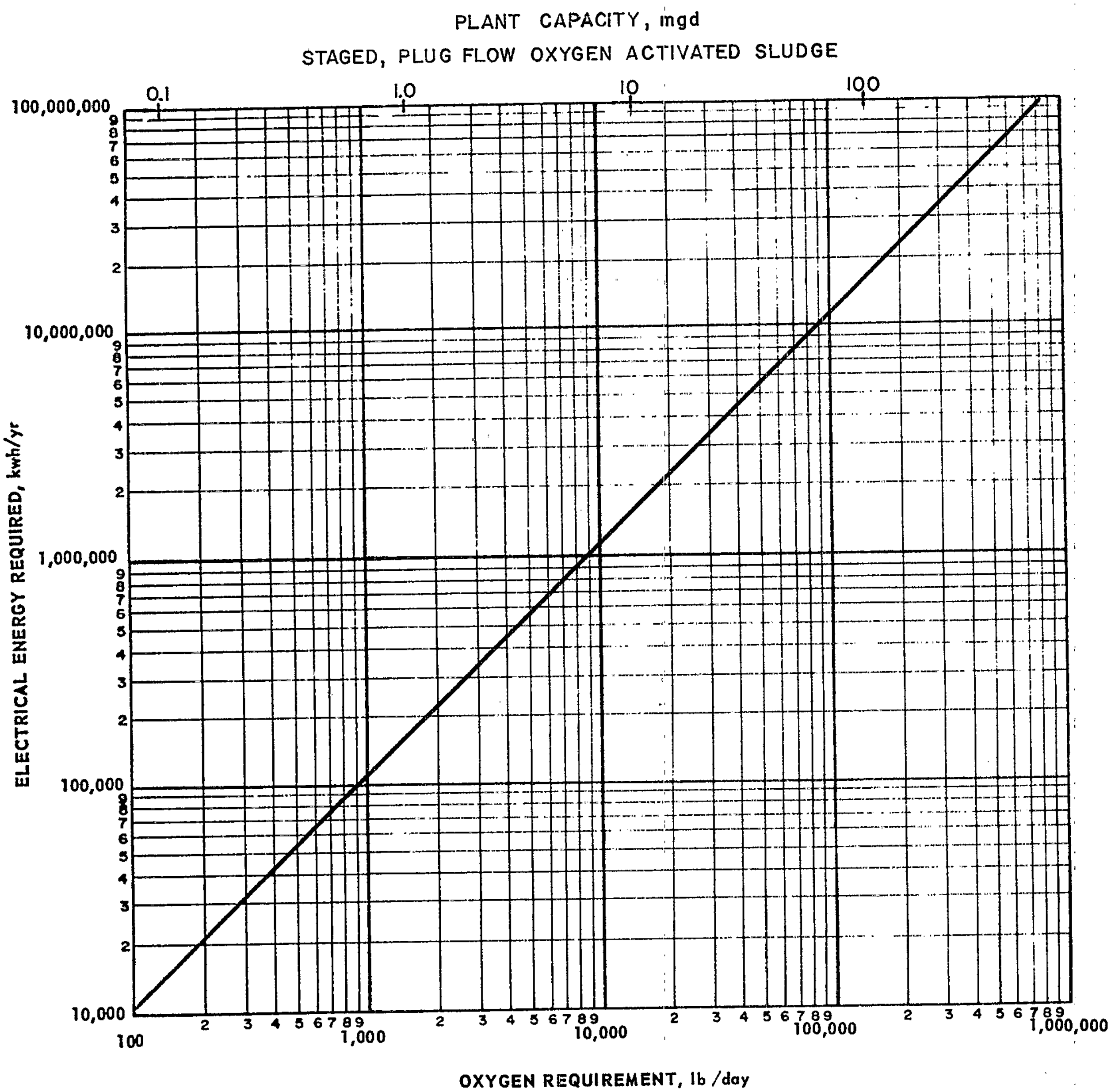
Oxygen transfer efficiency = 1.53 lb O_2/hp–hr (wire to water)
Rotating fine bubble diffusers for dissolution
Includes oxygen generation

Operating Parameter:

Oxygen requirement = 1.1 lb O_2 consumed / lb BOD_5 removed

Type of Energy Required: Electrical

FIGURE 3–23



OXYGEN ACTIVATED SLUDGE –COVERED REACTOR WITH CRYOGENIC OXYGEN GENERATION

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:

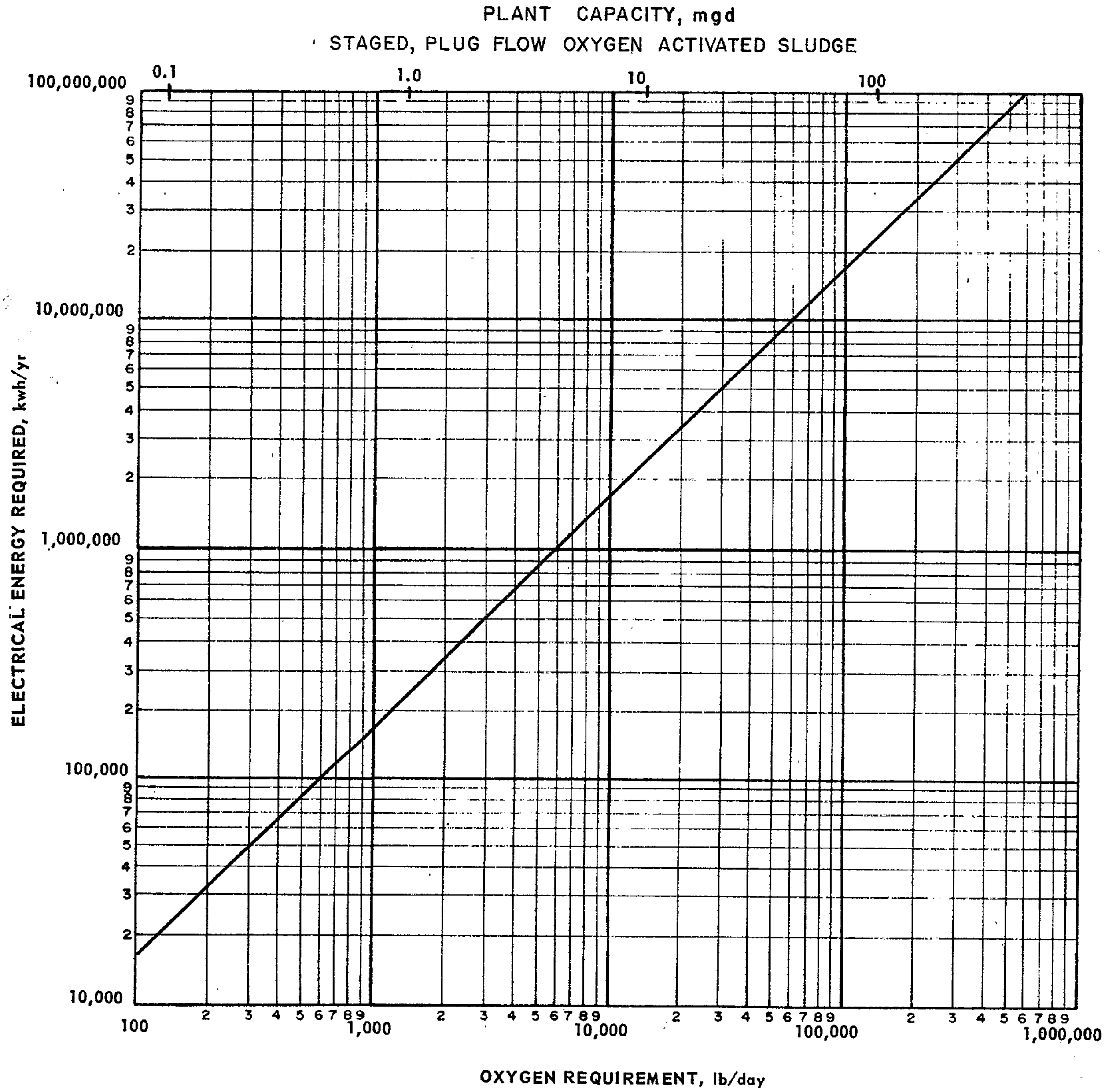
Oxygen transfer efficiency in wastewater = 2.07 lb O_2/hp-hr (wire to water)
Surface aerators for dissolution
Includes oxygen generation

Operating Parameter:

Oxygen requirement = 1.1 lb O_2 supplied / lb BOD_5 removed

FIGURE 3–24

Type of Energy Required: Electrical



OXYGEN ACTIVATED SLUDGE – COVERED REACTOR WITH PSA OXYGEN GENERATION

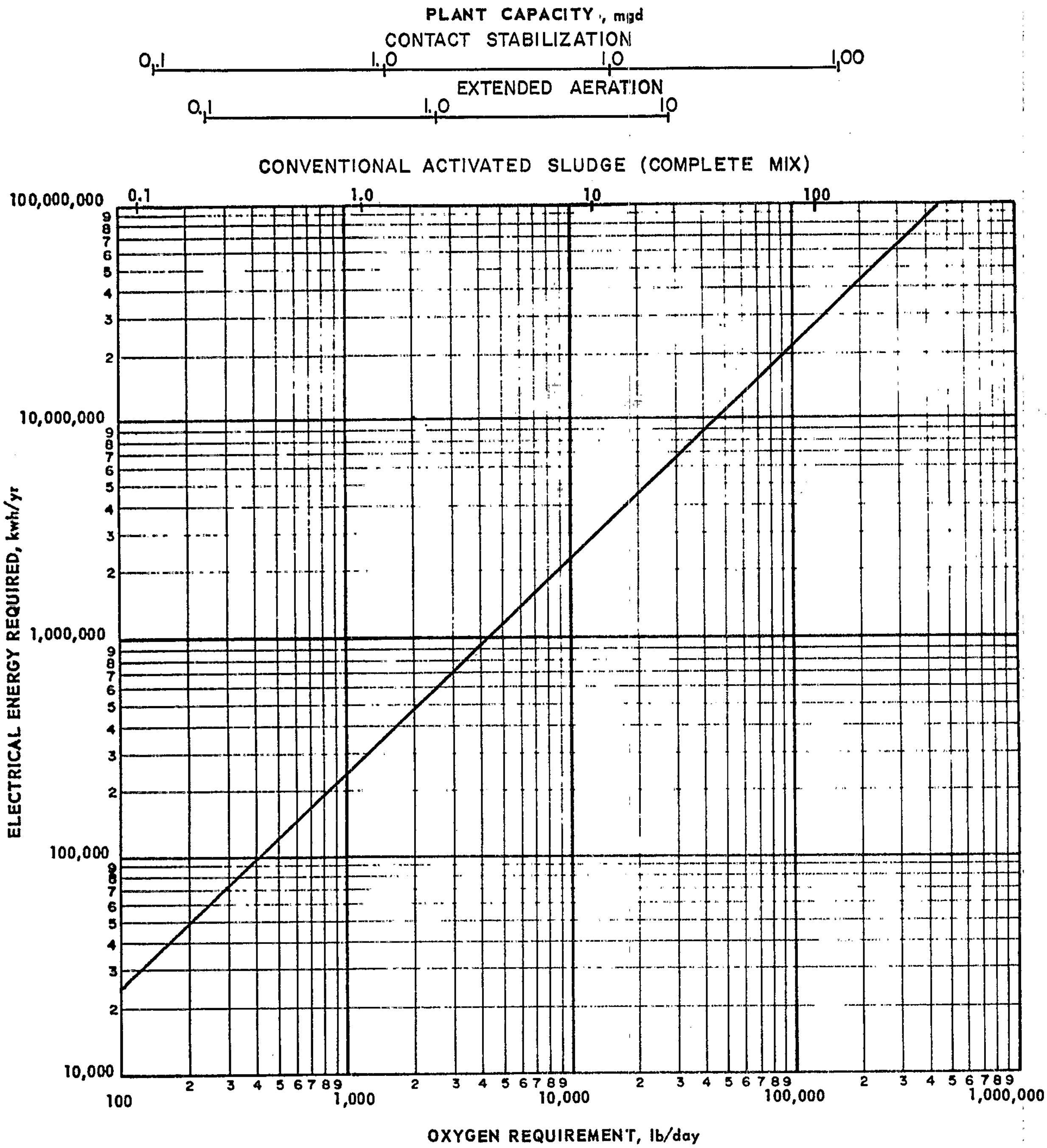
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:
- Oxygen transfer efficiency in wastewater = 1.53 lb O_2/hp-hr (wire to water)
- Surface aerators for dissolution
- Includes oxygen generation

Operating Parameter:
- Oxygen Requirement = 1.1 lb O_2 consumed /lb BOD_5 removed

Type of Energy Required: Electrical

FIGURE 3–25



ACTIVATED SLUDGE – COARSE BUBBLE DIFFUSION

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

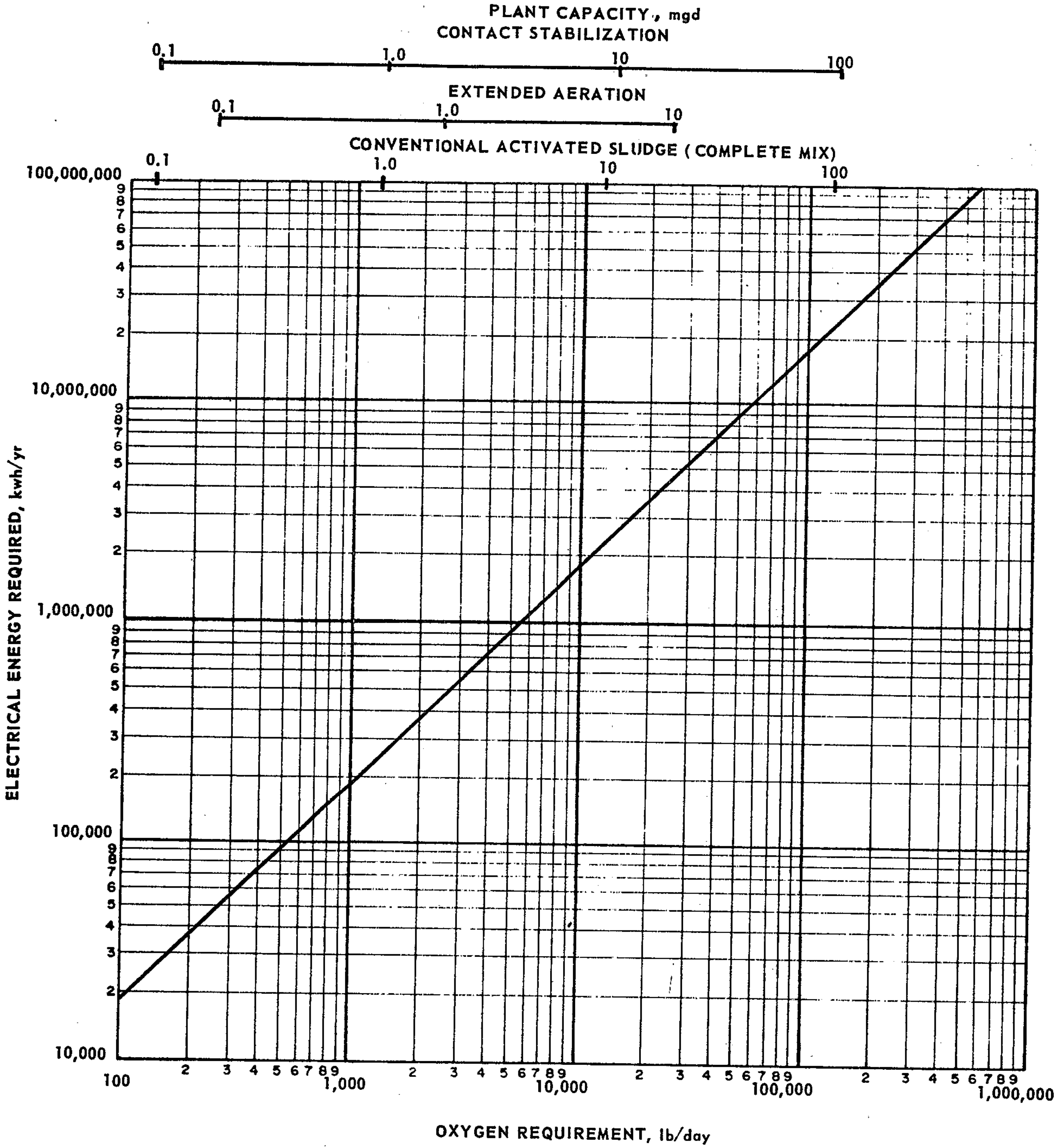
Design Assumptions:

Oxygen transfer efficiency in wastewater = 1.08 lb O_2/hp-hr (wire to water, including blower)
Average value for all types of diffusers

Operating Parameters:

Conventional activated sludge oxygen requirement = 1.0 lb O_2 consumed/lb BOD_5 removed
Extended aeration oxygen requirement = 1.5 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in reactor feed) Oxidized
Contact stabilization oxygen requirement = 1.1 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in recycle sludge) oxidized during reaeration

FIGURE 3-26



ACTIVATED SLUDGE – FINE BUBBLE DIFFUSION

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:

Oxygen transfer efficiency in wastewater = 1.44 lb O_2/hp hr (wire to water, including blower)
Average value for all types of diffusers

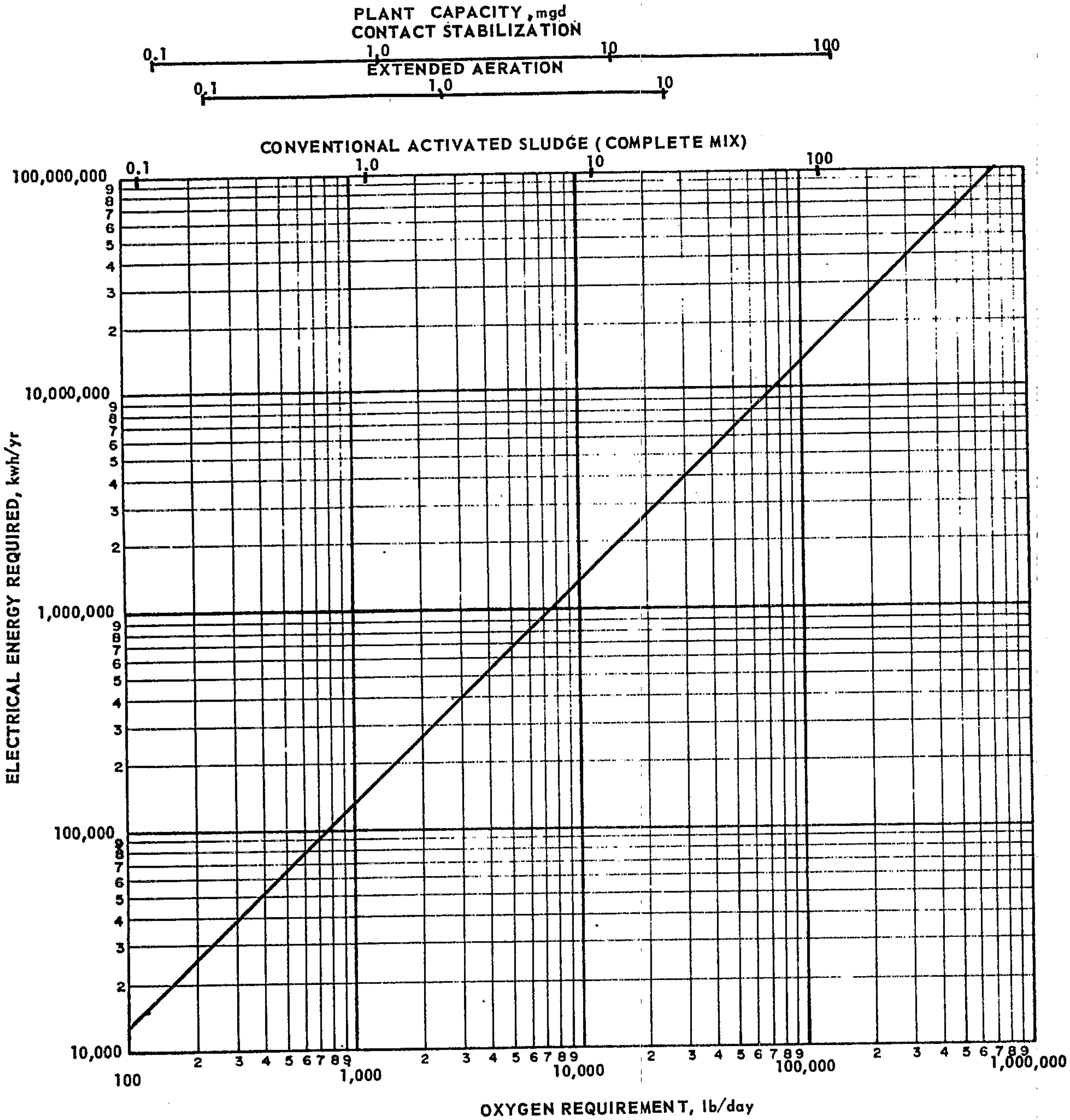
Operating Parameters:

Conventional activated sludge oxygen requirement = 1.0 lb O_2 consumed/lb BOD_5 removed

Extended aeration oxygen requirement = 1.5 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4–N (in reactor feed) oxidized

Contact stabilization oxygen requirement = 1.1 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4–N (in recycle sludge) oxidized during reaeration **FIGURE 3–27**

Type of Energy Required: Electrical



ACTIVATED SLUDGE TREATMENT -- MECHANICAL AERATION

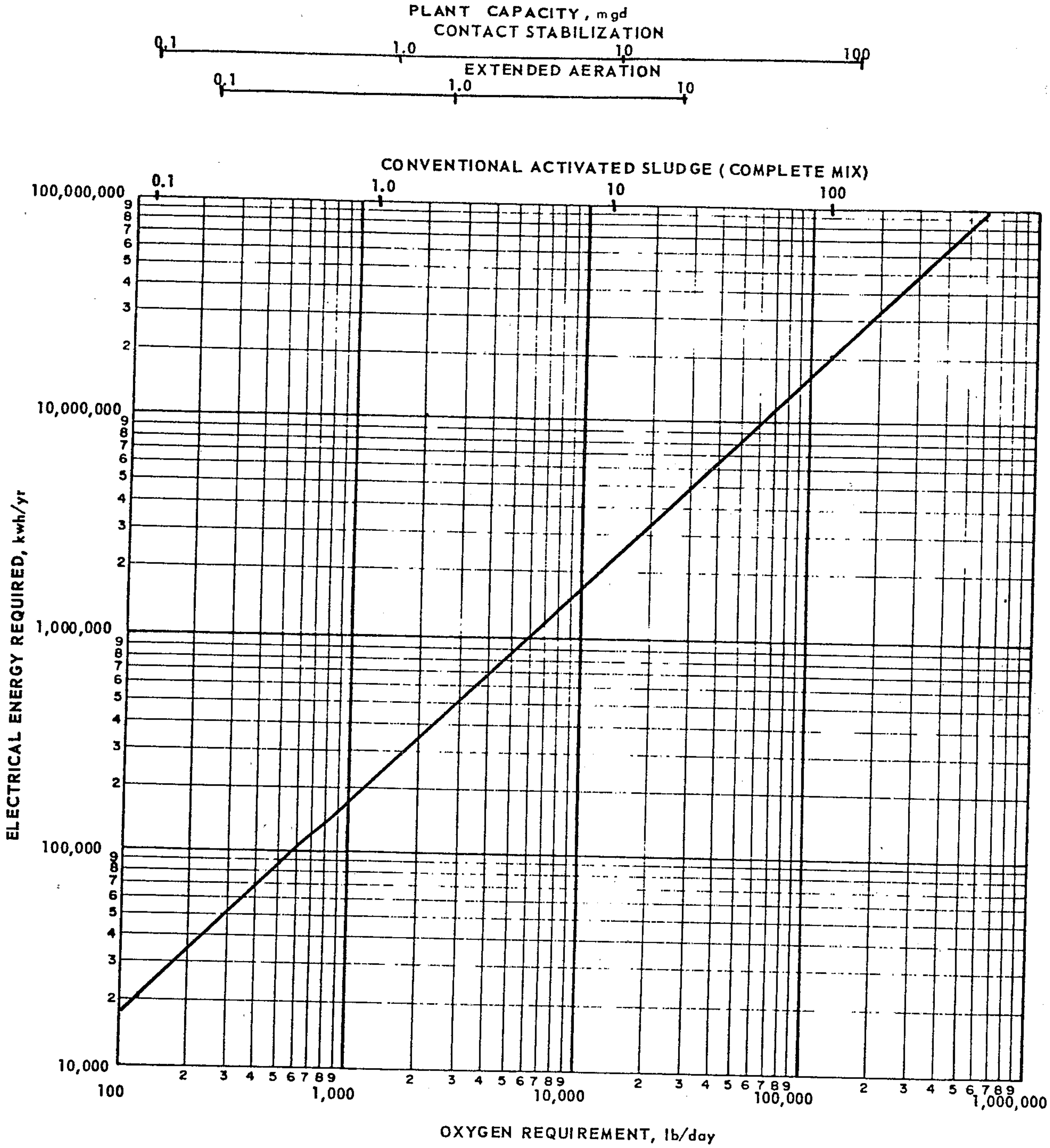
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:
- Oxygen transfer efficiency = 1.8 lb O_2/hp-hr (wire to water)
- Surface aerator, high speed

Operating Parameters:
- Conventional activated sludge requirement = 1.0 lb O_2 consumed / lb BOD_5 removed
- Extended aeration oxygen requirement = 1.5 lb O_2 consumed / lb BOD_5 removed + 4.6 lb O_2 consumed / lb NH_4-N (in reactor feed) oxidized
- Contact stabilization oxygen requirement = 1.1 lb O_2 consumed / lb BOD_5 removed + 4.6 lb O_2 consumed / lb NH_4-N (in recycle sludge) oxidized during reaeration

FIGURE 3-28

Type of Energy Required: Electrical



ACTIVATED SLUDGE – TURBINE SPARGER

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:

Oxygen transfer efficiency in wastewater = 1.6 lb O_2/hp-hr (wire to water)

Operating Parameters:

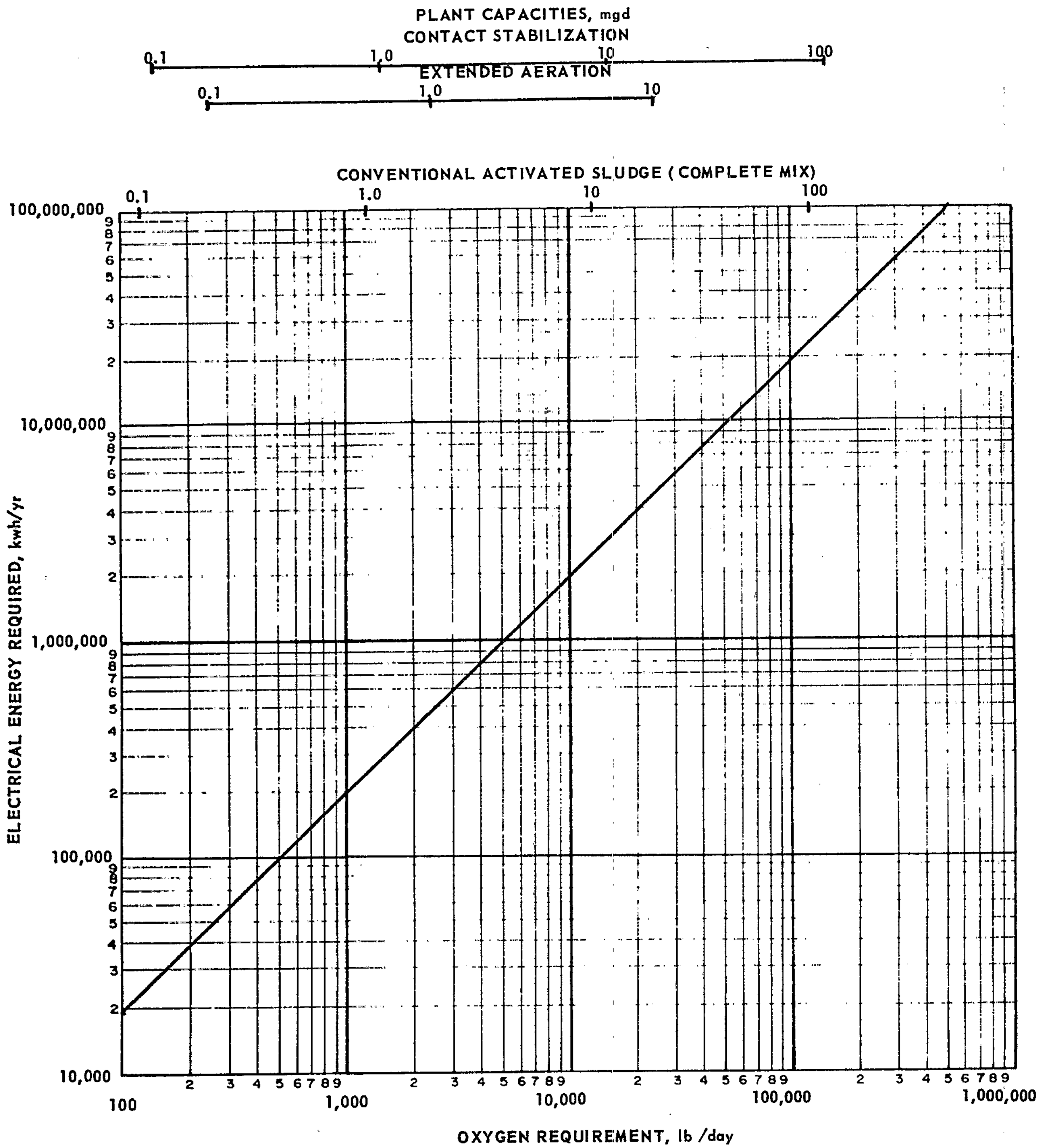
Conventional activated sludge oxygen requirement = 1.0 lb O_2 consumed/lb BOD_5 removed

Extended aeration oxygen requirement = 1.5 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in reactor feed) oxidized

Contact stabilization oxygen requirement = 1.1 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in recycle sludge) oxidized during reaeration

Type of Energy Required: Electrical

FIGURE 3–29



ACTIVATED SLUDGE – STATIC MIXER

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:

Oxygen transfer efficiency = 1.44 lb O_2/hp-hr (wire to water)

Operating Parameters:

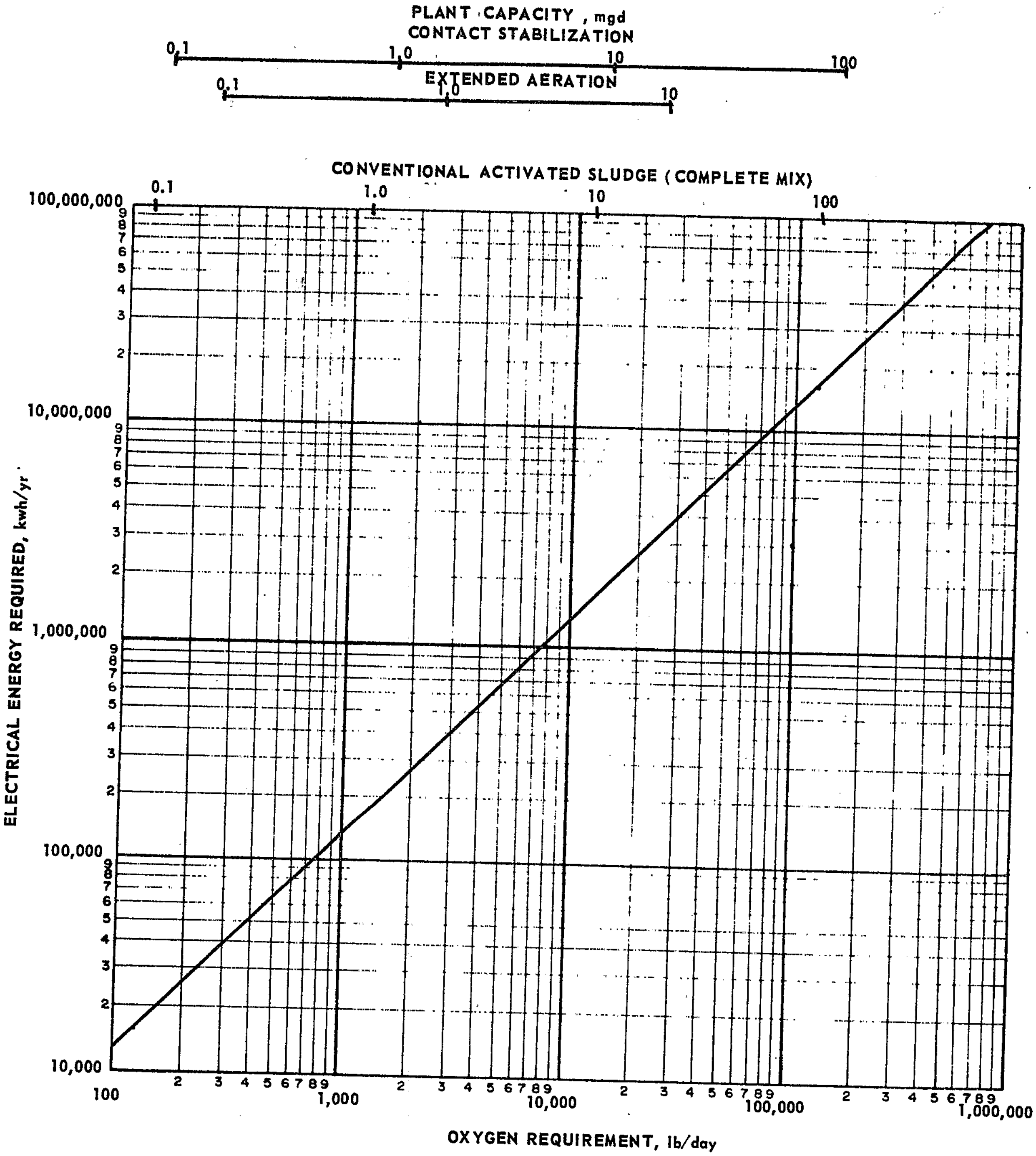
Conventional activated sludge oxygen requirement = 1.0 lb O_2 consumed/lb BOD_5 removed

Extended aeration oxygen requirement = 1.5 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4–N (in reactor feed) oxidized

Contact stabilization oxygen requirement = 1.1 lb O_2 consumed/lb BOD_5 removed + 4.6 lb. O_2 consumed/lb NH_4–N (in recycle sludge) oxidized during reaeration

Type of Energy Requirement: Electrical

FIGURE 3–30



ACTIVATED SLUDGE –JET DIFFUSER

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20
Suspended Solids	80	20

Design Assumptions:

Oxygen transfer efficiency in wastewater = 1.8 lb O_2/hp-hr (wire to water)

Operating Parameters:

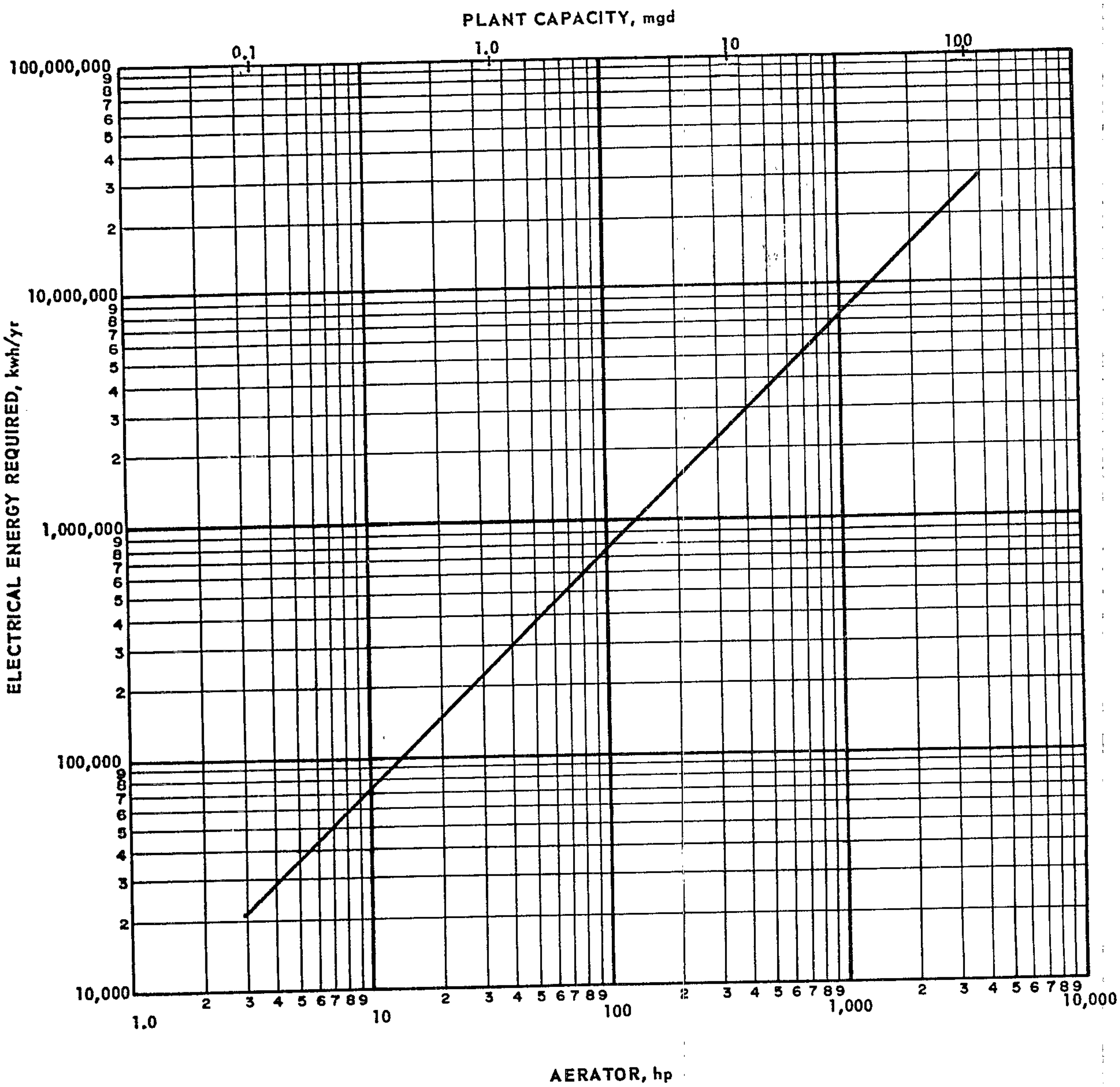
Conventional activated sludge oxygen requirement = 1.0 lb O_2 consumed/lb BOD_5 removed

Extended aeration oxygen requirement = 1.5 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in reactor feed) oxidized

Contact stabilization oxygen requirement = 1.1 lb O_2 consumed/lb BOD_5 removed + 4.6 lb O_2 consumed/lb NH_4-N (in recycle sludge) oxidized during reaeration

Type of Energy Required: Electrical

FIGURE 3–31



AERATED PONDS

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
BOD_5	210	25
Suspended Solids	230	25

Design Assumptions:

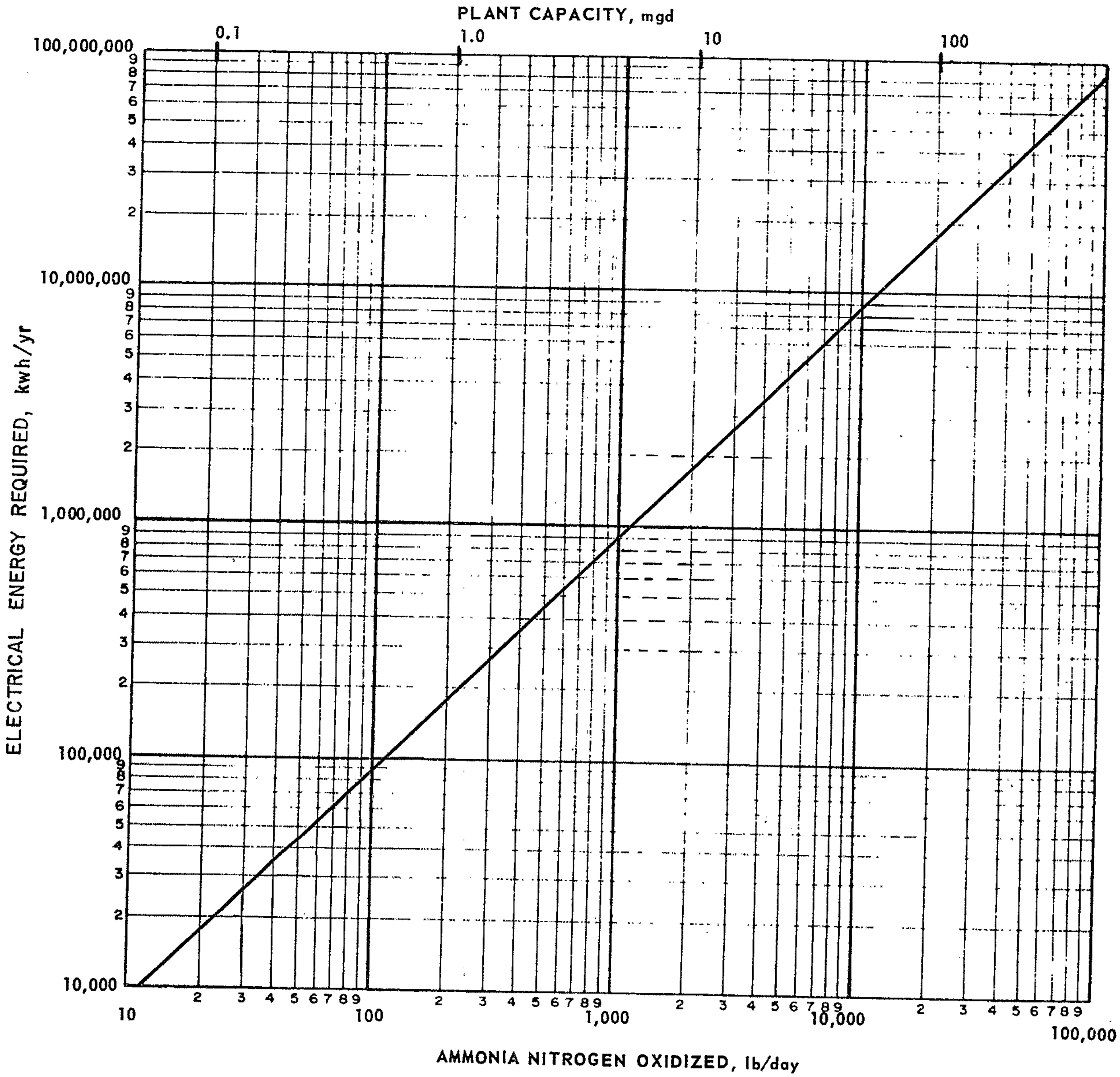
Low-speed mechanical surface aerators
Motor efficiency = 90%
Aerator efficiency = 1.8 lb O_2/hp-hr (wire to water)
3 cells - Ist cell aerated
Total detention time = 30 days

Operating Parameter:

Oxygen requirement = 1.0 lb O_2/lb BOD_5 removed

Type of Energy Required: Electrical

FIGURE 3-32



NITRIFICATION – SUSPENDED GROWTH

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
Ammonia as N	25	1
BOD_5	50	10

Design Assumptions:

Mechanical aeration, oxygen transfer efficiency = 1.8 lb O_2/hp–hr (wire to water)

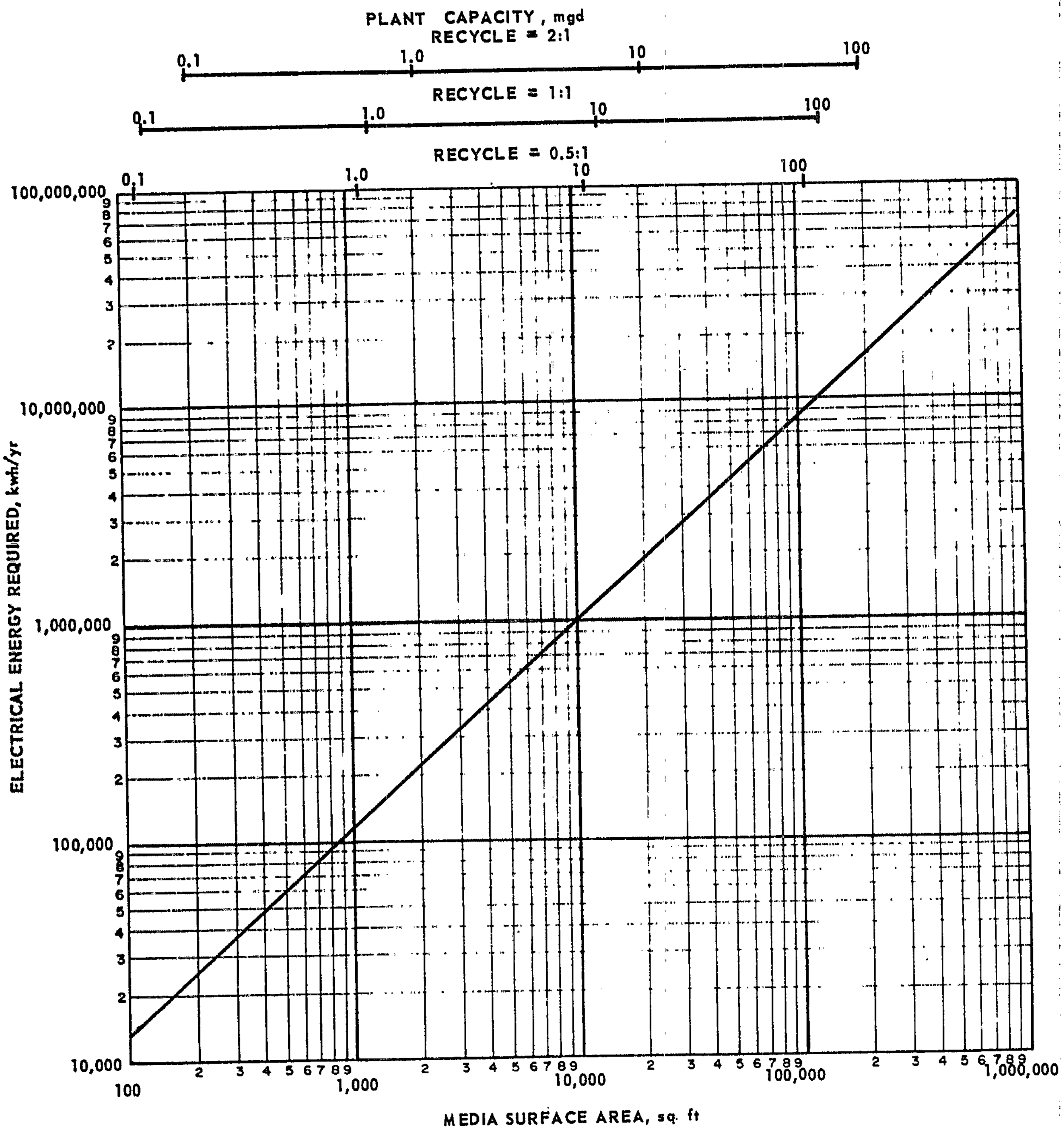
Use of lime has no significant impact on energy requirement

Operating Parameter:

Oxygen requirement = 4.6 lb O_2/lb NH_4-N + 1.0 lb O_2/lb BOD_5

Type of Energy Required: Electrical

FIGURE 3–33



NITRIFICATION, FIXED FILM REACTOR

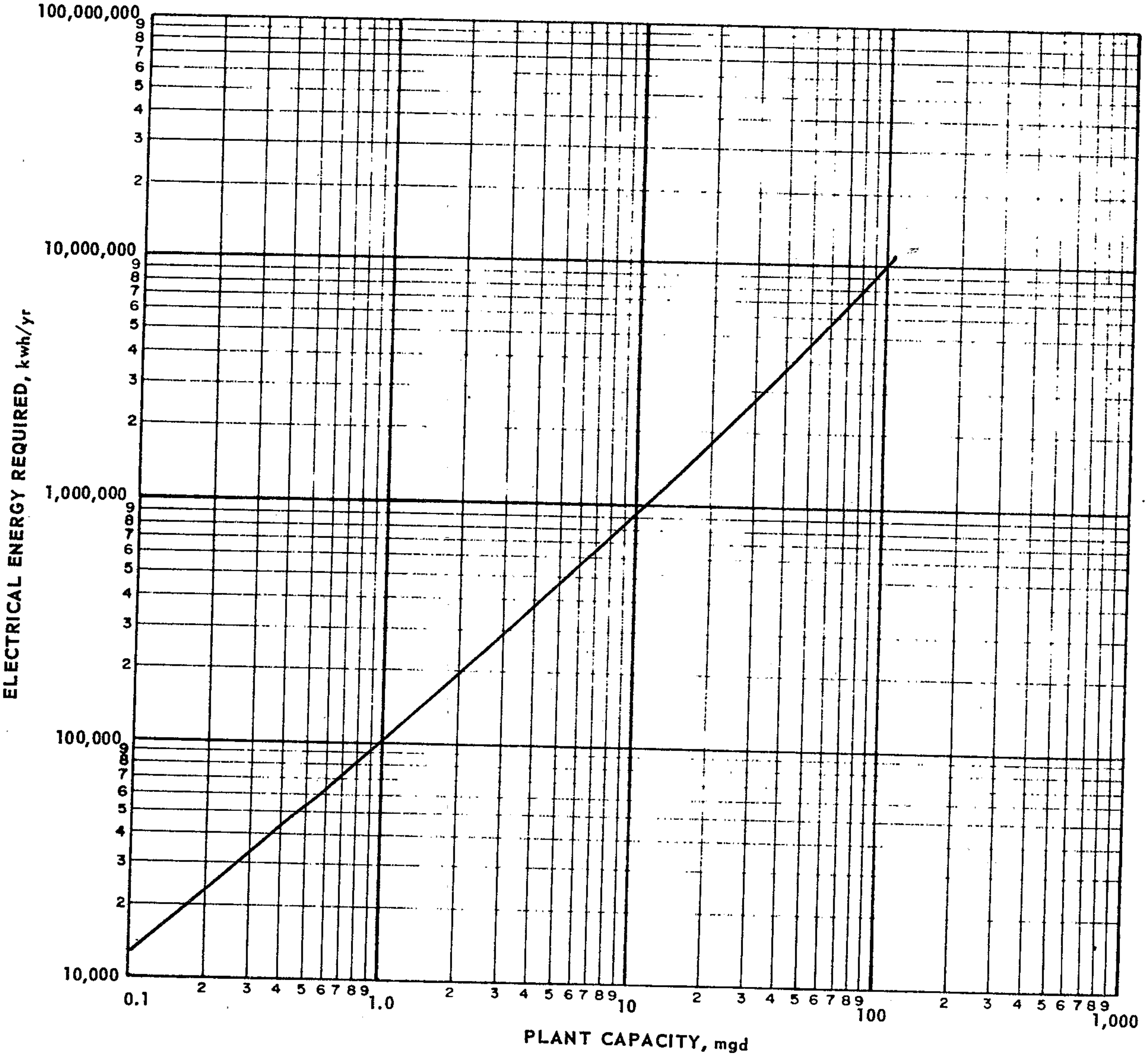
Water Quality:	Influent (mg/l)	Effluent (mg/l)
Ammonia as N	25	2.5
BOD_5	50	10

Design Assumptions:

No forced draft
Plastic media
Pumping TDH = 40 ft

Type of Energy Required: Electrical

FIGURE 3–34



DENITRIFICATION – SUSPENDED GROWTH (OVERALL)

(Includes Methanol addition, reaeration, sedimentation and sludge recycle)

Water Quality:	Influent (mg/l)	Effluent (mg/l)
NO_3–N	25	0.5

Design Assumptions:

Methanol – Nitrogen ratio 3:1

Remaining design assumptions and operating parameters are shown on the following curves

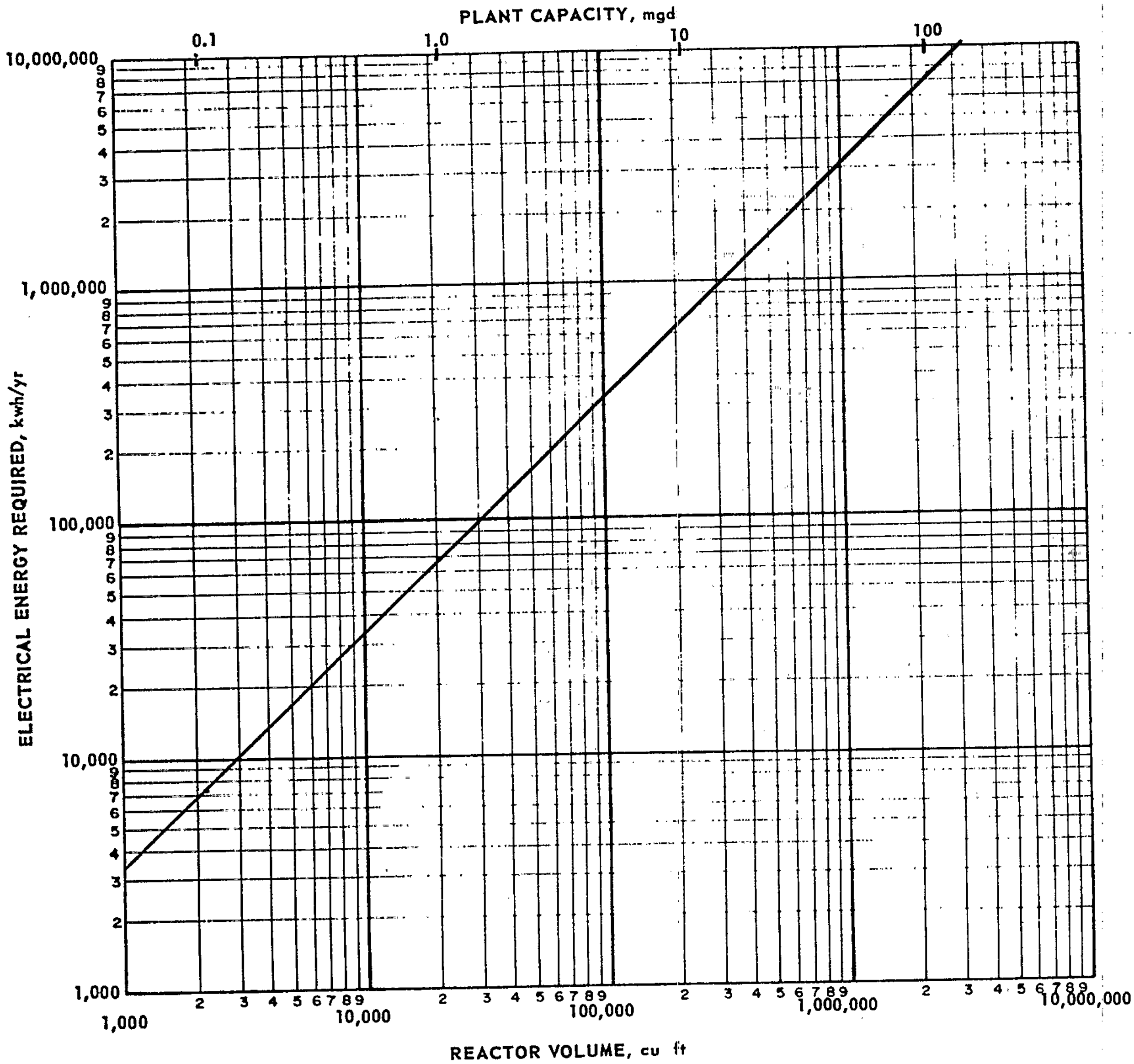
Denitrification Reactor, Figure 3–36

Reaeration, Figure 3–37

Sedimentation and Sludge Recycle, Figure 3–38

Type of Energy Required: Electrical

FIGURE 3–35



DENITRIFICATION – SUSPENDED GROWTH REACTOR

Design Assumptions:

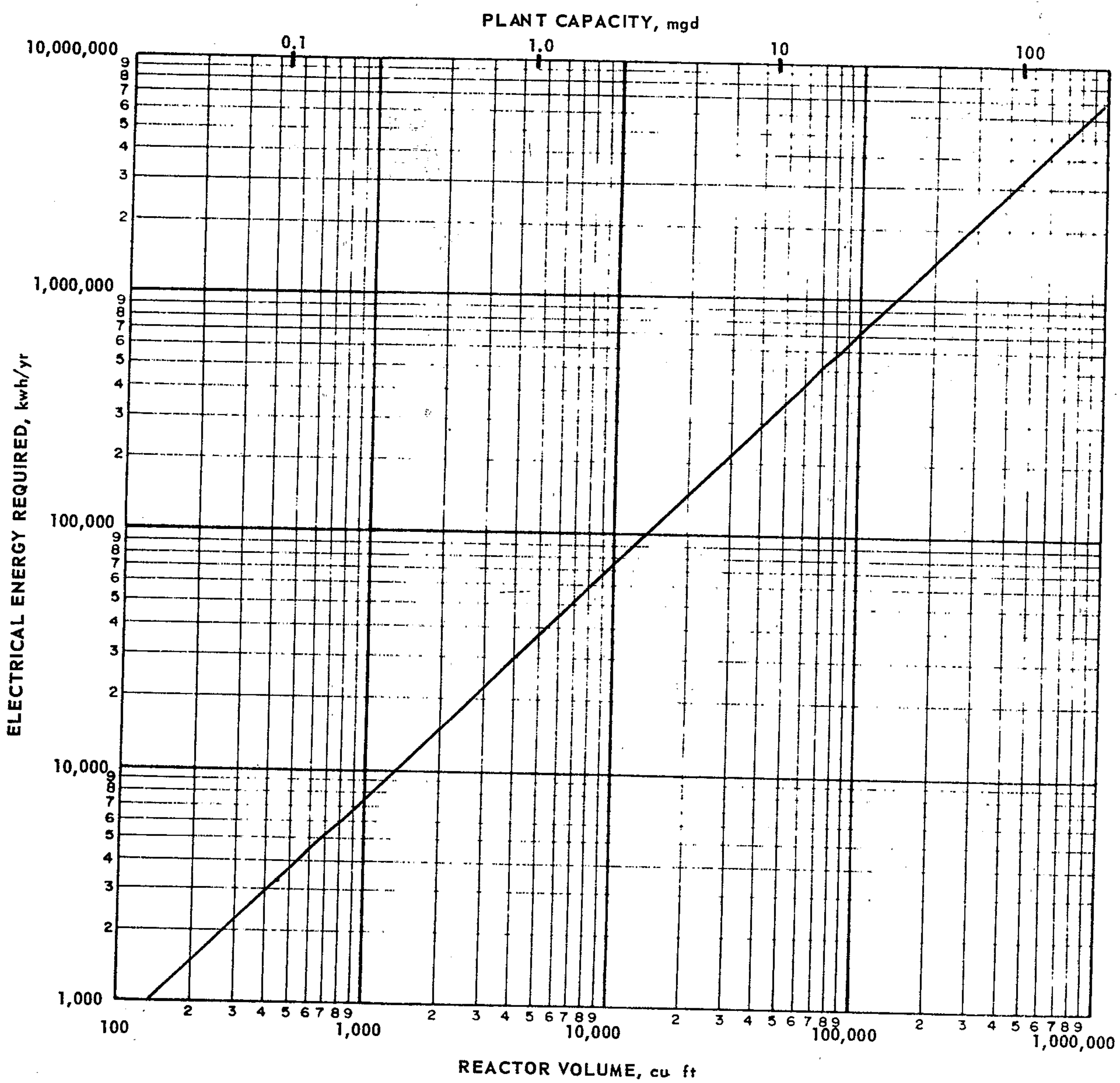
Temperature = 15° C
Nitrate removal = 0.1 lb NO_3–N/lb MLVSS/day
Mixing device, submerged turbines, hp = 0.5 hp/1000 cu ft
Methanol addition is included

Operating Parameter:

MLVSS = 1500 mg/l

Type of Energy Required: Electrical

FIGURE 3–36



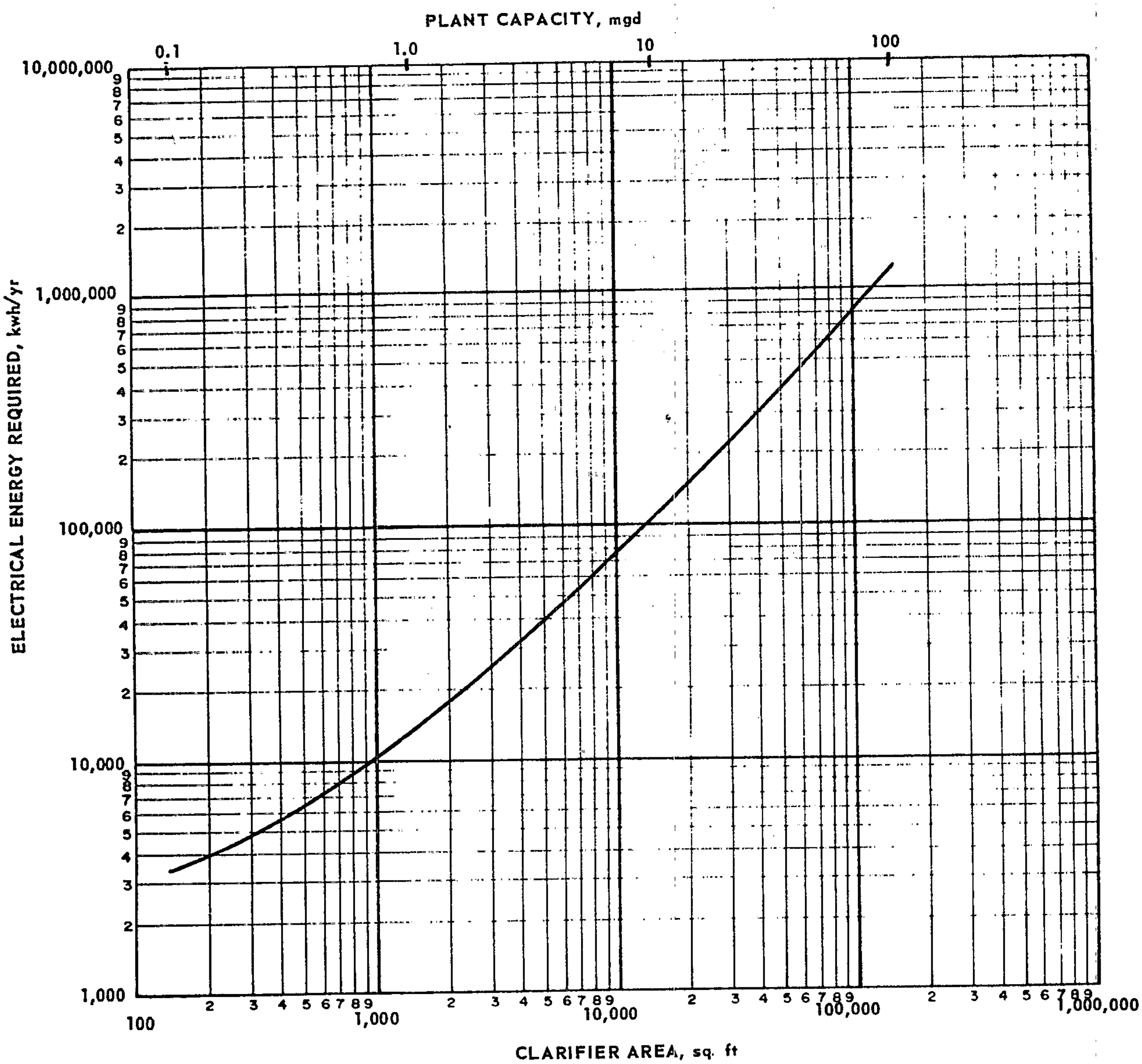
DENITRIFICATION, AERATED STABILIZATION REACTOR

Desing Assumptions:

Detention time ≃ 50 min
Mechanical aeration ≈ 1 hp/1000 cu ft

Type of Energy Required: Electrical

FIGURE 3–37

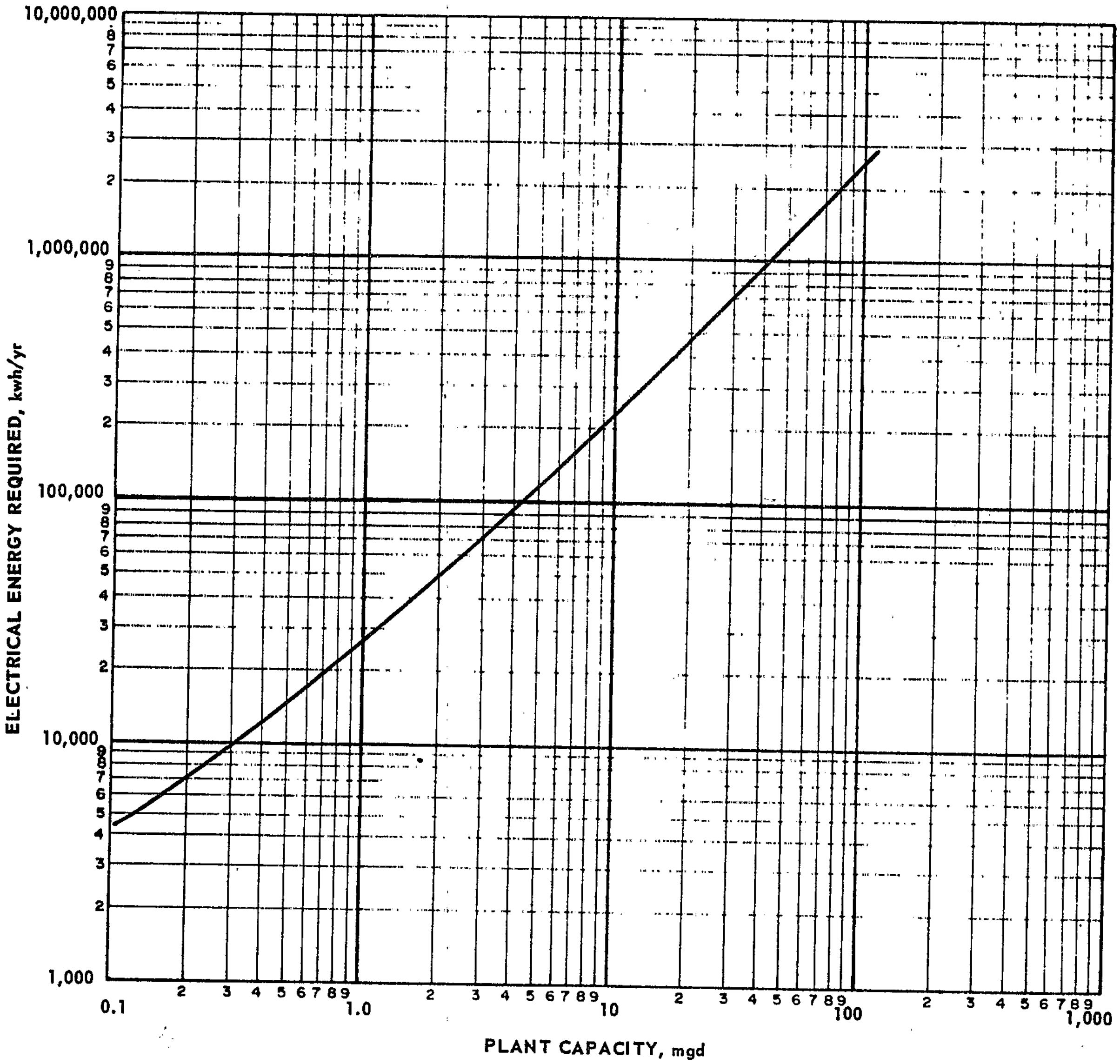


DENITRIFICATION, SEDIMENTATION AND SLUDGE RECYCLE

Design Assumptions:
Surface loading = 700 gpd/sq. ft
Sludge recycle = 50% @ 15 ft TDH

Type of Energy Required: Electrical

FIGURE 3–38



DENITRIFICATION – FIXED FILM, PRESSURE

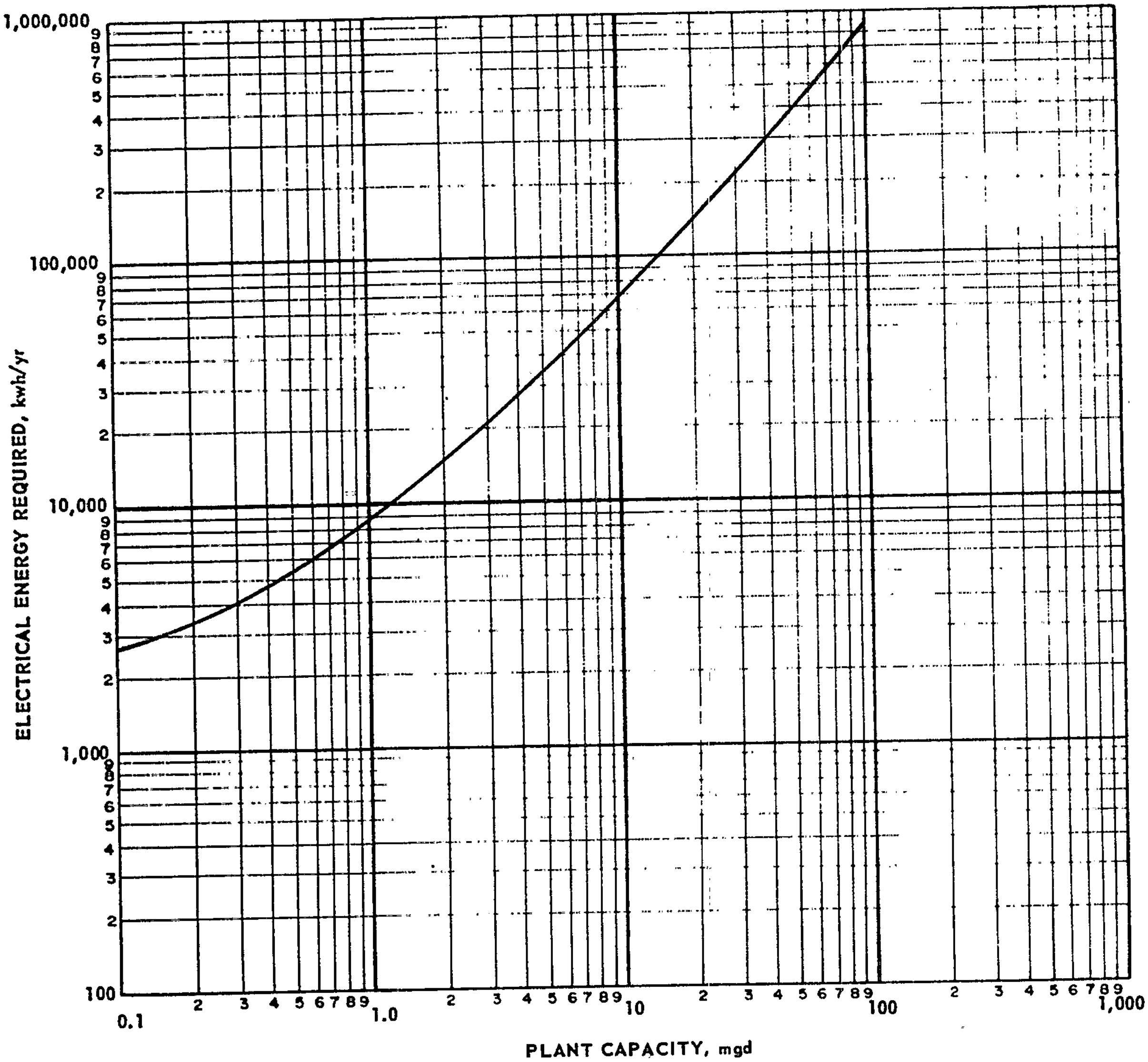
Water Quality:	Influent, (mg/l)	Effluent (mg/l)
Nitrate as N	25	0.5

Design Assumptions:
- Sand media size = 2–4 mm
- Influent pumping TDH = 15 ft
- Loading rate = 1.7 gpm/sq. ft
- Temp = 15°C
- Depth = 6 ft.

Operating Parameters:
- Backwash every 2 days for 15 min @ 25 gpm/sq ft and 25 ft TDH
- Methanol addition = 3:1 ($CH_3OH:NO_3-N$)

Type of Energy Required: Electrical

FIGURE 3–39



DENITRIFICATION – FIXED FILM, GRAVITY

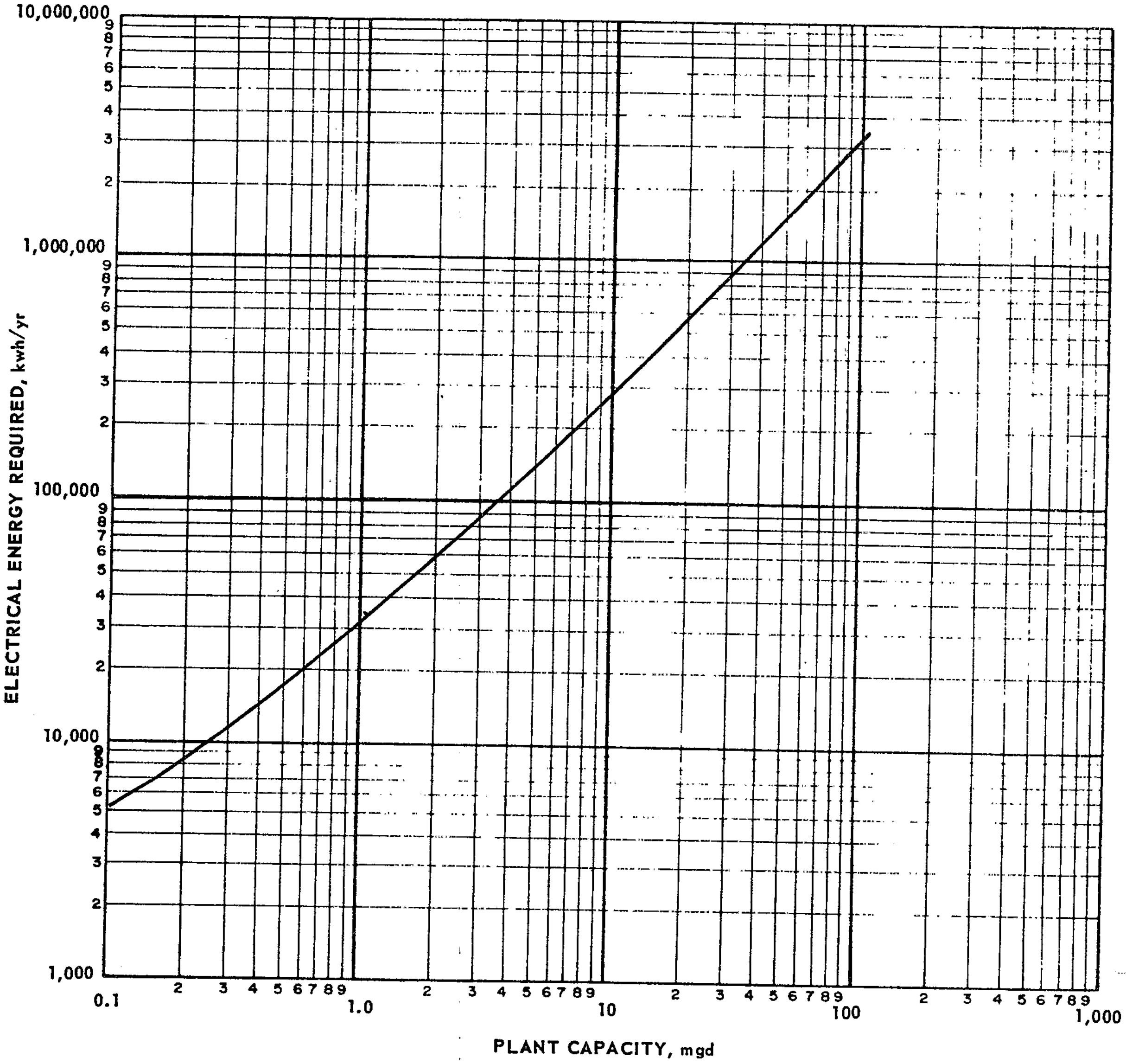
Water Quality:	Influent (mg/l)	Effluent (mg/l)
Nitrate as N	25	0.5

Design Assumptions:
- Sand media size = 2–4 mm
- Depth = 6 ft
- Loading rate = 1.7 gpm /sq ft
- Temperature = 15°C

Operating Parameters:
- Backwash 15 min/day @ 25 gpm/sq ft and 25 ft. TDH
- Methanol addition = 3:1 (CH_3OH: NO_3 –N)

Type of Energy Required: Electrical

FIGURE 3–40



DENITRIFICATION – FIXED FILM, UPFLOW
(BASED ON EXPERIMENTAL DATA)

Water Quality:	Influent (mg/l)	Effluent (mg/l)
Nitrate as N	25	0.5

Design Assumptions:

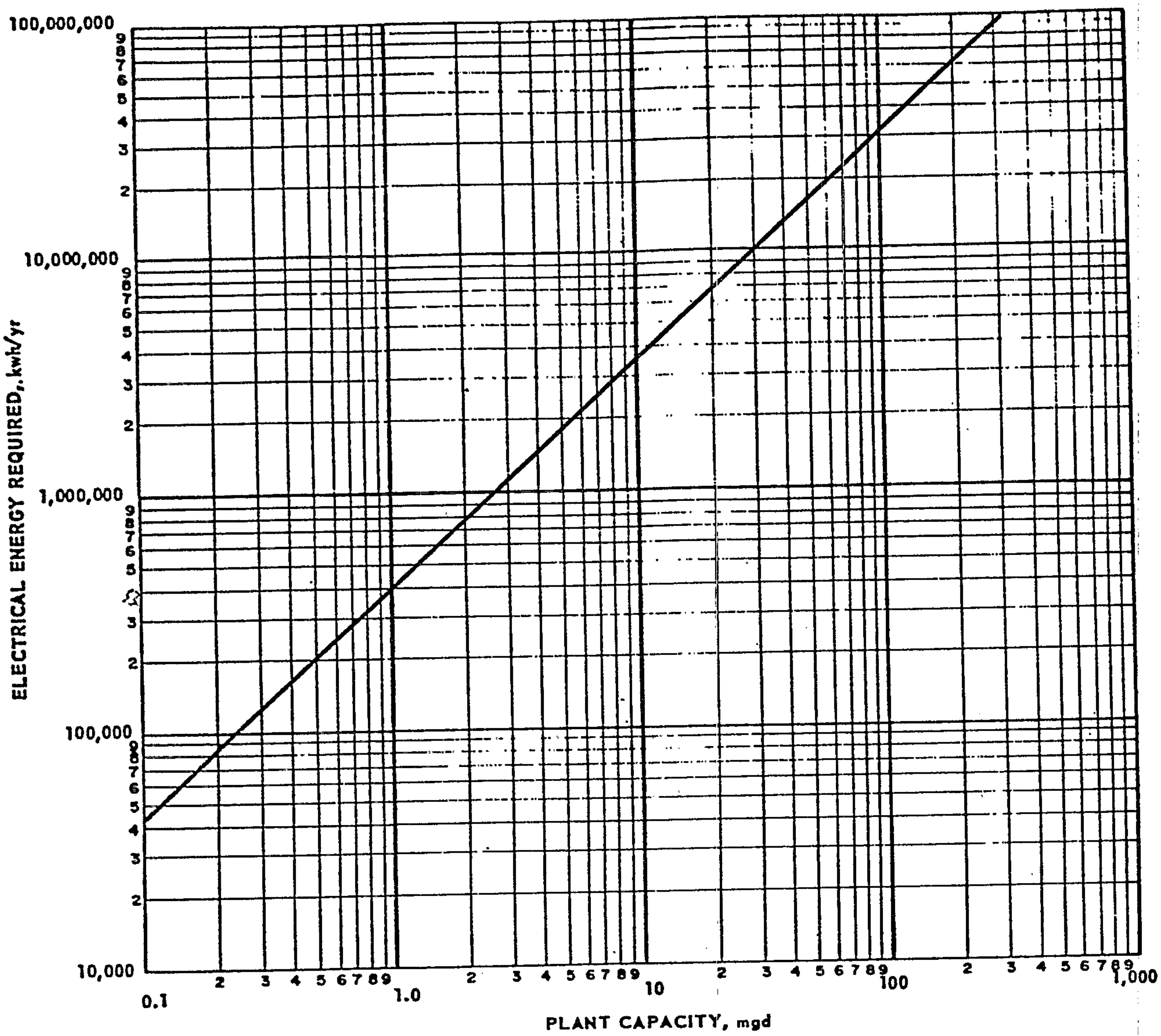
Sand media size ≑ 0.6 mm
Fluidized depth = 12 ft
Influent pumping TDH = 20 ft
Temperature = 15°C

Operating Parameters:

Methanol addition = 3:1 ($CH_3OH:NO_3$–N)

Type of Energy Required: Electrical

FIGURE 3–41



SINGLE STAGE CARBONACEOUS, NITRIFICATION, AND DENITRIFICATION WITHOUT METHANOL ADDITION, PULSED AIR

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	210	20
TKN	30	7.5
Temperature	15°C	–

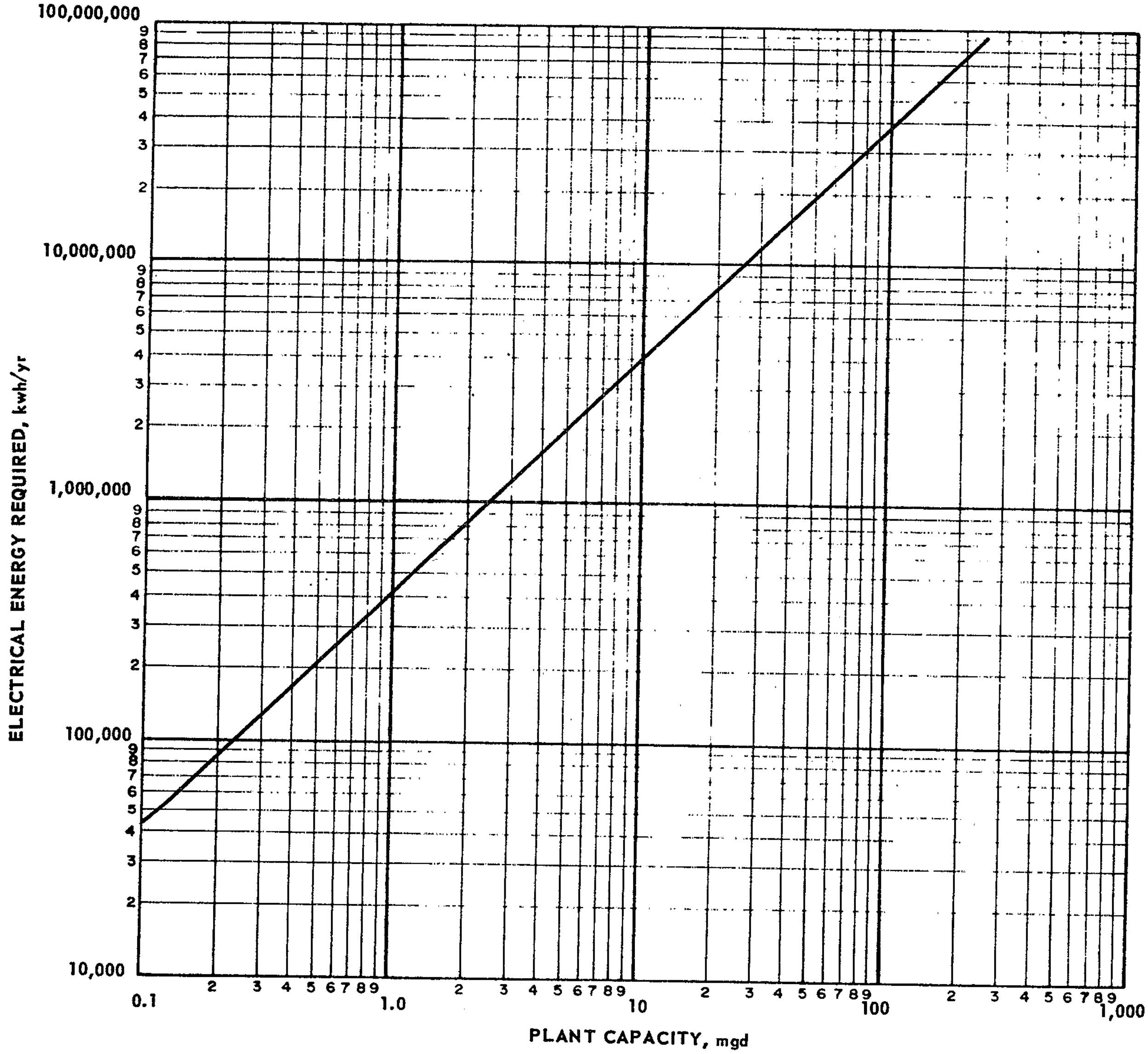
Operating Parameters:

Oxygen supply for nitrification/denitrification = 1.2 BOD_5 removed + 4.2 (TKN removed) – 4.6 (0.6 TKN applied)*
Mechanical aeration
Denitrification mixing = 0.5 hp/1000 cu ft
Detention time = 12 hours
Includes final sedimentation @ 300 gpd/sq ft and 50% sludge recycle

Type of Energy Required: Electrical

* Reference: Bishop, D.F., et. al., WPCF Journal, p. 520 (1976)

FIGURE 3–42



SEPARATE STAGE CARBONACEOUS, NITRIFICATION AND DENITRIFICATION WITHOUT METHANOL ADDITION
(BASED ON EXPERIMENTAL DATA)

Water Quality:

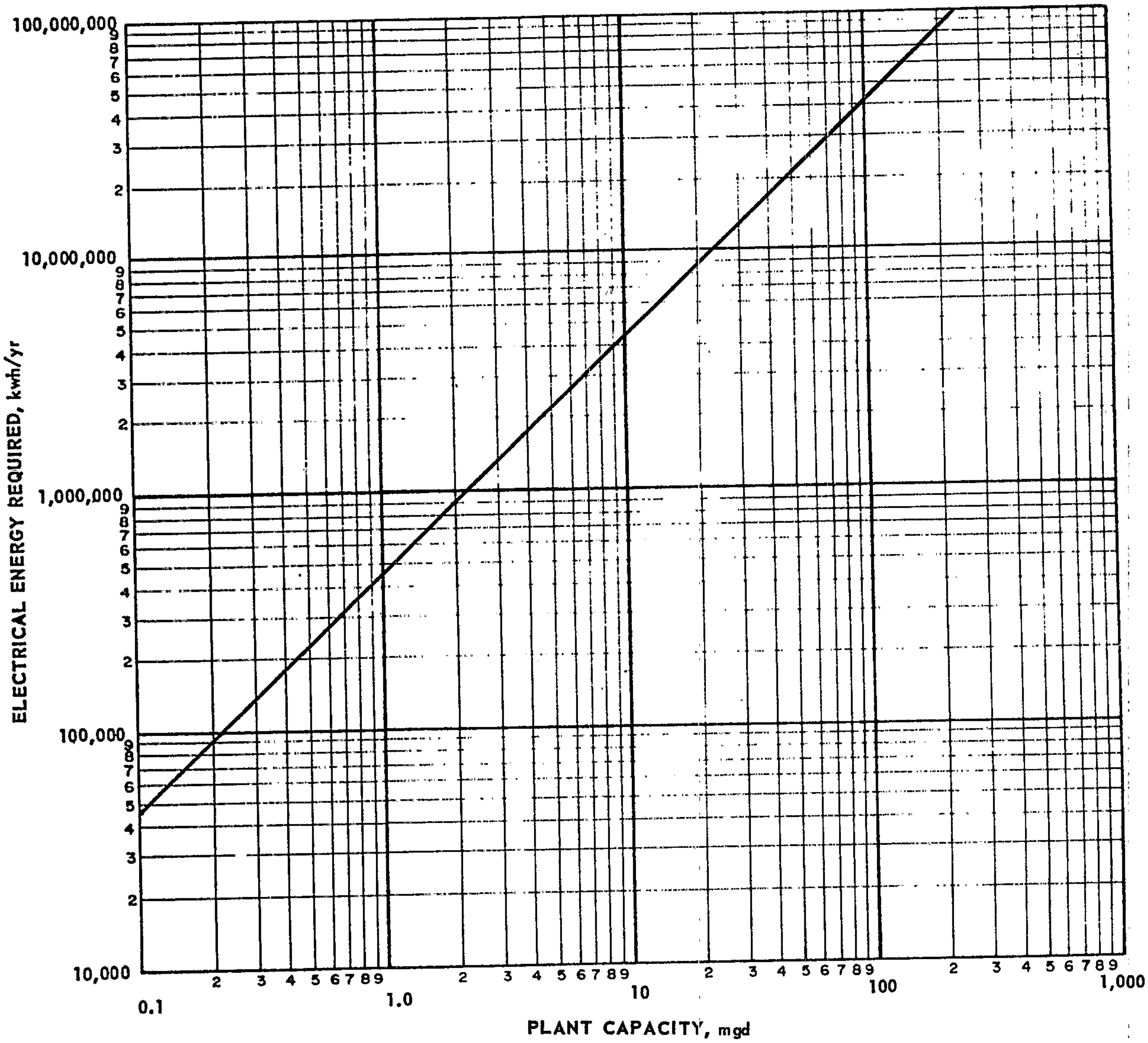
	Influent (mg/l)	Effluent (mg/l)
BOD_5	210	20
NH_3-N	30	7.5
Temperature	15°C	-

Operating Parameters:

Air supply for nitrification ≃ 1.1 lb O_2/lb BOD removed + 4.6 lb O_2/lb NH_4-N removed
Mechanical aeration, 1.8 lb O_2 transferred/hp-hr
Denitrification mixing ≃ 0.5 hp/1000 cu ft; 3 hr detention
Final aeration stage ≃ 1 hr detention; 1 hp/1000 cu ft
Sedimentation @ 700 gpd/sq ft; 30% recycle

Type of Energy Required: Electrical

FIGURE 3-43



SINGLE STAGE CARBONACEOUS, NITRIFICATION, AND DENITRIFICATION WITHOUT METHANOL ADDITION -- ORBITAL PLANTS *

(BASED ON EXPERIMENTAL DATA)

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
BOD	210	15
NH_3-N	30	4.5
Temperature	15°C	

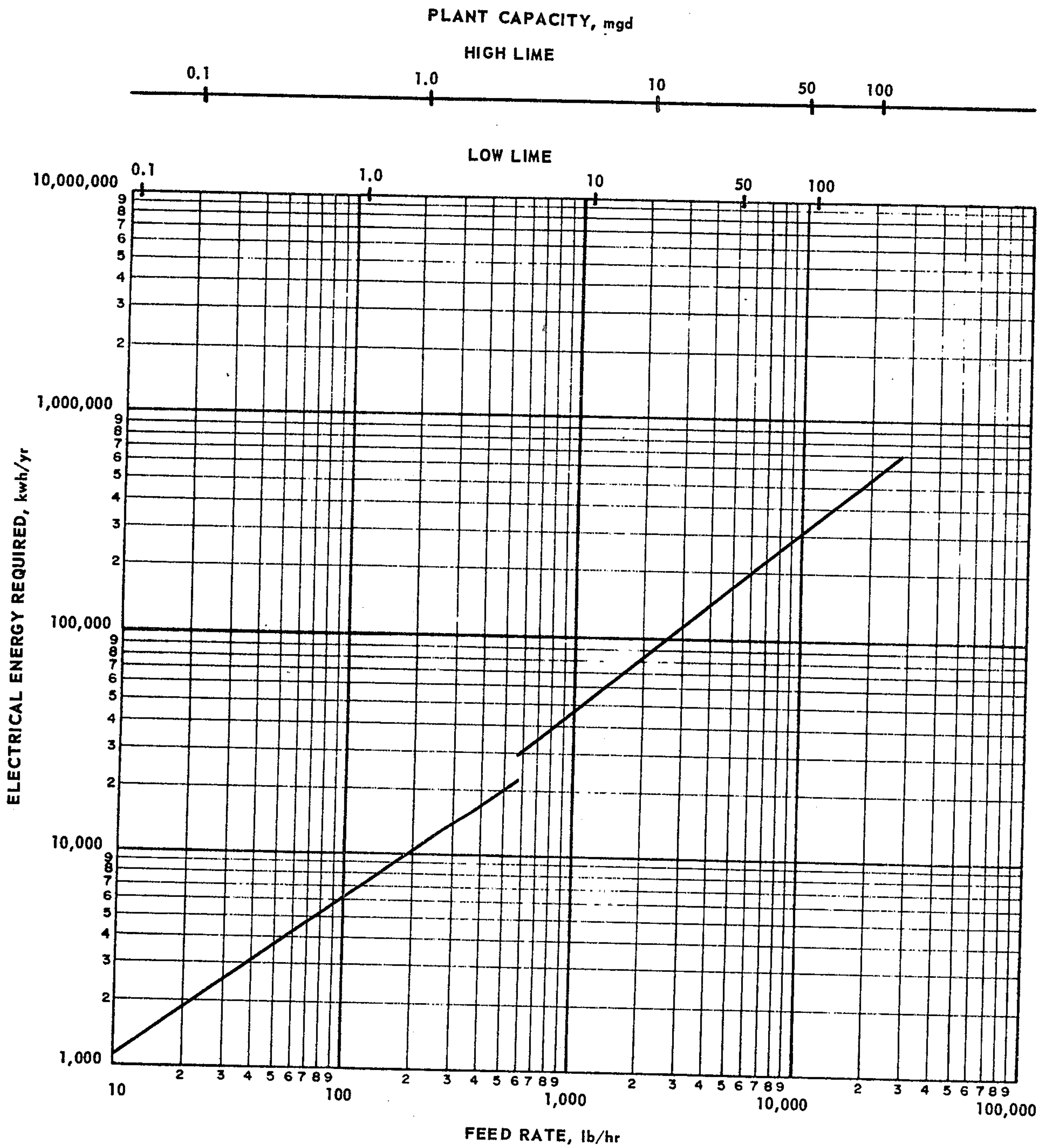
Operating Parameters:

Total aeration ditch detention time = 8 hr
F/M ratio = 0.16
Rotor aeration
Sedimentation @ 700 gpd/sq ft; 50% recycle

Type of Energy Required: Electrical

* Reference: Natsche, N.F. and Spatzierer, G., Austrian Plant Knocks Out Nitrogen, Water & Wastes Engr., p. 18 (Jan, 1975)

FIGURE 3–44



LIME FEEDING

Design Assumptions:

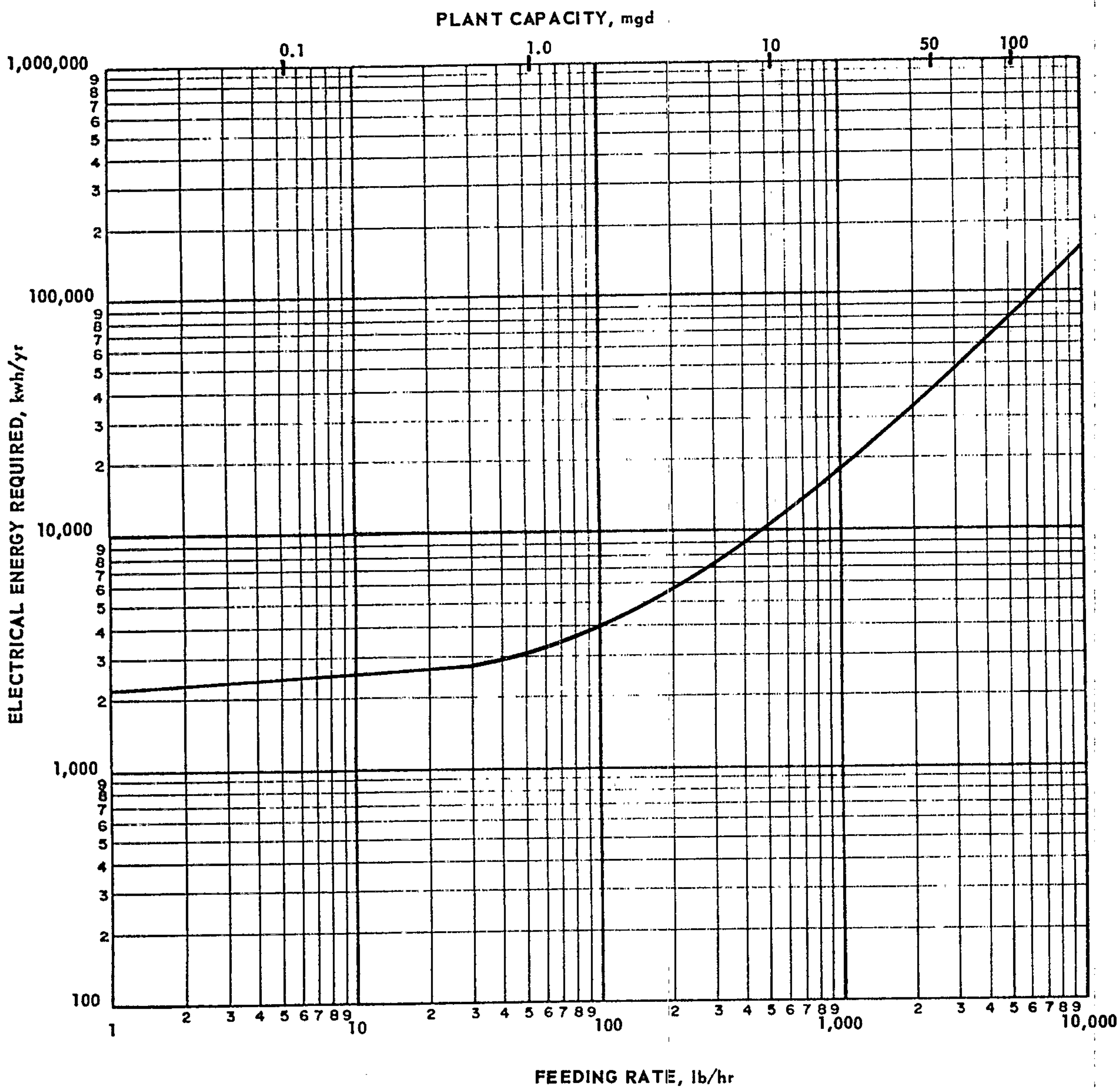
Slaked lime used for 0.1–5 mgd capacity plants
Quicklime used for 5–100 mgd capacity plants

Operating Parameters:

300 mg/l, Low Lime as $Ca(OH)_2$
600 mg/l, High Lime as $Ca(OH)_2$

Type of Energy Required: Electrical

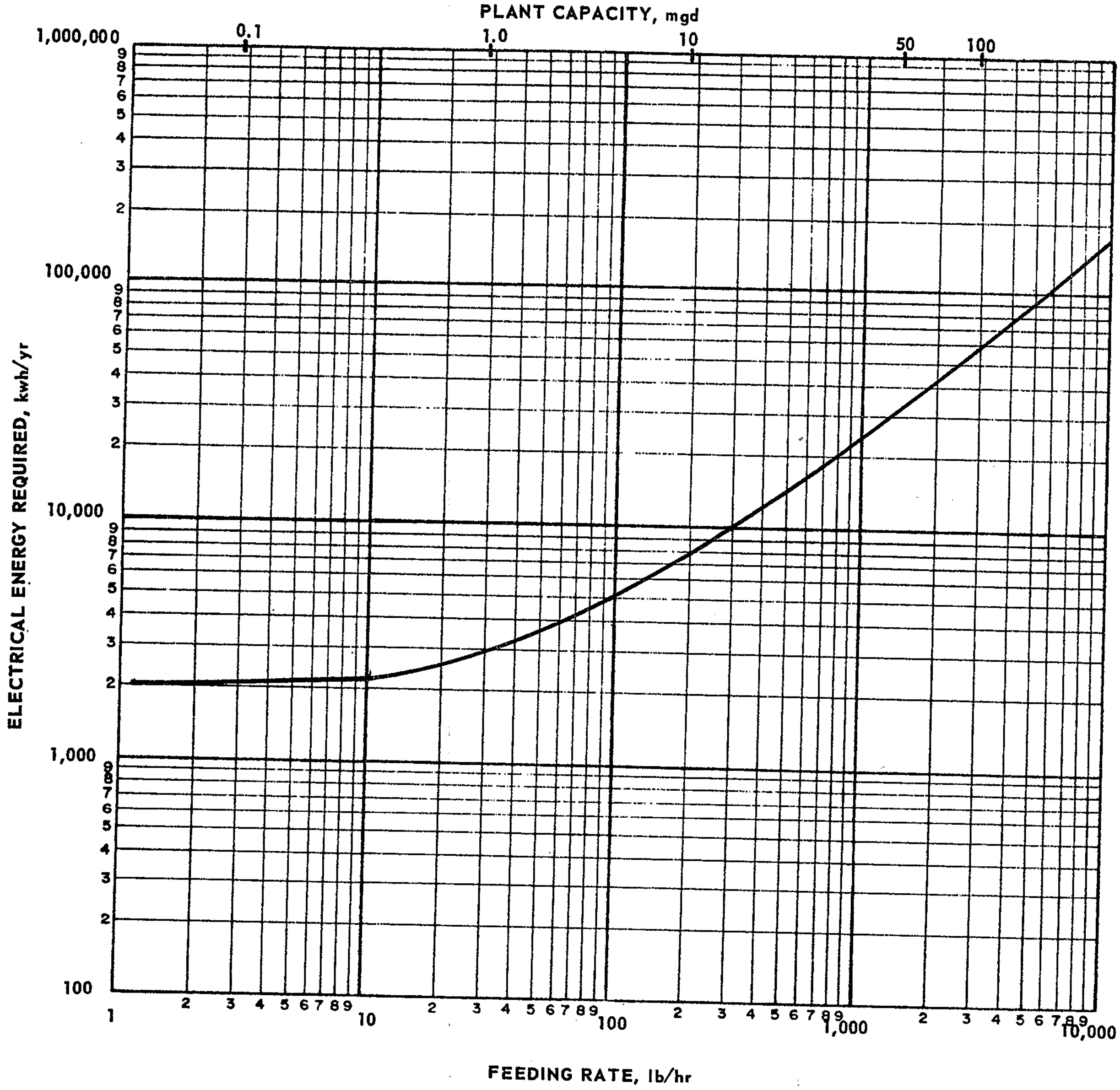
FIGURE 3–45



ALUM FEEDING

Operating Parameters:
Dosage — 150 mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$
Type of Energy Required: Electrical

FIGURE 3–46



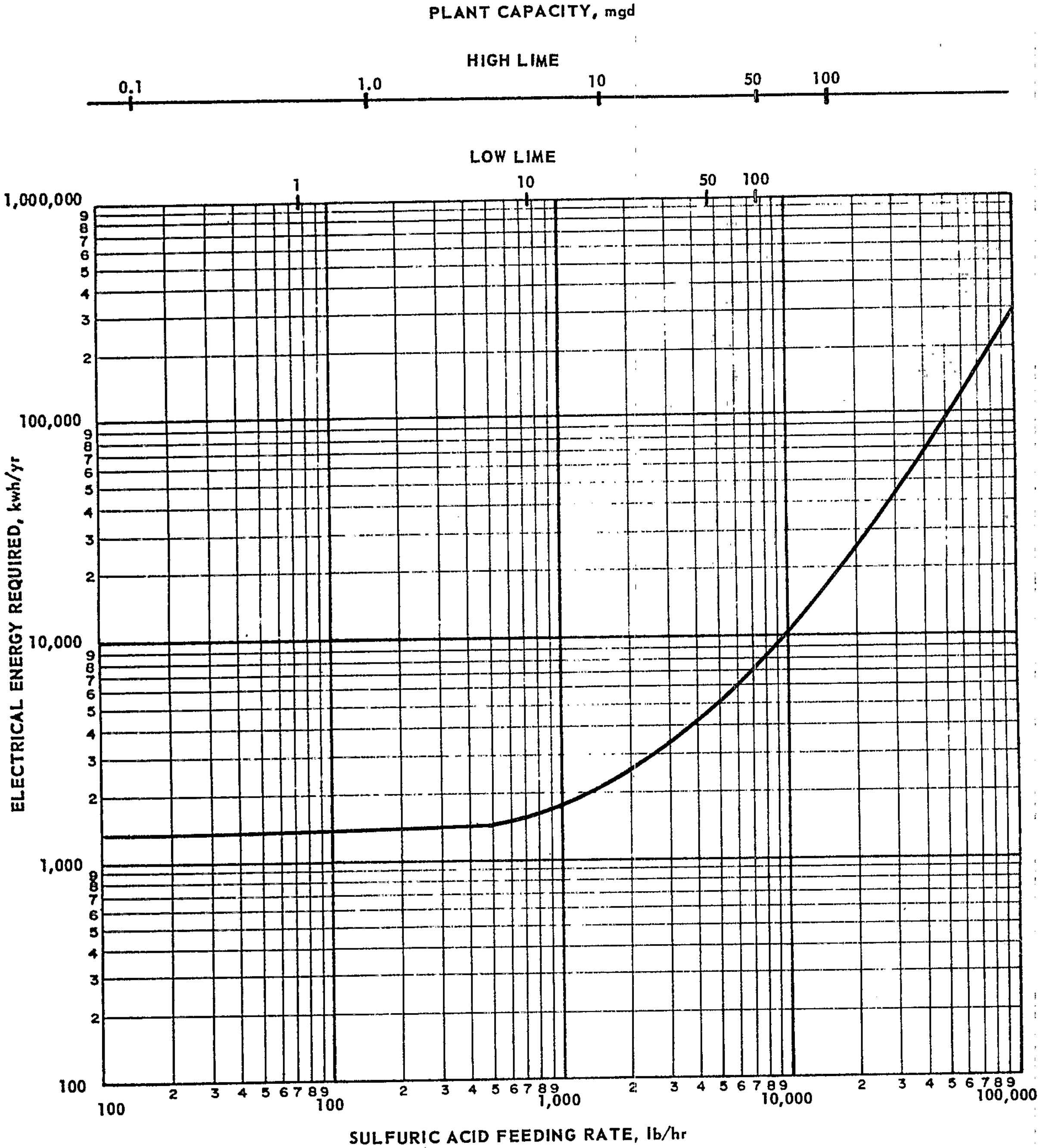
FERRIC CHLORIDE FEEDING

Operating Parameter:

Dosage—85 mg/l as $FeCl_3$

Type of Energy Required: **Electrical**

FIGURE 3–47

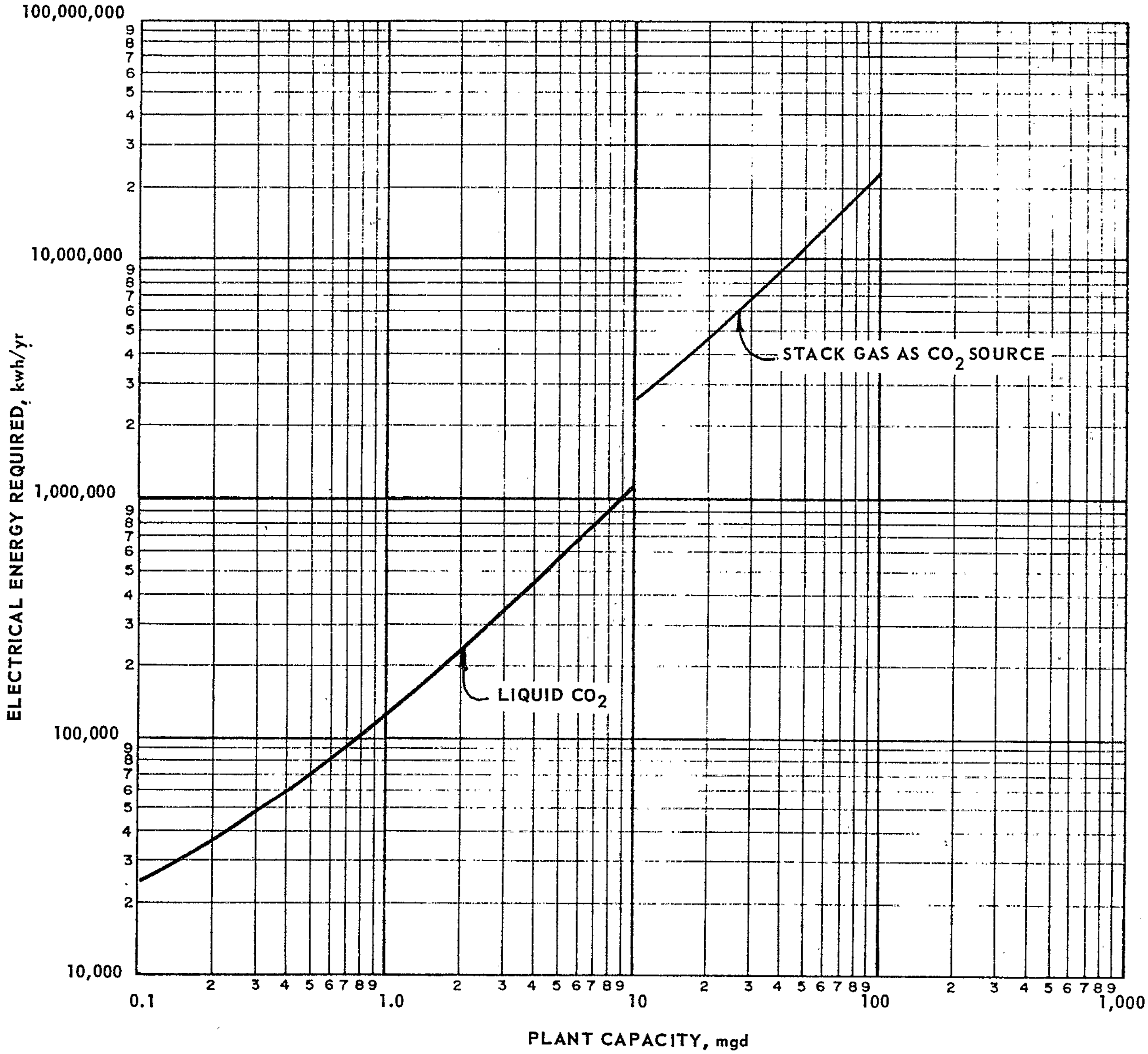


SULFURIC ACID FEEDING

Operating Parameter:
Dosage = 450 mg/l (high lime system)
Dosage = 225 mg/l (low lime system)

Type of Energy Required: Electrical

FIGURE 3–48



SOLIDS CONTACT CLARIFICATION – HIGH LIME, TWO STAGE RECARBONATION

(Includes reactor clarifier, high lime feeding, sludge pumping, two stage recarbonation)

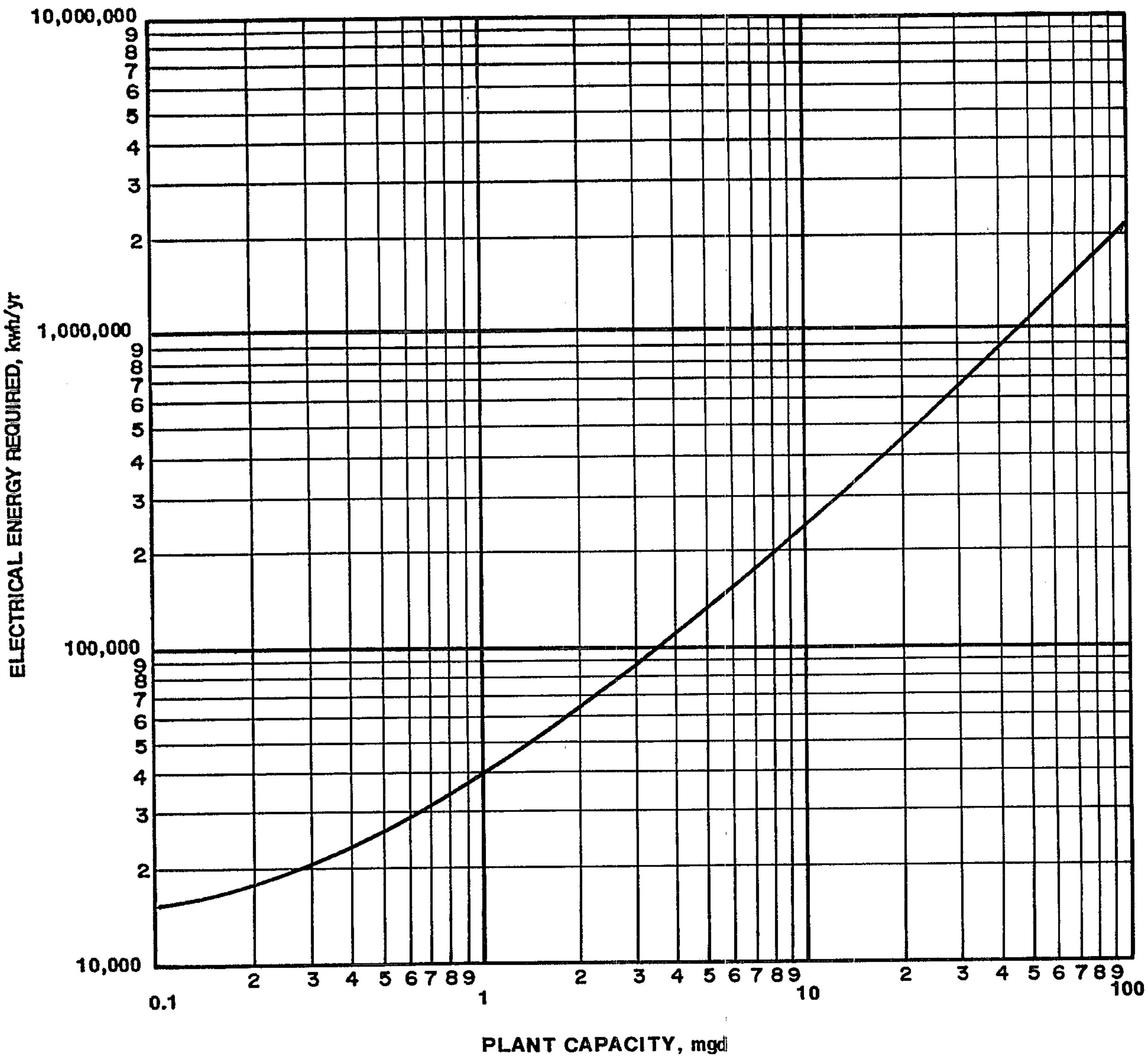
This curve is valid for chemical treatment of both raw sewage and primary effluent.

Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of primary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	250	10	Suspended Solids	80	10.0
Phosphate as P	11.0	1.0	Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves: Lime Feeding, Figure 3–45; Reactor Clarifier, 3–53; Sludge Pumping, 3–4; Recarbonation, 3–60, 3–61; Recarbonation Clarifier, 3–15

Type of Energy Required: Electrical

FIGURE 3–49



SOLIDS CONTACT CLARIFICATION, HIGH LIME, SULFURIC ACID NEUTRALIZATION

(Includes reactor clarifier, high lime feed, chemical sludge pumping, sulfuric acid feed)

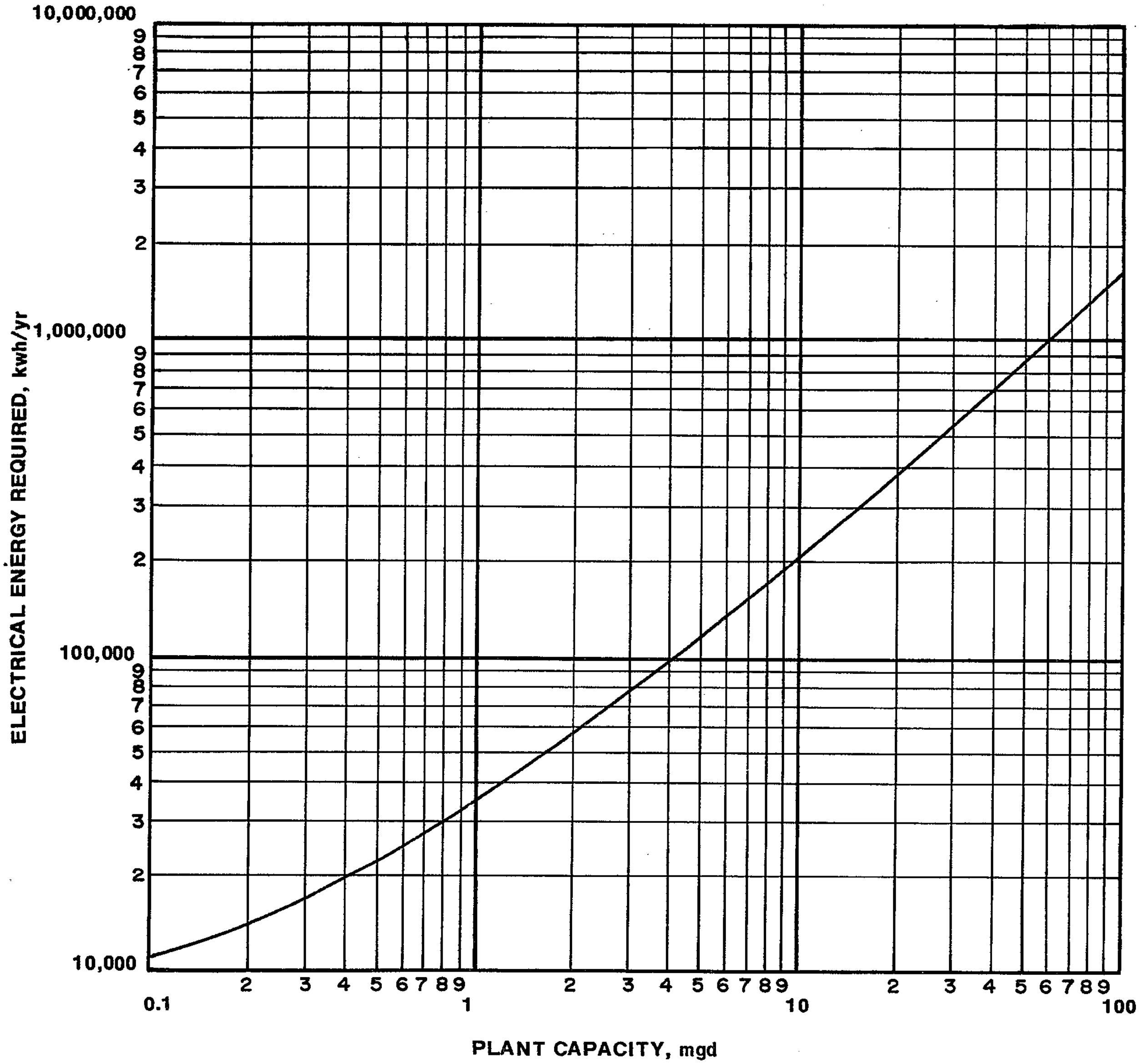
This curve is valid for chemical treatment of both primary and secondary effluents.

Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of secondary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended solids	250	10	Suspended Solids	30	10
Phosphate as P	11.0	1.0	Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves:
Lime Feeding, Figure 3–45 ; Reactor Clarifier, 3–53 ; Sludge Pumping, 3–4 ; Sulfuric Acid Feeding, 3–48

Type of Energy Required: Electrical

FIGURE 3–50



SOLIDS CONTACT CLARIFICATION SINGLE STAGE LOW LIME WITH SULFURIC ACID NEUTRALIZATION

(Includes reactor clarifier, low lime feeding, sludge pumping, sulfuric acid feeding)

This curve is valid for chemical treatment of both raw sewage and primary effluents.

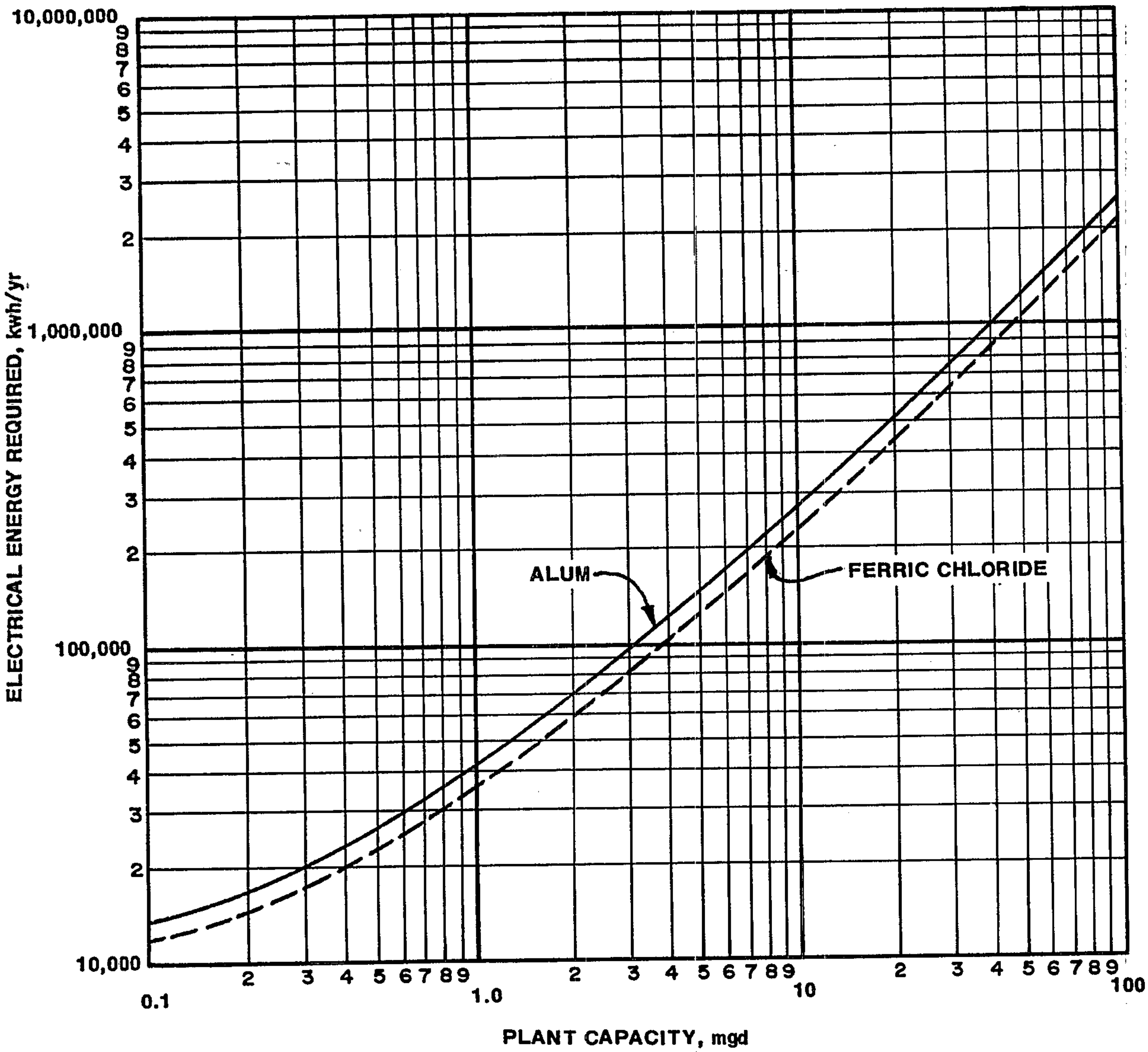
Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of primary effluent):	Influent (mg/l)	Effluent (mg/l)
Suspended solids	250	20	Suspended Solids	30	20
Phosphate as P	11.0	2.0	Phosphate as P	11.0	2.0

Design Assumptions and Operating Parameters are shown on the following curves:

Lime Feeding, Figure 3–45 ; Reactor Clarifier, 3–53 ; Sludge Pumping, 3–4 ; Sulfuric Acid Feeding, 3–48

Type of Energy Required: Electrical

FIGURE 3–51



SOLIDS CONTACT CLARIFICATION, ALUM OR FERRIC CHLORIDE ADDITION

(Includes chemical feeding, reactor clarifier, sludge pumping)

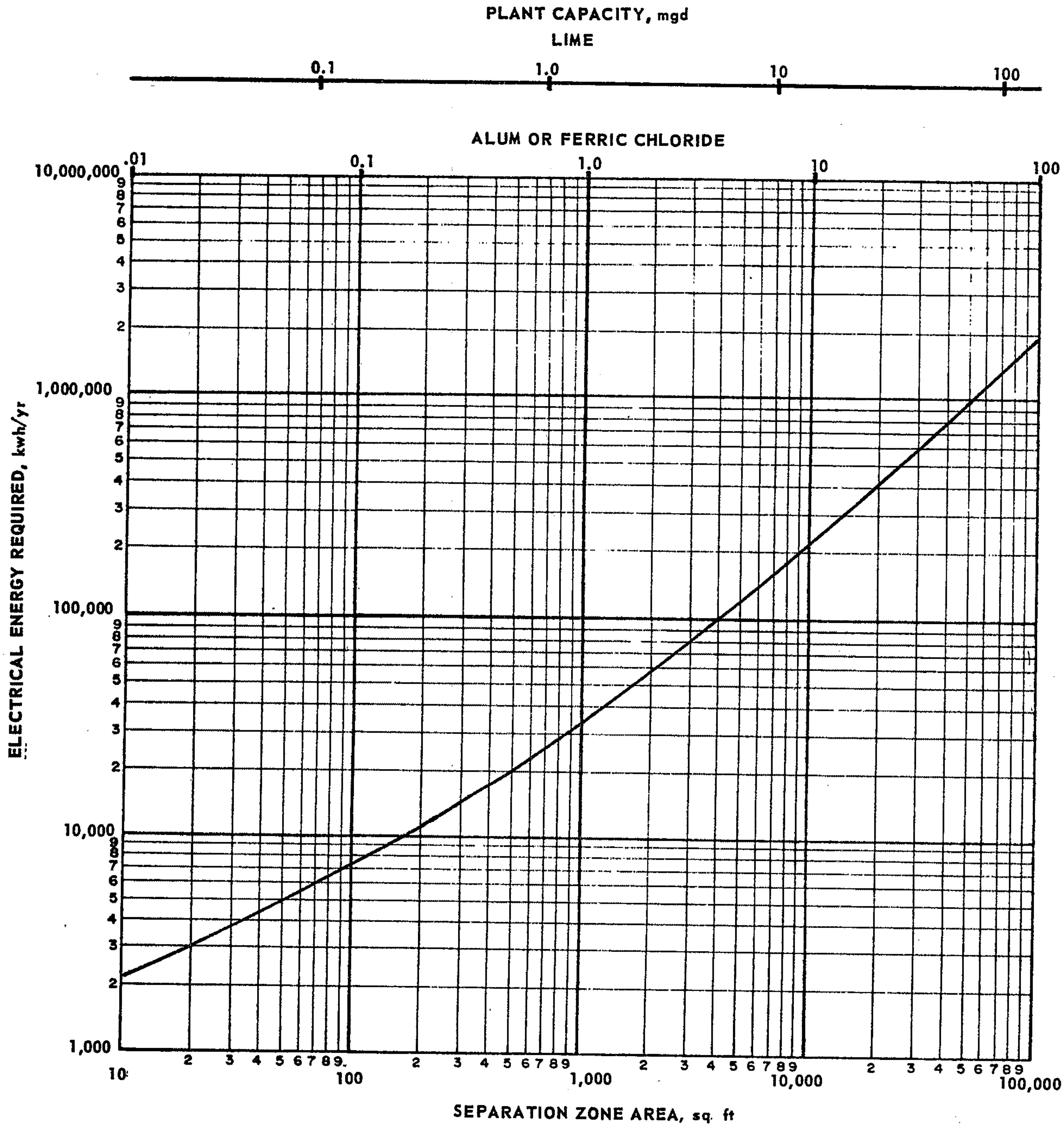
This curve is valid for chemical treatment of both raw sewage and primary effluent)

Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of primary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended solids	250	30	Suspended Solids	80	10
Phosphate as P	11.0	1.0	Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves:
Alum or Ferric Chloride Feeding, Figure 3–46,3–47; Reactor Clarifier, 3–53 ; Sludge Pumping, 3–5, 3–6.

Type of Energy Required: Electrical

FIGURE 3–52



REACTOR CLARIFIER

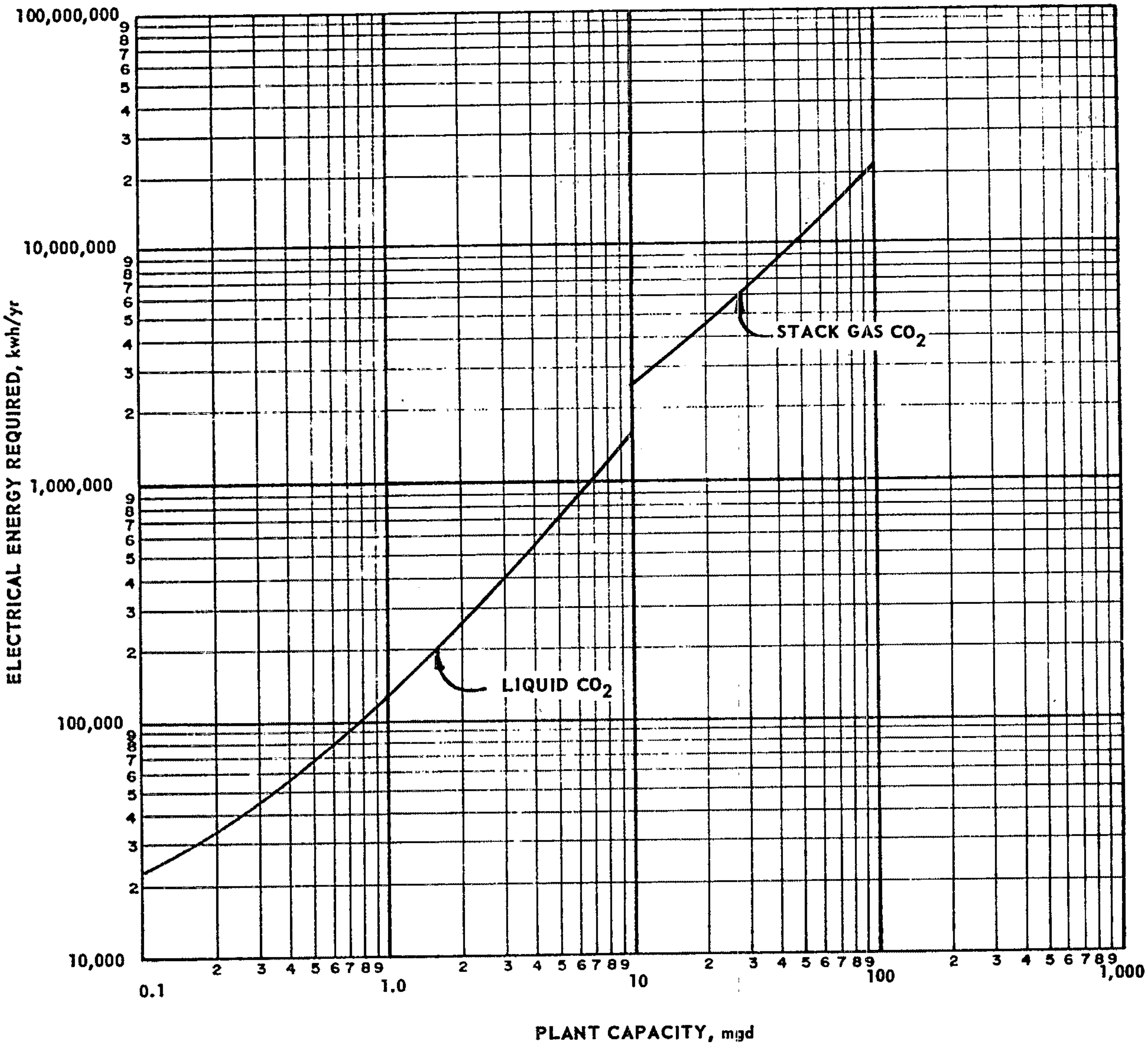
Operating Parameters:

Separation zone overflow rate, lime = 1400 gpd/sq. ft

Separation zone overflow rate, alum or ferric chloride = 1000 gpd/sq. ft

Type of Energy Required: Electrical

FIGURE 3–53



SEPARATE RAPID MIXING, FLOCCULATION, SEDIMENTATION HIGH LIME, TWO STAGE RECARBONATION

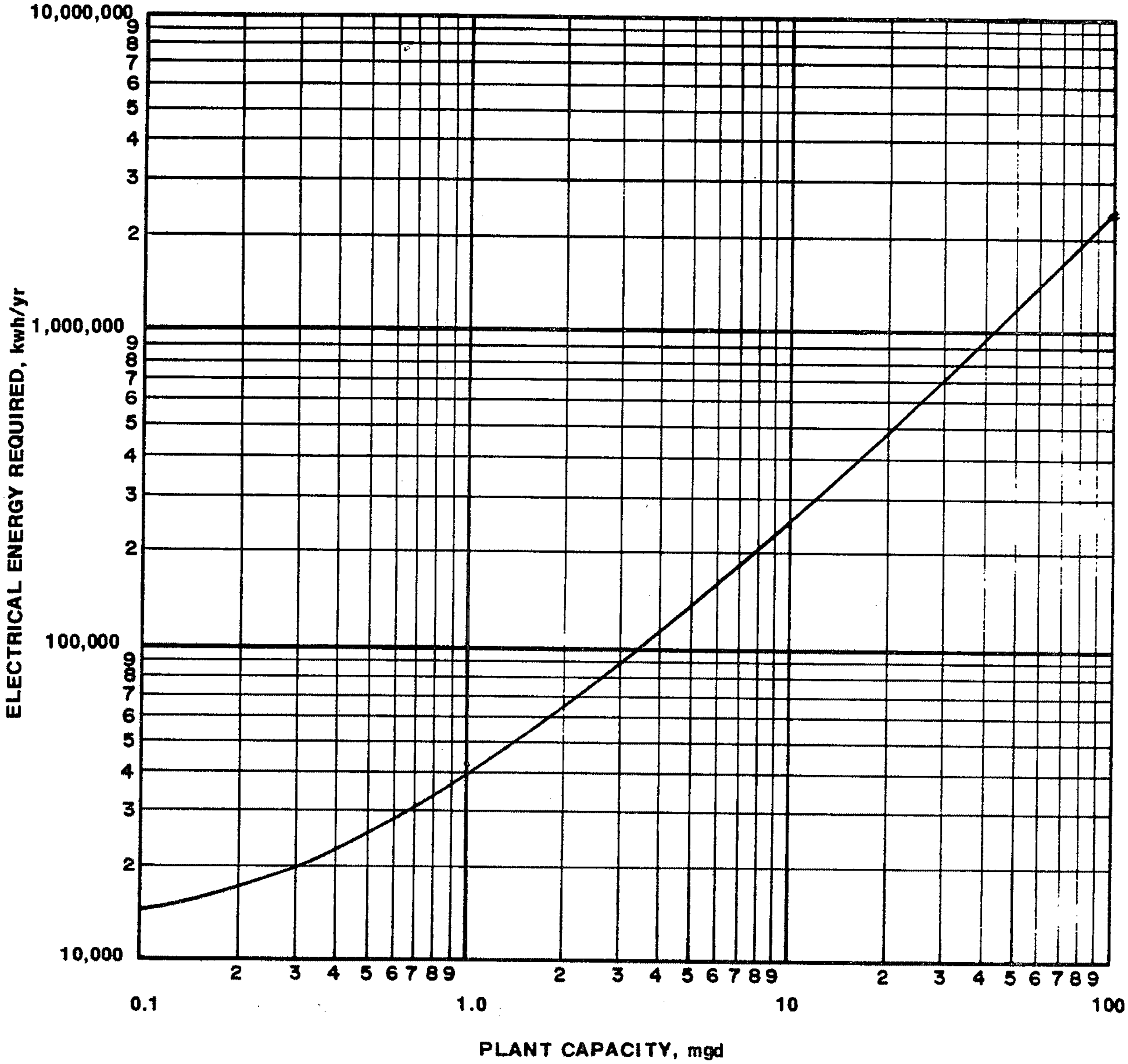
This curve is valid for chemical treatment of both raw sewage and secondary effluent.

Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of secondary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	250	10	Suspended Solids	30	10.0
Phosphate as P	11.0	1.0	Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves:
Lime Feeding, Figure 3–45; Rapid Mixing, 3–58 ; Flocculation, 3–59 ; Sedimentation, 3–15 ; Recarbonation, 3–60, 3–61; Sludge Pumping, 3–4

Type of Energy Required: Electrical

FIGURE 3–54



SEPARATE RAPID MIXING, FLOCCULATION, SEDIMENTATION SINGLE STAGE HIGH LIME, NEUTRALIZATION WITH SULFURIC ACID

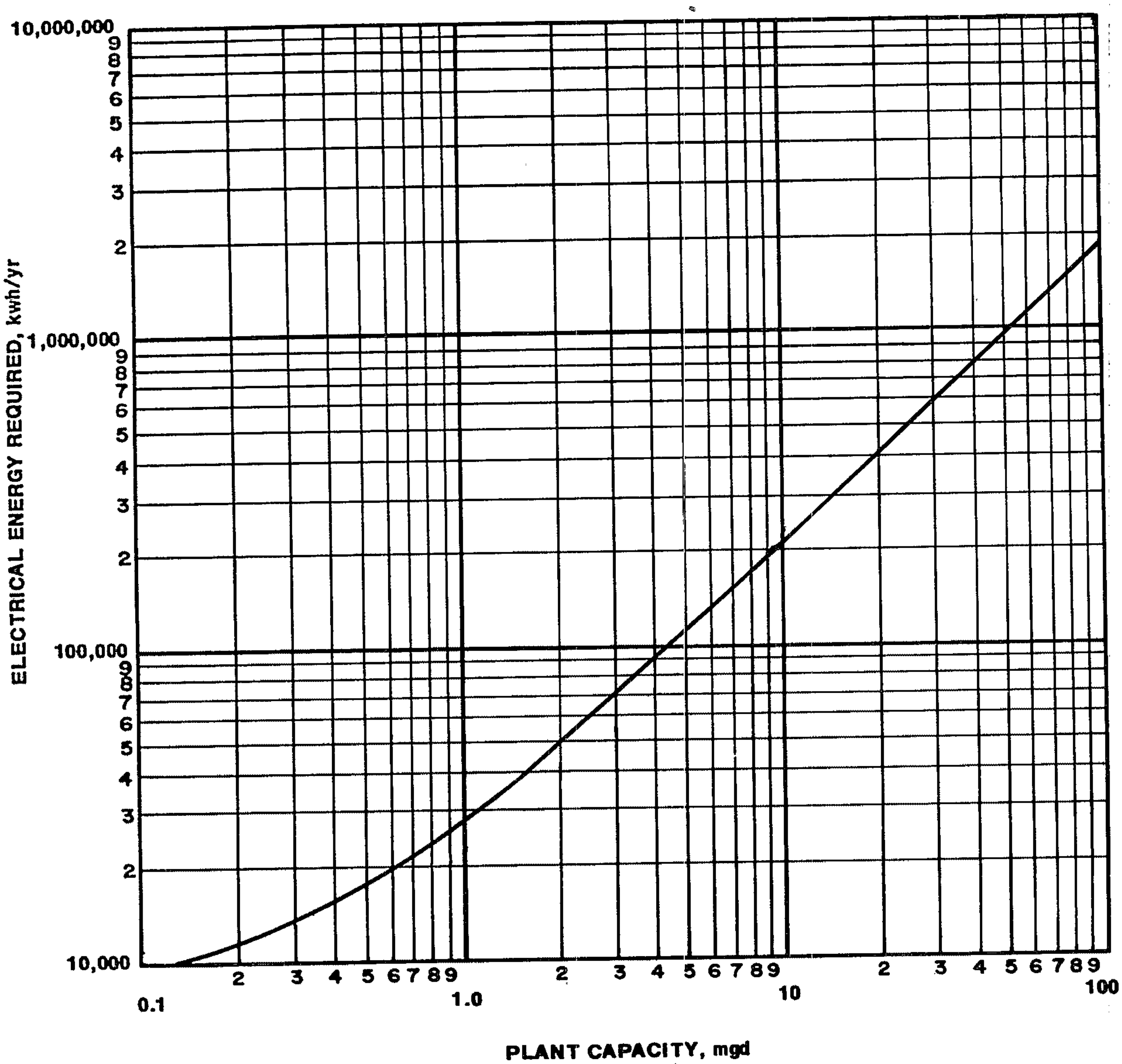
This curve is valid for chemical treatment of both raw sewage and secondary effluent.

Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of secondary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended solids	250	10	Suspended Solids	30	10
Phosphate as P	11.0	1.0	Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves:
Lime Feeding, Figure 3–45 ; Rapid Mixing, 3–58 ; Flocculation, 3–59 ; Sedimentation, 3–15 ; Sludge Pumping, 3–4 ; Sulfuric Acid Feeding, 3–48

Type of Energy Required: Electrical

FIGURE 3–55



SEPARATE RAPID MIXING, FLOCCULATION, SEDIMENTATION LOW LIME, NEUTRALIZATION WITH SULFURIC ACID

This curve is valid for chemical treatment of both raw sewage and secondary effluent.

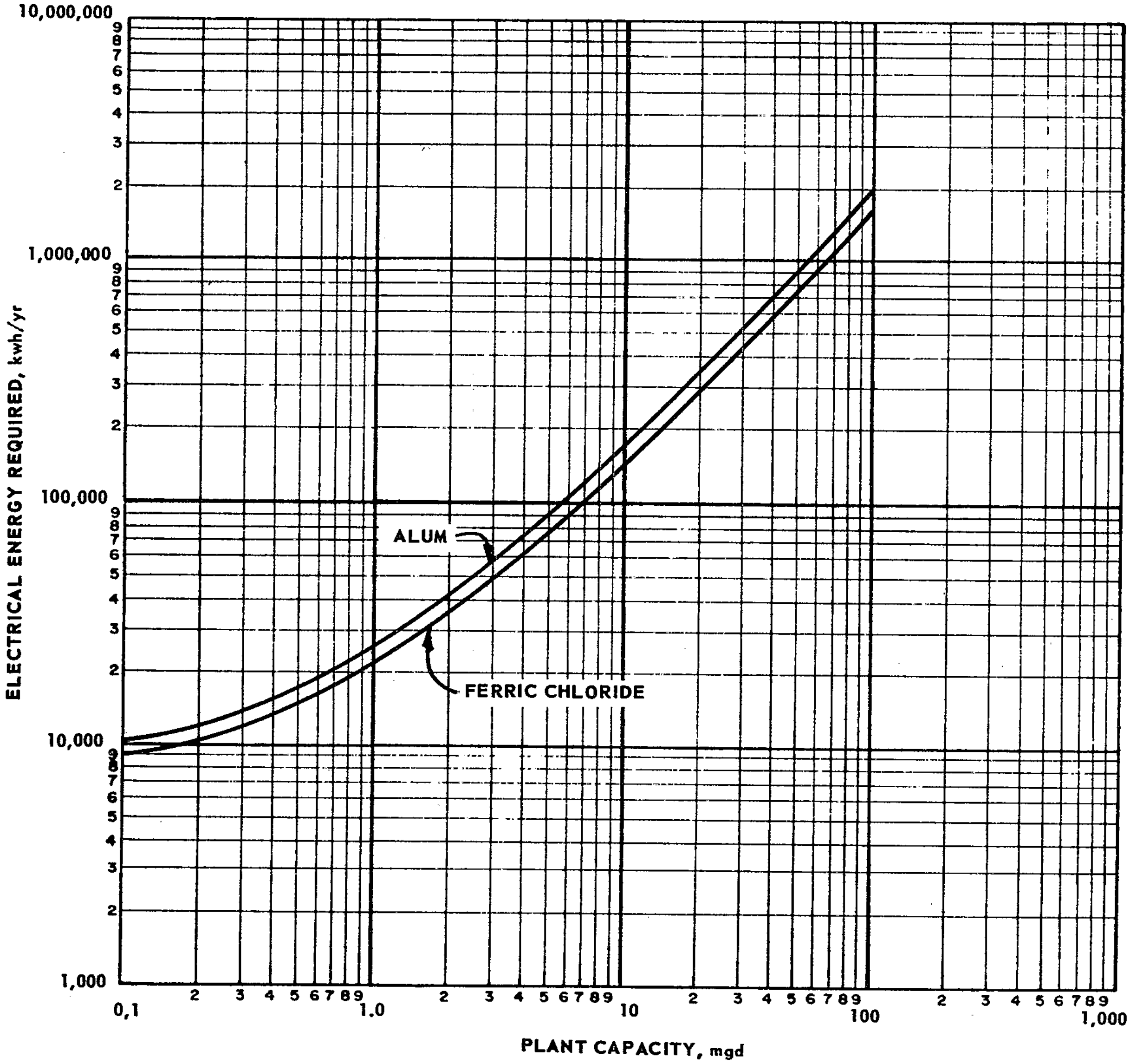
Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)
Suspended solids	250	10
Phosphate as P	11.0	1.0

Water Quality: (treatment of secondary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	30	10
Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves:
Rapid Mixing, Figure 3–58 ; Flocculation, 3–59 ; Sedimentation, 3–15 ; Lime Feeding, 3–45 ; Sulfuric Acid Feeding, 3–48 ; Chemical Sludge Pumping, 3–4

Type of Energy Required; Electrical

FIGURE 3–56



SEPARATE RAPID MIXING, FLOCCULATION, SEDIMENTATION ALUM OR FERRIC CHLORIDE ADDITION

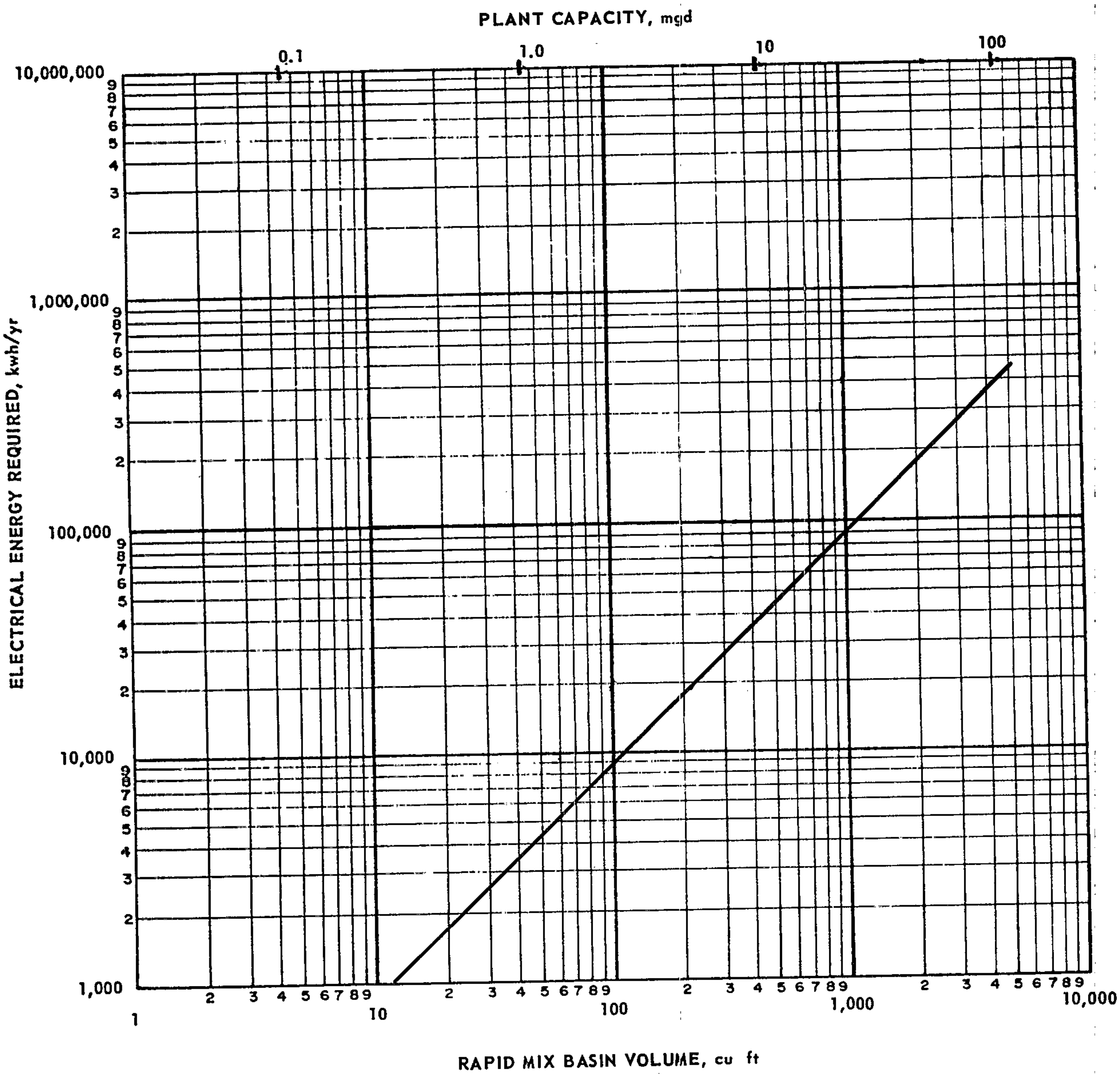
This curve is valid for chemical treatment of both raw sewage and secondary effluent.

Water Quality: (treatment of raw sewage)	Influent (mg/l)	Effluent (mg/l)	Water Quality: (treatment of secondary effluent)	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	250	10	Suspended Solids	30	10.0
Phosphate as P	11.0	1.0	Phosphate as P	11.0	1.0

Design Assumptions and Operating Parameters are shown on the following curves:
Alum or Ferric Chloride Feeding, Figures 3-46 and 3-47; Rapid Mixing, 3-58; Flocculation, 3-59; Sedimentation, 3-14; Sludge Pumping, 3-5 and 3-6

Type of Energy Required: Electrical

FIGURE 3-57



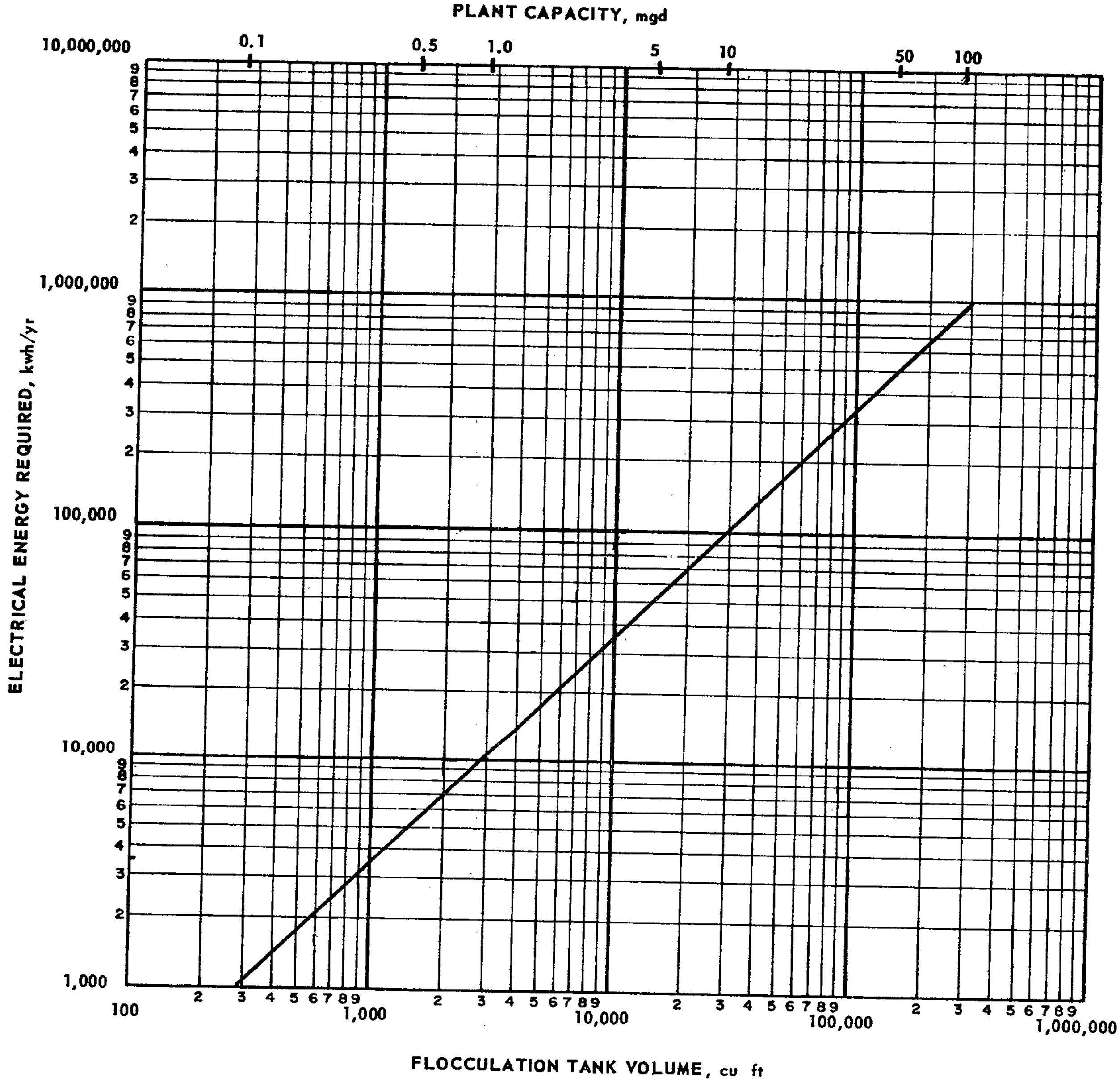
RAPID MIXING

Design Assumptions:

- Detention time = 30 seconds
- $G = 600\ sec^{-1}$
- Temperature = 15°C
- Coagulant: lime or alum or ferric chloride

Type of Energy Required: Electrical

FIGURE 3–58



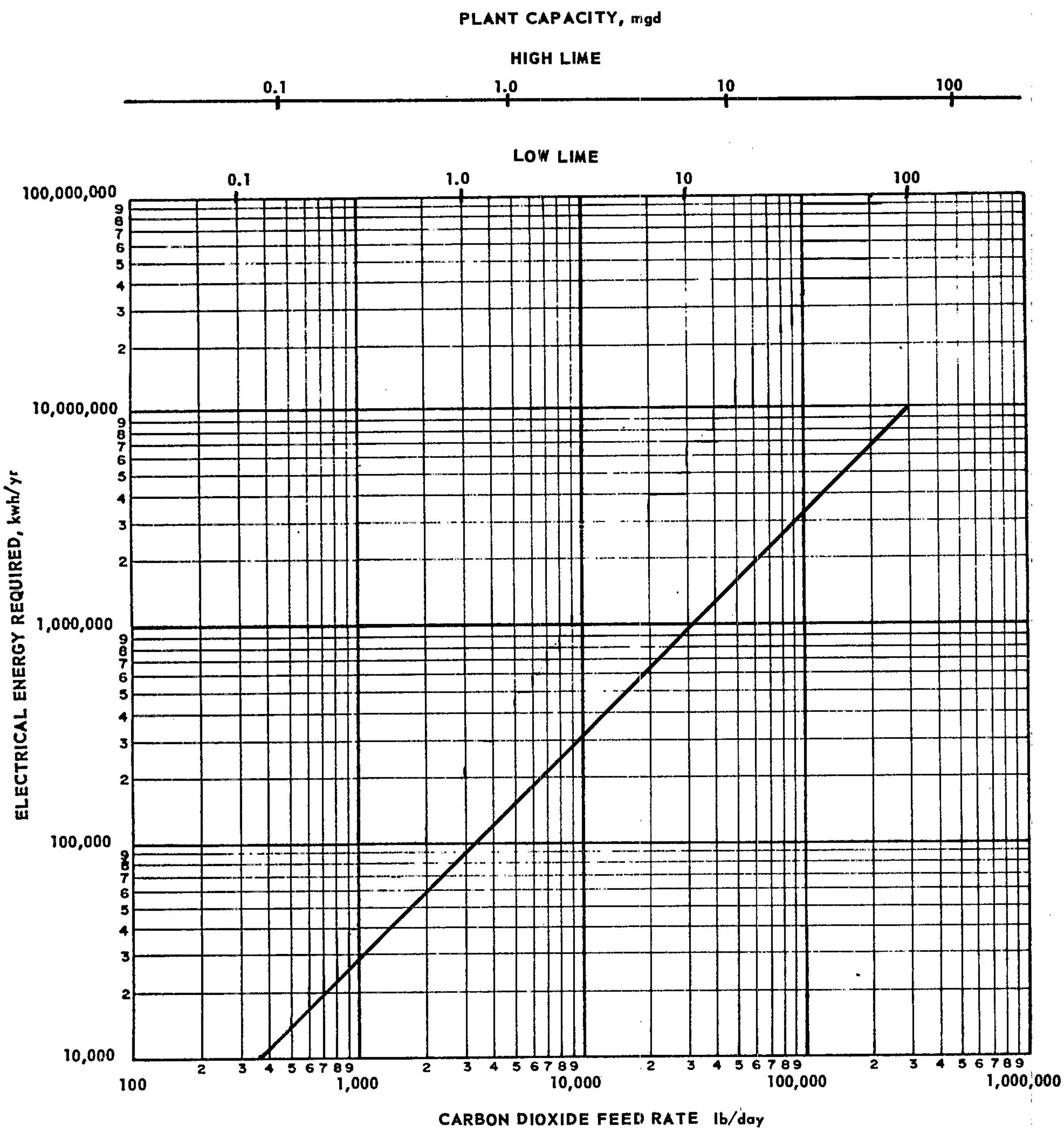
FLOCCULATION

Design Assumptions:

Detention time = 30 minutes
G = 110 sec−1
Temperature ≈ 15°C
Coagulant: lime or alum or ferric chloride

Type of Energy Required: Electrical

FIGURE 3–59



RECARBONATION – SOLUTION FEED OF LIQUID CO_2 SOURCE

Design Assumptions:

Vaporizer = 25 lb CO_2 /kwh

Injector pumps = 42 gpm/1000 lb CO_2 @ 65 psi

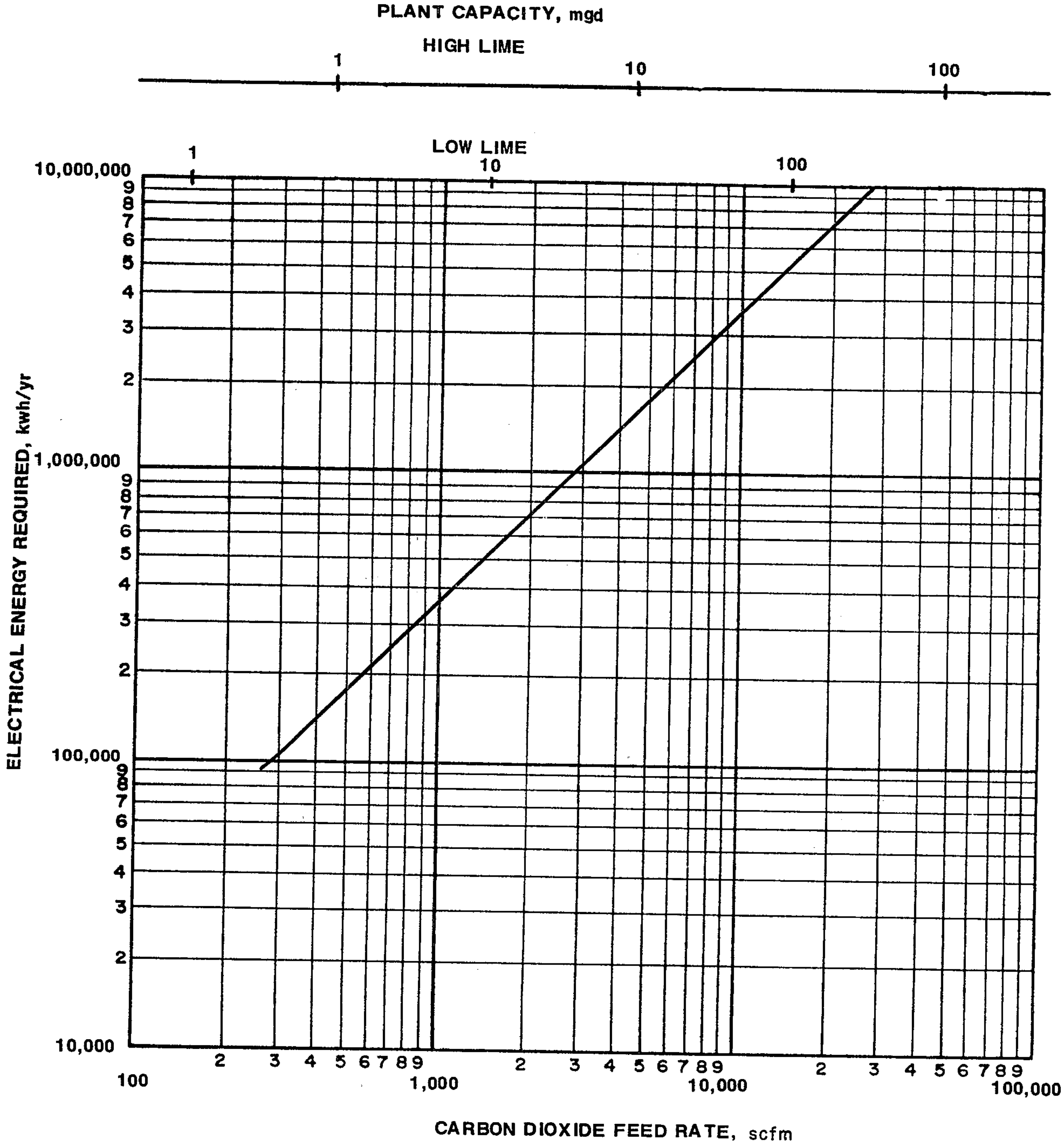
Operating Parameters:

Low lime = 3000 lb CO_2/mil gal

High lime = 4500 lb CO_2 /mil gal

Type of Energy Required: Electrical

FIGURE 3–60



RECARBONATION – STACK GAS AS CO_2 SOURCE

Design Assumptions:

Stack Gas = 10% CO_2, 0.116 lb CO_2 /cu ft at standard conditions (60°F, 14.7 psia); operating temperature, 110°F (following scrubbing)

Loss to atmosphere = 20%

Injection pressure = 8 psi

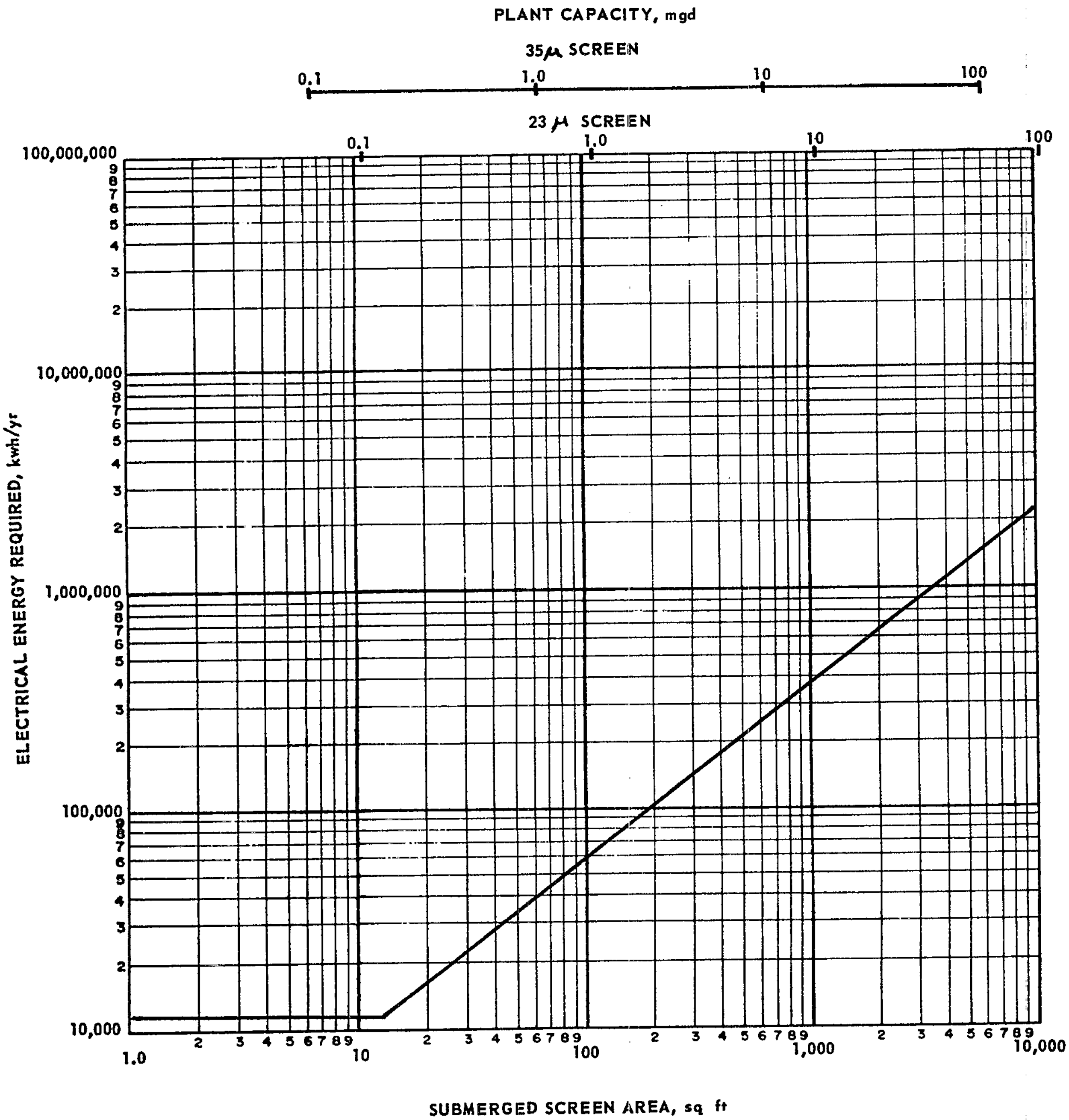
Operating Parameters:

Low lime = 3000 lb CO_2 /mil gal

High lime = 6000 lb CO_2 / mil gal

Type of Energy Required: Electrical

FIGURE 3–61



MICROSCREENS

Water Quality:

	Influent (mg/l)	Effluent (mg/l)
Suspended Solids (35μ)	20	10
Suspended Solids (23μ)	20	5

Design Assumptions:

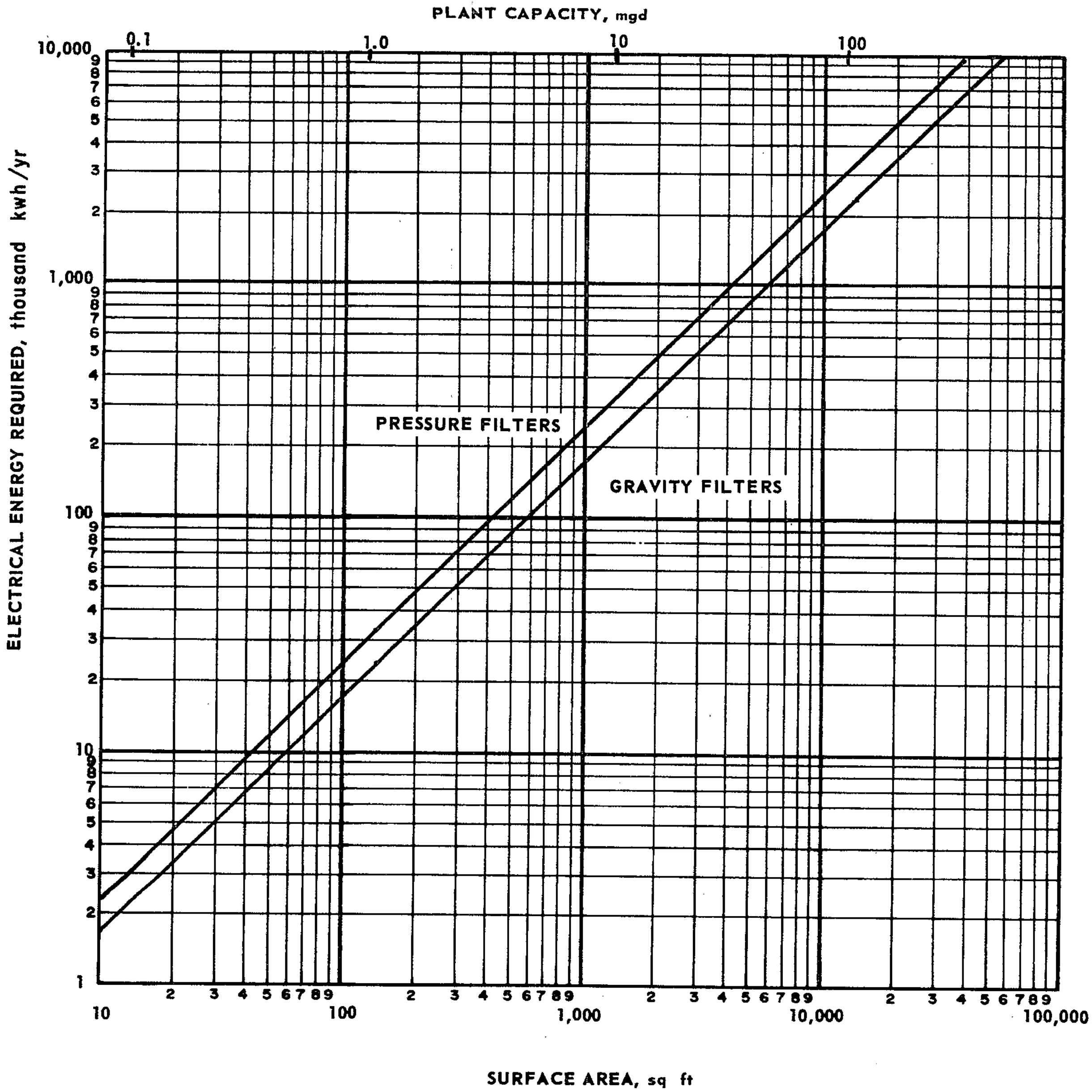
Loading rate (35μ) = 10.0 gpm/sq ft
Loading rate (23μ) = 6.7 gpm/sq ft

Operating Parameters:

80% submergence

Type of Energy Required: Electrical

FIGURE 3–62



PRESSURE AND GRAVITY FILTRATION

Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	20	<10

Design Assumptions:

Includes filter supply pumping (or allowance for loss of treatment system head); filter backwash supply pumping, and hydraulic surface wash pumping (rotating arms).
Pump Efficiency: 70%; motor efficiency: 93%

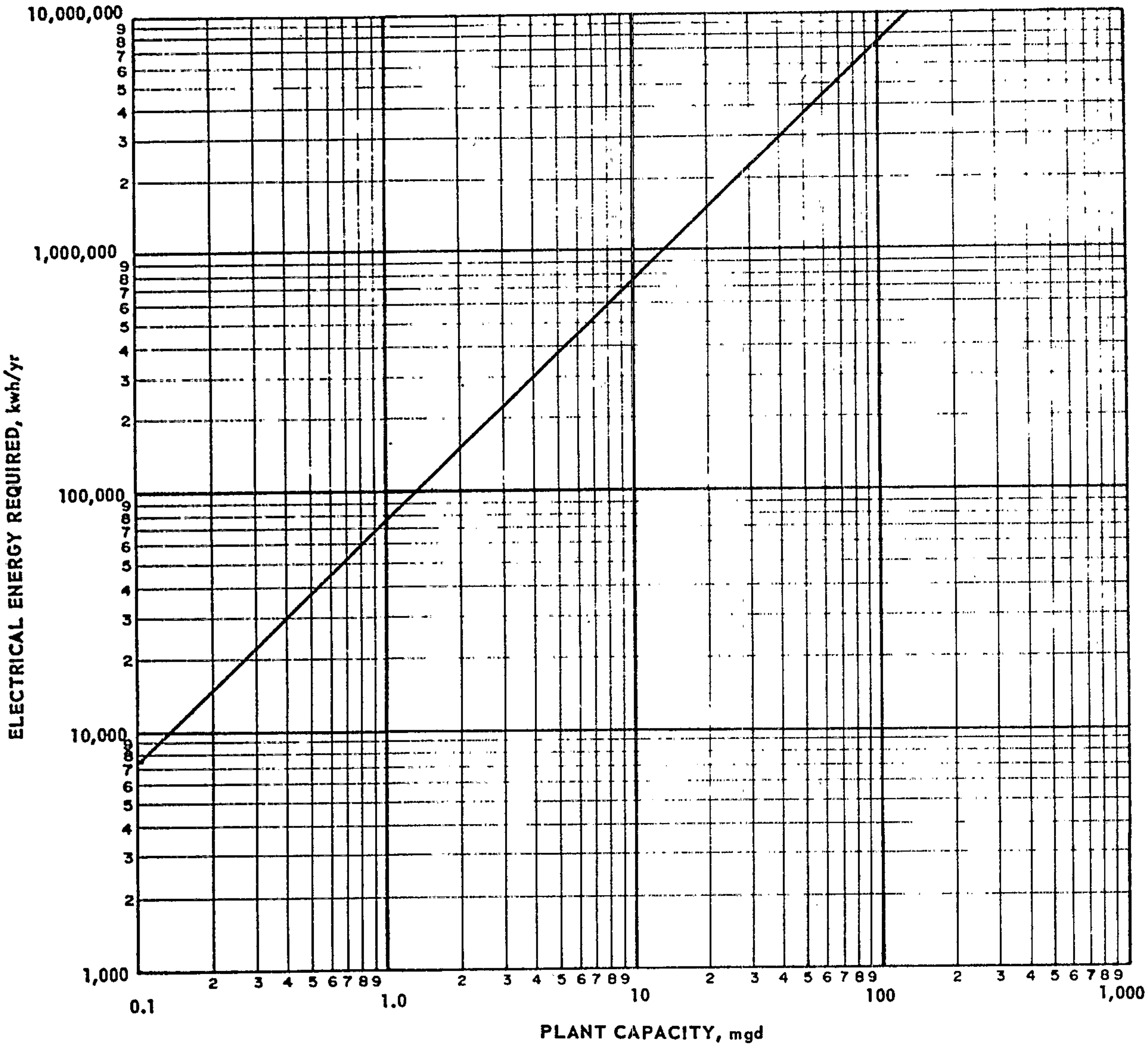
Filter and back wash head: gravity filters, 14 ft. TDH; pressure filters, 20 ft. TDH.
Surface wash pumping: 200 ft. TDH
Filtration rate (both filters): 5 gmp/sq ft.
Back wash rate (both filters): 18 gpm/sq ft.
Hydraulic surface wash rate(rotating arm): 1 gpm/sq ft. (average)

Operating Parameters:

Filter run: 12 hrs. for gravity, 24 hrs. for pressure.
Back wash pumping (both filters): 15 min. per backwash.
Surface wash pumping (both filters): 5 min. per backwash.

FIGURE 3–63

Type of Energy Required: Electrical



GRANULAR CARBON ADSORPTION – DOWNFLOW PRESSURIZED CONTACTOR

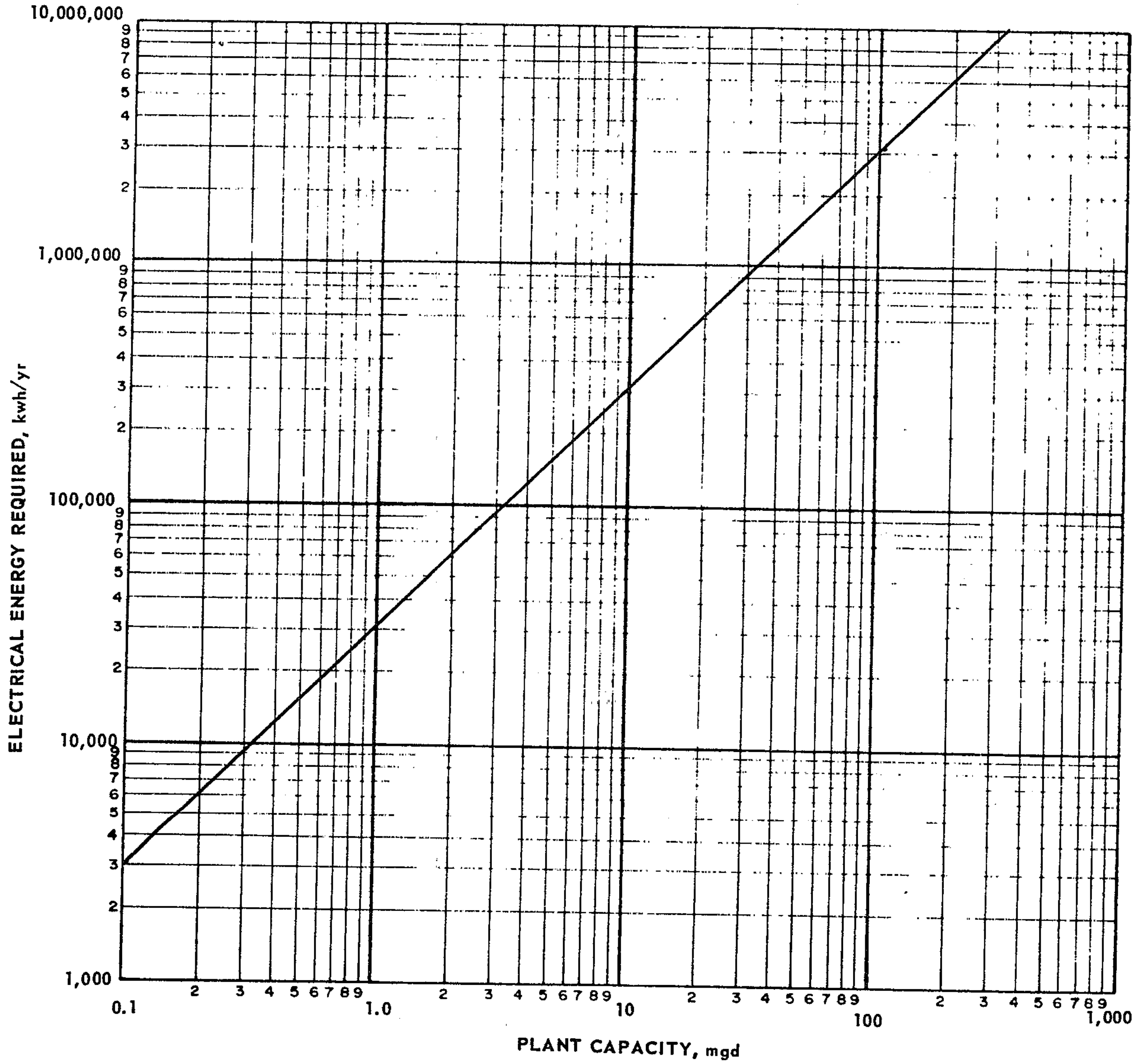
Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	20	10
COD x	40	15

Design Assumptions:
8 x 30 mesh carbon, 28 ft. carbon depth, 30 min. contact.
Filtration head: 28 ft. TDH (carbon depth) + 9 ft. TDH, (piping and freeboard)
Filtration pumping: 7 gpm/sq ft. @ 37 ft. TDH, (average)
Back wash pumping: 18 gpm/sq ft. @ 37 ft. TDH, (average0 (average)

Operating Perameters:

Operate to 20 ft. head loss building before backwashing.
Backwash pumping: 15 min per backwash
Type of Energy Required: Electrical

FIGURE 3–64



GRANULAR CARBON ADSORPTION – DOWNFLOW GRAVITY CONTACTOR

Water Quality:

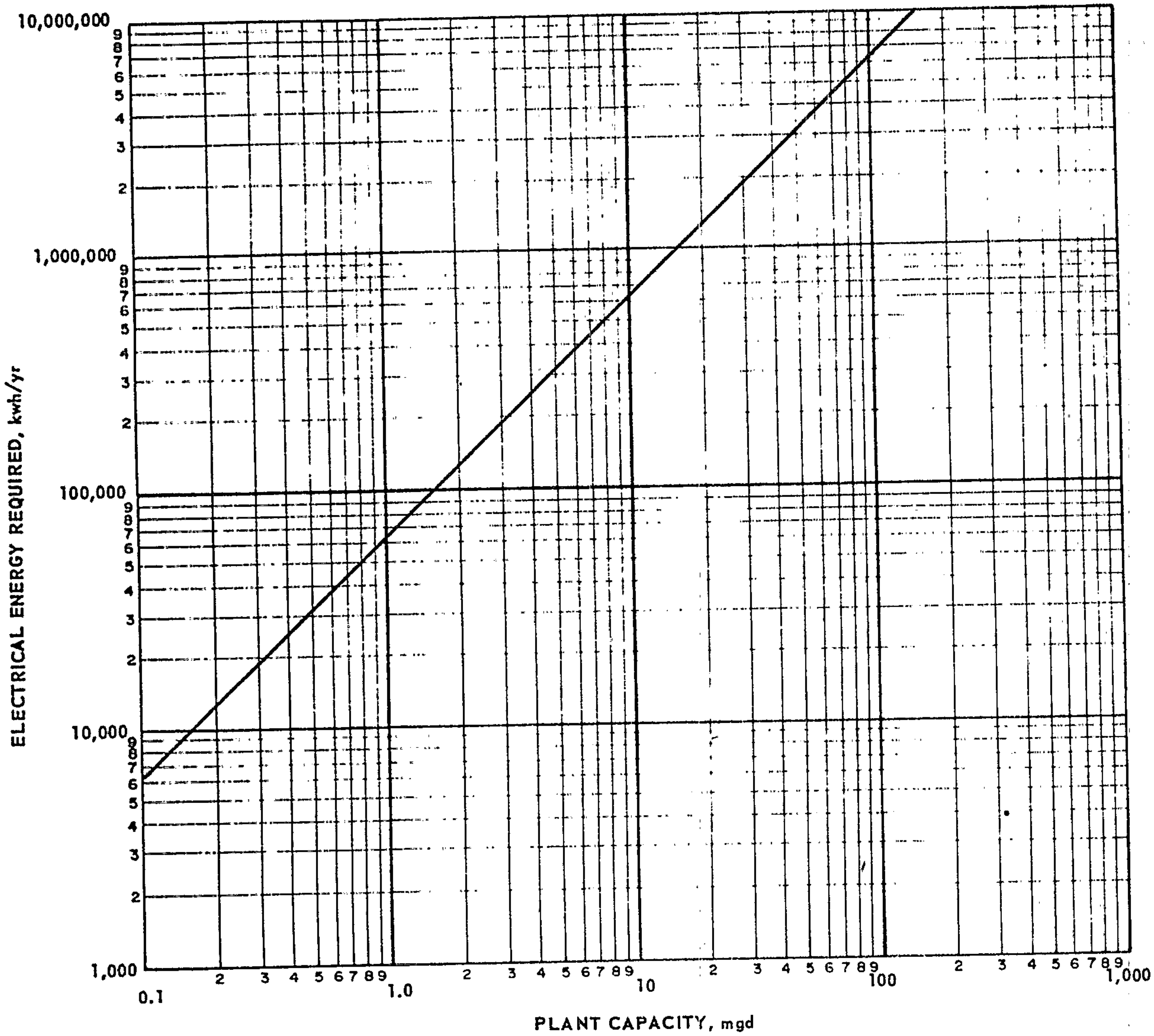
	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	20	10
COD	40	15

Design Assumptions:

8 X 30 mesh carbon
3.5 gpm/sq ft
30 min contact (14 ft carbon depth)
Operate to 6 ft headloss buildup before backwashing

Type of Energy Required: Electrical

FIGURE 3–65



GRANULAR CARBON ADSORPTION – UPFLOW EXPANDED BED

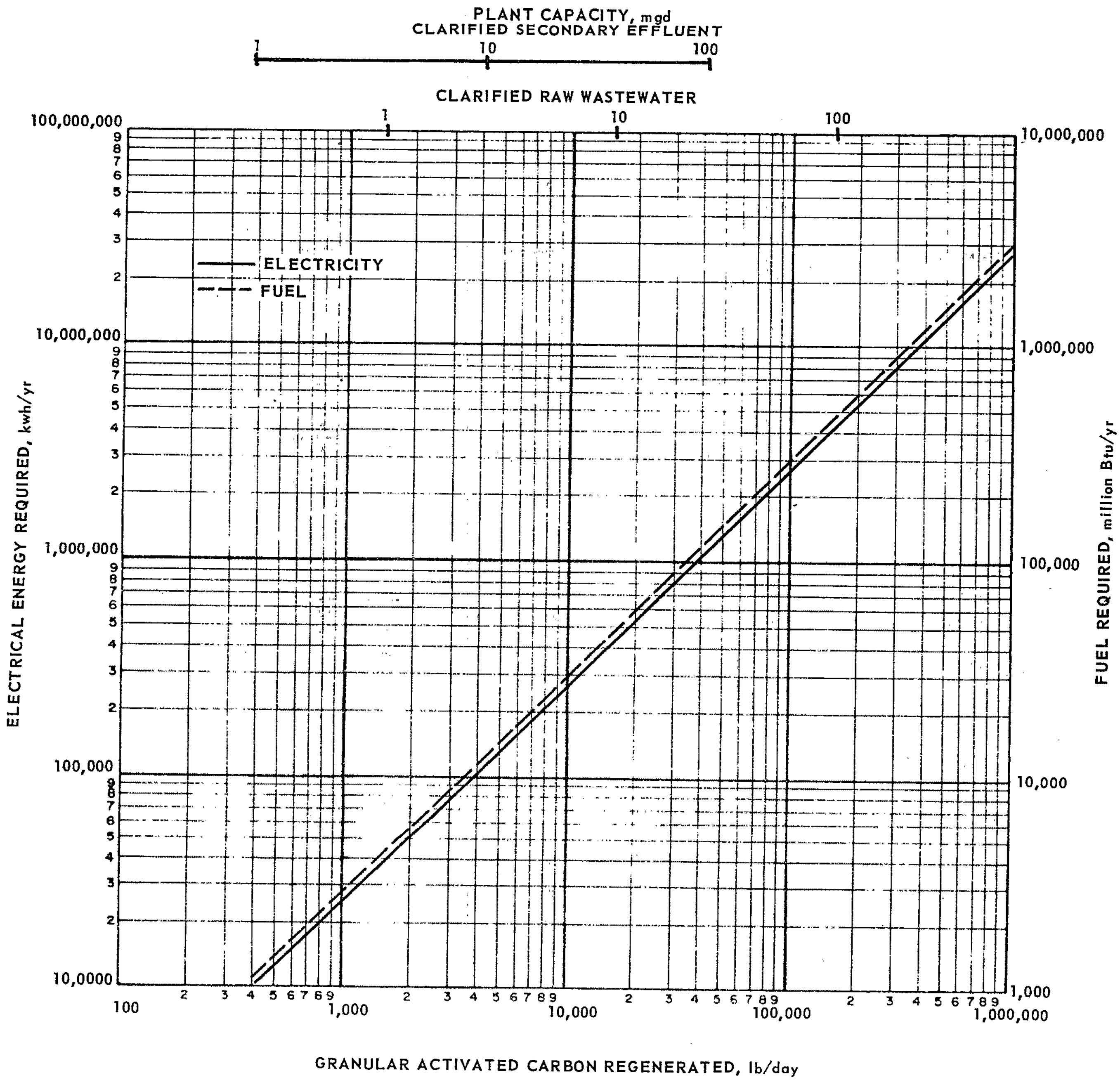
Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	20	20
COD	40	15

Design Assumptions:

30 minutes contact
12 X 40 mesh carbon
15% expansion, 7 gpm/sq ft (28 ft carbon depth)
3 ft freeboard

Type of Energy Required: Electrical

FIGURE 3–66



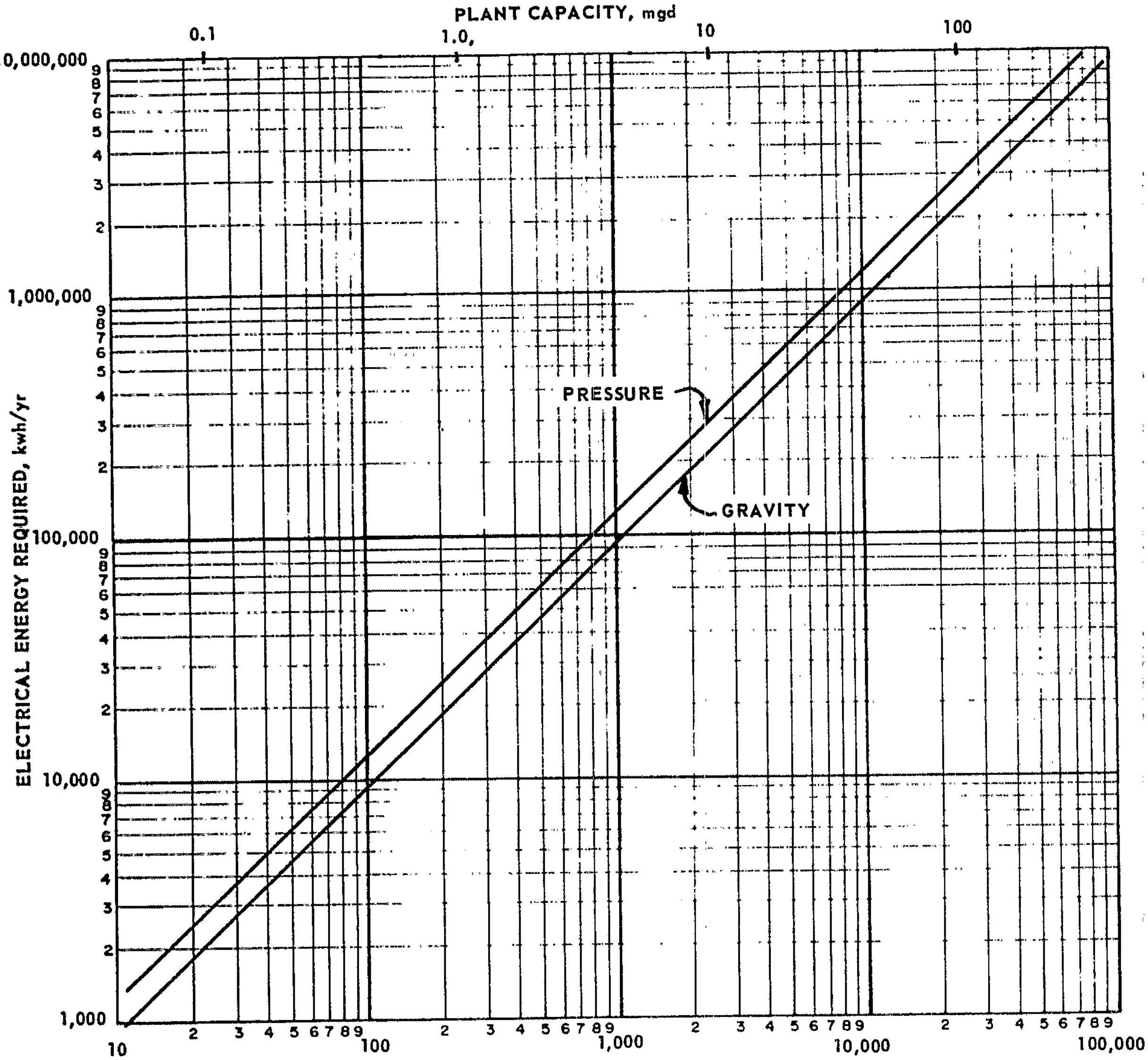
GRANULAR ACTIVATED CARBON REGENERATION

Design Assumptions:
- Electricity includes furnace driver, afterburner, scrubber blowers and carbon conveyors.
- Fuel required per lb Carbon regenerated:
  - Furnace = 3,600 Btu
  - Steam = 1,600 Btu
  - Afterburner = 2,400 Btu

Operating Parameters:
- Carbon dose: Clarified raw wastewater, 1500 lb /mil gal
  - Clarified secondary effluent, 400 lb /mil gal

Type of Energy Required: Electrical and Fuel

FIGURE 3–67



ION EXCHANGE FOR AMMONIA REMOVAL, GRAVITY AND PRESSURE

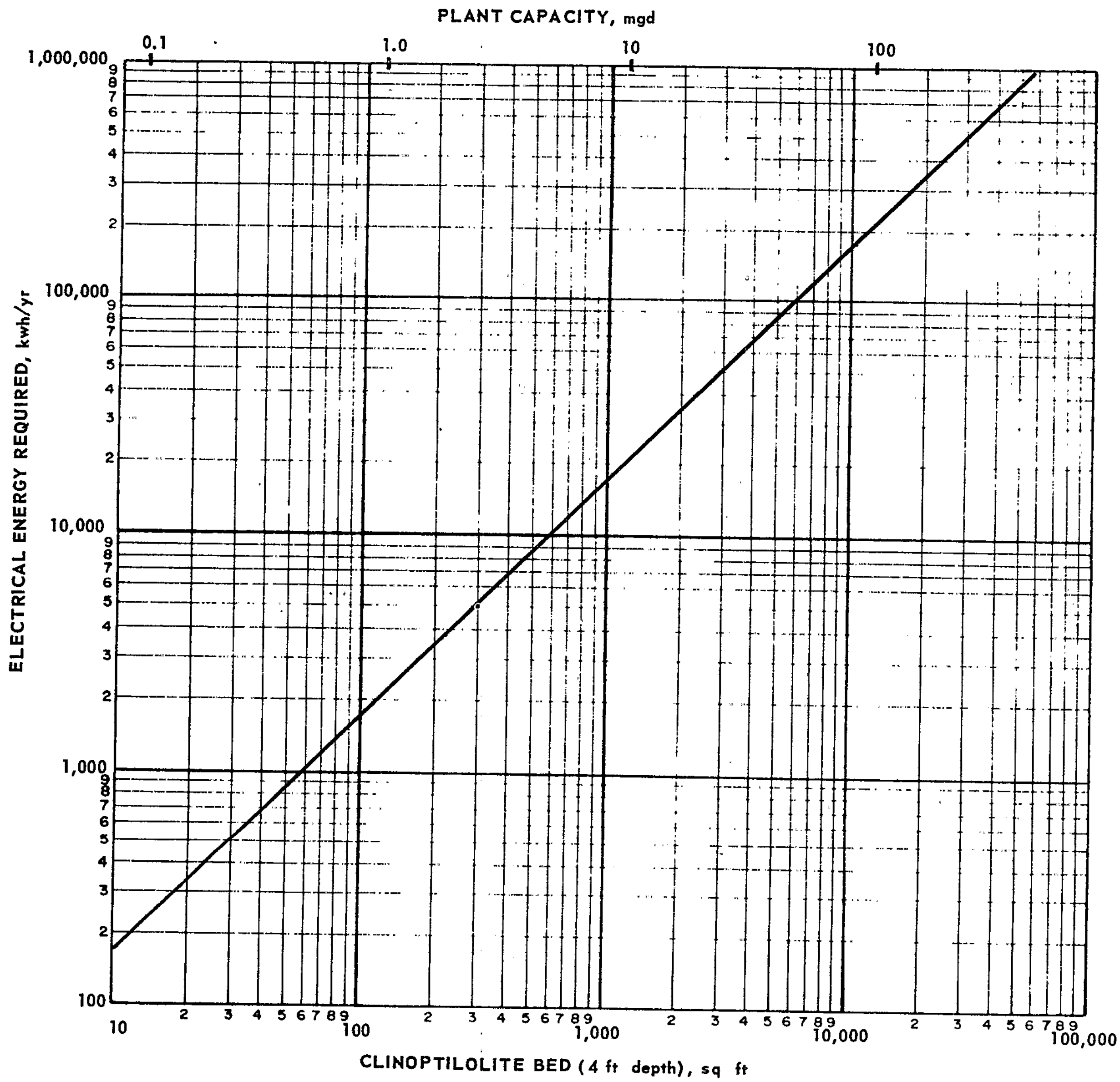
Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	5	5
NH_3–N	15	0.1–2

Design Assumptions:

150 bed volumes throughput/cycle
6 bed volumes/hr loading rate
Gravity bed, available head ≃ 7.25 ft
Pressure bed, average operating head ≃ 10 ft
Includes backwash but not regeneration nor regenerant renewal
10% downtime for regeneration

Type of Energy Required: Electrical

FIGURE 3–68



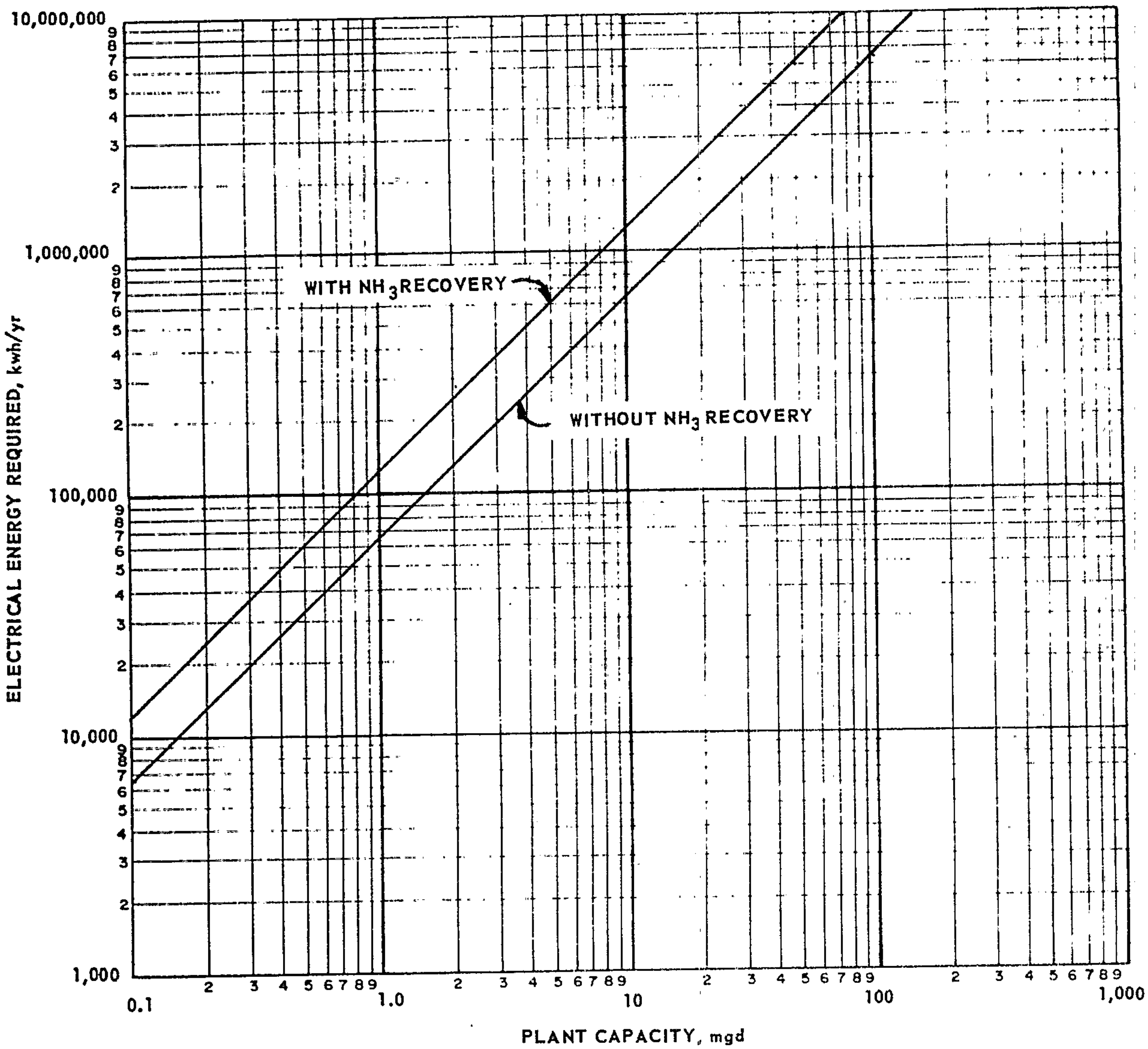
ION EXCHANGE FOR AMMONIA REMOVAL – REGENERATION

Design Assumptions:

Regeneration with 2% NaCl
40 BV/regeneration; 1 regeneration/24 hrs
Total head = 10 ft
Does not include regenerant renewal
Applicable to gravity or pressure beds

Type of Energy Required: Electrical

FIGURE 3–69



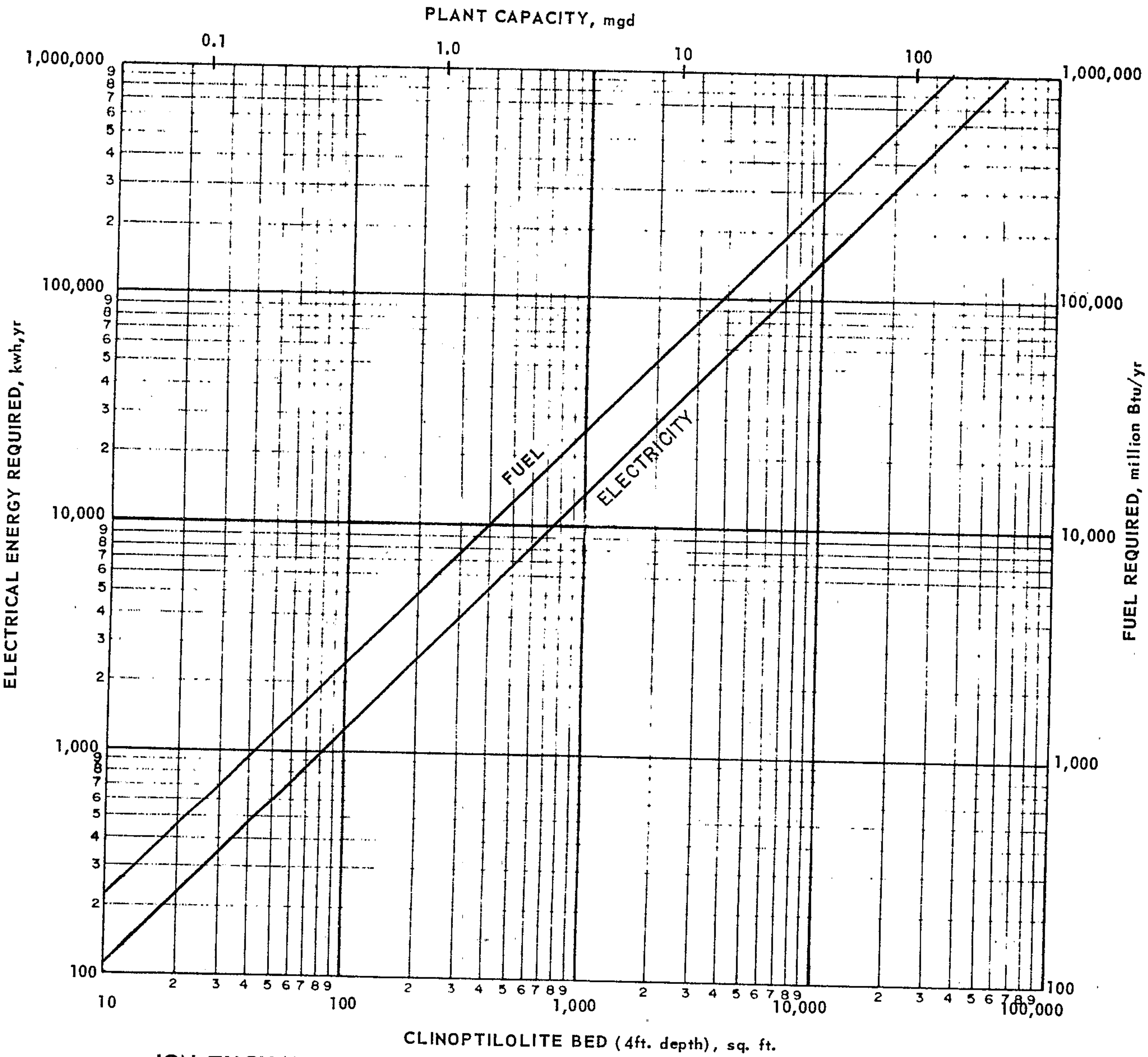
ION EXCHANGE FOR AMMONIA REMOVAL – REGENERANT RENEWAL BY AIR STRIPPING

Design Assumptions:

Regenerant softened with NaOH, clarified at 800 gpd/sq ft
40 BV/regeneration cycle; 150 BV throughput per cycle
Regenerant air stripped; tower loaded at 760 gpd/sq ft with 565 cu ft air/gal
Stripping tower overall height = 32 ft
Ammonia recovered in absorption tower with H_2SO_4

Type of Energy Required: Electrical

FIGURE 3–70



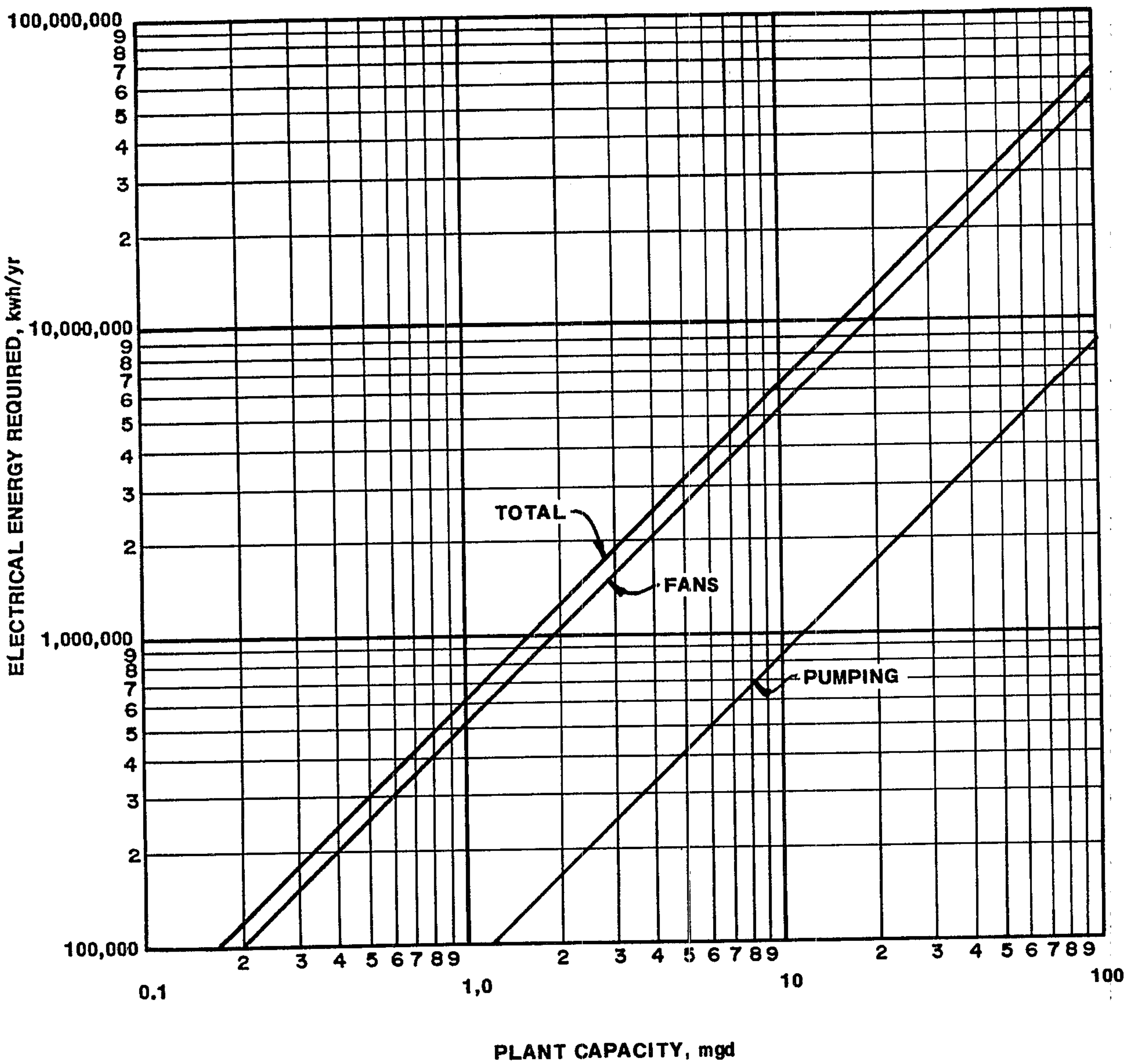
ION EXCHANGE FOR AMMONIA REMOVAL, REGENERANT RENEWAL BY STREAM STRIPPING

Design Assumptions:

- Steam stripping used
- Spent regenerant softened with soda ash at pH ≈ 12
- Steam stripper height ≈ 18 ft
- 4.5 BV/regeneration cycle; 150 BV throughput/ion exchange cycle
- Power includes softening, pH adjustment, pumping to stripping tower
- Fuel based on 15 lb steam required,/1,000 gal wastewater treated
- NH_3 recovered

Type of Energy Required: Electrical and fuel

FIGURE 3–71



AMMONIA STRIPPING

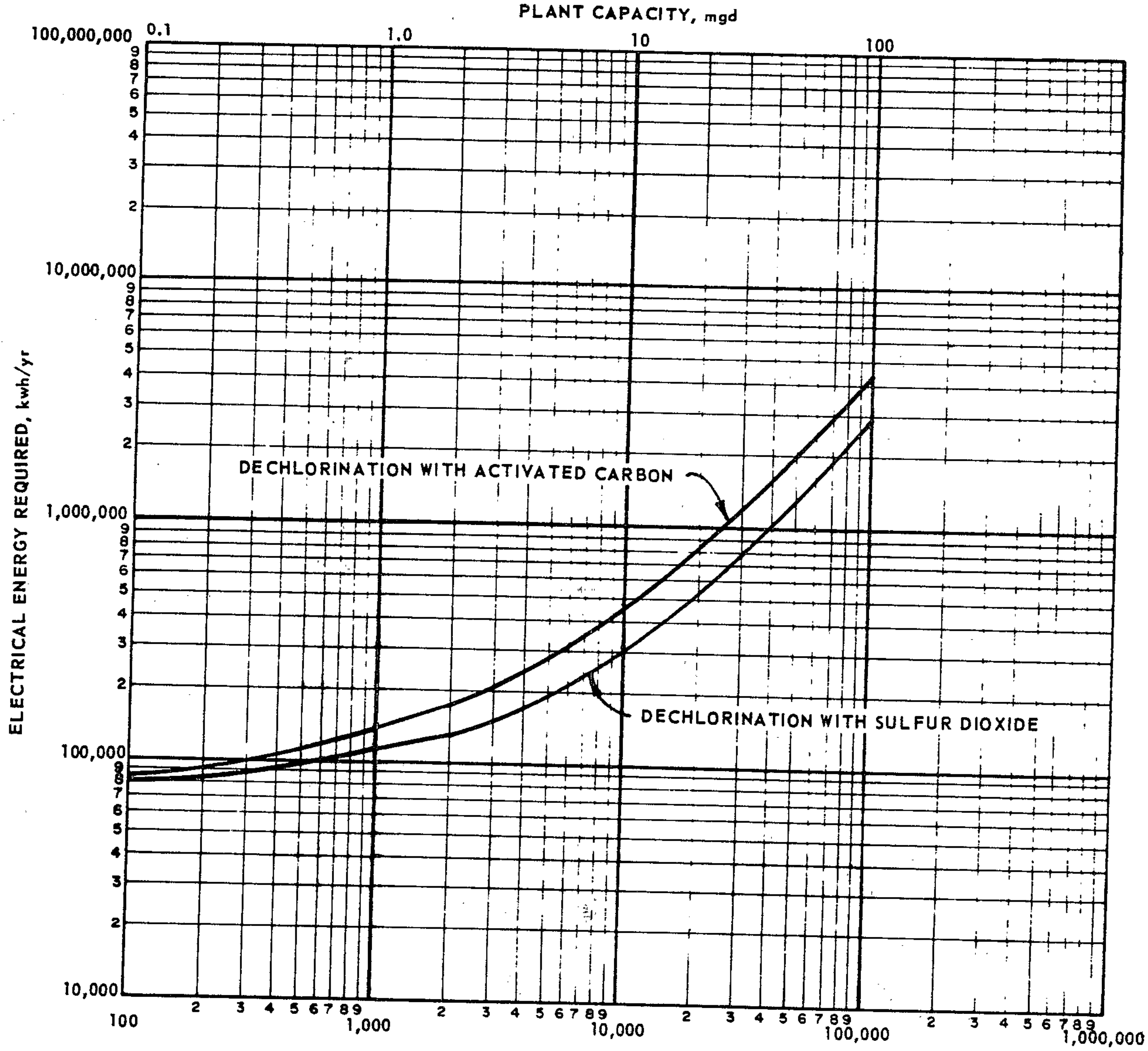
Water Quality:	Influent	Effluent
pH	11	11
Air temp., °F	70	70
NH_3 –N, mg/l	15	3

Design Assumptions:
Pump TDH = 50 ft.

Operating Parameters:
Hydraulic loading = 1.0 gpm /sq ft
Air/Water ratio = 400 cu ft /gal

Type of Energy Required: Electrical

FIGURE 3–72



BREAKPOINT CHLORINATION WITH DECHLORINATION

Water Quality:	Influent (mg./l)	Effluent (mg./l)
NH_4-N	15	0.1

Design Assumptions:

Dosage ratio, $Cl_2:NH_4$-N is 8:1

Residual Cl_2 = 3 mg./l

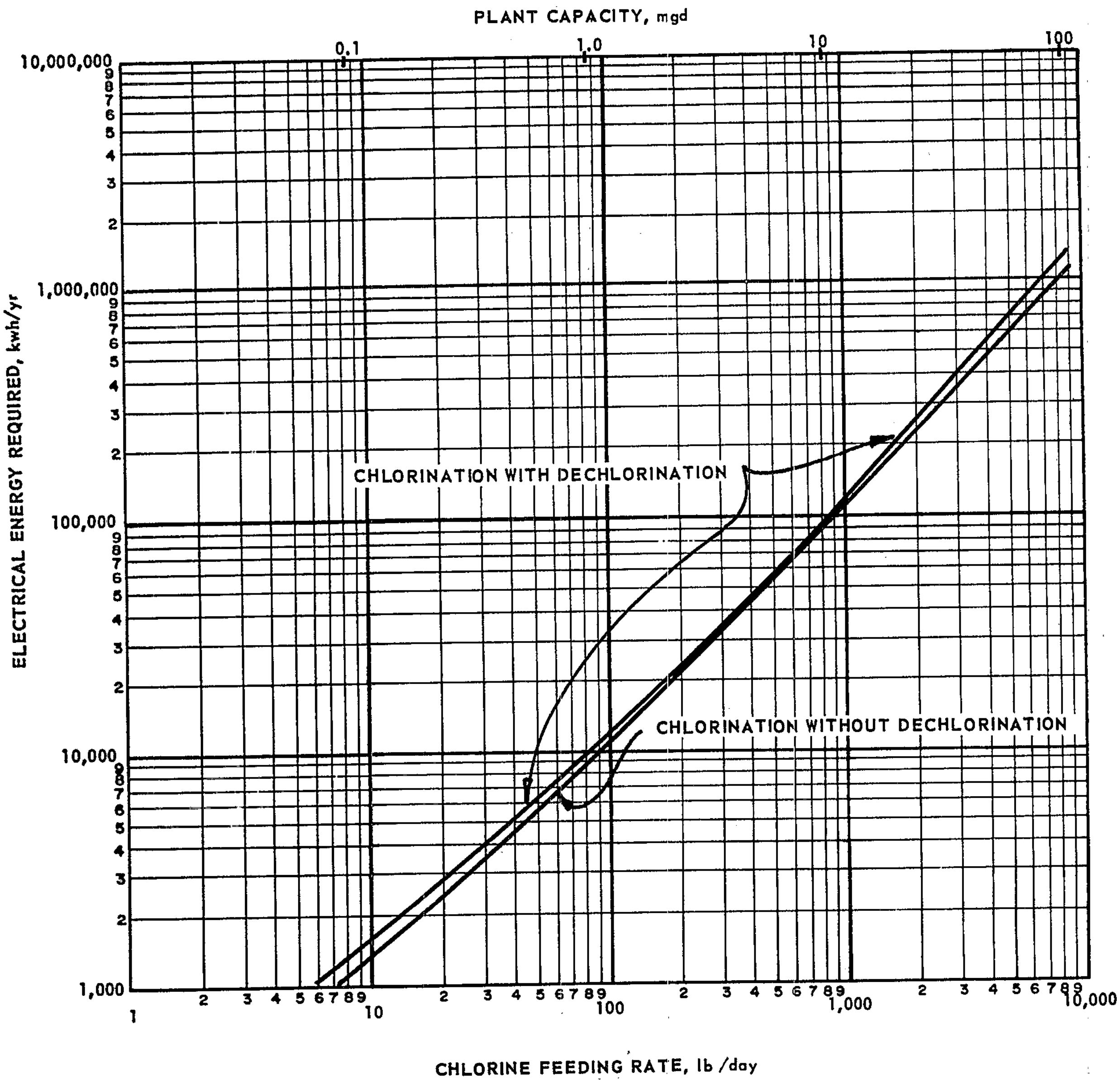
Detention time in rapid mix = 1 min.

Sulfur Dioxide feed ratio, $SO_2:Cl_2$ = 1:1

Activated carbon pumping, TDH = 10 ft

Type of Energy Required: Electrical

FIGURE 3-73



CHLORINATION AND DECHLORINATION FOR DISINFECTION

Water Quality:	Influent	Effluent
BOD_5, mg/l	20	20
Suspended Solids, mg/l	20	20
Coliform, no./100 ml	> 1,000	200

Design Assumptions:

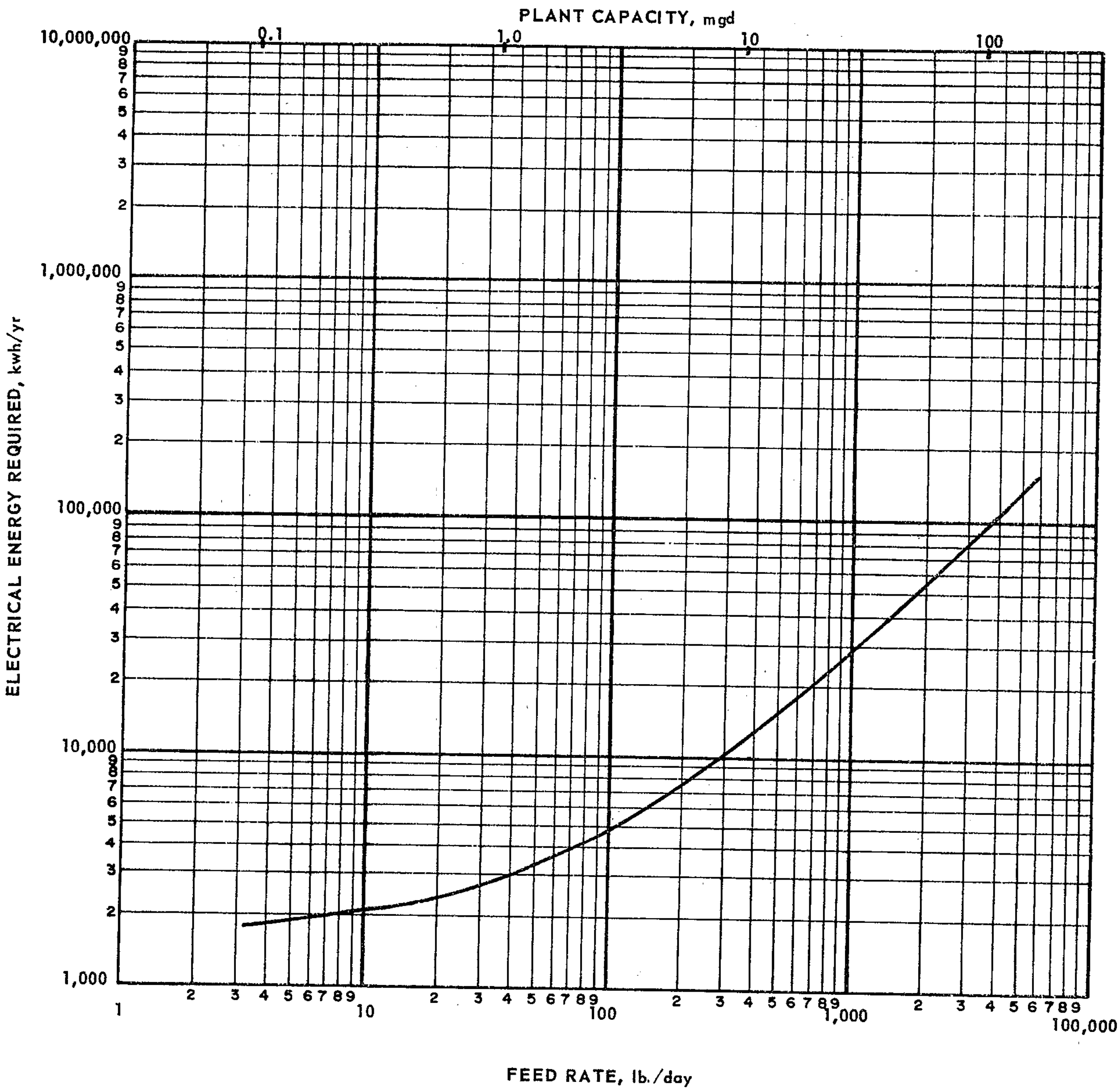
Evaporator used for dosages greater than 2000 lb/day
Dechlorination by SO_2 assuming an SO_2:Cl_2 ratio of 1:1 and SO_2 : Cl_2 residual of 1 : 1
No evaporator for SO_2

Operating Parameters:

Chlorine dosage ≃ 10 mg/l
Chlorine residual = 1 mg/l

Type of Energy Required: Electrical

FIGURE 3–74



CHLORINE DIOXIDE GENERATION AND FEEDING

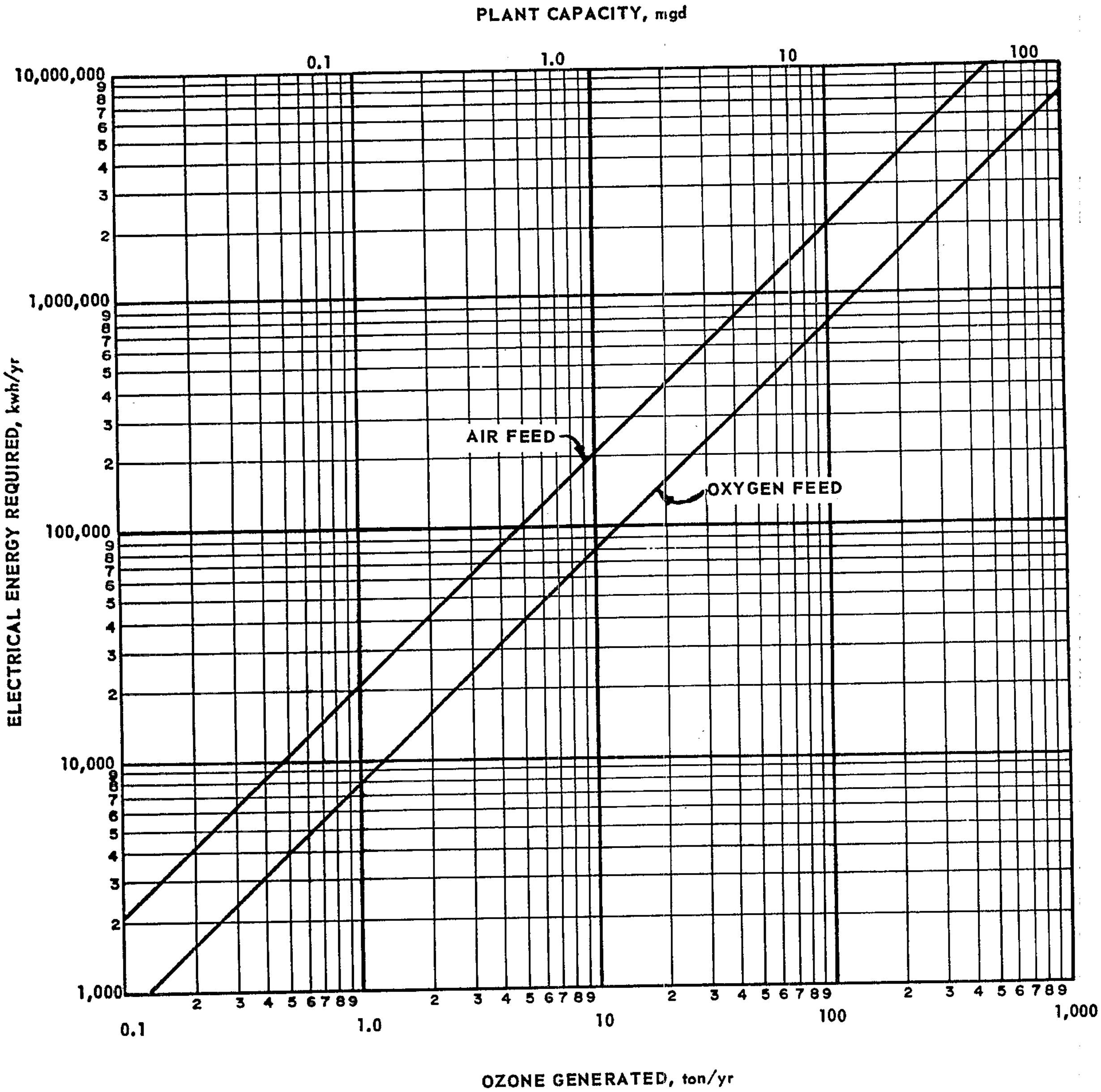
Design Assumptions:

Chlorine Dioxide dosage is 4 mg/l (equivalent to 10 mg/l Cl_2)

Sodium Chlorite: Chlorine Dioxide ratio ≈ 1.68 to 1

Chlorine: Chlorine Dioxide ratio ≈ 1.68 to 1

Type of Energy Required: Electrical



OZONE DISINFECTION

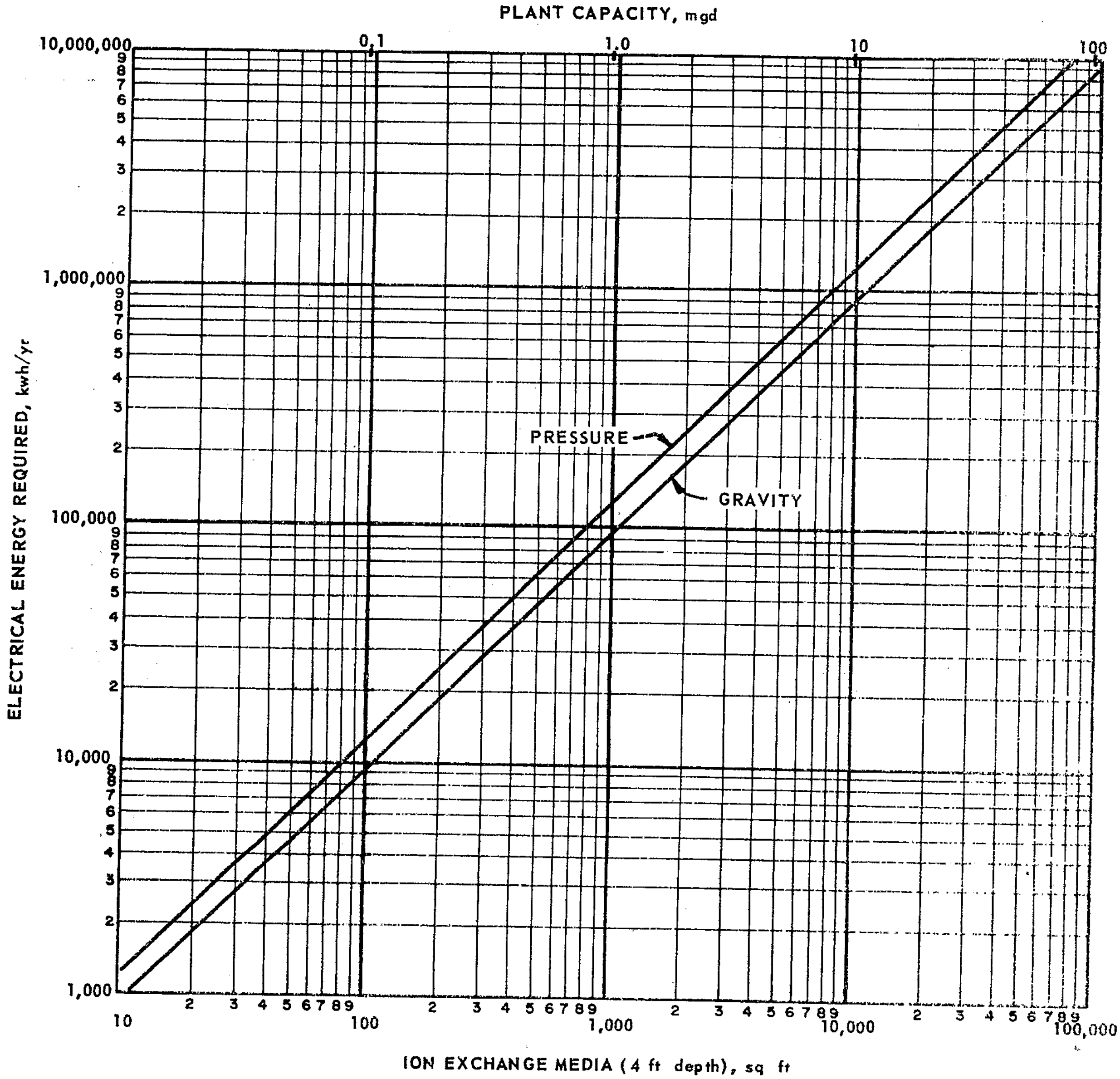
WATER QUALITY:	Influent	Effluent
Suspended Solids, mg/l	10	10
Fecal coliforms/100 ml	10,000	200

Design Assumptions:
Ozone generated from air @ 1.0% wt. concentration and oxygen @ 2.0%

Operating Parameters:
Ozone dose = 5 mg/l

Type of Energy Required: Electrical

FIGURE 3–76



ION EXCHANGE FOR DEMINERALIZATION, GRAVITY AND PRESSURE

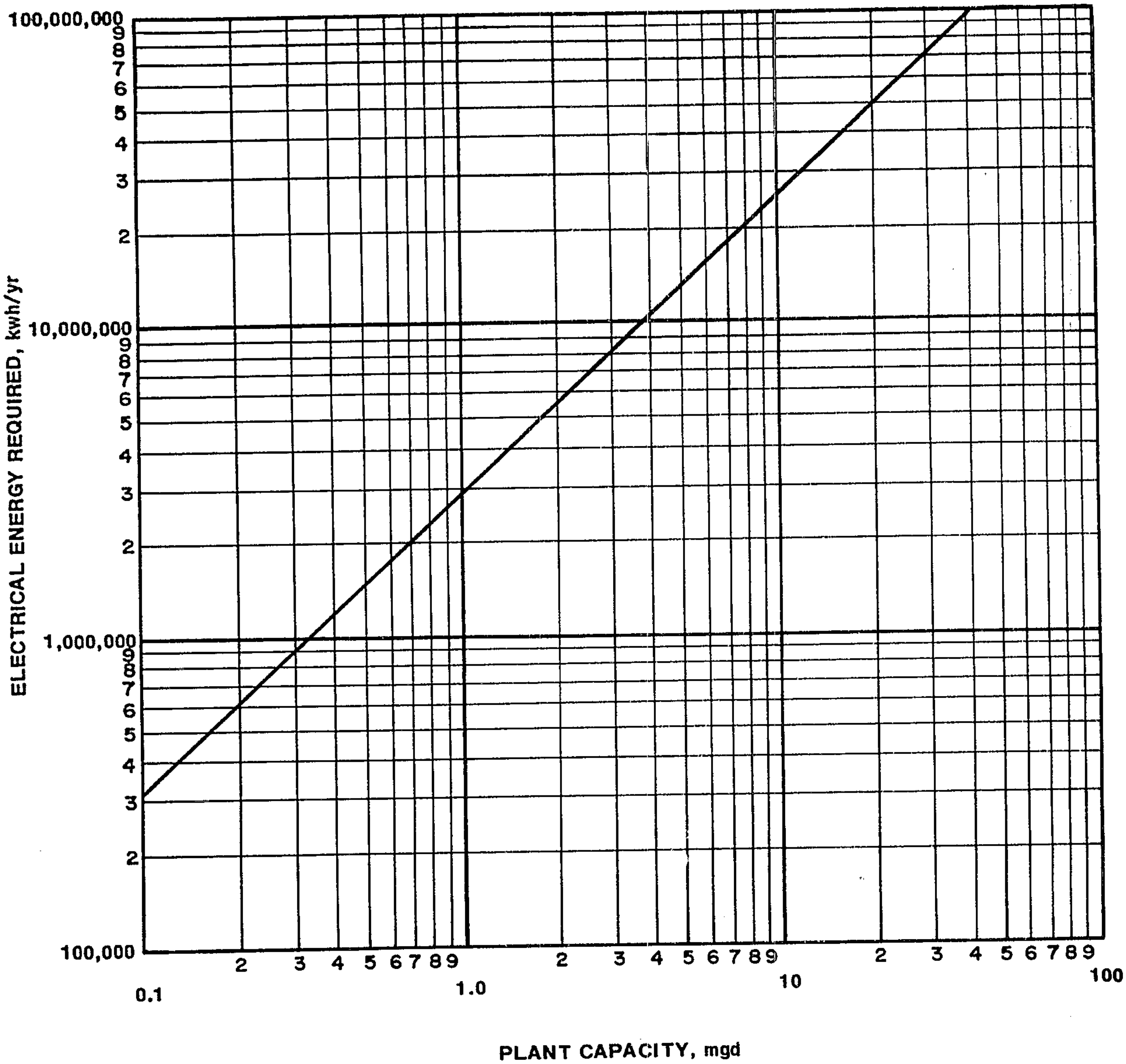
Water Quality:	Influent (mg/l)	Effluent (mg/l)
TDS	500	50

Design Assumptions:

- Loading rate = 3 gpm/cu ft
- Gravity bed, available head = 7.25 ft
- Pressure bed, average operating head = 10 ft
- Includes backwash but not regeneration nor regenerant disposal

Type of Energy Required: Electrical

FIGURE 3-77



REVERSE OSMOSIS

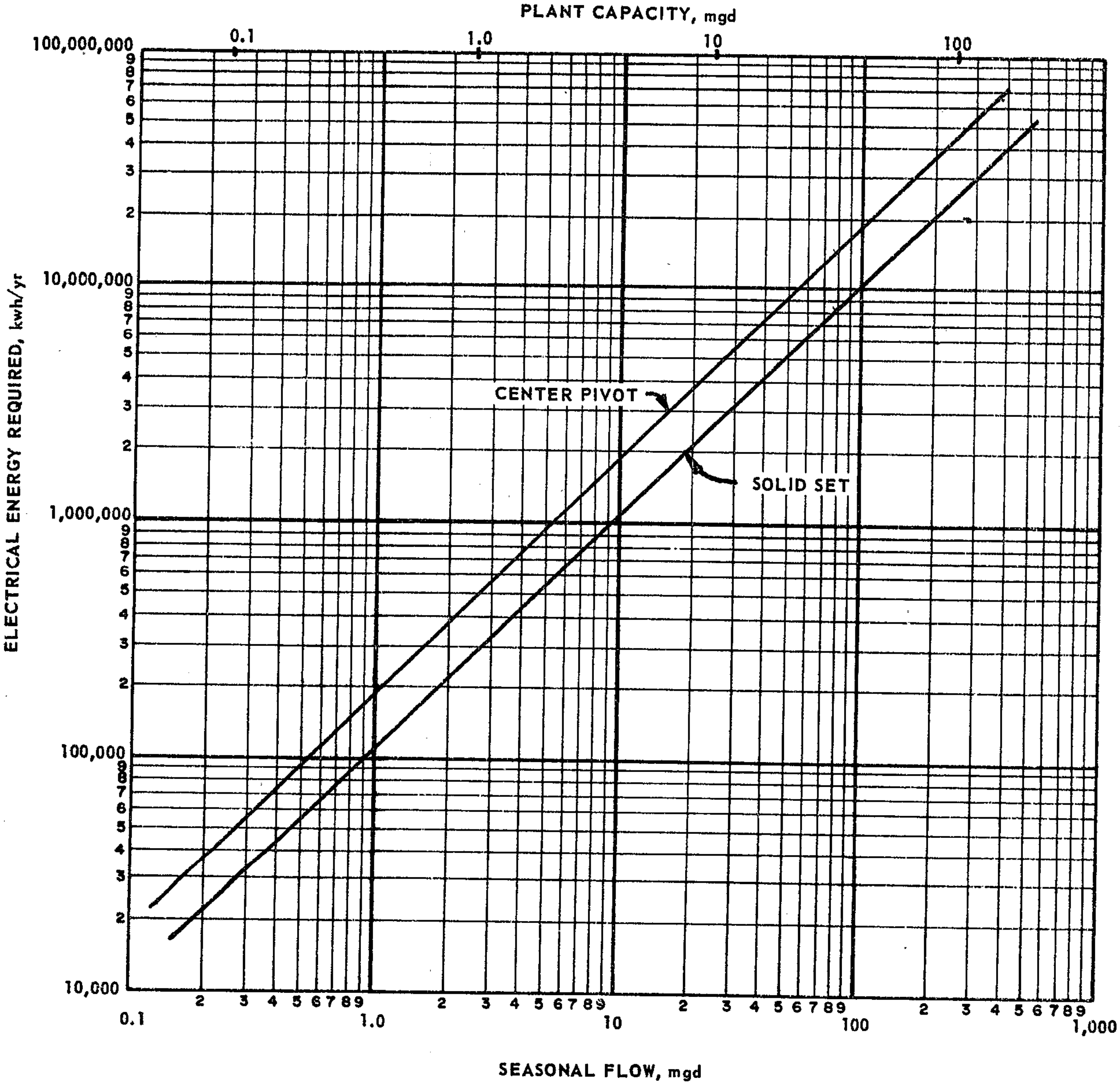
Water Quality:	Influent	Effluent
pH	6	7
Turbidity, JTU	<1.0	0.1
TDS, mg/l	500–1300	100–200

Design Assumptions:
Feed pressure ≅ 600 psi
Single pass system

Operating Parameters:
Water recovery: 0.1–1 mgd 75%
1–10 mgd 80%
10–100 mgd 85%

Type of Energy Required: Electrical

FIGURE 3–78



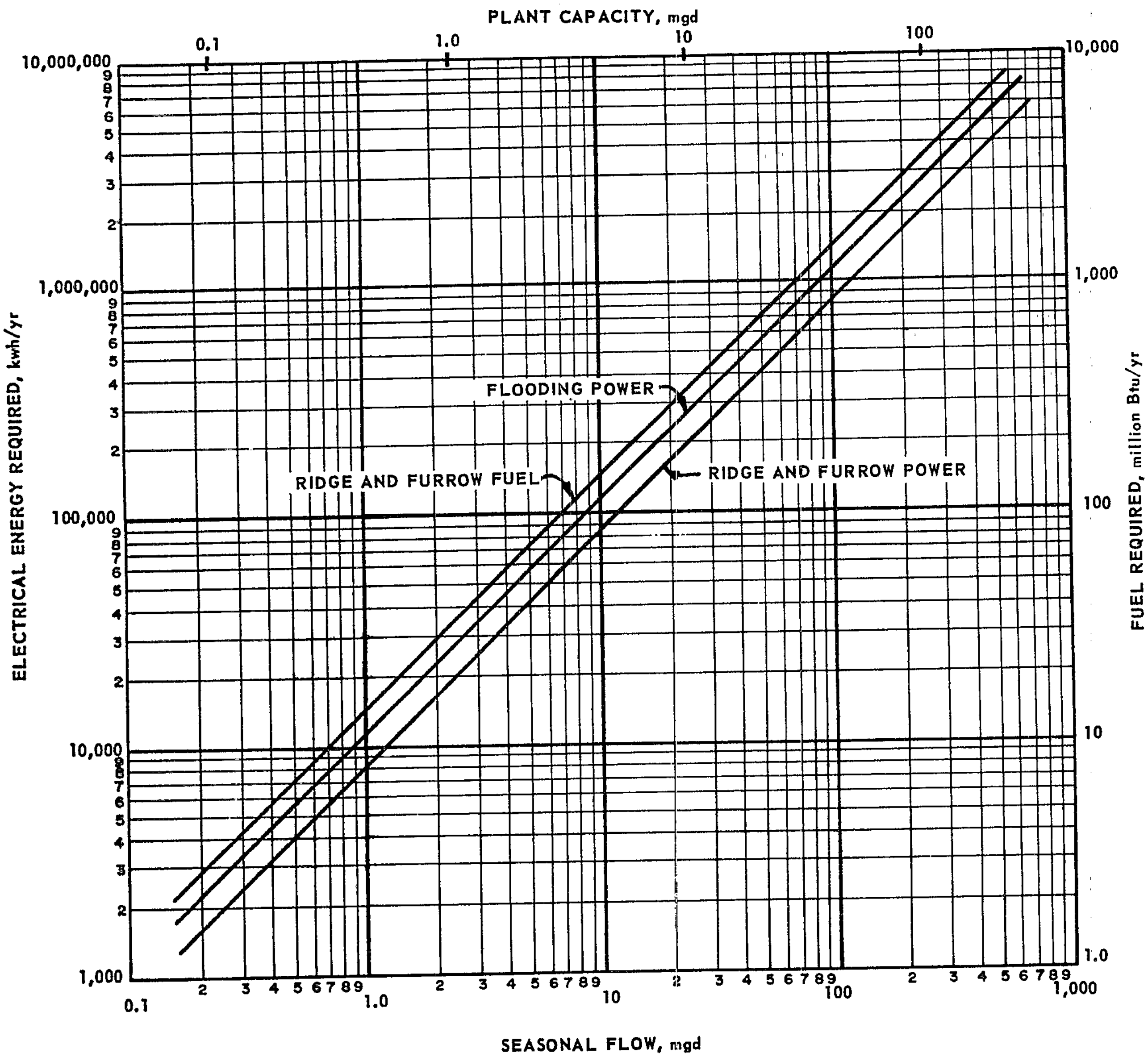
LAND TREATMENT BY SPRAY IRRIGATION

Design Assumptions:

Irrigation season is 5 months/yr
Application rate is 0.33 in/day
Center pivot, TDH = 196 ft
Solid set, TDH = 175 ft

Type of Energy Required: Electrical

FIGURE 3–79



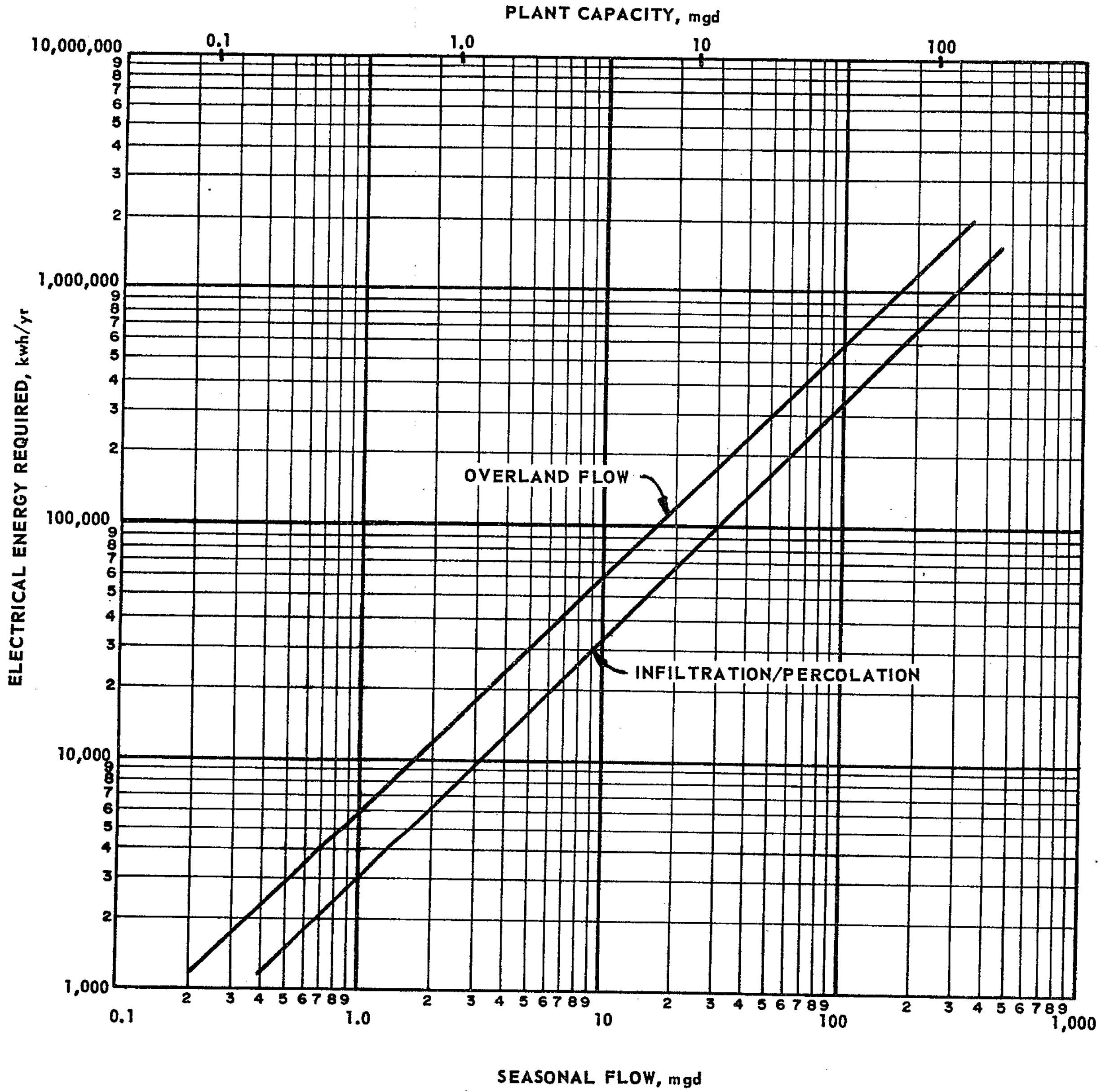
LAND TREATMENT BY RIDGE AND FURROW IRRIGATION AND FLOODING

Design Assumptions:

- Irrigation season is 5 months per year
- Application rate is 0.33 in /day
- Power includes runoff return pumping
- Fuel for annual leveling and ridge and furrow replacement

Type of Energy Required: Electrical and Diesel Fuel

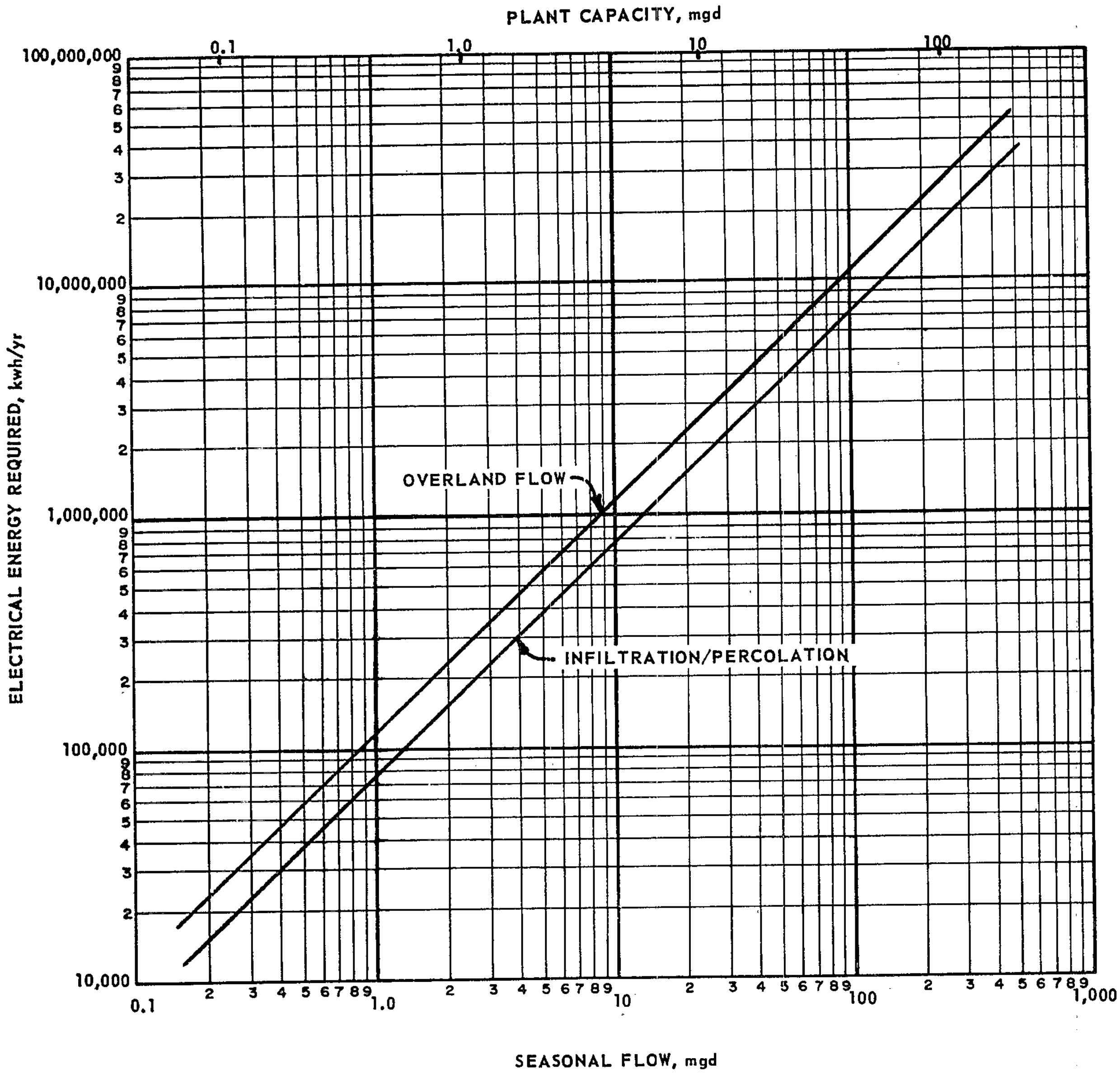
FIGURE 3–80



INFILTRATION/PERCOLATION AND OVERLAND FLOW BY FLOODING

Design Assumptions:
Infiltration/percolation, TDH = 5 ft
Overland flow, TDH = 10 ft
Disposal time is 5 month/yr

Type of Energy Required: Electrical

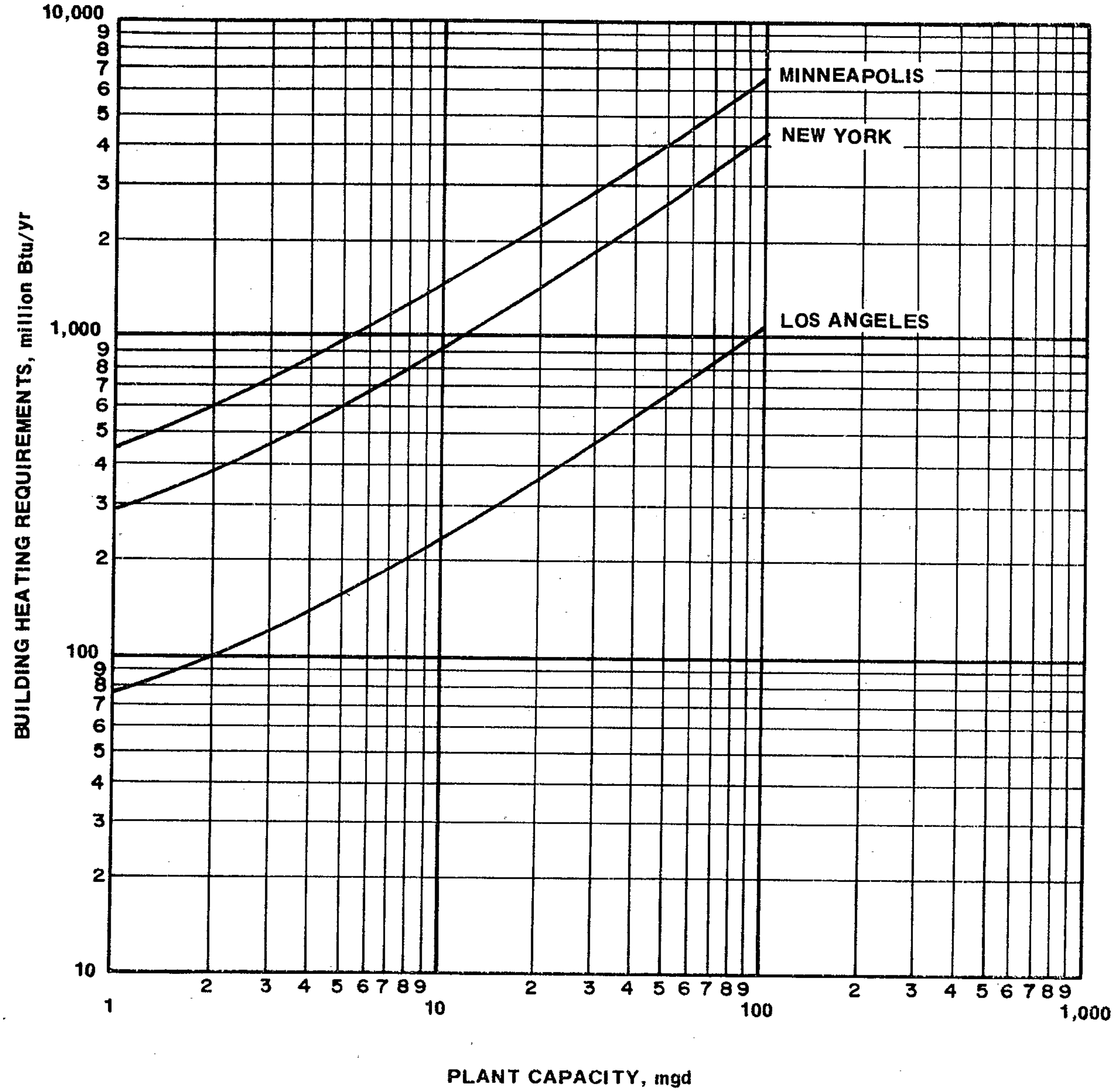


INFILTRATION/PERCOLATION AND OVERLAND FLOW BY SOLID SET SPRINKLERS

Design Assumptions:
- Infiltration/percolation spray, TDH = 115 ft
- Overland flow spray, TDH = 175 ft
- Disposal time is 5 month/yr

Type of Energy Required: Electrical

FIGURE 3–82



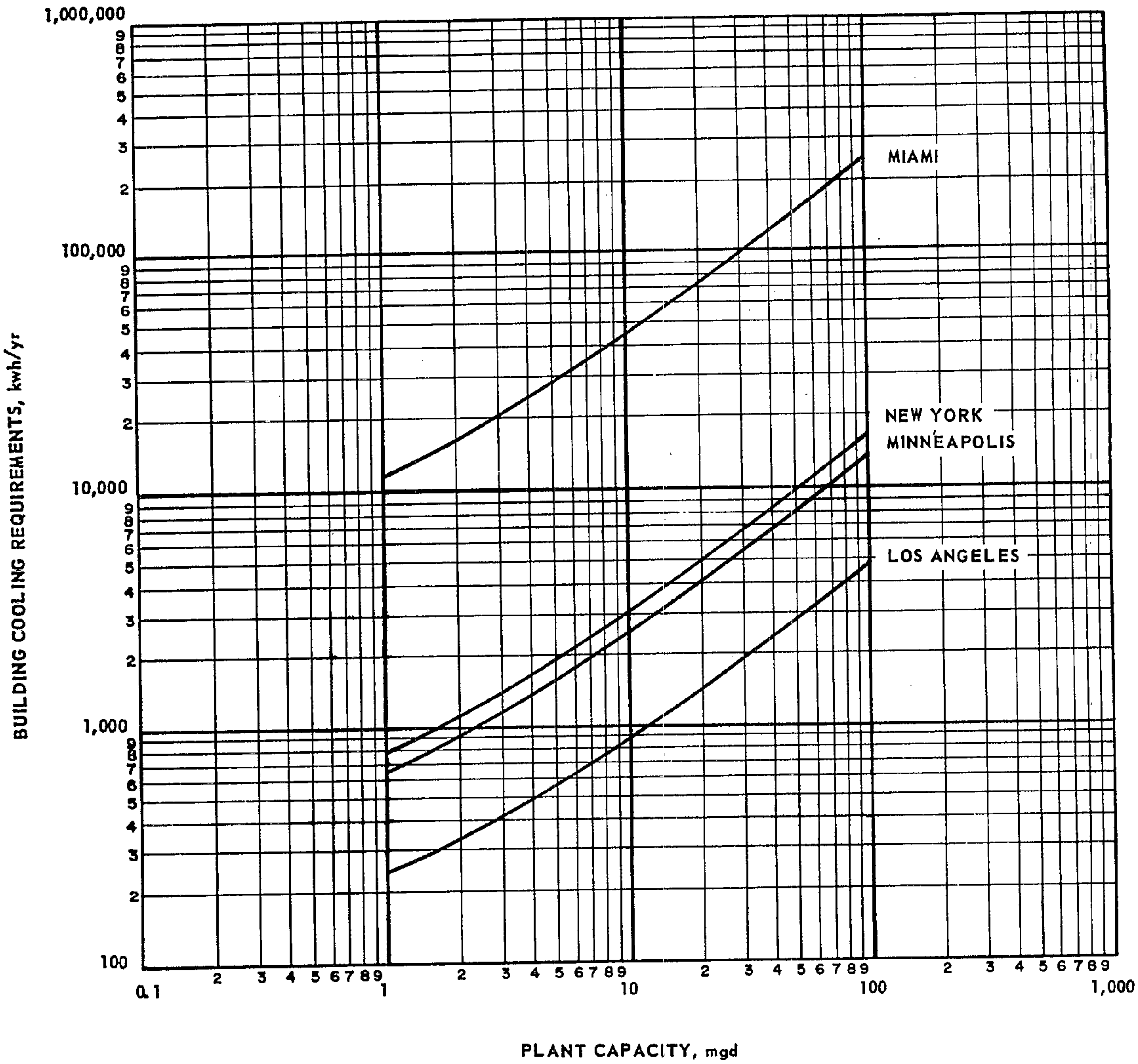
WASTEWATER TREATMENT PLANT
BUILDING HEATING REQUIREMENTS

Design Assumptions:

- Four fresh air changes/hr
- Storm windows and insulated walls and ceilings
- 70 percent fuel utilization factor

(See Chapter 5, pages 5–2 to 5–7)

FIGURE 3–83



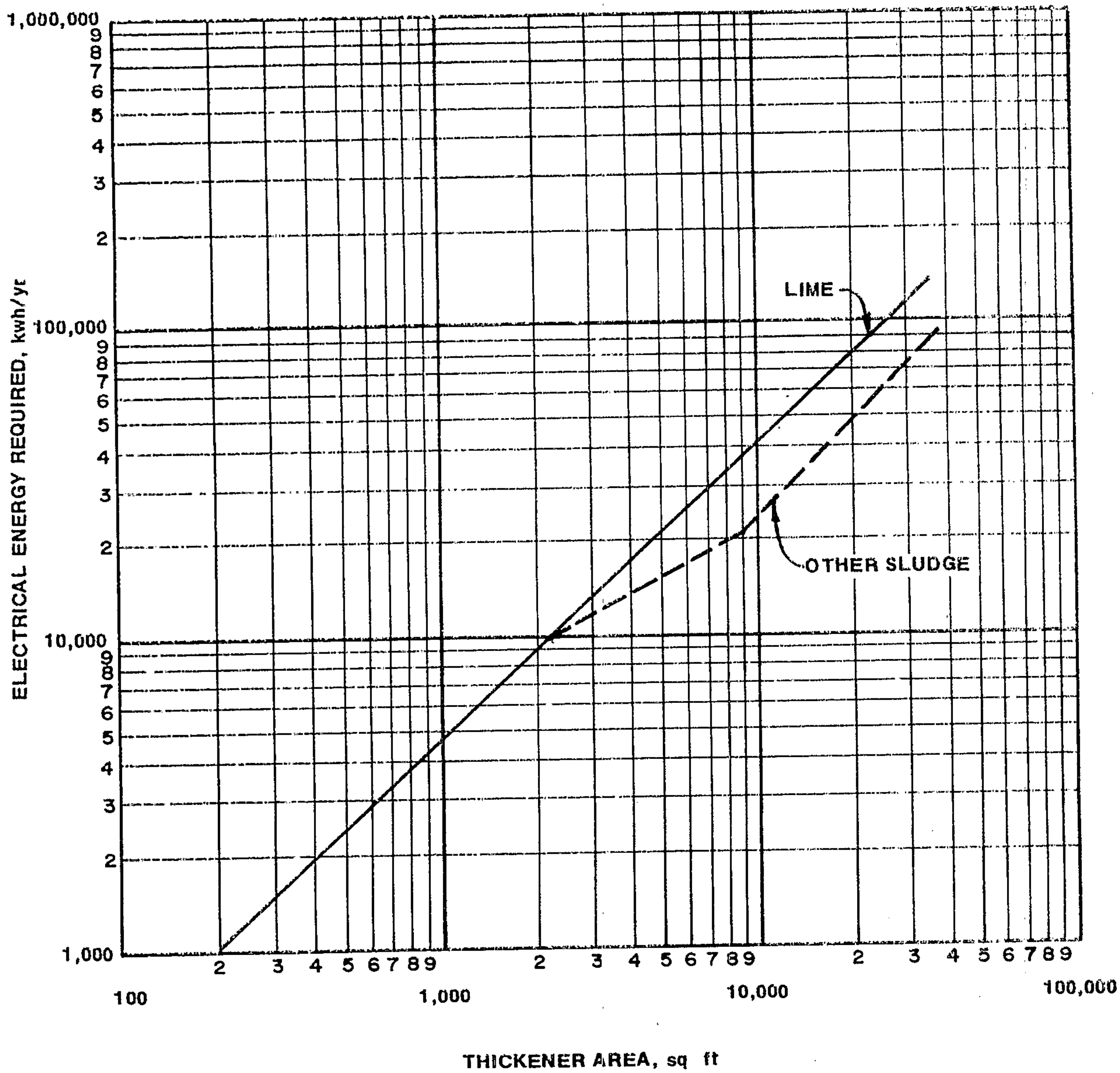
Note: See chapter 5, pages 5–8 to 5–10

WASTEWATER TREATMENT PLANT BUILDING COOLING REQUIREMENTS

FIGURE 3–84

TABLE 3-4
GRAVITY THICKENING
(No Chemical Conditioning)

Sludge Type	Feed Solids Concentration (Percent)	Typical Loading Rate (lb/sqft/day)	Thickened Sludge Concentration (Percent)
Primary	5.0	20	8.0
Primary + $FeCl_3$	2.0	6	4.0
Primary + Low Lime	5.0	20	7.0
Primary + High Lime	7.5	25	12.0
Primary + WAS	2.0	10	4.0
Primary + (WAS + $FeCl_3$)	1.5	6	3.0
(Primary + $FeCl_3$) + WAS	1.8	6	3.6
Digested Primary	8.0	25	12.0
Digested Primary + WAS	4.0	15	8.0
Digested Primary + (WAS + $FeCl_3$)	4.0	15	6.0
Tertiary, 2 stage high lime	4.5	60	15.0
Tertiary, low lime	3.0	60	12.0



GRAVITY THICKENING

See table 3-4 for design assumptions and operating parameters.
Lime curve based on tertiary system at 60 lb/sq ft/day

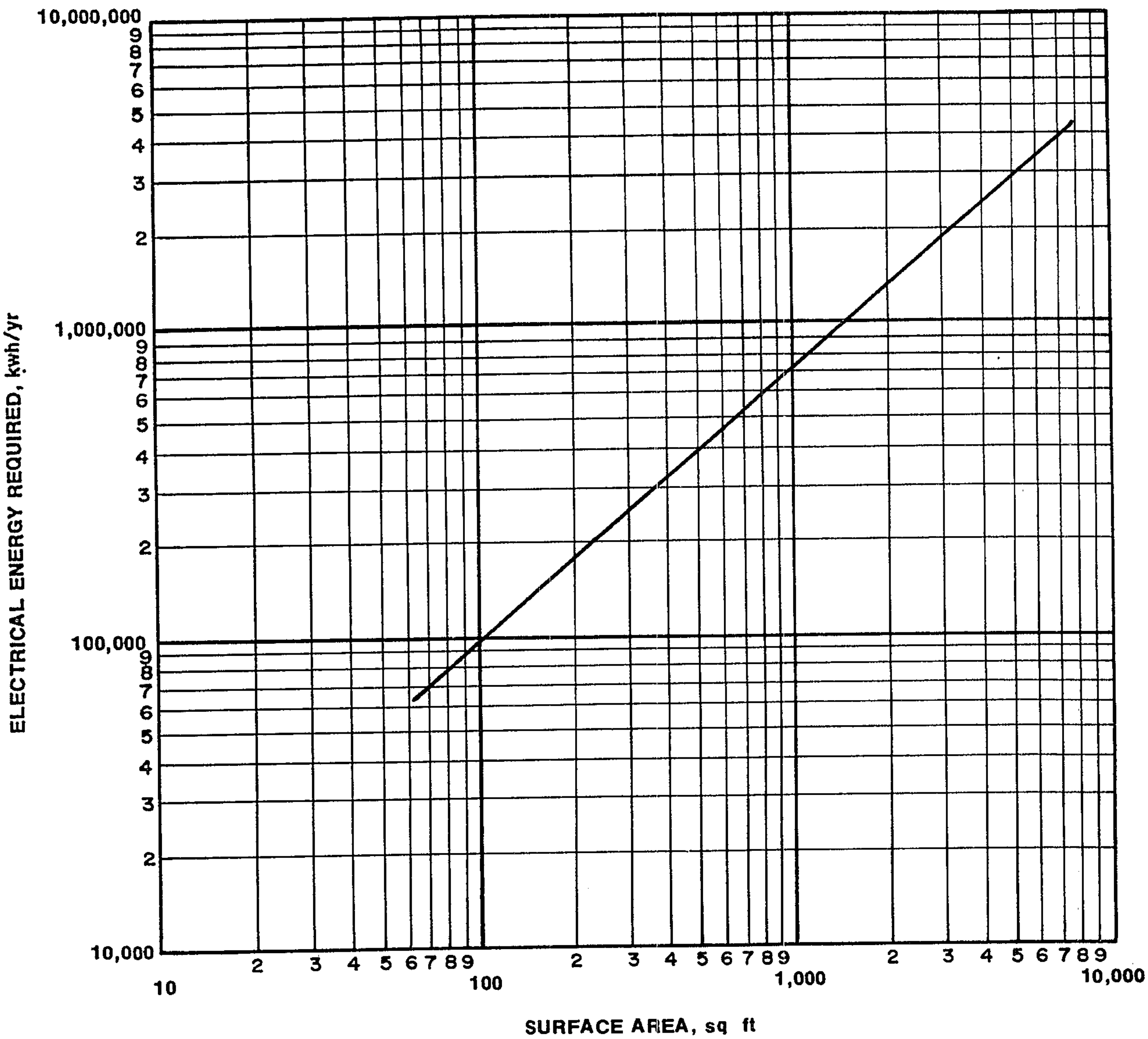
Type of Energy Required : Electrical

FIGURE 3-85

TABLE 3-5

FLOTATION THICKENING

Sludge Type	Feed Solids Concentration (Percent)	Typical Loading Rate Without Polymer (lb/sqft/day)	Typical Loading Rate With Polymer (lb/sqft/day)	Float Solids Concentration (Percent)
Primary + WAS	2.0	20	60	5.5
Primary + (WAS + $FeCl_3$)	1.5	15	45	3.5
(Primary + $FeCl_3$) + WAS	1.8	15	45	4.0
WAS	1.0	10	30	3.0
WAS + $FeCl_3$	1.0	10	30	2.5
Digested Primary + WAS	4.0	20	60	10.0
Digested Primary + (WAS + $FeCl_3$)	4.0	15	45	8.0
Tertiary, Alum	1.0	8	24	2.0



AIR FLOTATION THICKENING

See Table 3-5 for design assumptions and operating parameters. Curve corresponds to a maximum air requirement of 0.2 lb/lb solids and average of 0.3 scfm air/sq ft surface area

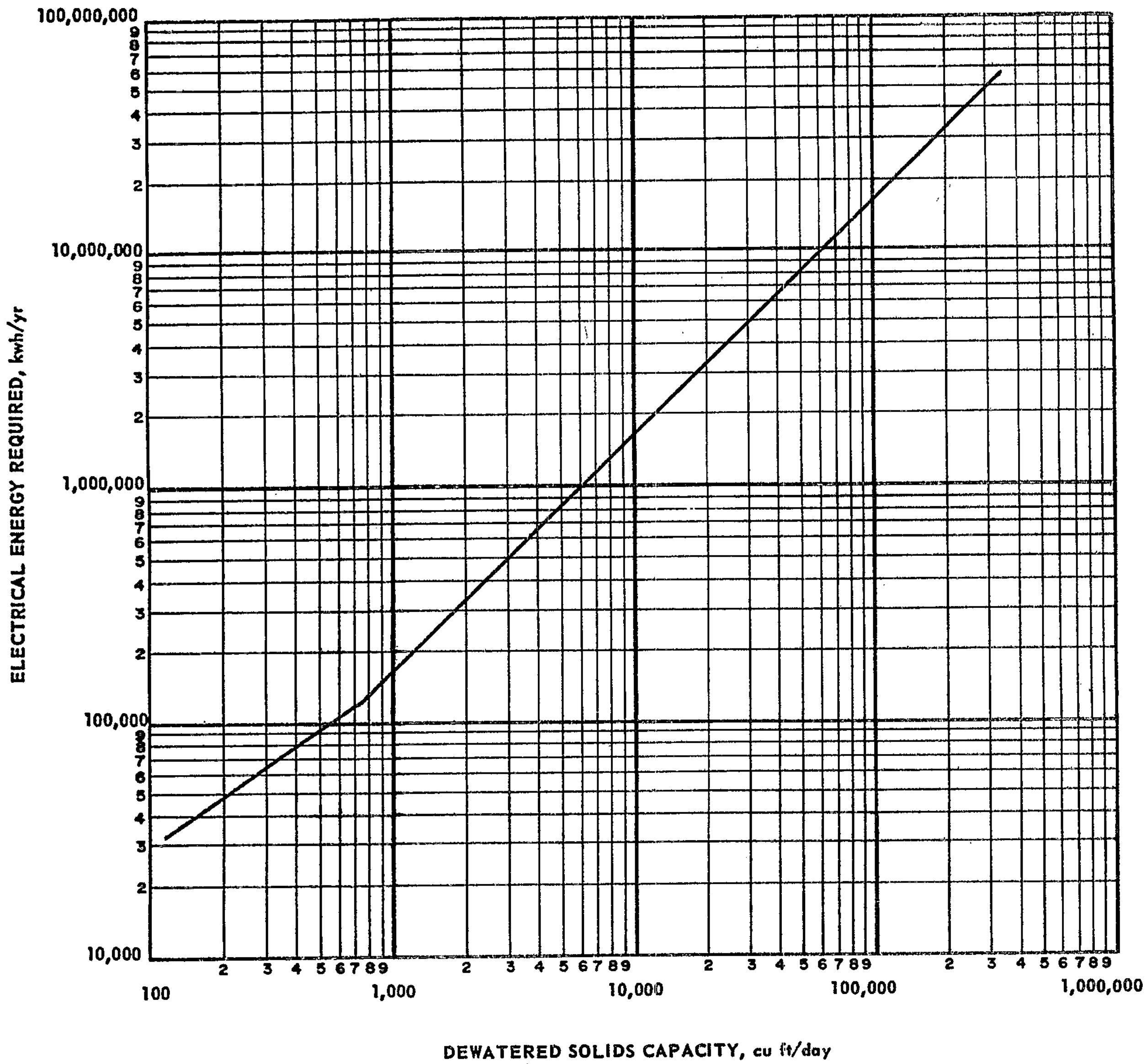
Type of Energy Required: Electrical

FIGURE 3-86

TABLE 3-6

BASKET CENTRIFUGE, SLUDGE CHARACTERISTICS

Sludge	Feed Concentration, %	Cake Concentration, %
Primary + WAS	2.0	9-12
Primary + WAS (+$FeCl_3$)	1.5	9-10
WAS	1.0	8-9
Digested Primary	8.0	25
Digested Primary + WAS	4.0	20
Digested Primary + WAS (+$FeCl_3$)	4.0	20



BASKET CENTRIFUGE

Design Assumptions:

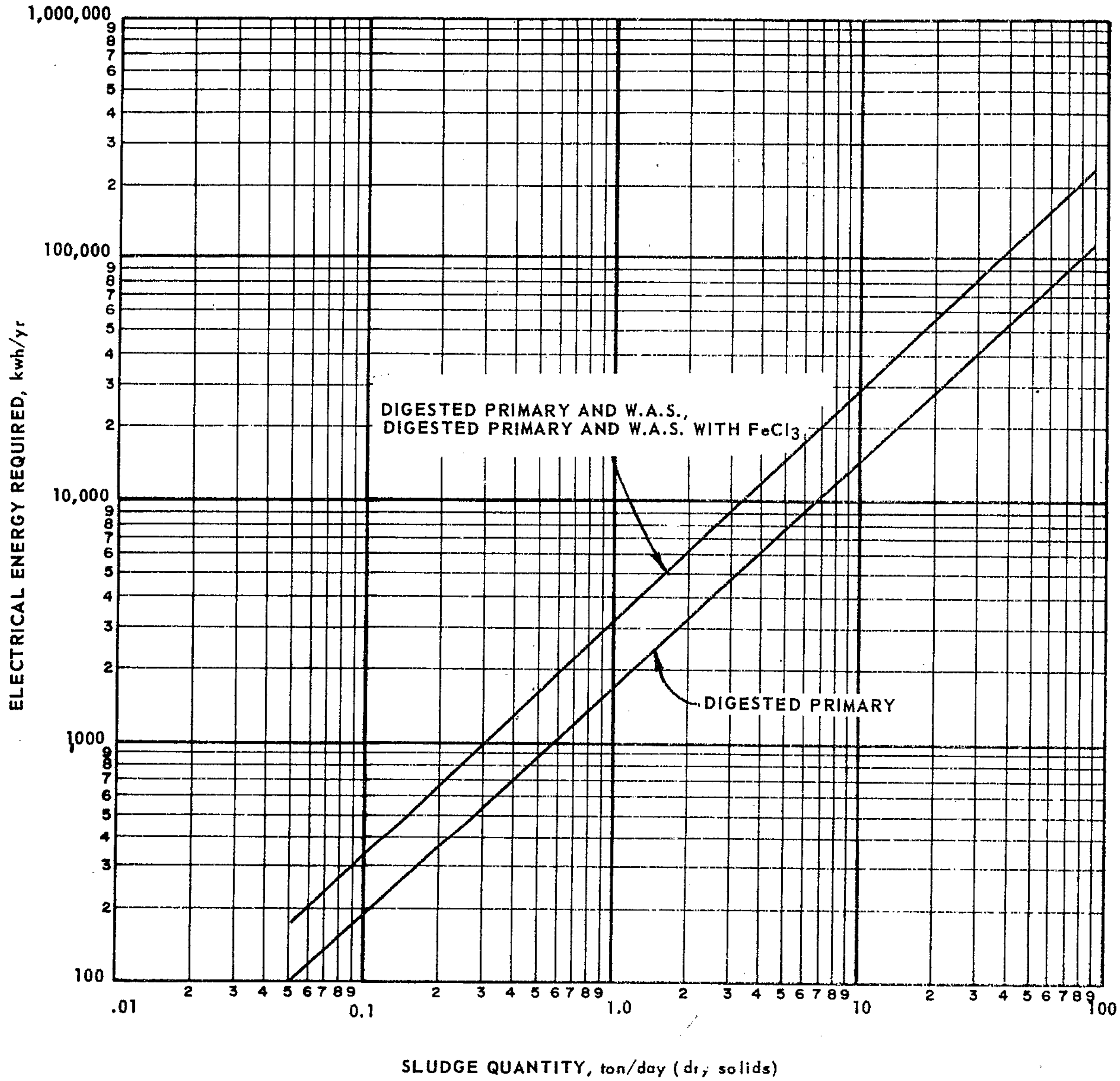
Operating hp is .375 times rated hp
See Table 3-6 for specific sludge characteristics.
Multiple units required above 800 cu ft/day cpacity

Operating Parameters:

Machines run for 20 min, are off for 10 min
10 min allowed for unloading, restarting and attaining running speed

Type of Energy Required: Electrical

FIGURE 3-87



ELUTRIATION

Sludge

1. Digested primary @ 8% solids
2. Digested primary+W.A.S. @ 4% solids
3. Digested primary+W.A.S. (+$FeCl_3$) @ 4% solids

Design Assumptions:

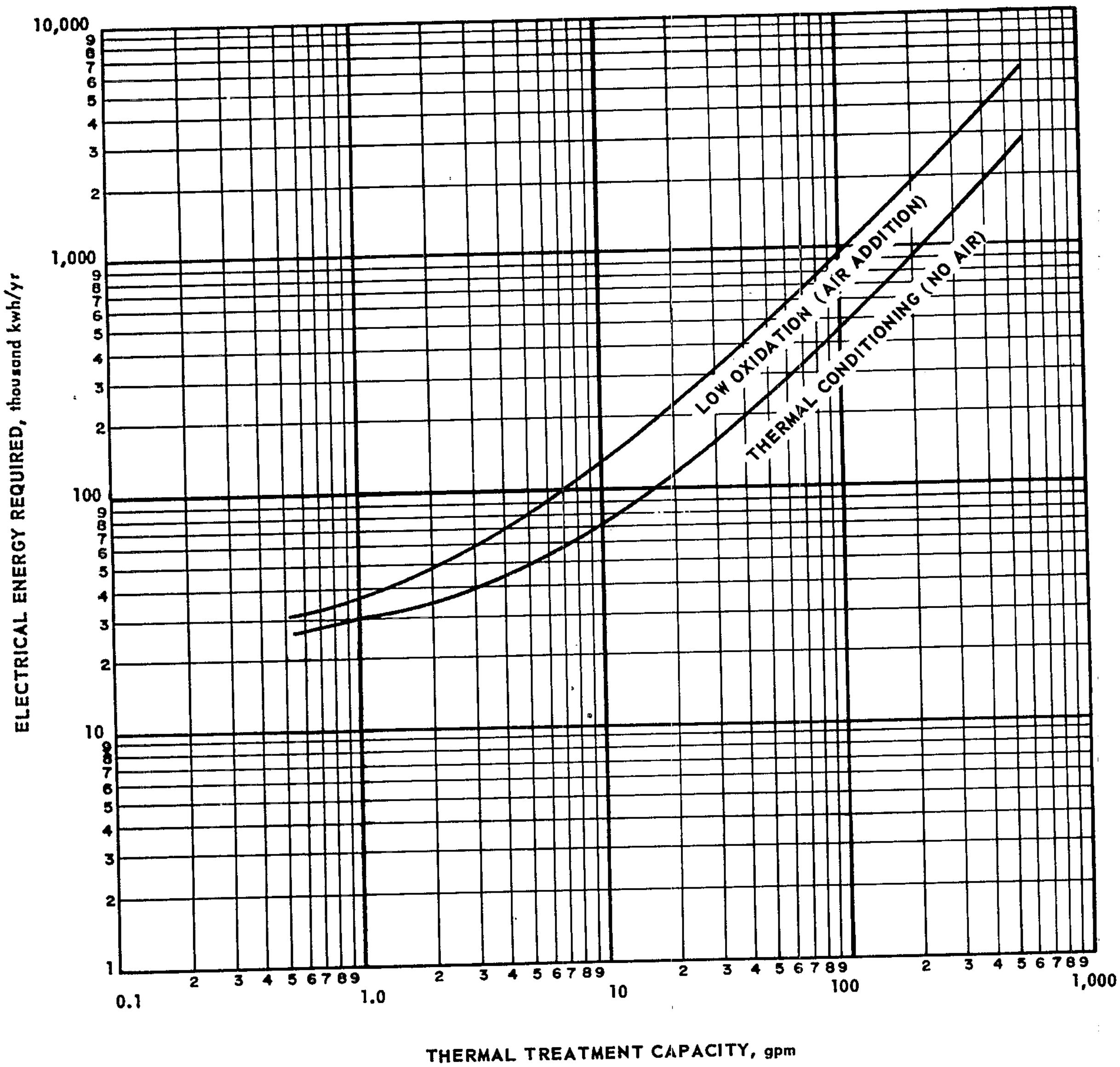
Overflow rates = 800 gpd/sq ft for 1
500 gpd/sq ft for 2 & 3
Mixing energy: G = 200 sec^{-1} for 5 min per stage
TDH = 30 ft for sludge and 25 ft for water

Operating Parameters:

Two - stage, countercurrent system with separate mixing & settling tanks
Wash water to sludge ratio = 4:1

Type of Energy Required: Electrical

FIGURE 3-88



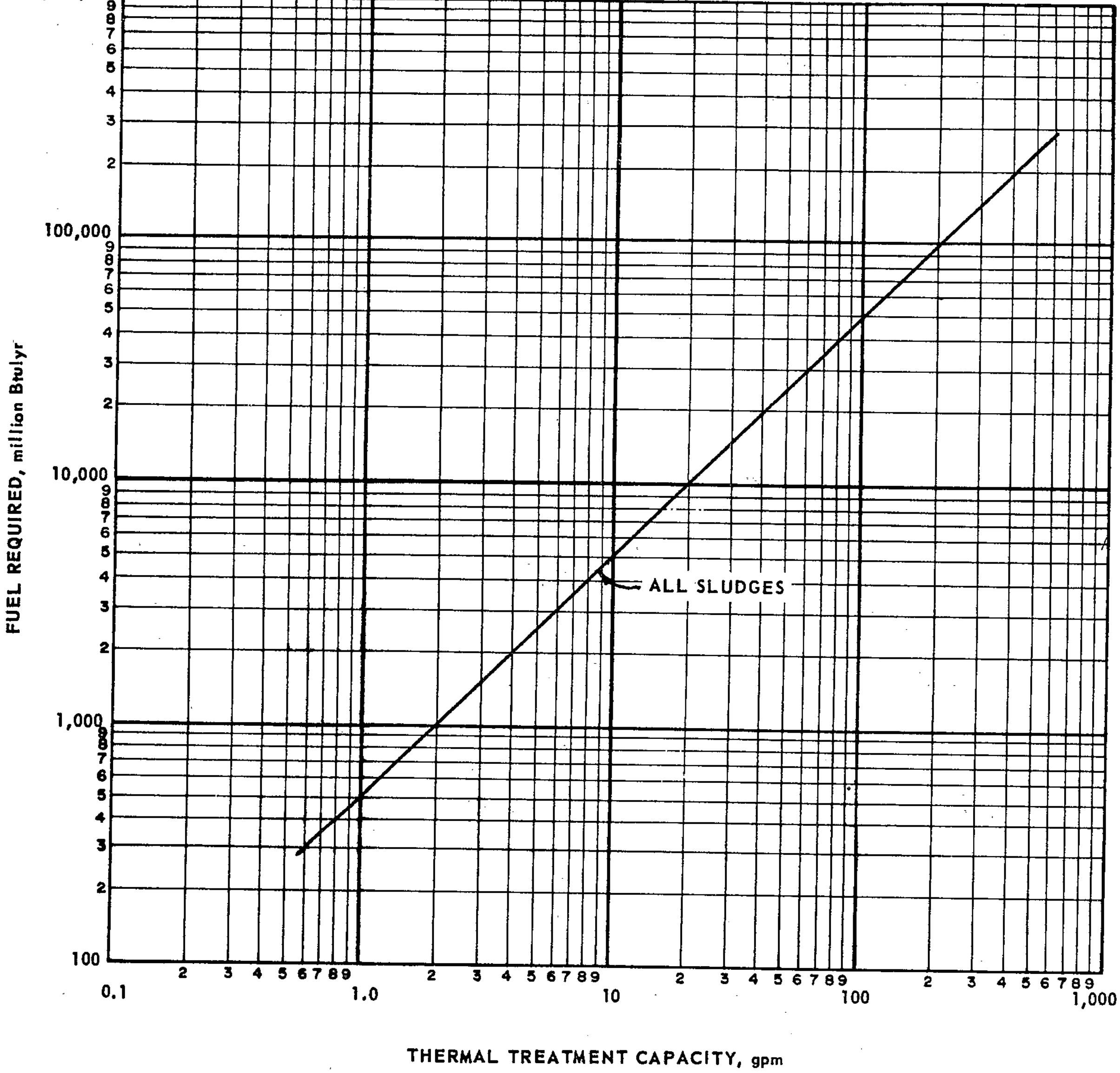
HEAT TREATMENT

Design Assumptions:
- Reactor conditions = 300 psig at 350°F
- Heat exchanger ΔT = 50°F
- Continuous operation
- See Table 5-9 for sludge description and text in Chapter 5

Curve includes:
- Pressurization pumps
- Sludge grinders
- Post-thickener drives
- Boiler feed pumps
- Air compressors

Type of Energy Required: Electrical

FIGURE 3-89



HEAT TREATMENT – WITHOUT AIR ADDITION

Design Assumptions:

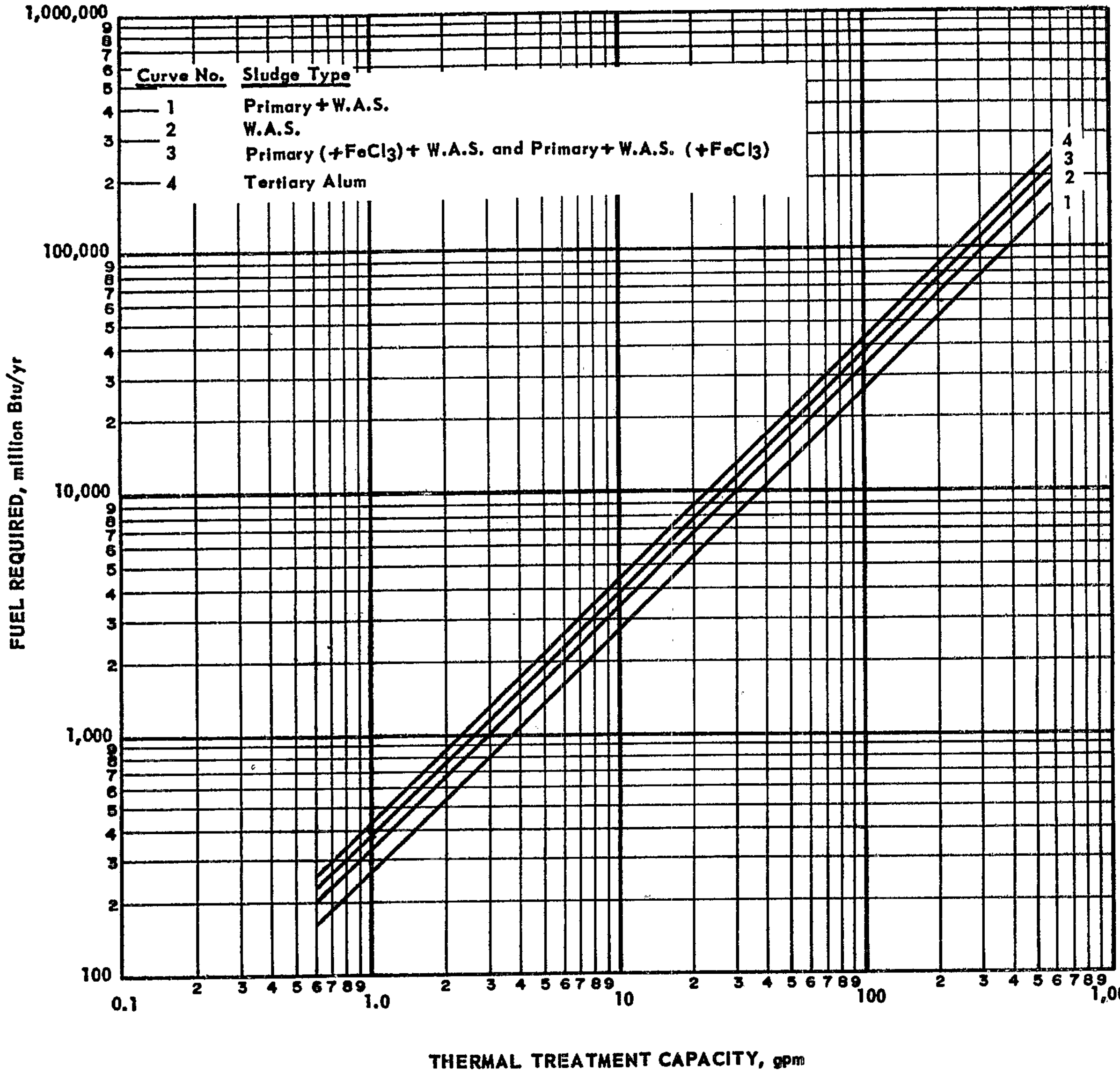
Reactor conditions– 300 psig at 350°F
Heat exchanger $\Delta T = 50°F$
Continuous operation
See Table 5–9 for sludge description and text of Chapter 5.

Curve includes:

Fuel to produce steam necessary to raise reactor contents to operating temperature

Type of Energy Required: Fuel

FIGURE 3–90



HEAT TREATMENT – WITH AIR ADDITION

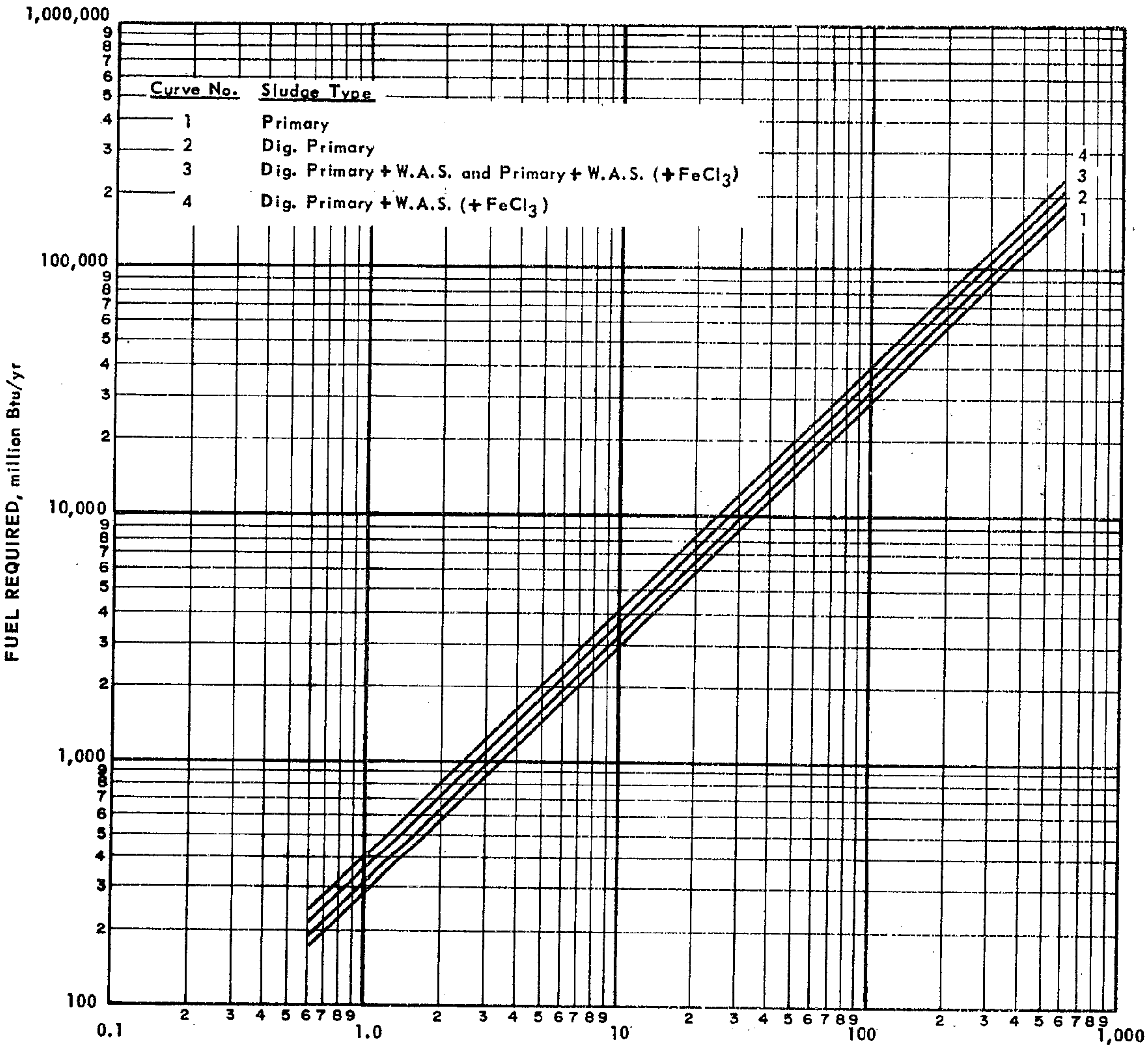
(Curve 1 of 2)

Design Assumptions:
Reactor conditions– 300 psig at 350 F
Heat exchanger $\Delta T = 50°F$
Continuous operation
See Table 5–9 for sludge description and text of Chapter 5.

Curve includes:
Fuel to produce steam necessary to raise reactor contents to operating temperature

Type of Energy Required: Fuel

FIGURE 3–91



HEAT TREATMENT – WITH AIR ADDITION

(Curve 2 of 2)

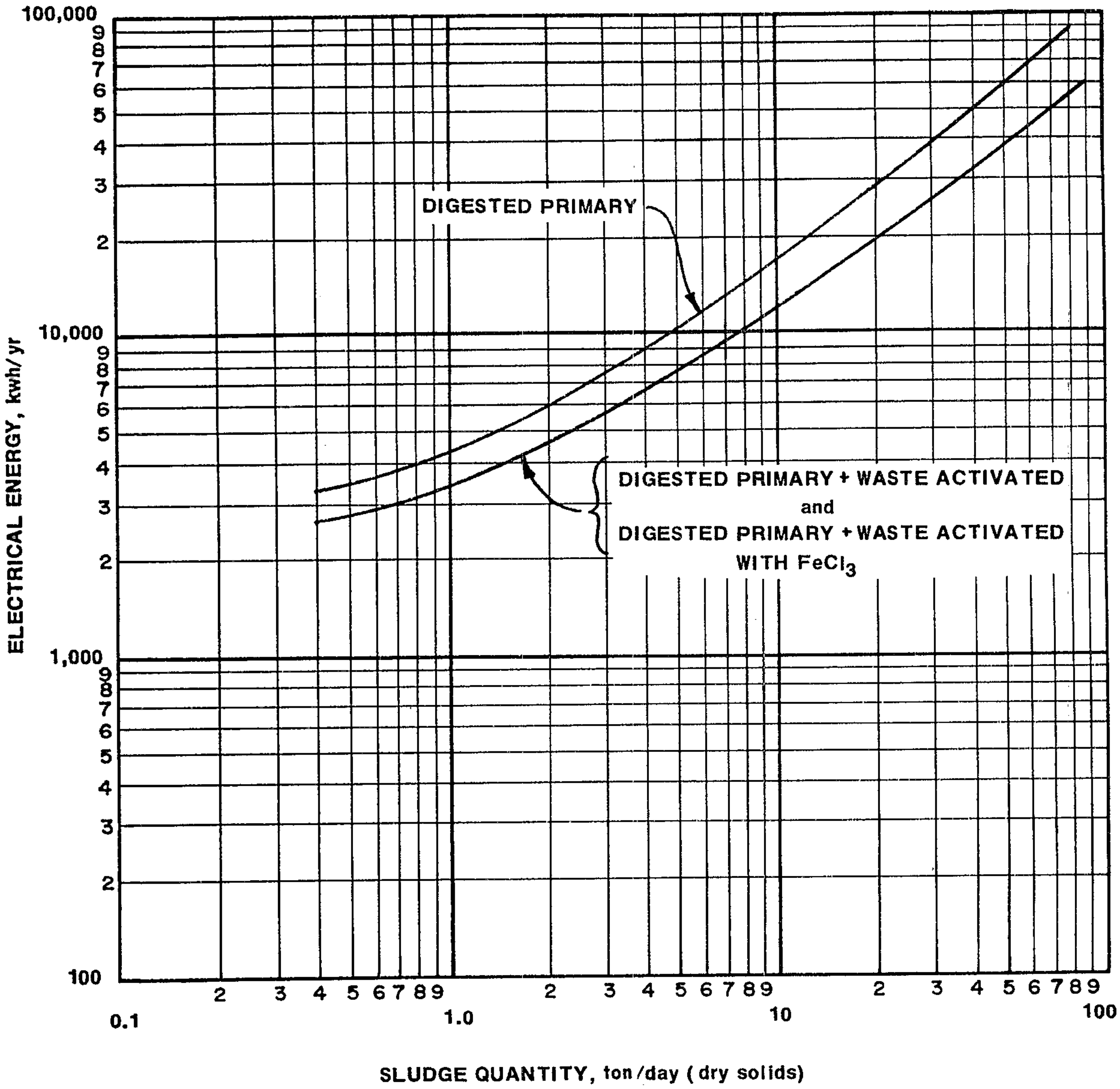
Design Assumptions:

Reactor conditions– 300 psig at 350 F
Heat exchanger $\Delta T = 50°F$
Continuous operation
See Table 5–9 for sludge description and text of Chapter 5.

Curve includes:

Fuel to produce steam necessary to raise reactor contents to operating temperature

Type of Energy Required: Fuel



CHEMICAL ADDITION
(Digested Sludges)

Design Assumptions:

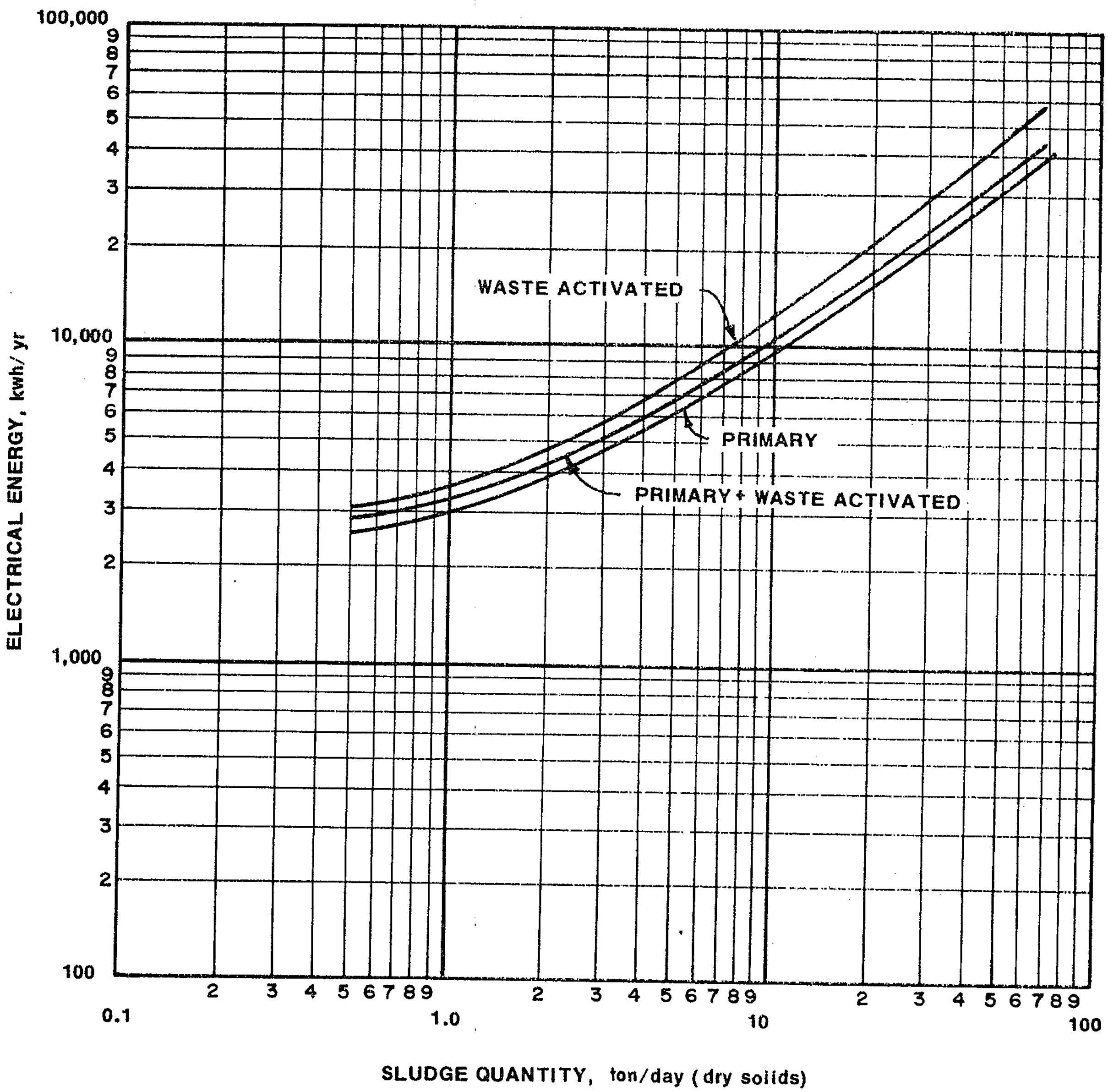
See Table 3-8 preceding Figure 3-96 for chemical quantities
Pumping head = 10 ft TDH

Curves Include:

Chemical feeding and handling
Sludge pumping
Sludge—chemical mixing

Type of Energy Required: Electrical

FIGURE 3–93



CHEMICAL ADDITION
(Undigested Sludges)

Design Assumptions:

Pumping head =10 ft TDH

Curves include:

Chemical feeding and handling
Sludge pumping
Sludge–chemical mixing

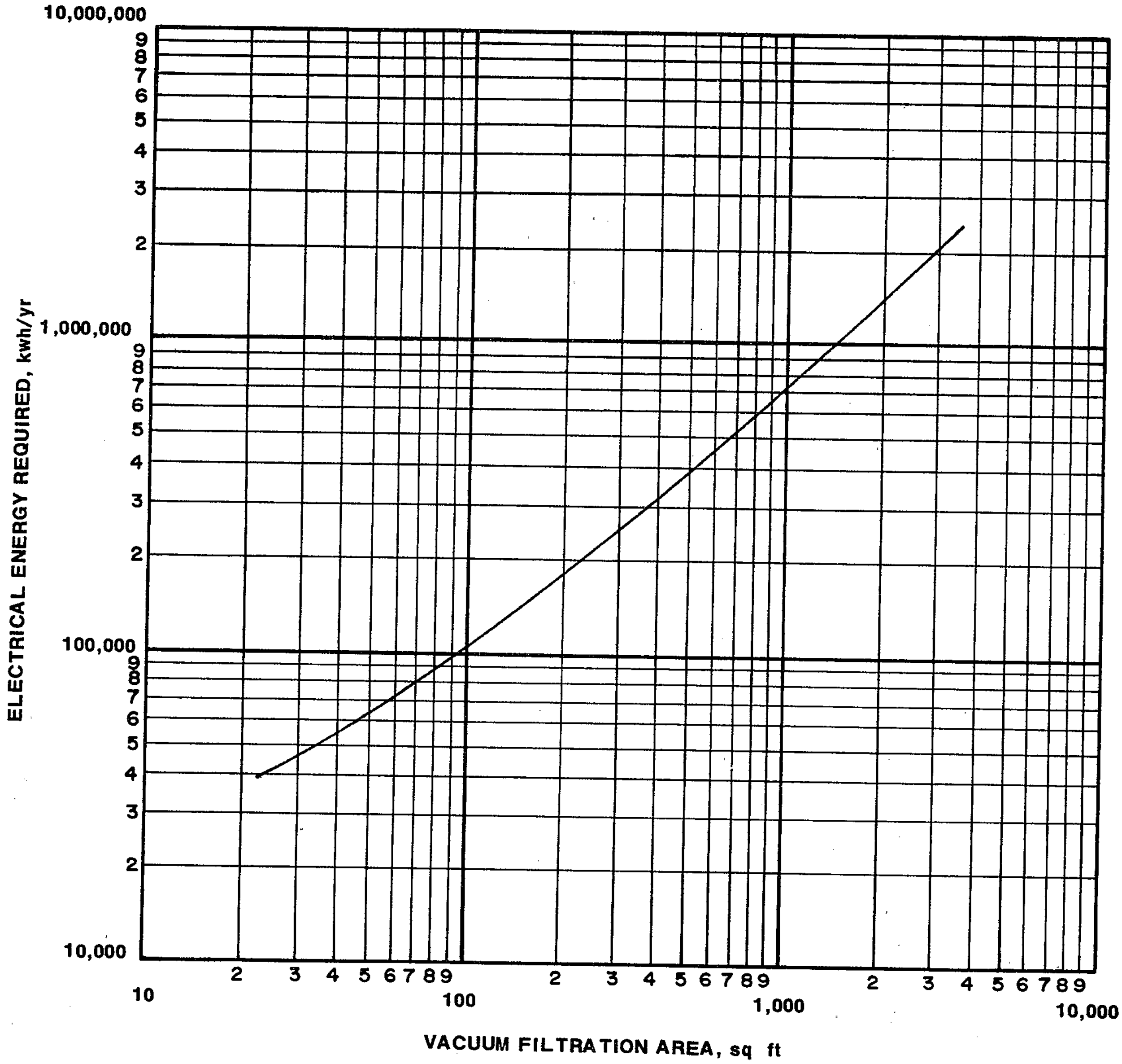
Type of Energy Required: Electrical

FIGURE 3-94

TABLE 3-7

VACUUM FILTRATION

Sludge Type	Design Assumptions	Percent Solids To VF	Typical Loading Rates, (psf/hr)	Percent Solids VF Cake
Primary	Thickened to 10% solids polymer conditioned	10	8-10	25-38
Primary + $FeCl_3$	85 mg/l $FeCl_3$ dose Lime conditioning Thickening to 2.5% solids	2.5	1.0-2.0	15-20
Primary + Low Lime	300 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	6	32-35
Primary + High Lime	600 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	10	28-32
Primary + WAS	Thickened to 8% solids Polymer conditioned	8	4-5	16-25
Primary + (WAS + $FeCl_3$)	Thickened to 8% solids $FeCl_3$ & lime conditioned	8	3	20
(Primary + $FeCl_3$) + WAS	Thickened primary sludge to 2.5% Flotation thickened WAS to 5% Dewater blended sludges	3.5	1.5	15-20
Waste Activated Sludge (WAS)	Thickened to 5% solids Polymer conditioned	5	2.5-3.5	15
WAS + $FeCl_3$	Thickened to 5% solids Lime + $FeCl_3$ conditioned	5	1.5-2.0	15
Digested Primary	Thickened to 8-10% solids Polymer conditioned	8-10	7-8	25-38
Digested Primary + WAS	Thickened to 6-8% solids Polymer conditioned	6-8	3.5-6	14-22
Digested Primary + (WAS + $FeCl_3$)	Thickened to 6-8% solids $FeCl_3$ + lime conditoned	6-8	2.5-3	16-18
Tertiary Alum	Diatomaceous earth precoat	0.6-0.8	0.4	15-20



VACUUM FILTRATION

See Table 3-7 for design assumptions.

Operating Parameters:
- 2 scfm/sq ft
- 20–22 inches Hg vacuum
- Filtrate pump, 50 ft TDH
- Curve includes: drum drive, discharge roller, vat agitator, vacuum pump, filtrate pump.

Type of Energy Required: Electrical

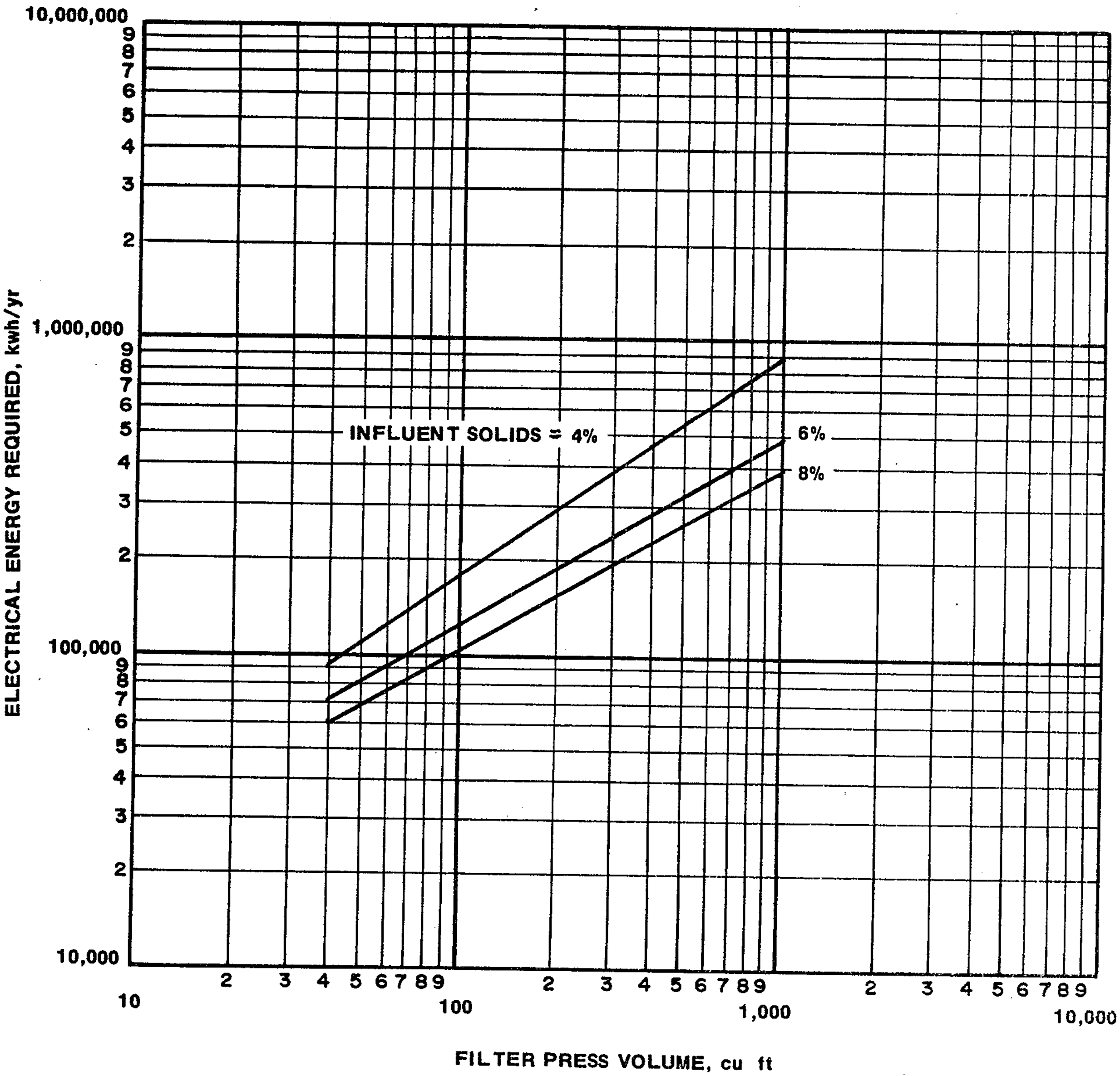
FIGURE 3–95

TABLE 3-8

SLUDGE CHARACTERISTICS - FILTER PRESSING

Sludge Type	Conditioning	Percent Solids To Pressure Filter	Typical Cycle Length	Percent Solids Filter Cake
Primary	5% $FeCl_3$, 10% Lime	5	2 hours	45
Primary + $FeCl_3$	10% Lime	4*	4	40
Primary + 2 stage high lime	None	7.5	1.5	50
Primary + WAS	5% $FeCl_3$, 10% Lime	8*	2.5	45
Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	8*	3	45
(Primary + $FeCl_3$) + WAS	10% Lime	3.5*	4	40
WAS	7.5% $FeCl_3$, 15% Lime	5*	2.5	45
WAS + $FeCl_3$	5% $FeCl_3$, 10% Lime	5*	3.5	45
Digested Primary	5% $FeCl_3$, 10% Lime	8	2	45
Digested Primary + WAS	7.5% $FeCl_3$, 15% Lime	6-8*	2.5	45
Digested Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	6-8*	3	40
Tertiary Alum	10% Lime	4*	6	35
Tertiary Low Lime	None	8*	1.5	55

*Thickening used to achieve this solids concentration



FILTER PRESSING

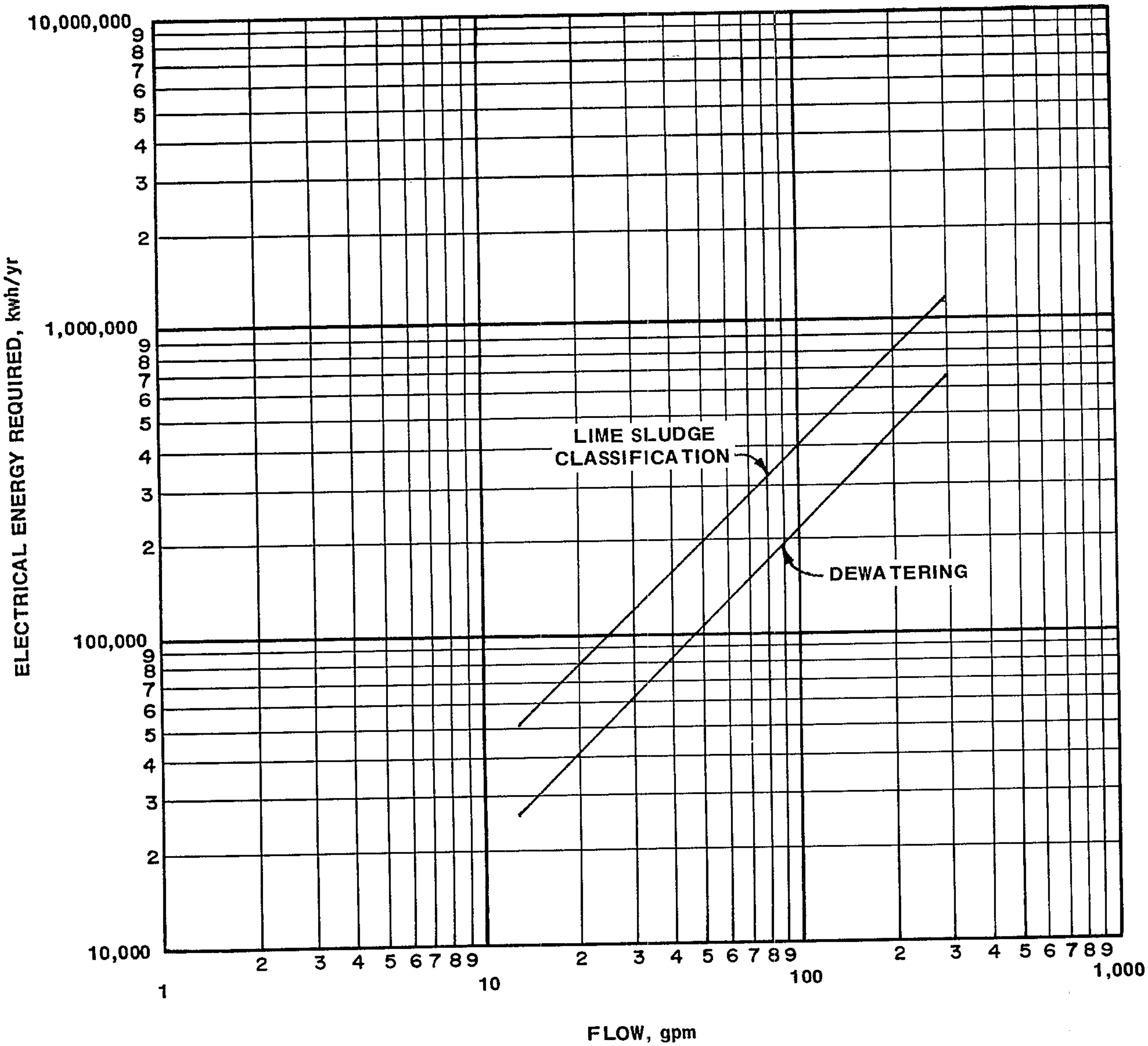
See table (preceding) page for design assumptions.

Operating Parameters:

- Power consumption based on continuous operation, 225 psi operating pressure
- Curve includes:
  - Feed Pump (hydraulically driven, positive displacement piston pump)
  - Opening and closing mechanism

Type of Energy Required: Electrical

FIGURE 3-96



CENTRIFUGING

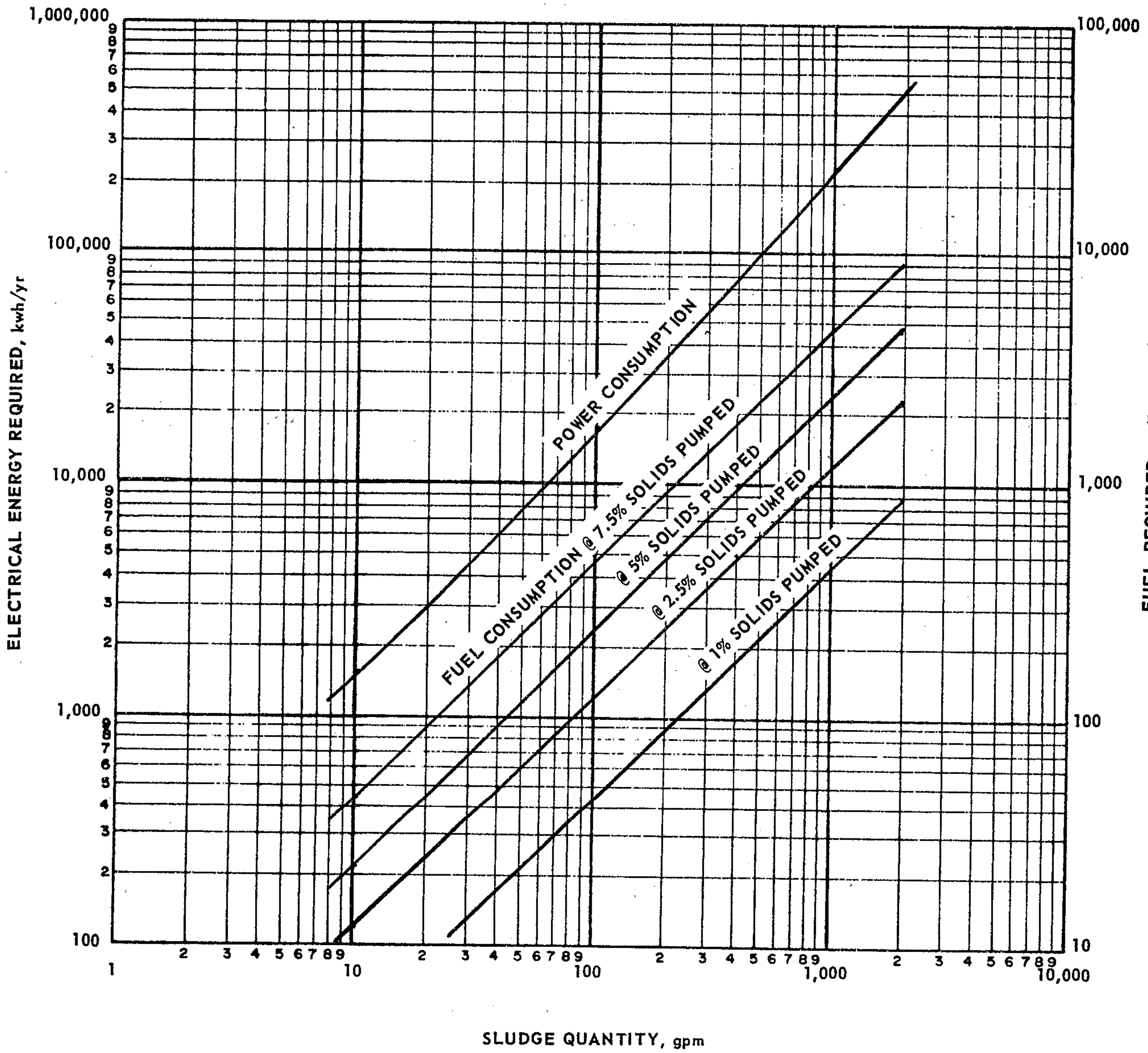
Operating Conditions:

Power consumption based on continuous operation
Dewatering accomplished with low speed centrifuge, G= 700 sec^{-1}

Sludge Type	Conditions
Primary + Low Lime	No classification
Tertiary + Low Lime	No classification
Primary + 2 Stage High Lime	Classification followed by dewatering
Tertiary + 2 Stage High Lime	Classification followed by dewatering

Type of Energy Required: Electrical

FIGURE 3–97



SAND DRYING BEDS

Design Assumptions:

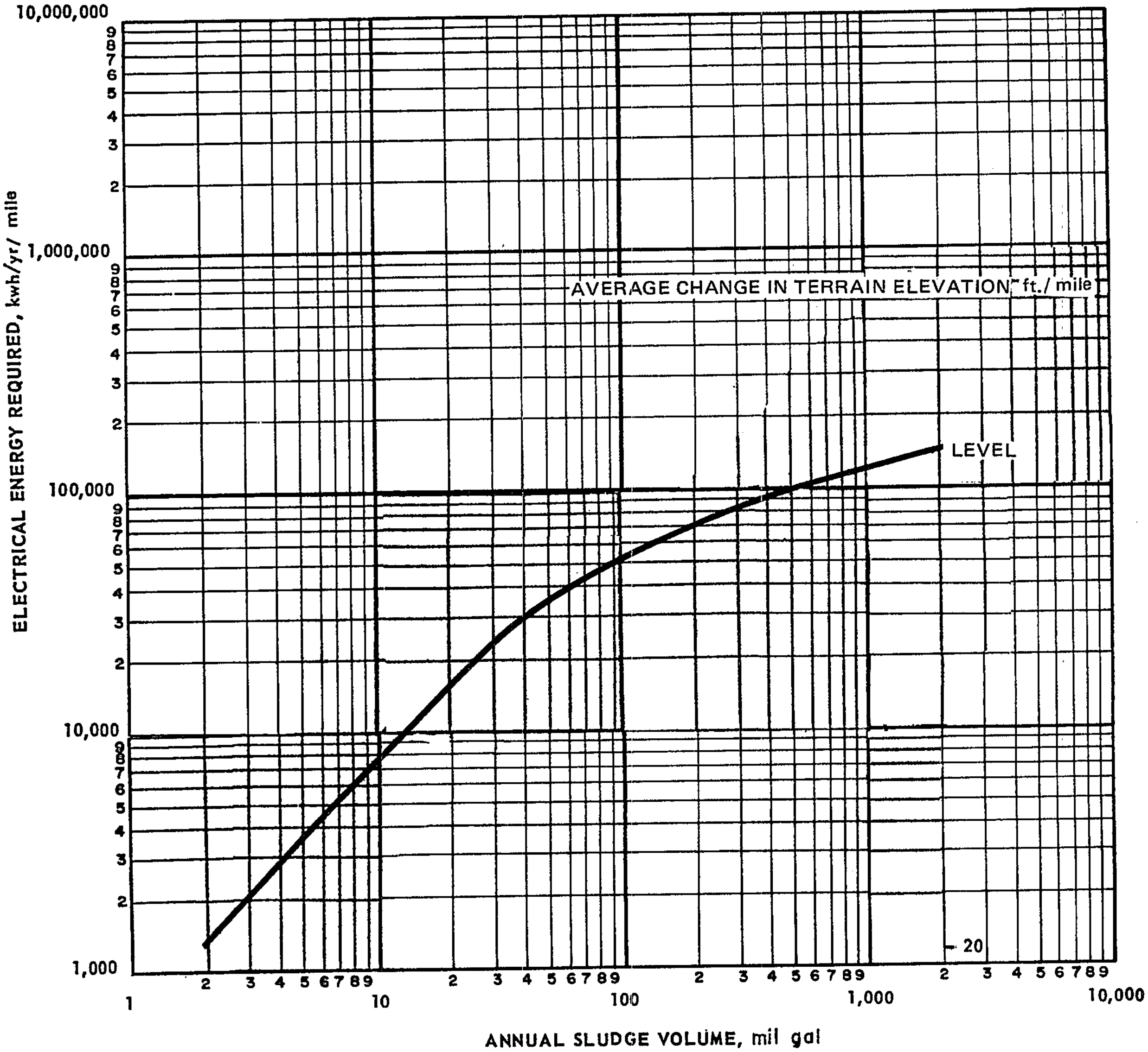
Power consumption based on pumping to drying beds at TDH = 15 ft

Fuel consumption based on:

- drying to 50% solids, 70 lbs/cu ft
- loading with front end loader, 8 gal/hr use of diesel fuel (140,000 Btu/gal)
- 15 minutes required to load 30 cu yd truck

See Table 3-3 for quantities of various sludges/mil gal treated

Type of Energy Required: Electrical and fuel



SLUDGE PUMPING

Design Assumptions:

4% solids maximum (Dilute to 4% if greater)
4 inch pipeline minimum, design velocity 3fps
Pipeline effective "c" factor 85
Pumping based on centrifugal non–clog or slurry pumps, 68% efficiency
20 hours per day average operation

Operating Parameters:

See Table 3–9 for sludge characteristics for disposal.

Type of Energy Required: Electrical

FIGURE 3–99

TABLE 3-9

SLUDGE CHARACTERISTICS

SLUDGE DISPOSAL

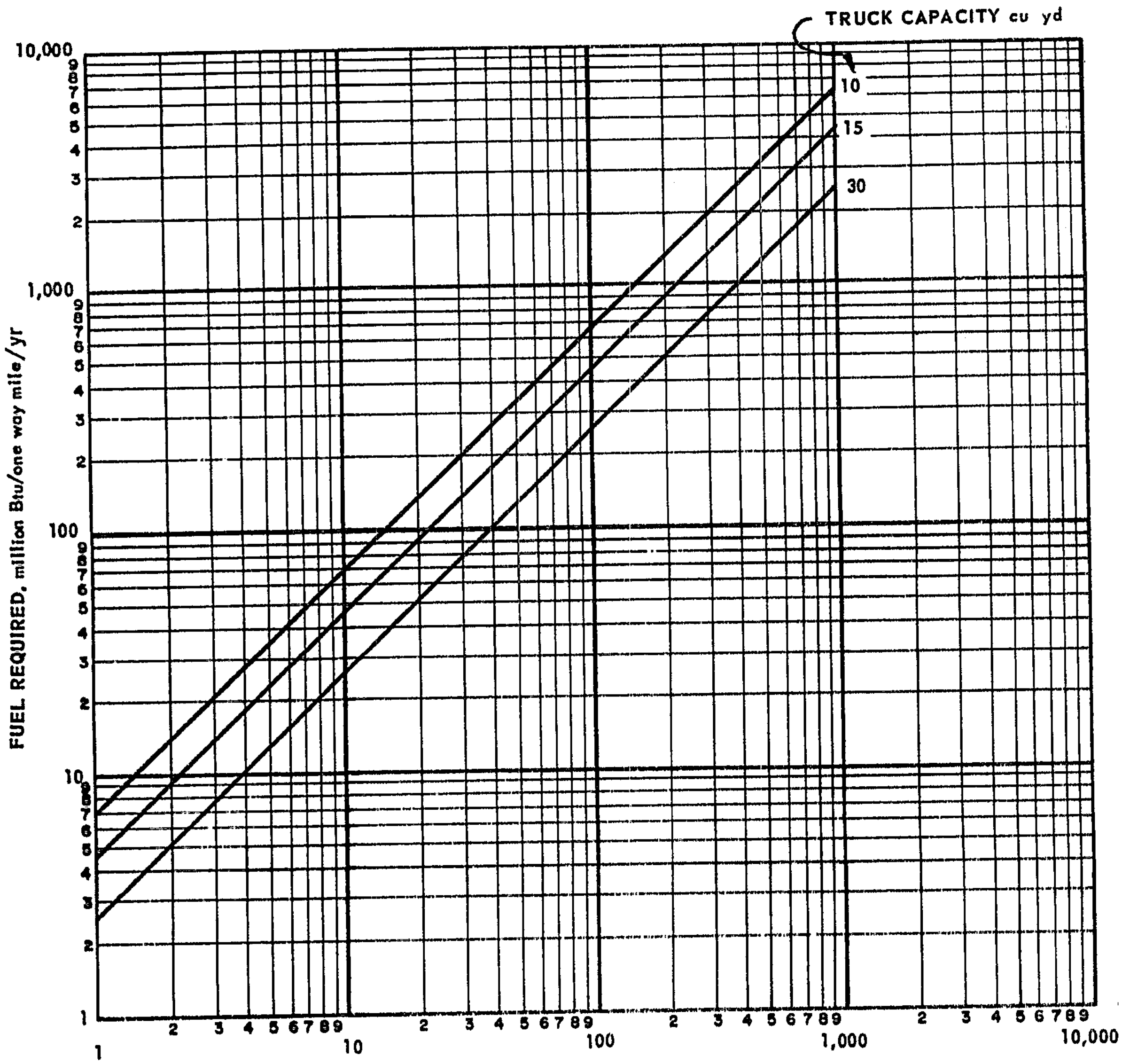
Sludge Type	Liquid Sludge: Percent Solids	Liquid Sludge: Volume (gal/mil gal)	Liquid Sludge: Volume For Pumping (1) (Pipeline) (gal/mil gal)	Dewatered Sludge: Percent Solids	Dewatered Sludge: Volume(4) (cu yd/mil gal)
Primary	5	2,760	3,450(1)	31(2)	2.7
Primary + $FeCl_3$	2	16,500	16,500	18(2)	11.3
Primary + Low Lime	5	11,940	14,925(1)	34(2)	10.8
Primary + High Lime	7.5	15,680	29,400(1)	30(2)	24.2
Primary + WAS	2	12,565	12,565	20(2)	7.8
Primary + (WAS+$FeCl_3$)	1.5	21,480	21,480	20(2)	9.9
(Primary + $FeCl_3$) + WAS	1.8	20,960	20,960	18(2)	12.9
Waste Activated Sludge (WAS)	1.0	11,330	11,330	15(2)	4.7
WAS + $FeCl_3$	1.0	18,400	18,400	15(2)	7.6
Digested Primary	8.0	1,210	2,420(1)	31(2)	1.9
Digested Primary + WAS	4.0	3,680	3,680	18(2)	5.0
Digested Primary + (WAS + $FeCl_3$)	4.0	5,455	5,455	17(2)	7.9
Tertiary Alum	1.0	8,390	8,390	17(2)	3.0
Tertiary High Lime	4.5	21,690	24,400(1)	50(3)	12.1
Tertiary Low Lime	3.0	13,235	13,235	50(3)	4.9

(1) Sludge diluted to 4.0% for pumping

(2) Vacuum filtration

(3) Centrifuge

(4) Average sludge density 50 lb/cu ft



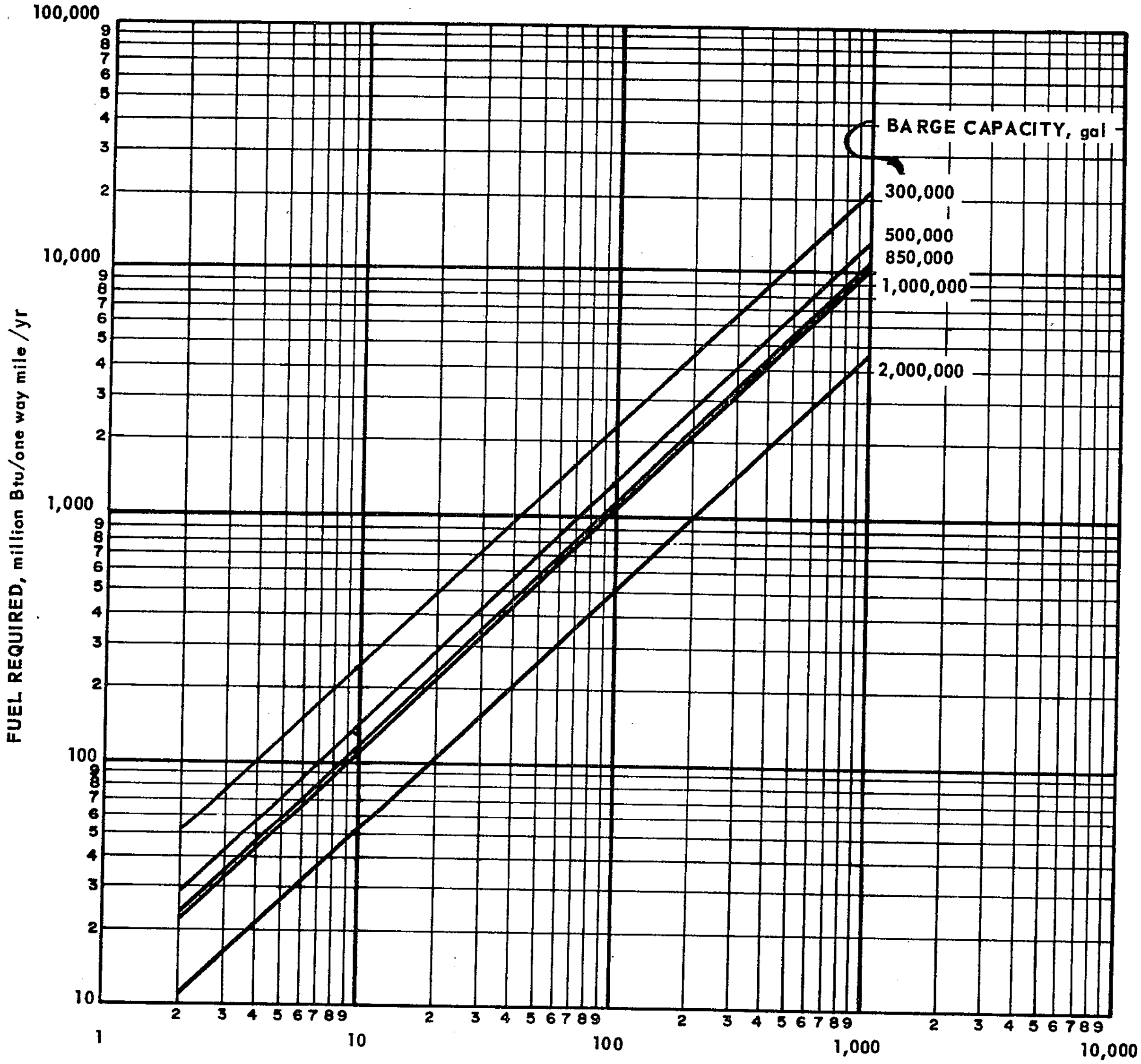
DEWATERED SLUDGE HAUL BY TRUCK

Design Assumptions:
1 gal diesel (#2) = 140,000 Btu
Diesel powered dump trucks

Operating Parameters:
Operation 8 hr per day
Average speed; 25 mph for first 20 miles and 35 mph thereafter
Truck fuel use 4.5 mpg avg
See Table 3-9 for sludge characteristics for disposal.

Type of Energy Required: #2 Diesel fuel

FIGURE 3-100



LIQUID SLUDGE HAULING BY BARGE

Design Assumptions:

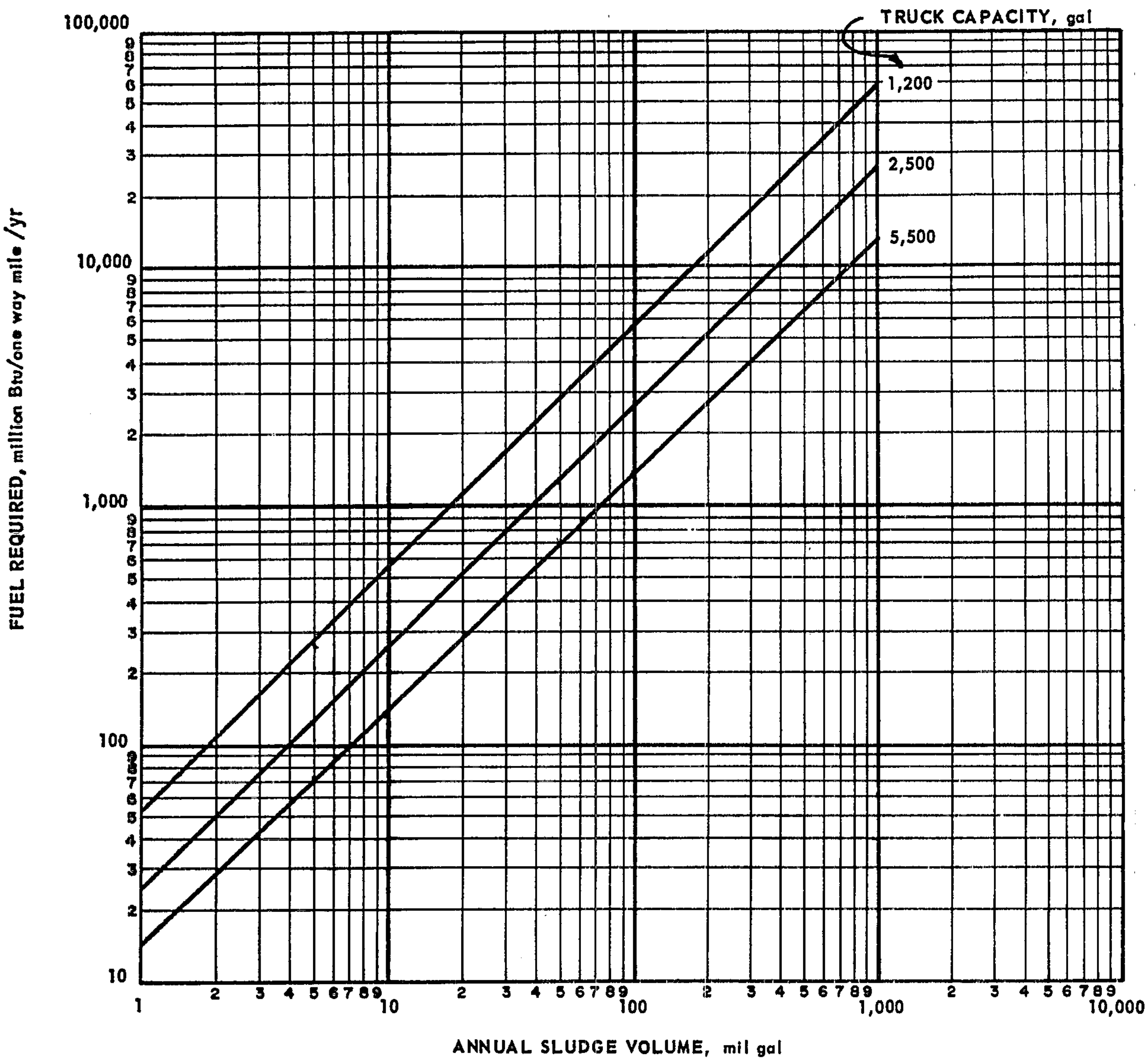
1 gal marine diesel = 140,000 Btu
Non-propelled barges moved with tugs

Operating Parameters:

Operation 24 hrs per day
Average speed 4 mph
Tug size: 300,000 gal barge – 1,200 hp
500,000 & 850,000 gal barge – 2,000 hp
1,000,000 & 2,000,000 gal barge – 2,500 hp

See Table 3-9 for sludge characteristics for disposal.

Type of Energy Required: Marine diesel fuel



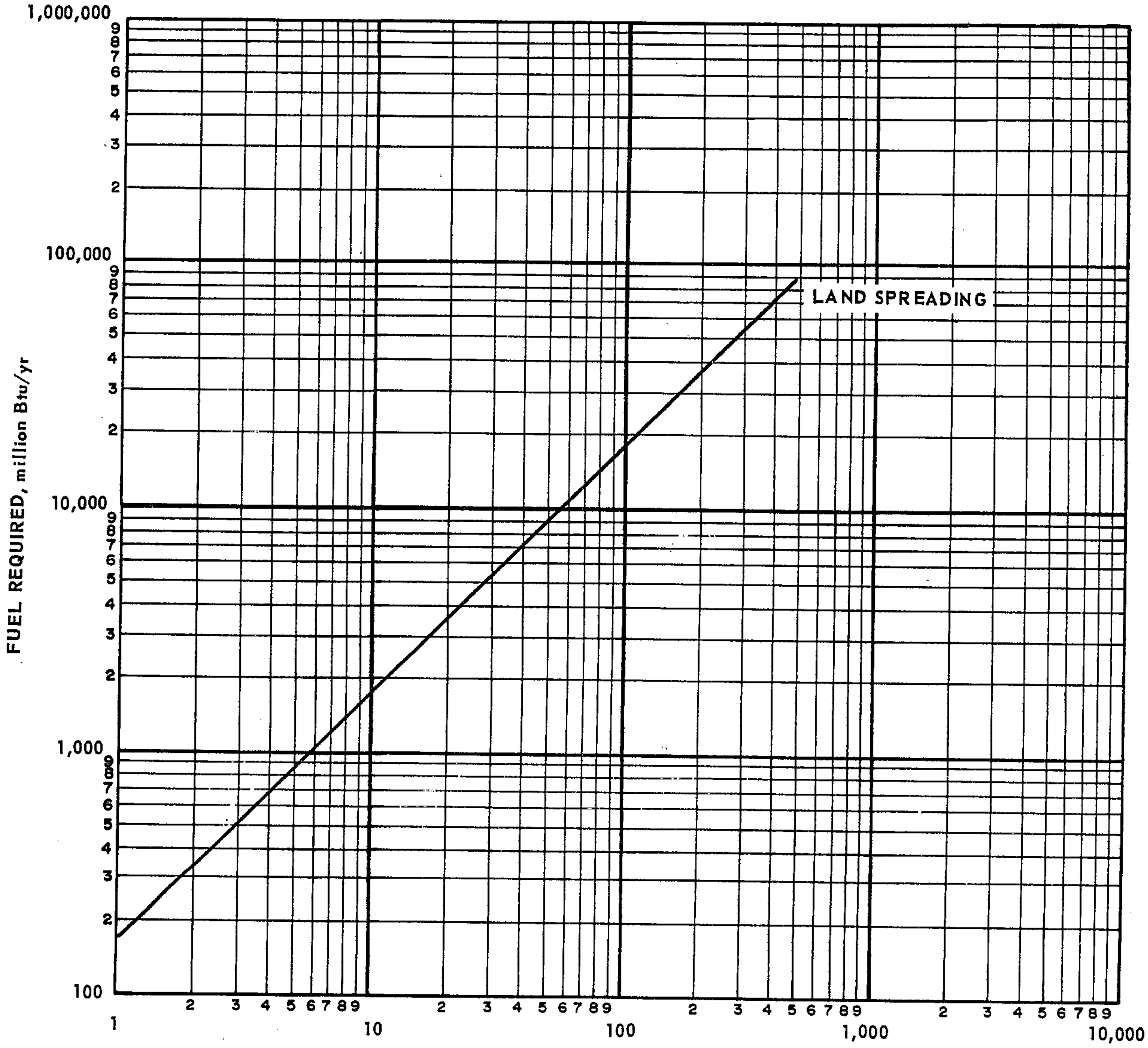
LIQUID SLUDGE HAULING BY TRUCK

Design Assumptions:
1 gal diesel (#2) = 140,000 Btu
Diesel powered tank trucks

Operating Parameters:
Operating 8 hrs per day
Average speed; 25 mph for first 20 miles and 35 mph thereafter
Truck fuel use 4.5 mpg avg
See Table 3-9 for sludge characteristics for disposal.

Type of Energy Required: #2 Diesel fuel

FIGURE 3-102

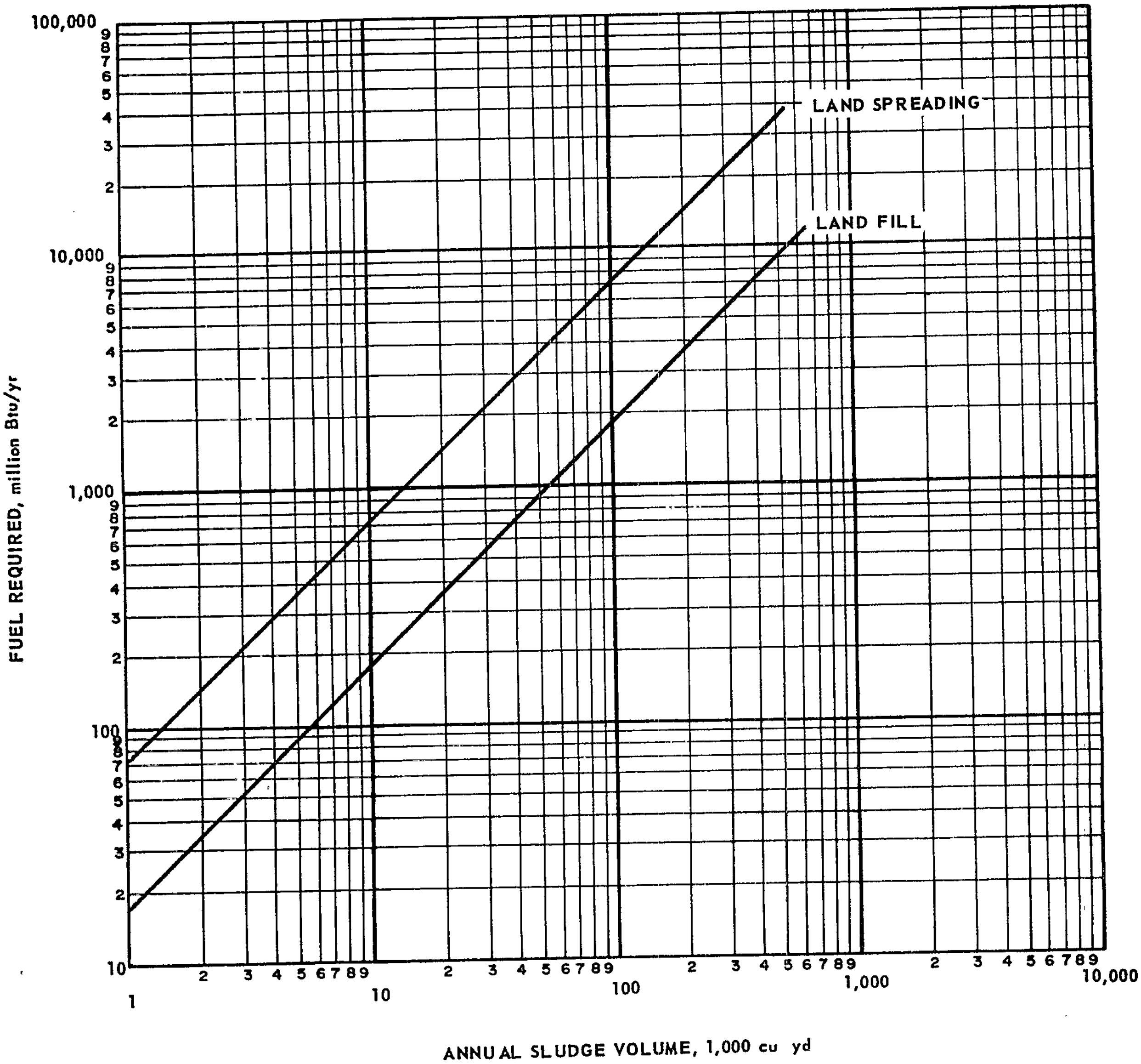


UTILIZATION OF LIQUID SLUDGE

Design Assumptions:
Fuel use: spreading truck – 2 gal/trip
1 gal diesel (#2) = 140,000

Operating Parameters:
1600 gal big wheel type spreader, 15 minute round trip. Truck is self loading.
See Table 3-9 for sludge characteristics for disposal.

Type of Energy Required: #2 Diesel fuel



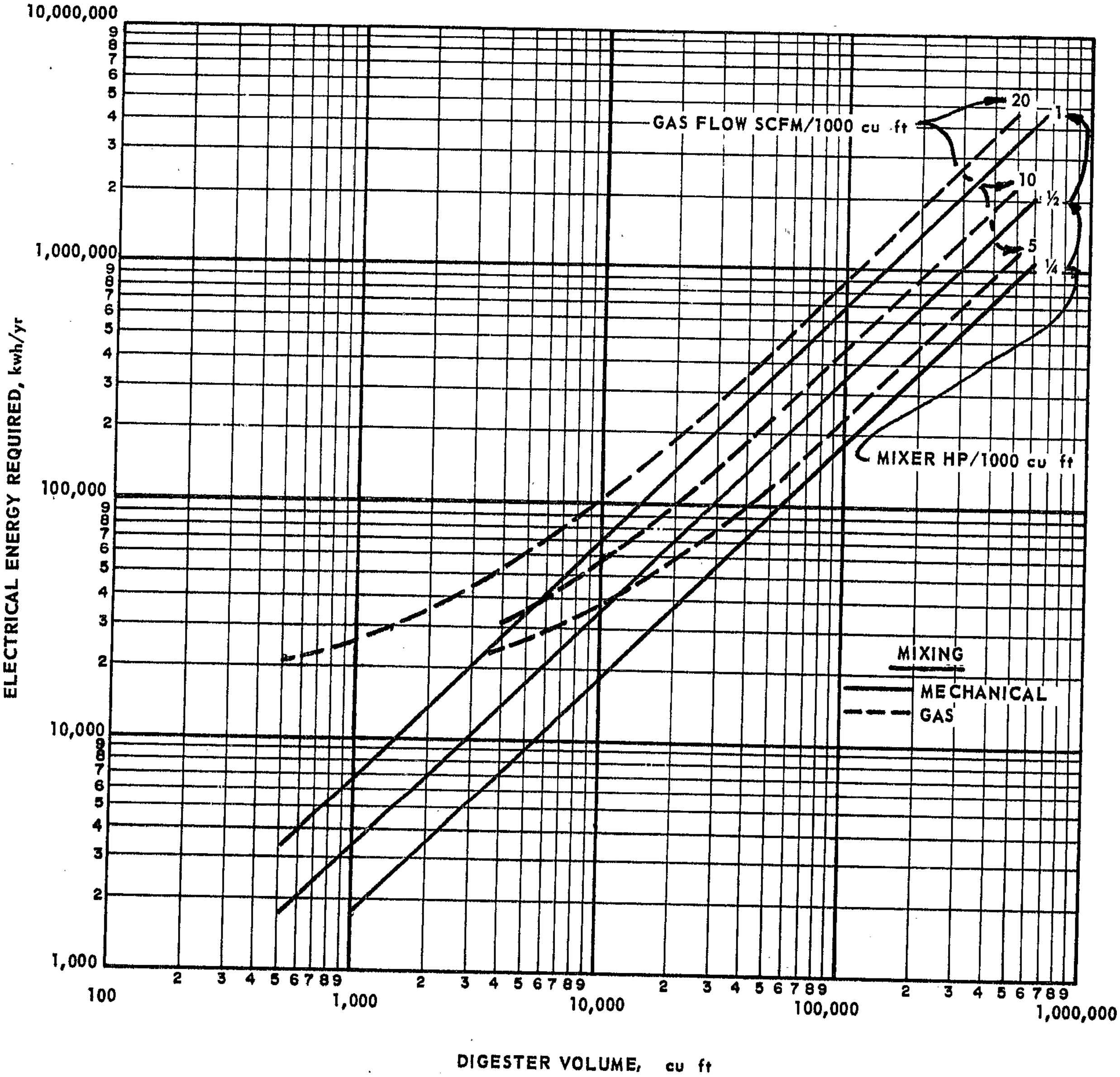
UTILIZATION OF DEWATERED SLUDGE

Design Assumptions:
Fuel use: Bulldozer – 8 gal/hr
Front end loader – 8 gal/hr
Spreading truck – 3 gal/trip
1 gal diesel (#2) = 140,000 Btu

Operating Parameter:
Landfill: 30 minutes bulldozer time per 30 cu yd truckload of sludge
Spreading: 7.2 cu yd big wheel type spreader, 20 minute trip time
See Table 3-9 for sludge characteristics for disposal.

Type of Energy Required: #2 Diesel fuel

FIGURE 3–104

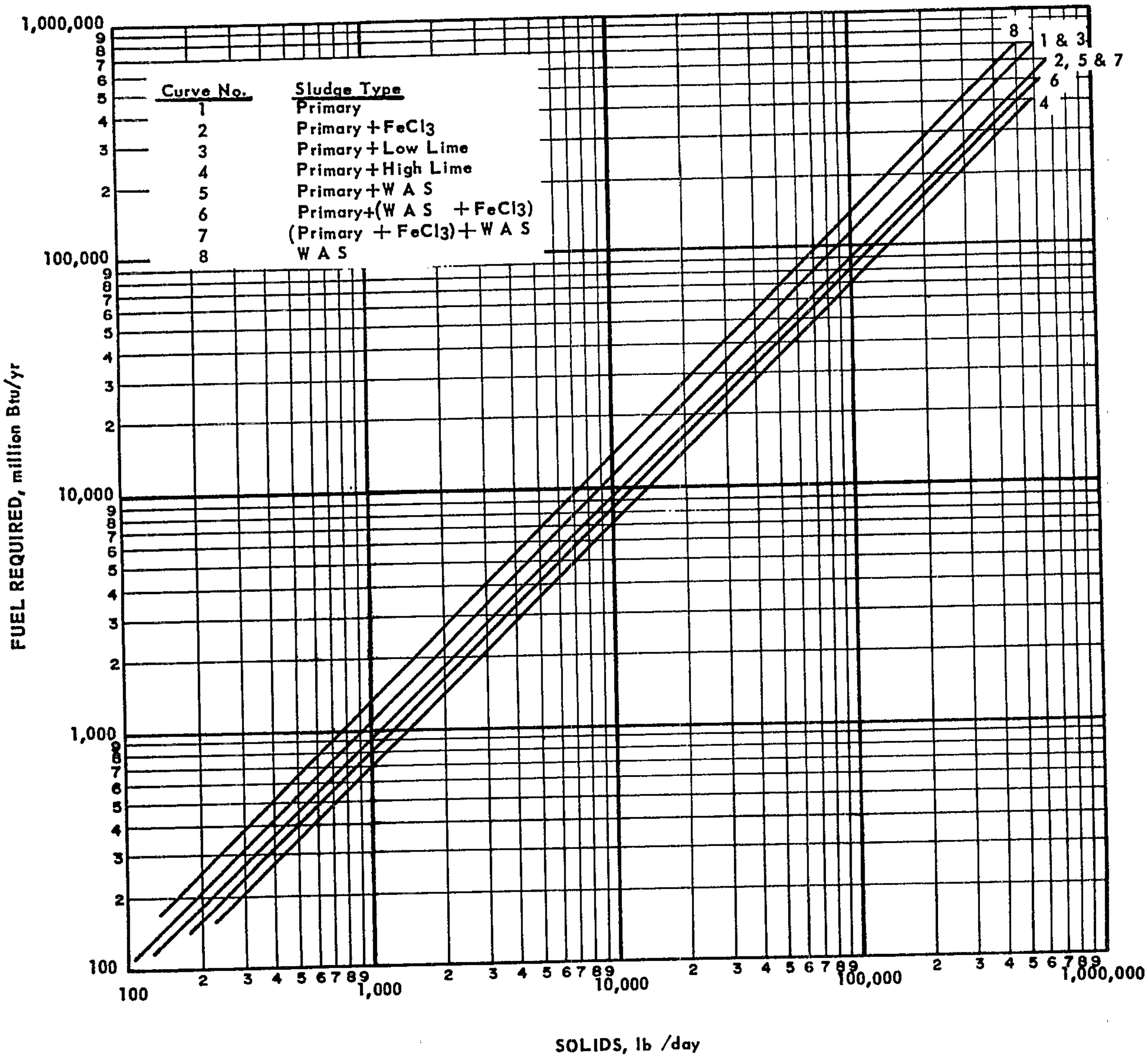


ANAEROBIC DIGESTER – HIGH RATE

Design Assumptions:
- Continuous operation
- 20 ft submergence for release of gas
- Motor efficiency varies from 85% to 93% depending on motor size.

Type of Energy Required: Electrical
See Chapter 5, pages 5–11 to 5–14 and Figure 3–106 for fuel requirements.

FIGURE 3–105



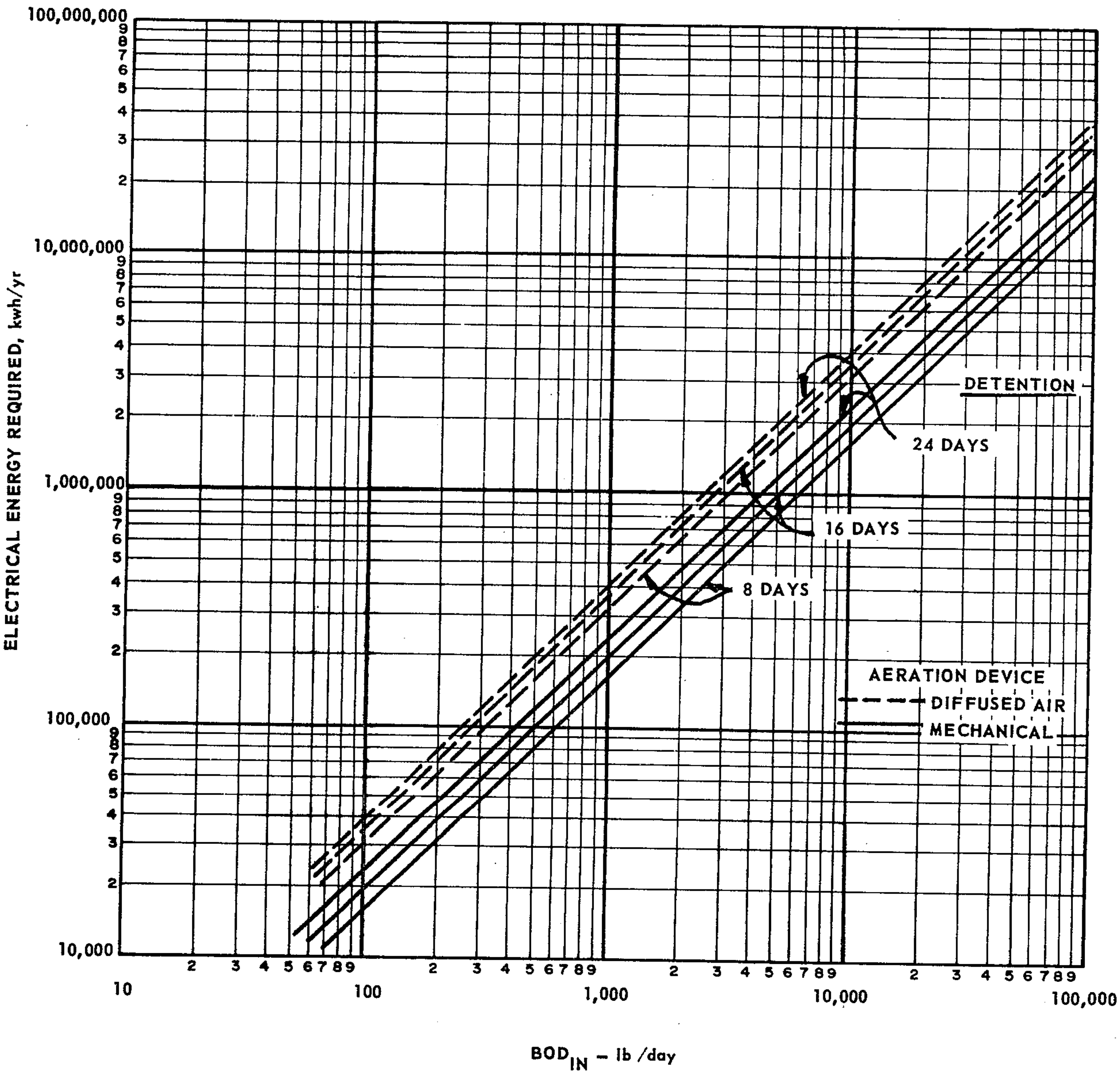
THERMOPHILIC ANAEROBIC DIGESTION

Design Assumptions:
Fuel requirements are shown for northern states, for central locations multiply by 0.5, for southern locations multiply by 0.3.

Operating Parameter:
Digester temperature 130°F
See Figure 3–105 for mixing energy
See Table 3–3 for sludge characteristics.

Type of Energy Required: Fuel or Natural Gas

FIGURE 3–106



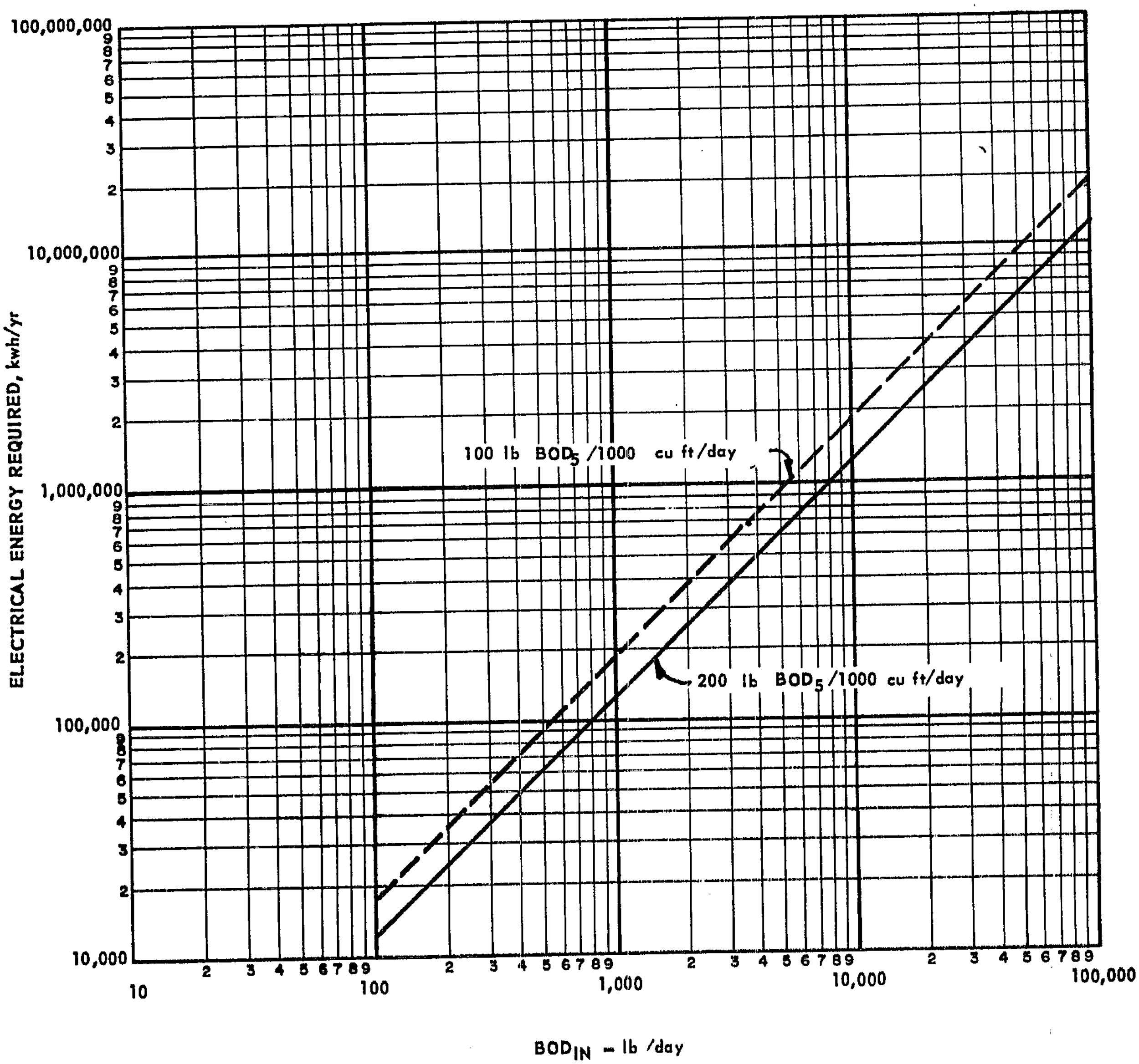
AEROBIC DIGESTION

Design Assumptions:

Energy based on oxygen supply requirements; mixing assumed to be satisfied.
Mechanical aeration based on 1.5 lb O_2 transfer/hp–hr
Diffused aeration based on 0.9 lb O_2 transfer/hp–hr
Temperature of waste ≈ 20°C
Oxygen for nitrification is not included in values presented – for nitrification O_2 demand + BOD demand multiply value from curve by 1.3

Type of Energy Required: Electrical

FIGURE 3–107



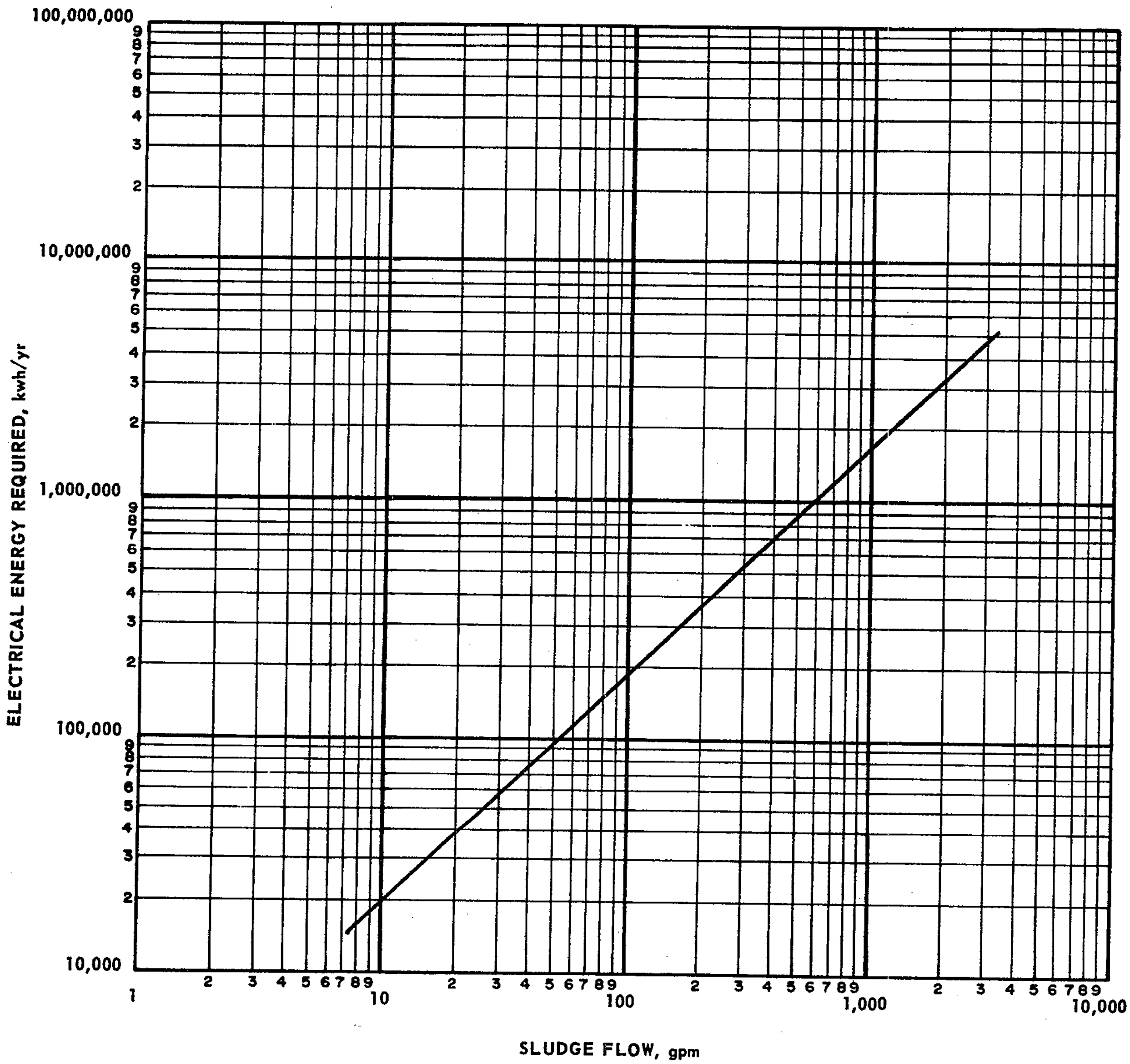
THERMOPHILIC AEROBIC DIGESTION

Design Assumptions:

- Process is autothermophilic
  - Pure oxygen provided for oxygen transfer having the following power demands:
    - 1.5 hp/1,000 cu ft. mixing
    - 2.9 lb O_2 /hp–hr PSA generation
    - 4.2 lb O_2 /hp–hr Cryogenic generation
  - Cryogenic systems assumed for greater demands than 5 ton/day

Type of Energy Required: Electrical

FIGURE 3–108

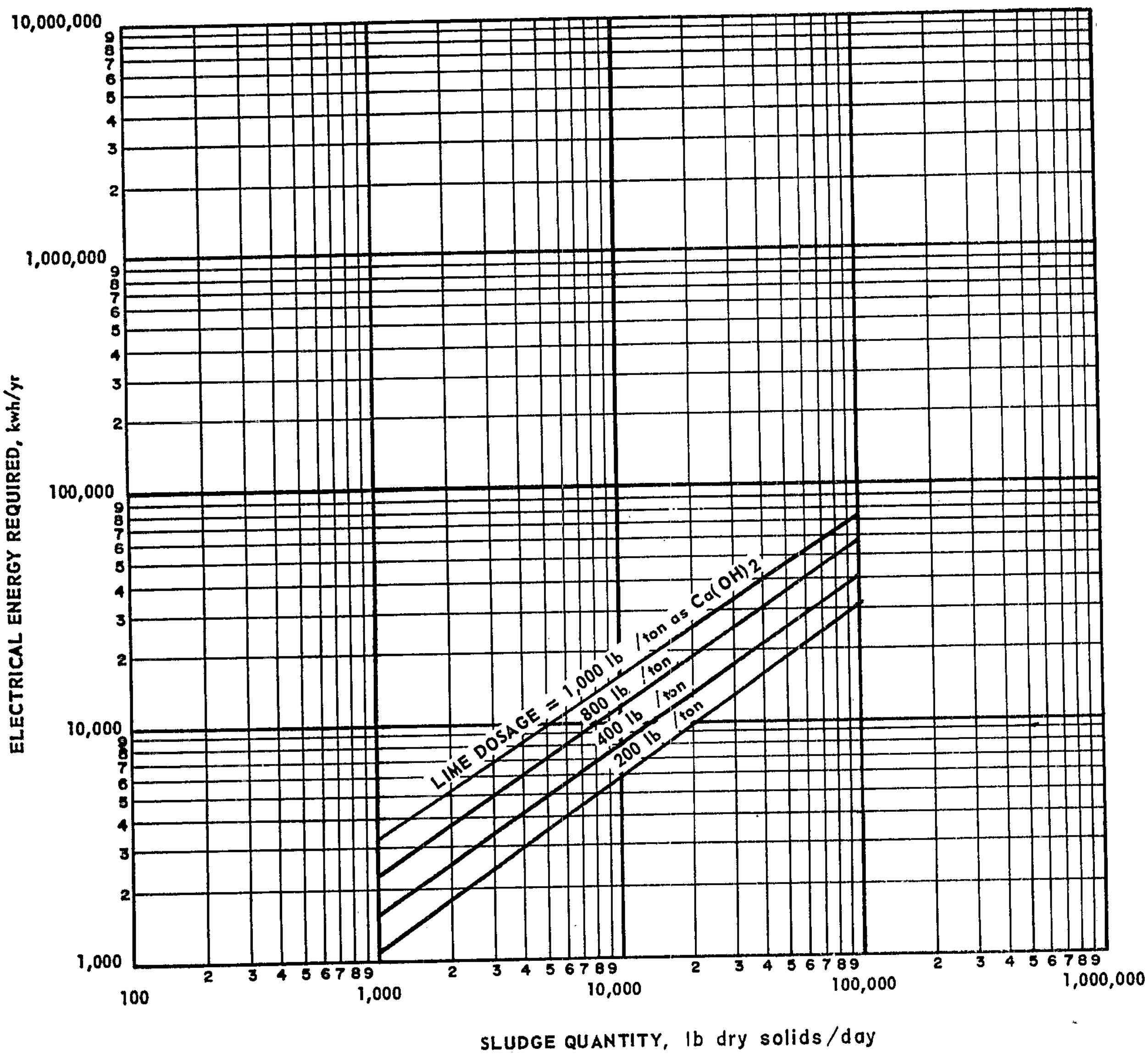


CHLORINE STABILIZATION OF SLUDGE

Design Assumptions:
- Operating pressure = 35 psi
- Recirculation ratio = 5:1
- Chlorine feed = 4 lbs/1,000 gal

Type of Energy Required: Electrical

FIGURE 3–109



LIME STABILIZATION OF SLUDGES

Design Assumptions:
- Pumped feed of slaked lime
- Mix lime and sludge for 60 seconds at $G = 600\ sec^{-1}$
- Sludge pumping not included (see Figure 3-4 if pumping required)

Type of Energy Required: Electrical

FIGURE 3-110

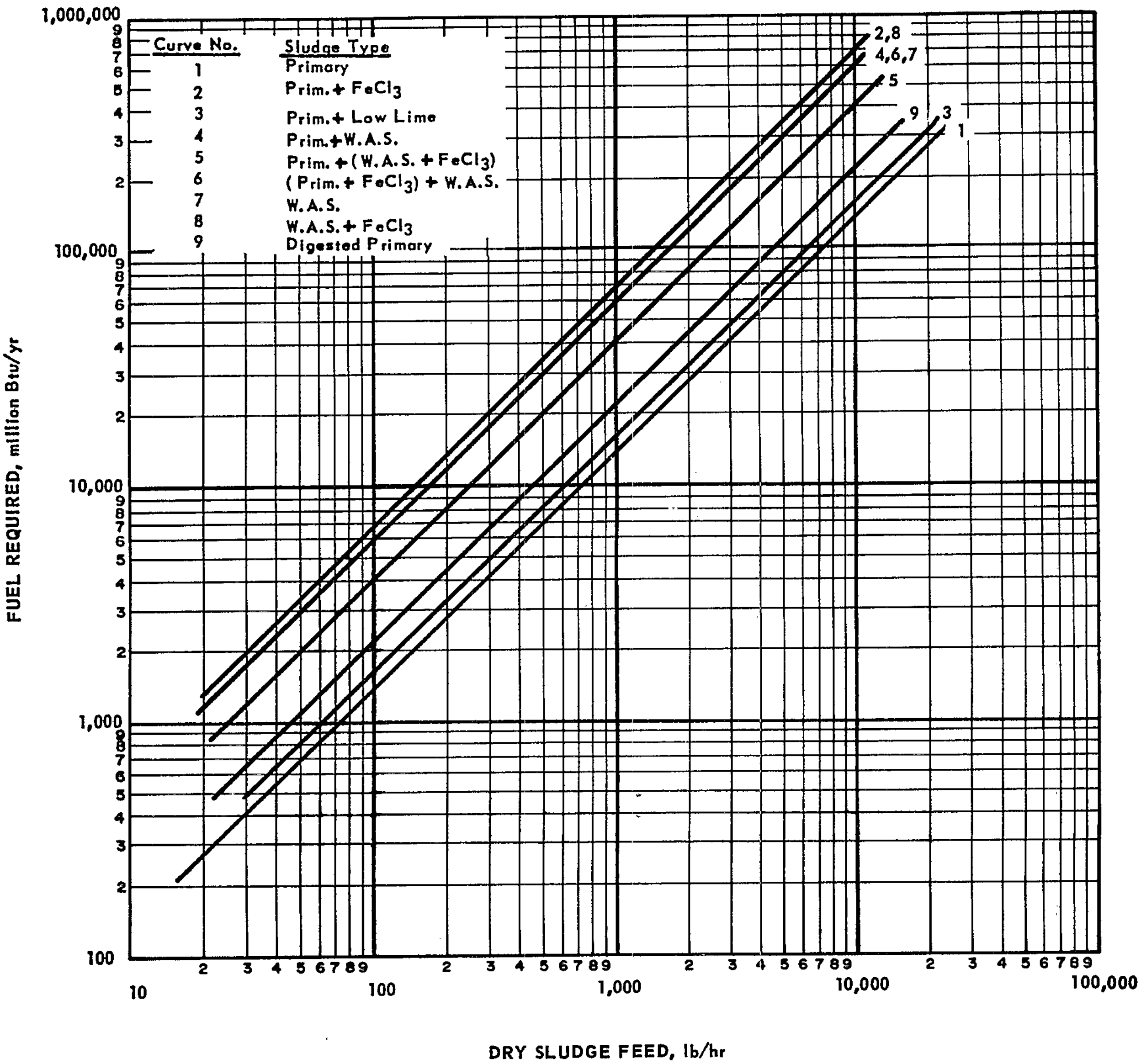
TABLE 3-10

MULTIPLE HEARTH FURNACE

Type of Sludge	Percent Solids	Percent VS	Chemical Concentration* (mg/l)	Typical Wet Sludge Loading Rate** lb/hr/sqft
1. Primary	30	60	N/A	7.0 - 12.0
2. Primary + $FeCl_3$	16	47	20	6.0 - 10.0
3. Primary + Low Lime	35	45	298	8.0 - 12.0
4. Primary + WAS	16	69	N/A	6.0 - 10.0
5. Primary + (WAS + $FeCl_3$)	20	54	20	6.5 - 11.0
6. (Primary + $FeCl_3$) + WAS	16	53	20	6.0 - 10.0
7. WAS	16	80	N/A	6.0 - 10.0
8. WAS + $FeCl_3$	16	50	20	6.0 - 10.0
9. Digested Primary	30	43	N/A	7.0 - 12.0

* Assumes no dewatering chemicals

** Low number is applicable to small plants, high number is applicable to large plants



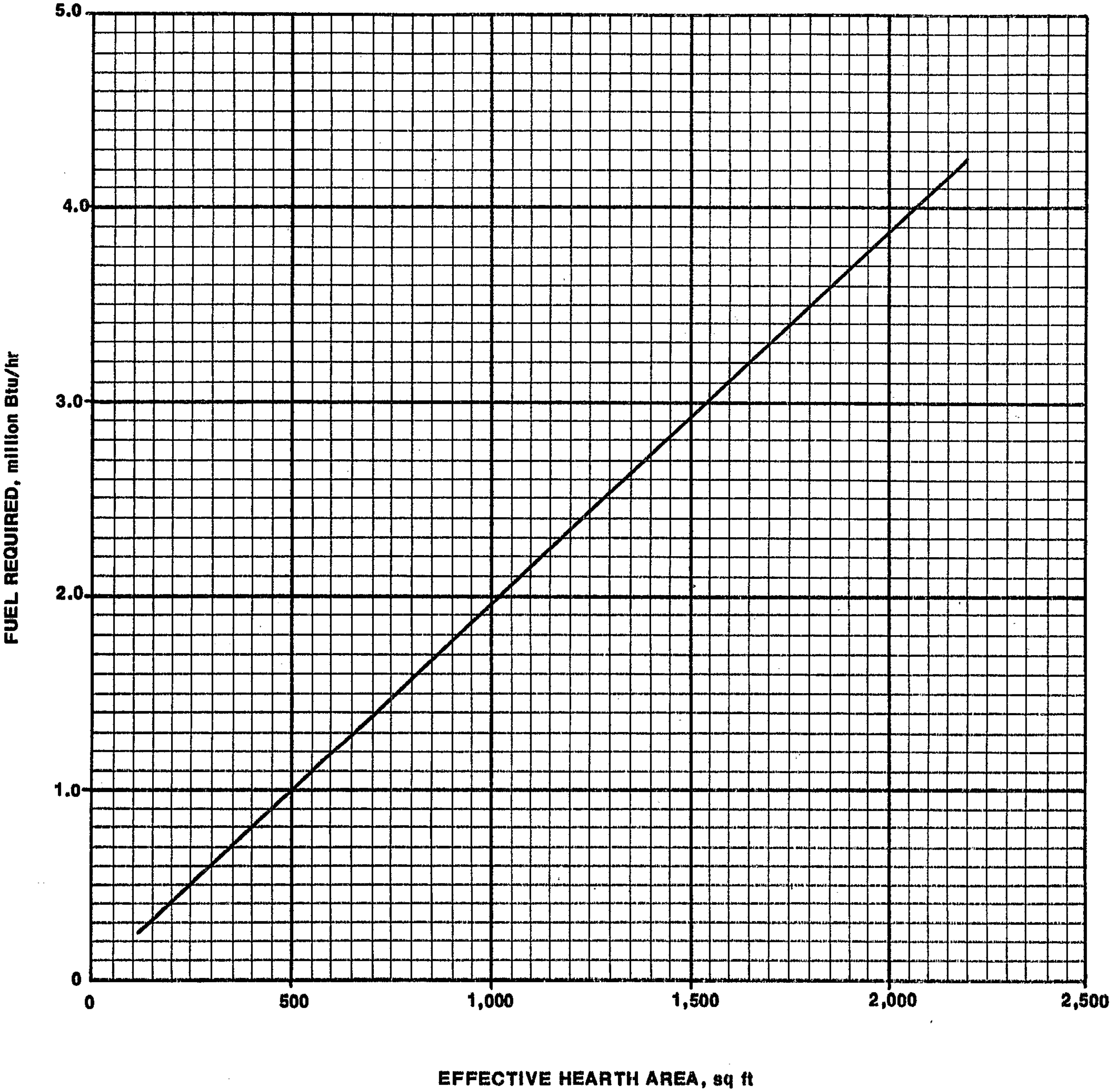
MULTIPLE HEARTH FURNACE INCINERATION
(SEE FIGURE 3–112 FOR START–UP FUEL)

See Table 3-10 for design assumptions.

Operating Parameters:
- Incoming slidge temperature is 57 F
- Combustion temperature is 1400 F
- Downtown for cool-down equals start-up time
- Frequency of start-ups is a function of individual systems.
- Excess air is 100%

Type of Energy Required: Fuel Oil or Natural Gas

FIGURE 3–111



MULTIPLE HEARTH FURNACE INCINERATION START-UP FUEL

Design Assumptions:

Use in conjunction with Figure 3-111 to determine total fuel required.

Heatup time:

Effective Hearth Area sq ft	Heatup time hr
less than 400	18
400–800	27
800–1400	36
1400–2000	54
greater than 2000	108

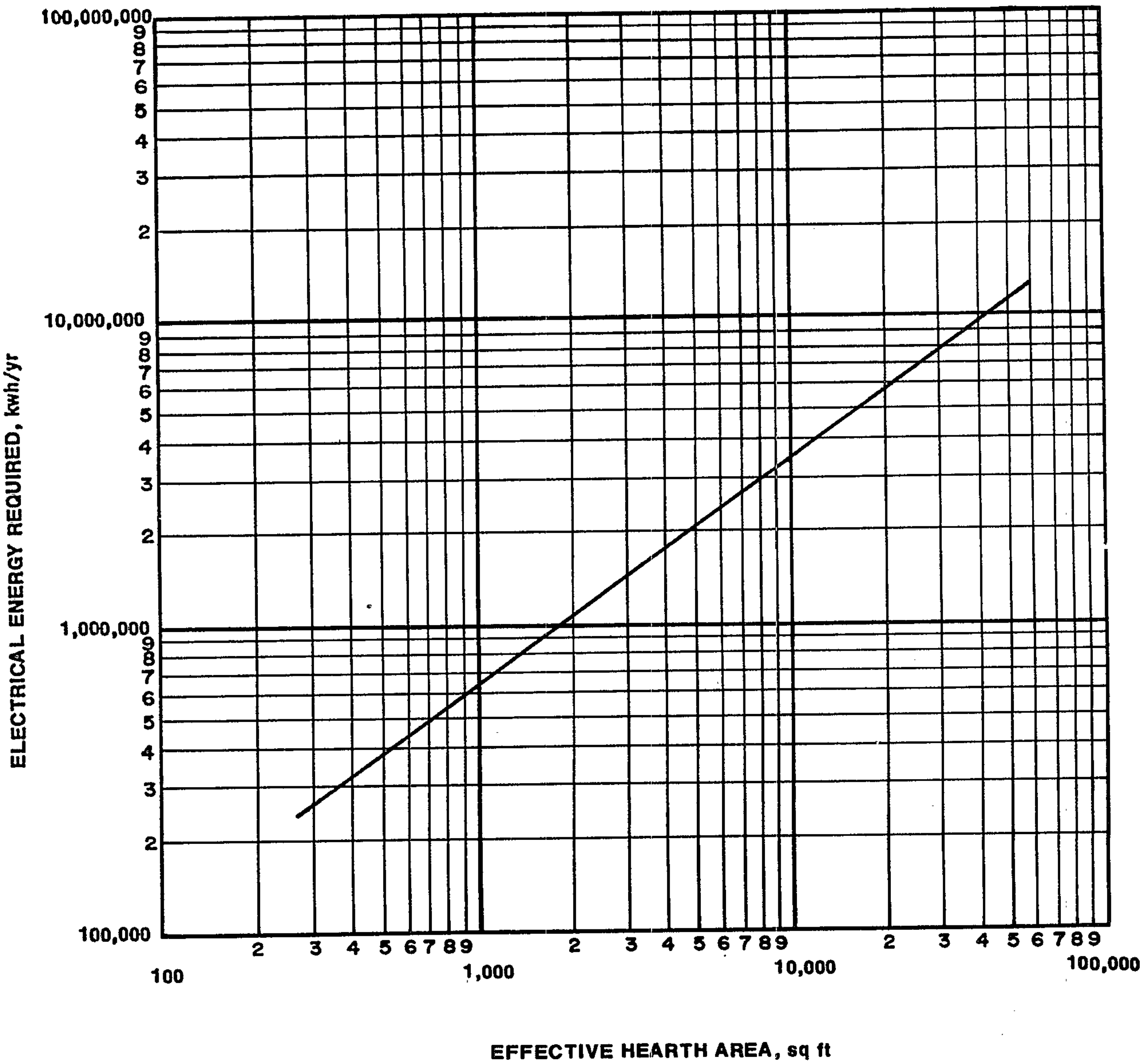
Operating Assumptions:

Heatup time to reach 1400° F temperature

Frequency of start-up is a function of individual system

Type of Energy Required: Fuel Oil or Natural Gas

FIGURE 3-112

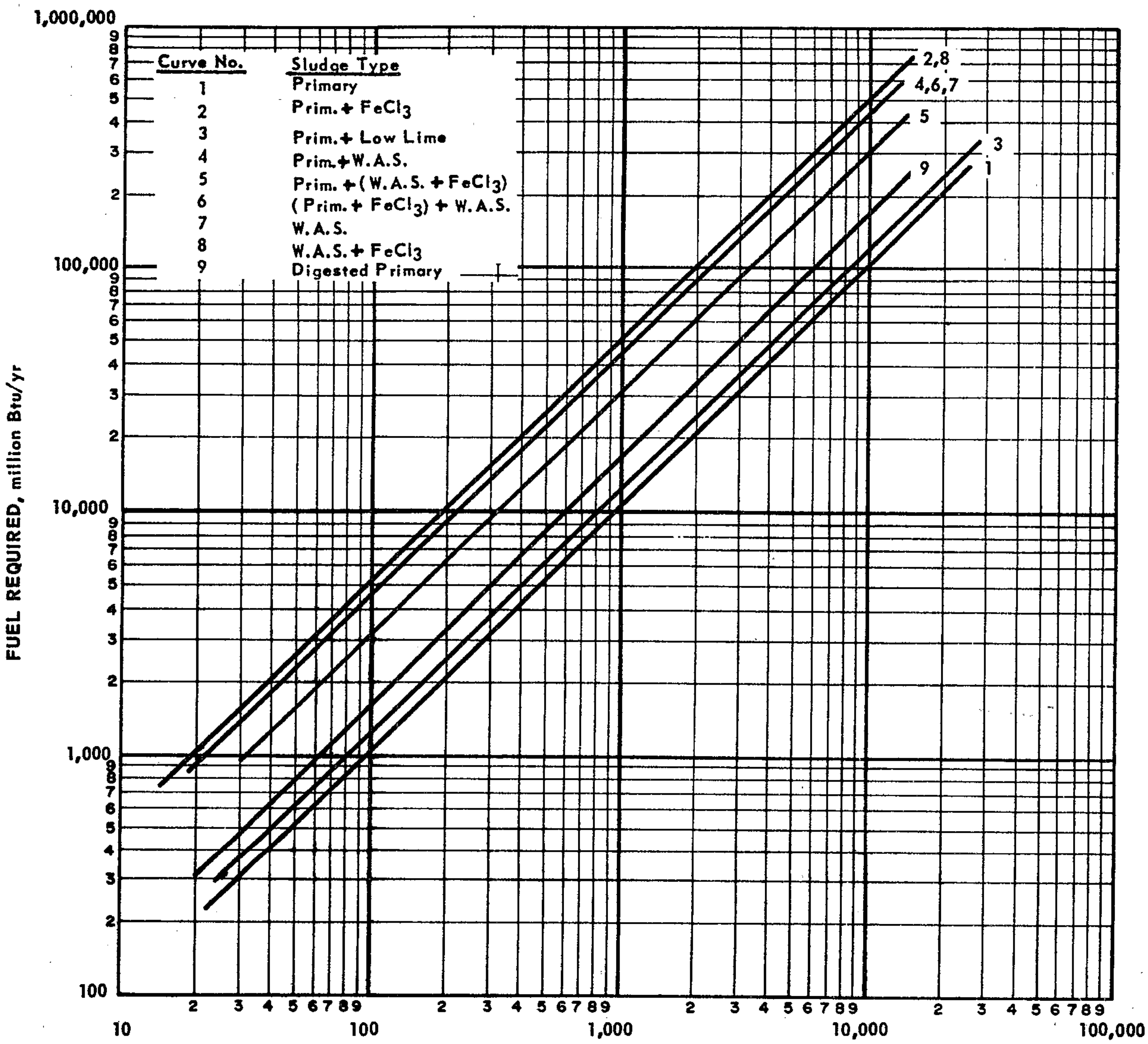


MULTIPLE HEARTH FURNACE INCINERATION

Design Assumptions: Solids Concentration, %	Loading Rates, lb/hr/sq ft (wet sludge) Small plants < 25mgd	Large plants > 25mgd
14–17	6.0	10.0
18–22	6.5	11.0
23–30	7.0	12.0
31	8.0	12.0

Operating Parameter:
System operates 100% of the time.

FIGURE 3–113



FLUIDIZED BED FURNACE INCINERATION

Design Assumptions:

Heat value of volatile solids is 10,000 Btu/lb
Loading rates, lb/sq ft/hr:

Curve No.	Rate
1,9	14
2,4,6,7,8	6.8
3	18
5	8.4

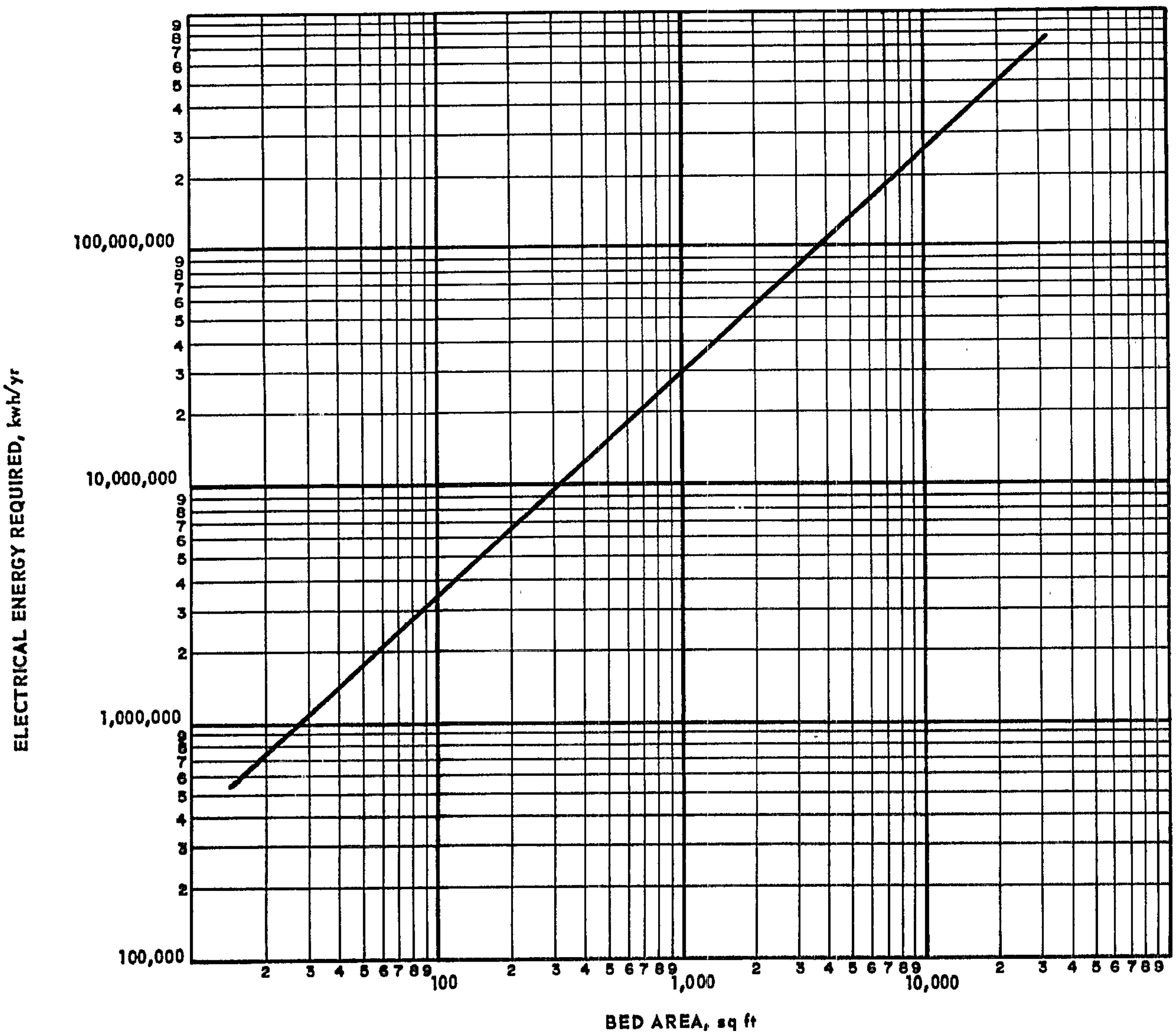
See Table 3-10 preceding Figure 3-111 for more design assumptions

Operating Conditions:

Combustion temperature is 1400° F
Downtime is a function of individual system
40% excess air, no preheater
Startup not included, 73,000 Btu/sq ft for startup

Type of Energy Required: Fuel oil or Natural Gas

FIGURE 3–114



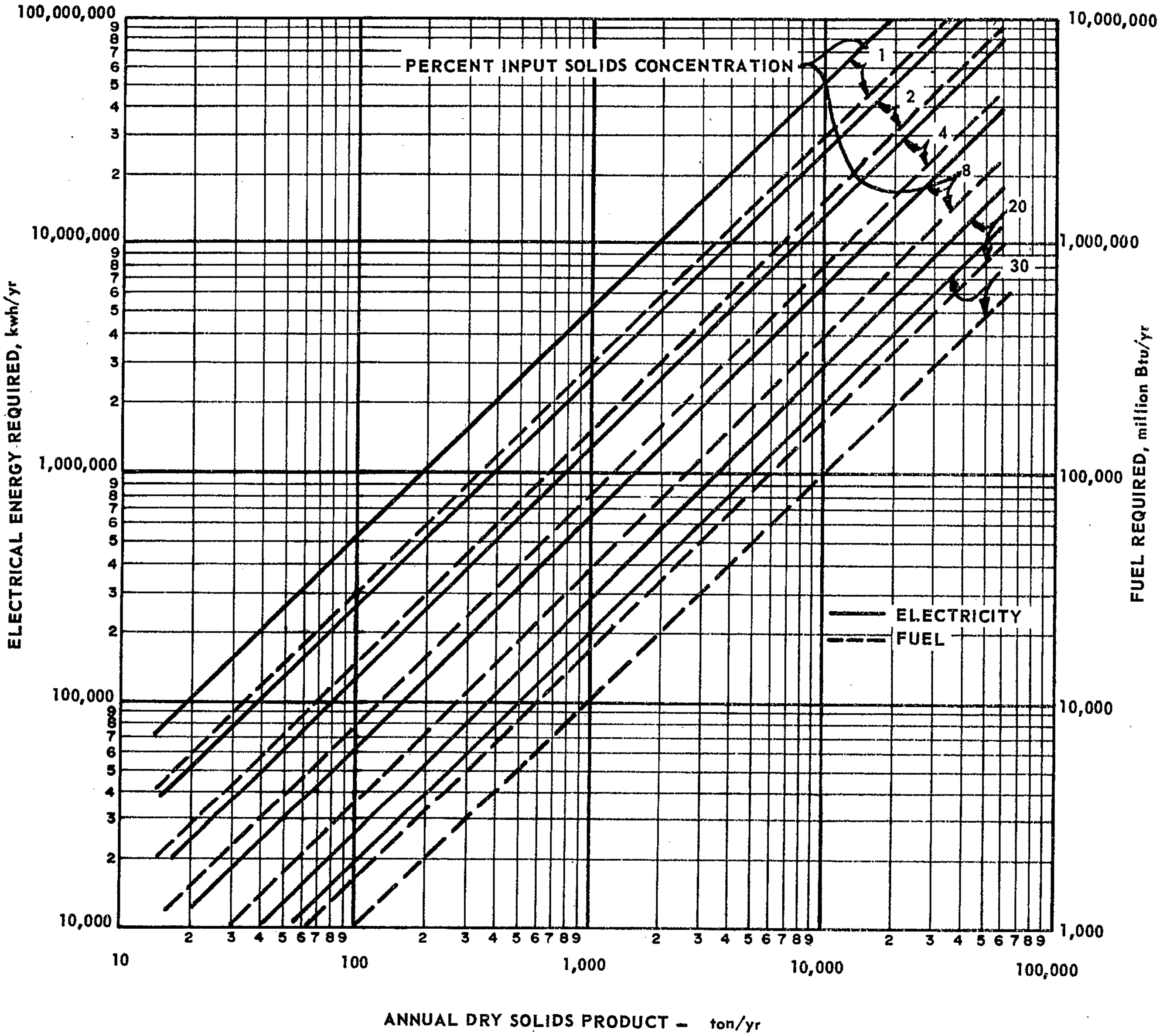
FLUIDIZED BED FURNACE INCINERATION

See Table 3-10 preceding Figure 3-111 for design assumptions

Operating Parameters:
Full time operation

Type of Energy Required: **Electrical**

FIGURE 3–115

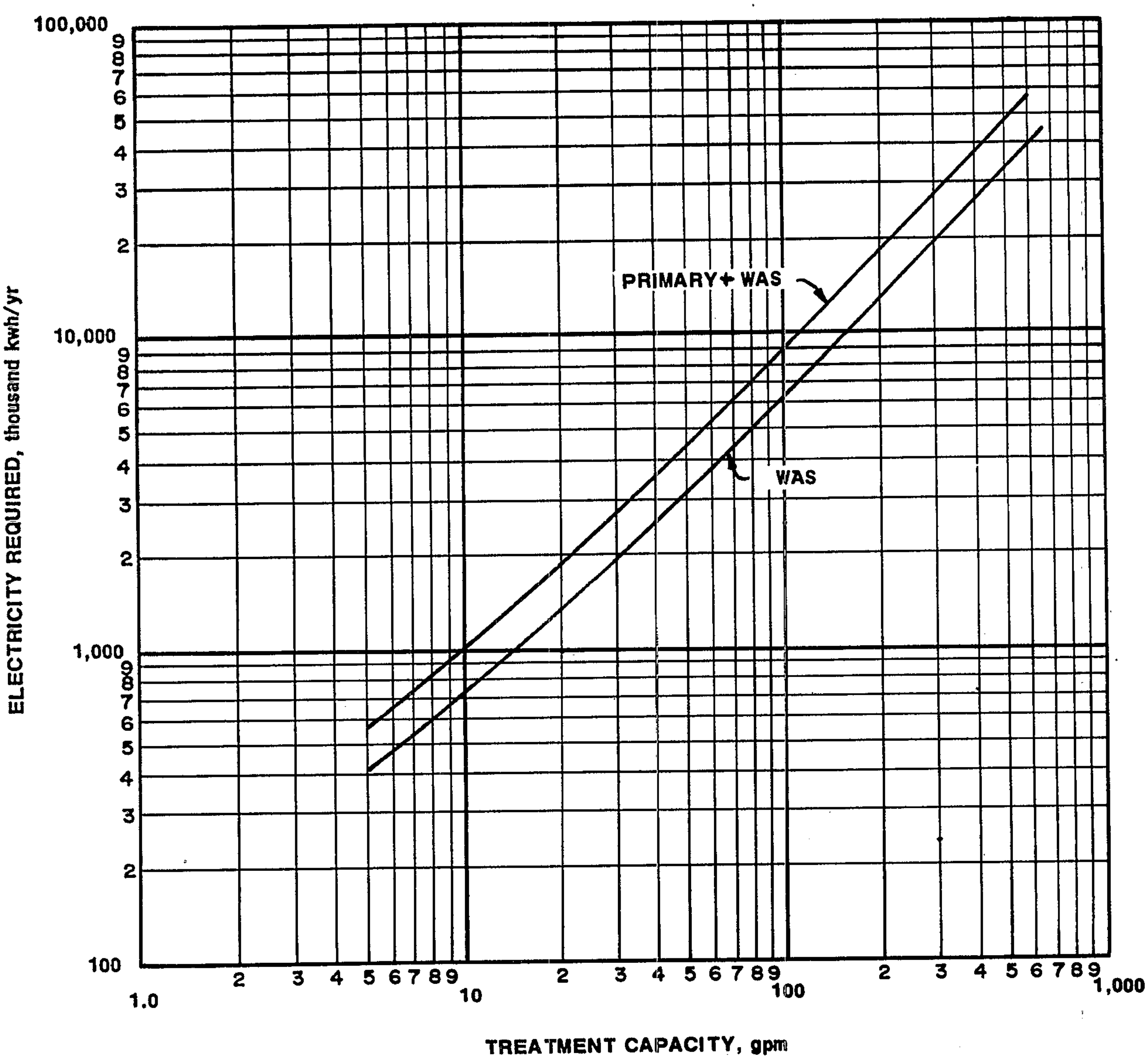


SLUDGE DRYING

Design Assumptions:
- Continous operation
- Dryer Efficiency 72%
- Product moisture content 10%
- Power includes blowers, fans, conveyors

Type of Energy Required: Fuel and Electricity

FIGURE 3–116



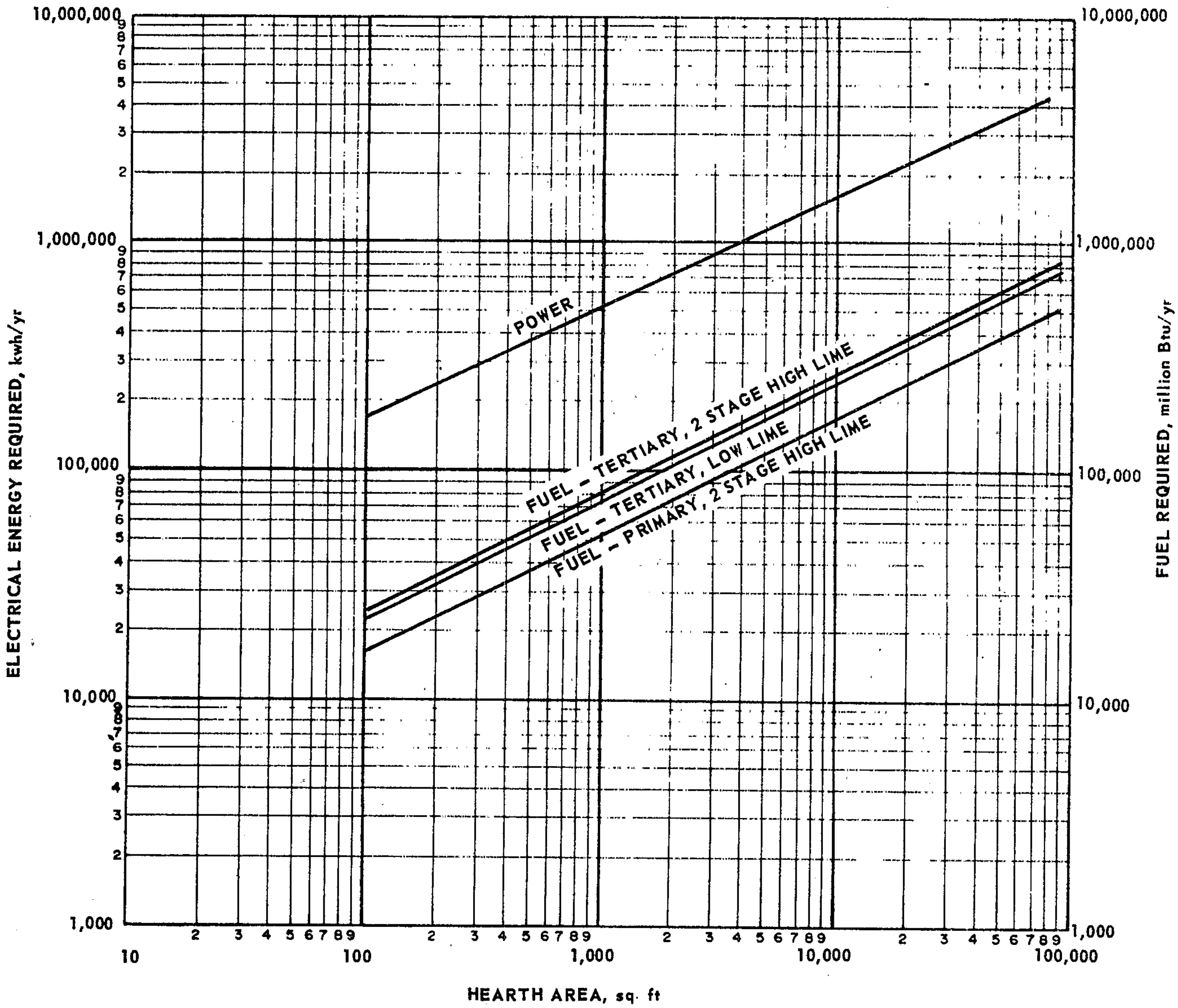
WET AIR OXIDATION

Design Assumptions:
- Reactor pressure
  - Primary + WAS = 1700 psig
  - WAS = 1800 psig
- Continuous operation
- See Table 5–9 for sludge description and text in Chapter 5

Curve Includes:
- Pressurization pumps
- Sludge grinders
- Decant tank drives
- Boiler feed pumps
- Air Compressors

Type of Energy Required: Electrical
Note: Fuel is required only at start–up

FIGURE 3–117



LIME RECALCINING – MULTIPLE HEARTH FURNACE

Design Assumptions:
- Continuous operation
- Multiple hearth furnace
- 7 lbs/sq ft/hr loading rate (wet basis)
- Gas outlet temperature = 900°F
- Product outlet temperature ≃1400°F
- Power includes center shaft drive, shaft cooling fan, burner turboblowers, product cooler, and induced draft fan

Sludge Composition:	$CaCO_3$	$Mg(OH)_2$	Other Inerts	Combustibles
Primary, 2 stage high lime	65%	2%	13%	20%
Tertiary, low lime	71	10	16	3
Tertiary, 2 stage high lime	86.1	4.3	6.1	3.5

Type of Energy Required: Fuel and Electrical

FIGURE 3–118

CHAPTER 4

SECONDARY ENERGY REQUIREMENTS

This chapter presents some of the secondary energy required in municipal wastewater treatment. Secondary energy is defined in this report as the energy required to manufacture the consumables used in municipal wastewater treatment. Secondary energy estimates are provided for the following consumable materials used in wastewater treatment processes discussed in Chapter 3.

activated carbon	methanol
alum	oxygen
ammonium hydroxide	polymer
carbon dioxide	sodium chloride
chlorine	sodium hydroxide
ferric chloride	sulfur dioxide
lime (calcium oxide)	sulfuric acid

Data from these curves and tables is essentially supplemental to any cost-effectiveness comparison a municipality may perform in submitting a planning or design proposal. Indirectly, however, the data might indicate which consumables will be relatively more expensive in the future, as high energy costs imply higher dollar costs. Municipal planners might wish to take note of this fact in choosing treatment trains, as lower energy costs often imply lower user charges. Because of the limitations of the data, however, it would be incorrect at this time for municipal planners to build into present value alternatives cost comparisons relatively higher or lower costs of a particular consumable over time.

Energy required to manufacture consumable materials was estimated based on data obtained from several sources including: (1) manufacturing companies, (2) technical journals and books, and (3) calculations based on descriptions of production processes contained in the technical literature or furnished by manufacturers.

Specific energy requirements for some materials are somewhat difficult to obtain for the following reasons:

1. Some companies consider this type of information proprietary and will not release details of the manufacturing process or the energy required. Other companies could not, or would not, furnish energy data for a variety of reasons such as, a) believed it would jeopardize competitive position, and b) insufficient records.

2. Some manufacturing processes produce more than one product, e.g., chlorine and sodium hydroxide, or a primary product and by-product, e.g., ammonia and carbon dioxide.

3. By-product or waste from one process used as feedstock in manufacturing process, e.g., ferric chloride and sulfuric acid.

4. Most chemicals are produced by more than one process, or with different methods of obtaining feedstock, with different energy requirements, e.g., sulfuric acid, carbon dioxide and methanol.

The estimated energy requirements for production are summarized in Table 4-1. Data from Table 4-1 is shown graphically in Figures 4-1 through 4-14 with treatment plant capacities and typical dosages. These figures show the principal production energy for each of the 14 consumables used in municipal wastewater treatment. The additional abscissas relate energy requirements to facility sizings and application dosages. When using these additional abscissas, the user should add the term "per day" to the regular ordinates and abscissas shown on the graphs.

If two products are manufactured in one reaction, the total amount of energy utilized is attributed to the product under discussion. The total amount of energy required does not include any special environmental clean-up requirements. The manufacture of most of the consumables shown in Table 4-1 does not require special air or water pollution control equipment. The production of lime and activated carbon does require the use of air pollution control equipment, but the energy required for this equipment is not shown in Table 4-1.

Energy required for the transportation of consumables is not included in Table 4-1 or in the figures. The following discussion illustrates a method that may be used to estimate transportation energy requirements.

Consumable materials are normally transported by railroad and/or truck. A 25 ton diesel truck, averaging 4 mpg and using fuel with a heat value of 142,500 Btu/gal, requires 1,425 Btu/ton-mile. An energy study for the Ford Foundation[1] gives 670 Btu/ton-mile for railroad transportation of freight. A one-way delivery distance of 100 miles by truck then requires about 142,500 Btu/ton (or about 285,000 Btu/ton assuming the truck returns empty). This amount of energy for delivery varies from about 14 percent of the total required for alum production to 0.3 percent for activated carbon.

Activated carbon, lime and some of the other consumables are usually delivered to or near the point of use by railroad. Activated carbon probably requires the longest delivery distance of any consumable for most plant locations. A railroad transportation distance of 1500 miles plus 50 miles round trip by truck gives a total energy requirement for transportation of about 1,148,000 Btu/ton. This amount of energy for transportation is about 1.1 percent of the total energy required for production of activated carbon.

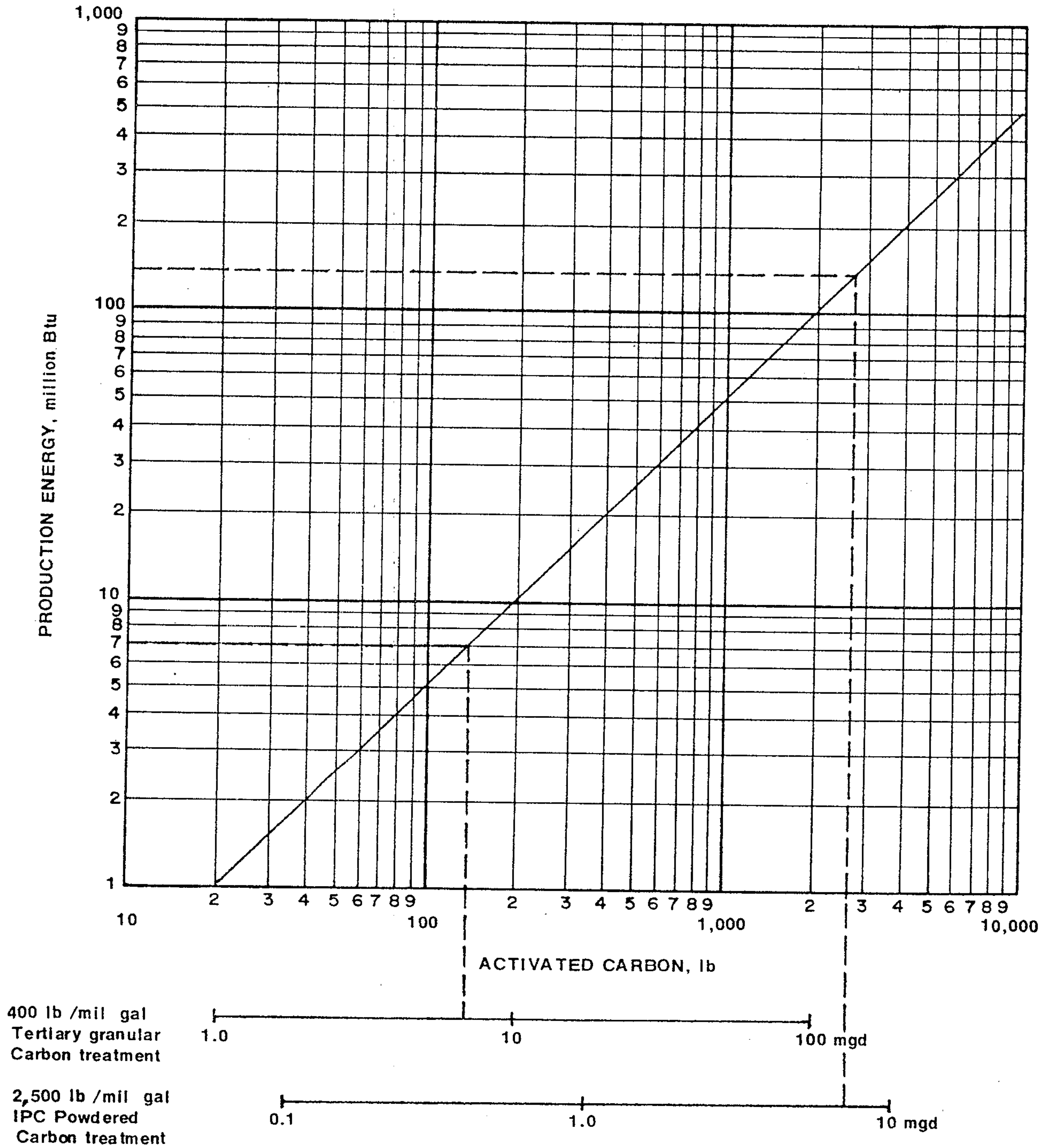
[1] *"Energy Consumption in Manufacturing," report to the Energy Policy Project of the Ford Foundation, Ballinger Publishing Company, Cambridge, Mass., 1974.*

TABLE 4-1

ESTIMATED ENERGY REQUIREMENTS FOR THE PRODUCTION
OF CONSUMABLE MATERIALS

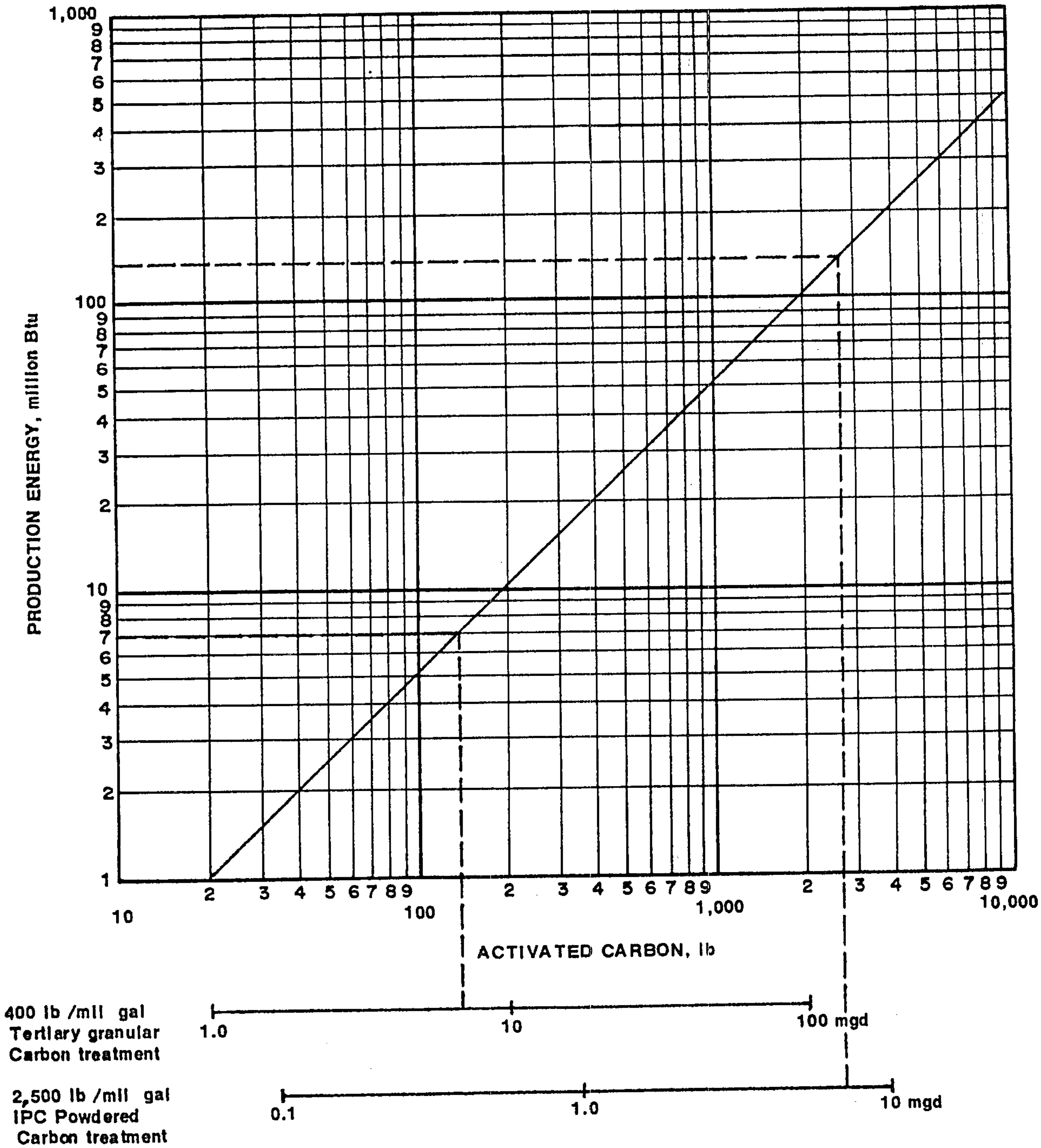
Material	Fuel Million Btu/ton	Electricity kwh/lb
Activated Carbon	102*	4.9
Alum	2*	0.1
Ammonium Hydroxide	41*	2.0
Carbon Dixoide	2	0.1*
Chlorine	42	2.0*
Ferric Chloride	10	0.5*
Lime (Calcium Oxide)	5.5*	0.3
Methanol	36 *	1.7
Oxygen	5.3	0.25*
Polymer	3*	0.1
Salt (Sodium Chloride)		
Evaporated	4*	0.2
Rock & Solar	0.5	0.024*
Sodium Hydroxide	37	1.8*
Sulfur Dioxide	0.5	0.024*
Sulfuric Acid	1.5*	<0.1

*Indicates principal type of energy used in production.



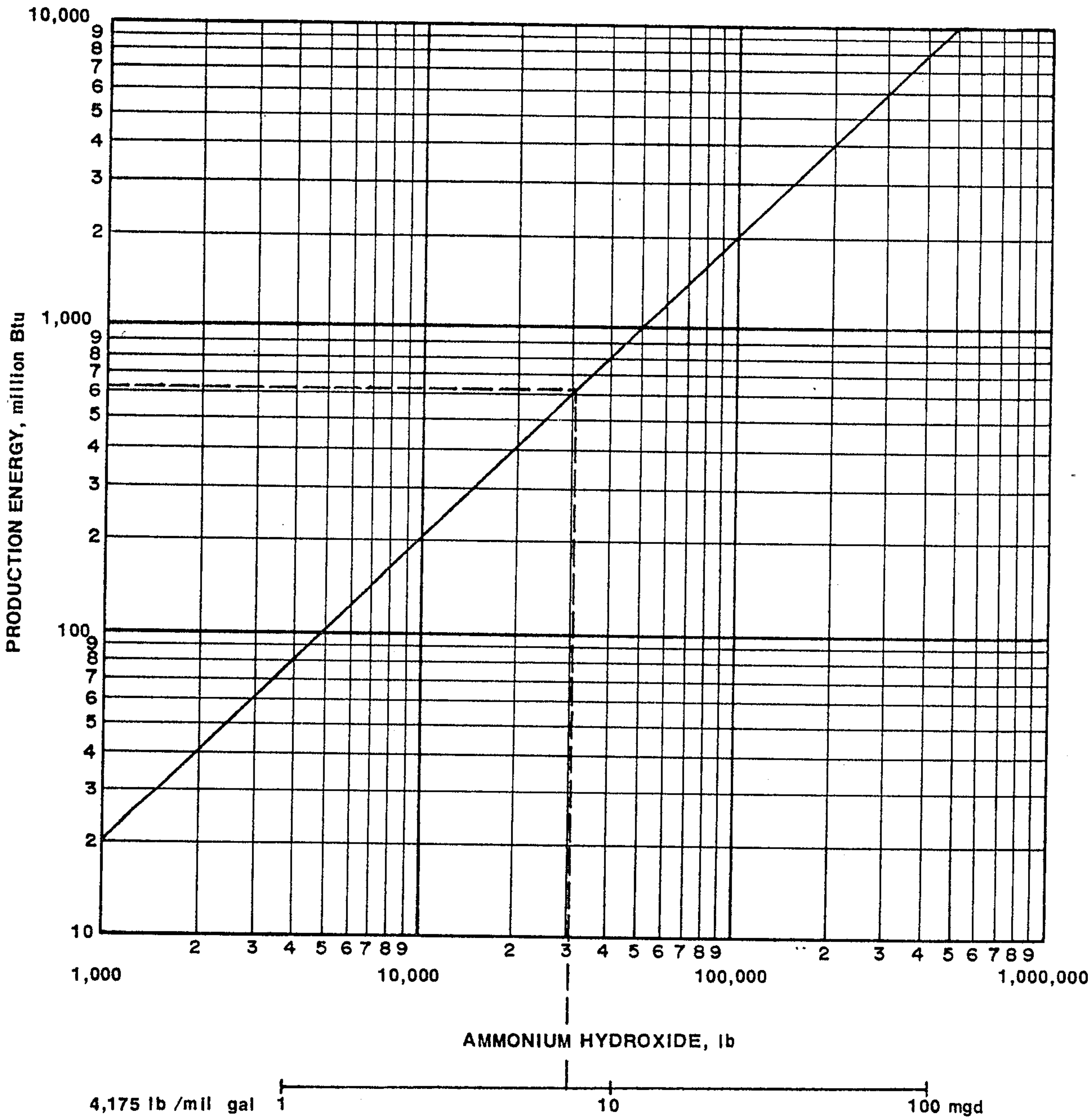
ACTIVATED CARBON
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-1



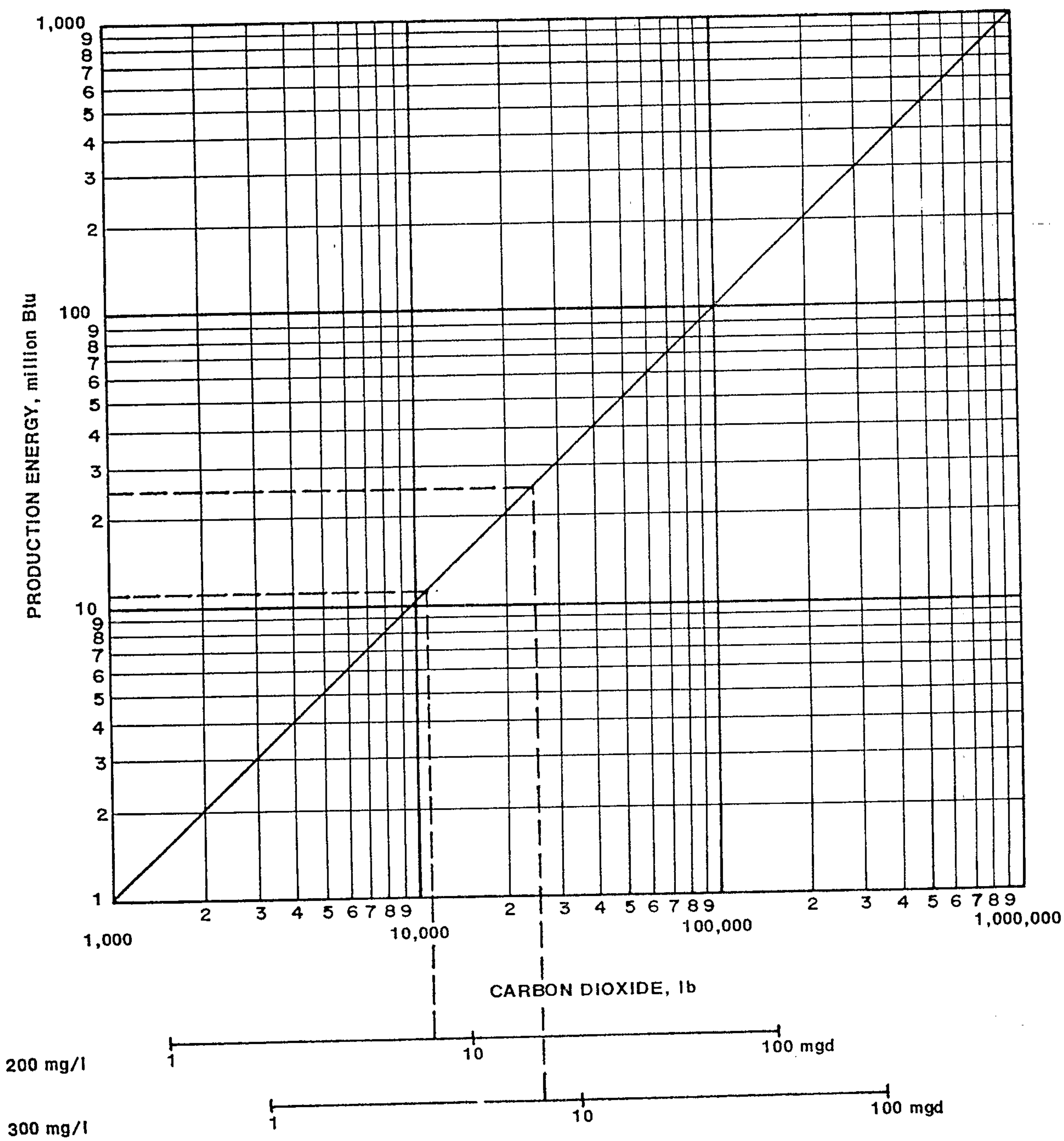
ACTIVATED CARBON
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-1



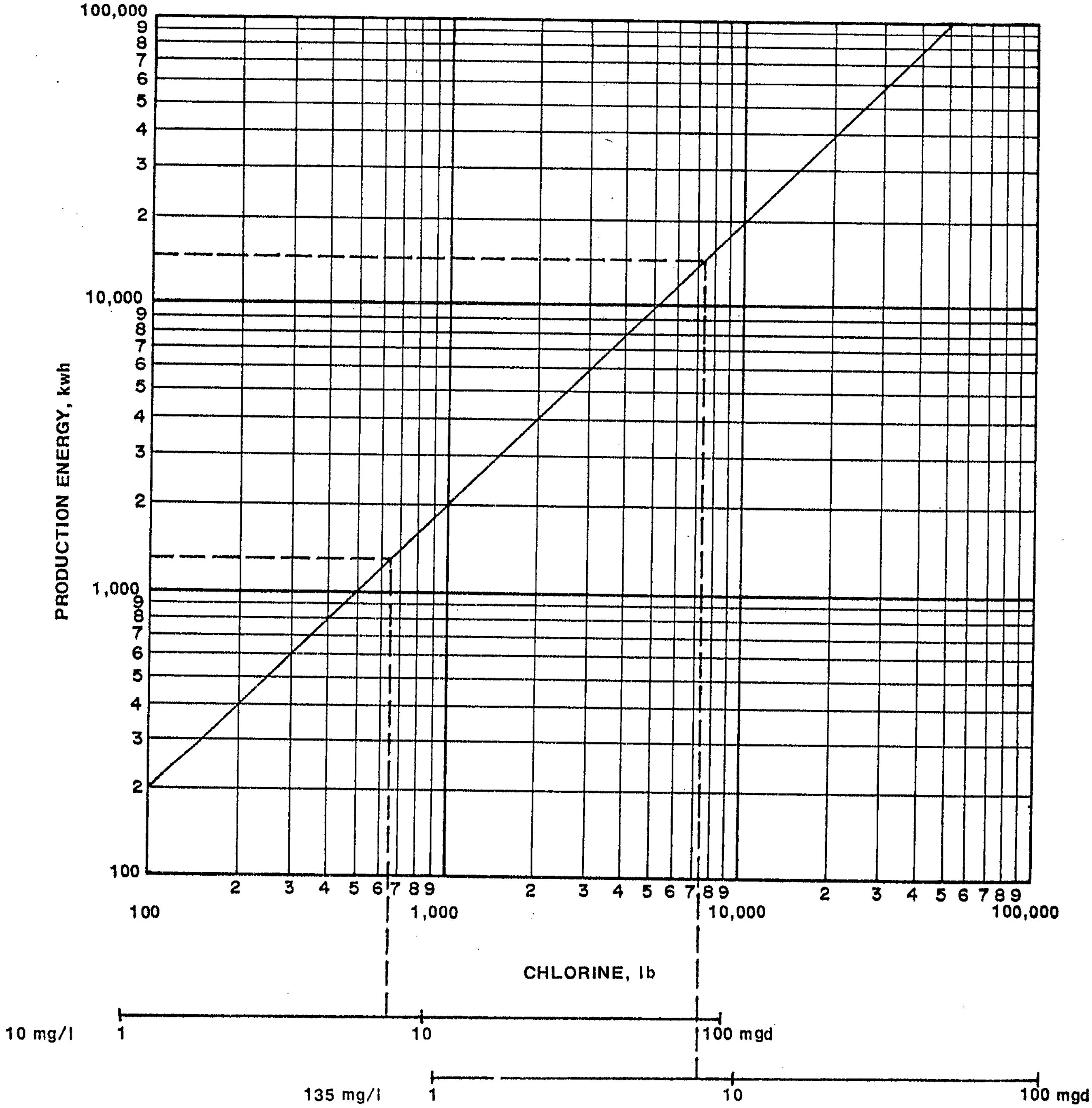
AMMONIUM HYDROXIDE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4–3



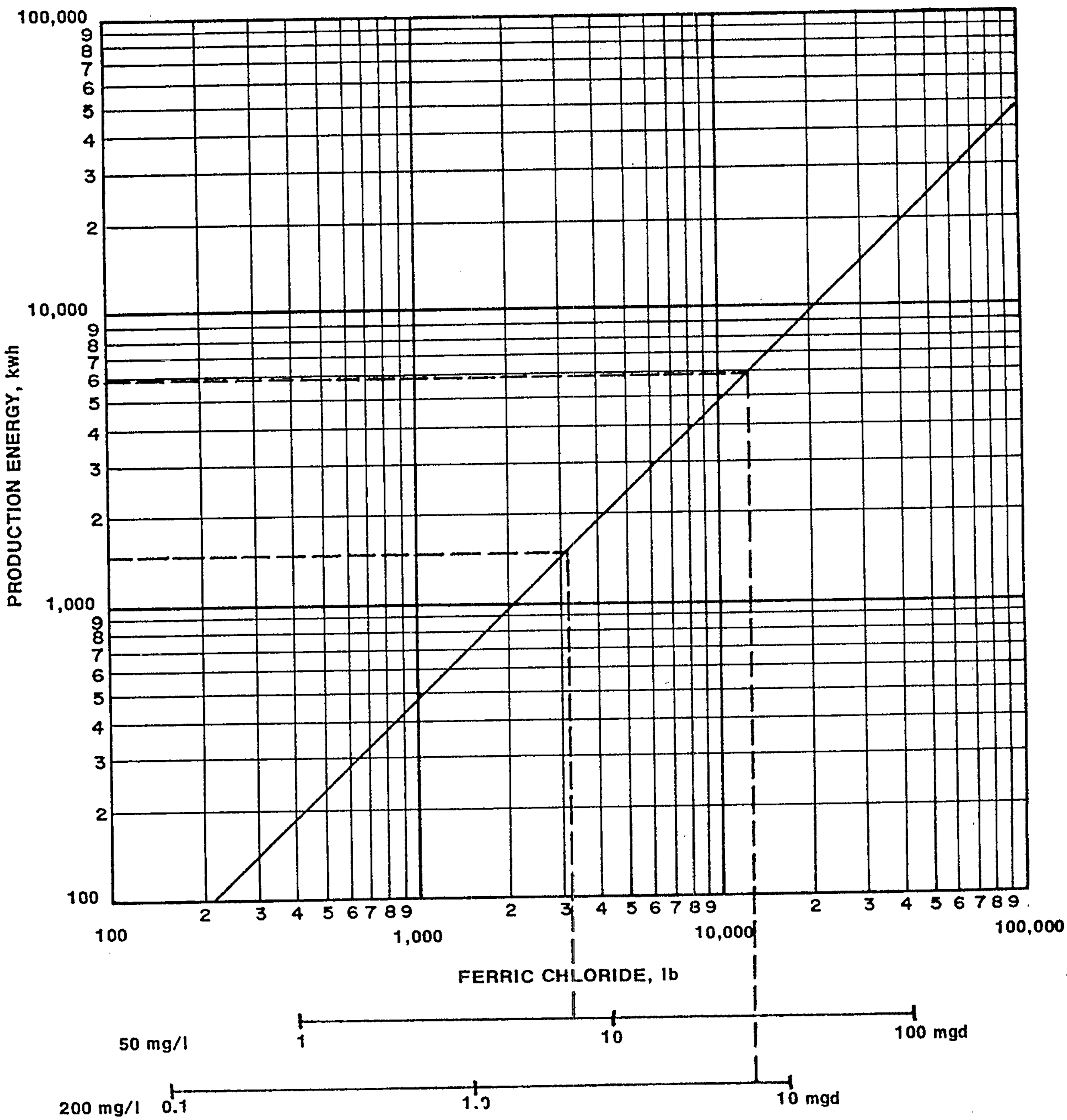
CARBON DIOXIDE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-4



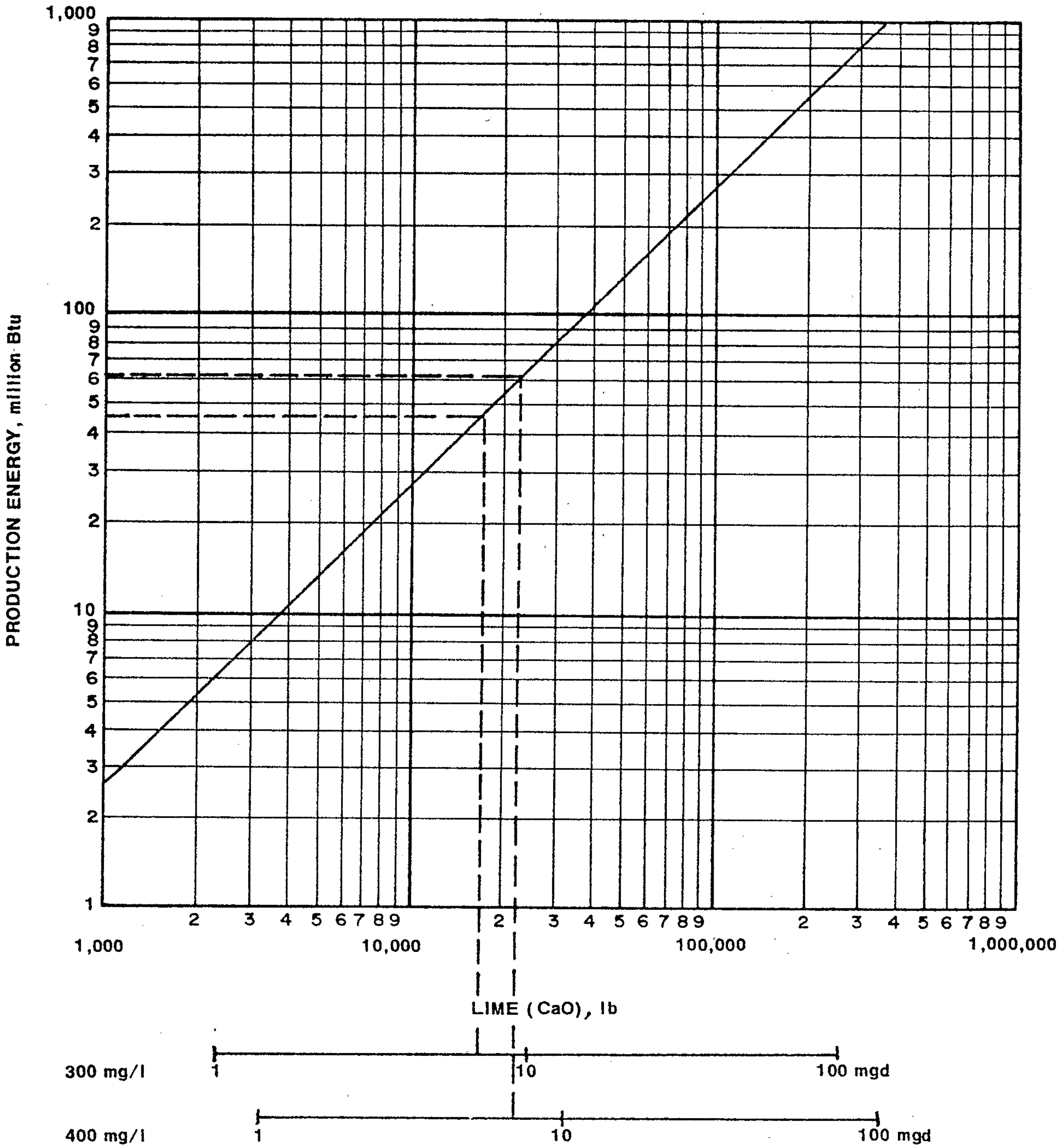
CHLORINE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-5



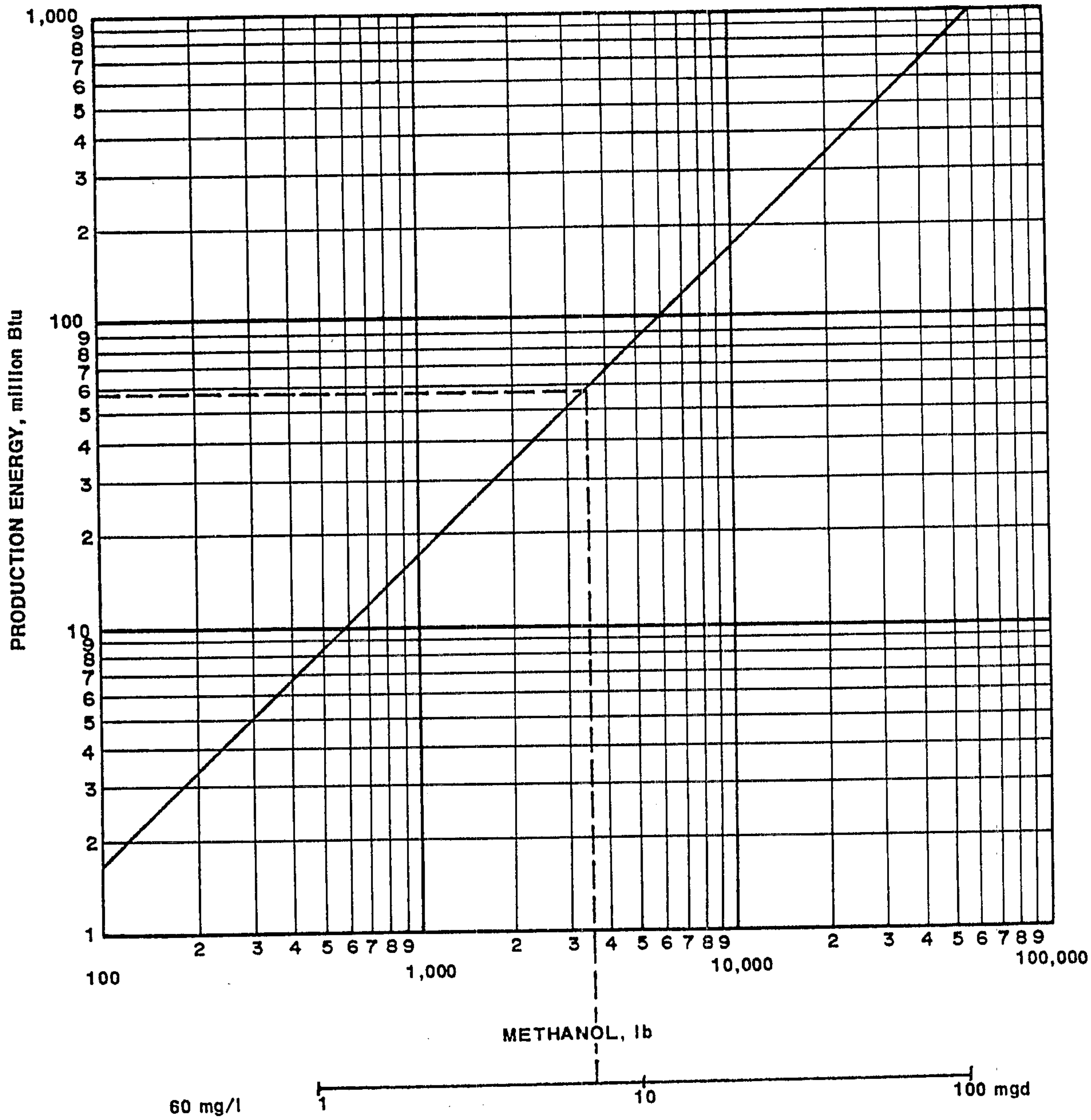
FERRIC CHLORIDE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-6



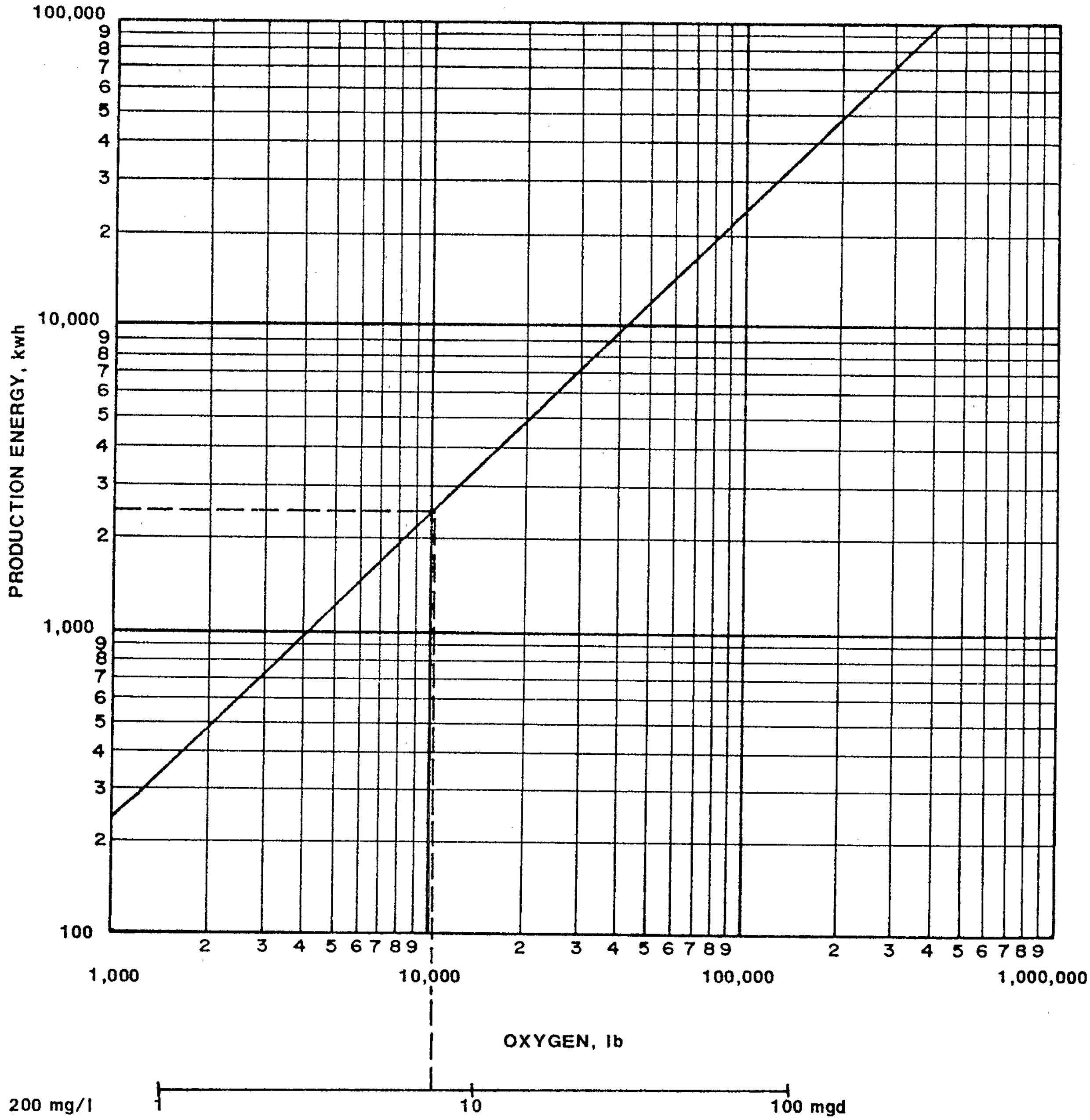
LIME (CALCIUM OXIDE)
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-7



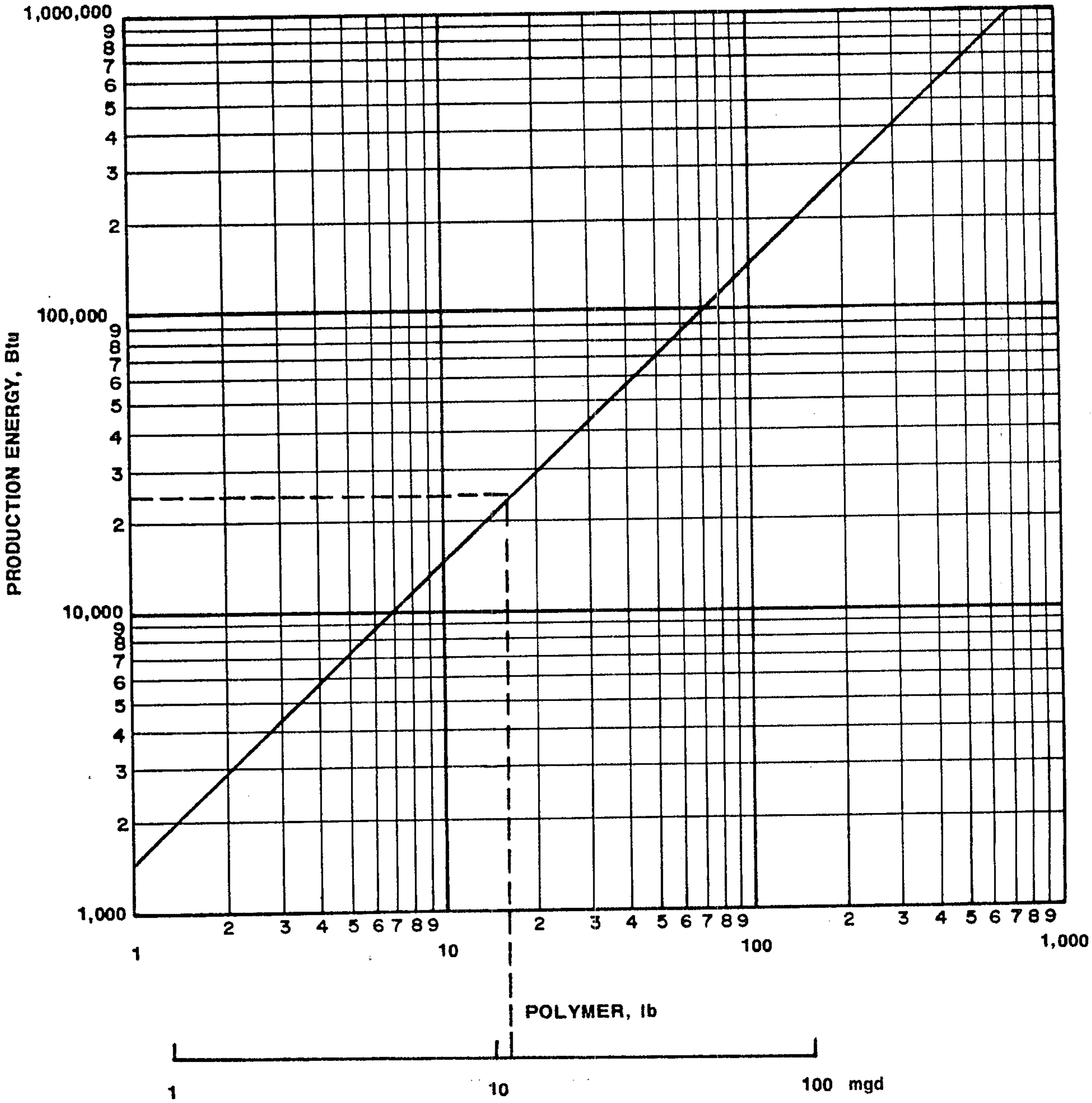
METHANOL
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-8



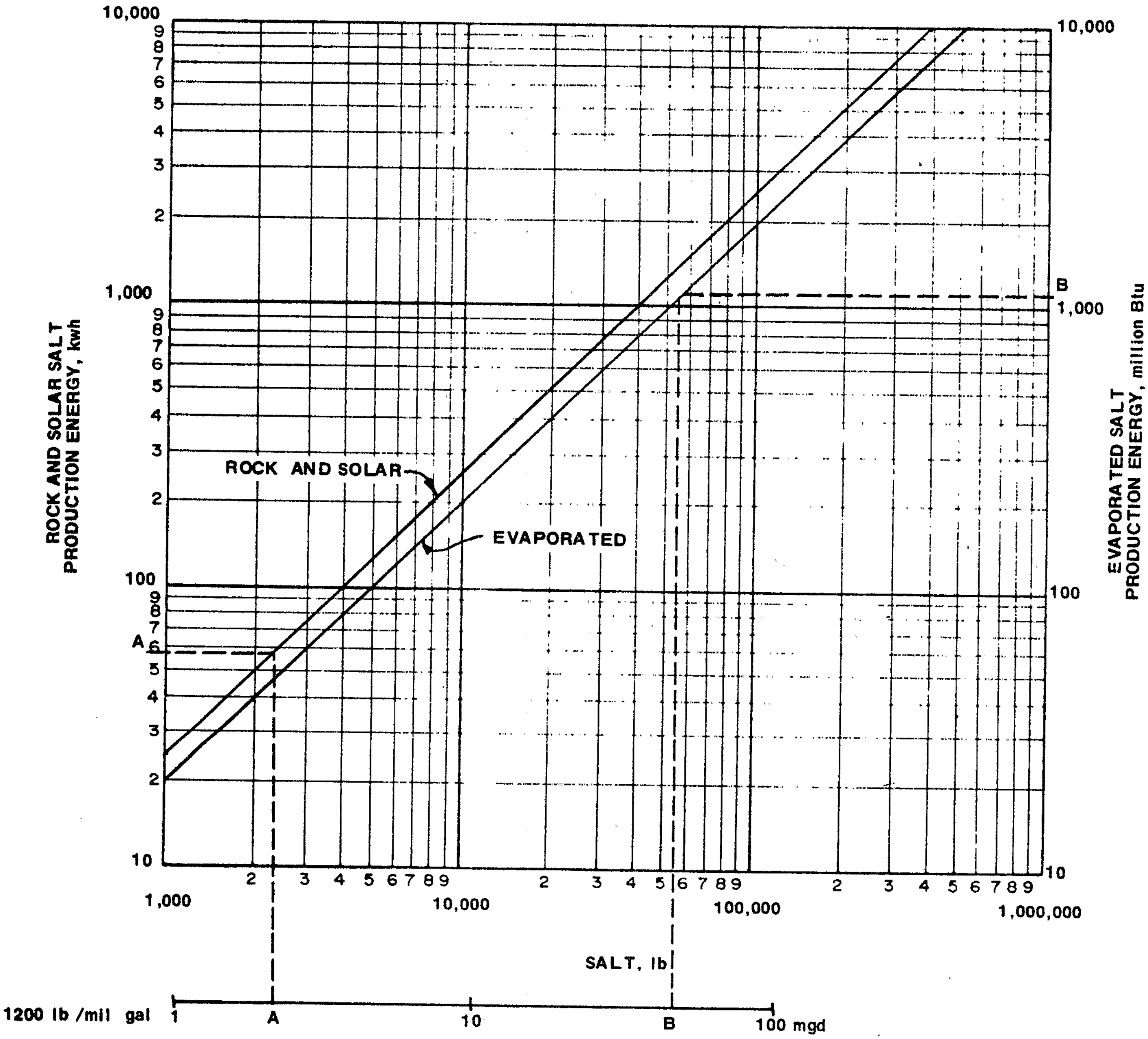
OXYGEN
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-9



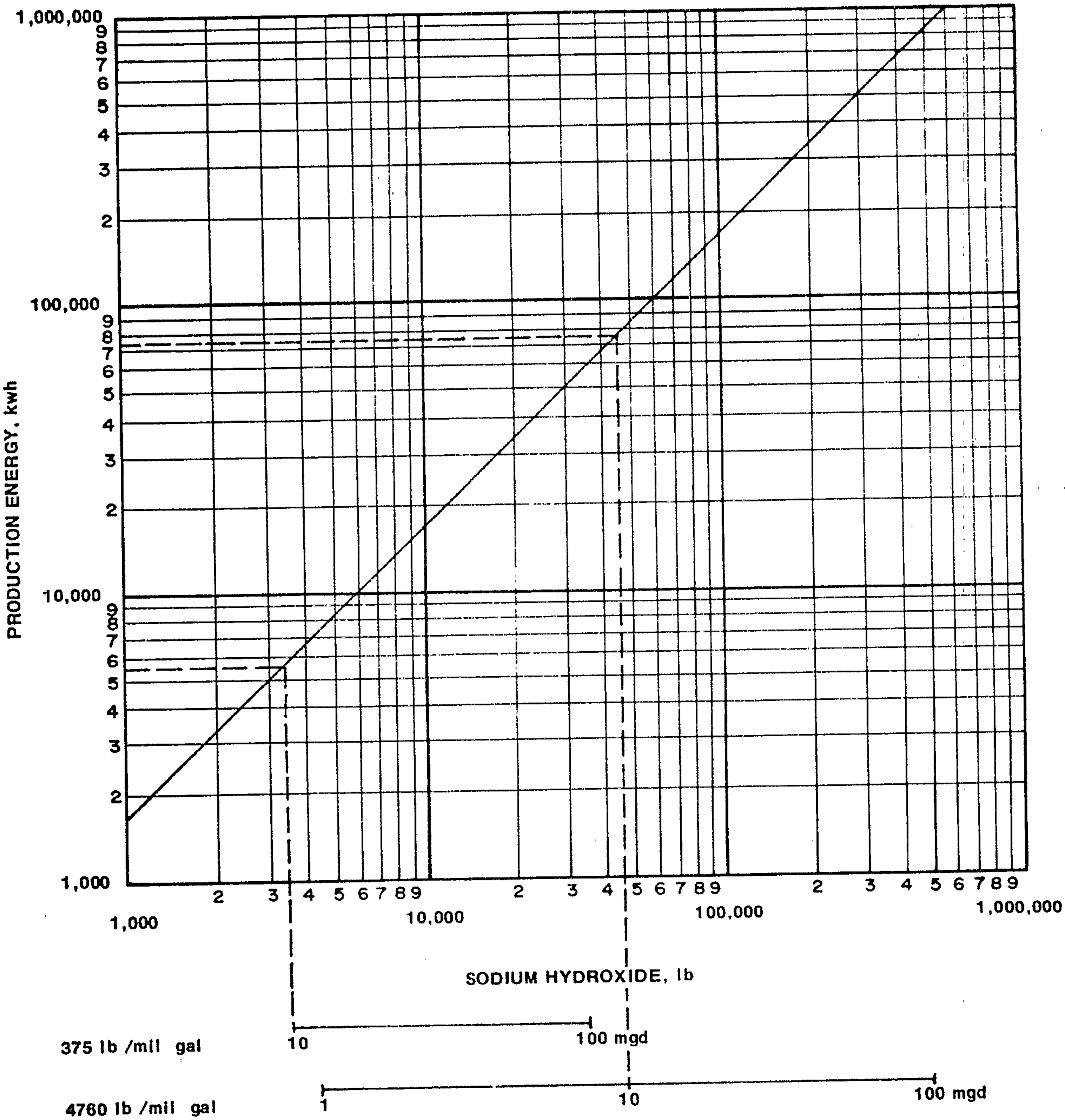
POLYMER
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-10



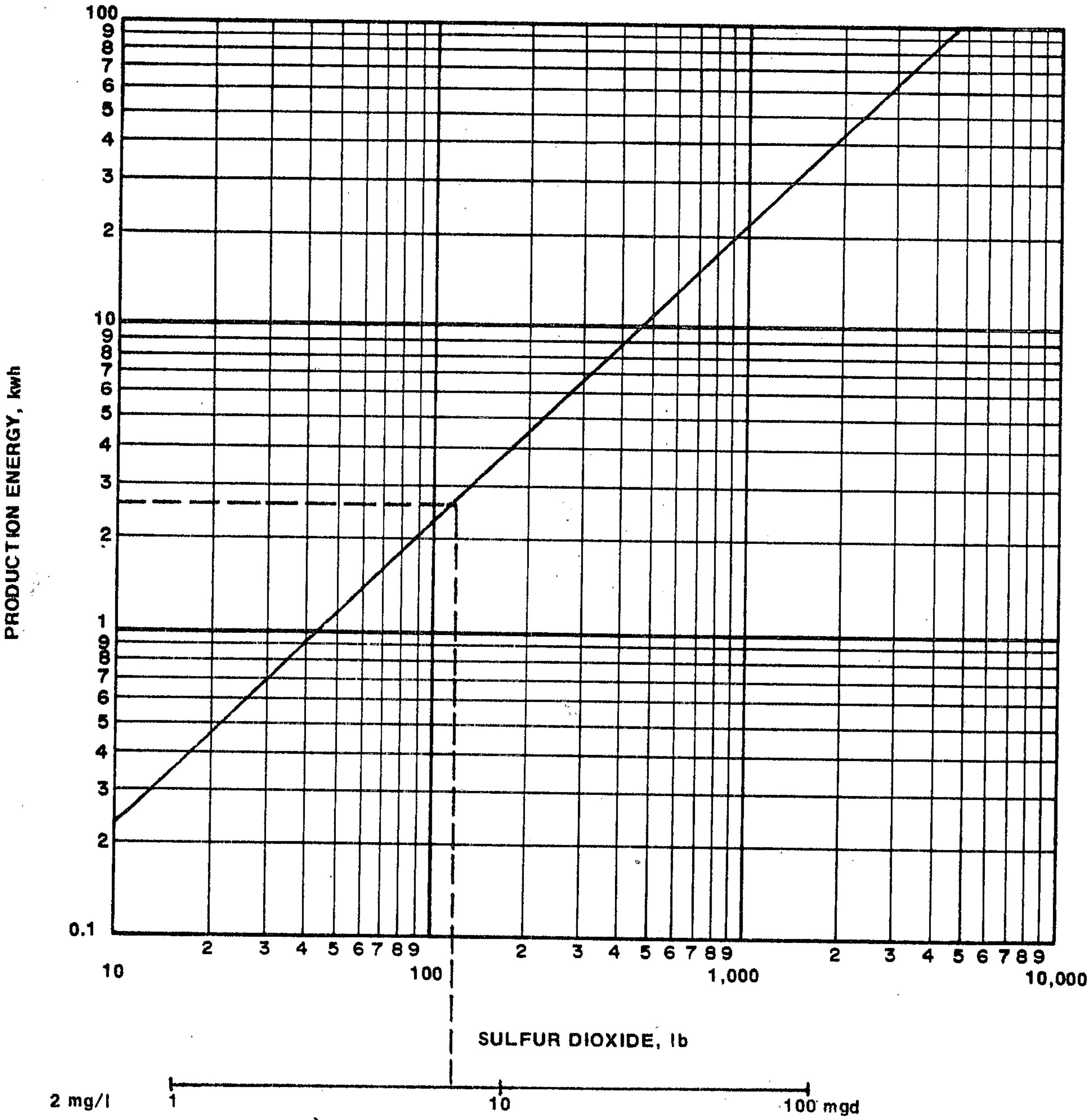
SODIUM CHLORIDE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4–11



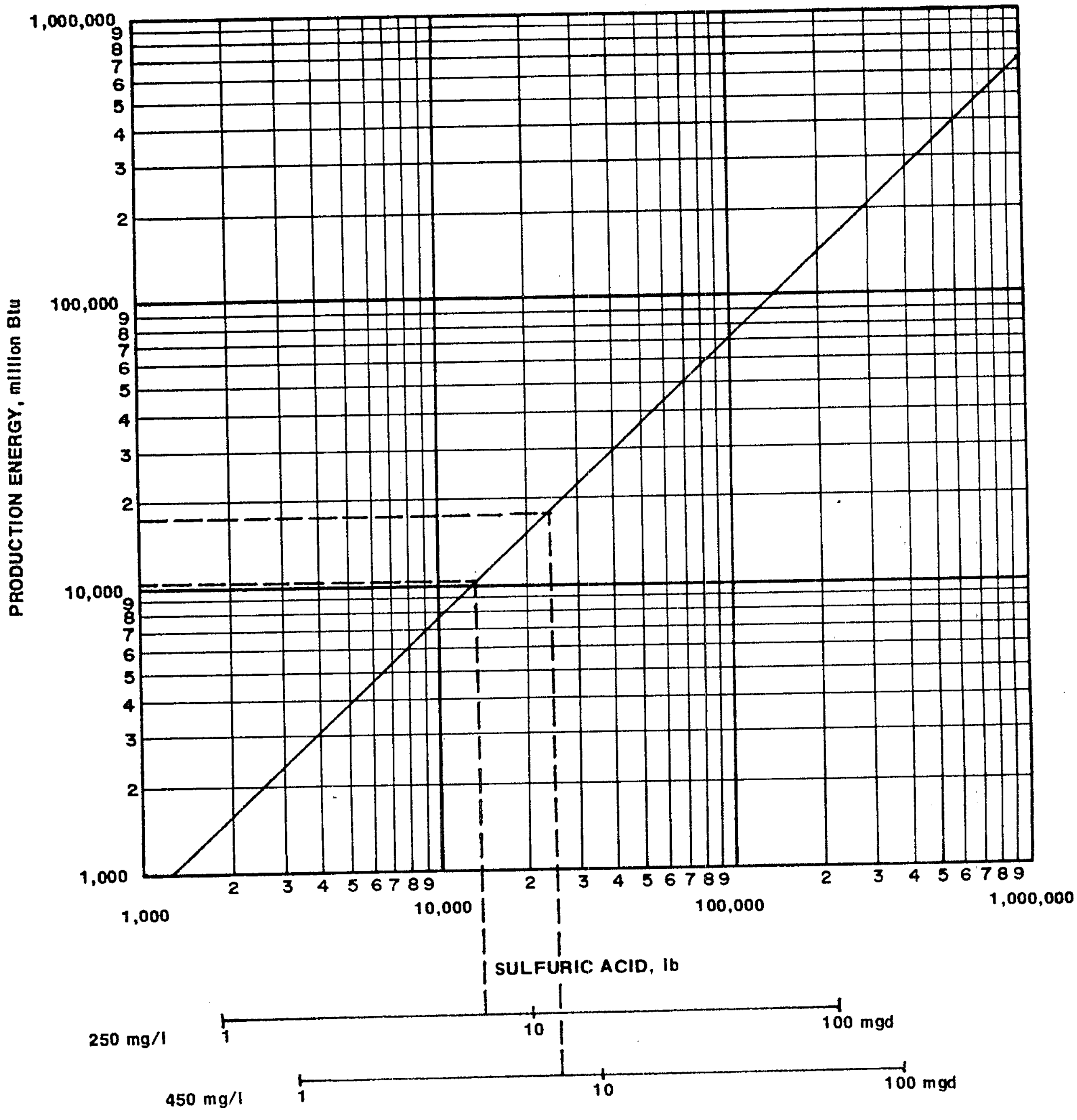
SODIUM HYDROXIDE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-12



SULFUR DIOXIDE
SECONDARY ENERGY REQUIREMENTS

FIGURE 4-13



SULFURIC ACID
SECONDARY ENERGY REQUIREMENTS

FIGURE 4–14

CHAPTER 5
IN-PLANT ENERGY RECOVERY AND RECYCLING

INTRODUCTION

The purpose of this chapter is to (1) present heat requirements for various wastewater treatment processes and (2) describe and evaluate processes and methods that could be used to supply some of the heat and electrical energy required by wastewater treatment plants. Heat requirements are presented for the following:

- Building heating and air conditioning
- Anaerobic digestion
- Heat conditioning of sludge to improve dewatering
- Wet oxidation of sludge
- Lime recovery by recalcination
- Granular and powdered carbon regeneration
- Ion exchange regenerant renewal

After the section on heat requirements, the remainder of this chapter is devoted to the following recovery and recycling systems:

Anaerobic Digester Gas - Gas production, methods for use, including electrical power generation, and cost estimates are presented.

Incineration - Various incineration systems are briefly described and waste heat recovery is discussed. Incineration of sludge and combinations of sludge and solid waste are evaluated. Cost estimates are given for multiple hearth furnaces. Energy requirements for air pollution control devices are not included in the curves.

Pyrolysis - Several commercially available pyrolysis systems are briefly described and the potential for energy recovery and reuse is discussed. Treatment of sludge and solid waste combined is evaluated.

Heat Treatment - Energy requirements and the potential for waste heat recovery are discussed.

Heat Pumps - Systems to utilize the heat in wastewater and air are described and cost estimates presented.

Solar Energy - Solar energy systems are briefly described and an example for space heating is presented.

Energy Conservation - Conservation procedures that could be used in existing wastewater treatment facilities are discussed.

HEAT REQUIREMENTS IN WASTEWATER TREATMENT PLANTS

Building Heat

Energy required for space heating in a wastewater treatment plant depends upon several factors including: (1) building size, (2) location (climate), and (3) type of construction. The degree-day (deg-day) system is one method of estimating energy required for space heating.

The deg-day is defined as 65°F minus the mean temperature for the day. If the mean temperature of the day is 65°F or greater, then the number of deg-days for heating is zero. The deg-day method is based on the findings of the American Gas Association that the quantity of energy required for heating is proportional to the number of deg-day. For example, a building requires twice as much heat on a day when the temperature is 45°F (20 deg-day) than when it is 55°F (10 deg-day). Table 5-1 shows the average number of deg-day per month computed from about 30 years of record, for 25 cities in the United States.

CITY	AVE WINTER TEMP	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	YEARLY TOTAL
Atlanta, Ga	51.7	0	0	18	124	417	648	636	518	428	147	25	0	2961
Baltimore, Md	46.2	0	0	27	189	486	806	859	762	629	288	65	0	4111
Birmingham, Ala	54.2	0	0	6	93	363	555	592	462	363	108	9	0	2551
Boston, Mass	40.0	0	9	60	316	603	983	1088	972	846	513	208	36	5634
Charlotte, N.C.	50.4	0	0	6	124	438	691	691	582	481	156	22	0	3191
Chicago, Ill	38.9	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882
Cincinnati, Ohio	45.1	0	0	39	208	558	862	915	790	642	294	96	6	4410
Cleveland, Ohio	37.2	9	25	105	384	738	1088	1159	1047	918	552	260	66	6351
Dallas, Texas	55.3	0	0	0	62	321	524	601	440	319	90	6	0	2363
Denver, Colo	40.8	0	0	90	366	714	905	1004	851	800	492	254	48	5524
Detroit, Mich	37.2	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232
Houston, Texas	62.0	0	0	0	0	165	288	363	258	174	30	0	0	1278
Kansas City, Mo	43.9	0	0	39	220	612	905	1032	818	682	294	109	0	4711
Los Angeles, Cal	60.3	0	0	6	31	132	229	310	230	202	123	68	18	1349
Miami, Fla	72.5	0	0	0	0	0	40	56	36	9	0	0	0	141
Milwaukee, Wis	32.6	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635
Minneapolis, Minn	28.3	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382
New Orleans, La	61.8	0	0	0	12	165	291	344	241	177	24	0	0	1254
New York, N.Y.	42.8	0	0	30	233	540	902	986	885	760	408	118	9	4871
Philadelphia, Pa	44.5	0	0	30	205	513	856	924	823	691	351	93	0	4486
Pittsburgh, Pa	42.2	0	0	60	291	615	930	983	885	763	390	124	12	5053
St. Louis, Mo	44.8	0	0	36	202	576	884	977	801	651	270	87	0	4484
San Francisco, Cal	55.1	192	174	102	118	231	388	443	336	319	279	239	180	3001
Seattle, Wash	46.9	50	47	129	329	543	657	738	599	577	396	242	117	4424
Trenton, N.J.	42.4	0	0	57	264	576	924	989	885	753	399	121	12	4980

TABLE 5-1

AVERAGE MONTHLY DEGREE DAYS (HEATING) FOR VARIOUS CITIES

The general equation used for estimating energy required for space heating is:

$$E = \frac{24 \times H \times D}{U} \qquad (5\text{-}1)$$

E = energy consumption, Btu

U = utilization efficiency

H = hourly heat loss for building, Btu/hr/^{0}F

D = deg-day, ^{0}F day

The utilization efficiency is the ratio of the heat loss from the structure to the heat input and is a function of several factors including control of heating equipment and type of construction. Values from 45 to 90 percent have been reported. The hourly heat loss can be computed using ASHRAE methods[1] or can be measured directly. It is expressed in Btu/hr/^{0}F and includes the heat losses through the walls, ceiling, floor, windows and infiltration air. This quantity is highly variable from structure to structure depending on insulation, building materials and ratio of floor area to volume. Some representative heat loss values have been published for insulated and uninsulated walls and ceilings.[2] Based on these values, and neglecting air infiltration rate, H values were determined for the following three cases:

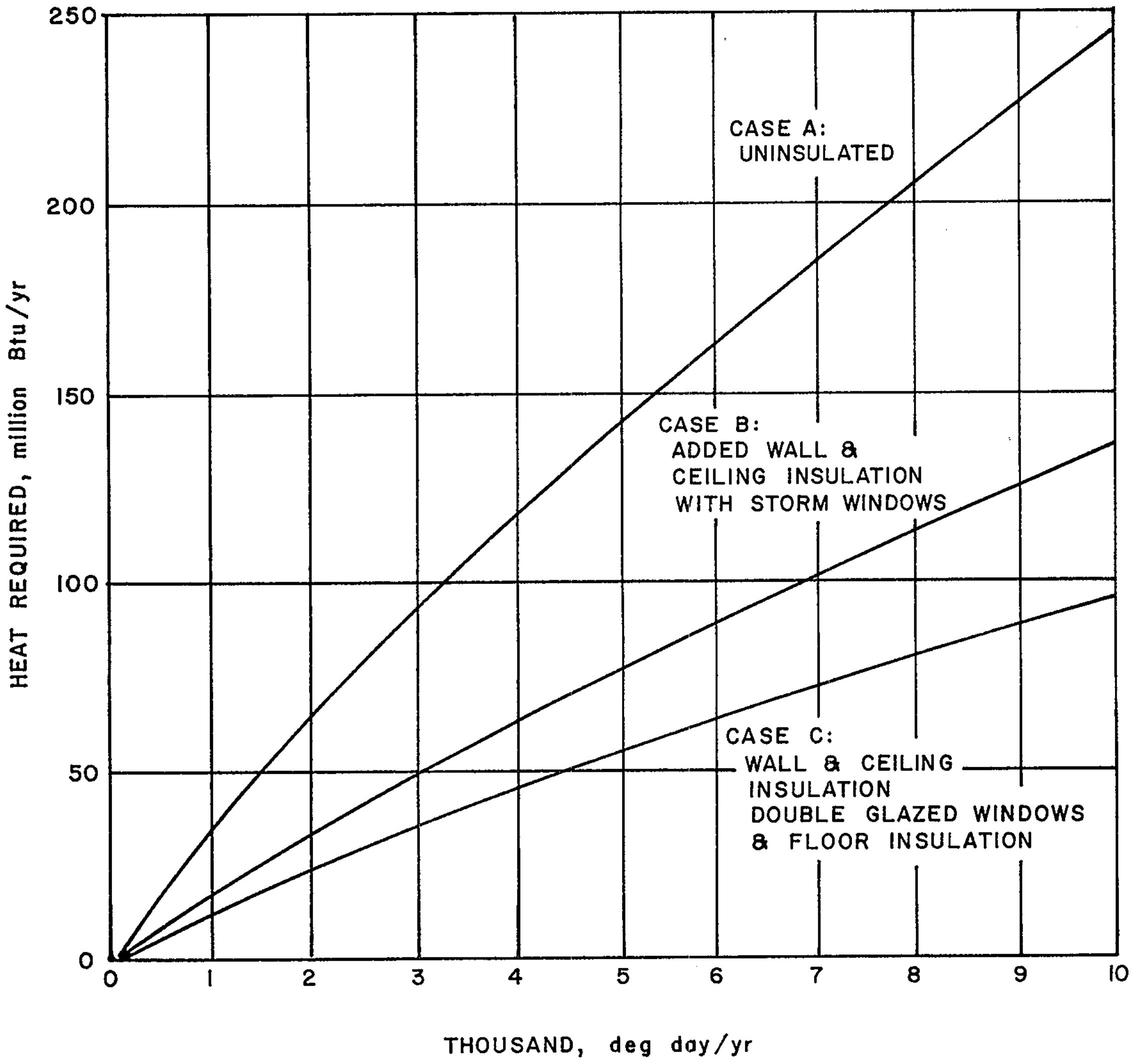
- Case A corresponds to an uninsulated building of 1,000 sq ft with H = 820 Btu/hr/^{0}F.
- Case B is a 1,000 sq ft building with 3.5 in. wall insulation, 6 in. ceiling insulation and storm windows. The insulation and storm windows give a reduction of about 45 percent in the heat loss rate and H = 450 Btu/hr/^{0}F.
- Case C is the same as Case B, but includes double glazed windows and floor insulation and gives H = 325 Btu/hr/^{0}F.

These three cases are shown in Figure 5-1 as a function of the number of deg-day and a U of 0.70. Infiltration air can substantially increase the values in Figure 5-1. For example, an infiltration rate of 1.5 times the building volume per hour will increase the values for Cases A, B and C by 13, 24 and 33 percent, respectively.

In wastewater treatment plants, 4 to 6 air changes per hour is a common design standard.[3] This rate will increase the heating requirement and should not be neglected. For example, assuming 4 air changes/hr, 70 percent utilization factor, 5000 deg-day climate, and 1000 sq ft area with an 8 ft ceiling gives an additional heat requirement of about 99 million Btu/yr.

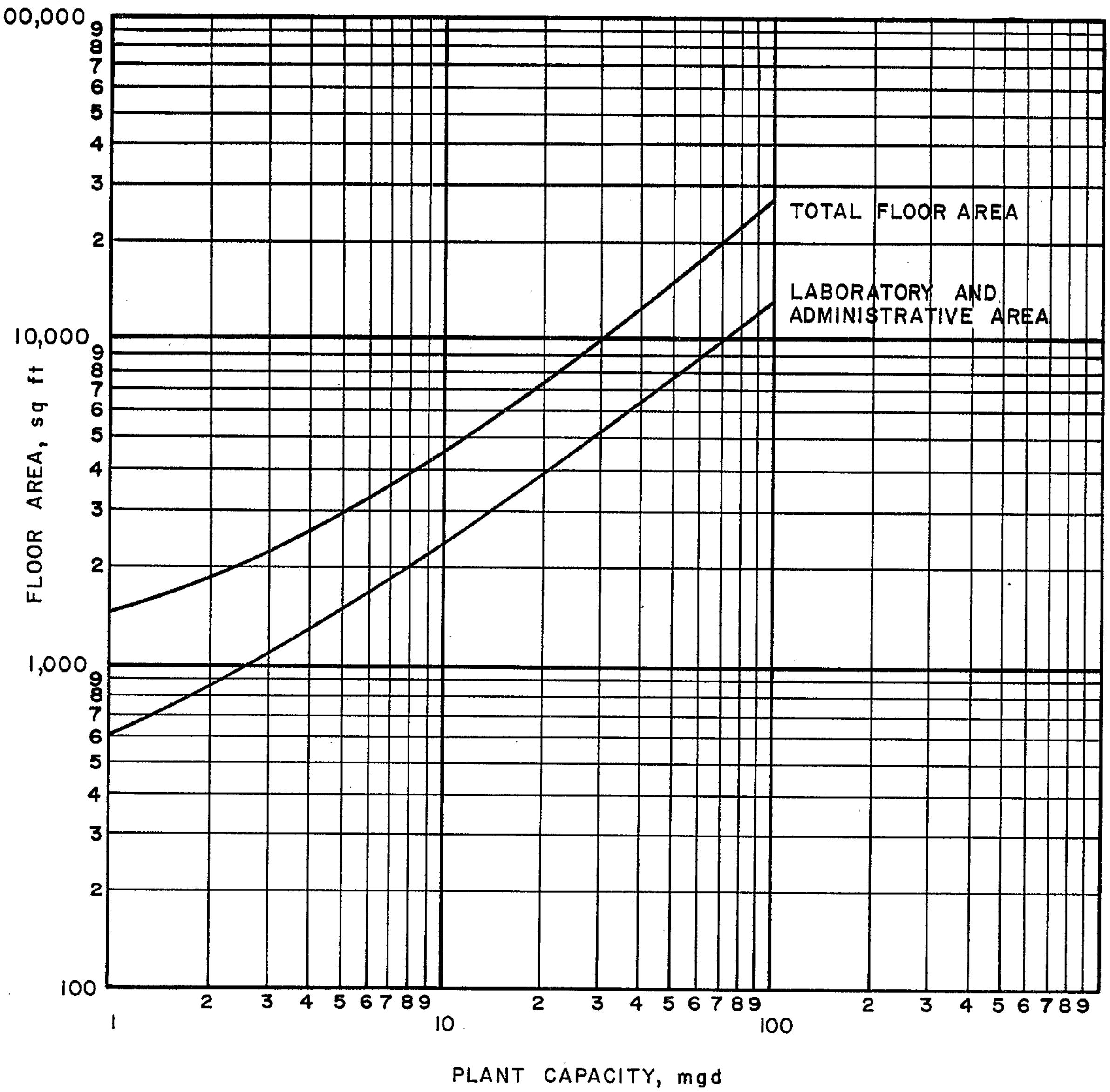
Building heating requirements for wastewater treatment plants can be estimated from the above information if the total floor area is known. Typical floor areas as a function of treatment plant size are given in another EPA report[4] and are shown in Figure 5-2. The data in these tables and figures can be used to estimate building heating requirements. As an example, the curves shown in Chapter 3, Figure 3-83 were derived from these data for Los Angeles, New York and Minneapolis.

This simple method of estimating heating loads does not apply to large commercial buildings. The relationship of the external heat losses and the internal heat gains must be considered when determining the total system energy balance. For example, some larger buildings generate enough heat from operating equipment that cooling is required throughout most of the year. Other buildings may require simultaneous cooling of the hotter inner rooms and heating of the cooler outer rooms.



ESTIMATED HEAT REQUIREMENTS
1000 SQ FT BUILDING

FIGURE 5-1



ESTIMATED FLOOR AREA FOR WASTEWATER TREATMENT PLANTS
(FROM REFERENCE 4)

FIGURE 5-2

Building Cooling

Similar to the deg-day method for estimating heating requirements a method of estimating energy consumption for cooling has also been devised.[5] This method uses cooling deg-day above 70^0F as a criterion. Although tabulated values of cooling deg-day are not available, approximate values can be obtained from published deg-day maps.[6] Estimated values at the same 25 cities used for heat estimates are shown in Table 5-2.

The cooling deg-day method is based on the following equations:

$$E = PT \qquad (5\text{-}2)$$

$$T = (24\ HD)\ /\ C\ (tm-70) \qquad (5\text{-}3)$$

where

- E = yearly energy requirement, kwh/yr
- P = power input to equipment, kw
- T = predicted operating time of equipment, hr
- H = average hourly cooling load on a design day, Btu/hr
- D = number of deg-days above 70^0F, deg-day
- C = total cooling capacity of equipment, Btu/hr
- tm = design outdoor dry-bulb temperature minus one-half the daily temperature range, ^{0}F

The cooling capacity, C, of the air conditioning unit may be determined experimentally, or obtained from the manufacturer. The cooling load or average hourly heat gain, H, is dependent on factors such as the sun's radiation, daily temperature range, shading effect, insulation, the number of people and internal heat sources in the building.

TABLE 5-2

ESTIMATED COOLING DEGREE DAYS FOR 25 CITIES

CITY	DESIGN DRY BULB TEMPERATURE (°F)	TEMP RANGE (°F)	DEG-DAYS COOLING
Atlanta, Ga	92	19	1200
Baltimore, Md	92	17	530
Birmingham, Ala	94	21	1250
Boston, Mass	88	16	0
Charlotte, NC	94	20	750
Chicago, Ill	91	15	175
Cincinnati, Ohio	92	21	400
Cleveland, Ohio	89	22	100
Dallas, Texas	99	20	1260
Denver, Colo	90	28	100
Detroit, Mich	88	20	85
Houston, Texas	94	18	1625
Kansas City, Mo	97	20	580
Los Angeles, Cal	90	20	45
Miami, Fla	90	15	2500
Milwaukee, Wis	87	21	80
Minneapolis, Minn	89	24	100
New Orleans, La	91	16	1675
NY,NY	90	1	150
Philadelphia, Pa	90	21	100
Pittsburgh, Pa	88	19	250
St. Louis, Mo	94	18	550
San Francisco, Cal	77	14	0
Seattle, Wash	79	19	0
Trenton, NJ	90	19	250

Based on the following assumptions the cooling loads in Btu/hr/100 sq ft, for Los Angeles, New York, Minneapolis and Miami were determined by the Carrier 24 hour method[7] to be 7,970; 8,817; 7,408 and 8,640; respectively.

Roof overhang	-	24 in.
Building size	-	1000 sq ft
Window area	-	15 percent of floor area
Construction	-	frame or heavy masonry, pitched roof
Exterior	-	light color

The heat gain from people must be added to the above values. One estimate of treatment plant staff[8] is: 3.8 people for a 1 mgd plant, 28 for 10 mgd and 153 for 100 mgd plants. The system cooling load is 360 Btu/hr/person.[7]

Equations (5-2) and (5-3) can be used to determine the total energy required for cooling if the unit capacity and power input are known. In this report it is assumed that the cooling capacity is equal to the cooling load and that the system coefficient of performance for cooling is 2.5.[9]

Using the cooling load, H, and the data in Table 5-2 and Figure 5-2 building cooling requirements can be estimated for various treatment plant sizes. As an example, the curves shown in Chapter 3, Figure 3-84, were derived from this data for Los Angeles, New York, Minneapolis and Miami. Effects from an average amount of infiltration air are included; however, air changes of 4 to 6 volumes per hour could increase the energy requirements in Figure 3-84 by 50 to 100 percent.

Anaerobic Digestion

Heat is required in the anaerobic digestion process to (1) raise the temperature of the influent sludge to the level of the digester, and (2) compensate for heat losses from the digester through its walls, bottom and cover.

The WPCF Manual of Practice No. 8 contains the following discussion on digestion temperatures.[10]

> *The optimum temperature of sludge digestion in the mesophilic range is about 98°F; in the thermophilic range, about 128°F. Although the optimum sludge-digestion temperature may vary somewhat with local conditions, the temperature generally adopted for sludge digestion falls within the range of 90°F to 95°F.*

The heat required to raise the influent sludge temperature can be calculated from the following relationship:

$$Q = WC\,(T_D - T_S) \qquad (5\text{-}4)$$

Q = heat required, Btu

W = weight of influent sludge, lb

C = specific heat of sludge, 1.0 Btu/lb/°F for 1-10% solids sludge

T_D = temperature in digester, °F

T_S = temperature of influent sludge, °F

The WPCF Manual of Practice No. 8, gives the following criteria for digester heating:[10]

> *Data accumulated from numerous digester installations have made it convenient to use factors for estimation of heat losses from digesters without considering separately the loss through each element of the*

digester. For the normal installation it is assumed that a 1°F drop in temperature occurs for the entire tank contents in 24 hr. A correction factor is applied for outside temperature, depending upon location and special conditions, such as the presence of ground water. For each 1,000 cu ft of contents, this amounts then to 1,000 x 62.5 x 1.0 = 62,500 Btu per day; or $\frac{62,500}{24}$ *= 2,600 Btu per hr. Correction factors for geographical location by which the value of 2,600 Btu per hr is multiplied are as follows:*

Northern United States	*1.0*
Middle United States	*0.5*
Southern United States	*0.3*

The following organic loading rates are used in standard and high rate digestion:

	Loading, lb VS/day/cu ft
Standard rate	0.03 to 0.1
High rate	0.1 to 0.4

Detention time of 30 days are often used for standard rate digestion and 15 to 20 days for high rate digestion.

Digester heat requirements in this report are based on loadings of 0.05 and 0.15 lb VS/day/cu ft. These criteria give the following digester capacities:

Sludge Type	Solids Content (percent)	Total Solids (lb/mil gal)	Volatile Solids (lb/mil gal)	Total** Sludge (lb/mil gal)	Digester Capacity (cu ft/mil gal) Loading (lb VS/day/cu ft) 0.05	0.15
Primary	5	1,155	690	23,100	13,800	4,600
Primary	4.5*	2,096	1,446	46,600	28,900	9,600

*Thickened

**Water and Solids

The total heat required for digestion at 95°F is shown in Figure 5-3 for primary sludge and Figure 5-4 for primary plus waste activated sludge. These heat requirements are based on the above criteria for sludge heating and digester heat loss and 75 percent heat transfer efficiency.

Heat Treatment of Sludge

Requirements for heat conditioning of sludge to improve dewatering and wet oxidation of sludge are discussed in the following heat treatment section of this chapter. Fuel requirements for heat treatment of various sludges are summarized in Table 5-9 and are shown in Figures 3-89 through 3-92.

Lime Recalcination

Recalcining may be accomplished in multiple hearth or fluidized bed furnaces. The energy required is dependent on several factors such as sludge composition, furnace loading operating temperatures and type of furnace. Heat requirements for multiple hearth furnaces are shown in Figures 3-111 and 3-112 and for fluidized bed furnaces in Figure 3-114.

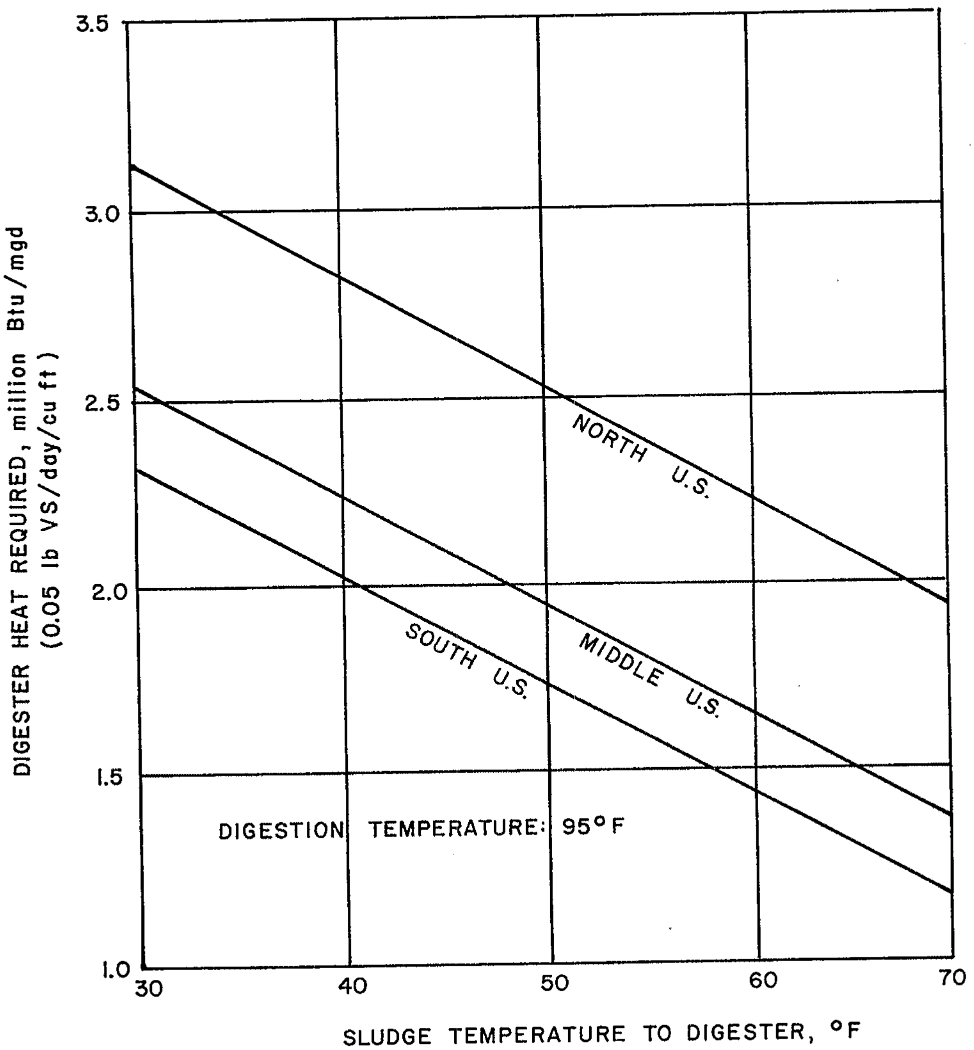
Granular and Powdered Activated Carbon Regeneration

1. Granular Carbon

   The heat required for granular carbon regeneration is shown in Figure 3-67. The heat required for the furnace, afterburner and steam is about 7,600 Btu/lb of carbon regenerated. Furnaces used in carbon regeneration systems can be equipped with waste heat recovery systems.

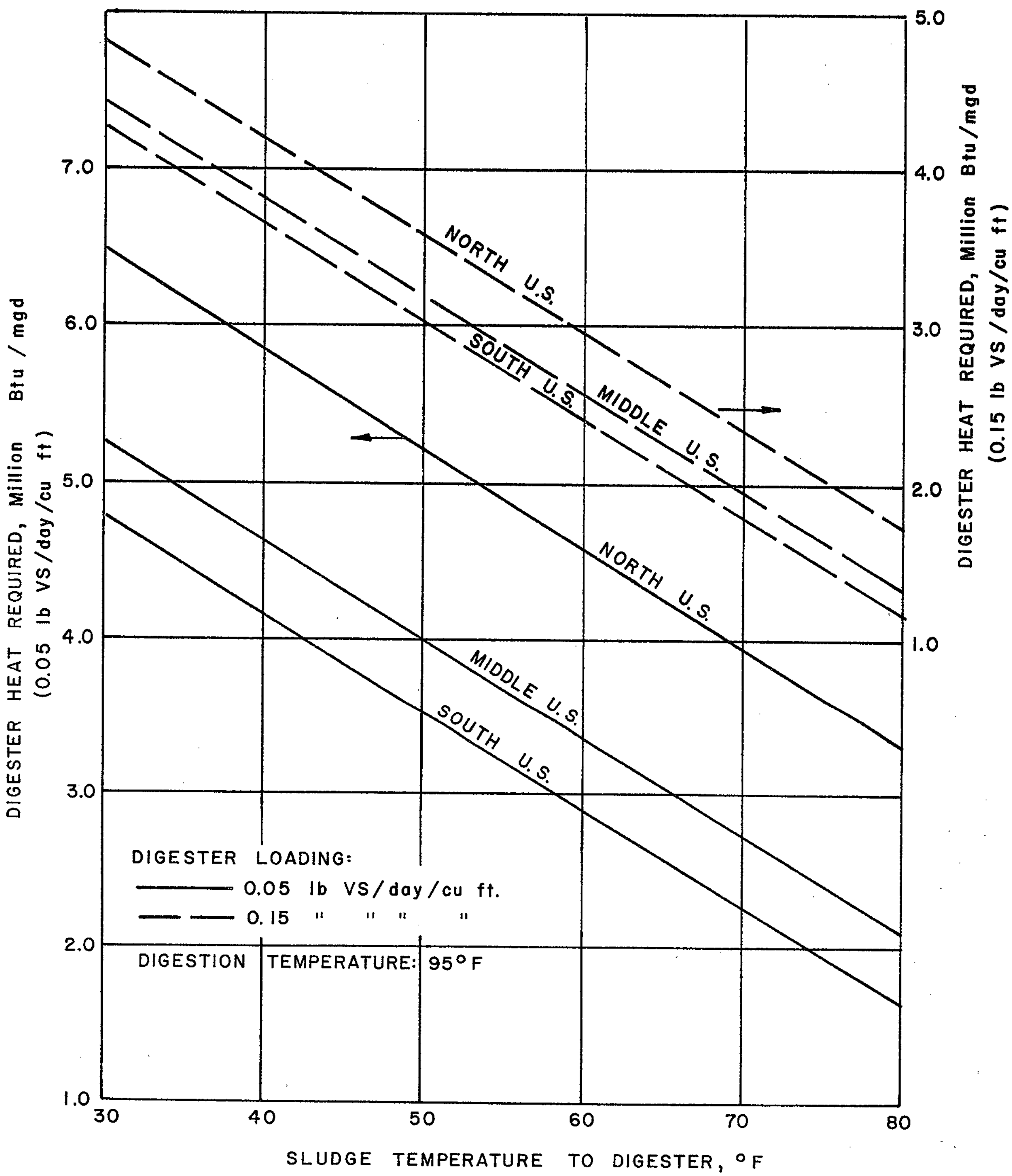
2. Powdered Carbon

   Difficulty with regeneration has been the major factor limiting the use-



ANAEROBIC DIGESTER HEAT REQUIREMENTS
FOR PRIMARY SLUDGE

FIGURE 5-3



ANAEROBIC DIGESTER HEAT REQUIREMENTS FOR PRIMARY PLUS WASTE ACTIVATED SLUDGE

FIGURE 5-4

fulness of powdered activated carbon in the treatment of wastewaters. There are at least three alternate systems of powdered carbon regeneration under development: (1) fluidized bed furnace, (2) wet air oxidation, and (3) transport system. None of these three systems has been used in a full scale municipal wastewater treatment plant. The estimated fuel requirements shown in Figure 5-5 are based on fluidized bed furnace pilot studies and information from manufacturers and must be used with caution.

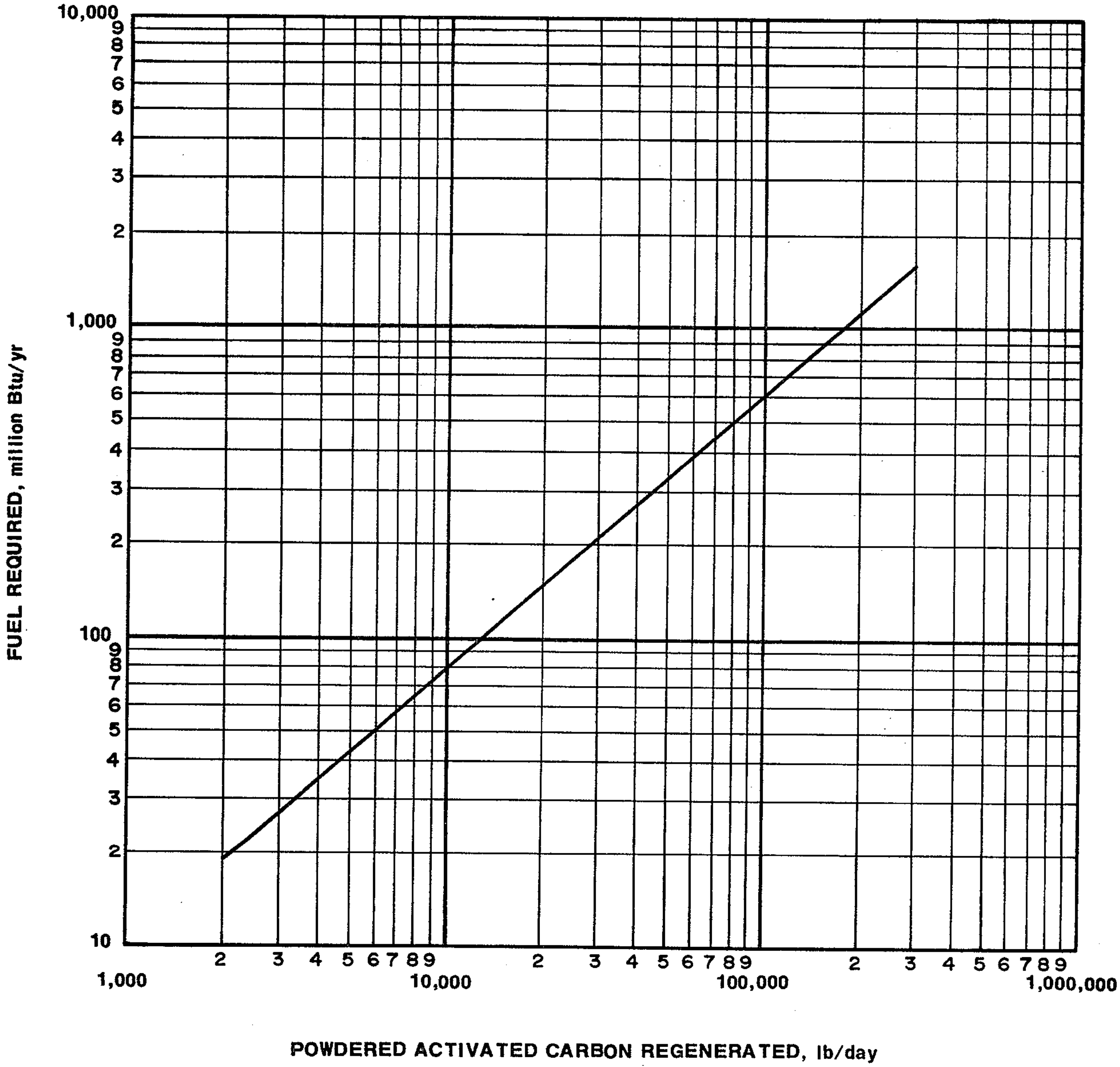
Some estimates indicate that the wet air oxidation regeneration system used in the bio-physical process may be self sustaining except for start-up and shutdown periods. Fuel requirements for the transport regeneration system may be higher than shown in Figure 5-5.

Ion Exchange Regenerant Renewal

The regeneration of clinoptilolite beds, used for the removal of ammonium ions from wastewater, produces a regenerant solution with a high concentration of ammonia. Ammonium can be removed from the regenerant solution and the regenerant reused. Energy requirements for regenerant renewal by air stripping are shown in Figure 3-70; requirements for the steam stripping method are shown in Figure 3-71.

UTILIZATION OF ANAEROBIC DIGESTER GAS

Digester gas can be used for on-site generation of electricity and/or for any in-plant purpose requiring fuel. Digester gas could also be used off-site in a natural gas supply system. Off-site use of digester gas will usually require treatment to remove trace impurities such as hydrogen sulfide and moisture; in most cases the heat value of the digester gas must



HEAT REQUIREMENTS
POWDERED ACTIVATED CARBON REGENERATION

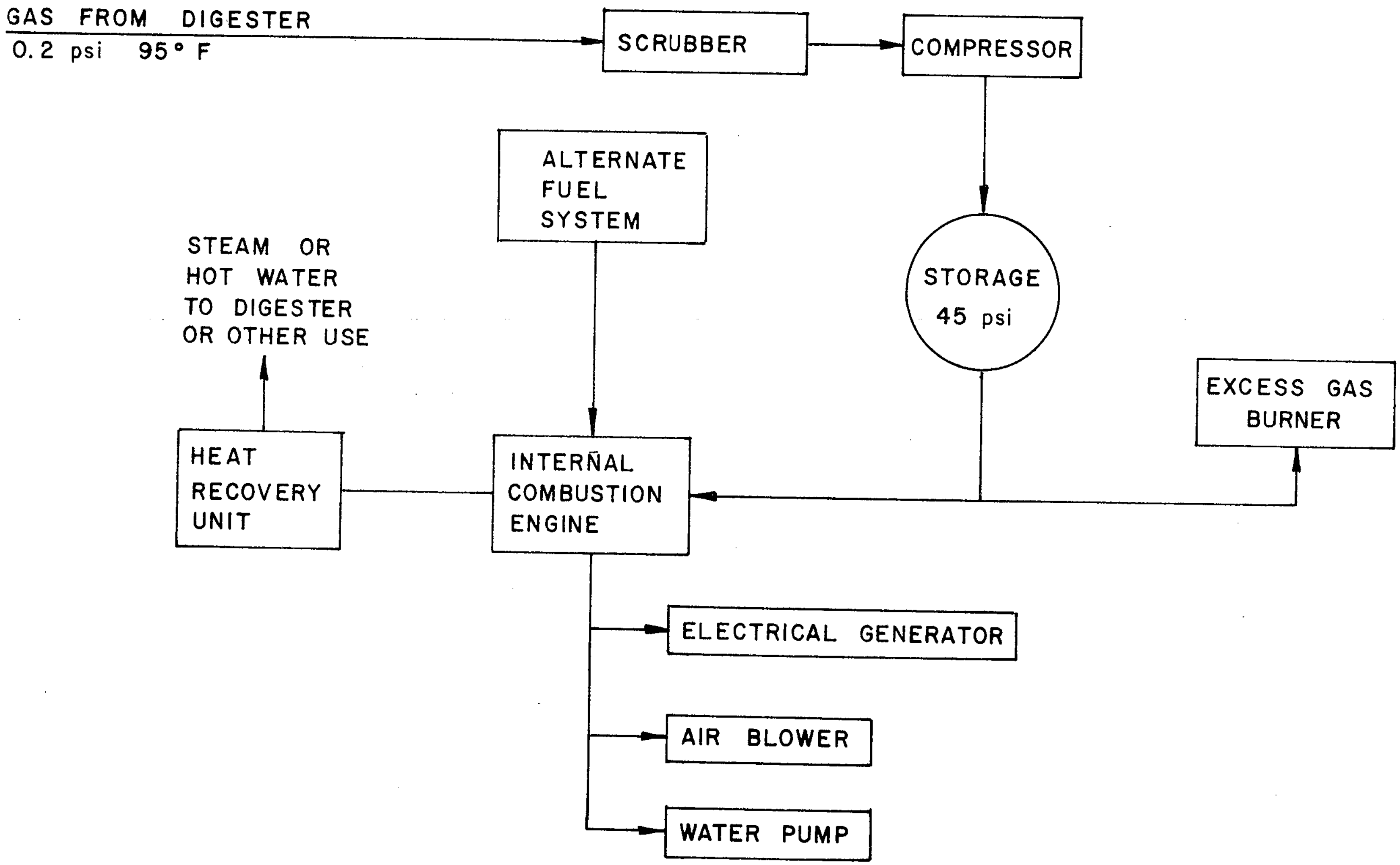
FIGURE 5-5

be increased by removal of carbon dioxide before it could be used in a natural gas system. In-plant energy requirements for primary and secondary treatment always exceed the energy available from digester gas; therefore, the remainder of this section is devoted to on-site use as fuel in internal combustion (IC) engines. A schematic of a typical system to utilize digester gas in an IC engine is shown in Figure 5-6. As indicated in this figure the engine could be coupled to a generator, blower or pump.

Gas produced by anaerobic digestion is about two-thirds methane and one-third carbon dioxide with relatively small amounts of water, hydrogen sulfide, ammonia and other gases also present. The heat value of the gas varies from one plant to another but is typically about 600 Btu/scf. In some installations the gas is used directly from the digester while in others water and hydrogen sulfide are removed to protect engines and other equipment.

Gas Production

One of the most important design criterion that must be selected is the volume of gas produced per unit of organic material destroyed in the digester. An earlier EPA report on energy[4] used 17.5 scf gas produced per lb of VS destroyed in the digester (This was based largely on data from treatment plants in the City of Cincinnati). The Water Pollution Control Federation manual on sewage treatment plant design[10] gives 15 scf/lb VS destroyed. Data collected from operating plants during this study indicates that 17 to 18 scf/lb VS destroyed is not routinely obtained even at some well operated facilities and much lower values are reported in some presumably well operated plants. Therefore, 15 scf/lb VS destroyed is recommended for sizing typical digester gas utilization systems.



ANAEROBIC DIGESTER GAS UTILIZATION SYSTEM

FIGURE 5-6

The amount of sludge produced in a wastewater treatment plant, and the VS content of the sludge, varies with the influent suspended solids concentration, the BOD and type and efficiency of the biological treatment process. The following sludge quantities used in Chapter 3 are based on a review of data from several sources and are considered representative of typical primary and activated sludge plants:

	Sludge Solids (lb/mil gal)		
Sludge Type	Total	Volatile	
Primary	1,151	690	(60%)
Waste Activated	945	756	(80%)
TOTAL	2,096	1,446	

A review of the literature and data collected from operating plants indicates that about 50 percent of the volatile solids are destroyed by anaerobic digestion and that the gas produced has a heat value of about 600 Btu/scf.

These criteria give the following estimates for gas and heat available from anaerobic digestion:

	Primary Sludge	Waste Activated Sludge	Total
Gas Produced, scf/ mil gal	5,175	5,670	10,845
Heat Available, Btu/ mil gal	3,105,000	3,402,000	6,507,000

For planning purposes, and in the absence of more specific information, it may be assumed that about 6.5 mil Btu are available from gas produced by anaerobic digestion of primary and conventional activated sludge treatment of one million gallons of wastewater.

Gas Utilization

Diesel or gas IC engines can be used to drive electric generators, air blowers or pumps in a wastewater treatment plant.

Diesel engines operate on fuel oil that is ignited entirely by the heat resulting from the compression of the air supplied for combustion. Gas-Diesel engines operate on a combustible gas (anaerobic digester gas in this case) as primary fuel; the ignition of the digester gas is accomplished by the injection of a small amount of pilot fuel oil. Commonly 8 to 10 percent fuel oil is required to operate a dual fuel engine. Dual fuel Diesel engines are equipped to operate on fuel oil only or as a gas-Diesel. Fuel oil is normally used in the alternate fuel system for dual fuel engines in a wastewater treatment plant; however, it is possible to equip this type of engine to also operate on natural gas or propane.

A gas engine is an IC engine that operates on a combustible gas fuel (anaerobic digester gas in this case) that is ignited by an electric spark. Natural gas or propane could be used as an alternate source of fuel in a gas engine.

There are many variations in engine design, and auxiliary equipment required, for these two basic engine types. The operating speed and turbocharging are basic differences between engines supplied by different manufacturers. These variations in engine types result in equipment cost and operation and maintenance cost variations.

The EPA Report[4] assumes that work can be produced by an IC engine operating on digester gas at the rate of 1 hp-hr per 7000 Btu (since 1 hp-hr = 2547 Btu, the assumed efficiency is 36.4 percent). The efficiency of engines varies depending on the basic engine design and method of operation. In general, low speed, turbo-charged or dual fuel engines require less fuel per hp-hr than higher speed naturally aspirated engines. However, capital costs are greater for the more efficient engines. Fuel required at an IC engine-generator set efficiency of 30 percent is about 11,400 Btu/kwh.

The use of heat recovery equipment will increase the overall efficiency. Heat recovery from IC engines has been used successfully for many years particularly with large slow speed engines. Waste heat that is recovered is most often used for digester and/or space heating. The waste heat could be used for any application requiring hot water or low pressure steam.

Typical heat recovery rates in percent of fuel supplied to the engine are: jacket water, 18 to 20 percent; exhaust, 10 to 13 percent; combination of both jacket water and exhaust heat recovery, 20 to 33 percent. This recovered heat added to the 30 to 37 percent efficiency of the engine results in a total thermal efficiency ranging between 50 and 70 percent.

One generally used method of recovering jacket water heat is through ebullient cooling, that is, raising the jacket water temperature to just above the boiling point (215^0 to 220^{0}F) and collecting the steam in an external separator. The low pressure steam thus produced may be used for digester heating, sludge drying, building heating or other purposes. Exhaust heat is typically recovered by use of combination exhaust silencer and heat recovery boilers. In some installations the jacket water and exhaust heat are recovered in a single combined unit.

Table 5-3 is a summary of gas, heat and power available for various size treatment plants based on the following criteria:

TABLE 5-3

ANAEROBIC DIGESTER GAS PRODUCTION AND USE

(1) Plant Capacity (mgd)	(2) Total Dry Solids to Digester (lb/day)	(3) Volatile Solids Destroyed (lb/day)	(4) Gas Produced (scf/day)	(5) Heat Available (mil Btu/day)	(6) Power Available From IC Engines (hp)	(7) Power Available From Engine-Generator set (kw)	(8) Heat Recovered From IC Engine (mil Btu/day)
1	2,096	723	10,845	6.5	38	24 *	1.62
5	10,480	3,615	54,225	32.5	190	120 *	8.12
10	20,960	7,230	108,450	5.0	380	240	16.25
25	52,400	18,075	271,125	162.5	950	600	40.62
50	104,800	36,150	542,250	325.0	1,900	1,200	81.25
75	157,200	54,225	813,375	487.5	2,850	1,800	121.87
100	209,600	72,300	1,084,500	650.0	3,800	2,400	162.50

Column (2) Primary and conventional activated sludge treatment

(3) Primary sludge solids 70% volatile, WAS 80% volatile; 50% volatiles destroyed

(4) 15 scf per lb VS destroyed

(5) Net heat = 600 Btu/scf (9,000 Btu/lb VS destroyed)

(6) Efficiency = 36.4%; 7000 Btu/hp-hr

(7) Efficiency = 30%; 11,400 Btu/kw-hr

(8) 25% recovery

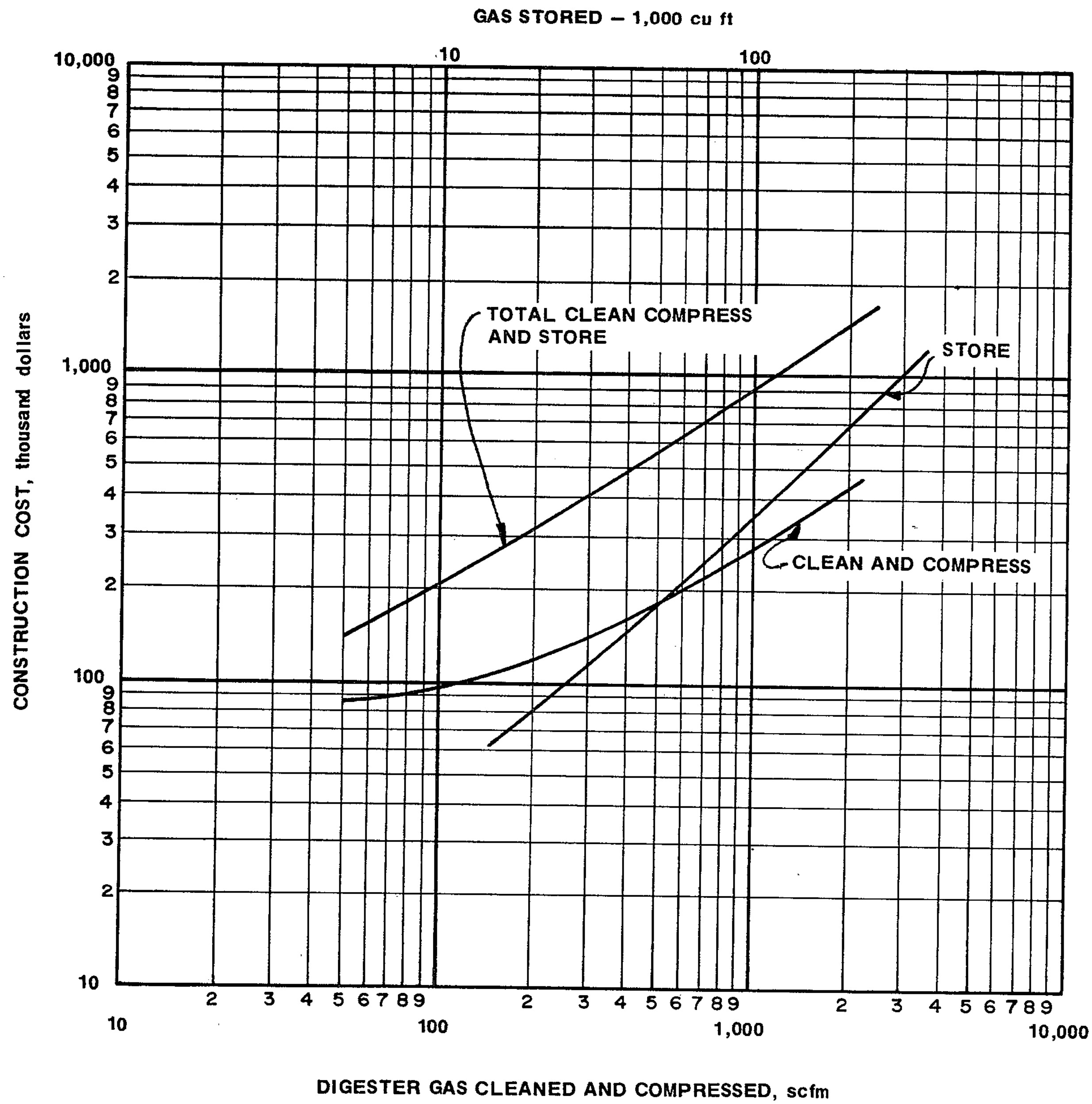
* Commercial equipment is not commonly available in these sizes

1. Total dry solids to digester = 2,096 lb/mil gal and VS = 1,446 lb/mil gal from primary and conventional activated sludge treatment.
2. Fifty percent of VS destroyed by digestion.
3. Digester gas produced = 15 scf/lb VS destroyed.
4. Heat available = 600 Btu/scf gas or 9,000 Btu/lb VS destroyed.
5. IC engine efficiency = 36.4 percent (7,000 Btu/hp-hr)
6. Engine-generator efficiency = 30 percent (11,400 Btu/hp-hr)

Cost Estimates-Digester Gas Utilization

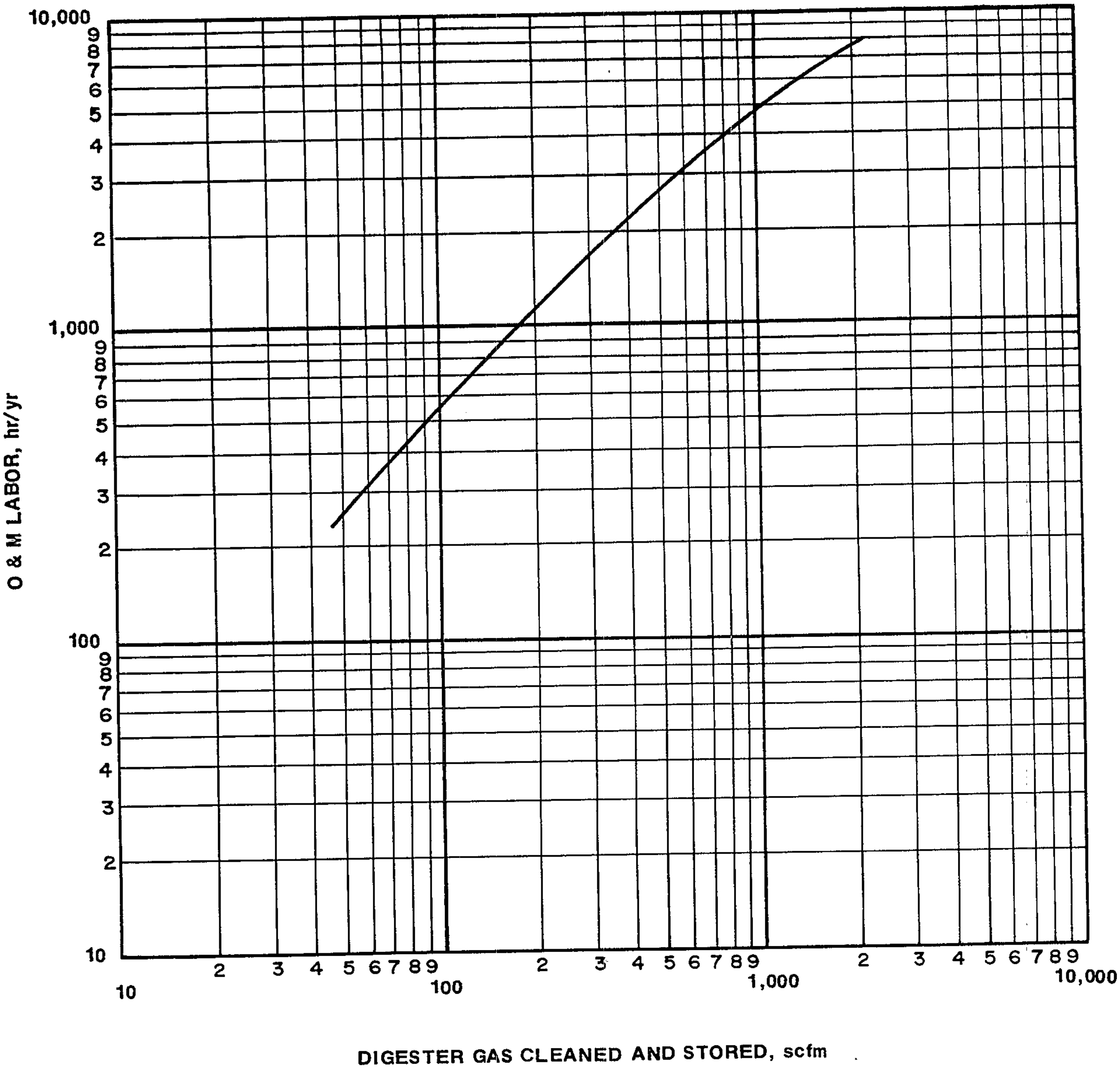
Construction costs in this section include all elements of construction cost a contract bidder would normally encounter in furnishing a complete facility. Construction costs include materials, labor, equipment, electrical, normal excavation and contractor overhead and profit. Construction costs do not include costs for land, engineering, legal, fiscal and administrative services or interest during construction. Equipment costs were obtained through quotes from various suppliers and manufacturers. Construction costs include allowances for the following: overhead and profit (25 percent), equipment installation (35 percent), electrical (15 percent), piping and miscellaneous items (15 percent) and, other site work and contingency (15 percent). Operating and maintenance is broken down into three categories: (1) operating and maintenance labor in hr/yr, (2) materials and supplies in $1,000/yr, and (3) energy in kwh/yr or Btu/yr.

Estimated construction costs to clean and store digester gas are shown in Figure 5-7; operation and maintenance data are shown in Figures 5-8 5-9, and 5-10. Hydrogen sulfide (H_2S) can be removed from digester gas by treatment in a chemical scrubbing system using sodium hypochlorite or



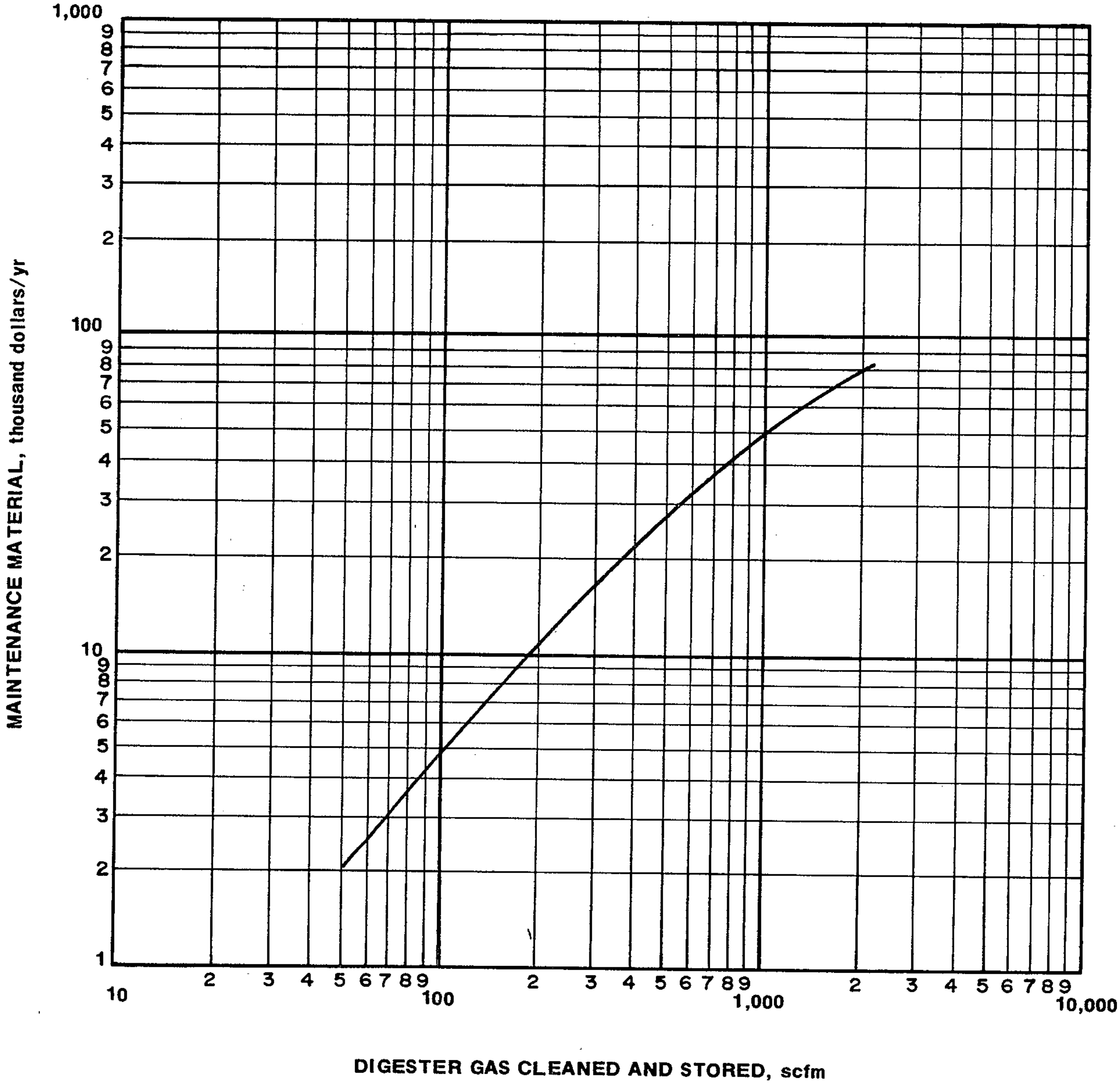
DIGESTER GAS CLEANING AND STORAGE CONSTRUCTION COSTS

FIGURE 5-7



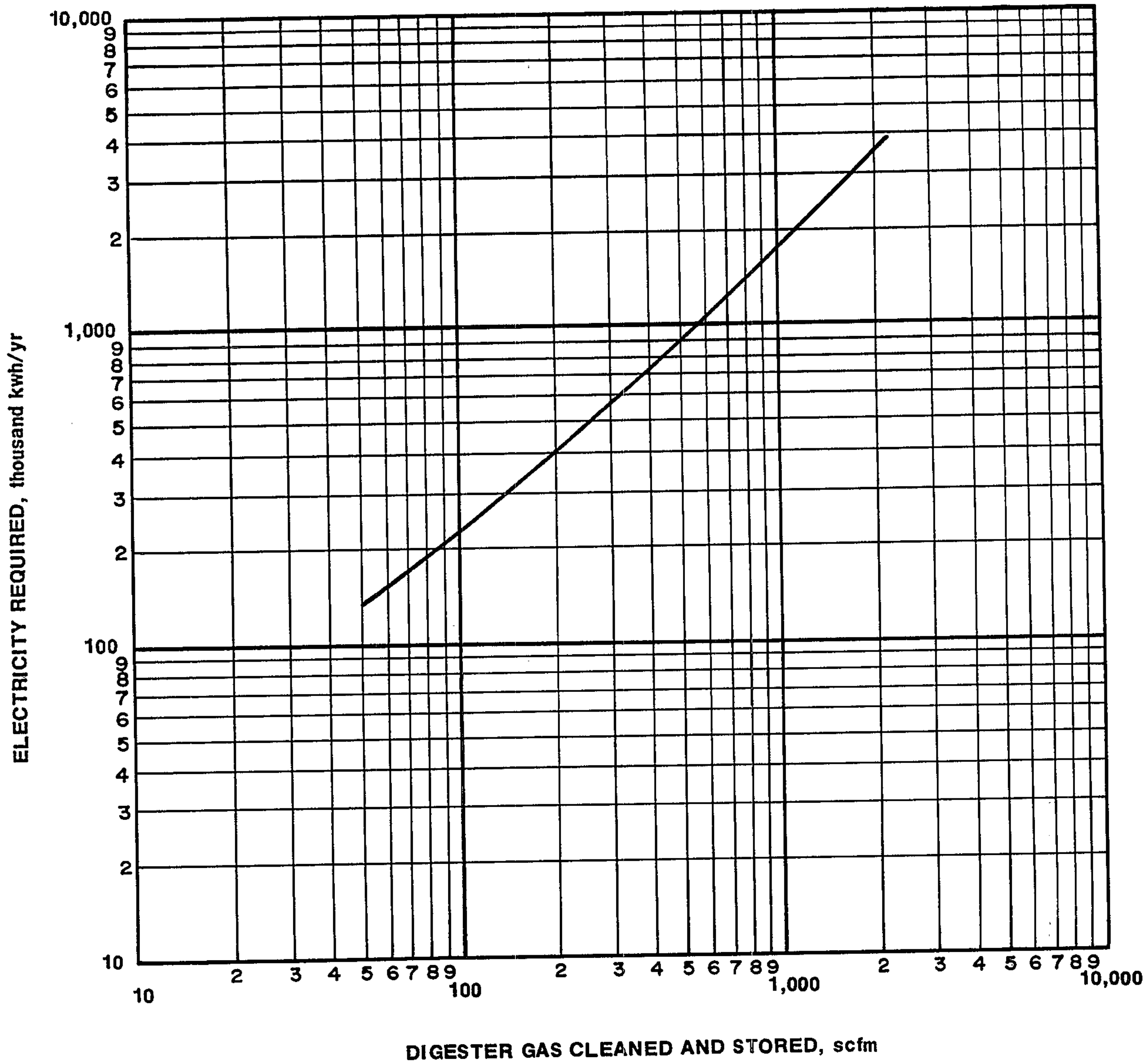
DIGESTER GAS CLEANING AND STORAGE
O & M LABOR REQUIREMENTS

FIGURE 5-8



DIGESTER GAS CLEANING AND STORAGE
MAINTENANCE MATERIAL COSTS

FIGURE 5-9



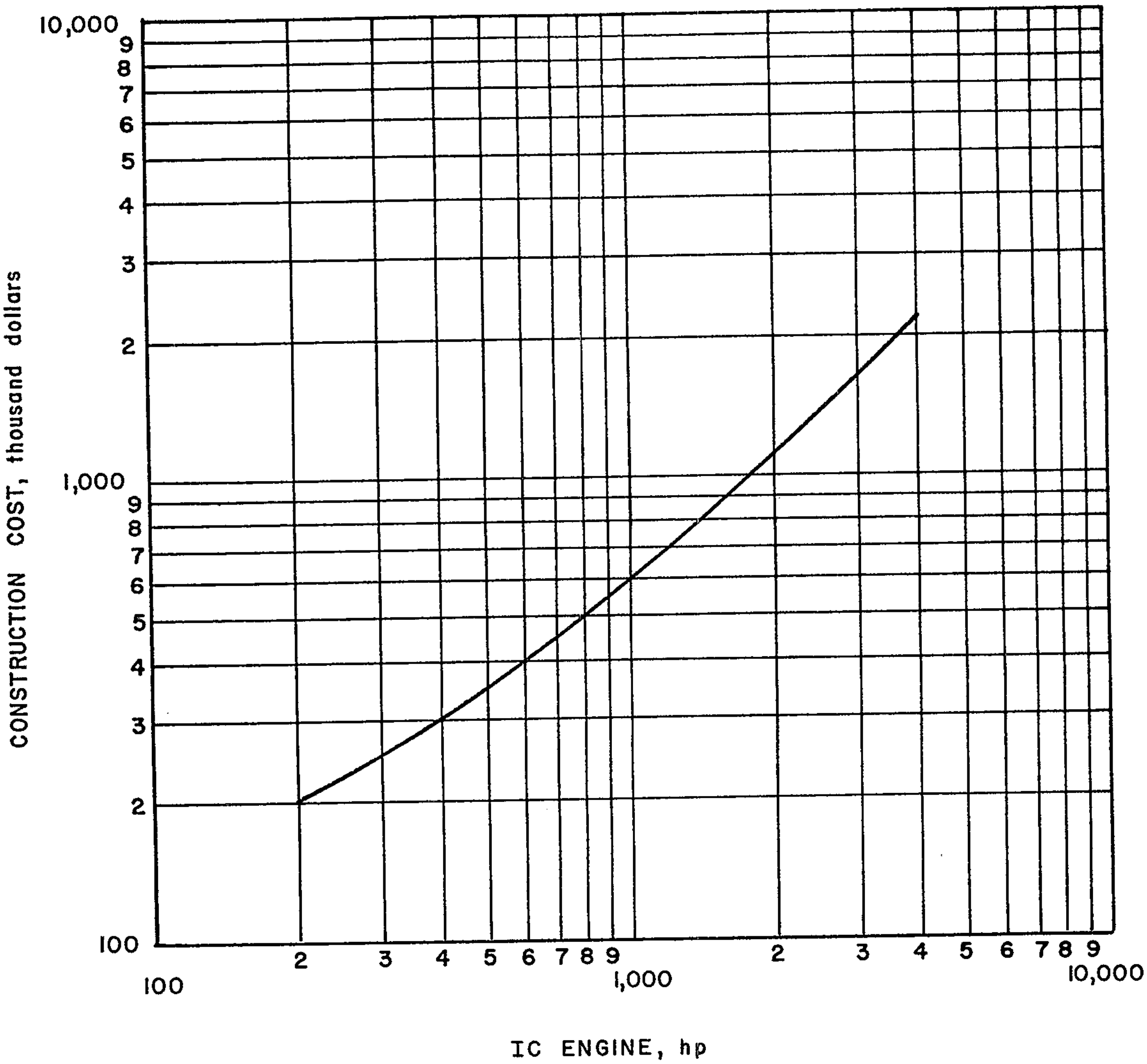
DIGESTER GAS CLEANING AND STORAGE
ENERGY REQUIREMENTS

FIGURE 5-10

other oxidizing agents. Construction costs for scrubbing with NaOCl in a packed tower include on-site hypochlorite generation. Operating and maintenace costs for this type of scrubbing system assume the removal of 1,000 ppm H_2S from the digester gas. It is possible to use activated carbon for H_2S removal but the carbon must be regenerated with steam. Chemical scrubbing systems appear to be more economical and simpler to operate. It may be possible to use other chemicals, or other sources of hypochlorite, to furnish less expensive scrubbing systems than shown herein. Iron sponge scrubbers have been installed in some treatment plants. Construction costs for cleaning and storing digester gas are greatly influenced by the storage capacity provided. The storage capacity used in these estimates is based on one sphere per plant.

Estimated construction costs for 600 rpm IC engines equipped with heat recovery and alternate fuel systems are shown in Figure 5-11; operation and maintenance estimates are shown in Figures 5-12, 5-13 and 5-14. These cost curves include data for both dual fuel and gas engines. Operation and maintenance costs are greatly affected by the alternate fuel consumed. Propane alternate fuel systems are more costly than fuel oil systems; however, gas engines that would require propane are less costly than dual fuel engines that require fuel oil. Dual fuel engines require about 10 percent fuel oil on an average annual basis. Gas engines could operate without using any alternate fuel. However, for these estimates, it is assumed that 10 percent propane would be consumed. Propane would have to be used (or at least paid for) to obtain contracts for a firm supply.

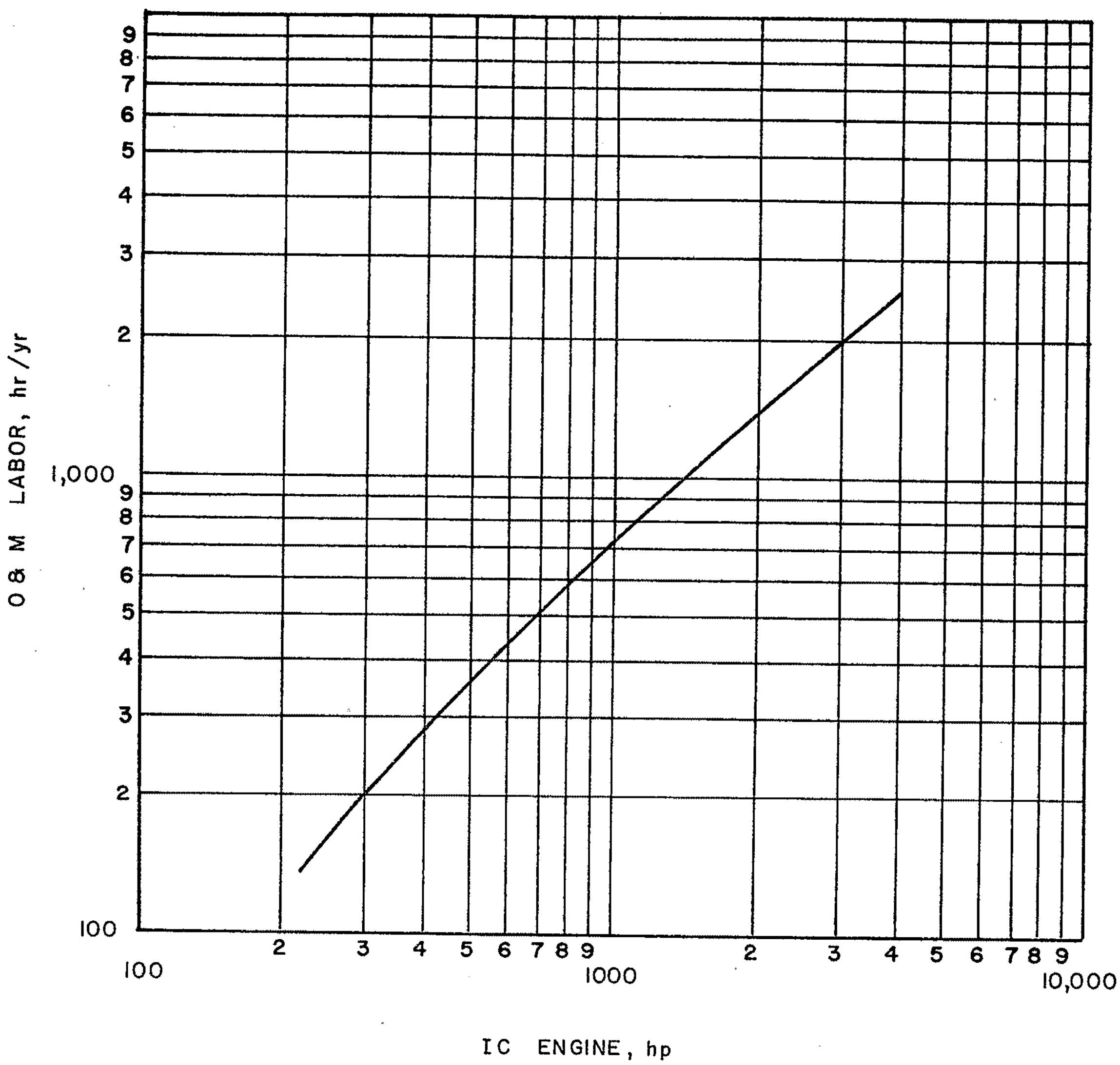
Construction costs for complete systems to generate electricity with digester gas are shown in Figure 5-15; operation and maintenance data are shown in Figures 5-16, 5-17, and 5-18. These costs are for a system as shown in Figure 5-6.



INTERNAL COMBUSTION ENGINE
CONSTRUCTION COSTS

600 rpm engine with heat
recovery and alternate fuel system

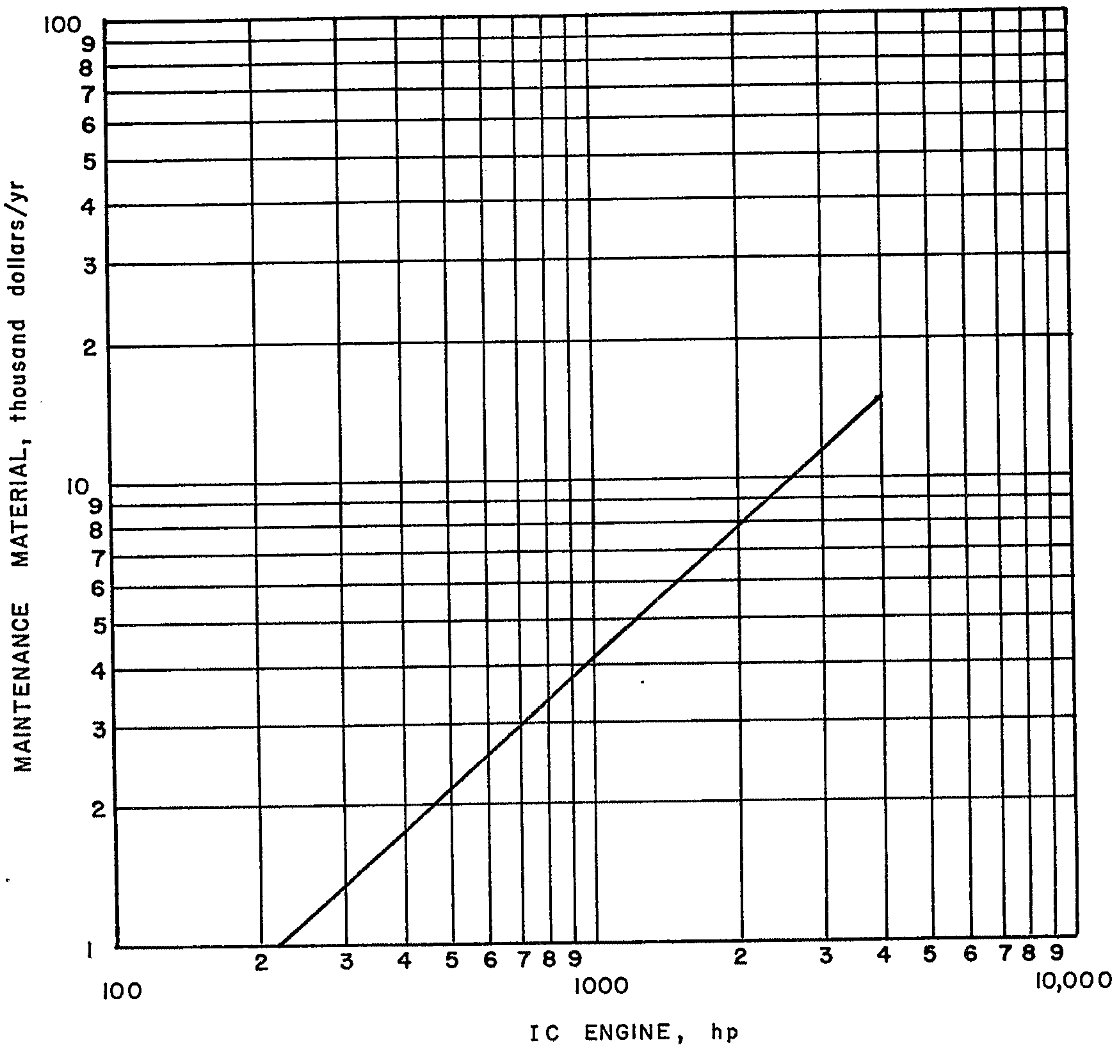
FIGURE 5-11



INTERNAL COMBUSTION ENGINE
O & M LABOR REQUIREMENTS

600 rpm engine with heat
recovery and alternate fuel system

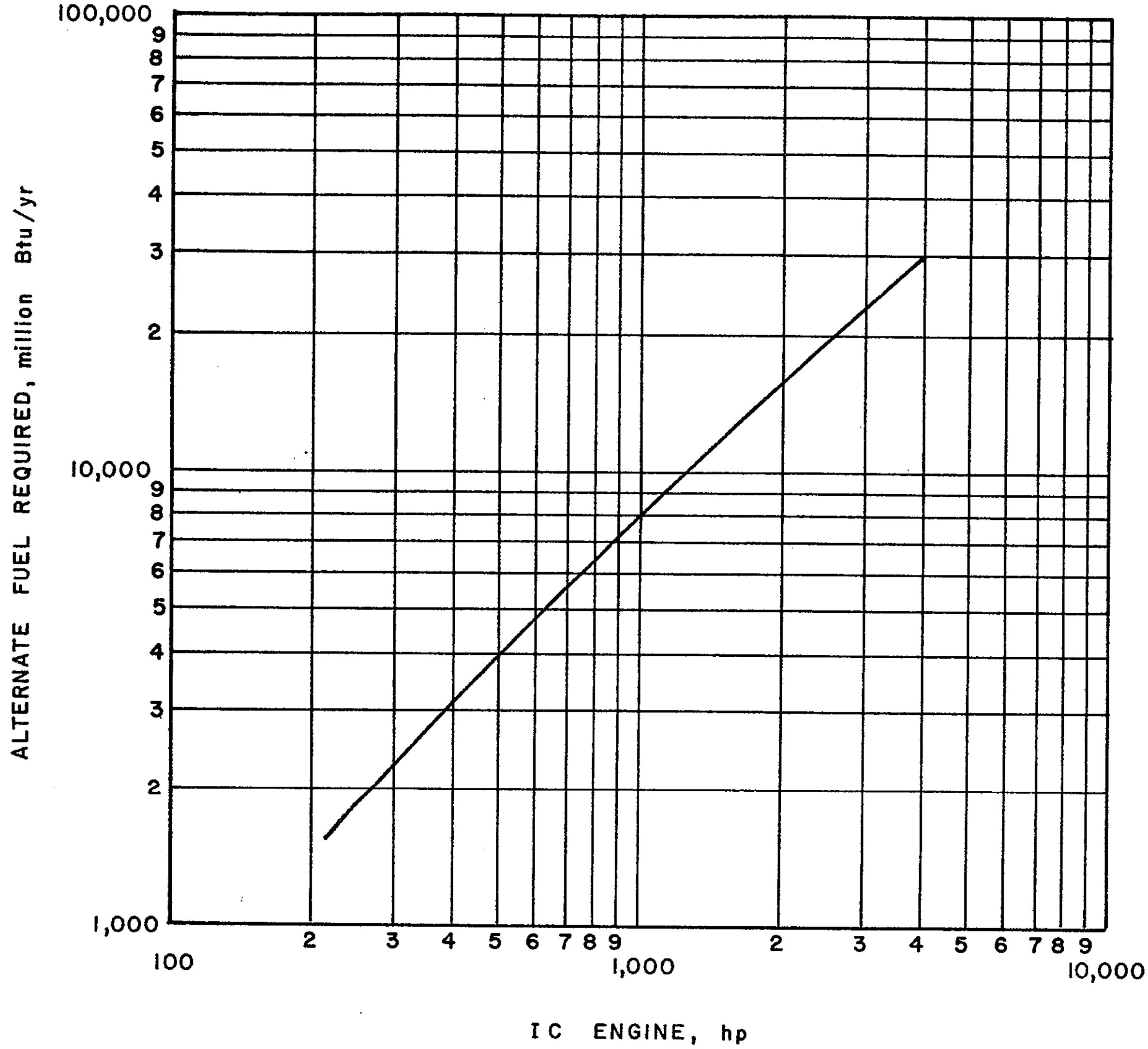
FIGURE 5-12



INTERNAL COMBUSTION ENGINE
MAINTENANCE MATERIAL COSTS

600 rpm engine with heat
recovery and alternate fuel system

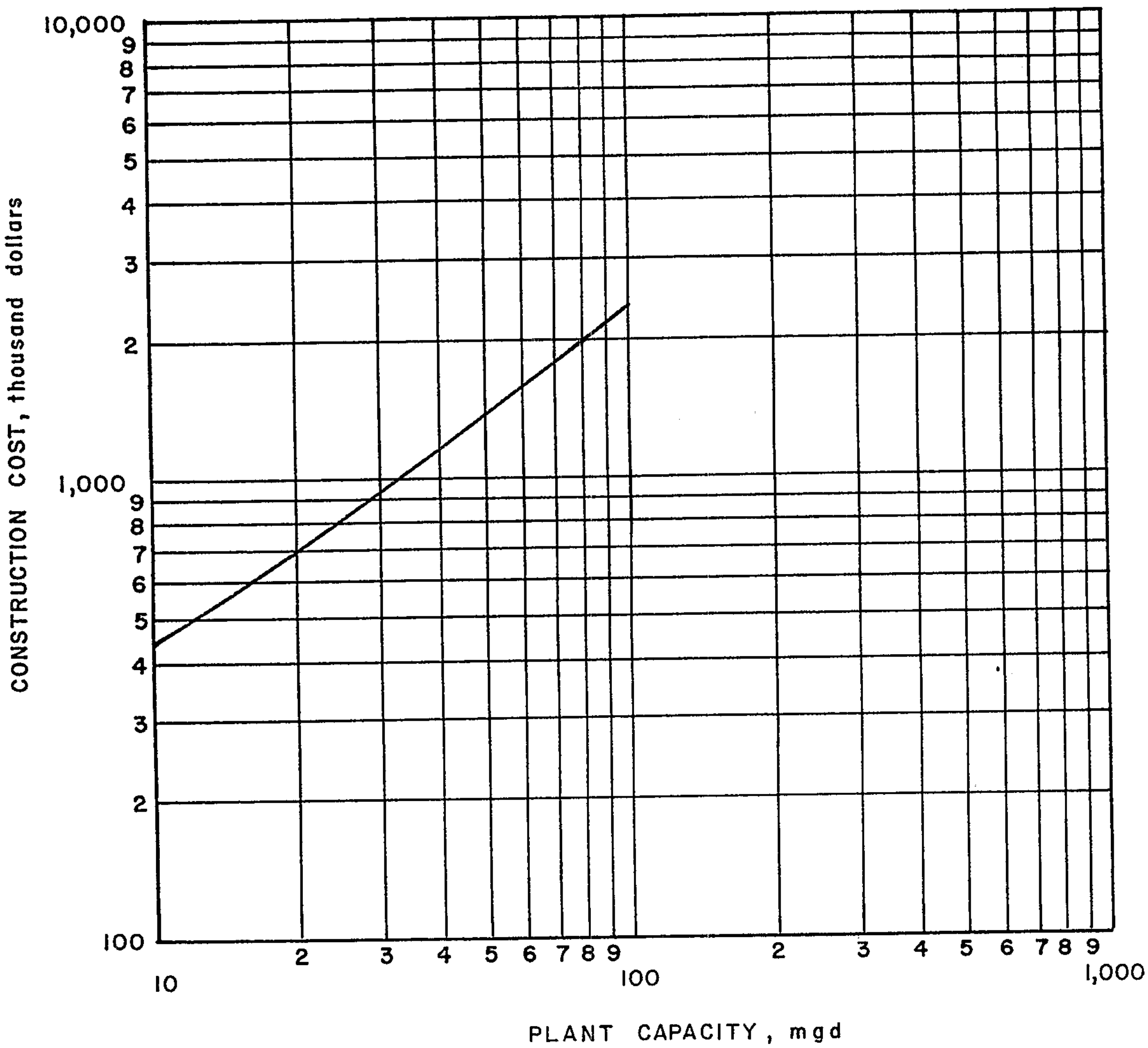
FIGURE 5-13



INTERNAL COMBUSTION ENGINE
ALTERNATE FUEL REQUIREMENTS

600 rpm engine with heat
recovery and alternate fuel system

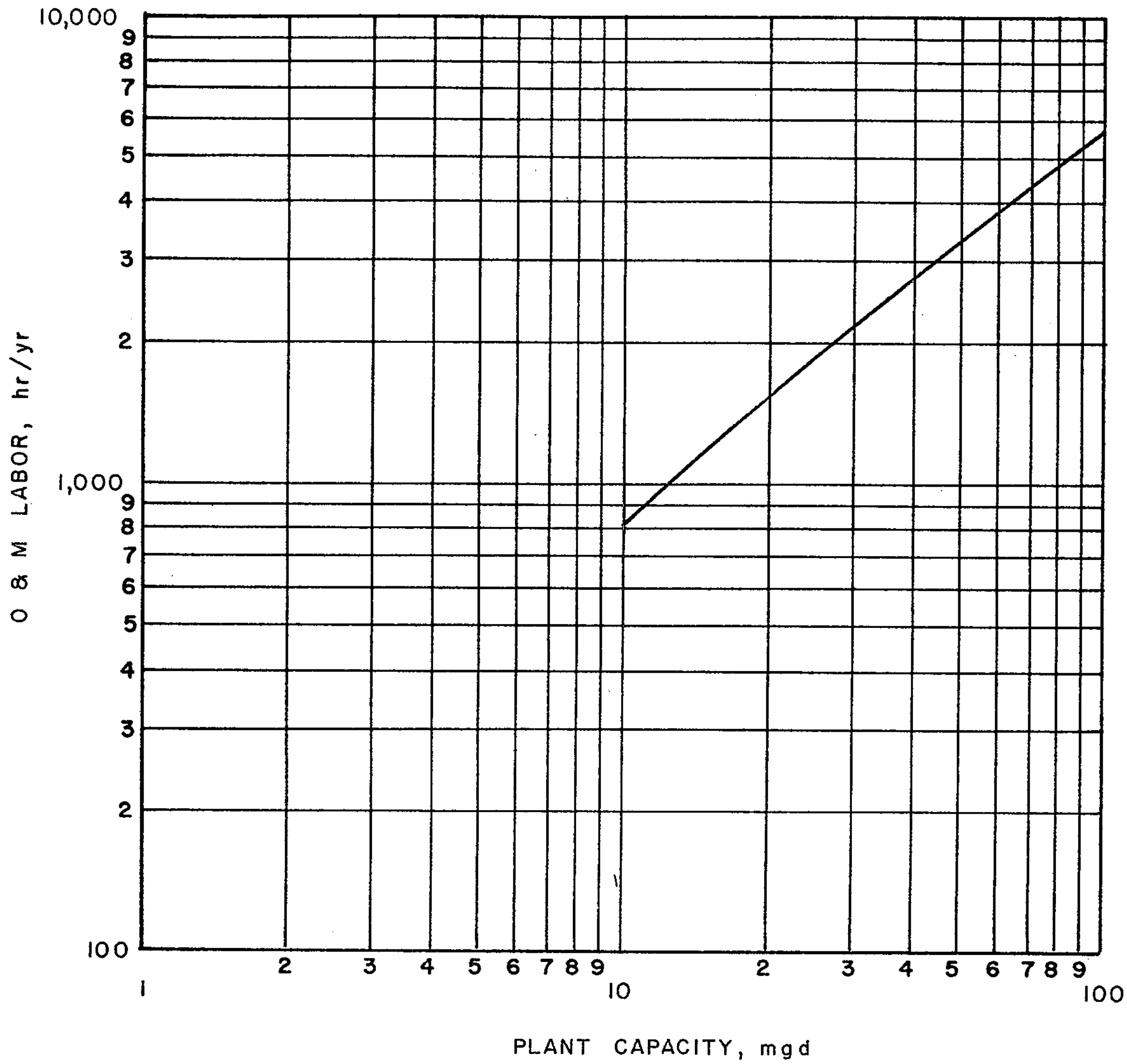
FIGURE 5-14



DIGESTER GAS UTILIZATION SYSTEM
CONSTRUCTION COSTS

Complete electricity generation system
as shown in Figure 5-6

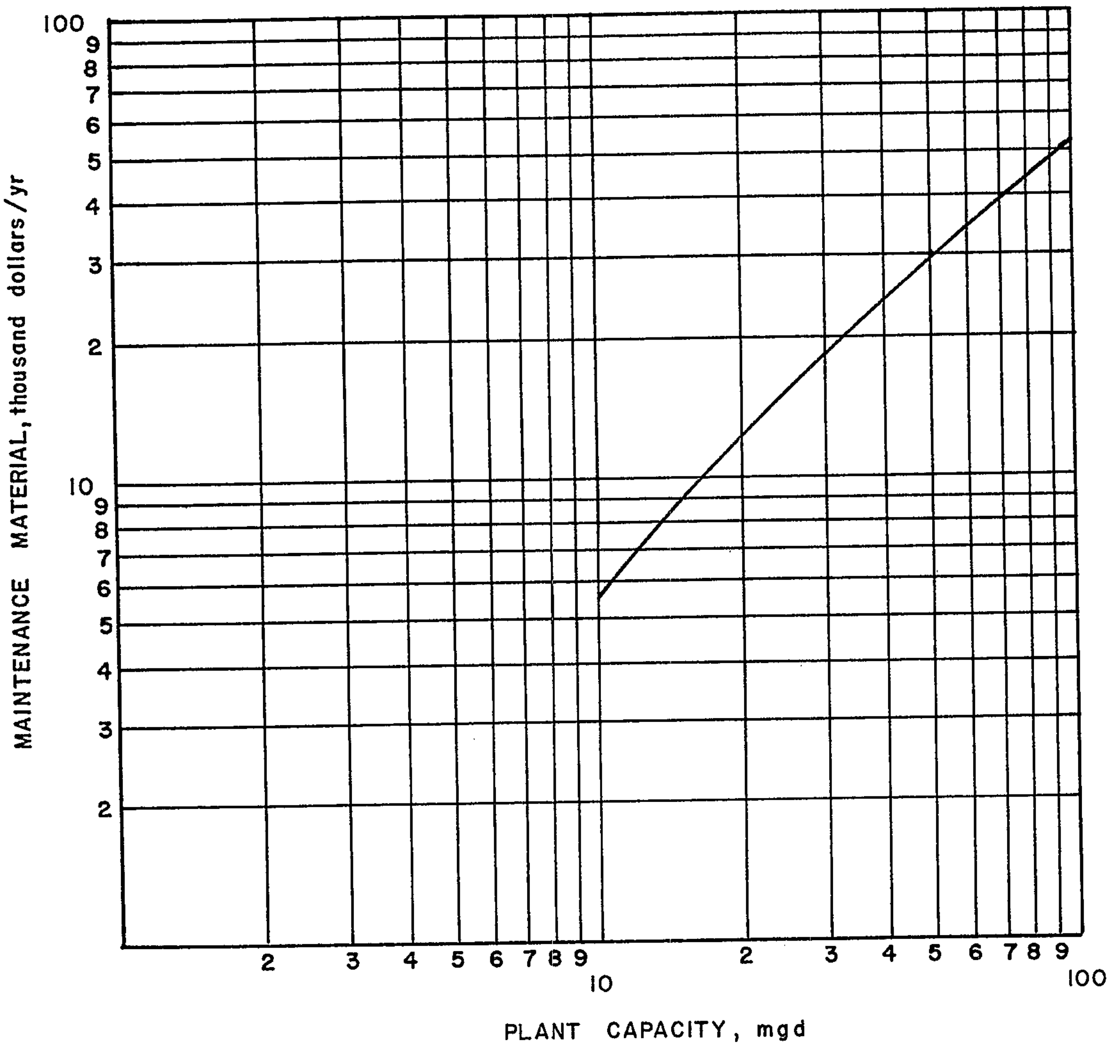
FIGURE 5-15



DIGESTER GAS UTILIZATION SYSTEM
O & M LABOR REQUIREMENTS

Complete system for electricity generation as shown in Figure 5-6

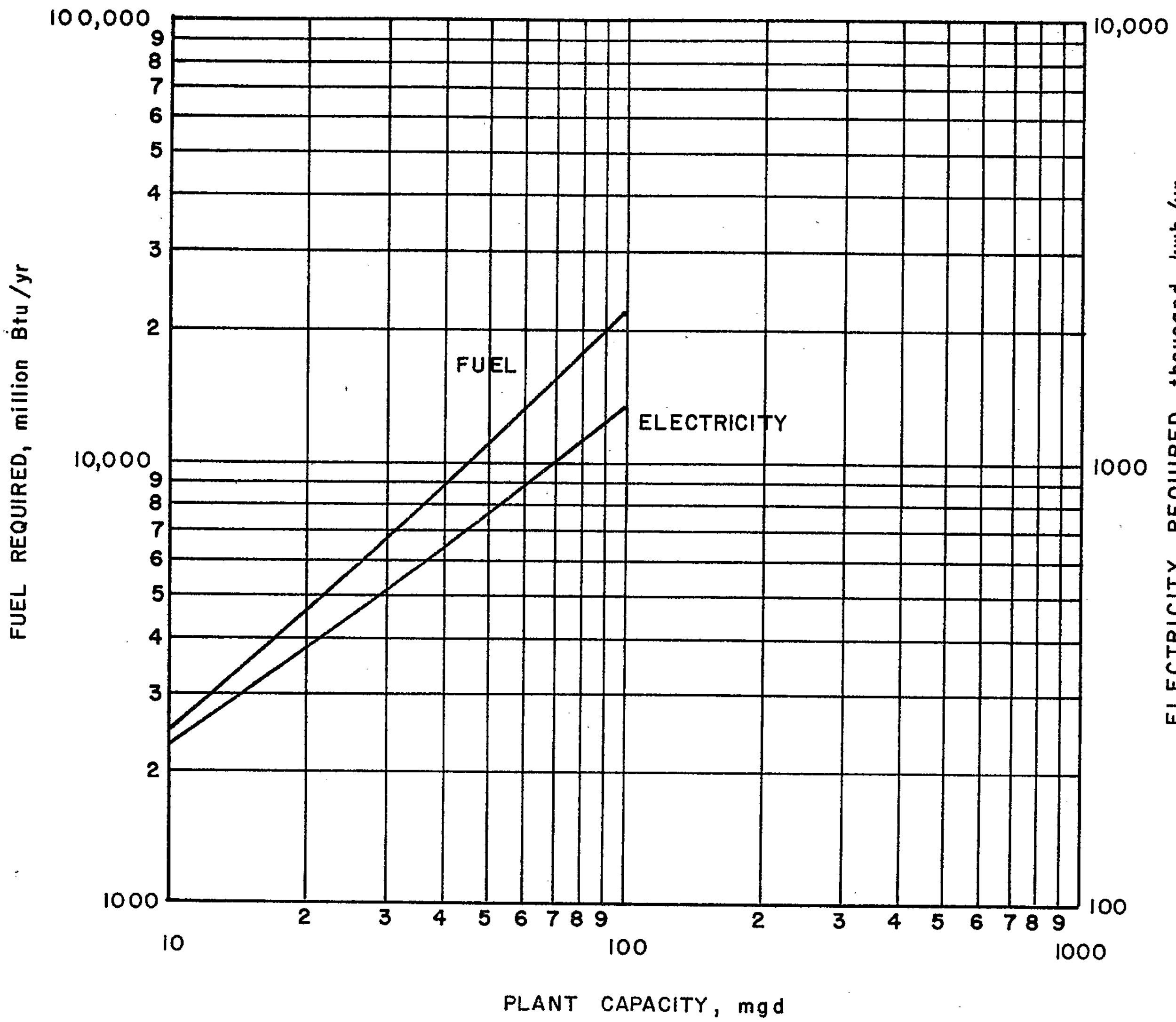
FIGURE 5-16



DIGESTER GAS UTILIZATION SYSTEM
MAINTENANCE MATERIAL COSTS

Complete system for electricity generation as shown in Figure 5-6

FIGURE 5-17



DIGESTER GAS UTILIZATION SYSTEM
ENERGY REQUIREMENTS

Complete system for electrical generation
as shown in Figure 5-6

FIGURE 5-18

INCINERATION

Sludge incineration processes involve two steps: drying and combustion. The drying step should not be confused with preliminary dewatering. Dewatering, usually by mechanical means, precedes the incineration process in most systems. The drying and combustion process consists of raising the temperature of the feed sludge to 212^{0}F, evaporating water from the sludge and increasing the temperature of the dried sludge volatiles to the ignition point. Various types of incineration systems are available including (1) multiple hearth furnace, (2) fluidized bed furnace, (3) cyclonic reactors, and (4) electric furnace.

Multiple Hearth Furnace

A multiple hearth furnace consists of a circular steel shell surrounding a number of solid refractory hearths and a central rotating shaft to which rabble arms are attached. When burning a normal load of sludge a multiple hearth furnace provides three rather distinct zones:

1. Two or more upper hearth on which most of the free moisture is evaporated.

2. Two or more intermediate hearths on which sludge burns at temperatures exceeding 1500^{0}F.

3. A bottom hearth that serves as an ash cooling zone by giving up heat to the cooler incoming air.

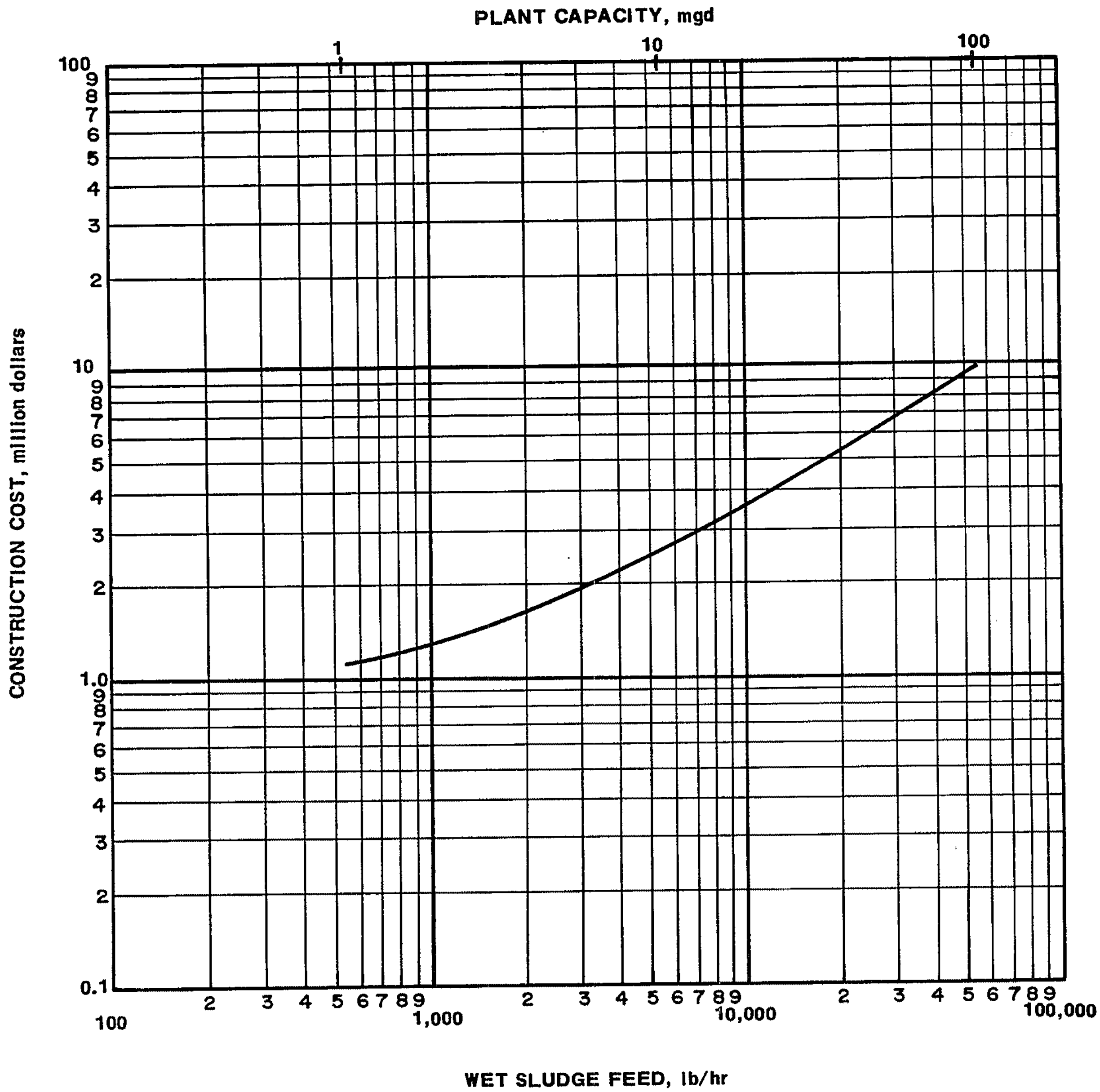
During evaporation of moisture in the first zone the sludge temperature is not raised higher than about 140^{0}F. At this temperature no significant quantity of volatile matter is driven off, and hence no obnoxious odors are produced. Exhaust gases need not be raised to 1400°F in an afterburner to destroy odors. Distillation of volatiles from sludge containing 75 percent moisture does not occur until 80-90 percent of the water has been driven off and, by this time, the sludge is down far enough in the incinerator to encounter gases hot enough to burn the volatiles. Generally, when fuel is required to maintain combustion in a multiple hearth furnace, a gas outlet temperature above 900°F indicates too much fuel is being burned.

Construction cost estimates for multiple hearth incineration are shown in Figure 5-19; operation and maintenace data are shown in Figures 5-20 and 5-21. Energy requirements are given in Figures 3-111, 3-112 and 3-113.

Fluidized Bed Furnace

A fluidized bed furnace is a vertical cylindrical vessel with a grid in the lower section to support a bed of graded silica sand. Dewatered sludge is injected above the grid and combustion air flows upward at a pressure of 3.5 to 5.0 psi, fluidizing the mixture of hot sludge and sand. Sufficient air is used to keep the sand in suspension but not to carry it out of the reactor. The quantity of excess air is maintained at 20 to 25 percent to minimize fuel costs. The heat reservoir provided by the sand bed also enables start-up times to be reduced when the unit is shut down for relatively short periods. An air preheater can be used to reduce fuel costs. However, since air preheaters can represent 15 percent of the fluidized bed furnace cost, a careful economic analysis is required to determine its feasibility for a given situation.

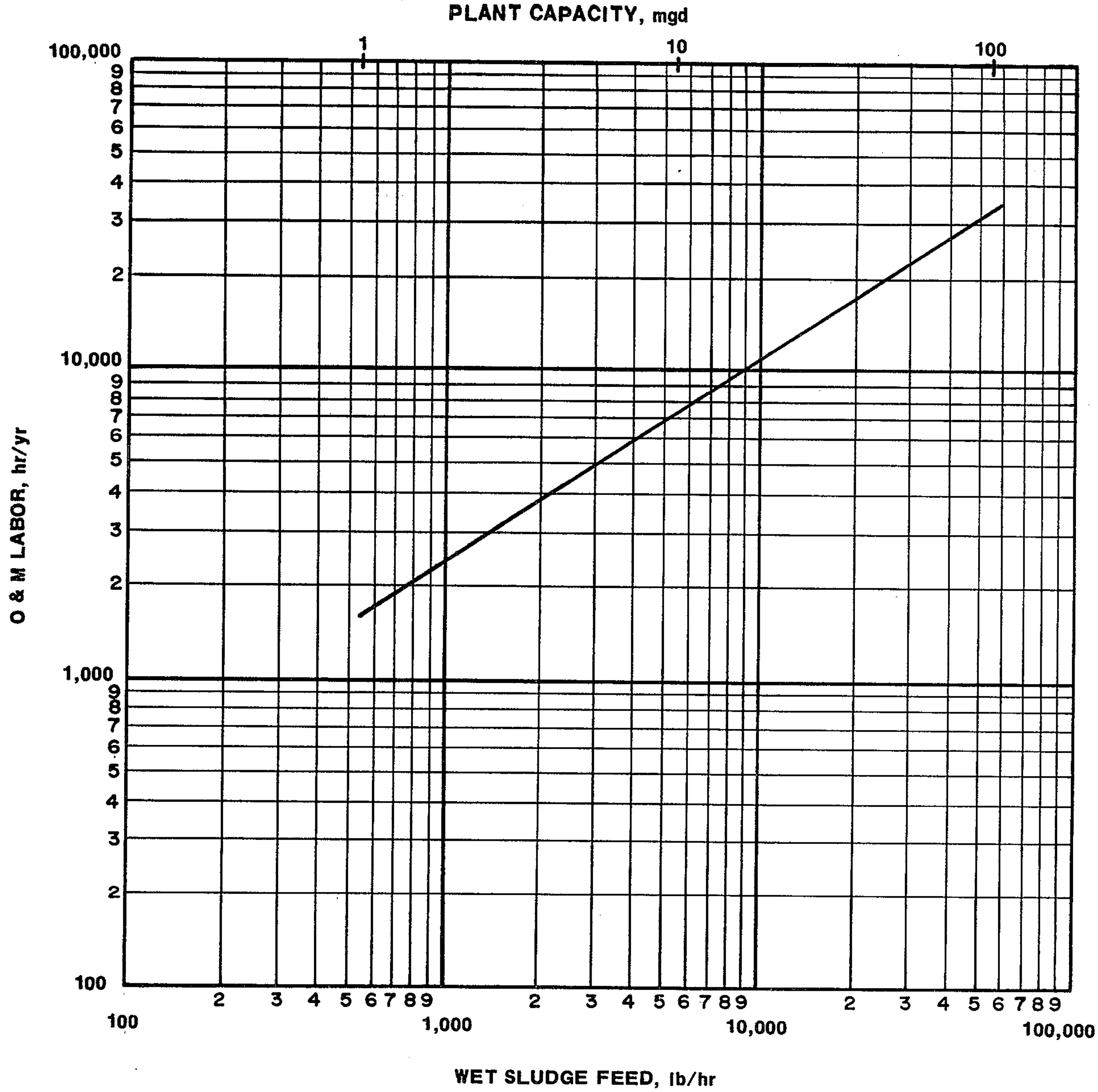
Exhaust gases are usually scrubbed with treatment plant effluent and ash solids are separated from the liquid in a hydrocyclone. An oxygen analyzer in the stack controls air feed and a temperature recorder controls the auxiliary fuel feed rate.



MULTIPLE HEARTH INCINERATION CONSTRUCTION COST

Design and Operation Assumptions:
Loading rate = 6 lb/sq ft/hr
Sludge: Primary + WAS sludge = 16% solids

FIGURE 5–19



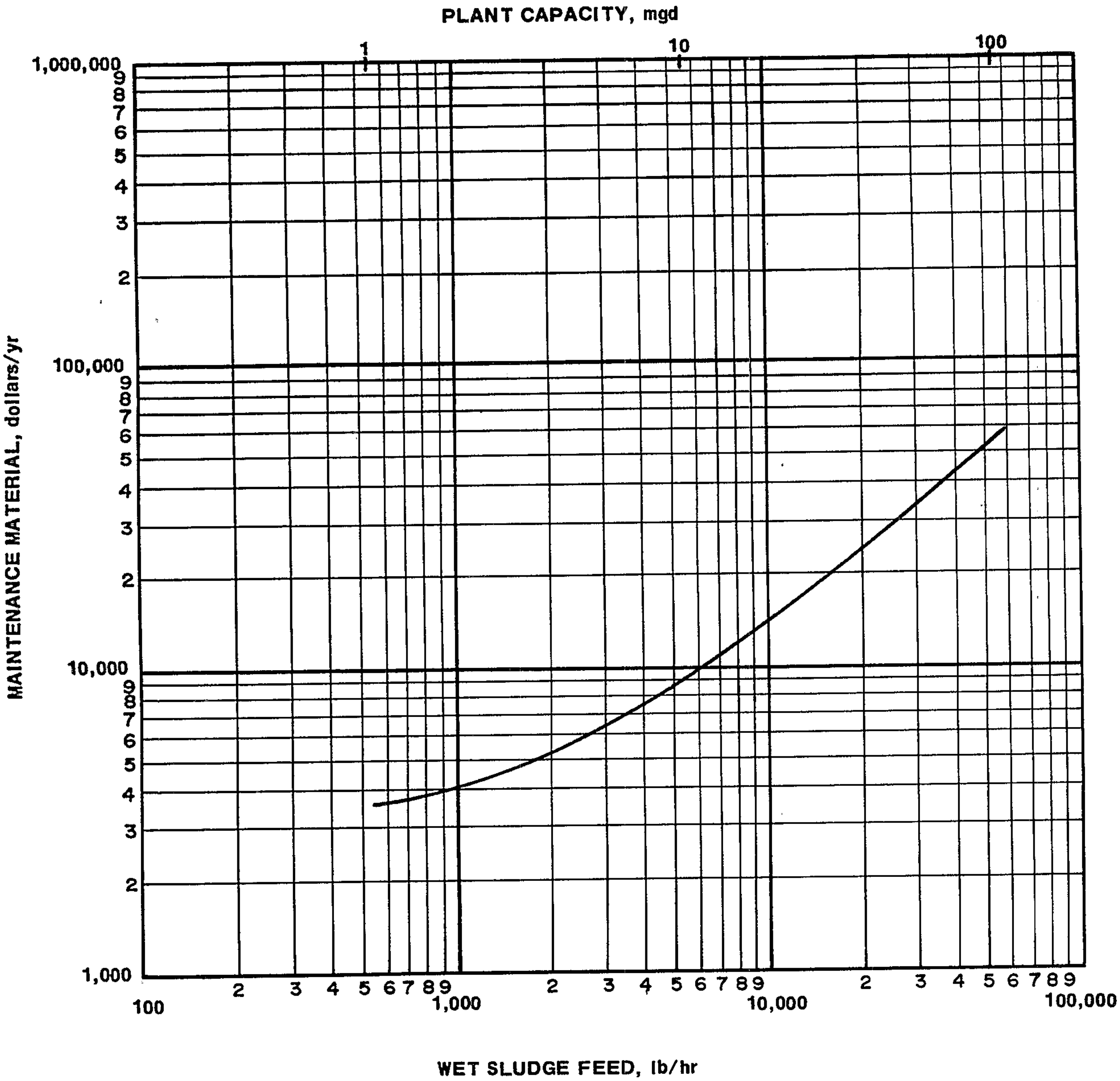
MULTIPLE HEARTH INCINERATION O &M REQUIREMENTS

Design and Operation Assumptions:

Loading rate = 6 lb/sq ft/hr

Sludge: Primary + WAS sludge = 16% solids

FIGURE 5–20



MULTIPLE HEARTH INCINERATION MAINTENANCE MATERIAL COSTS

Design and Operation Assumptions:

Loading rate = 6 lb/sq ft/hr
Sludge: Primary + WAS sludge = 16% solids

FIGURE 5–21

Cyclonic Reactor

Cyclonic reactors are designed for sludge disposal in smaller wastewater treatment plants. In a cyclonic reactor high velocity air, preheated with combustion gases from a burner, is introduced tangentially into a cylindrical combustion chamber. Concentrated sludge solids are sprayed radially towards the intensely heated walls of the combustion chamber. Combustion takes place rapidly so that no material adheres to the walls and the ash residue is carried off in the cyclonic flow and passes out of the reactor.

The components of this sludge combustion system are very similar to those used in a fludized bed system. Degritted, thickened primary plus activated sludge is pumped to a centrifuge. The dewatered cake drops into a hopper and is subsequently pumped into the cyclonic reactor with a small amount of compressed air. These reactors process combined primary plus secondary sludge at nominal rates up to 100 to 130 lb dry solids per hour.

Electrically Heated Furnace

An electrically heated furnace uses infrared lamps for its heat source. The lamps are high temperature tungston filament quartz lamps with an average life expectancy of 5000 hr at rated voltage. Because the heat is transferred by radiation rather than conduction or convection, the air is not heated and combustion air requirements are reduced. The dewatered sludge is conveyed through the furnace by a high temperature belt conveyor which carries the sludge through a drying zone and then into a combustion zone. In the combustion zone, mounted just above the belt, is a battery of infrared lamps which initiates and maintains the combustion. The belt then discharges the ash into a hopper at the end of the machine. The lamps and end seals are cooled by drawing outside air through the cooling air ducts. This preheated air is then used as combustion air is then exhausted through a wet gas scrubber or necessary air pollution equipment.

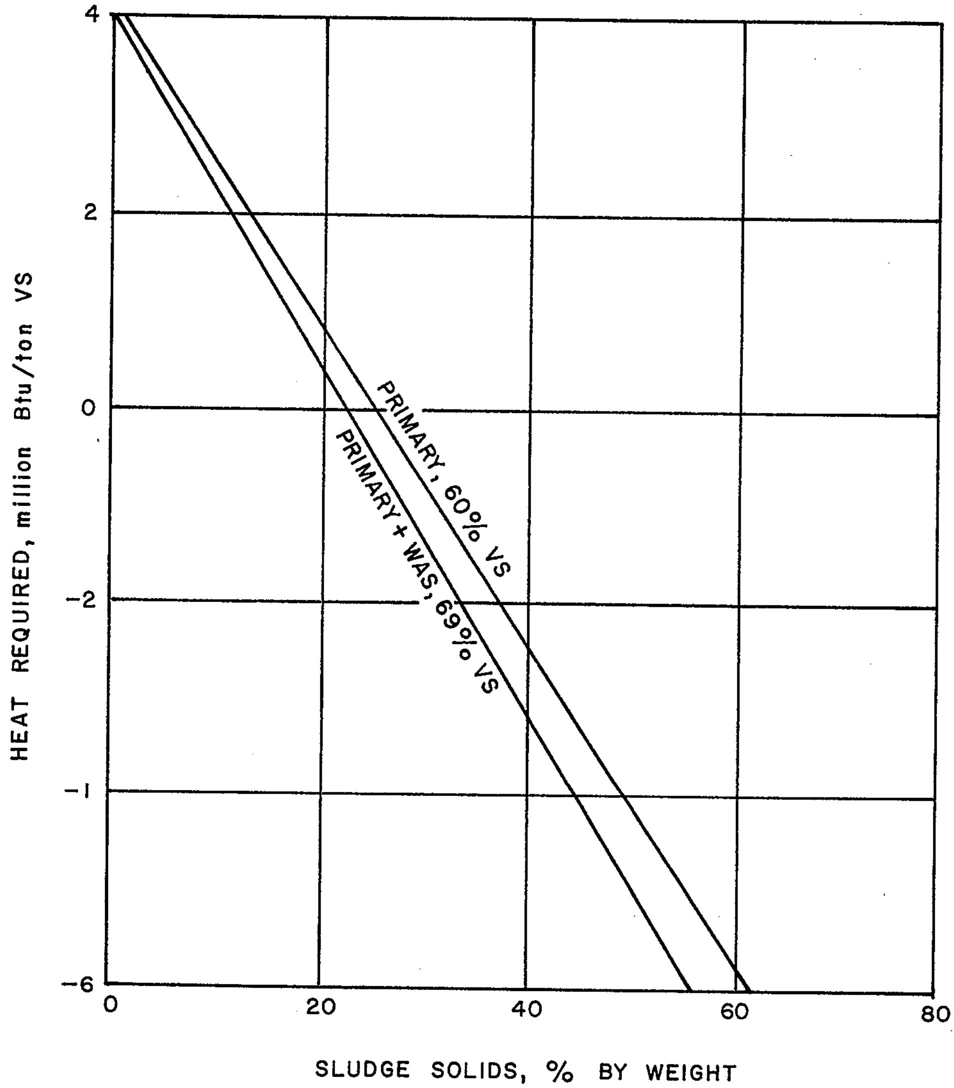
Although natural gas or oil may be a cheaper source of heat than electricity, other savings associated with the infrared system may offset higher fuel costs. Electric furnaces may be particularly attractive for small plants and applications requiring intermittent operation. The incinerator can be brought from ambient temperature to 1,600^{0}F to 1,800^{0}F within one hour. This system also shows potential for the regeneration of activated carbon. A 50 lb/hr unit is in operation for carbon regeneration in an industrial application in Baton Rouge, Louisiana.

Incineration Heat Requirements and Waste Heat Recovery

Incineration of sewage sludge may require auxiliary fuel to sustain combustion depending on the sludge moisture and volatile solids content. The relationship between auxiliary fuel required and sludge solids concentration is shown in Figure 5-22 for primary and primary plus WAS. These curves indicate that incineration is self sustaining at sludge solids concentrations of about 26 percent for primary sludge and 23 percent for primary plus WAS.

Incineration will always require some fuel because of startup requirements. Also, fuel may be required for afterburner emissions control equipment. Although incineration will always be a net consumer of fuel because of these requirements, the process is not necessarily a net consumer of energy. Incineration of sludge produces heat that can be recovered as steam and reused. Incineration of high solids sludge can produce more energy in waste heat (recovered as steam) than is required in auxiliary fuel (natural gas or fuel oil).

Determining the net heat recovered from incinerators normally requires a detailed analysis of the system heat inputs and heat losses. Heat inputs are combustion of sludge and auxiliary fuel, if any is used. Heat losses include latent heat of free moisture and moisture of combustion, sensible heat of flue gases and ash leaving the system, and furnace losses.



ASSUMPTIONS:
10,000 Btu/lb VS

AUXILARY HEAT REQUIRED TO SUSTAIN COMBUSTION OF SLUDGE

FIGURE 5-22

In the following discussion recovered heat is calculated as the actual heat recovered from incinerator or afterburner flue gases by heat exchange equipment. Net heat recovered is the excess energy remaining after all system heat inputs and energy requirements have been deducted from the recovered heat. This analysis of heat recovered is independent of the type of incinerator used for combustion of sludge because only the combustion products or flue gases are considered. The concept of heat recovery used herein assumes that a separate heat exchanger following the incinerator is used to extract heat from the gases leaving the stack of the incinerator or afterburner.

The temperature at which gases enter the heat exchange equipment is the initial temperature and the temperature of gases leaving the heat exchanger is the final temperature. The quantity of heat recovered from the flue gases is dependent on the initial and final temperatures and is given by the following equation:

$$H_R = C_p (T_1 - T_2) W \qquad (5\text{-}5)$$

where

H_R = heat recovered, Btu/hr

C_p = specific heat of exhaust gases, Btu/lb-^{0}F

T_1 = initial temperature of flue gases, ^{0}F

T_2 = final temperature of flue gases, ^{0}F

W = mass flow of flue gases, lb/hr

The following example illustrates the use of equation 5-5:

Given:

flue gas temperature 800^{0}F
specific heat of flue gas 0.33 Btu/lb-^{0}F
flue gas flow rate 4700 lb/hr
final flue gas temperature 500^{0}F

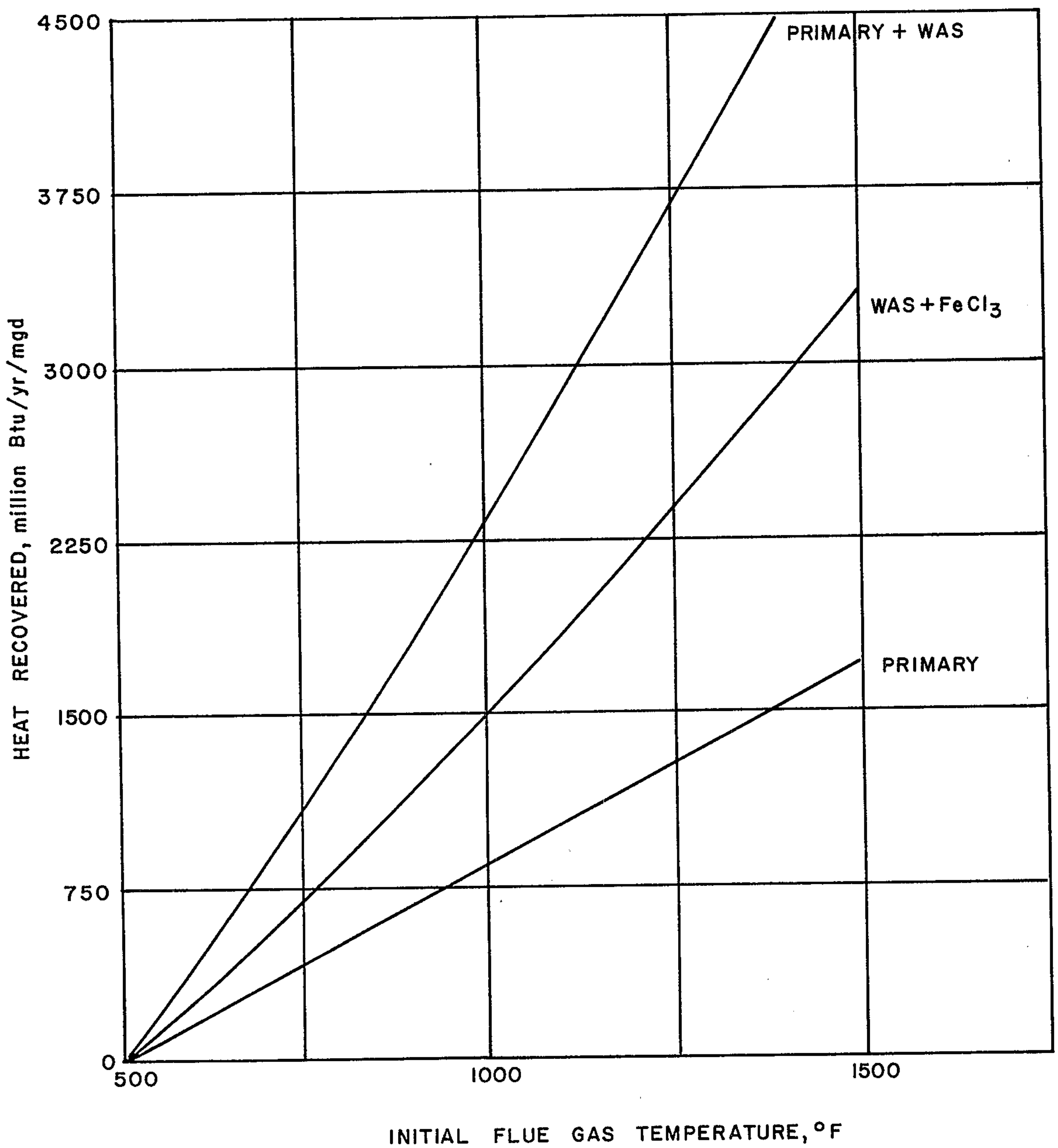
Then:

$$H_R = (0.33\ \text{Btu/lb-}^0\text{F})\ (800\text{-}500^0\text{F})\ (4700\ \text{lb/hr})$$
$$= 465{,}300\ \text{Btu/hr}$$

Based on the sludge characteristics and operating conditions in Chapter 3, (see Table preceding Figure 3-111), the heat recovered from the incineration of primary and waste activated sludge is shown in Figure 5-23. The calculated flow rate and percent moisture of the flue gases are based on stoichiometric equations and include 100 percent excess air.

The energy requirements for incineration in a multiple hearth furnace (not including sludge dewatering) are shown in Figures 3-111 through 3-113. An example of sludge incineration energy requirements and heat recovered in a 10 mgd plant is shown in Table 5-4.

The largest heat loss is from evaporating moisture contained in the sludge and therefore incineration of drier (higher solids content) sludge results in less auxiliary fuel use and more net heat recovered. Heat treatment of sludge prior to dewatering may result in sludge solids concentrations in the 25 to 40 percent range after dewatering. Heat recovered from incineration may also be used in a heat treatment system. Several municipal treatment plants have recently been put into operation that incorporate incineration of high solids content sludge, waste heat recovery and heat treatment in an integrated system. The costs and energy requirements of the complete sludge treatment system should be analyzed for each application. Because of their substantial energy and cost impacts, it is important to include the requirements for treatment of high strength liquors and odorous gases produced in heat treatment reactors. Heat treatment is discussed in more detail in a following section in this chapter.



ASSUMPTIONS:

FINAL STACK TEMP = 500° F

100 % EXCESS AIR

SEE TABLE PRECEDING FIGURE 3-III FOR SLUDGE CHARACTERISTICS

HEAT RECOVERED FROM INCINERATION OF SLUDGE

FIGURE 5-23

TABLE 5-4

EXAMPLE OF SLUDGE INCINERATION ENERGY REQUIREMENTS

	Energy Required for Incineration - 10 mgd Plant				Recovered Heat	Net Recovered Heat
	Fuel Million Btu/yr					
Sludge Type	Start up (Fig. 3-112)	Operation (Fig. 3-111)	Electricity Thousand kwh/yr (Fig. 3-113)	Total Million Btu/yr	Million Btu/yr (Fig. 5-24)	Million Btu/yr
Primary	650	9,100	290	12,800	15,000	+2,210
Primary +WAS	1,700	75,000	600	83,000	44,000	-39,000

Assumptions:

- Primary Sludge 30% solids

  Dry solids = 1151 lb/mil gal
  Wet sludge = 3837 lb/mil gal
  Sludge feed rate to incinerator = 7 lb/hr/sq ft
  Hearth area required = 33 sq ft/mil gal (70% operation)
  Operates 5 days/week; 52 start ups/yr; 18 hr required for start up

- Primary +WAS Sludge 16% solids

  Dry solids = 2096 lb/mil gal
  Wet sludge = 13,100 lb/mil gal
  Sludge feed rate to incinerator = 7 lb/hr/sq ft
  Hearth area required = 91 sq ft/mil gal (86% operation)
  Operates 6 days/week; 26 start ups/yr; 36 hr required for start up

- Heat Recovery - flue gas @ 1400°F cooled to 500°F

Combustion Air Feed To Incinerator

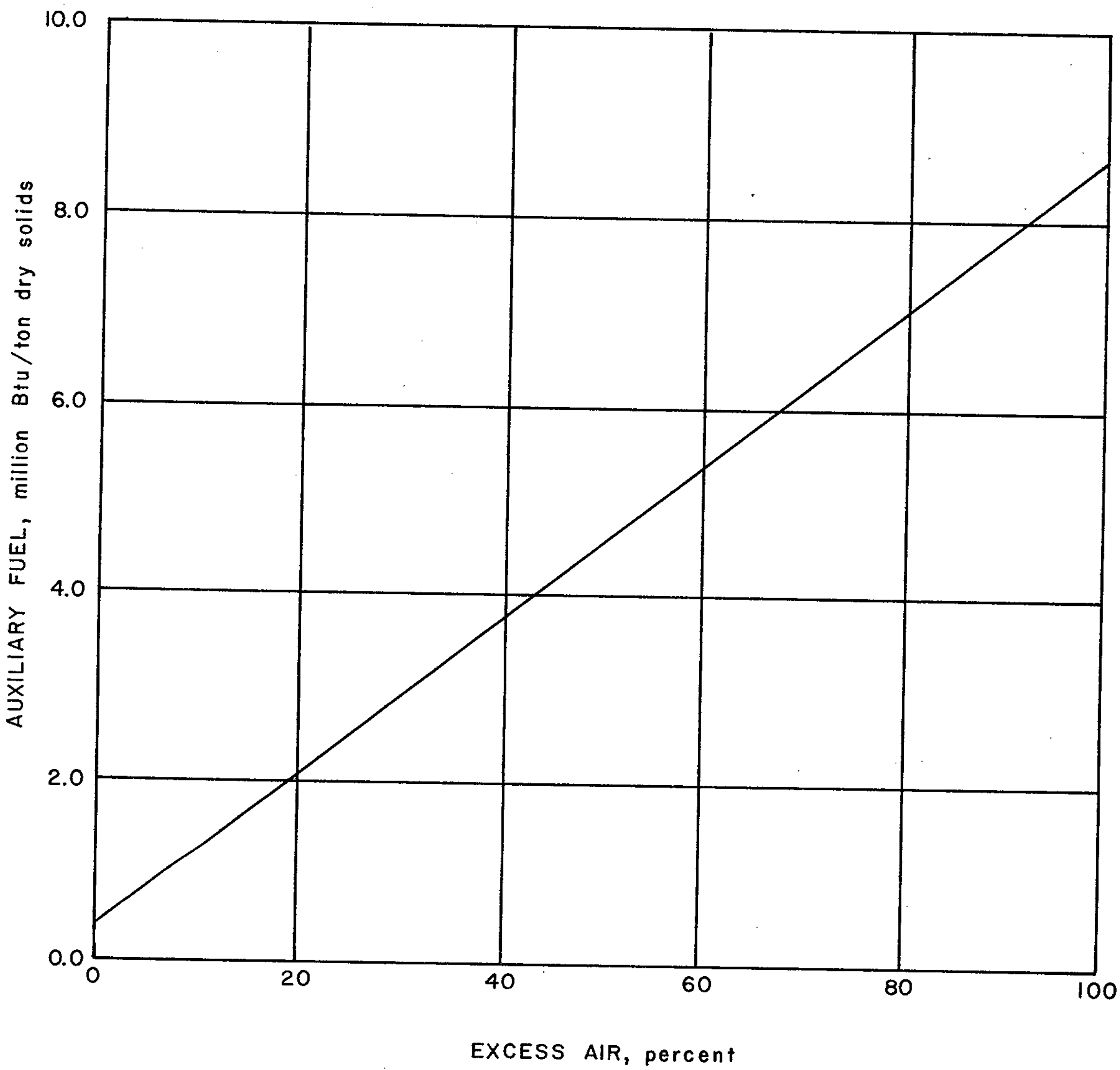
Practical operation of an incinerator requires that air in excess of theoretical requirements must be supplied to the combustion chamber. This increases the opportunity of contact between fuel and oxygen which is necessary if combustion is to proceed. Fluidized bed furnaces commonly use less than 50 percent excess air over the stoichiometric amount of air required in the combustion zone. Multiple hearth furnaces commonly use 100 percent excess air. Excess air in the 100 to 200 percent range is undesirable because it wastes fuel. However, when the amount of excess air is inadequate, only partial combustion occurs, resulting in the formation of carbon monoxide, soot and odorous hydrocarbons in the stack gases.

Therefore, a closely controlled minimum excess air flow is desirable for maximum thermal economy. The amount of excess air required varies with the type of burning equipment, the nature of the sludge to be burned and the disposition of the stack gases. The impact of use of excess air on auxiliary fuel required for sludge incineration is shown in Figure 5-24. Increasing exhaust gas temperature increases auxiliary fuel requirements.

Preheating combustion air reduces the auxiliary fuel required and affords an increase in capacity for a given size reactor since the combustion gas volume is used more effectively. It should be noted that preheat exchangers require significant capital expenditures and are recommended only after a complete economic evaluation of the process.

Incineration of Combined Sludge and Solid Waste

Incineration of sewage sludge and solid waste combined has been suggested



ASSUMPTIONS:

SOLIDS 30%
EXHAUST TEMP. 1400°F
VOLATILES 70%

IMPACT OF EXCESS AIR ON THE AMOUNT OF AUXILIARY FUEL FOR SLUDGE INCINERATION

FIGURE 5-24

as a means of reducing the auxiliary fuel required for combustion of sludge. Co-incineration of 5 percent solids sludge mixed with solid wastes is being practiced in a fluidized bed furnace at Franklin, Ohio.

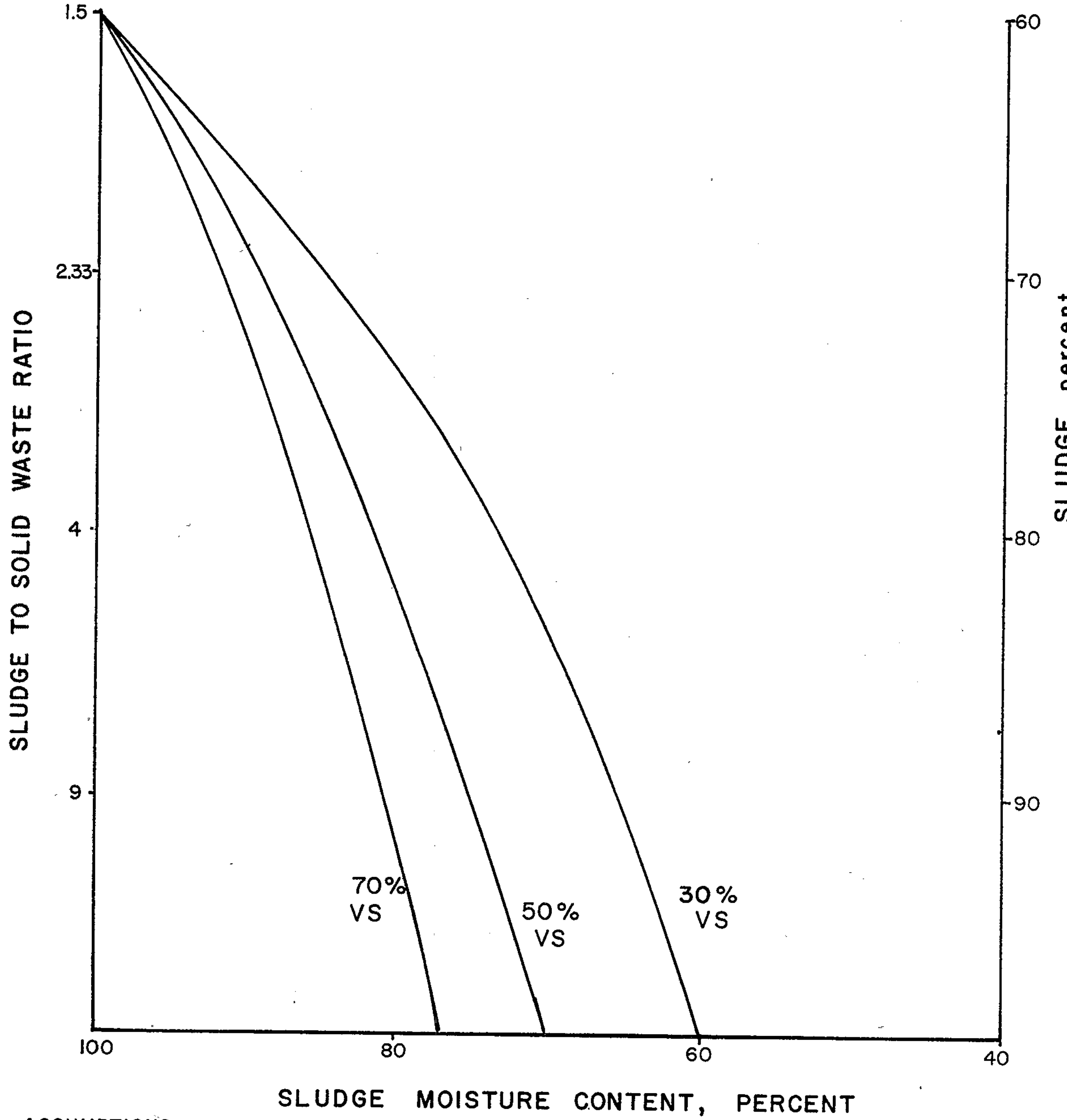
The sludge to refuse ratio necessary to just sustain combustion is determined by calculating a heat balance for the particular sewage sludge incinerated. The heat inputs are the sludge and the refuse while the heat losses are estimated to be 1,800 to 2,500 Btu per pound of water evaporated in a furnace.[11] The quantity of refuse required to sustain combustion shown in Figure 5-25 was determined with the following assumptions:

Heat value of sludge:	10,000 Btu/lb VS
Heat value of solid waste	4,750 Btu/lb
Moisture in solid waste	25 percent
Heat required to evaporate water in furnace:	2,100 Btu/lb water

Using these assumptions, sludge with 5 percent TS and 70 percent VS requires at least 28 percent refuse to sustain combustion.

PYROLYSIS

Pyrolysis is a process in which organic material is decomposed at high temperature in an oxygen deficient environment. The action, causing an irreversible chemical change, produces three types of products: gas, oil and char (solid residue). Water vapor is also produced, usually in relatively large amounts depending on the initial moisture content of the materials being pyrolysed. Residence time, temperature and pressure in the reactor are controlled to produce various combinations and compositions of the products. Two general types of pyrolysis processes may be used. The first, true pyrolysis, involves applying all required heat external



ASSUMPTIONS:

HEAT VALUE OF SLUDGE	10,000 Btu/lb VS
HEAT VALUE OF REFUSE	4750 Btu/lb
MOISTURE IN SOLID WASTE	25 %
HEAT REQUIRED TO EVAPORATE WATER IN FURNACE	2100 Btu/lb WATER

COMBUSTION OF SLUDGE AND SOLID WASTE

(RELATIONSHIPS REQUIRED TO SUSTAIN COMBUSTION)

FIGURE 5-25

to the reaction chamber. The other, sometimes called partial combustion and gasification, involves the addition of small amounts of air or oxygen directly into the reactor. The oxygen sustains combustion of a portion of the reactor contents which in turn produces the heat required to dry and pyrolyse the remainder of the contents.

Pyrolysis of municipal refuse and of sewage sludge has been considered as a means for ultimate disposal of wastes for several years.[12-16] The results of various studies and pilot programs indicate that if the moisture content of a sludge is below 70 to 75 percent, enough heat can be generated by combustion of the oil and gases produced from the pyrolysis of sludge for the process to be thermally sustaining. Pyrolysis of municipal refuse, and combinations of refuse and wastewater sludges will provide energy in excess of that required in the pyrolytic process.[14,16]

Laboratory, pilot and full-scale demonstration systems for pyrolysis of wastewater sludges have been tested but no full-scale systems are in continuous operation. Therefore, the data and energy recovery estimates presented in this section must be considered preliminary. The reader is cautioned that the data and energy estimates presented should not be used for design or even planning purposes without further verification. Pyrolysis systems are in the developmental stages and additional information will become available as research and development work and the operation of full-scale plants progresses.

Table 5-5 is a summary of information for most of the pyrolysis systems presently under investigation. The main by-products and status of development for the systems are shown in this table. The systems which are fairly well developed are described in the following pages.

TABLE 5-5

MUNICIPAL SOLID WASTE AND SEWAGE SLUDGE

PYROLYSIS PROCESSES

Developer	Products	Pilot Plant Scale	First Major Demonstration Plant
Monsanto Envirochem Systems Inc., St. Louis, Mo. (Landgard)	Fuel Gas or Steam, Ferrous Metal, Wet Char, Glass Aggregate	36 ton/day	1000 ton/day solid wastes (Baltimore, MD) co-pyrolysis considered
Occidental Research Corp. (formerly Garrett), La Verne, Calif.	Pyrolytic Oil, Char, Glass, Ferrous Metal, Nonferrous Metal, Organics in Condensate	4 ton/day	200 ton/day solid wastes; start-up schedule for late 1976 (San Diego, CA)
Union Carbide Corp., New York, N. Y. (Purox)	Fuel Gas, Slag	200 ton/day	Solid waste; scheduled for co-pyrolysis. Pilot plant still in operation late 1976 (S. Charleston, WV)
Carborundum Environmental Systems, Inc., Niagara Falls, N. Y. (Torrax)	Steam (or Fuel Gas), Slag	75 ton/day	200 ton/day commercial plant under construction in Europe (Andco, Inc.)
BSP Division Envirotech Belmont, California	Steam (Fuel Gas)	3 ton/day	145 ton/day co-pyrolysis (Concord, CA) Cowlitz County, Wash. - Planned to be in operation by 1978.
Jet Propulsion Laboratory, California Institute of Technology Pasadena, California	Activated Carbon and Fuel Gas	Initial pilot plant operated at 10,000 gpd - sewage	1 mgd pilot plant in operation (Fountain Valley, CA)
DECO/Enterprise Co. Santa Ana, Calif.	Fuel Gas and Oil	5 ton/day	150 ton/day started in June 1976, solid waste and solid waste/sludge (South Gate, CA)
Battelle Pacific Northwest Laboratories, Richland, Washington	Steam (or Fuel Gas)	2 ton/day; 150 ton/day demonstration plant under consideration	---
Pyrolytic Systems, Inc. Riverside, Calif.	Fuel Gas or Electric Power	50 ton/day by late 1976	---
DEVCO Management, Inc. New York, N.Y.	Fuel Gas	50 ton/day	---
Pollution Control, Ltd. Copenhagen, Denmark	Fuel Gas	5 ton/day	---
Urban Research & Development Corp., East Granby, Conn.	Slag, Fuel Gas	120 ton/day	---

Rotary Kiln Reactor

In this process shredded waste materials are heated indirectly by combusting a portion of the pyrolytic gases produced. The remaining gases are burned to produce steam in a utility boiler. The char is not combusted and requires disposal, however, it does have characteristics similar to some activated carbons and eventually may be usable. The reactor is a refractory-lined, rotary kiln; temperatures in the outlet from the reactor reach 1,800^{0}F. Residue discharged from the kiln is water-quenched and then treated by flotation to separate the char from metal and glass wastes. The off-gases from the reactor are drawn into a waste gas burner where they are burned in air. The hot exhaust gases from the burner pass through a water-tube boiler and then through a final cooler and air pollution control equipment. Operating on municipal solid wastes, the process will produce slightly less than 2.5 tons of steam per ton of waste.

Vertical Shaft Reactor

The vertical shaft reactor system is a gasification or partial combustion process which maximizes gas production. Pure oxygen is used in one commercially available system and air is used in another. In the system using oxygen, coarsely unshredded waste materials from which ferrous metals have been removed are charged into the top of a vertical shaft furnace. Hot combustion gases, essentially free of oxygen, rise through the furnace and pyrolyse the descending wastes into fuel gas, oil and additional char. The resulting gaseous mixture rises further, drying the incoming wastes. Water and oil are condensed from the gaseous stream which is then cleaned for use. The condensed oil is returned to the furnace for combustion and further production of gas. The end result is a clean-burning fuel with a heat value of about 300 to 500 Btu/scf produced at a rate of about 7.5 million Btu/ton of solid waste. This system will receive unprocessed trash and, as a result of the high combustion temperature of the char, produce a molten metal and glass slag. The slag is water-quenched and reportedly is suitable for use as a construction fill material.

A variation of this process uses air, not pure oxygen, to support combustion. Char is combusted to provide the heat necessary for pyrolysis. The result is a diluted fuel gas with a low heating value (120-150 Btu/scf) best utilized by combustion on-site to produce steam.

Unprocessed wastes are fed to the primary reactor and are pyrolysed with the heat from burning char as in the pure oxygen system. The pyrolytic gases then flow through a secondary combustion chamber where they are completely combusted with air. The resulting hot exhaust gases flow through a waste heat boiler, a final cooler and air pollution control component before being discharged to atmosphere. A portion of the hot gas from the secondary combustion chamber is recycled and used to preheat incoming combustion air to the primary reactor.

Another process that utilizes a vertical shaft reactor produces oil as its main product. A finely divided, organic feed is supplied to the pyrolysis reactor. Dividing is accomplished in a two-stage shredding operation which also reduces the inorganic content of raw refuse through air classification and screening to less than 4 percent by weight. The process, using the finely divided feed, permits flash pyrolysis at atmospheric pressure for maximum oil production. Discharge from the reactor goes first to a char separator and then to a gas-liquid separator where gases and water are separated from the oil. The relatively small amounts of char and gases produced are recycled to produce heat for the reaction. The pyrolytic oil produced has a heating value of about 10,500 Btu/lb and about 0.2 tons of oil are produced per ton of solid waste processed. This oil is best utilized by blending with No. 6 fuel oil for use in utility boilers and has the advantage of being storable and transportable.

Multiple Hearth Furnace Reactor

Research and development work has been conducted on using multiple hearth furnaces, similar in design to conventional sludge incinerators, for pyrolysis of wastewater sludges and municipal solid wastes. Shredded and classified solid wastes and dewatered sludge are fed to the furnace either in a mixture or separately with the wetter sludge fed higher in the furnace. Recirculated hot shaft cooling air and supplemental outside combustion are fed to the lower hearths to sustain partial combustion of the wastes circulating own through the furnace. Fuel gas produced through the pyrolysis reaction is then burned in a high temperature afterburner. The resulting heat can be used in a waste heat boiler to produce high pressure steam. It may also be possible to burn the fuel gases directly in a boiler. Char from the process is not used but, because it has some fuel value, it may be usable as an industrial fuel. Multiple hearth furnaces, when fitted with flexible control systems and operated properly, allow all the char to be burned.

The multiple hearth process offers the following advantages: (1) usable in much smaller plants than most other pyrolysis systems, (2) employs modifications of well developed sludge incineration equipment, (3) produces high temperature gases without raising temperatures in the solid phase to the slagging point, and (4) conversion from existing conventional sludge incineration systems is a relatively simple procedure. Disadvantages include: (1) fuel value of the char is not used, (2) high temperature fuel gases must be used on-site, and (3) incoming solid wastes must be well classified if solid wastes are used at all.

It is estimated that this process will produce between 2 and 2.5 tons of steam from one ton of a 2:1 mixture of municipal solid waste and sludge.

Horizontal Shaft Reactor

This process is actually a complete sewage treatment system employing pyrolysis as one element. Screened, degritted raw sewage is mixed with powdered activated carbon in a two-stage adsorption and settling system. Activated carbon is added to the second stage mixing tank and settled in the second stage settling basin. A mixture of partially exhausted carbon and sludge is then transferred to the primary mixing tank and mixed with incoming sewage. Sludge from the primary settling basin is dewatered, flash dried and transferred to a rotary kiln or calciner. In the kiln the carbon-sludge mixture is pryolysed to produce gas and a carbon-char mixture. The gas has a fuel value of 350 to 400 Btu/cu ft. Steam is added to the carbon-char mixture in the kiln to produce activated carbon for recycling to the secondary mixing tank. Waste heat from the kiln is used in the flash dryer and pryolytic gases can be burned to heat the kiln and to produce steam.

A 10,000 gpd unit has been tested[17] and a 1 mgd pilot plant began operation in August 1976. The process may be an alternative to existing methods of wastewater treatment and sludge disposal; however, results of ongoing tests must be evaluated before operating efficiencies and costs can be developed.

Heat Recovery

Analyses of available excess heat for some of these systems have been presented for pyrolysis of solid wastes.[14,16] An analysis has also been presented for the pyrolysis of sludge using a rotary kiln reactor. The following estimates for pyrolysis of refuse and sludge combined are based on assumptions presented in the references. Estimates are provided for two types of systems only, however, they should be representative of most pyrolysis systems since the main interest is in a heat balance for the overall concept and not in the unit heating values for an individual product. Process differences result in variations in the composition and quantities of fuel produced, but should result in relatively minor variations in net heat output. Thermodynamically, the main difference between the two systems is whether or not the char is combusted. The estimates show that considerable heating value is lost by wasting the combustible portion of the char.

The assumptions used in calculating excess heat are shown in Table 5-6. Estimated heat balance for inputs of 50 percent sludge and 50 percent refuse, and for sludge alone, for the two systems are shown in Tables 5-7 and 5-8. A municipal sludge with a moisture content of 70 percent, a volatile fraction of 70 percent and a high heating value of 7,000 Btu/lb was used. Values for pyrolysis of refuse alone were taken from the references noted in the tables. Calculations for inputs of other refuse to sludge ratios result in the curves shown in Figures 5-26 and 5-27. The refuse to sludge ratio for a typical residential community is in the range of 10:1 to 15:1 on a dry solids basis and 3:1 to 8:1 on a wet solids basis, indicating that more than enough refuse is generally available for mixing with sludge to operate the process without the need for an external energy source.

Heat recovery percentages are, in general, higher for the pure oxygen system because the combustible part of the char is burned to provide process heat. Other variations in heat losses between the two systems are due to process differences. These calculations estimate that both systems would probably be self-sustaining using a typical municipal sludge as fuel but that no appreciable amount of usable excess heat could be expected. Sludge with a moisture content below about 65 percent, corresponding to a filter-pressed sludge, will provide some excess heat; as the moisture content increases above 75 percent, external heat must be added to the process. There are enough variations in energy balances for different conditions that complete calculation should be made for any application being considered.

TABLE 5-6

ASSUMPTIONS USED
FOR CALCULATION OF EXCESS HEAT

Refuse

Moisture	25% by weight
Higher Heating Value	4750 Btu/lb

Sludge

Moisture	70% by weight
Solids	30% by weight
Volatile fraction	70%
Higher Heating Value	7000 Btu/lb solids

Carbonaceous (combustible) fraction of char

Refuse	10% of weight
Sludge	14% of solids
Higher Heating Value	13,000 Btu/lb

Other Assumptions

	Rotary Kiln Reactor System	Vertical Shaft Reactor System
Input temp	$60^{o}F$	$60^{o}F$
Flue gas temp	$500^{o}F$	$200^{o}F$
Latent & sensible heat for gases & residue (% of total heat input)	17.2%	11.2%
Fuel gas uses	---	792,000 Btu/ton input
Electrical energy required	65 kwh/ton input	120 kwh/ton input

TABLE 5-7

ROTARY KILN REACTOR PYROLYSIS

Waste Input		Refuse (Reference 14)	50% Refuse + 50% Sludge	Sludge Only
Available Energy Input (per ton)		9,500,000 Btu	6,850,000 Btu	4,200,000 Btu
Losses:				
Moisture				
latent		530,000	1,007,000	1,484,000
sensible		99,000	188,000	277,000
Other*		1,633,000	1,177,000	722,000
Loss from not combusting char		2,600,000	1,846,000	1,092,000
Electric Power** used in plant		678,000	678,000	678,000
Total Energy recovery or waste heat	Total	3,960,000 Btu	1,954,000 Btu	-53,000 Btu
	per lb input	1,980 Btu/lb	980 Btu/lb	-30 Btu/lb
	% recovery	42%	29%	-1%

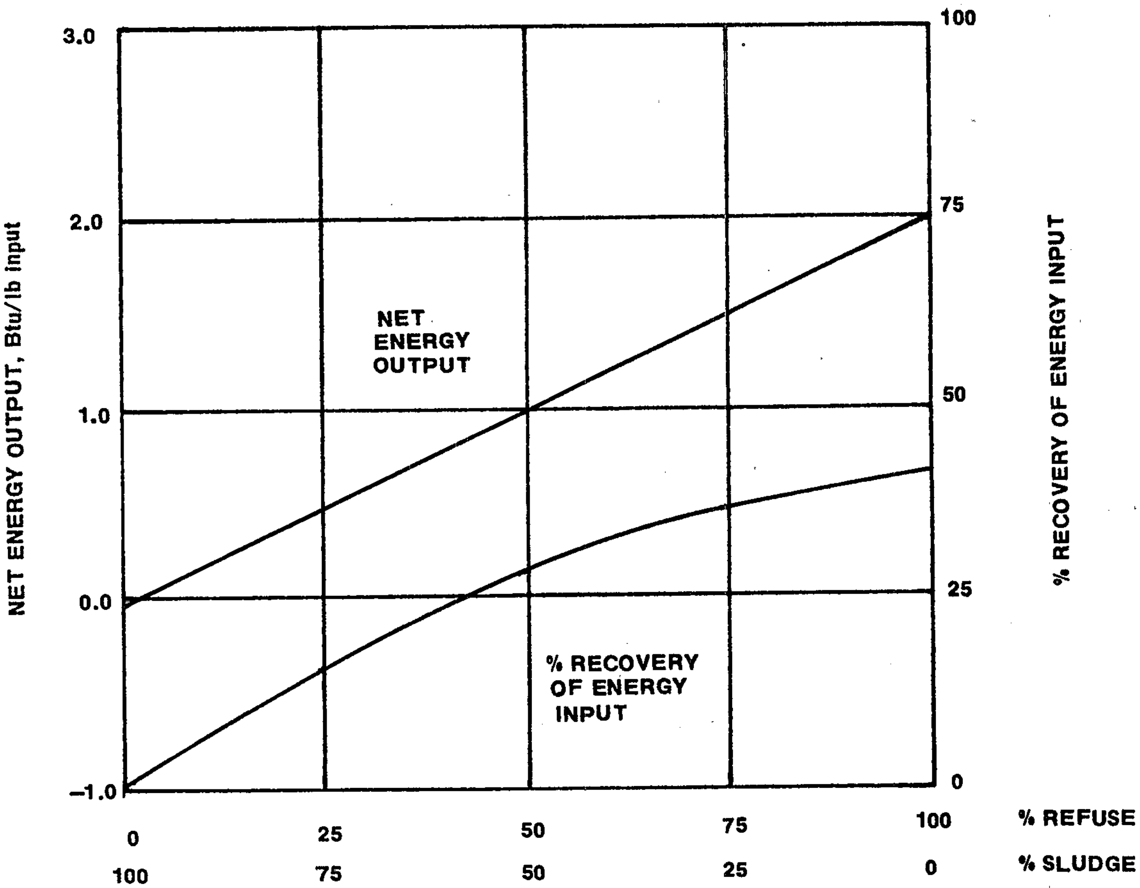
* Includes sensible and latent heat of product gases and sensible heat of char.
** Assumes an overall efficiency of 32.5% or 10,500 Btu/kwh.

TABLE 5-8

PURE OXYGEN VERTICAL SHAFT REACTOR SYSTEM HEAT BALANCE

Waste Input		Refuse Only (Reference 16)	50% Refuse 50% Sludge	Sludge Only
Available Energy (per ton) Input		9,500,000 Btu	6,850,000 Btu	4,200,000 Btu
Losses:				
Moisture input latent		530,000	1,007,000	1,484,000
sensible		31,000	60,000	88,000
Other* (11.2%)		1,064,000	767,000	470,000
Fuel Gas Uses:		792,000	792,000	792,000
Electric Power** used in plant		1,252,000	1,252,000	1,252,000
Total Energy Recovery or	Total	5,831,000 Btu	2,972,000 Btu	114,000 Btu
	per lb input	2,920 Btu/lb	1,490 Btu/lb	57 Btu/lb
Waste heat	% energy recovered	61%	43%	3%

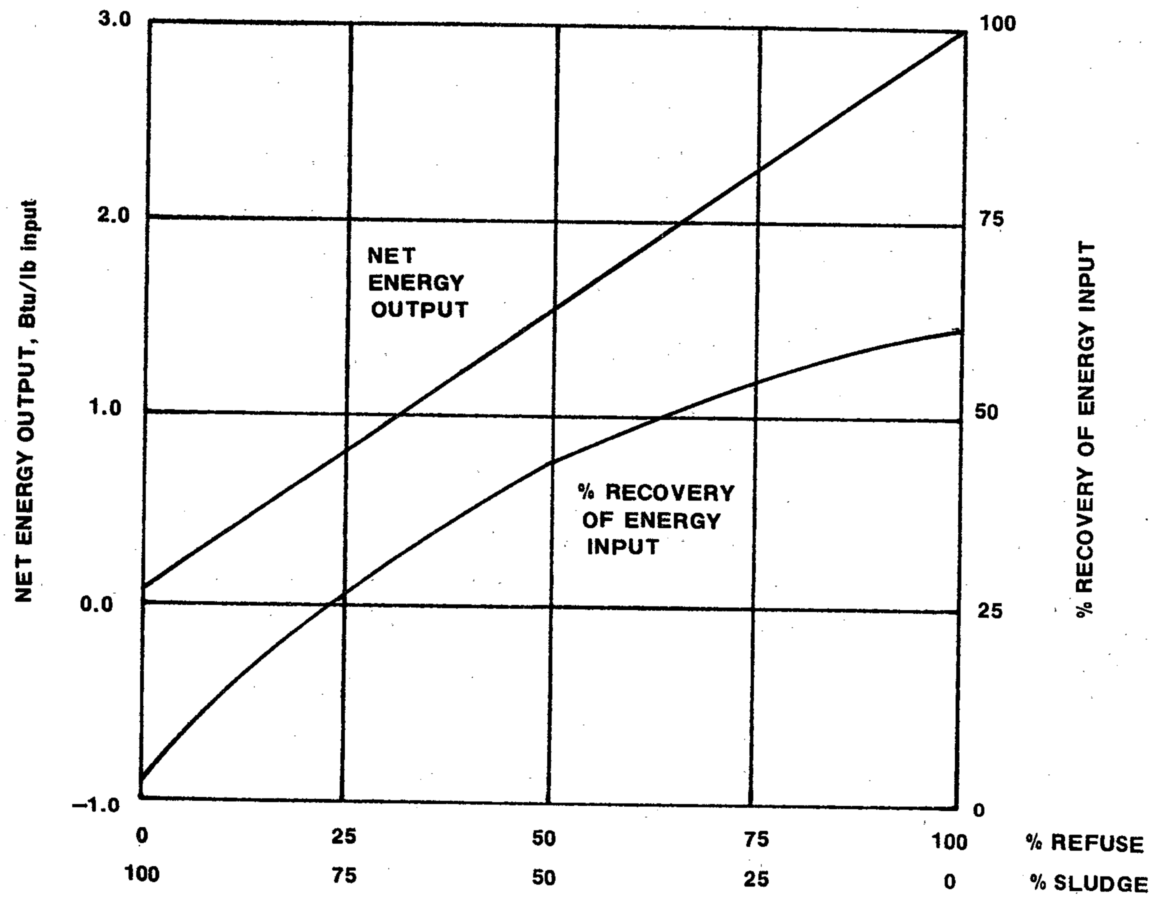
* Includes sensible latent heat of product gases and sensible heat of char
** Assumes an overall efficiency of 32.5% or 10,500 Btu/kwh



ENERGY RECOVERY

ROTARY KILN REACTOR PYROLYSIS SYSTEM

FIGURE 5–26



ENERGY RECOVERY
VERTICAL SHAFT REACTOR PURE OXYGEN PYROLYSIS SYSTEM

FIGURE 5-27

INCINERATION VERSUS PYROLYSIS

Pyrolysis appears to have several advantages over incineration. For example, some pyrolysis processes can convert wastes to storable, transportable fuels such as fuel gas or oil while incineration only produces heat that must be converted to steam. Air pollution is not as severe a problem in pyrolysis systems because the volume of stack gases and the quantity of particulates in the stack gases are less.

On the other hand, pyrolysis is essentially still in the developmental stage and, with few exceptions, viable commercial systems are not readily available. Most of the pyrolytic fuel gases have relatively low heat values and the pyrolytic oil is corrosive, requiring it to be mixed with other fuel oil for best results.

The construction and operating costs for most pyrolysis systems are much more uncertain than for incineration. Reliable cost data for pyrolysis systems will not be available until significant operating experience is developed from the ongoing and planned demonstration projects.

HEAT TREATMENT OF WASTEWATER SLUDGES

Heat treatment comprises several related processes in which sludges are heated for conditioning prior to dewatering or for stabilization prior to disposal. All the processes involve heating sludge for relatively short periods of time in pressurized reactors. The reactor's environment - temperature, pressure, residence time and oxygen content - is selected based on the desired degree of sludge conditioning or stabilization. As the temperature and amount of available oxygen are increased a greater amount of stabilization or oxidation takes place. Heat treatment processes are divided into two main categories depending on the desired results: thermal conditioning and wet oxidation.

Thermal Conditioning

Thermal conditioning is used to condition sludge for subsequent dewatering. Sewage sludges, particularly biological sludges, are normally difficult to dewater and some form of conditioning to aid the dewatering processes is required. Conditioning is often accomplished by adding coagulating chemicals such as lime, ferric chloride and cationic polymers to the sludge prior to a mechanical dewatering process. Thermal conditioning on the other hand uses heat to change the physical and chemical natures of the sludge. A dewaterable sludge is thus produced without the addition of chemicals.

Under heat and pressure in a reactor, bound water and intercellular water are released from the sludge and much of the smaller and more hydrated particulate matter is solubilized. The result is a mixture of relatively innocuous, sterile particulate matter and a liquid. The two phases are easily separated after discharge by decantation and mechanical dewatering processes. The dewatered solids are inoffensive and can be used as soil conditioner. The liquid phase is highly colored, often has a very offensive odor and has a BOD ranging between 3,000 and 15,000 mg/l.

For thermal conditioning of most municipal sludges, reactor temperatures and pressures range from about 300^{o} to 500^{o}F and 100 to 700 psi, respectively. Residence time in the reactor is usually about 30 to 45 minutes at design flow. A primary purpose in pressurizing the reactor is to prevent the liquid contents from flashing to steam at the high temperatures involved. Air may be added to the system to assist with heat transfer and to partially oxidize the sludge.

Wet Oxidation

This process oxidizes organic materials in the sludge to ash. Wet oxidation is similar to thermal conditioning in that sludge is heated in a pressurized reactor, but it's purpose is to stabilize the sludge rather than condition it for dewatering. This requires an increase in reactor temperatures and pressures to a range from about 450^o to 700^{o}F and 400 to 3,000 psi, respectively. The reactor's environment is selected based on the characteristics of the sludge and the degree of oxidation desired. Air is added to the reactor to supply the oxygen needed by the chemical reactions taking place. The degree of oxidation of the sludge can be controlled and can range up to over 95 percent of the influent COD for some sludges. This is equivalent to results attainable in dry incineration processes, but in wet oxidation, temperatures are much lower, fly ash is not a problem and the sludge need not be dewatered before being oxidized.

Energy Requirements

In order to operate any heat treatment process, the temperature of the incoming sludge must be raised to the selected reactor temperature. To heat one gallon of sludge from 50^{o}F to a thermal conditioning temperature of 350^{o}F requires 2,500 Btu and to raise the temperature to 700^{o}F for complete oxidation requires about 5500 Btu. Thus a 10 mgd treatment plant producing 10 tons per day of sludge requires approximately 150 mil Btu/day for thermal conditioning and 320 mil Btu/day for wet oxidation. These values are net heats required by the sludge and must be increased to reflect the efficiency of the heat generating and transferring system and losses from the overall system. The actual energy input is, therefore, almost double the above figures.

Heat exchangers are incorporated into the processes to capture the heat from the treated sludge in the reactor outlet. In this manner, incoming sludge is heated to within 40 to 50^{0}F of the reactor temperature with a corresponding drop in required input energy. With an efficient heat exchange system, about 420 Btu/gal is required to reach the reactor temperature and, accounting for system inefficiencies, a total energy input of about 900 Btu/gal is required. This heat is normally supplied by injecting steam into the reactor.

Heat to generate the steam is usually produced in gas or oil-fired boilers. However, when sludge incinerators follow thermal conditioning plants, waste heat boilers deriving heat from the incinerator stack gases have been used successfully to provide all the required heat.

Injection of air into the reactor allows heat-producing oxidation reactions to occur. In those thermal conditioning systems where air is supplied, oxidation of about 5 to 10 percent of the volatile solids takes place. Assuming typical wastewater sludges and a heat value of 10,000 Btu/lb of volatile solids, the required heat input is reduced from 900 Btu/gal to between 500 and 700 Btu/gal. This reduction in required heat is accompanied, however, by an increase in electrical energy needed to compress the air. Table 5-9 shows the heat input required for thermal conditioning of several sludges and Figures 3-89 through 3-92 show the annual heat requirements for the same sludges.

By increasing the degree of oxidation, as is done in wet oxidation, to 20 to 30 percent of the volatile solids content, enough heat is produced in the reactor to offset the need for supplementary steam. Steam is then needed only to initially heat the system to the reaction temperature. Further increase in the degree of oxidation produces excess heat which may be used to generate steam or hot water for other uses.

TABLE 5-9

FUEL REQUIREMENTS FOR THERMAL TREATMENT WITH AIR ADDITION

Sludge[1]	Sludge Quantity (lb/mil gal)	Solids Concentration to Reactor (Percent)	Volatile Solids (Percent)	Heat Value of Sludge[2] (Btu/gal)	Heat Liberated[3] (Btu/gal)	Fuel Input Required[4] (Btu/gal)
P	1151	5	60	2502	155	564
P + WAS	2096	4.5	69	2590	165	542
P + WAS(+$FeCl_3$)	2685	3.5	54	1576	95	693
P(+$FeCl_3$)+WAS	3144	3	53	1326	80	726
WAS	945	2.5	80	1668	110	661
WAS(+$FeCl_3$)	1535	3	50	1251	80	726
Dig P	806	6	43	2152	135	607
Dig P + WAS	1226	4	47	1578	95	693
Dig P+WAS(+$FeCl_3$)	1817	4	33	1100	65	758
Tert Alum	700	2	30	500	35	822

[1] Abbreviations:

P = Primary Sludge
WAS = Waste Activated Sludge
Dig = Digested
Tert = Tertiary
$FeCl_3$ = Ferric Chloride

[2] Based on 10,000 Btu/lb VS

[3] Based on 5 - 10% oxidation of VS

[4] Based on 62% overall system efficiency

Or, hot, pressurized off-gases from the reactor can be expanded through a turbine to drive process equipment or an electrical generator.

The recoverable energy from a wet oxidation system treating the primary and waste activated sludge mixture described in Table 5-9 can yield almost 16 horsepower per gpm of capacity. Comparing this recoverable energy with the energy required to operate the system shows that the output very nearly equals input. Of course, the energy balance will change for different sludges and system conditions, but in all systems a large amount of the input energy is recoverable.

Sidestreams

Besides the direct energy requirements of heat treatment, other related areas of energy use must be considered. These are the treatment of the high-strength liquors produced in the reactor and the treatment of odorous gases emanating from air-water separators, storage tanks, and subsequent dewatering processes. Often, costs and energy requirements for these operations are incorrectly excluded when making feasibility studies involving the processes. Their impacts on energy consumption can be substantial.

Strong liquors from thermal conditioning processes which include supernatant from decanting operations and filtrate or centrate from dewatering operations, must be treated before discharge. These liquors are usually treated in one of three ways: (1) separate biological treatment (aerobic or anaerobic) perhaps followed by adsorption on activated carbon, (2) recycled directly back to the primary or secondary treatment plant, or (3) biological pretreatment and then recycled back to the main treatment plant for additional treatment. Because of its high-strength (BOD of 3,000 to 15,000 mg/l and suspended solids of 10,000 to 20,000 mg/l) and even though the volume is low (0.4 to 0.8 percent of the inflow to the treatment plant), the increased load due to recycling or separately treating can be quite significant. Recycling strong liquor directly to an activated sludge plant can increase the air requirement, and consequently the energy requirement, by as much as 30 percent.

Most of the various systems available to control concentrated process odors also consume relatively large amounts of energy. The methods most commonly used and most generally effective for controlling odors from thermal treatment are high temperature incineration, adsorption on activated carbon, and chemical scrubbing. Table 5-10 shows the requirements for the three methods based on a typical 1,000 cfm odor control system. A concentrated gas stream of 1,000 cfm corresponds to a thermal treatment plant size of 200 to 250 gpm or a sewage treatment plant size of 50 to 60 mgd. The energy requirements developed for the three methods represent the needs of complete odor control systems and include requirements for collection of gases; ducting; fans; chemical feeding, mixing, and storage equipment; automatic control systems; disposal of removed and waste materials; and discharge of treated gases as well as for odor removal itself.

The incineration or afterburning process considered consists of pretreatment by water scrubbing using treated effluent in a packed bed and direct-flame incineration at 1,500^{0}F with recovery of 40 percent of the input heat. The carbon adsorption process includes prescrubbing with effluent, dual-bed adsorption on activated carbon, regeneration of carbon with low pressure steam, condensation of vapors, and incineration of the waste organic stream. The chemical scrubbing system utilizes three stages of scrubbing in packed beds. The first two stages use secondary effluent and a final stage uses a buffered, potassium permanganate solution.

TABLE 5-10

ENERGY CONSUMPTION FOR ODOR CONTROL SYSTEMS

	Incineration	Carbon Adsorption	Chemical Scrubbing
Electrical Energy[1]			
kwh/1000 cu ft	122	146	146
kwh/yr (1 mgd)[2]	1285	1540	1540
kwh/yr (1 gpm)[3]	321	385	385
Fuel[1]			
million Btu/1000 cu ft	36.8	1	---
million Btu/yr (1 mgd)[2]	387	11	---
million Btu/yr (1 gpm)[3]	97	2.7	---

[1]Based on continuous operation.

[2]1 mgd indicates approximate sewage treatment plant capacity.

[3]1 gpm represents approximate thermal treatment plant capacity.

HEAT PUMPS

Some of the heat in sewage effluent can be recovered through the use of heat pumps. Since heat pumps operate on a refrigeration cycle their components and circuit diagram are similar to a conventional refrigeration system. A refrigeration system operates in a cycle with the net result being the absorption of some heat at a low temperature (at the evaporator), the rejection of a larger amount at a higher temperature (at the condenser), and a net amount of work done on the working substance or refrigerant (by the compressor). A heat pump provides relatively cool temperatures at the evaporator (less than 45^{0}F) and relatively warm temperatures at the condenser (greater than 90^{0}F). The changeover from heating to cooling is permitted either by valves in the refrigerant lines that effectively interchange the positions of the evaporator and condenser or by valves in the lines of the fluid that carry heat from source or to sink.

Heat pumps are classified by the type of heat source or heat sink and the distribution fluid. For example, a heat pump that uses water for a heat source or sink to condition air in a building is a water to air heat pump. Some common types of heat pumps include the following:

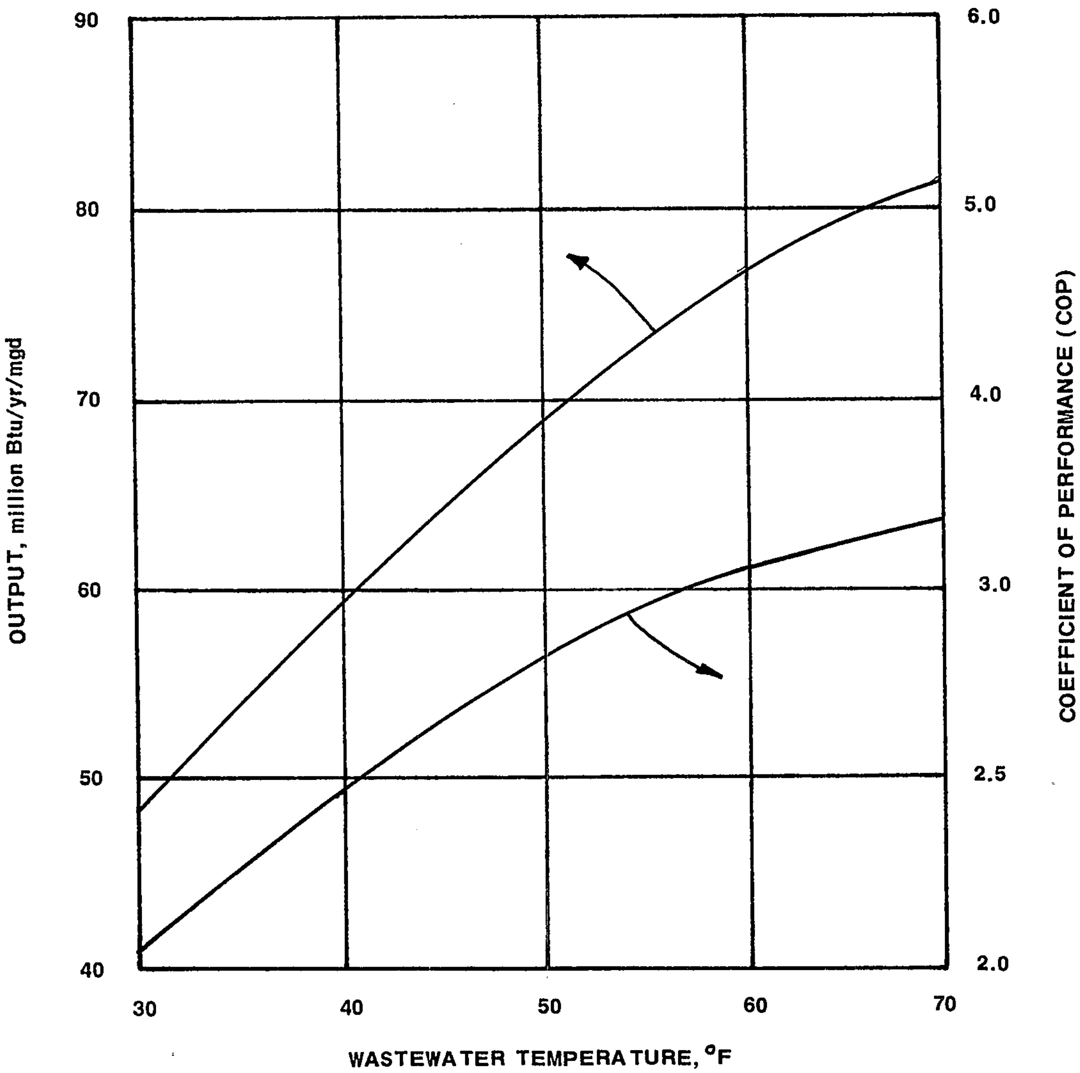
Heat Source/Sink	Distribution Fluid
Water	Water
Water	Air
Air	Air
Air	Water
Earth	Air

The choice of heat pump depends on several factors such as location, climate and application. The types of heat pumps best suited for application in wastewater treatment plants include the first three listed above: water to water, water to air and air to air.

Water to air and water to water heat pumps may use sewage effluent for the heat source or sink. The water to air heat pump can be used for space heating or space cooling. With sewage effluent at 50°F, relatively high efficiencies should be obtained in either cooling or heating operation. No such application of a heat pump is known to exist at this time. However, a water to water heat pump is planned for the wastewater treatment plant at Wilton, Maine. Its purpose is to extract heat from 50°F effluent for heating sludge digester influent. The total energy supplied by the heat pump will be 31 million Btu/yr with a coefficient of performance (COP) of 2.8. The COP indicates the quantity of heat derived from a given heat input. Figure 5-28 illustrates the varying output and COP that can be expected for a heat pump operating at various wastewater temperatures under the conditions at Wilton, Maine.

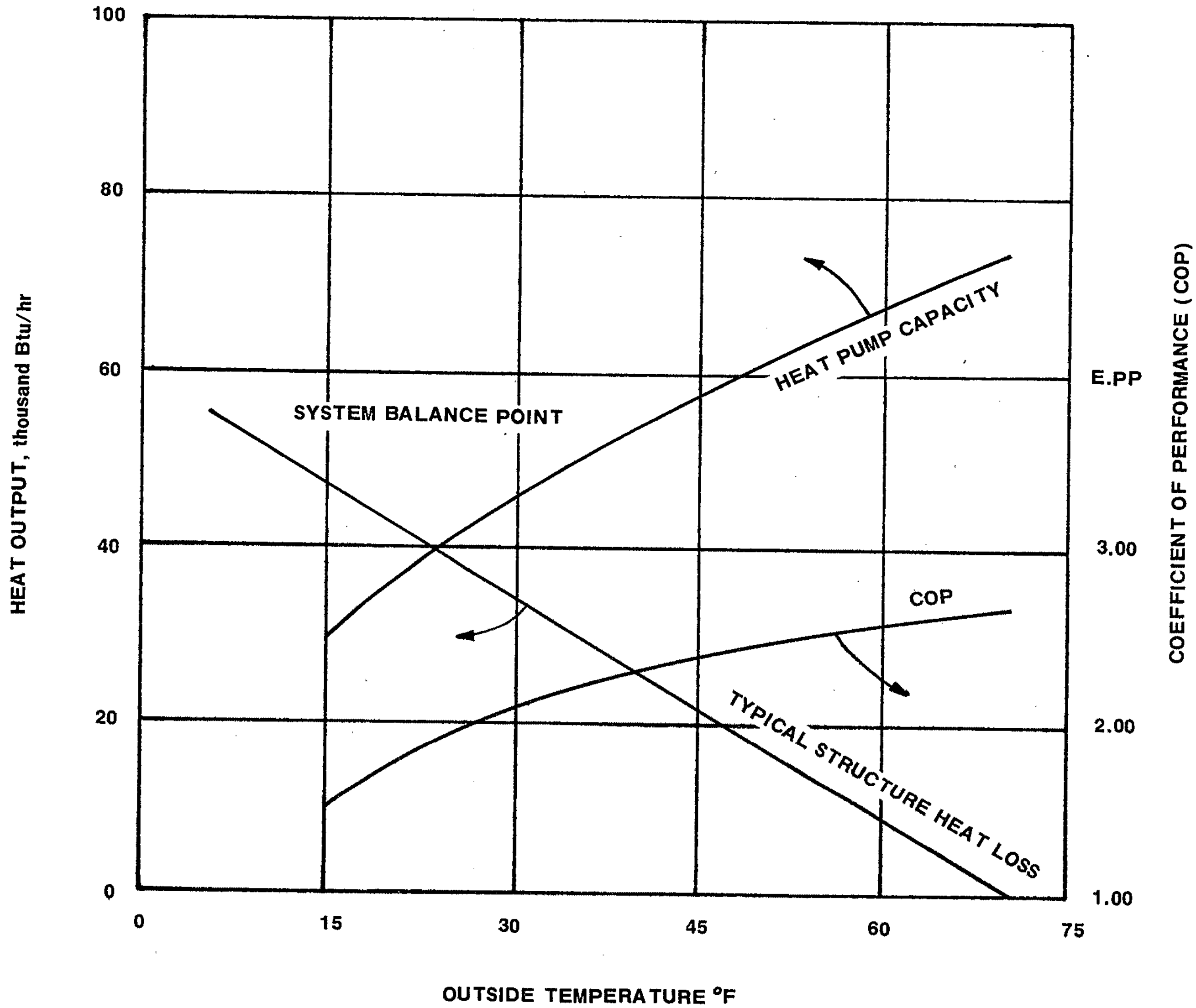
Heat pumps using the atmosphere as the source/sink are usually air to air systems used for space heating and cooling. A typical performance curve for such a heat pump on a heating cycle is shown in Figure 5-29. Curves of this type are available from manufacturers for specific systems and indicate the variability of the system COP and heating capacity as a function of the temperature of the heat source or outside air.

Also shown in Figure 5-29 is the heat loss of a typical structure. Because the heating capacity decreases with the outside air temperature while the building heat requirements are increasing, a temperature is reached which is defined as the system balance point. At this temperature the heat pump capacity equals the heating requirements of the building. For the example shown in Figure 5-29, the system balance point is 23°F. If the outside air drops below this temperature, supplemental heating will be required to maintain indoor design temperatures. The heat pump capacity and COP curves terminate at a heat source temperature of 15°F because this particular heat pump will not operate below that temperature. Outside air temperature below 15°F will require the use of a backup system to provide the entire heating load.



HEAT PUMP OUTPUT BASED ON WILTON PLANT DESIGN
OPERATING CONDITIONS FOR VARIOUS EFFLUENT TEMPERATURES

FIGURE 5-28



AIR TO AIR HEAT PUMPS
TYPICAL PREFORMANCE CURVE

FIGURE 5–29

Cost Estimates - Heat Pumps

The heat output capacity of the Wilton plant system is 320,000 Btu/hr at the condenser, while the cooling capacity at the evaporator is 228,000 Btu/hr. The unit is basically a water chiller modified to withstand the corrosive environment of chlorinated wastewater and will be a back-up source of heat for digester influent. The primary digester heat source in the Wilton plant is solar energy. It is expected that the heat pump will only operate about 100 hr/yr.

Estimated construction costs for water to water heat pumps similar to the Wilton installation are shown in Figure 5-30. Estimated operating and maintenance data are shown in Figures 5-31, 5-32 and 5-33. These cost curves are also applicable to water to air heat pump systems. Figure 5-34 shows the estimated construction cost for air to air heat pump systems; operation and maintenance data are shown in Figures 5-35, 5-36 and 5-37.

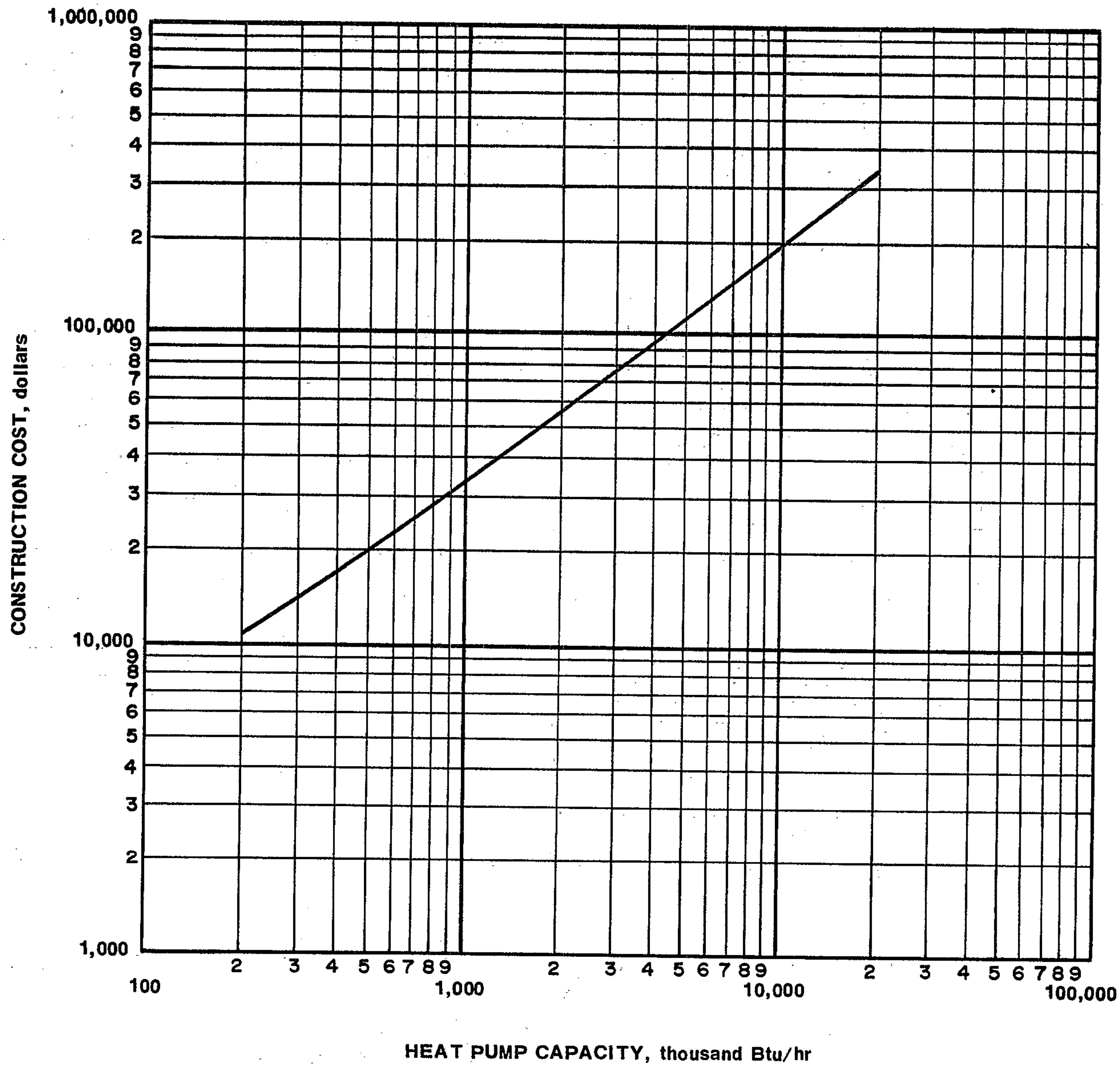
SOLAR ENERGY USE IN WASTEWATER TREATMENT PLANTS

Solar energy may be used for space and process heating in wastewater treatment plants through three different types of collector systems:

1. Active solar collection (water collectors)

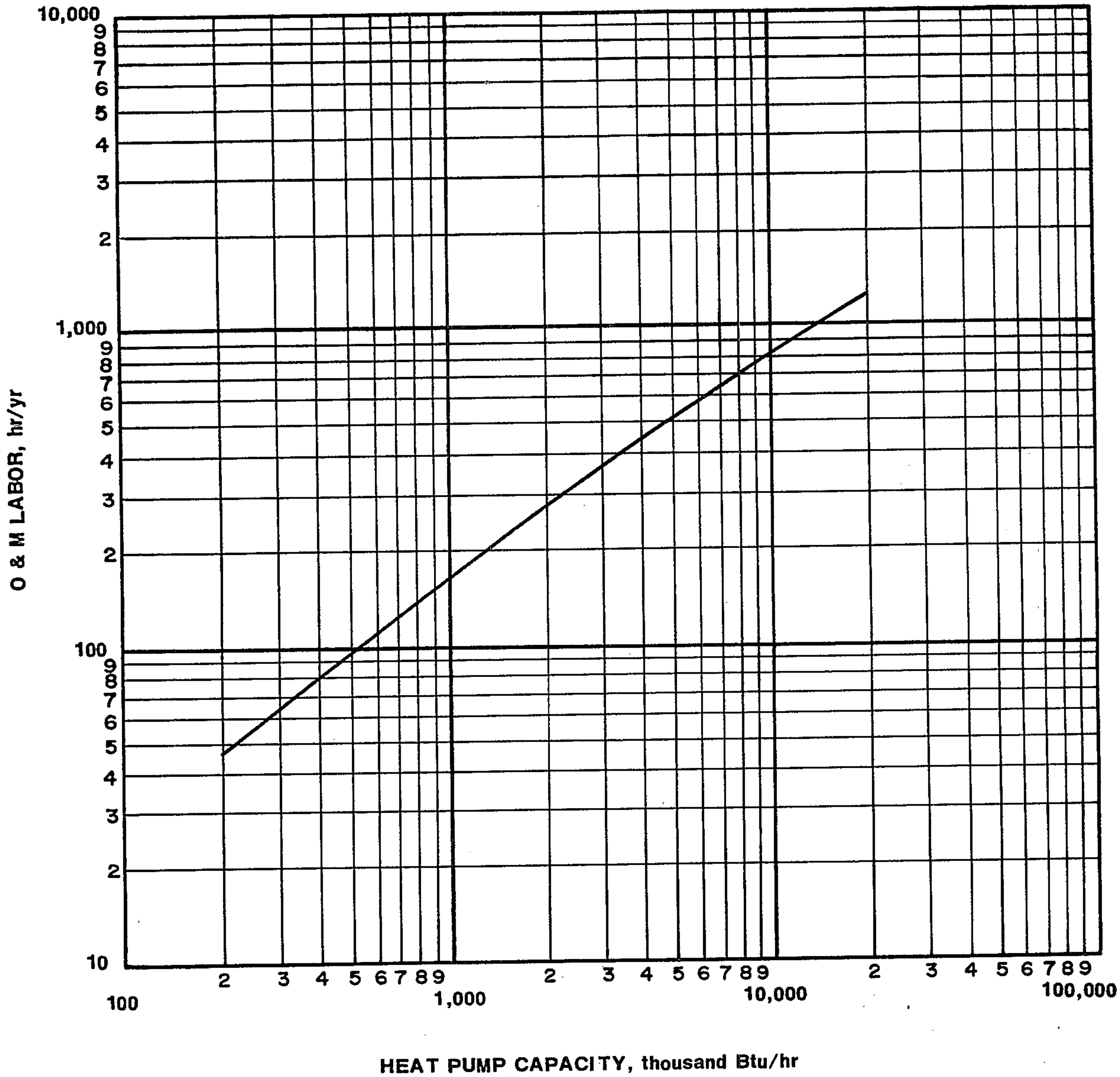
2. Passive solar collectors (insulated translucent panels)

3. Atmospheric solar collection (to be used by heat pump outside coil). The use of this type of system is discussed in the section on heat pumps.



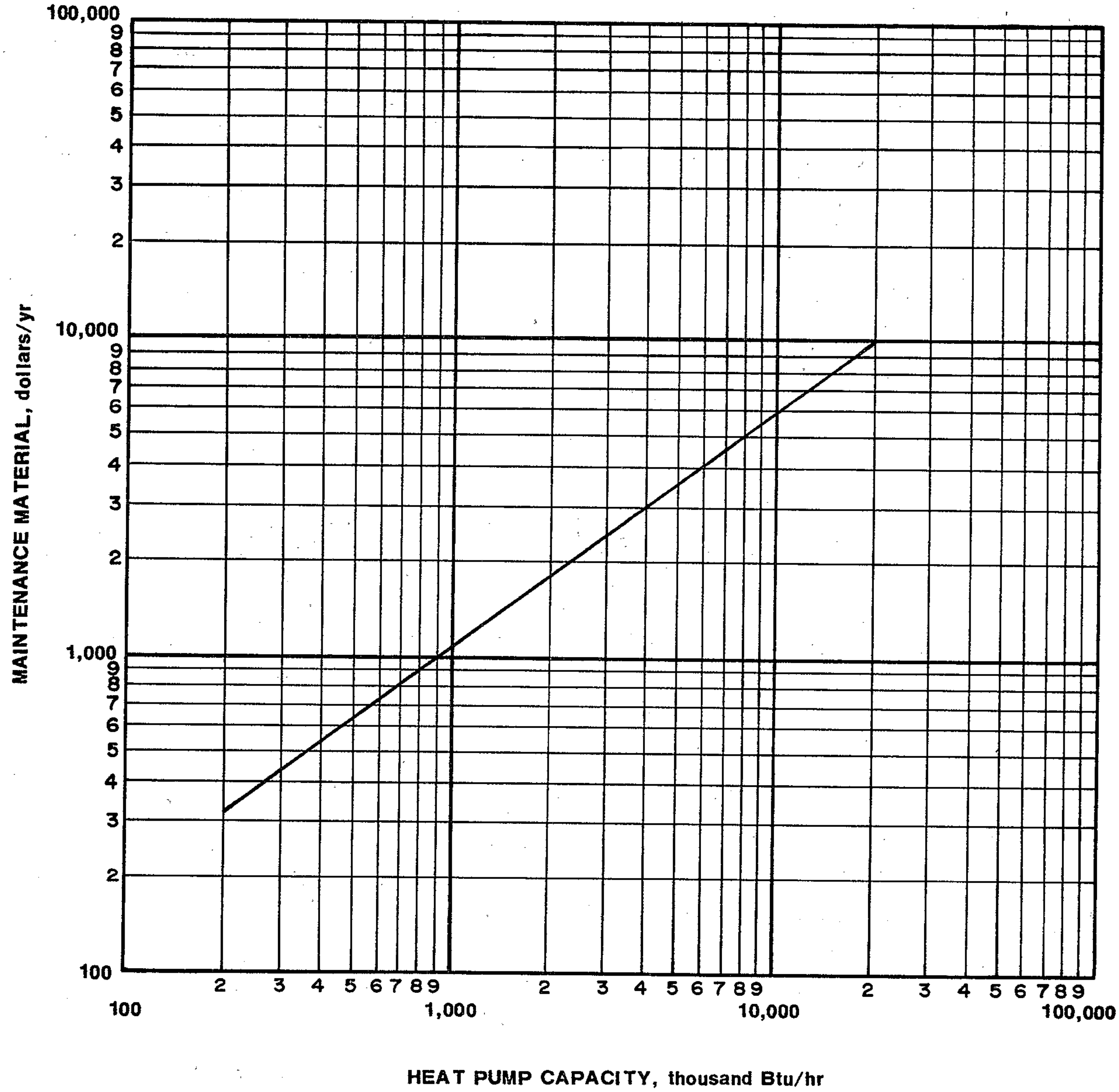
WATER TO WATER/WATER TO AIR HEAT PUMPS
CONSTRUCTION COST

FIGURE 5–30



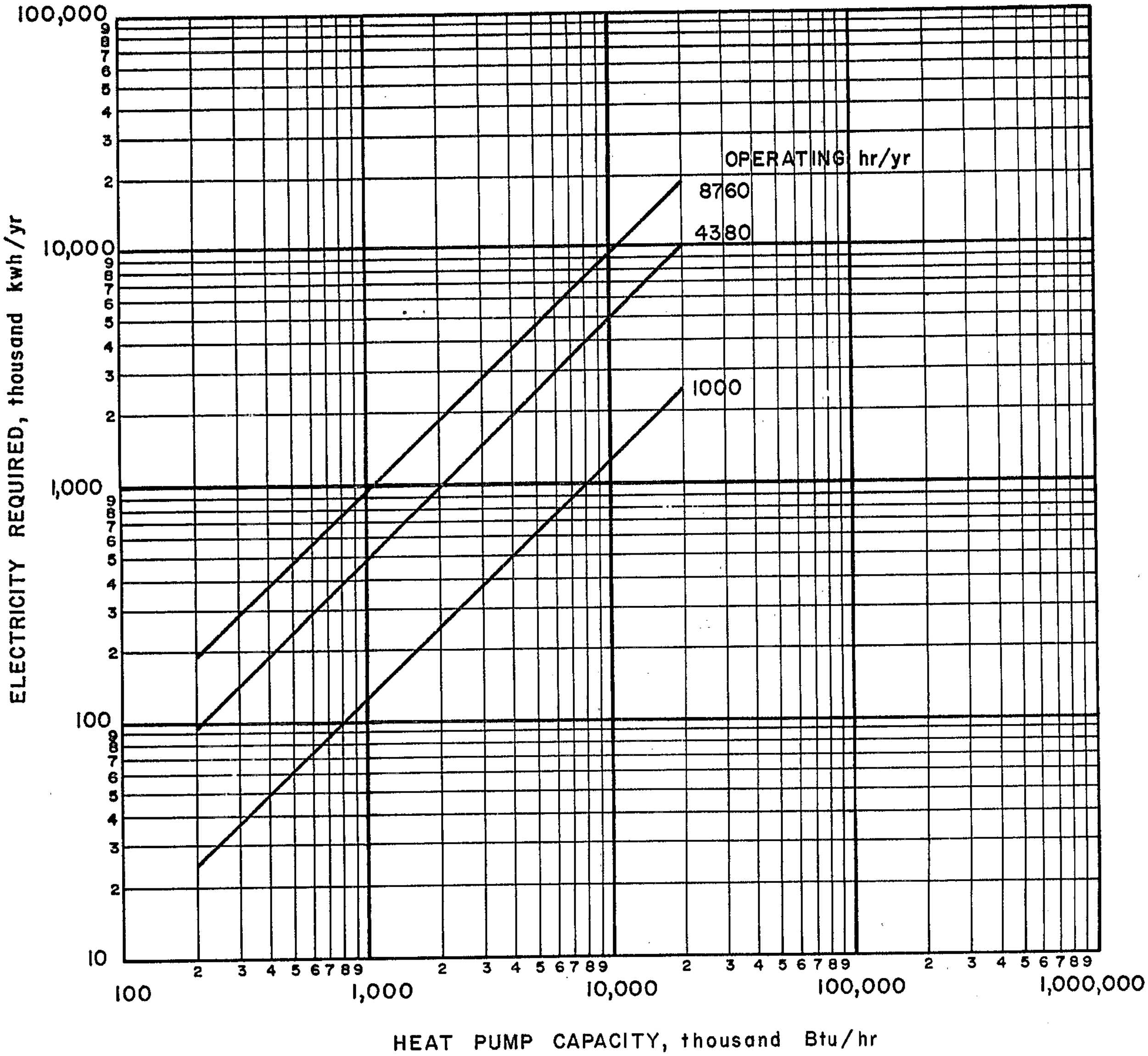
WATER TO WATER/WATER TO AIR HEAT PUMPS
O & M LABOR REQUIREMENTS

FIGURE 5-31



WATER TO WATER/WATER TO AIR HEAT PUMPS
MAINTENANCE MATERIAL COSTS

FIGURE 5-32

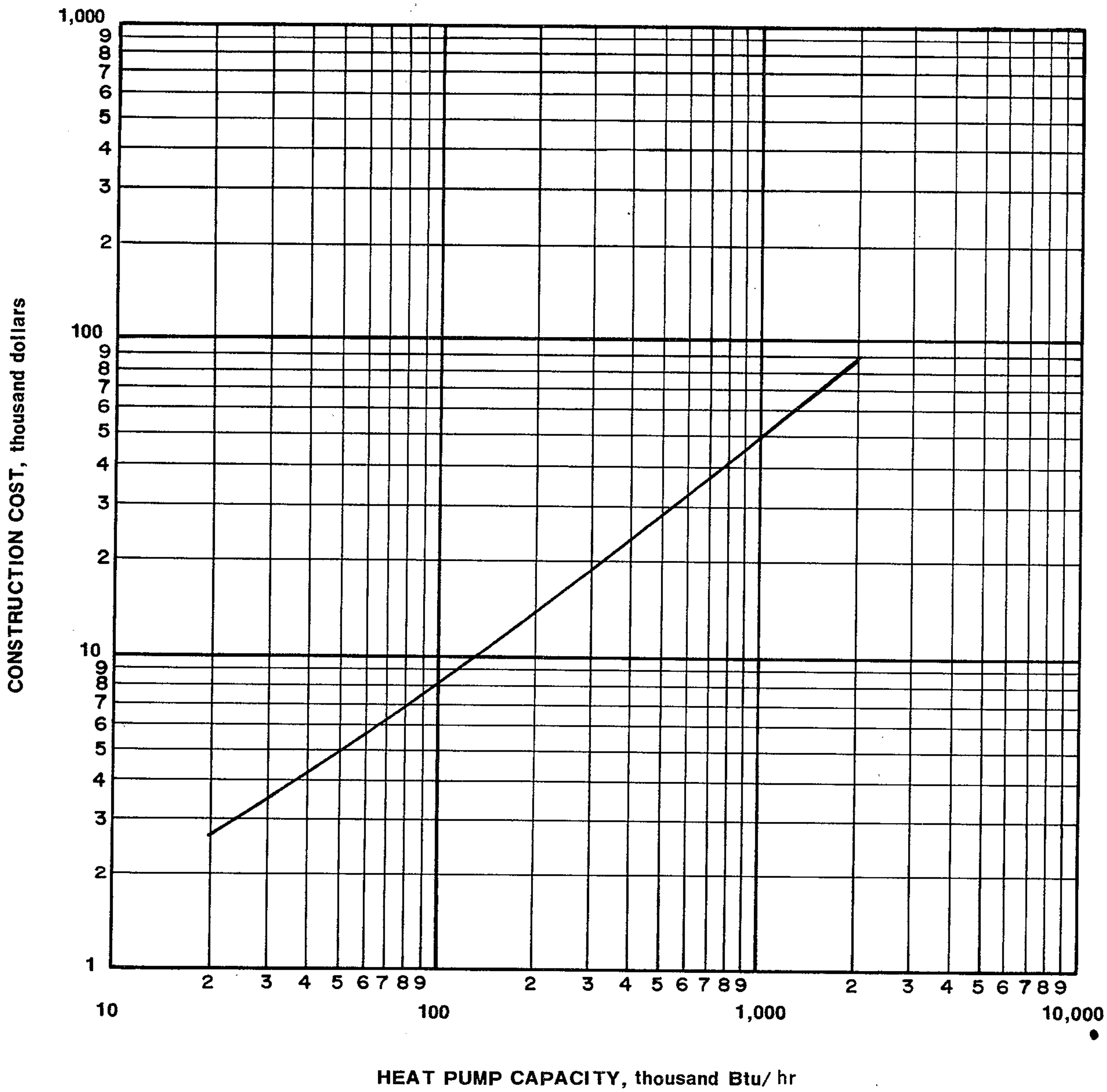


WATER TO WATER / WATER TO AIR HEAT PUMPS ENERGY REQUIREMENTS

OPERATING CONDITIONS:

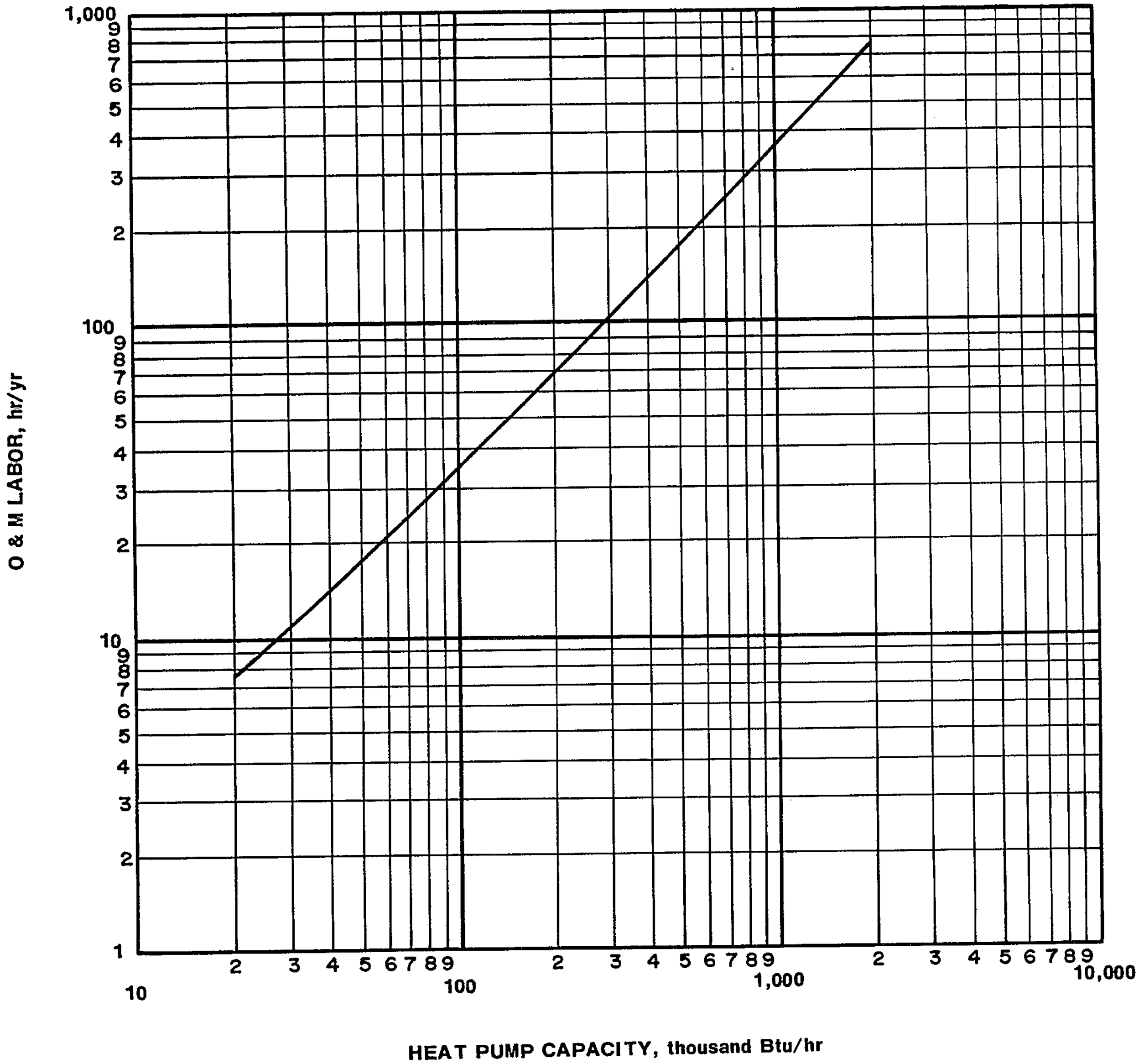
COP = 2.8
OUTSIDE TEMPERATURE = 50°F

FIGURE 5-33



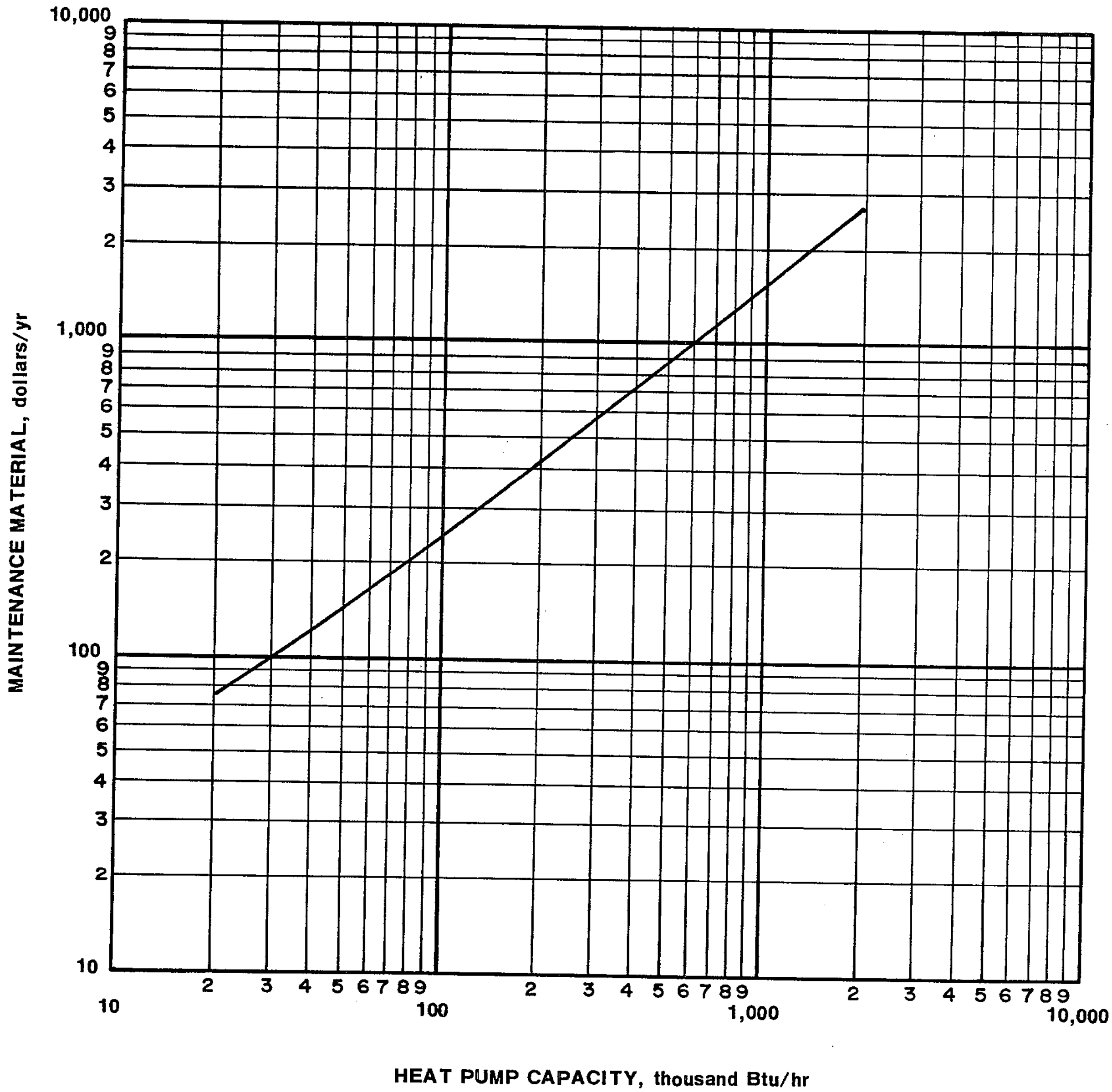
AIR TO AIR HEAT PUMPS
CONSTRUCTION COST

FIGURE 5-34



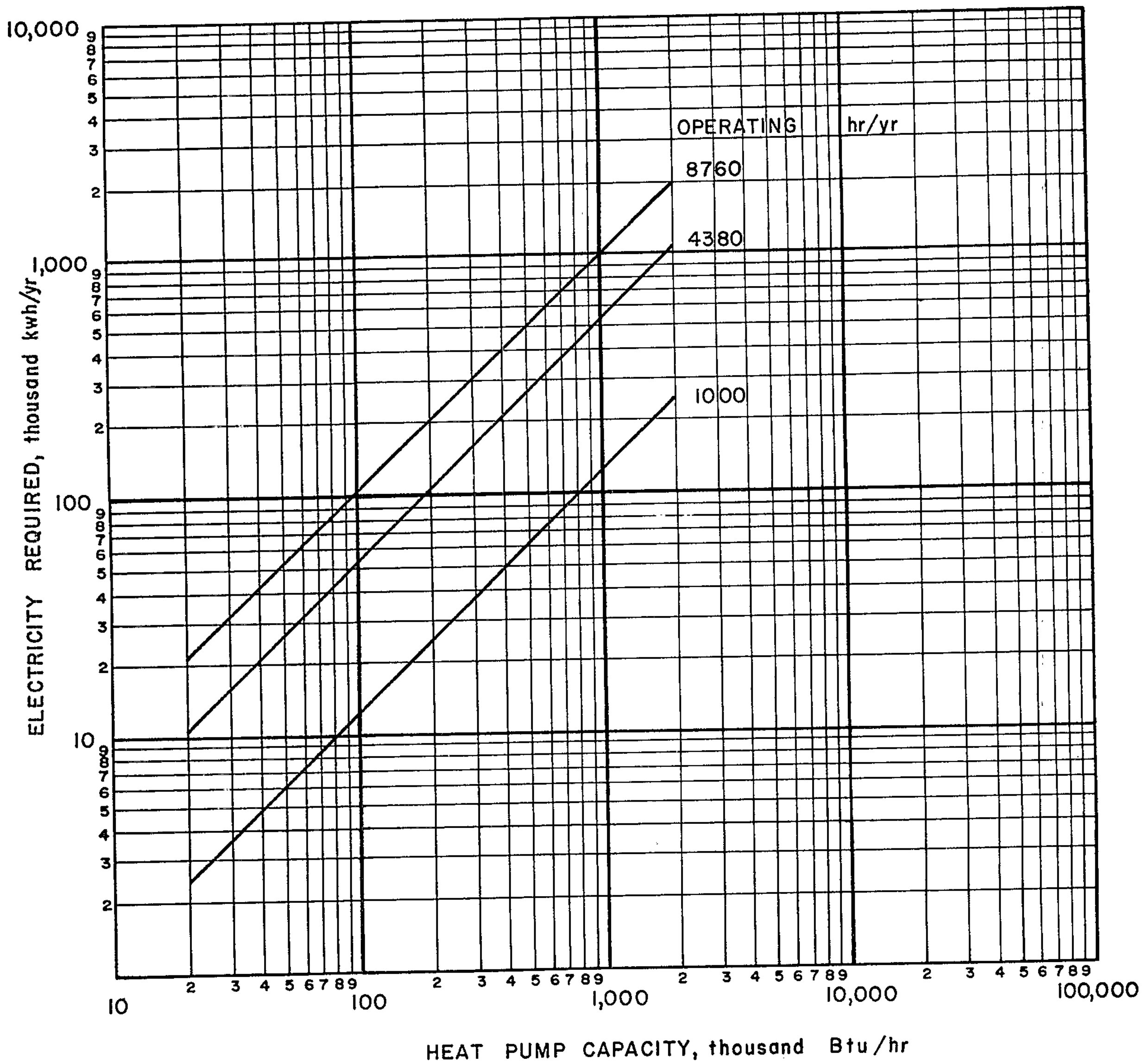
AIR TO AIR HEAT PUMPS
O & M LABOR REQUIREMENTS

FIGURE 5-35



AIR TO AIR HEAT PUMP
MAINTENANCE MATERIAL COSTS

FIGURE 5-36



AIR TO AIR HEAT PUMP ENERGY REQUIREMENTS

OPERATING CONDITIONS:

COP = 2.4
OUTSIDE TEMPERATURE = 45°F

FIGURE 5-37

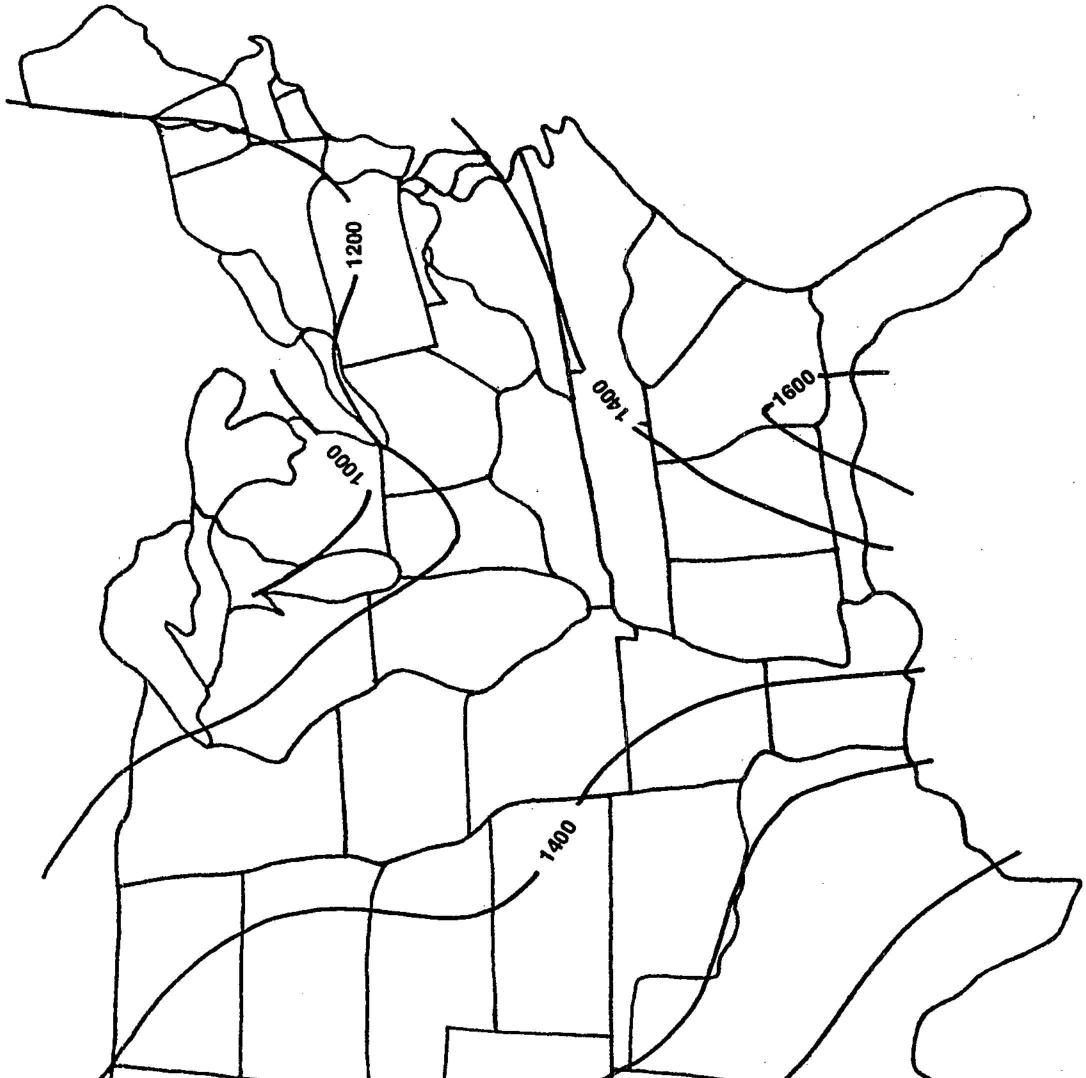
Solar Insolation

The solar energy, termed insolation or irradiation, available at a particular location on the earth varies greatly throughout the year due to atmospheric absorption and angle of the sun above the horizon. This variation in the United States is illustrated in Figure 5-38. The daily average variation in solar energy at three cities in California is shown in Figure 5-39. Data for solar insolation curves are compiled by the U. S. Weather Bureau and are available in several publications.[18,19]

Active Solar Collection

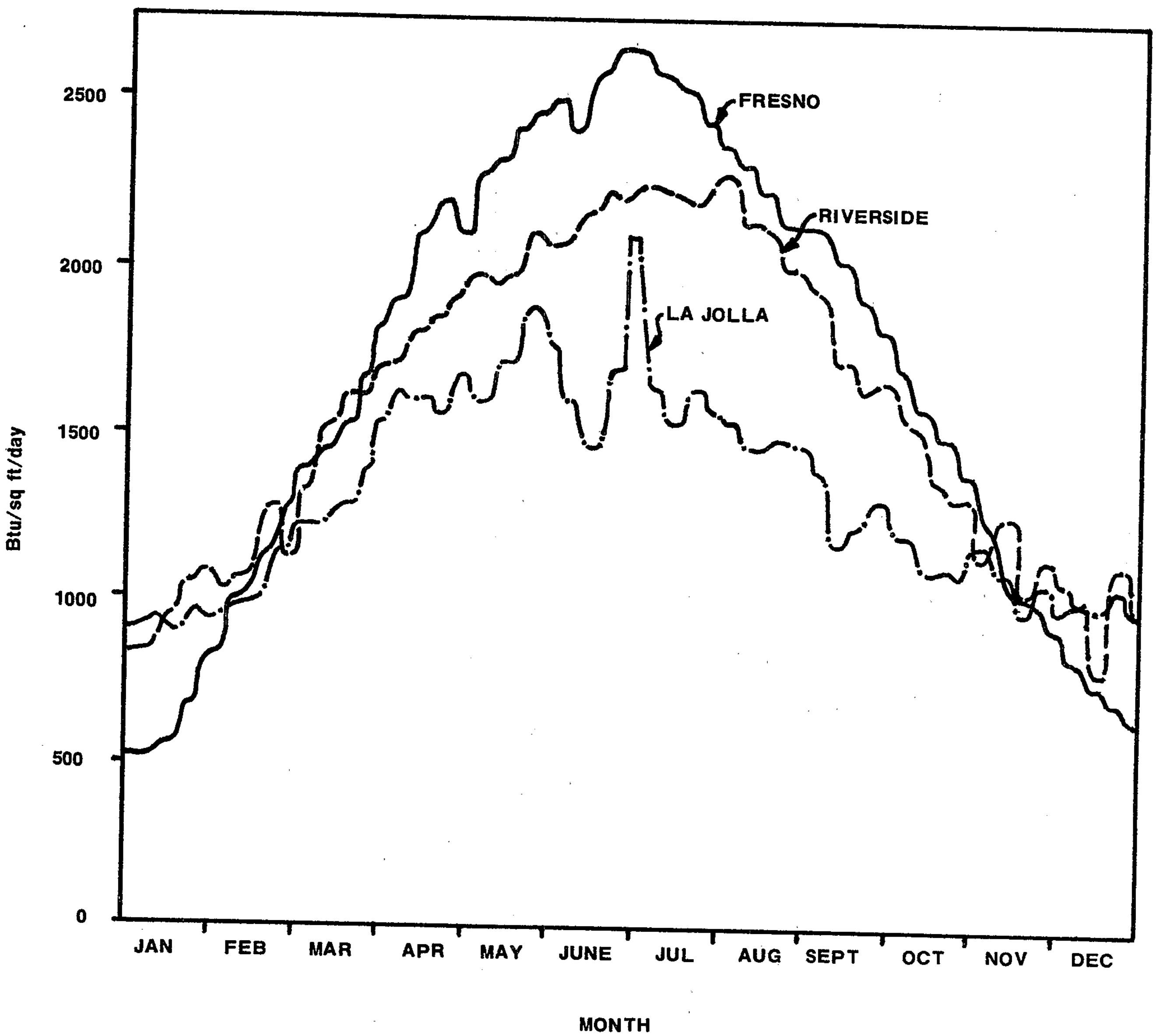
The sun's energy can be collected and utilized in various ways. The most common use of solar energy is by active solar collection. This type of system in general is composed of solar collector, heat storage system, heat exchanger and various pipes and pumps for circulating a working fluid which transfers the heat absorbed at the collector to the storage device. Common working fluids used are water, a water and glycol mixture and air. Typical storage devices are a large tank of water, a bed of rocks or a combination of the two. The working fluid is pumped through the collectors to the storage device throughout the day as long as the temperature of the fluid coming from the collector is higher than the temperature of the fluid in storage. For space and water heating purposes, fluid is circulated from storage through a heat exchanger and back to storage. A schematic of the general concept for space and water heating is shown in Figure 5-40.

The most common type of collectors are "flat plate" collectors. Other types of collectors such as concentrating and sun following collectors have been used and are available. Concentrating collectors use reflective devices or lenses to focus a large amount of solar radiation upon



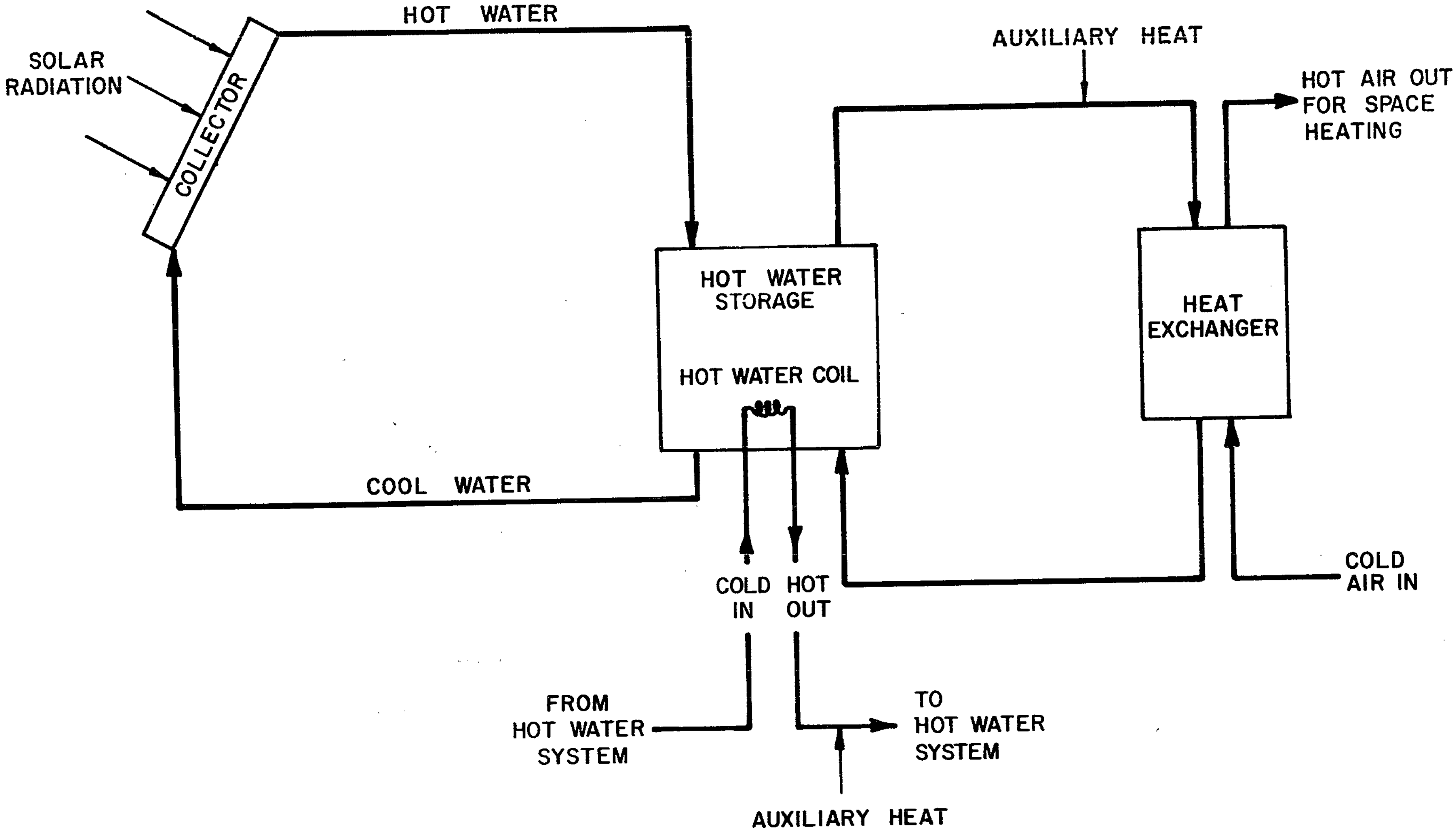
ANNUAL AVERAGE DAILY SOLAR INSOLATION
(Btu/sq ft)

FIGURE 5-38



DAILY AVERAGE VARIATION IN SOLAR ENERGY
AT THREE CITIES IN CALIFORNIA

FIGURE 5–39



SOLAR WATER AND SPACE HEATING SYSTEMS

FIGURE 5-40

a relatively small collection area. These devices normally require accurate tracking systems so that the sun's rays always strike the concentrating equipment at the proper angle. Because only direct radiation can be concentrated these devices are not very effective on cloudy days when diffuse radiation prevails. Due to many variables such as the amount of solar insolation, heat losses from reflection and radiation, differences in glazing surfaces and fluctuations in ambient temperature, collectors operate at continuously varying efficiencies throughout the day.

Materials with a fairly high heat capacity are used to store heat during periods when the sun is not available, such as night heating or periods of cloudiness. Water, with a heat capacity of 1.0 Btu/lb/^{0}F, is often used to store heat where freezing is not a problem. Water is usually the fluid circulated in collectors. A concrete or steel tank is the most common storage device. Rocks have a specific heat of about 0.2 Btu/lb/^{0}F and are also used, especially if the circulating fluid is air. Another device for storing heat, presently being investigated, is the heat of fusion for melting and freezing salt hydrates. These materials can store far greater quantities of heat for a given weight and volume of material (90 to 118 Btu/lb at 96 to 122^{0}F).

Passive Solar Collection

Passive solar collectors consist of translucent panels of glass, fiberglass, or plastic normally located in the wall or roof of a building. Solar energy passing through these panels is absorbed by surfaces and objects below. This concept was used in the design of the wastewater treatment plant in Wilton, Maine for the passive collection of solar energy into the clarifier and onto darkly painted masonry and concrete surfaces for the retention of heat in a building.[20] The heat collected from such a system depends on solar energy available and size of panels. For example, panels of the type used at the Wilton plant cover 960 sq ft, have a light transmission factor of 45 percent and a heat loss factor of 0.24 Btu/^{0}F/sq ft/hr.

Example - Solar System For Space Heating

Determination of the actual useful amount of solar radiation collected is a somewhat involved procedure. The continuously changing solar input to the collector plus the constantly varying collection efficiency suggest that an hourly or even minute by minute calculation for the entire year is necessary for accurate determination of the solar energy collected Computer programs are available to do such calculations. A simplified approach is used in this example by averaging the daily variations into monthly variations.

The treatment plant location used in this example is 40 deg latitude in the vicinity of Detroit, Michigan. Solar insolation data for this location, collector output and heat requirements for 2,000 sq ft floor area are summarized in Table 5-11. These data show that about 2,700 sq ft of collector area are required to heat a 2,000 sq ft building in December and January and virtually no heating is required in the summer.

Solar System Costs

Costs for solar systems vary considerably at the present time. For custom designed systems, costs as high as $80 per square foot have been reported.[21] Commercial flat plate collectors ranging from $4 to $15/sq ft, or more, are available. The less expensive units have no glazing or cover glass and are generally used for swimming pool heating. The more expensive units are applied to space and process heating and cooling. The glazed collectors generally

TABLE 5-11

SOLAR SPACE HEATING EXAMPLE DETROIT MICHIGAN

(1) Month	(2) No. Days	(3) Monthly Mean Temp. (°F)	(4) Deg-Day (°F-day/month)	(5) Solar Insolation (Btu/sq ft/month)	(6) Fraction of Monthly Sunshine	(7) Hourly Mean Solar Insolation (Btu/hr/sq ft)	(8) Collector Efficiency	(9) Collector Output (Btu/sq ft/month)	(10) Heating Requirement for 2,000 sq ft (mil Btu/month)	(11) Solar Collector Area Required For Heating 2,000 sq ft (sq ft)
Jan	31	25	1181	56110	0.35	242	0.42	8250	22.3	2700
Feb	28	30	1058	60536	0.46	240	0.43	11970	19.9	1660
Mar	31	35	936	72230	0.53	265	0.49	18760	17.6	940
Apr	30	50	522	69600	0.59	238	0.51	20940	9.8	470
May	31	60	220	70184	0.65	211	0.50	22810	4.2	180
June	30	70	42	66720	0.69	212	0.55	25320	0.8	30
July	31	75	0	69130	0.72	204	0.56	27870	0	0
Aug	31	70	0	69998	0.72	224	0.57	28730	0	0
Sept	30	65	87	66840	0.69	246	0.57	26290	1.6	60
Oct	31	55	360	63860	0.65	223	0.50	20750	6.8	330
Nov	30	40	738	53340	0.42	237	0.46	10310	13.9	1350
Dec	31	30	1088	50654	0.40	220	0.40	8100	20.5	2530

Column (4) from Table 5-1

Column (11) = Column (10) divided by Column (9) range from $12 to $15/sq ft. The costs for other system components and installation increases the cost to about $25 sq ft for a complete flat plate collector system.[21]

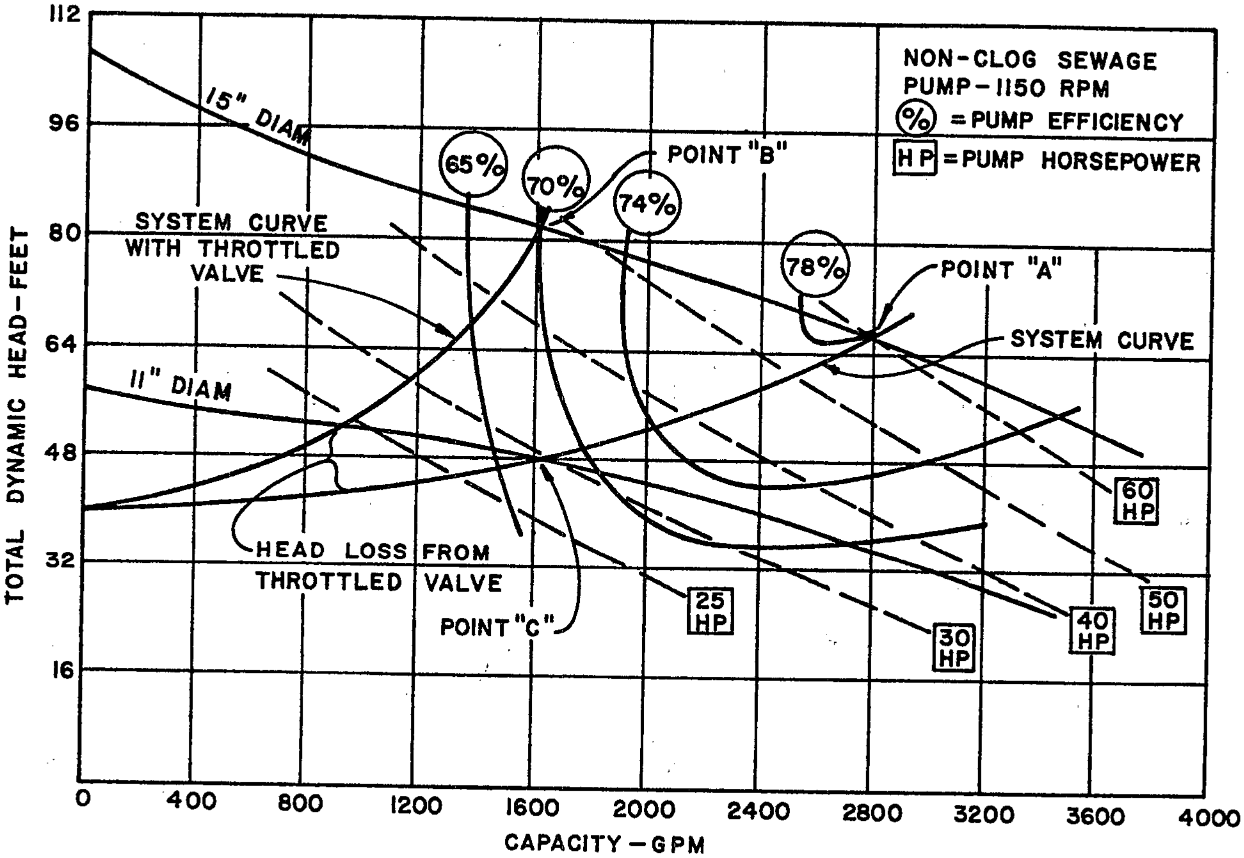
Passive solar collector costs vary from about $5 to $7/sq ft, depending on the size of each panel, thickness and material. Installation costs are about $1.50/sq ft.

ENERGY CONSERVATION IN EXISTING WASTEWATER TREATMENT FACILITIES - INVOLVING NO CAPITAL OUTLAYS

Reductions in energy use in existing treatment plants can be accomplished by several methods including: (1) adjusting pumping and air flow rates during periods of low flow, (2) optimizing the timing of sludge treatment processes such as thermal conditioning, sludge drying, and incineration, (3) varying the solids retention time in activated sludge processes, and (4) scheduling the use of various forms of in-plant (recovered) energy to minimize the demand for outside energy. The methods can vary from modifying equipment to installing new equipment, simply turning off unneeded lights, keeping air filters clean and changing working hours for plant personnel.

Pumping Adjustments

One of the prime users of energy in most plants is pumping. Typically, the pumps using the majority of the total pumping energy--influent, effluent and recirculation pumps--are of the centrifugal type. Centrifugal pumps normally have characteristics similar to those shown in Figure 5-41 which indicates that, for a given pump and impeller, as the pumping head is increased both flow and power consumption are decreased. As shown in the figure, partially closing the pump discharge



EFFECTS OF THROTTLING AND IMPELLER TRIMMING ON POWER REQUIREMENTS FOR PUMPS

FIGURE 5-41

valve creates an artificial head which results in moving the pumping point on the curve from "A" to "B". Such adjustments can be made to cover slack periods or the initial phases of plant operation when in- flows are low. Some caution must be exercised so that valves are not closed so far that they plug, that line velocities are not reduced to the point where solids will deposit, or that in cycling operations the pumps don't just operate longer at reduced efficiency with no savings in energy.

Several other methods are available to reduce pumping energy including: changes to the pump, changes in the number of pumps and changes in pump speed. If a pump is to be operated at a reduced capacity for a consi- derable period of time, energy can be saved by installing a smaller impeller in the same pump. As shown in Figure 5-41 by point "C", this method reduces flow, as does throttling, but reduces power consumption to a greater extent than throttling. A comparison based on the case shown in Figure 5-41 is given in the following tabulation:

Comparison of Energy Required for Pumping
at Reduced Flows

Condition	Flow gpm	Pump Efficiency Percent	Pump Input Power hp	Motor Input Power* kw
Initial Design (Point A)	2800	78	60	49
Throttled Discharge (Point B)	1600	70	48	40
Smaller Impeller (Point C)	1600	67	30	25

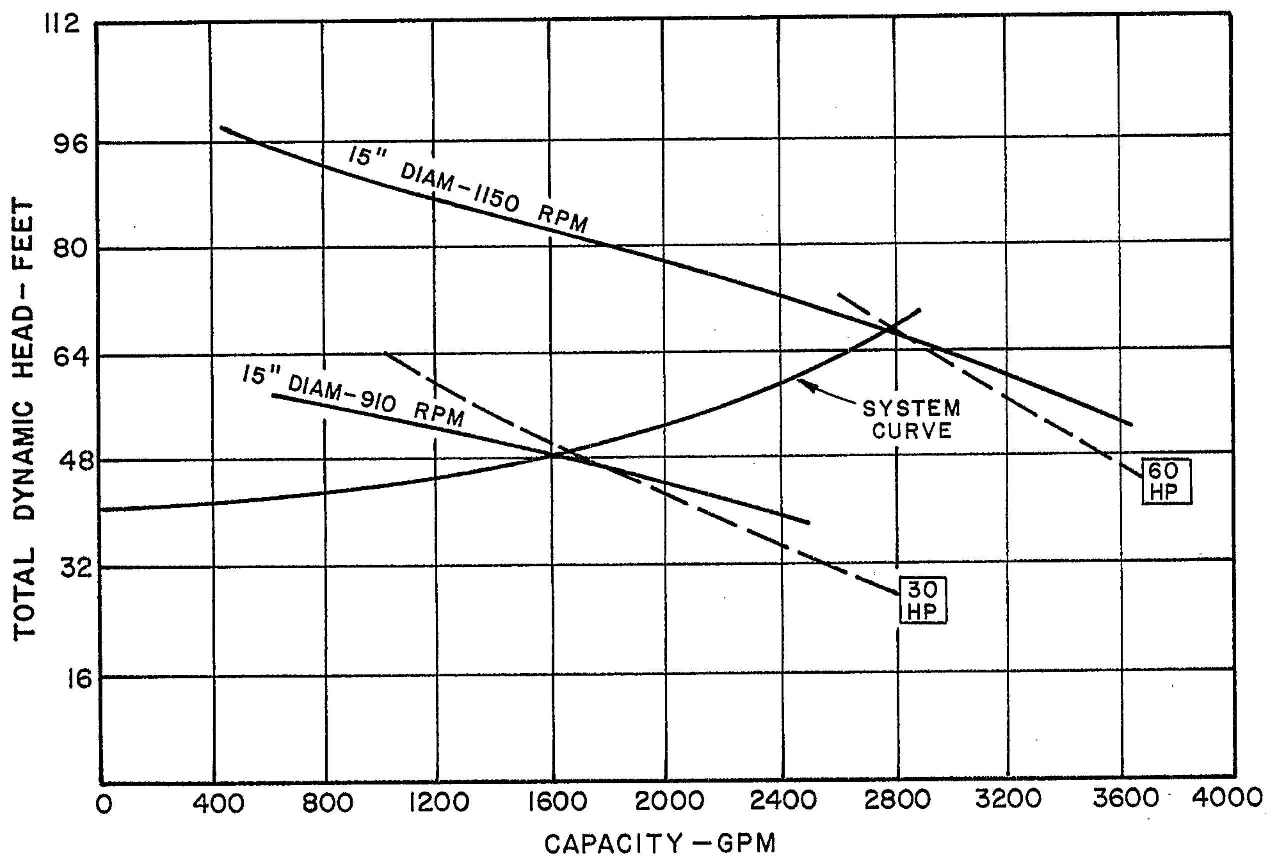
* Corrected for motor efficiency based on 75 hp motor

Perhaps the most common method to vary pumping rate and conserve pumping energy for larger plants is control or adjustment of pump speed. Speed can be controlled in several ways depending on the pumping conditions and the desire for automation. Simple, semi-permanent methods involve changing pulley sizes for belt-drives or changing motors to lower speed designs. As the desire for flexibility increases, drives using manually adjustable pulley and belt systems, two speed motors and various manually controlled electronic drives can be employed. These methods require only that operating personnel turn a handcrank, push a button or turn a knob to adjust pump speed.

For centrifugal pumps, the effect of a change in speed on pumping energy is illustrated in Figure 5-42. Note that reducing pump speed rather than trimming impeller diameter allows the use of the more efficient, full-size impeller and at the same time provides for a quick, easy way to increase pumping capacity should that become necessary. Operation at lower speed also results in longer pump life.

The next step in flexibility and control is variable speed pumping. In true variable speed pumping, pump speed is regulated automatically by either varying motor speed or by the use of a variable speed drive between the pump and motor. Speed is controlled to pace the pump flow in accordance with a selected process variable such as wet well level or discharge pressure. This method offers great flexibility and potential for energy savings. However, efficiency loss in the variable speed drive, initial cost of the drive and controller and increased maintenance cost of drive and controller must be taken into account and may offset any anticipated savings in energy. As with most energy-saving proposals, life-cycle cost and true benefits must be analyzed.

Not all pumps exhibit the characteristics indicated above for centrifugal pumps. Propeller or axial flow pumps normally exhibit the characteristic of an increasing power requirement for an increase in discharge



EFFECT OF SPEED REDUCTION ON
POWER REQUIREMENTS FOR PUMPS

FIGURE 5-42

head. Power requirements for positive displacement pumps vary almost in direct proportion to discharge pressure.

Energy savings can best be realized from these pumping systems, particularly from positive displacement systems, by varying pump speed. Nearly all of the speed control methods discussed above for centrifugal pumps may be used effectively with positive displacement pumps. Small positive displacement pumps, such as those used for chemical feeding, sludge pumping and activated carbon transfer are often equipped with built-in, calibrated means to control either the length or timing of their pumping strokes. Adjustments to these types of pumps are made easily and quickly, either manually or automatically. An adjustable timer can be used to control the percent of time the pump operates.

Energy savings can also be accomplished by sharing the pumping load among several pumps in a system. If multiple units are available, only the number of pumps necessary to handle the required volume need be operated at any time. Turn-down is easily accomplished by starting and stopping pumps.

An energy-saving concept often overlooked for both centrifugal and positive displacement pumping systems is the use of internal combustion engines equipped with adjustable or variable speed controls. Manual control of an engine's speed requires only an adjustment to the throttle or governor mounted on the engine. Automatic control requires installation of a speed controller costing only a few hundred dollars.

Pump Maintenance and Operation

Besides the adjustments to pumps discussed above, several factors related to operation and maintenance of pumping systems affect energy consumption. The plant maintenance program should provide for periodic checks of the systems' efficiency and corrections should be made where indicated. Some items to check are:

1. Partial clogging or closures in valves, pipelines and pumps.

2. Wear on pump impellers and casings increasing clearances between fixed and rotating parts thereby decreasing efficiency. Installation or replacement of wear rings or adjustment of the impeller setting is all that may be required to regain original efficiencies.

3. Improper adjustment of packing causing binding of the pump shaft. Power requirements can be increased up to 5 percent and shaft wear can be greatly accelerated by improper adjustment of packing.

4. Improper settings for start-stop controls causing too frequent cycling of pumps and resulting in increased power costs as well as increased wear on the pumping system.

Another area of review for potential energy conservation is over-pumping of sludge from settling basins. Over-pumping usually results in pumping of sludge with an undesirably low solids content. In addition to increasing the energy required to pump the sludge, there can be a chain effect throughout the plant. Over-pumping often occurs during low-flow periods and results either from a failure to reset the pumping cycle to reflect the new flow or sludge production condition or from purposely over-pumping to avoid any possibility of any septic sludge floating on the basin surface.

The effects of pumping sludge with 4 percent solids versus 5 percent solids include: (1) increase of 20 to 25 percent in initial pumping energy, (2) increased volume of sludge can affect loadings, efficiencies and energy requirements for thickeners, supernatant return pumps, chemical feeding and mixing equipment, digester heating systems and dewatering systems, and (3) adverse effects on digester gas production and incinerator operation.

It should also be noted that under-pumping can result in loss of clarifier removal efficiency, increased odors, and additional loading on secondary treatment processes. Pumping must, therefore, be optimized under a variety of conditions for each plant.

Aeration System Adjustments

Aeration or oxygenation in secondary treatment is, like pumping, one of the greatest users of energy in treatment plants. Frequently, energy required for aeration in activated sludge plants far exceeds all other uses in the plants. Because of this, the possibility of savings deserves a great deal of attention by operating personnel.

In conventional diffused-air plants, the primary energy user is the blower. Like pumps, blowers can be either centrifugal or positive displacement (centrifugal blowers are used almost exclusively in large plants and are used quite frequently in small plants).

Centrifugal blowers can be controlled in much the same way as discussed above for centrifugal pumps. Air flow can be controlled by partial closure of a throttling valve on the blower discharge, by changing impeller design, or by changing speed. One of the easiest, most efficient and most common ways, however, is by adjustment of the valve on the suction side of the blower. This method reduces energy consumption more than throttling the discharge valve for the same reduction in air flow. Figure 5-43 illustrates the effects of the two methods of throttling to achieve the same reduced flow. Note that since the restriction in the inlet to the blower changes the pressure and volume of the inlet stream, point "C" representing the operating condition with a throttled suction does not fall on the original characteristics curve. Because most blower installations already provide the necessary valving, the only expenditures are for operating labor.

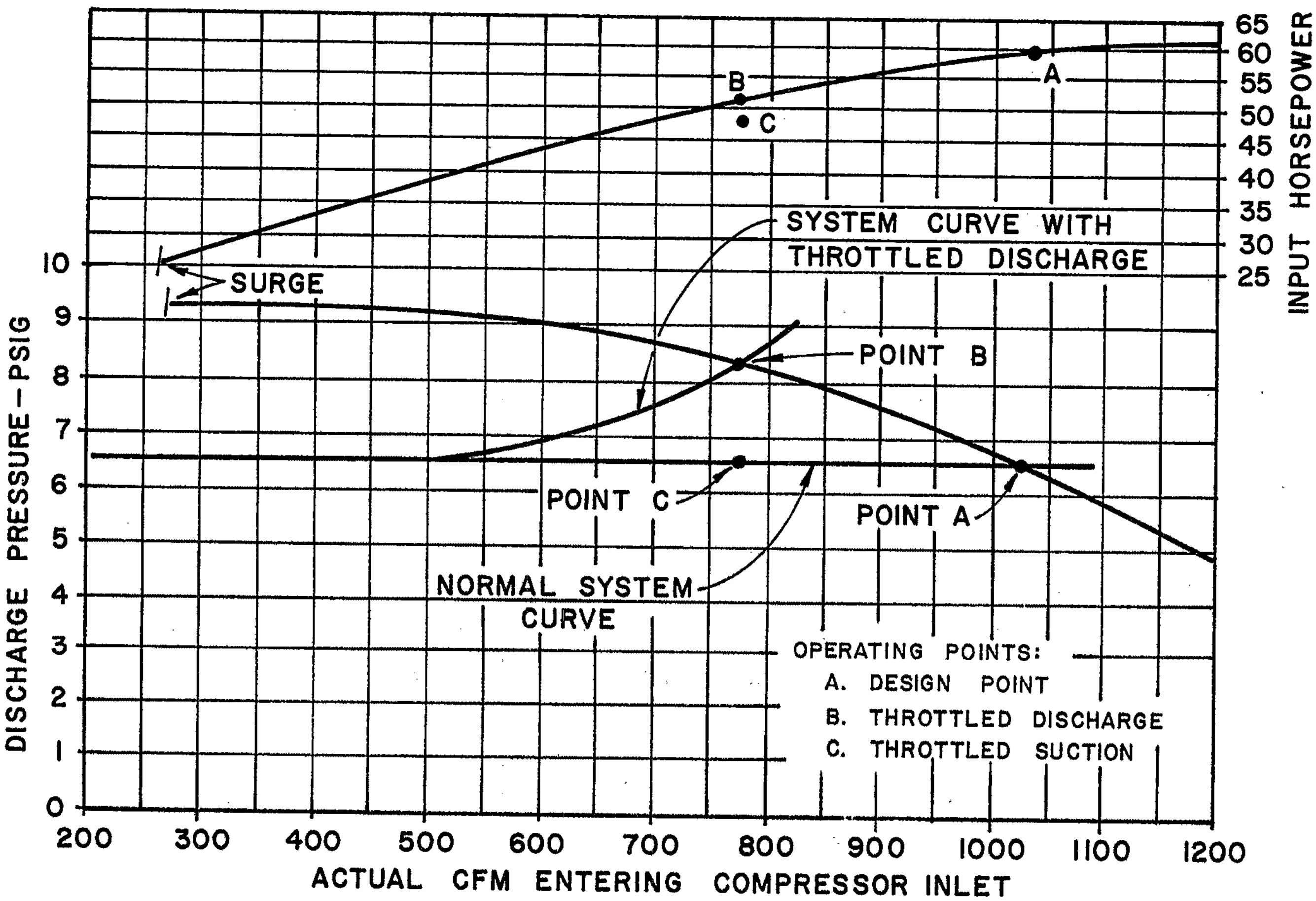
Control of the suction valve can be easily and inexpensively automated and controlled from a program matching historic daily variation in flow or oxygen requirements, from the influent flow meter or from dissolved oxygen monitors in the aeration tanks.

Air flow and hence energy consumption also can be controlled for positive displacement blowers. Here, as with positive displacement pumps, control of speed or the use of several units are the only ways to effectively reduce energy consumption.

Related to savings through control of air flow are savings through maintenance. Blowers, too, have bearings, seals, clearances, etc. which must be properly maintained to minimize energy use. Likewise, air filters and diffusers must be kept clean. Dirty filters and diffusers can account for increased pressure drops of up to 20 percent for some systems.

Effects of Solids Retention Time on Overall Energy Utilization

Management of the use of electrical energy at treatment plants by manipulating the solids retention time (SRT) results in a tradeoff between aeration basin power and additional sludge production. The amount of



EFFECTS OF THROTTLING ON POWER
REQUIREMENTS FOR CENTRIFUGAL BLOWERS

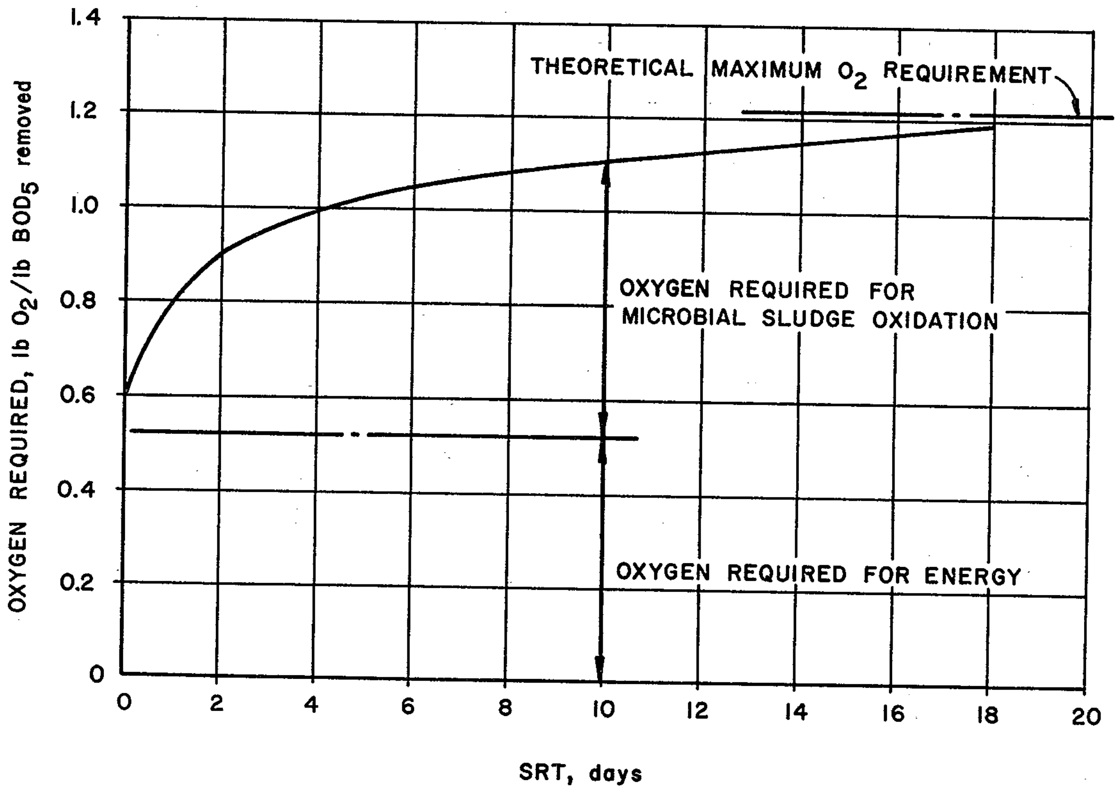
FIGURE 5-43

energy used in the aeration basin is a function of the oxygen demand in the aeration basin. Figure 5-44 shows the theoretical oxygen requirement per pound of BOD versus SRT. The practical limits of SRT vary from 3 days to about 15 days and by varying the SRT, the energy requirements may vary more than 20 percent.

Sludge production increases with decreasing SRT. Figure 5-45 shows the theoretical sludge production per pound of BOD removed. The waste sludge quantity is predicated on an effluent solids concentration of 20 mg/l. Over the 3 to 15 day SRT range, the amount of waste activated sludge varies from 0.58 lb/lb BOD_5 to 0.42 lb/lb BOD_5.

The energy associated with disposal of the solids depends on the sludge treatment and disposal methods used. For instance, if the sludge is to be digested, the net plant energy utilization would not change since oxygen demand not satisfied in the aeration basin would need to be satisfied in the aerobic digester. On the other hand, if the sludge produced is to be treated in an energy-intensive system prior to disposal, it may be prudent to increase the SRT to reduce solids production. The reverse situation would apply to a low energy use disposal system.

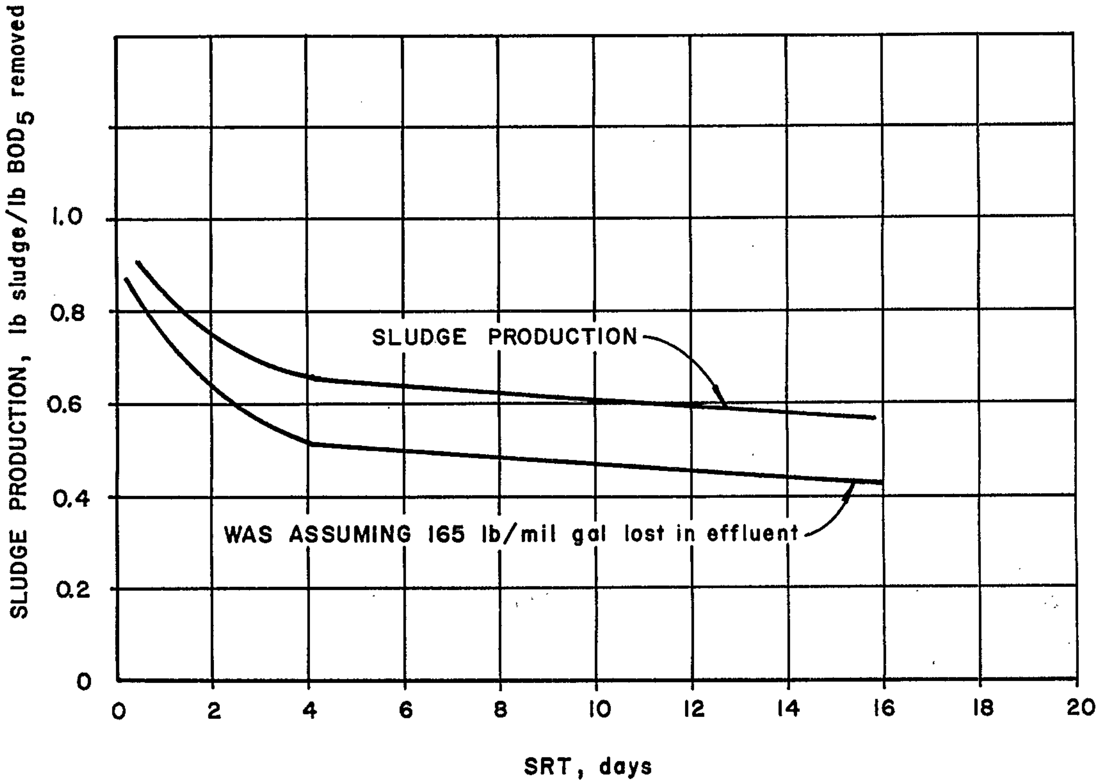
It is presumed that any modification of the SRT would not affect the effluent quality to such a degree that less than the required quality results; that nitrification in the aeration basin must be considered; and the turn-down capability of the aeration equipment is such that power utilization is a direct function of oxygen demand. In practice, these limitations can be met; however, there are few plants having the capability to do so.



SOLIDS RETENTION TIME AND OXYGEN REQUIREMENT

(OXYGEN REQUIRED FOR NITRIFICATION MUST BE ADDED — NITRIFICATION REQUIREMENT IS NOT INCLUDED IN THIS CURVE)

FIGURE 5-44



SOLIDS RETENTION TIME
AND SLUDGE PRODUCTION

FIGURE 5-45

To exemplify the magnitude of the energy use for varying SRT values an example is presented in Table 5-12 for waste activated sludge which is thickened, dewatered and hauled to disposal. The example is a moderate energy use system and, without consideration of secondary energy requirements for polymer, indicates that a short SRT should be maintained.

Intermittent Operation of Sludge Treatment Processes

The following discussion considers the intermittent operation of three sludge treatment processes: heat treatment, dewatering and incineration. The discussion will center on energy implications, but will also consider costs. The situations considered for the three processes are abbreviated in detail from the analyses which should be made in actual situations. In studies for actual cases, costs of constructing and operating sludge storage tanks, variations in utility rate structures for changing demands, labor required for clean-up after each operating cycle, and many other items must also be reviewed in greater detail.

1. Heat Treatment - Energy requirements for heat treatment processes have been summarized previously in this chapter. As noted, an input heat energy of approximately 900 Btu/gal is required for thermal conditioning. This figure varies as the process and reactor conditions vary to the point where the process becomes energy-producing. The energy requirements given represent the total heat input to the boiler and reflect the overall efficiency of the system during continuous operation at design capacity. The overall efficiency takes into account the efficiency of the boiler and heat transfer systems and the heat lost to atmosphere through radiation.

TABLE 5-12

SOLIDS RETENTION TIME AND ENERGY USE
10 mgd SECONDARY PLANT

Influent to aeration - 945 lb solids/mil gal
1300 lb BOD/mil gal

SRT, days	3	9	15
Aeration			
lb O_2/lb BOD	0.96	1.14	1.22
lb O_2/day	12,480	14,820	15,860
WAS			
lb WAS/lb BOD	0.58	0.46	0.42
lb WAS/yr	2,752,000	2,183,000	2,000,000

Energy Required, million kwh/yr

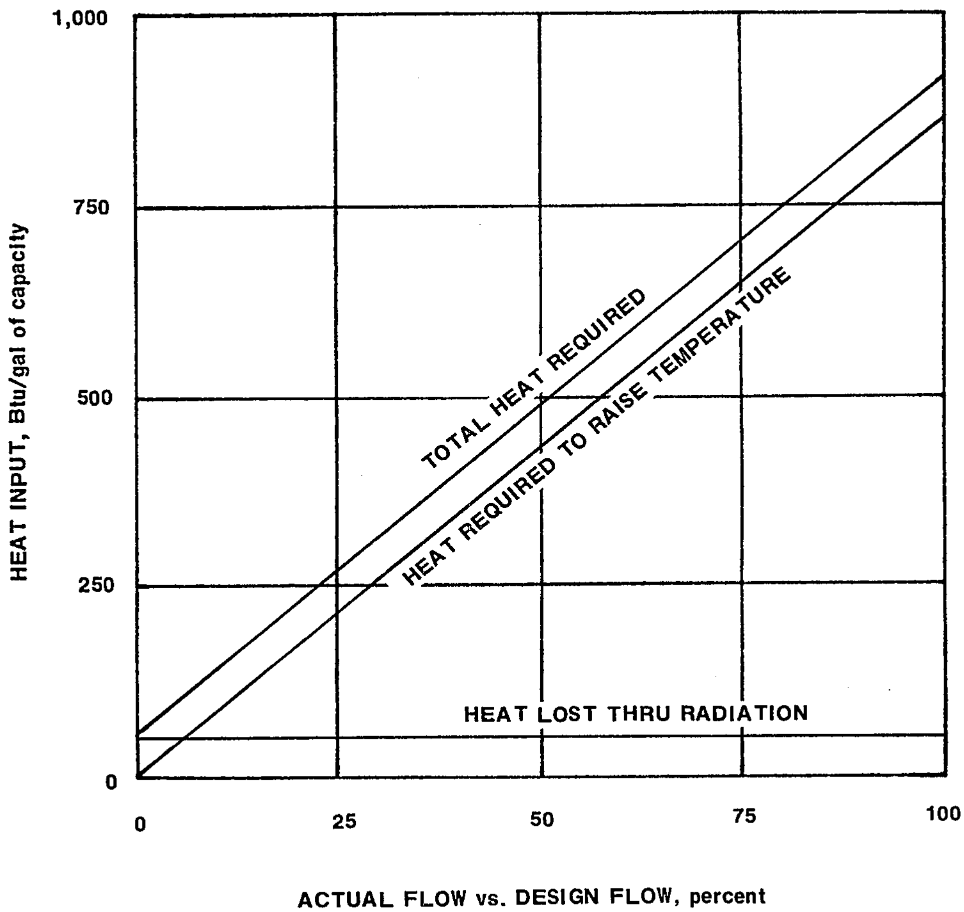
Aeration	4.60	5.40	5.80
Pumping	0.01	0.01	0.01
Air Flotation	0.14	0.11	0.10
Vacuum Filter	0.08	0.07	0.06
Haul	0.06	0.05	0.04
TOTAL	4.89	5.64	6.01

When a thermal conditioning system is operated intermittently, the 900 Btu/gal heat input is still required. In addition, however, each time the operation is discontinued the system cools and must be reheated on start-up. Since after cooling there is no heat outflow from the reactor to preheat the incoming sludge, the entire heating load must be supplied from the boiler system. Approximately 260,000 Btu/gpm of system capacity is required for a high temperature, wet oxidation plant. This indicates that a considerable amount of excess heat energy must be expended if the schedule for intermittent operation requires frequent cycling and points out that from an energy-effectiveness standpoint operating cycles should be as long as possible. In actual plant operation, this can be done by operating continuously for two or three days at a time rather than for one shift per day every day.

In underloaded plants, some partial offsetting of the requirement for start-up energy can be realized by operating at full capacity even though intermittently. Because the system operates at the same temperature regardless of flow, heat is lost to the atmosphere at a nearly constant rate and becomes a more significant portion of the total heat required as the flow decreases. Figure 5-46 illustrates the fraction of heat lost to the atmosphere by operating at different percentages of design capacity.

A decrease in the consumption of electrical energy is usually noted for intermittent operation where no waste heat recovery is practiced. This results primarily from the increase in efficiency of process equipment as its size increases. Overall, the energy requirement increases as the number of operating cycles increases.

The greatest potential for savings from intermittent operation is in labor. The smaller the plant the greater the savings. Operating



HEAT REQUIREMENT FOR THERMAL CONDITIONING SYSTEM
AT LESS THAN DESIGN FLOW

FIGURE 5-46

labor accounts for over 60 percent of the total operation and maintenance costs for a 4 gpm, continuously operated plant. This figure drops rapidly as plant size increases, but still amounts to over 25 percent for a 400 gpm plant. Estimated costs for continuous and intermittent operation of a small plant treating a sludge flow of 4 gpm are shown in Table 5-13. Treating the equivalent of 4 gpm (corresponding to a sewage flow of 1 mgd) of sludge during five day shifts a week rather than continuously reduces the operating labor cost from $35,000 per year to $10,500 per year. Energy costs for the same conditions increase from $5,100 per year to $9,800 per year. For an operating schedule of one shift per day, five days per week, the intermittently operated plant will require a capacity of approximately 17 gpm. The analysis in Table 5-13 indicates that even with the increased energy consumption, cost for operating the larger plant intermittently is much lower than that for operating the smaller plant continuously. The difference between the two is reduced significantly, however, when amortized construction costs are added to determine total annual costs.

Table 5-13 also shows a similar breakdown of costs for a 40 gpm heat treatment plant (corresponding to a sewage flow of 10 mgd). Here, again, energy requirements increase when the plant is operated intermittently while the total operating costs continue to be lower. At this size, however, amortized construction cost more than offsets the savings in operating cost making the total annual cost of intermittent operation approximately 50 percent more than for continuous operation.

This review of heat treatment system operation indicates that: (1) The total costs for each system must be analyzed to determine if intermittent operation is cost-effective and, if so, what intermittent schedule produces the minimum cost, (2) Intermittent

TABLE 5-13

COMPARISON OF CONTINUOUS AND INTERMITTENT OPERATION
OF A HEAT TREATMENT PLANT

ITEM	COST[1,2]			
	1 mgd		10 mgd	
	Continuous	Intermittent[3]	Continuous	Intermittent[3]
Operating Labor	$35,000	$10,500	$52,500	$24,900
Maintenance Labor	9,100	2,600	11,900	5,200
Energy	5,700	9,800	62,500	96,000
Materials & Supplies	7,500	2,300	13,200	6,500
Total O & M	57,300	25,200	140,100	132,600
Cost per gallon	1.64	0.72	0.40	0.38
Construction Cost[4]	48,300	59,200	100,200	238,800
Total Annual Cost	105,600	84,400	240,300	371,400
Cost per gallon	3.00	2.40	0.69	1.06

[1]Costs are in dollars/year.

[2]Based on sludge volume of 4 gpm per mgd.

[3]Operation 5 days per week, one shift per day.

[4]Amortized at 7% for 15 years for continuous operation and at 7% for 20 years for intermittent operation.

operation of new plants not yet operating near their design capacities will normally be cost-effective based on operating costs alone. Only detailed analyses can show if a plant should be oversized to allow intermittent operation at design flows, and (3) As plant size increases the cost-to-size relationships change such that possible benefits from intermittent operation are reduced.

2. Dewatering - Physical processes which are operated at or near ambient temperature are the most amenable to savings through intermittent operation. Energy is used in these processes to drive mechanical equipment which can be started and stopped without the energy loss that occurs in processes operated at elevated temperatures. Also, because the efficiency of mechanical and electrical equipment usually increases as the size of the equipment increases, and equipment operated near design capacity has greater efficiency, operating intermittently at full-load results in greater overall system efficiency.

   An example of a dewatering system consisting of chemical conditioning and vacuum filtration is used to illustrate the potential for energy savings from the dewatering processes. Table 5-14 shows the energy requirements for 1 and 10 mgd plants operated intermittently and continuously. The data shows that intermittent operation can reduce energy consumption by approximately 45 percent for a 1 mgd plant and by over 20 percent for a 10 mgd plant. As the size of the plant increases, the saving continues to decrease, but at 100 mgd the saving is still about 15 percent.

   The total operating and maintenance costs for the above cases are also reduced through intermittent operation. The savings are approximately 20 percent for both 1 and 10 mgd plants.

TABLE 5-14

ENERGY REQUIREMENTS FOR CONTINUOUS AND INTERMITTENT

OPERATION OF A VACUUM FILTRATION SYSTEM

Treatment Plant Size	Energy Required, kwh/yr			
	1 mgd		10 mgd	
Operation	Continuous	Intermittent	Continuous	Intermittent
Vacuum Filtration	32,000	17,400	145,000	108,300
Chemical Conditioning	2,800	1,200	7,800	5,200
Storage	---	500	800	4,200
TOTAL	34,800	19,100	153,600	117,700

Notes:

1. Based on treatment of digested primary and waste activated sludge.
2. Intermittent operation is for five 8-hour shifts per week.

The summary of estimated costs as shown in Table 5-15 indicates that additional construction costs offset the savings in operating costs in a 1 mgd plant and the total annual costs are nearly the same. In a 10 mgd, however, construction costs increase with increasing capacity at such a rate that total annual cost for intermittent operation is almost 15 percent greater than for continuous operation.

3. Incineration - Incineration, like most physical and chemical processes for treating sludge can be operated intermittently but, because of the high temperatures involved, there is generally no reduction in energy consumption unless the periods between running cycles are quite long and/or waste heat recovery is employed. As with heat treatment, energy consumption may actually increase for intermittent operation.

Fuel requirements for incineration can be divided into three categories:

Auxiliary - fuel needed to assist with drying and combusting the sludge;

Start-up - fuel required to heat the incinerator to operating temperature at the beginning of each cycle; and

Maintenance - fuel need to maintain a desired temperature in the incinerator when it is not burning sludge.

The amount of auxiliary fuel required depends primarily on the amount of moisture and volatile material in the sludge as illustrated in Figure 5-23. On a unit basis, it can be assumed nearly constant whether the equipment is operated continuously or intermittently.

TABLE 5-15

COSTS FOR CONTINUOUS AND INTERMITTENT OPERATION OF A VACUUM FILTRATION SYSTEM[1]

Operating Mode	1 mgd Continuous	1 mgd Intermittent	10 mgd Continuous	10 mgd Intermittent
O & M Costs ($/yr)[2]				
Energy	900	500	3,800	2,900
Labor	10,500	8,700	46,900	35,100
Materials & Supplies[3]	3,700	2,700	19,200	14,200
Total O & M Costs	15,100	11,900	69,900	52,200
Cost per ton ($/ton)	67	53	31	23
Construction Cost ($)	114,600	176,100	272,800	692,500
Amortized Construction Cost[4]	10,800	14,200	25,500	66,800
Total Annual Cost ($/yr)	25,900	26,100	95,400	108,800
Cost per ton ($/ton)	116	118	43	49

1 Based on treating digested primary and waste activated sludge thickened to six percent solids
Filter loading is 4 lb/hr/sq ft
Chemical additions are 10 percent lime and 5 percent $FeCl_3$

2 O & M costs are based on: electrical energy at $0.025/kwh, labor at $7.00/hr.

3 Costs for materials and supplies do not include costs for chemicals.

4 20 year life and 7% interest for continuous operation and 30 year life and 7% interest for intermittent operation.

Requirements for start-up fuel are determined by the design of the incinerator, the initial and final temperatures involved and the heating time, while maintenancne fuel requirements are set by the design of the incinerator and the desired temperature. A trade off between start-up and maintenance fuel requirements determines the schedule of intermittent operation for a given set of conditions. Since, on a per hour basis, requirements for start-up fuel are typically 5 to 10 times the requirements for maintenance fuel, and heating and cooling times for incinerators are long, a wide variety of conditions must be considered in order to select the optimum schedule. Whether to let the furnace cool at all during periods when not in use or, if it is allowed to cool, how low to carry the temperature must be determined for each proposed schedule.

An example of fuel requirements for incineration of a typical dewatered sludge from a 5 mgd secondary treatment plant is summarized in Table 5-16. It should be noted that this example serves only as a comparison of several cases for one particular set of conditions. The following conclusions are based on the conditions assumed for this example: (1) continuous operation of a smaller incinerator requires less fuel than intermittent operation of a larger incinerator handling the same quantity of sludge, (2) for frequent cycling as in Case 2, less fuel will be used if incinerator operating temperatures are maintained between cycles, and (3) as the time between operating cycles increases as in Case 3, less fuel will be used if the unit is allowed to cool all the way to ambient temperature.

Table 5-17 shows the estimated costs for three of the cases presented in Table 5-16. These estimates indicate that amortized construction

TABLE 5-16

FUEL REQUIREMENTS FOR CONTINUOUS
AND
INTERMITTENT INCINERATION OF SLUDGE

Case	1	2A	2B	3A	3B	3C
Operation [1]	Continuous	Intermittent			Intermittent	
Schedule	___	8 hr/day - 5 day/week			24 hr/day - 3 day/week	
Incinerator size, sq ft	85	353			195	
Mode	___	maintain operating temp. between cycles [2]	cool to 1000^0F between cycles	cool to ambient between cycles	maintain operating temp between cycles	cool to 1000^0F between cycles
Fuel, million Btu/yr						
Auxiliary	5500	5500	5500	5500	5500	5500
Start up	___	___	620	220	___	70
Maintenance	___	740	470	___	310	250
Total	5500	6240	6590	5720	5810	5820

1 Treatment of 1825 tons per year of sludge from a 5 mgd primary/secondary treatment plant. Solids content of the sludge is 16 percent.

2 Operating temperature is 1500^0F.

TABLE 5-17

COST FOR CONTINUOUS AND INTERMITTENT INCINERATION OF SLUDGE

Case[1]	Costs, dollars per year 1	2A	3A
Operating Cost[2]			
Fuel	16,500	18,700	17,200
Electrical Energy	9,000	6,800	7,500
Labor	32,200	24,900	26,700
Materials & Supplies	6,000	3,300	4,000
Total O & M	63,700	53,700	55,400
Construction Cost[3]	169,900	349,200	254,900
Total Annual Cost	233,600	402,900	310,300

1 See Table 5-16 for description of cases

2 O & M costs are based on:

Fuel = $3.00/million Btu
Electricity = $0.025/kwh
Labor = $7.00/hr

3 Amortized -- 20 year life and 7% interest

costs far outweigh operating costs in all cases, and therefore, continuous operation of small incinerators will result in lower total cost than intermittent operation of a larger incinerator. The cost estimates also indicate that the total energy consumption - fuel and electrical energy - is nearly constant for all cases. This result is similar to most other sludge treatment processes in that labor is the most significant part of operating cost.

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CHAPTER 6

EXAMPLES - ENERGY REQUIREMENTS, RECOVERY AND RECYCLING

The purpose of this chapter is to illustrate the use of the curves and data presented in Chapters 3, 4 and 5. It is important to recognize that the analyses in this chapter are strictly in terms of energy utilization and in no way endorse the cost effectiveness of treatment trains described. The cost effectiveness of the alternative systems must be determined on a case by case basis, where factors such as facility size, capital cost of energy recovery systems, and labor costs are important.

Primary and secondary energy requirements are presented for each unit process in 14 example treatment systems. A flow diagram and effluent quality goals are given for each example system. Energy requirements, potential alternate energy sources, and energy recovery and recycling methods that might be used, are given in a table and also shown in a block diagram for each example.

EXAMPLE 1 - TRICKLING FILTER (ROCK MEDIA) WITH COARSE FILTRATION

This example is a 30 mgd plant in the Southern U.S. with high rate, rock media, trickling filters followed by coarse filtration. Sludge is treated by anaerobic digestion and digester gas is used as fuel for internal combustion engines. Engines are direct coupled to pumps and also used to generate electricity for motors and plant electrical equipment. Waste heat from the engines is recovered as low pressure steam and used to supply part of the digester heating requirement. The remainder of the digester heating requirement is supplied by solar energy heat pump systems. Solar energy is also used for building heating. It is assumed that raw sewage and trickling filter pumping, and building heating and cooling energy requirements can be reduced about 10 percent by conservation measures.

Data in the table and bar chart for this example indicate total treatment process requirements of 4.4 million kwh/yr and 33.8 billion Btu/yr. It can be calculated, by the methods outlined in Chapter 5, that about 49.3 billion Btu/yr is available in digester gas. Engines are direct coupled to pumps to furnish the following requirements:

	Thousand kwh/yr
Raw sewage	420
Trickling filter	1,350
Coarse filter	930
TOTAL	2,700

The remaining digester gas is used to generate 2.1 million kwh/yr of electricity for use as follows:

	Thousand kwh/yr
Preliminary treatment	23
Primary sedimentation	30
Secondary sedimentation	35
Chlorination	290
Gravity thickening	8
Anaerobic digestion	1,000
Sludge drying bed	15
Building cooling	90
TOTAL	1,491

This example system results in an excess of about 0.6 million kwh/yr which could be used for on-site generation of hypochlorite, thus reducing the secondary energy requirement for chlorine.

Assuming 25 percent of the fuel used by the engines is recovered as waste heat, the total waste heat recovered from the engines is 12.3 billion Btu/yr. All of this recovered heat is used to heat the digesters. Assuming influent sludge temperature of 60^0F, the digesters require another 19.4 billion Btu/yr for heating. In this example, half of this heat is supplied by heat pump and the other half by solar energy.

EXAMPLE 2 - ACTIVATED SLUDGE WITHOUT INCINERATION

This example is a 30 mgd activated sludge plant in the Southern U.S. using anaerobic digestion for sludge treatment. The digester gas is used as fuel for internal combustion engines which are direct coupled to pumps and also used to generate electricity. Waste heat from the engines and solar energy are used to heat the digesters.

Data in the table and bar chart for this example indicate total treatment process primary energy requirements of 8.9 million kwh/yr and 33.8 billion Btu/yr. About 71.2 billion Btu/yr is available in digester gas and this is utilized as follows:

Engines direct coupled to pumps and blowers:

	Thousand kwh/yr
Raw sewage pumping	420
Air flotation thickening	1,250
TOTAL	1,670

Electricity generated with digester gas:

	Thousand kwh/yr
Primary sedimentation	30
Aeration - mechanical	4,400
Anaerobic digestion	438
TOTAL	4,868

As shown in the table for this example, an additional 1.8 million kwh/yr must be supplied from outside sources. As in Example 1, all the waste heat recovered from the engines (about 17.7 billion Btu/yr) is used to heat the digesters, with the additional required 14 billion Btu/yr supplied by heat pump and solar energy.

EXAMPLE 3 - ACTIVATED SLUDGE WITH INCINERATION

This example is a 30 mgd activated sludge plant in the Northern U.S. with sludge disposal by incineration. Waste heat recovered from the incinerator, calculated by the methods given in Chapter 5, Figure 5-24 result in 132 billion Btu/yr. This heat is used for electricity generation by a steam turbine at the rate of 11,400 Btu/kwh (which is an efficiency of 32.8% - this efficiency may vary depending on the type of equipment used), resulting in 13.2 million kwh/yr of electricity to furnish the following requirements:

	Thousand kwh/yr
Raw sewage pump	420
Preliminary treatment	102
Primary sedimentation	30
Aeration - mechanical	4,400
Secondary sedimentation	250
Chlorination	290
Gravity thickening	8
Air flotation thickening	1,250
Vacuum Filter	630
Incineration	1,300
Building cooling	6
TOTAL	8,686

This recovered energy supplies all the plant's electrical needs with an excess of 4.5 million kwh/yr. Part of this excess could be used for on-site generation of hypochlorite this reducing the secondary energy requirements for chlorine.

The sludge disposal system in this example assumes thickening, vacuum filtration and incineration of 16 percent solids. An alternative sludge treatment system that is discussed in Chapter 5 uses waste heat from the incinerator for heat treatment. This allows a drier sludge, in the range of 30-45 percent solids, to be supplied to the incinerator and may result in a lower total energy requirement than for the example shown.

EXAMPLE 4 - EXTENDED AERATION

A one mgd plant in the Southern U.S. has little potential for energy recovery and recycling. Total energy requirements could be reduced through conservation methods and use of a solar energy system to supply building heating requirements.

EXAMPLE 5 - EXTENDED AERATION WITH SLOW SAND FILTER

This example is very similar to Example 4 with the addition of a slow sand filter after the extended aeration activated sludge process.

EXAMPLE 6 - ACTIVATED SLUDGE WITH CHEMICAL CLARIFICATION

This example is very similar to Example 2 except that chemical clarification and chemical sludge treatment are added and require additional energy. Chemical sludge treatment is by filter pressing and land disposal. Primary energy for sludge digestion is higher than Example 2 because the plant is located in Northern U.S. and more energy is required for digester heating.

EXAMPLE 7 - ACTIVATED SLUDGE WITH NITRIFICATION AND CHEMICAL CLARIFICATION

This example is similar to Example 6 with the addition of biological nitrification. Total energy requirements are increased somewhat while recovery and recycling potential from anaerobic digester gas utilization remains the same.

EXAMPLE 8 - ACTIVATED SLUDGE - HIGHER THAN SECONDARY TREATMENT

The treatment system for this example includes conventional activated sludge plus nitrification, chemical clarification with lime, filtration and carbon adsorption. Biological sludges are treated by anaerobic digestion and lime chemical sludge is recalcined and reused. Stack gas from the recalcining furnace is scrubbed and compressed for use in the recarbonation process. It may be possible to recover some of the waste heat from the recalcining process for other in-plant uses, however, this alternative is not considered here. Energy from the anaerobic digestion process is recovered and reused as in the previous examples and waste heat from the carbon regeneration furnace is converted to electricity by a steam turbine generator system.

EXAMPLE 9 - INDEPENDENT PHYSICAL/CHEMICAL - SECONDARY TREATMENT

The treatment system for this example does not use biological processes. Energy in the form of waste heat from the incinerator and carbon regeneration process is recovered and reused by generation of electricity as discussed in Example 3. It may be possible to utilize waste heat from incineration for heat treatment to increase solids concentration in the sludge supply to the incinerator. This process may change the net energy required somewhat.

EXAMPLE 10 - INDEPENDENT PHYSICAL/CHEMICAL - HIGHER THAN SECONDARY TREATMENT

The treatment system in this example is similar to Example 9 with additional unit operations to provide a higher degree of treatment resulting in higher energy requirements than in Example 9. Recovery and recycling is limited to generation of electricity utilizing steam recovered from the furnaces. As in the previous examples utilizing sludge incineration, it may be possible to produce a higher solids sludge by the use of heat treatment and thereby change the net energy requirements somewhat.

EXAMPLE 11 - PONDS

The treatment system in this example consists of an aerated pond followed by chlorination. There is no potential for energy recovery or recycling, however, it is assumed that a 10 percent savings in energy could be achieved in raw sewage pumping and pond aeration system operation by conservation techniques.

EXAMPLE 12 - LAND TREATMENT BY INFILTRATION/PERCOLATION

This example is similar to Example 11 with land treatment by infiltration/percolation following the aerated pond in place of chlorination. This system uses approximately 1.9 million kwh/yr less than Example 11 because of reduced secondary energy requirements for chlorine production. However, as in Example 11, there is no potential for energy recovery or recycling.

EXAMPLE 13 - LAND TREATMENT BY OVERLAND FLOW

This example is similar to Example 11 with the addition of land treatment by overland flow. This adds 410,000 kwh/yr to the primary energy required for treatment. All other energy considerations are identical to Example 11.

EXAMPLE 14 - LAND TREATMENT BY SOLID SET OR CENTER PIVOT IRRIGATION

This example is similar to Example 11 with the addition of land treatment by spray irrigation at an application rate of 0.33 inches per day. Two alternatives are presented. The solid set system uses approximately 7 million kwh/yr less than the center pivot system, but neither one contains any potential for energy recovery or recycling. As in Example 11, it is assumed that energy conservation techniques will reduce energy requirements by about 10 percent.

EXAMPLE 1

TRICKLING FILTER (ROCK MEDIA) WITH COARSE FILTRATION

30 mgd PLANT CAPACITY IN SOUTHERN U.S.

PROCESS	Figure No.	Primary Energy Required: Thousand kwh/yr	Primary Energy Required: Million Btu/yr	Secondary Energy Required: Thousand kwh/yr	Secondary Energy Required: Million Btu/yr	Recovery and Recycling Potential Energy Sources: Anaerobic Digester Gas Utilization Thousand kwh/yr	Anaerobic Digester Gas Utilization Million Btu/yr	Solar and Heat Pump Million Btu/yr	Conservation Thousand kwh/yr	Conservation Million Btu/yr	Energy Required from Other Sources: Thousand kwh/yr	Energy Required from Other Sources: Million Btu/yr
TREATMENT PROCESSES												
Raw Sewage Pumping	3-1	470				420[1]			50			
Preliminary Treatment		23				23[2]						
Bar Screen	3-7											
Comminutor	3-8											
Grit Removal - Non Aerated	3-10											
Primary Sedimentation - Circular	3-12	30				30[2]						
Trickling Filter - High Rate, Rock Media	3-16	1,500				1,350[1]			150			
Secondary Sedimentation	3-13	35				35[2]						
Coarse Filter	3-63	930				930[1]						
Chlorination	3-74/4-5	290		1,828		290[2]						
Sub Total		3,278		1,828		3,078			200			
Gravity Thicken	3-85	8				8[2]						
Anaerobic Digestion	3-105/5-4	1,000	31,755			1,000[2]	12,318[3]	19,437				
Drying Bed	3-98	15	150			15[2]						150
Land Disposal -Truck	3-100		1,400									1,400
Sub Total		1,023	33,305			1,023	12,318	19,437				1,550
Building Heat	3-83		500					450		50		
Building Cooling	3-84	100				90[2]			10			
Sub Total		100	500			90		450	10	50		
Total Treatment Process Energy		4,401	33,805	1,828		4,191	12,318	19,887	210	50		1,550
ENERGY RECOVERY PROCESSES												
Anaerobic Digester Gas Utilization System	5-18	510	6,600								510	6,600
Heat Pump	5-34	1,010									1,010	
Sub Total		1,520	6,600								1,520	6,600
Total Primary Energy With Recycling Facilities		5,921	40,405								1,520	8,150

1 IC engines fueled by digester gas coupled to pumps (engines rated @ 9387 Btu/kwh)

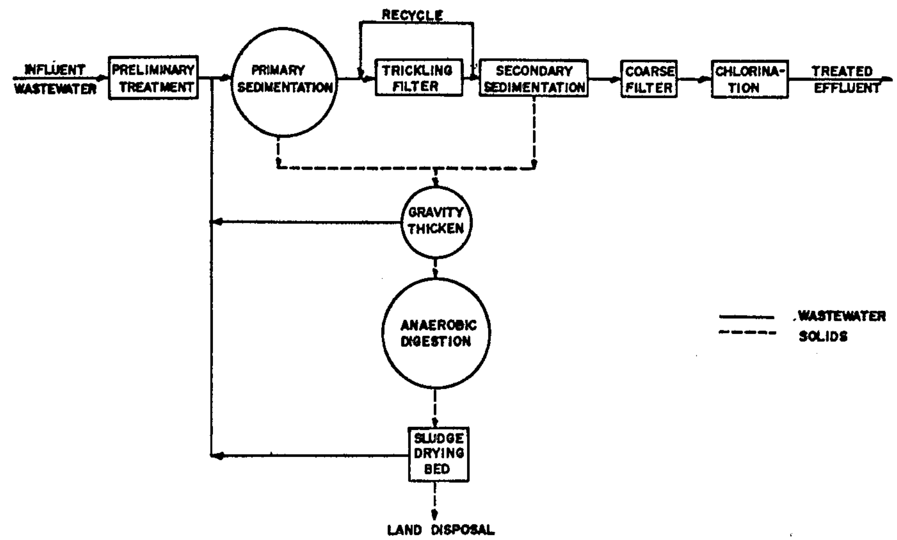
2 Electricity generated with digester gas

3 Waste heat recovered from IC engines = 25% of input to engines

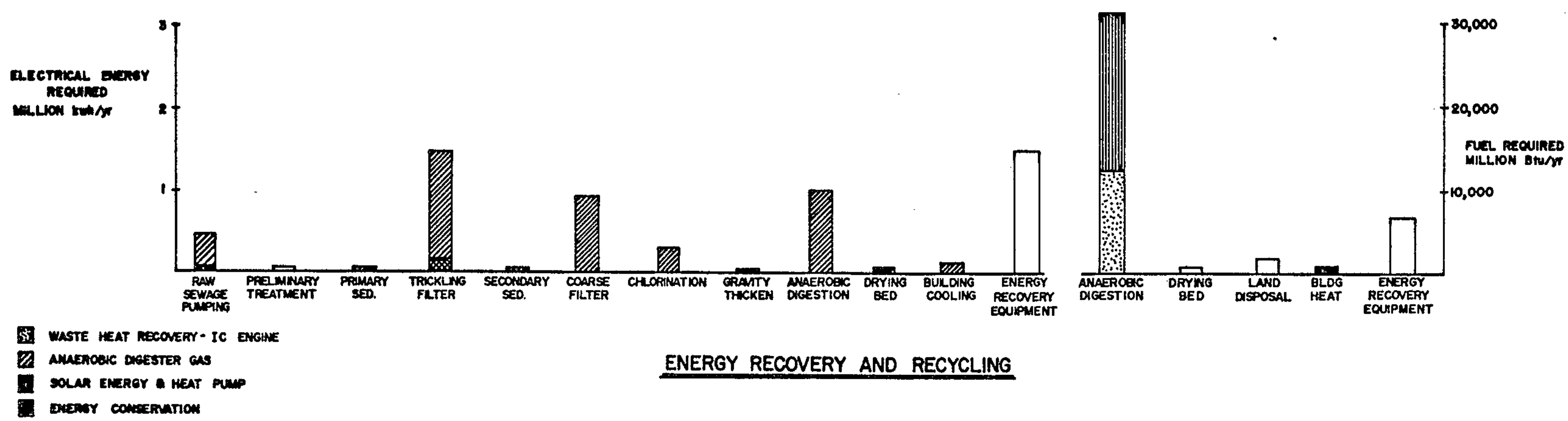
EXAMPLE I

TRICKLING FILTER WITH COARSE FILTRATION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 30mg/l, SS = 30mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 1 TO 100 mgd



PROCESS SCHEMATIC



ENERGY RECOVERY AND RECYCLING

EXAMPLE 2

ACTIVATED SLUDGE WITH ANAEROBIC DIGESTION

30 mgd PLANT CAPACITY IN SOUTHERN U.S.

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand khw/yr	SECONDARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES: Anaerobic Digester Gas Utilization Thousand kwh/yr	Anaerobic Digester Gas Utilization Million Btu/yr	Solar and Heat Pump Million Btu/yr	Conservation Thousand kwh/yr	Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES												
Raw Sewage Pumping	3-1	470				420[1]			50			
Preliminary Treatment		102									102	
Bar Screen	3-7											
Comminutor	3-8											
Grit Removal Aerated	3-9											
Primary Sedimentation - Circular	3-12	30				30[2]						
Aeration - Mechanical	3-28	4,900				4,400[2]			500			
Secondary Sedimentation	3-13	250									250	
Chlorination	3-74/4-5	290		1,828							290	
Sub Total		6,042		1,828		4,850			550		642	
Gravity Thicken	3-85	8									8	
Air Flotation Thicken	3-86	1,250				1,250[1]						
Anaerobic Digestion	3-105/5-4	1,500	31,755			438[2]	17,730[3]	14,025			1,062	
Sludge Drying Bed	3-98	15	150								15	150
Land Disposal - Truck	3-100		1,400									1,400
Sub Total		2,773	33,305			1,688	17,730	14,025			1,085	1,550
Building Heat	3-83		500					450		50		
Building Cooling	3-84	100							10		90	
Sub Total		100	500					450	10	50	90	
Total Treatment Process Energy		8,915	33,805	1,828		6,538	17,730	14,475	560	50	1,817	1,550
ENERGY RECOVERY PROCESSES												
Anaerobic Digester Gas Utilization System	5-18	510	6,600								510	6,600
Heat Pump	5-34	900									900	
Sub Total		1,410	6,600								1,410	6,600
Total Primary Energy With Recycling Facilities		10,325	40,405								3,227	8,150

1 IC engines fueled by digester gas coupled to pumps (engines rated @ 9387 Btu/kwh)

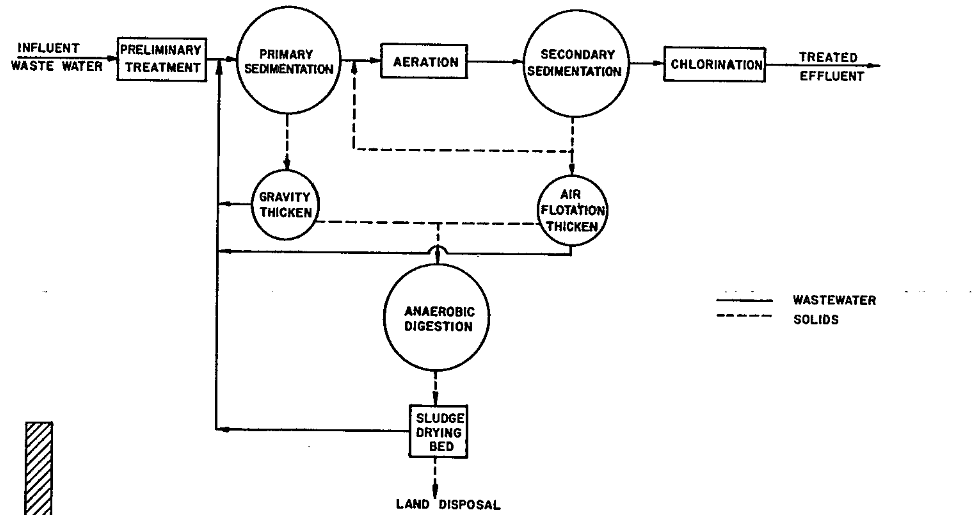
2 Electricity generated with digester gas

3 Waste heat recovered from IC engines = 25% of input to engines

EXAMPLE 2

ACTIVATED SLUDGE WITH ANAEROBIC DIGESTION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 30 mg/l, SS = 30 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 1 TO 100 mgd



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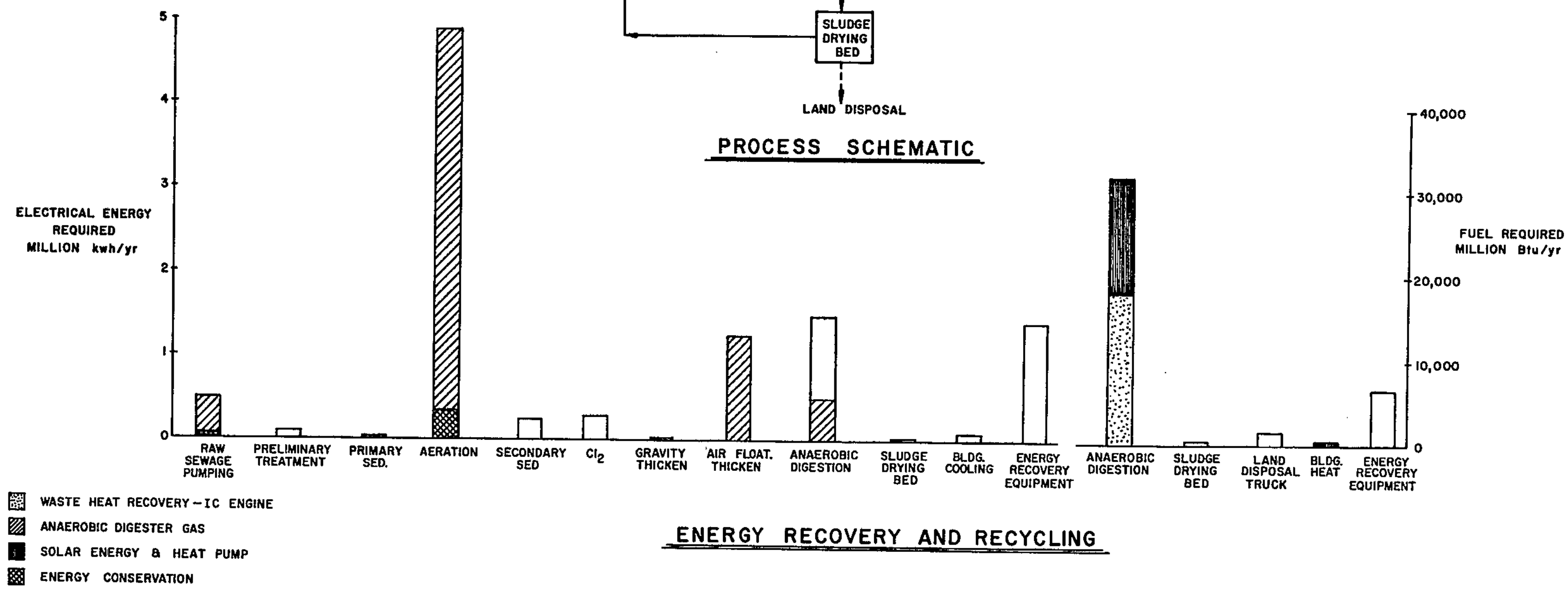


ENERGY RECOVERY AND RECYCLING

EXAMPLE 3

ACTIVATED SLUDGE (WITH INCINERATION)

30 mgd PLANT CAPACITY IN NORTHERN U.S.

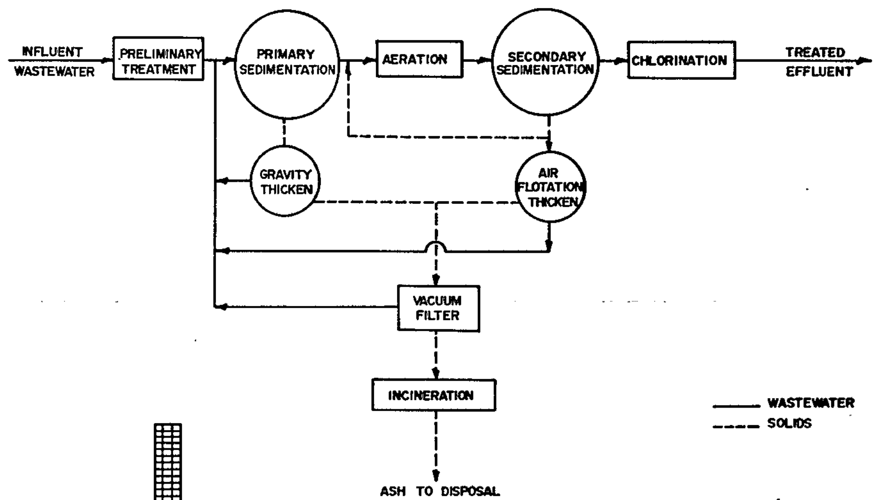
PROCESS	Figure No.	PRIMARY ENERGY REQUIRED		SECONDARY ENERGY REQUIRED		RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES					ENERGY REQUIRED FROM OTHER SOURCES	
						Incinerator Waste/Heat[1]		Solar Energy	Conservation			
		Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr
Treatment Processes												
Raw Sewage Pumping	3-1	470				420			50			
Preliminary Treatment		102				102						
Bar Screen	3-7											
Comminutor	3-8											
Grit Removal Aerated	3-9											
Primary Sedimentation - Circular	3-12	30				30						
Aeration - Mechanical	3-28	4,900				4,400			500			
Secondary Sedimentation	3-13	250				250						
Chlorination	3-74/4-5	290		1,828		290						
Sub Total		6,042		1,828		5,492			550			
Gravity Thicken	3-85	8				8						
Air Flotation Thicken	3-86	1,250				1,250						
Vacuum Filter	3-95	630				630						
Incineration	3-111/112/113	1,300	155,000			1,300						155,000
Ash Disposal			100									100
Sub Total		3,188	155,100									
Building Heat - New York	3-83		1,500					1,350		150		
Building Cooling - New York	3-84	6				6						
Total Treatment Process Energy		9,236	156,600	1,828		8,686		1,350	550	150		155,100

[1] If all available waste heat is converted to electrical energy at an overall efficiency of 30%, an excess of 4,500,000 kwh/yr above the plant needs is potentially available

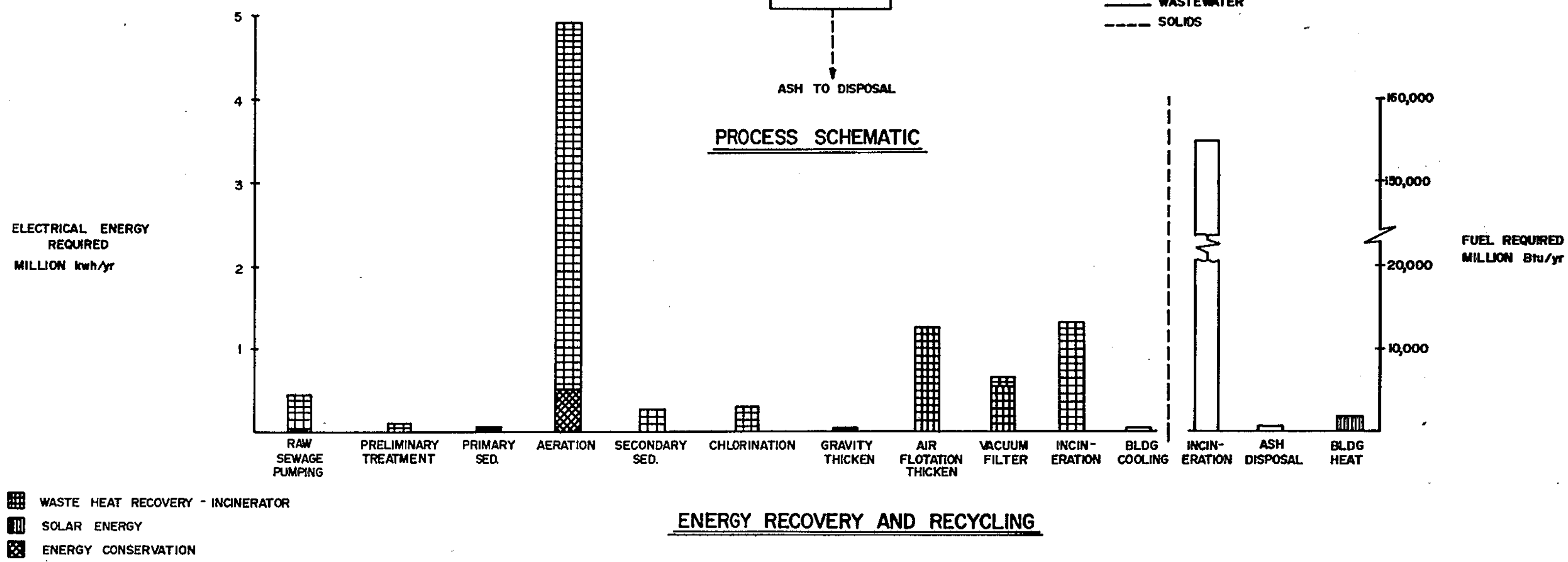
EXAMPLE 3

ACTIVATED SLUDGE WITH INCINERATION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY : BOD = 30mg/l, SS = 30mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 5 TO 100 mgd



PROCESS SCHEMATIC



ENERGY RECOVERY AND RECYCLING

EXAMPLE 4

EXTENDED AERATION

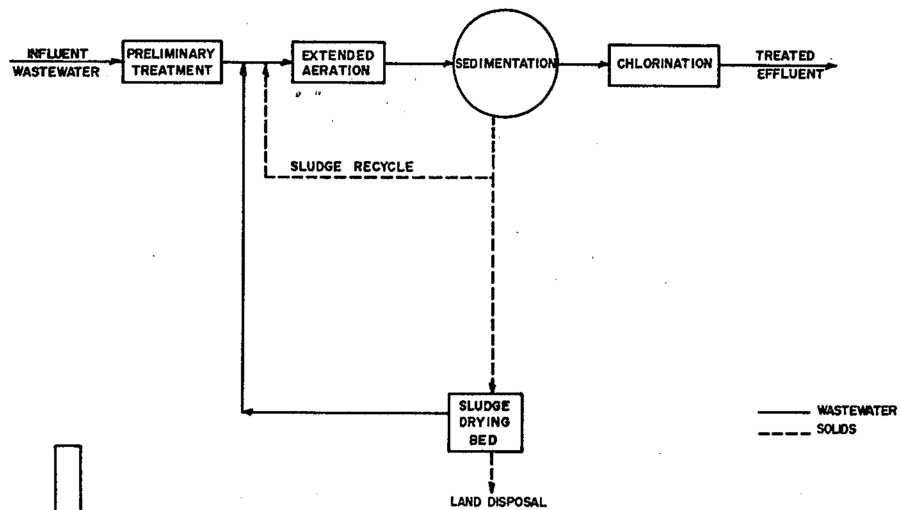
1 mgd PLANT CAPACITY IN SOUTHERN U.S.

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	SECONDARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Solar Energy Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
Treatment Processes										
Raw Sewage Pumping	3-1	20					2		18	
Preliminary Treatment		19							19	
Bar Screen	3-7									
Comminutor	3-8									
Grit Removal - Aerated	3-9									
Aeration	3-28	470					47		423	
Sedimentation	3-13	18							18	
Chlorination	3-74/4-5	10		61					10	
Sub Total		537					49		488	
Sludge Drying Bed	3-98	2	10						2	10
Land Disposal - Truck	3-100		60							60
Sub Total		2	70							
Building Heat	3-83		75			68		7		
Building Cooling	3-84	11					1		10	
Total Treatment Process Energy		550	145	61		68	50	7	500	70

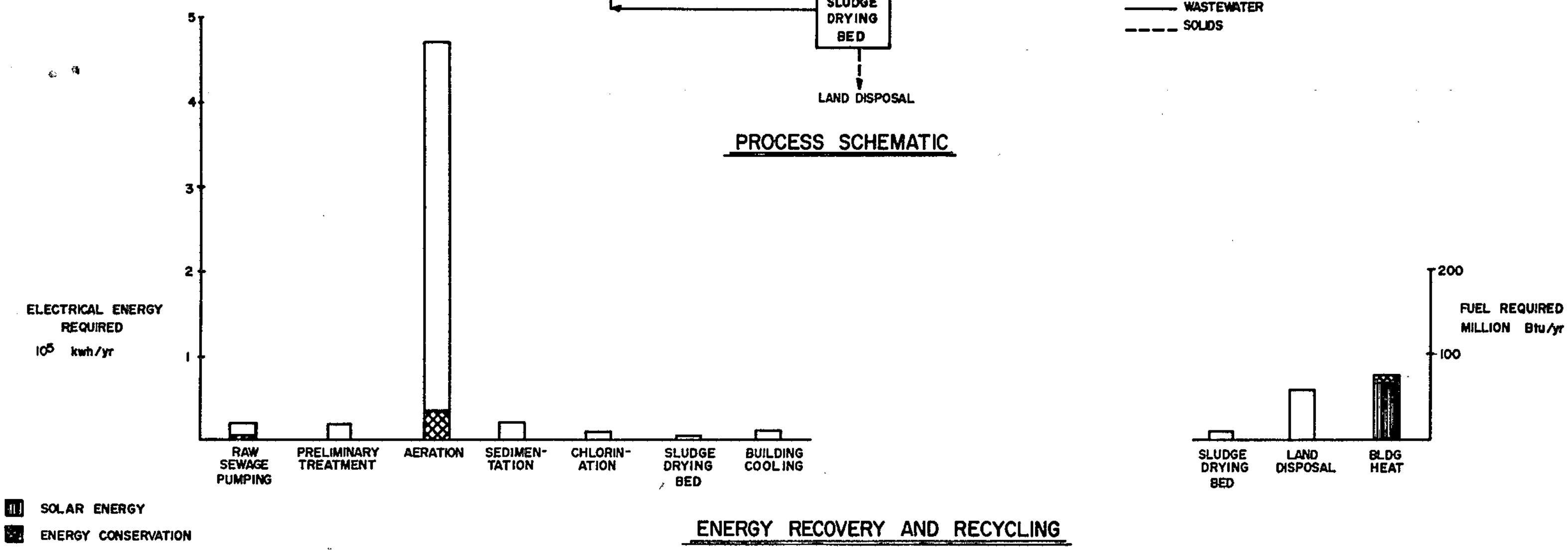
EXAMPLE 4

EXTENDED AERATION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY : BOD = 30 mg/l, SS = 30 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES LESS THAN 5 mgd



PROCESS SCHEMATIC



ENERGY RECOVERY AND RECYCLING

EXAMPLE 5

EXTENDED AERATION WITH SLOW SAND FILTER

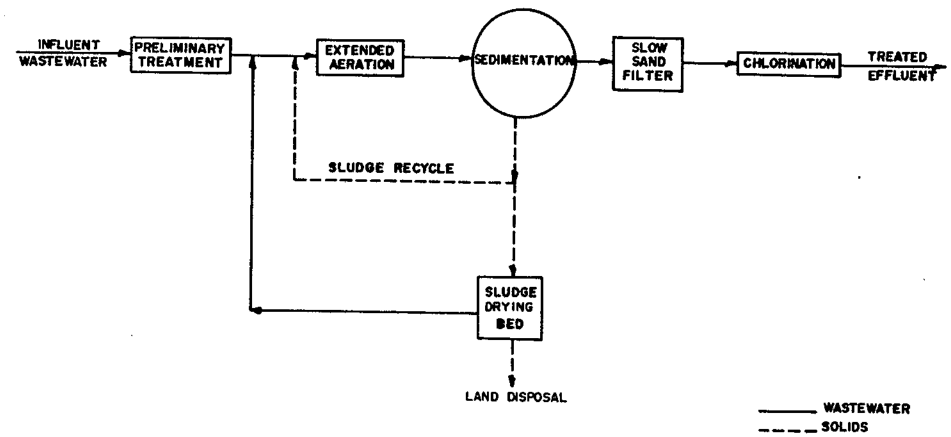
1 mgd PLANT CAPACITY IN SOUTHERN U.S.

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	SECONDARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Solar Energy Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES										
Raw Sewage Pumping	3-1	20					2		18	
Preliminary Treatment		19							19	
Bar Screen	3-7									
Comminutor	3-8									
Grit Removal - Aerated	3-9									
Aeration	3-28	350					35		315	
Sedimentation	3-13	18							18	
Slow Sand Filter	3-63	20							20	
Chlorination	3-74/4-5	10		61					10	
Sub Total		437		61			37		10	
Sludge Drying Bed	3-98	2	10						2	10
Land Disposal - Truck	3-100		60							60
Sub Total		2	70						2	70
Building Heat	3-83		75			68		7		
Building Cooling	3-84	11					1		10	
Total Treatment Process Energy		450	145	61		68	38	7	412	70

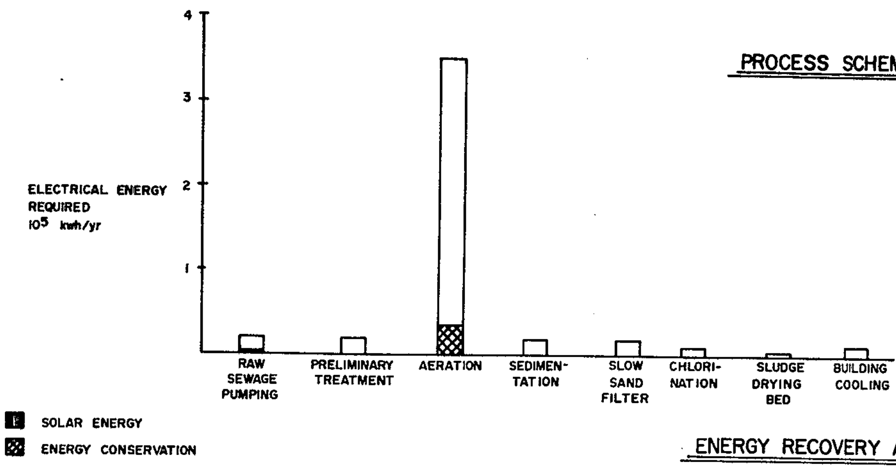
EXAMPLE 5

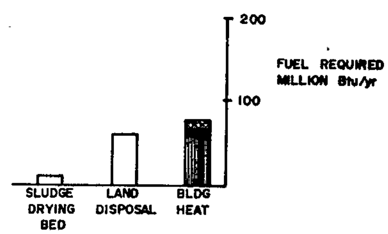
EXTENDED AERATION WITH SLOW SAND FILTER

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 20 mg/l, SS = 10 mg/l
- TREATMENT SYSTEM APPLICABLE FOR PLANT CAPACITIES OF LESS THAN 5 mgd



PROCESS SCHEMATIC





ENERGY RECOVERY AND RECYCLING

EXAMPLE 6

ACTIVATED SLUDGE WITH CHEMICAL CLARIFICATION

30 mgd PLANT CAPACITY IN NORTHERN U.S.

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED		SECONDARY ENERGY REQUIRED		RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES					ENERGY REQUIRED FROM OTHER SOURCES	
						Anaerobic Digester Gas Utilization		Solar and Heat Pump	Conservation			
		Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr
TREATMENT PROCESSES												
Raw Sewage Pumping	3-1	470				420[1]			50			
Preliminary Treatment		102									102	
Bar Screen	3-7											
Comminutor	3-8											
Grit Removal - Aerated	3-9											
Primary Sedimentation-Rectangular	3-12	52									52	
Aeration - Mechanical	3-28	4,900				4,400[2]			500			
Secondary Sedimentation	3-13	250									250	
Chemical Clarification (Alum)	3-57/4-2	520			18,286						520	
Chlorination	3-74/4-5	290		1,828							290	
Sub Total		6,584		1,828	18,286	4,820			550		1,214	
Thicken - Primary Sludge	3-85	8				8[2]						
Flotation Thicken	3-86	1,250				1,250[1]						
Anaerobic Digestion	3-105/5-4	1,500	57,000			438[2]	17,730[3]	39,270			1,062	
Sludge Drying Bed	3-98	15	150			15[2]						150
Land Disposal - Truck	3-100		1,400									1,400
Sub Total			58,550			1,711						1,550
Thicken Chemical Sludge	3-85	5									5	
Filter Press	3-96	350									350	
Land Disposal - Truck	3-100		1,200									1,200
Sub Total		355	1,200								1,417	1,200
Building Heating	3-83		1,500					1,350		150		
Building Cooling	3-84	7				7[2]						
Total Treatment Process Energy		9,719	61,250	1,828	18,286	6,538	17,730	40,620	550	150	2,631	2,750
ENERGY RECOVERY PROCESSES												
Anaerobic Digester Gas Utilization System	5-18	510	6,600								510	6,600
Heat Pump	5-34	3,800									3,800	
Sub Total		4,310	6,600								4,310	6,600
Total Primary Energy With Recycling Facilities		14,029	67,850								6,941	9,350

1 IC engines fueled by digester gas coupled to pumps (engines rated @ 9387 Btu/kwh)

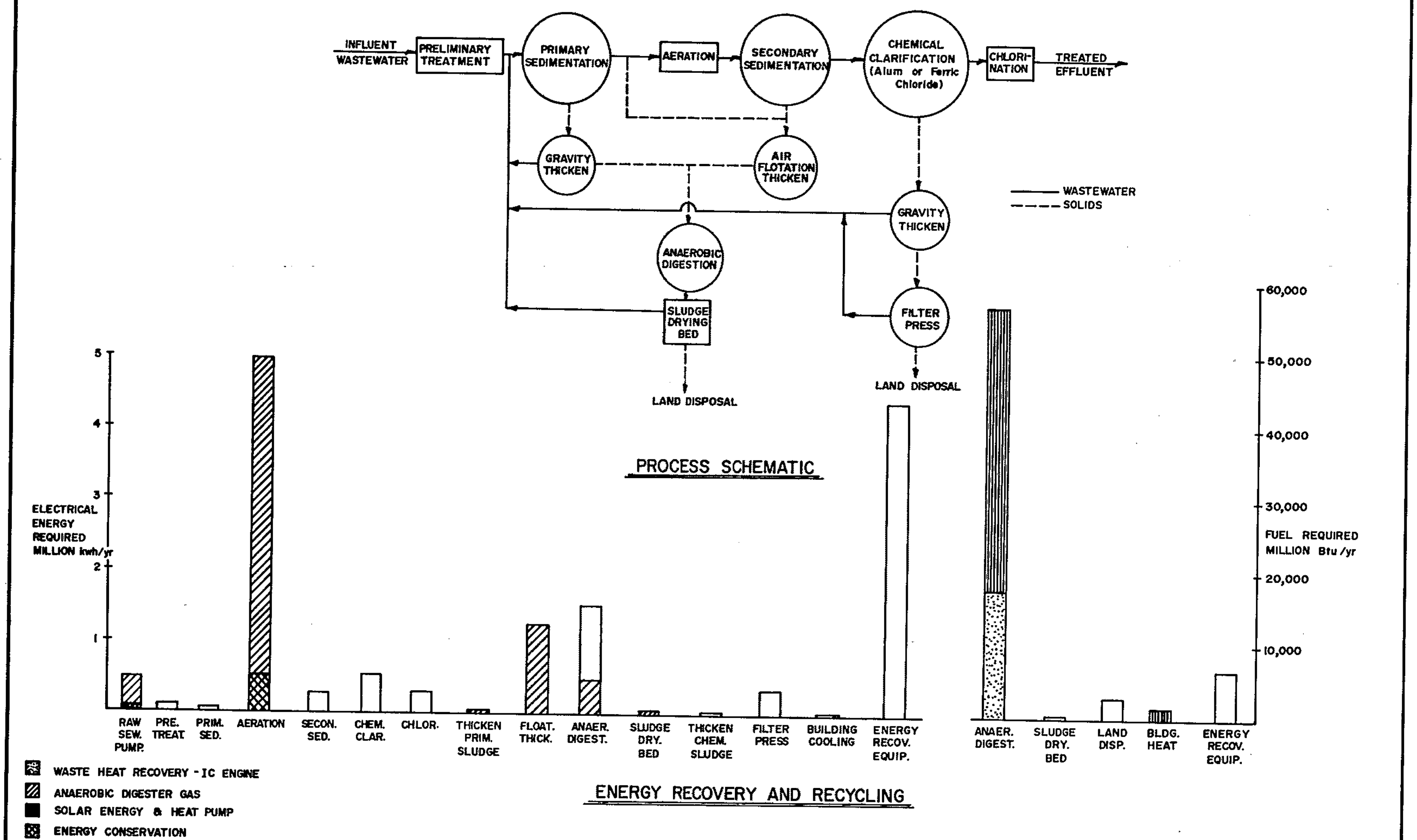
2 Electricity generated with digester gas

3 Waste heat recovered from IC engines = 25% of input to engines

EXAMPLE 6

ACTIVATED SLUDGE WITH CHEMICAL CLARIFICATION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY : BOD = 10 mg/l, SS = 5 mg/l, P = 1 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 1 TO 100 mgd



EXAMPLE 7

ACTIVATED SLUDGE WITH NITRIFICATION AND CHEMICAL CLARIFICATION

30 mgd PLANT CAPACITY IN NORTHERN U. S.

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	SECONDARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES: Anaerobic Digester Gas Utilization Thousand kwh/yr	Anaerobic Digester Gas Utilization Million Btu/yr	Solar and Heat Pump Million Btu/yr	Conservation Thousand kwh/yr	Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES												
Raw Sewage Pumping	3-1	470				420[1]			50			
Preliminary Treatment		102									102	
Bar Screen	3-7											
Comminutor	3-8											
Grit Removal - Aerated	3-9											
Primary Sedimentation - Rectangular	3-12	52									52	
Aeration - Mechanical	3-28	4,900				4,400[2]			500			
Secondary Sedimentation	3-13	250									250	
Nitrification - Suspended Growth	3-33	4,500									4,500	
Nitrification Sedimentation	3-38	330									330	
Chemical Clarification (Alum)	3-57/4-2	520			18,286						520	
Chlorination	3-74/4-5	290		1,828							290	
Sub Total		11,414		1,828	18,286	4,820			550		6,044	
Thicken - Primary Sludge	3-85	8				8[2]						
Flotation Thicken	3-86	1,250				1,250[1]						
Anaerobic Digestion	3-105/5-4	1,500	57,000			438[2]	17,730[3]	39,270			1,062	
Sludge Drying Bed	3-98	15	150			15[2]						150
Land Disposal - Truck	3-100		1,400									1,400
Sub Total		2,773	58,550			1,711	17,730	39,270				1,550
Thicken - Chemical Sludge	3-85	5									5	
Filter Press	3-96	350									350	
Land Disposal - Truck	3-100		1,200									1,200
Sub Total		355	1,200								1,417	1,200
Building Heating	3-83		1,500					1,350		150		
Building Cooling	3-84	7				7[2]						
Sub Total		7	1,500			7		1,350		150		
Total Treatment Process Energy		14,549	61,250	1,828	18,286	6,538	17,730	40,620	550	150	7,461	2,750
ENERGY RECOVERY PROCESSES												
Anaerobic Digester Gas Utilization System	5-18	510	6,600								510	6,600
Heat Pump	5-34	3,800									3,800	
Sub Total		4,310	6,600								4,310	6,600
Total Primary Energy With Recycling Facilities		18,859	67,850								11,771	9,350

1 IC engines fueled by digester gas coupled to pumps (engines rated @ 9387 Btu/kwh)

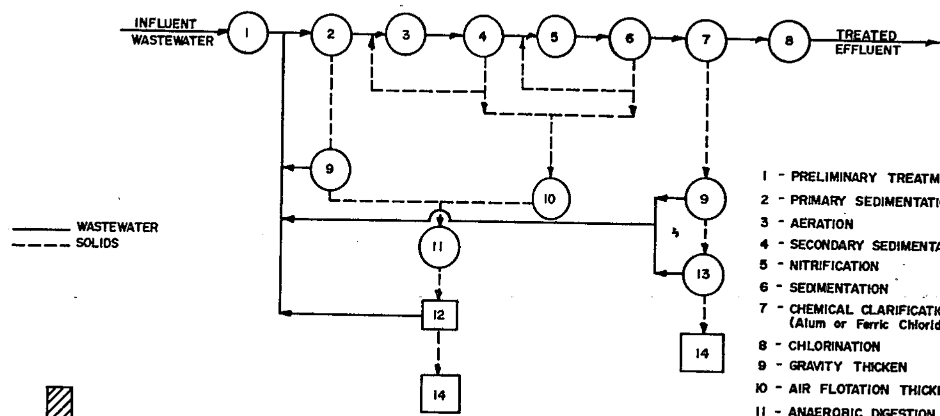
2 Electricity generated with digester gas

3 Waste heat recovered from IC engines = 25% of input to engines

EXAMPLE 7

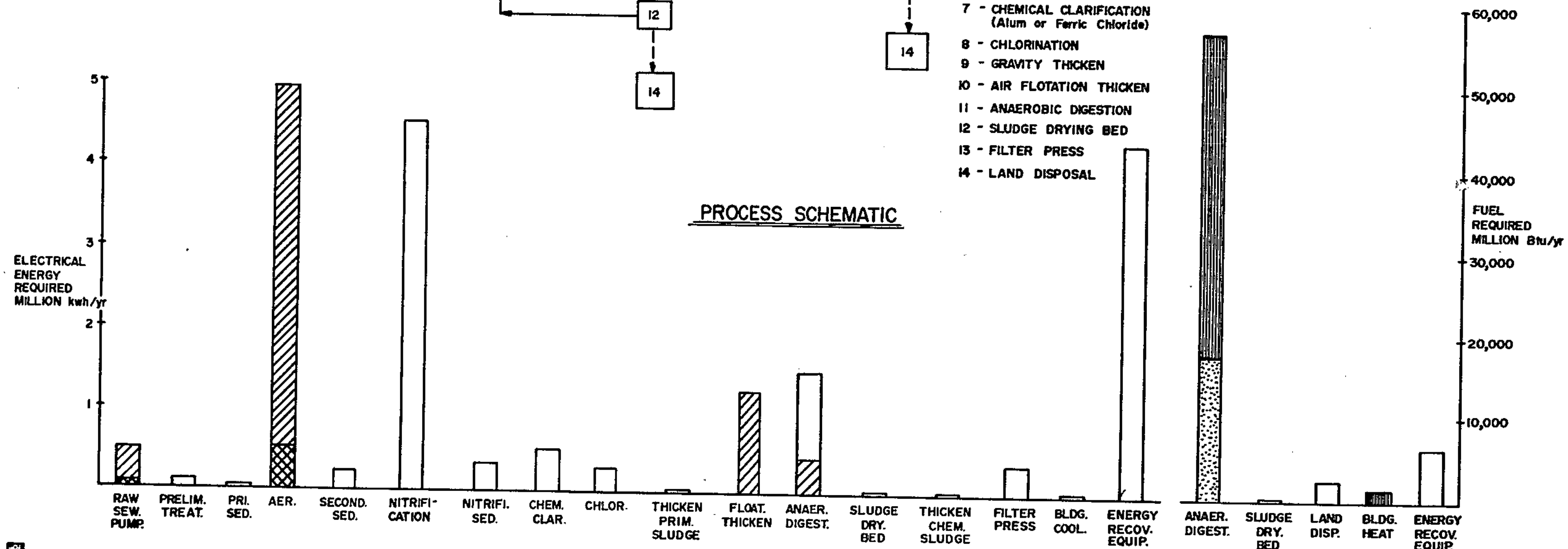
ACTIVATED SLUDGE WITH NITRIFICATION AND CHEMICAL CLARIFICATION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 10 mg/l, SS = 5 mg/l, P = 1 mg/l, NITRIFICATION
- TREATMENT SYSTEM APPLICABLE FOR PLANT CAPACITIES OF 1 TO 100 mgd



1 - PRELIMINARY TREATMENT
2 - PRIMARY SEDIMENTATION
3 - AERATION
4 - SECONDARY SEDIMENTATION
5 - NITRIFICATION
6 - SEDIMENTATION
7 - CHEMICAL CLARIFICATION (Alum or Ferric Chloride)
8 - CHLORINATION
9 - GRAVITY THICKEN
10 - AIR FLOTATION THICKEN
11 - ANAEROBIC DIGESTION
12 - SLUDGE DRYING BED
13 - FILTER PRESS
14 - LAND DISPOSAL

PROCESS SCHEMATIC



ENERGY RECOVERY AND RECYCLING

EXAMPLE 8

ACTIVATED SLUDGE - HIGHER THAN SECONDARY

30 mgd PLANT CAPACITY IN NORTHERN U.S.

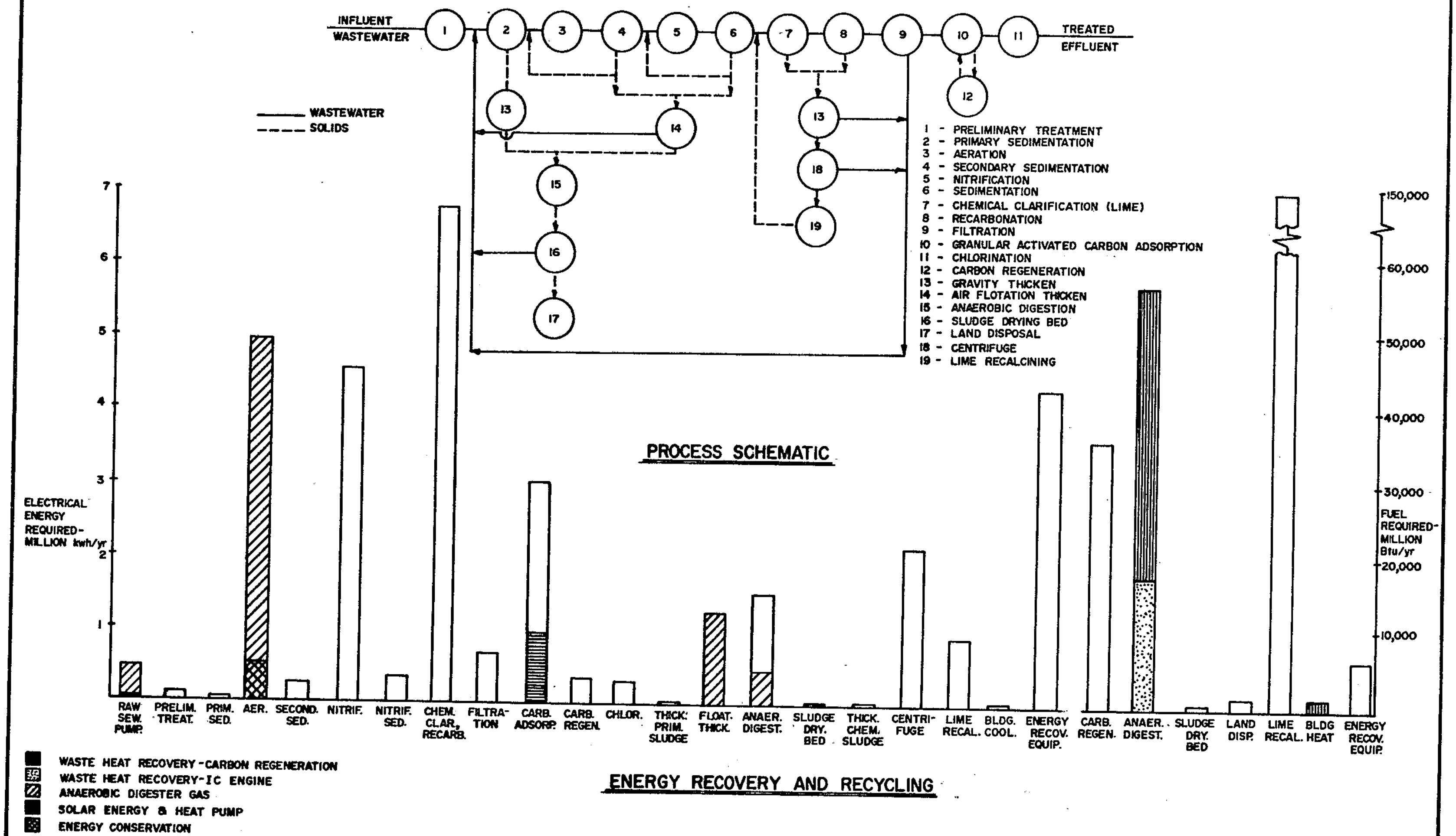
PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	SECONDARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES: Anaerobic Digester Gas Utilization Thousand kwh/yr	Anaerobic Digester Gas Utilization Million Btu/yr	Carbon Regeneration Waste Heat[4] Thousand kwh/yr	Carbon Regeneration Waste Heat[4] Million Btu/yr	Solar and Heat Pump Million Btu/yr	Conservation Thousand kwh/yr	Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES														
Raw Sewage Pumping	3-1	470				420[1]					50			
Preliminary Treatment		102											102	
Bar Screen	3-7													
Comminutor	3-8													
Grit Removal - Aerated	3-9													
Primary Sedimentation - Rectangular	3-12	52											52	
Aeration - Mechanical	3-28	4,900				4,400[2]					500			
Secondary Sedimentation	3-13	250											250	
Nitrification - Suspended Growth	3-33	4,500											4,500	
Nitrification Sedimentation	3-38	330											330	
Chemical Clarification (Lime) & Recarbonation	3-54/4-7	6,700			25,080								6,700	
Filtration - Gravity	3-63	670											670	
Carbon Adsorption - Pressure	3-64	3,000			33,507			965					2,035	
Carbon Regeneration	3-67	320	36,000										320	36,000
Chlorination	3-74/4-5	290		1,828									290	
Sub Total		21,584	36,000	1,828	58,587	4,820		965			550		15,249	36,000
Thicken - Primary Sludge	3-85	8				8[2]								
Flotation Thicken	3-86	1,250				1,250[1]								
Anaerobic Digestion	3-105/5-4	1,500	57,000			438[2]	17,730[3]			39,270			1,062	
Sludge Drying Bed	3-98	15	150			15[2]								150
Land Disposal - Truck	3-100		1,400											1,400
Sub Total		2,773	58,550			1,711	17,730			39,270				1,550
Thicken - Chemical Sludge	3-85	15											15	
Centrifuge	3-97	2,121											2,121	
Lime Recalcination	3-118	900	150,000										900	150,000
Sub Total		3,036	150,000										4,098	150,000
Building Heating	3-83		1,500							1,350		150		
Building Cooling	3-84	7				7[2]								
Sub Total		7	1,500			7				1,350		150		
Total Treatment Process Energy		27,400	246,050	1,828	58,587	7,250	17,730	965		40,620	550	150	19,347	187,550
ENERGY RECOVERY PROCESSES														
Anaerobic Digester Gas Utilization System	5-18	510	6,600										510	6,600
Heat Pump	5-34	3,800											3,800	
Sub Total		4,310	6,600										4,310	6,600
Total Primary Energy With Recycling Facilities		31,710	252,650										23,657	194,150

[1] IC engines fueled by digester gas coupled to pumps (engines rated @ 9387 Btu/kwh)
[2] Electricity generated with digester gas
[3] Waste heat recovered from IC engines = 25% of input to engines
[4] Waste heat is converted to electricity at an overall efficiency of 30 percent

EXAMPLE 8

ACTIVATED SLUDGE WITH NITRIFICATION, CHEMICAL CLARIFICATION, FILTRATION AND CARBON ADSORPTION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 2 mg/l, SS = 1 mg/l, P = 0.5 mg/l, NITRICATION
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 5 TO 100 mgd



ENERGY RECOVERY AND RECYCLING

EXAMPLE 9

INDEPENDENT PHYSICAL CHEMICAL - SECONDARY

30 mgd PLANT CAPACITY IN NORTHERN U. S.

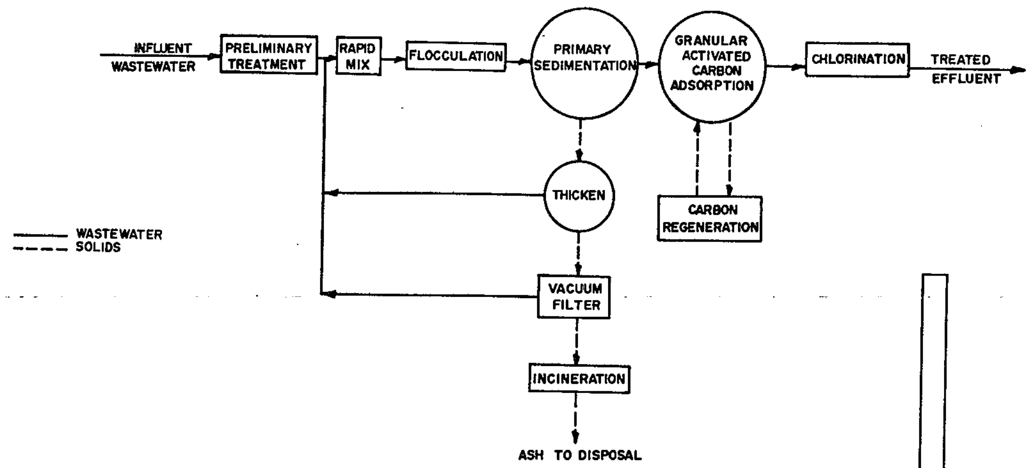
PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	SECONDARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES: Incinerator Waste Heat[1] Thousand kwh/yr	Incinerator Waste Heat[1] Million Btu/yr	Carbon Regeneration Waste Heat[1] Thousand kwh/yr	Carbon Regeneration Waste Heat[1] Million Btu/yr	Solar Million Btu/yr	Conservation Thousand kwh/yr	Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES														
Raw Sewage Pumping	3-1	470						420			50			
Preliminary Treatment		102						102						
Bar Screen	3-7													
Comminutor	3-8													
Grit Removal - Aerated	3-9													
Chemical Clarification-Ferric Chloride	3-57/4-6	430			2,286	430								
Carbon Adsorption - Expanded Bed	3-66	1,950			33,700			1,950						
Carbon Regeneration	3-67	1,250	140,000					1,250						140,000
Chlorination	3-74/4-5	290		1,828		290								
Sub Total		4,492	140,000	1,828	35,986	720		3,722			50			140,000
Gravity Thicken	3-85	14				14								
Vacuum Filter	3-95	1,050				1,050								
Incineration	3-111/112/113	1,500	238,000			1,500								238,000
Ash Disposal			200											200
Sub Total		2,564	238,200			2,564								238,200
Building Heating	3-83		1,500							1,350		150		
Building Cooling	3-84	7				7								
Sub Total		7	1,500			7				1,350		150		
Total Treatment Process Energy		7,063	379,700	1,828	35,986	3,291		3,722		1,350	50	150		378,200

[1] If all available waste heat is converted to electrical energy at an overall efficiency of 30 percent, an excess of 8,600,000 kwh/yr above the plant needs is potentially available

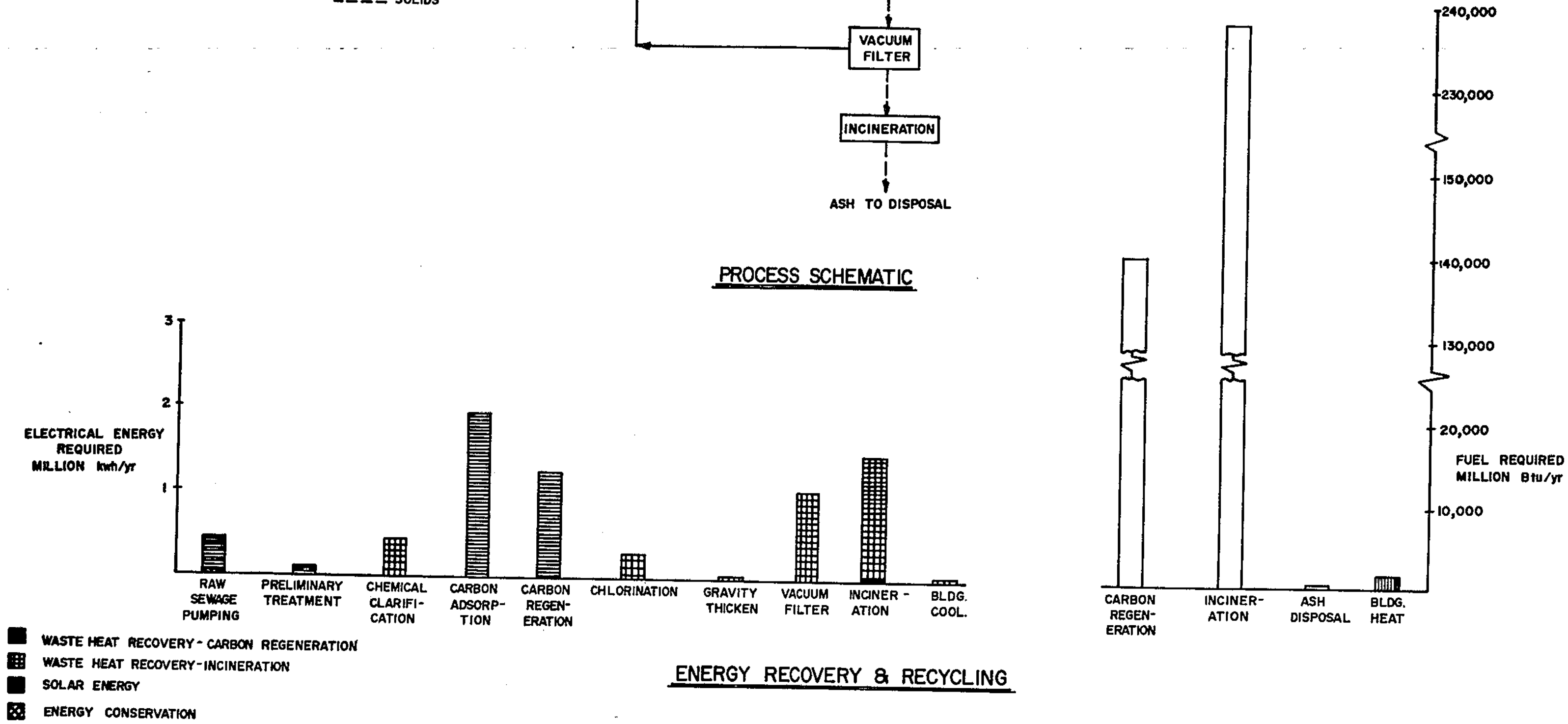
EXAMPLE 9

INDEPENDENT PHYSICAL CHEMICAL - SECONDARY EFFLUENT STANDARDS

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 30 mg/l, SS = 30 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 2 TO 100 mgd



PROCESS SCHEMATIC



ENERGY RECOVERY & RECYCLING

EXAMPLE 10

INDEPENDENT PHYSICAL CHEMICAL - HIGHER THAN SECONDARY

30 mgd PLANT CAPACITY IN NORTHERN U. S.

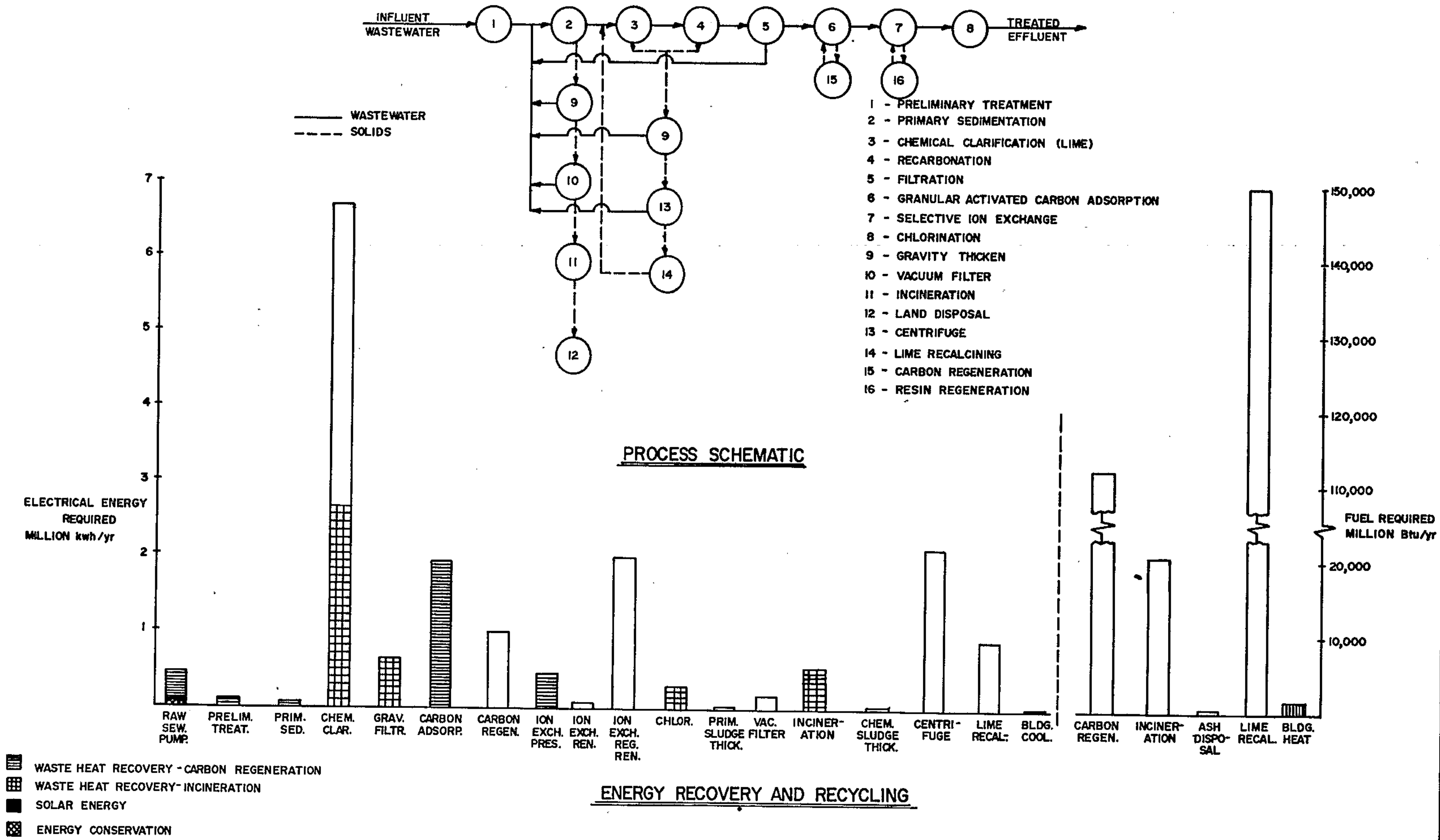
PROCESS	Figure No.	PRIMARY ENERGY REQUIRED		SECONDARY ENERGY REQUIRED		RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES							ENERGY REQUIRED FROM OTHER SOURCES	
						Incinerator Waste Heat[1]		Carbon Regeneration Waste Heat[1]		Solar	Conservation			
		Thousand kwh/yr	Million Btu/yr	Thousand khw/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr
TREATMENT PROCESSES														
Raw Sewage Pumping	3-1	470						420			50			
Preliminary Treatment		102						102						
Bar Screen	3-7													
Comminutor	3-8													
Grit Removal	3-9													
Primary Sedimentation - Rectangular	3-12	52						52						
Chemical Clarification - Lime	3-54/4-7	6,700			25,100	2,553							4,147	
Filtration - Gravity	3-63	670				670								
Carbon Adsorption	3-66	1,950			33,700			1,950						
Carbon Regeneration	3-67	1,000	112,000										1,000	112,000
Ammonia Removal														
Ion Exchange - Pressure	3-68	430						430						
Regeneration	3-69	60											60	
Regenerant Renewal	3-70	2,000											2,000	
Chlorination	3-74/4-5	290		1,828		290								
Sub Total		13,724	112,000	1,828	58,800	3,513		2,954			50		7,207	112,000
Thicken - Primary Sludge	3-85	8						8						
Vacuum Filter	3-95	180											180	
Incineration	3-111/112/113	480	20,900			480								20,900
Ash Disposal	---		100											100
Sub Total		668	21,000			480		8					180	21,000
Thicken - Chemical Sludge	3-85	15						15						
Centrifuge	3-97	2,121											2,121	
Lime Recalcination	3-118	900	150,000										900	150,000
Sub Total		3,036	150,000										3,021	150,000
Building Heat	3-83		1,500							1,350		150		
Building Cooling	3-84	7				7								
Sub Total		7	1,500			7		15		1,350		150		
Total Treatment Process Energy		17,435	284,500	1,828	58,800	4,000		2,977		1,350	50	150	10,408	283,000

[1] Waste heat is coverted to electricity at an overall efficiency of 30 percent

EXAMPLE 10

INDEPENDENT PHYSICAL CHEMICAL - HIGHER THAN SECONDARY EFFLUENT STANDARDS

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2.
- EFFLUENT QUALITY: BOD = 10 mg/l, SS = 5 mg/l, P = 1mg/l, N (TOTAL) = 2 to 4 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 2 TO 100 mgd



PROCESS SCHEMATIC

ENERGY RECOVERY AND RECYCLING

EXAMPLE 11

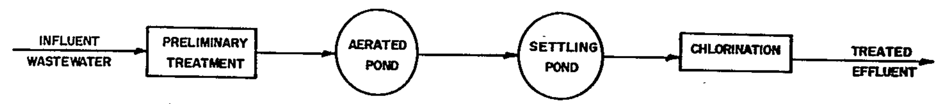
PONDS

30 mgd PLANT CAPACITY

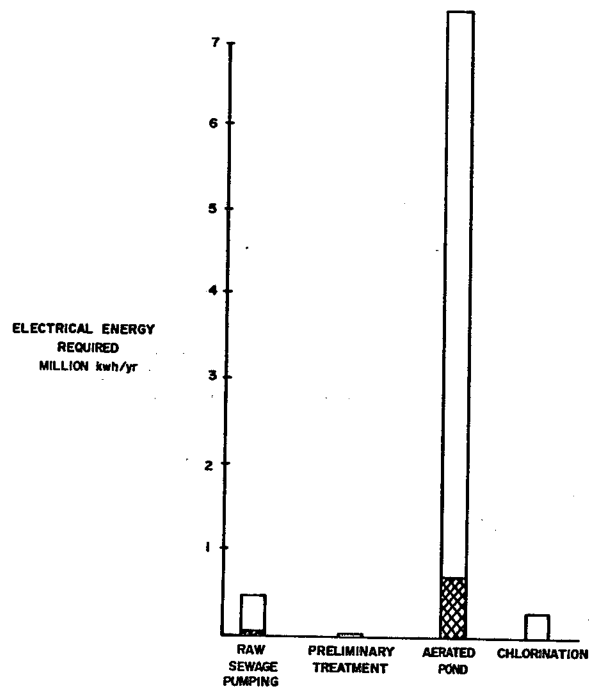
PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES								
Raw Sewage Pumping	3-1	470			50		420	
Preliminary Treatment		22					22	
Bar Screen	3-7							
Comminutor	3-8							
Aerated Pond	3-32	7,400			700		6,700	
Chlorination	3-74/4-5	290		1,828			290	
Total Treatment Process Energy		8,182		1,828	750		7,432	

EXAMPLE 11
PONDS

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY : BOD = 30 mg/l, SS = 30 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 0.1 TO 100 mgd



PROCESS SCHEMATIC



ENERGY CONSERVATION

ENERGY RECOVERY AND RECYCLING

EXAMPLE 12

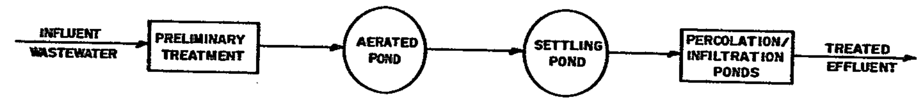
LAND TREATMENT BY INFILTRATION/PERCOLATION

30 mgd PLANT CAPACITY

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES							
Raw Sewage Pumping	3-1	470		50		420	
Preliminary Treatment		22				22	
Bar Screen	3-7						
Comminutor	3-8						
Aerated Pond	3-32	7,400		700		6,700	
Percolation Infiltration (Flooding)	3-81	240				240	
Total Treatment Process Energy		8,132		750		7,382	

EXAMPLE 12
LAND TREATMENT BY PERCOLATION/INFILTRATION

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 5 mg/l, SS = 1 mg/l, P = 2 mg/l, N = (TOTAL) = 10 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 0.1 TO 100 mgd



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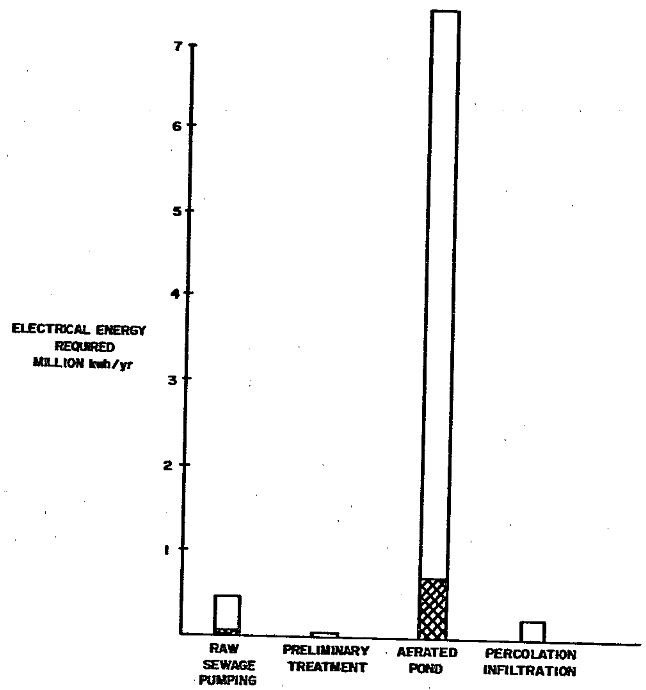


ENERGY CONSERVATION

ENERGY RECOVERY AND RECYCLING

EXAMPLE 13

LAND TREATMENT BY OVERLAND FLOW

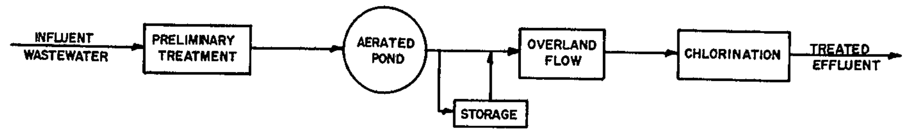
30 mgd PLANT CAPACITY

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED Thousand kwh/yr	PRIMARY ENERGY REQUIRED Million Btu/yr	SECONDARY ENERGY REQUIRED Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Thousand kwh/yr	RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES Conservation Million Btu/yr	ENERGY REQUIRED FROM OTHER SOURCES Thousand kwh/yr	ENERGY REQUIRED FROM OTHER SOURCES Million Btu/yr
TREATMENT PROCESSES								
Raw Sewage Pumping	3-1	470			50		420	
Preliminary Treatment		22					22	
Bar Screen	3-7							
Comminutor	3-8							
Aerated Pond	3-32	7,400			700		6,700	
Overland Flow (Flooding)	3-81	410					410	
Chlorination	3-74/4-5	290		1,828			290	
Total Treatment Process Energy		8,592		1,828	750		7,842	

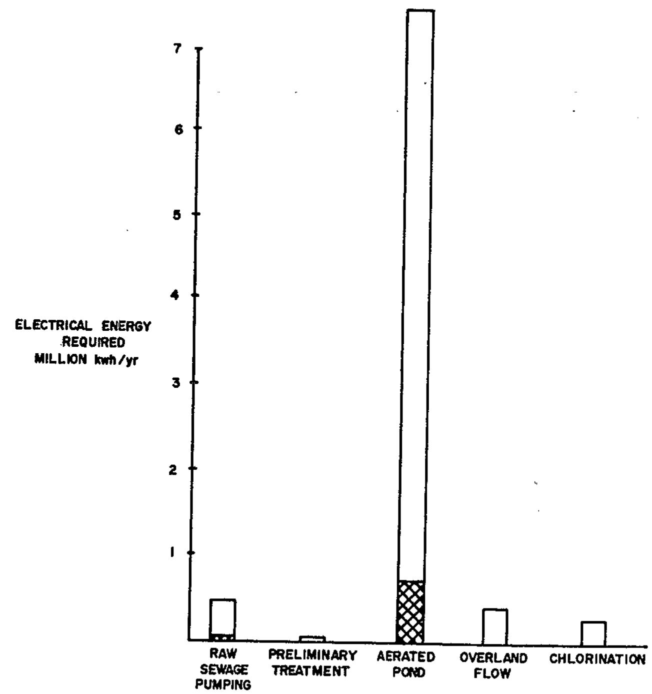
EXAMPLE 13

LAND TREATMENT BY OVERLAND FLOW

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 5 mg/l, SS = 5 mg/l, P = 5 mg/l, N (TOTAL) = 3 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 0.1 TO 100 mgd



PROCESS SCHEMATIC



ENERGY CONSERVATION

ENERGY RECOVERY AND RECYCLING

EXAMPLE 14

LAND TREATMENT BY SPRAY IRRIGATION

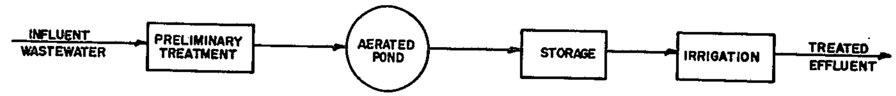
30 mgd PLANT CAPACITY

PROCESS	Figure No.	PRIMARY ENERGY REQUIRED		RECOVERY AND RECYCLING POTENTIAL ENERGY SOURCES (Conservation)		ENERGY REQUIRED FROM OTHER SOURCES	
		Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr
TREATMENT PROCESSES							
Raw Sewage Pumping	3-1	470		50		420	
Preliminary Treatment		22				22	
Bar Screen	3-7						
Comminutor	3-8						
Aerated Pond	3-32	7,400		700		6,700	
Sub Total		7,892					
Spray Irrigation	3-79						
Solid Set		8,200				8,200	
Center Pivot		15,000				15,000	
Total Energy-Solid Set		16,092		750		15,342	
Total Energy-Center Pivot		22,892		750		22,142	

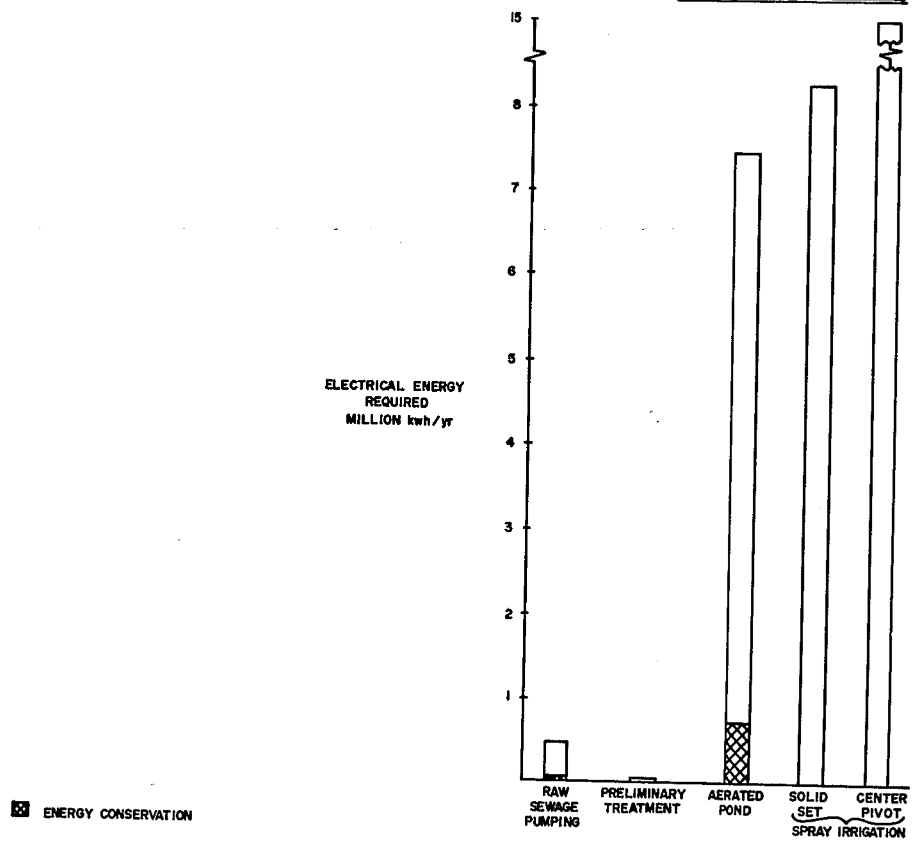
EXAMPLE 14

LAND TREATMENT BY SPRAY IRRIGATION (SOLID SET OR CENTER PIVOT)

- INFLUENT WASTEWATER QUALITY AS SHOWN IN TABLE 3-2
- EFFLUENT QUALITY: BOD = 1 mg/l, SS = 1 mg/l, P = 0.1 mg/l, N (TOTAL) = 3 mg/l
- TREATMENT SYSTEM IS APPLICABLE FOR PLANT CAPACITIES OF 0.1 TO 100 mgd



PROCESS SCHEMATIC



ENERGY RECOVERY AND RECYCLING

CHAPTER 7

ENERGY REQUIREMENTS FOR TREATMENT FACILITIES GREATER THAN 100 MGD AND LESS THAN 1 MGD

The purpose of this chapter is to discuss energy requirements that are unusual or unique for very large and very small treatment plants.

TREATMENT FACILITY CAPACITY LESS THAN 1 MGD

The requirements for small plants are important because, as shown by the data in Chapter 2, there are many small plants in the U.S. Most of the energy conservation measures described in Chapter 5 are more difficult to implement in small plants. Small plants usually do not have an operator on duty 24 hours per day. Also, skilled operation and maintenance personnel (personnel that are required to obtain energy savings through conservation) are often not available for small facilities.

Anaerobic digester gas utilization and the use of waste heat from incinerators is not feasible in small plants. Engines and other necessary equipment are not available for small capacity plants. The smallest commercial multiple hearth furnace has a hearth area of 85 sq ft. However, heat recovery from sewage through the use of heat pumps is possible even for very small plants.

Unit processes from Chapter 3 that are not usually applicable to treatment facilities with a capacity less than 1 mgd include the following:

1. High purity oxygen activated sludge systems.
2. Two stage recarbonation.

3. Heat Treatment.
4. Incineration.
5. Pyrolysis.
6. Lime recalcination.

TREATMENT FACILITIES WITH CAPACITIES GREATER THAN 100 MGD

Most of the unit processes presented in Chapter 3 are applicable to large plants. Processes which would normally not be considered for large plants include:

1. Low rate trickling filter.
2. Activated bio-filter.
3. Brush aeration oxidation ditch.
4. Aerated pond (as a primary treatment process).
5. Aerobic digestion.

The energy conservation and recycling methods discussed in Chapter 5 all have the potential of more effective application in large plants for the following reasons:

1. Minor efficiency improvements can result in large savings.
2. Multiple unit pumps and aeration equipment offer more opportunity to match design capacity and actual flows.

Recycling equipment for anaerobic digester gas and heat recovery systems are available in large sizes which result in more efficient operation.

CHAPTER 8

NATIONAL AND REGIONAL COST PROJECTIONS

INTRODUCTION

The purpose of Chapter 8 is to place the cost of energy in proper perspective with the other costs of wastewater treatment plant construction and operation. Regional variability in the relative price of energy, labor, construction, and consumables is important in a preliminary evaluation of the cost-effectiveness of a particular alternative. This chapter is divided into two major sections:

1. National Cost Projections present the best estimates available for the projected national costs of construction, operation and maintenance of wastewater treatment plants.

2. Regional Cost Variation presents the current regional cost variations for various cost categories that affect treatment plant construction and operation.

The estimates and projections may serve as a guide in planning wastewater treatment facilities, and should be considered preliminary to any present value alternative cost-effectiveness comparisons such as those contained in the following chapter. It is useful to know, for instance, at an early stage in the planning process, that a high labor cost for a particular municipality might offset in part the beneficial impact of a low energy alternative that is labor intensive in its operation.

NATIONAL COST PROJECTIONS

This section presents projections of national trends from 1975 to 1995 for the costs that impact wastewater treatment facility construction, operation and maintenance. Projections are presented for four cost categories: (1) electrical energy, (2) labor, (3) construction, and (4) consumables (as defined in Chapter 4). Government publications and reprints of hearings concerned with future costs of energy, future energy requirements and future economic trends are a major source of reference for this chapter.

Most projections are based on average percent increase of a cost index from one year to the next. A base year is selected and then the cost of a given item, such as electrical energy, is set at 100 for that year. For example, if the base year is 1967 and the cost rose 7 percent in 1968, the index for that year would be 1.07. If the cost rose 8 percent in 1969, the index for 1969 would be: $1.07 \times 1.08 = 1.1556$, or about 1.16. The projections presented in this chapter are computed in this fashion using cost indexing; 1975 is the base year and percent increase during 1975 - 1995 are computed.

The basis for cost indexes consists of specific costs of materials and/or labor, if applicable, for a given sector of the economy. For example, a construction index consists of costs for specific amounts of labor, concrete, steel, lumber and other items. The wholesale price index consists of costs for specific amounts of certain commodities. The costs of individual items are then proportioned to derive an index.

Cost indexes are used in this report because they are designed to measure changes and historically have proven to be fairly good indicators. However, they are not intended to measure absolute prices, and, in fact, some real price changes cannot be measured such as improvements in quality, hidden discounts or improved delivery schedules.[1] In addition, the projections of these cost indexes cannot be expected to give precise predictions, but only show the general trend in future costs based on current knowledge of the economy.

Electrical Energy

The trend for the cost of electrical energy shown in Figure 8-1 was projected from the wholesale cost index for fuel and power published by the Federal Energy Administration (FEA).[2] The FEA data includes projections to 1991. This data is a projection of a composite wholesale cost index for fuels and power and assumes a periodic increase in foreign oil prices and deregulation of domestic prices. The index also includes assumptions of price increases for other fuels such as natural gas and coal, and includes their effect on the overall cost of fuels. Therefore, while the index may not exactly predict the increases in the cost of fuel oil alone, it is expected to give a good indication of overall fuel costs.

The last four years are an extrapolation of the data determined by averaging the previous rates of increase. The projection shown in Figure 8-1 is that beyond 1980 the cost is expected to increase about the same as the general rate of inflation, 3 to 4 percent.[3]

Labor

Figure 8-2 shows the trend for unit labor cost. This data was also computed from projected yearly rates of increase with the last four years being extrapolated. This projection is based on data from the Bureau of Labor Statistics and the Department of Commerce published by the Federal Energy Administration.[2] Actual wage increases from 1975 to 1995 are expected to be about 6.5 percent per year, however, productivity gains are projected to increase at a rate of 2.5 percent per year. This causes the rate of increase for unit labor cost to be about 4 percent per year as shown in Figure 8-2.

Construction

The trend in construction costs is shown in Figure 8-3. The curve is based on projected average rates of increase in construction costs for electrical generation plants and transmission plants.[4] Long term projections of construction costs for wastewater treatment plants are not available. Most of the published projected costs concern residential construction. However, these residential costs were not used to predict treatment plant costs. The only available long term (to 1995) projected costs for non-residential construction are for electrical generation and transmission plants. These cost projections were compared to the percent increase in the EPA sewage treatment plant index from 1957 to 1973. It was found that the historical long term percent increase of the EPA index was about the same as the projected increase. Based on this favorable comparison the data for electrical plants is used to predict wastewater treatment plant construction cost increases shown in Figure 8-3. Figure 8-3 shows a projected construction cost rate of increase of about 4 percent per year through 1995.

Consumables

There are no available cost projections for individual consumables used in wastewater treatment. The trend for consumables is projected from the wholesale chemical price index (WCI).[6] Recent data indicates a slightly higher rate of increase for the chemical index than the wholesale price index (WPI) for all commodities. The WCI was 182.3 for October, 1975 while the WPI was 178.9 with the base year being 1967.[6,7] This indicates an absolute difference in the average annual rate of increase since 1967 of 0.25 percent or a relative difference of 3.4 percent. Data for the WPI gives the curve shown in Figure 8-4 and if the difference in the rate of increase of 0.25 percent between these two indexes continues, the WCI will increase as shown.

REGIONAL COST VARIATIONS

This section presents regional variations from the national averages for the four cost categories. The variations are presented through map presentation in four groups: (1) above average by greater than 25 percent, (2) above average by 5 to 25 percent, (3) average ± 5 percent, and (4) below average by greater than 5 percent.

Electrical Energy

Regional variations of electrical energy costs shown in Figure 8-5 were prepared for non-residential users by comparing the cost of an average electric bill in a given state to the average national electric bill.[8] The data used to prepare this figure are summarized in Table 8-1.

Labor

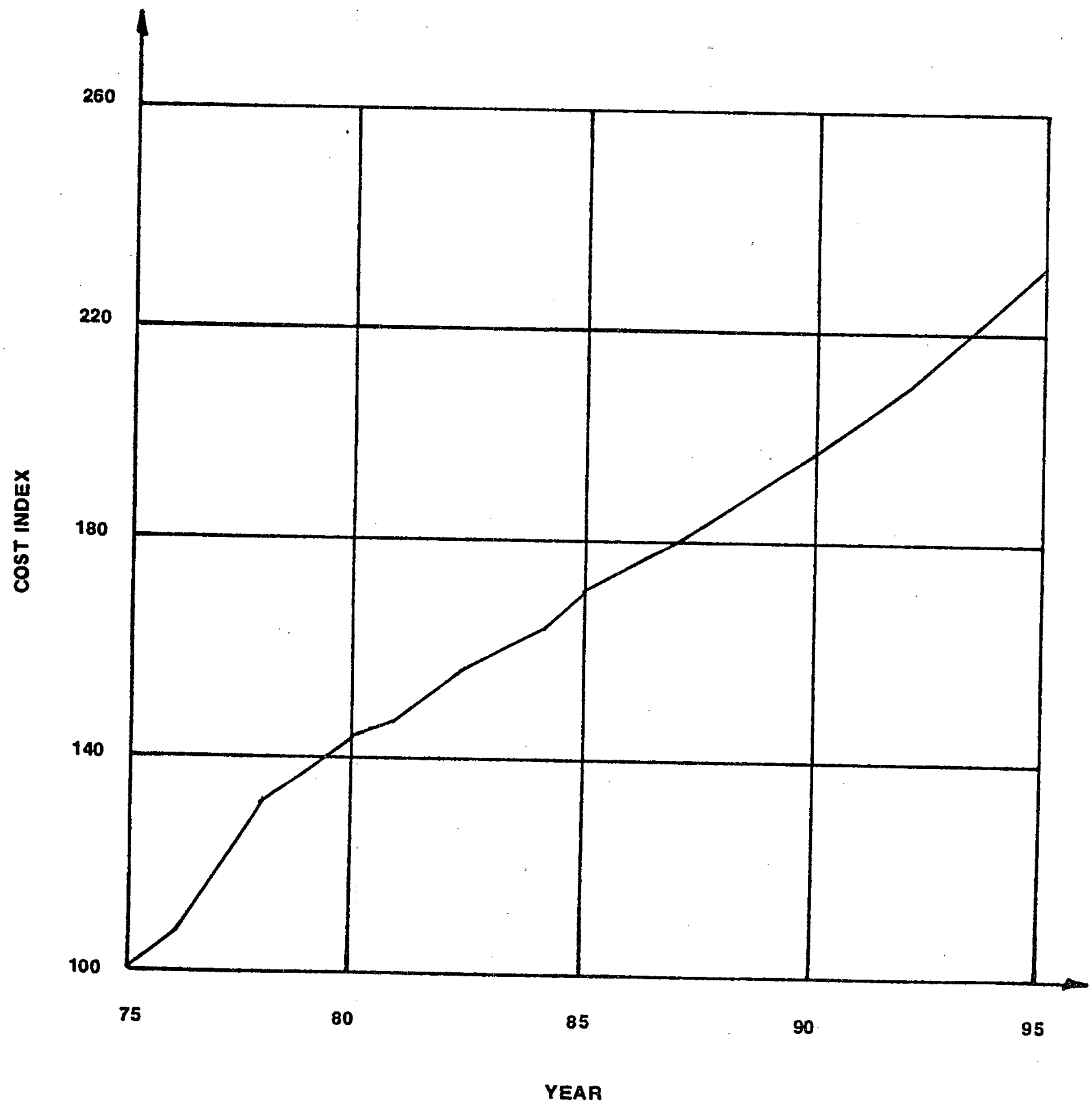
The regional variations for labor costs are shown in Figure 8-6. Cost for common laborers, reinforcement iron workers and carpenters are compiled for the EPA construction cost indexes, in manhours per $1000, for 25 large cities and 25 smaller cities. The labor costs for the cities are compared to the national averages resulting in the percent variations shown in Tables 8-2 and 8-3. The national averages were calculated by averaging the labor costs for the same cities. As shown in the tables, no labor costs exceeded the average by more than 25 percent; the highest is 18 percent for San Francisco and Bakersfield, California.

Construction

Regional variations in construction costs are shown in Figure 8-7. Data for this category were compiled from EPA cost indexes for constructing a 50 mgd activated sludge plant followed by chemical clarification and filtration in 25 large cities and a 5 mgd plant in smaller cities. These data are summarized in Tables 8-4 and 8-5. Percent variations were computed similar to the method used for labor costs.

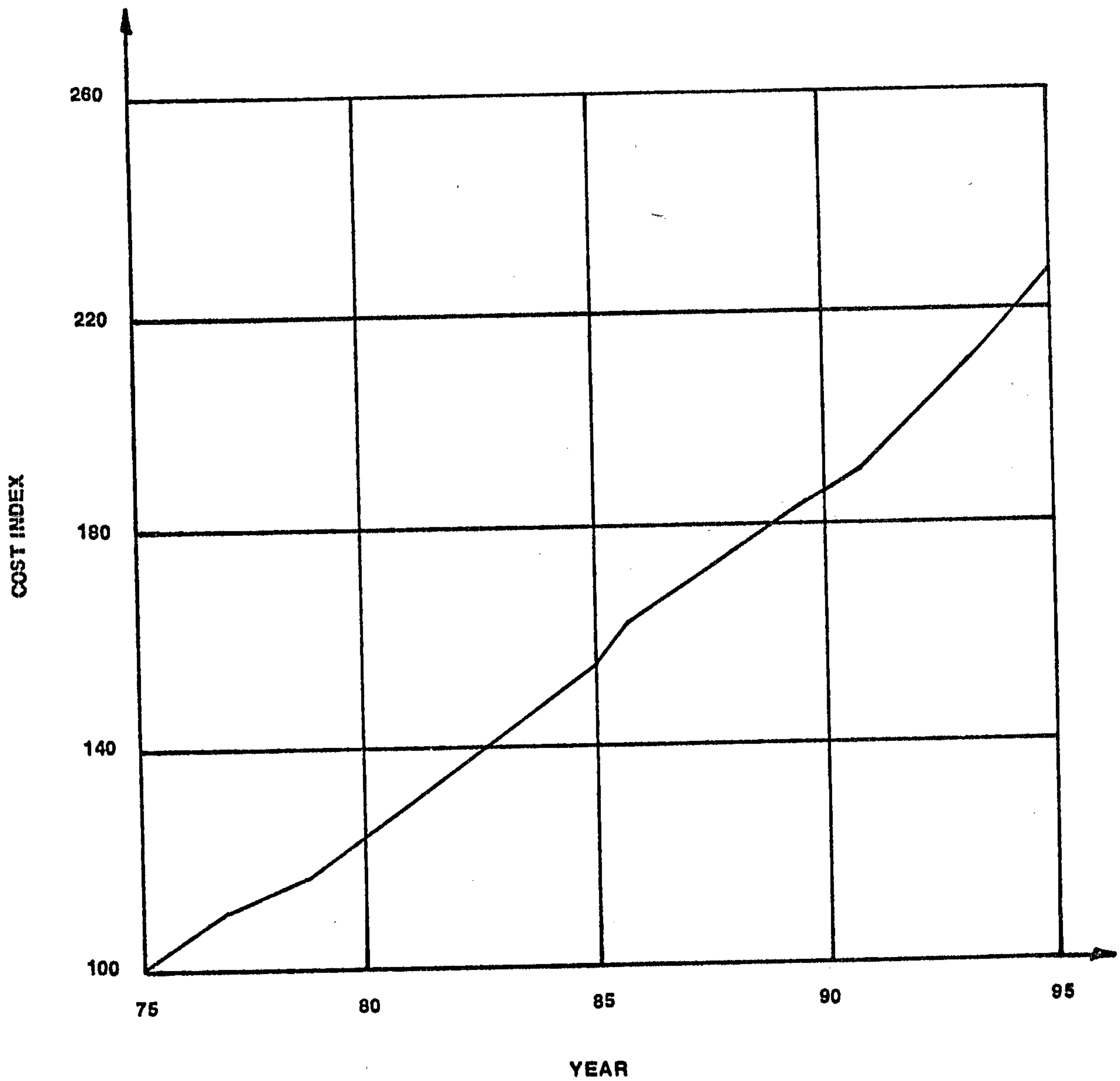
Consumables

No data are available for regional variations in the wholesale cost of chemicals used in wastewater treatment. Data for regional variations in the wholesale price index for all commodities are also not available. Because of the way the Bureau of Labor Statistics obtains information,[1,7] only national indications are possible; therefore, only one index is computed. Regional variations are available for the consumer price index[11] and these data indicate all cities are within the "average ± percent" category as shown in Table 8-5. The extreme deviations occurred in New York (+3.5 percent) and Seattle (-3.9 percent).



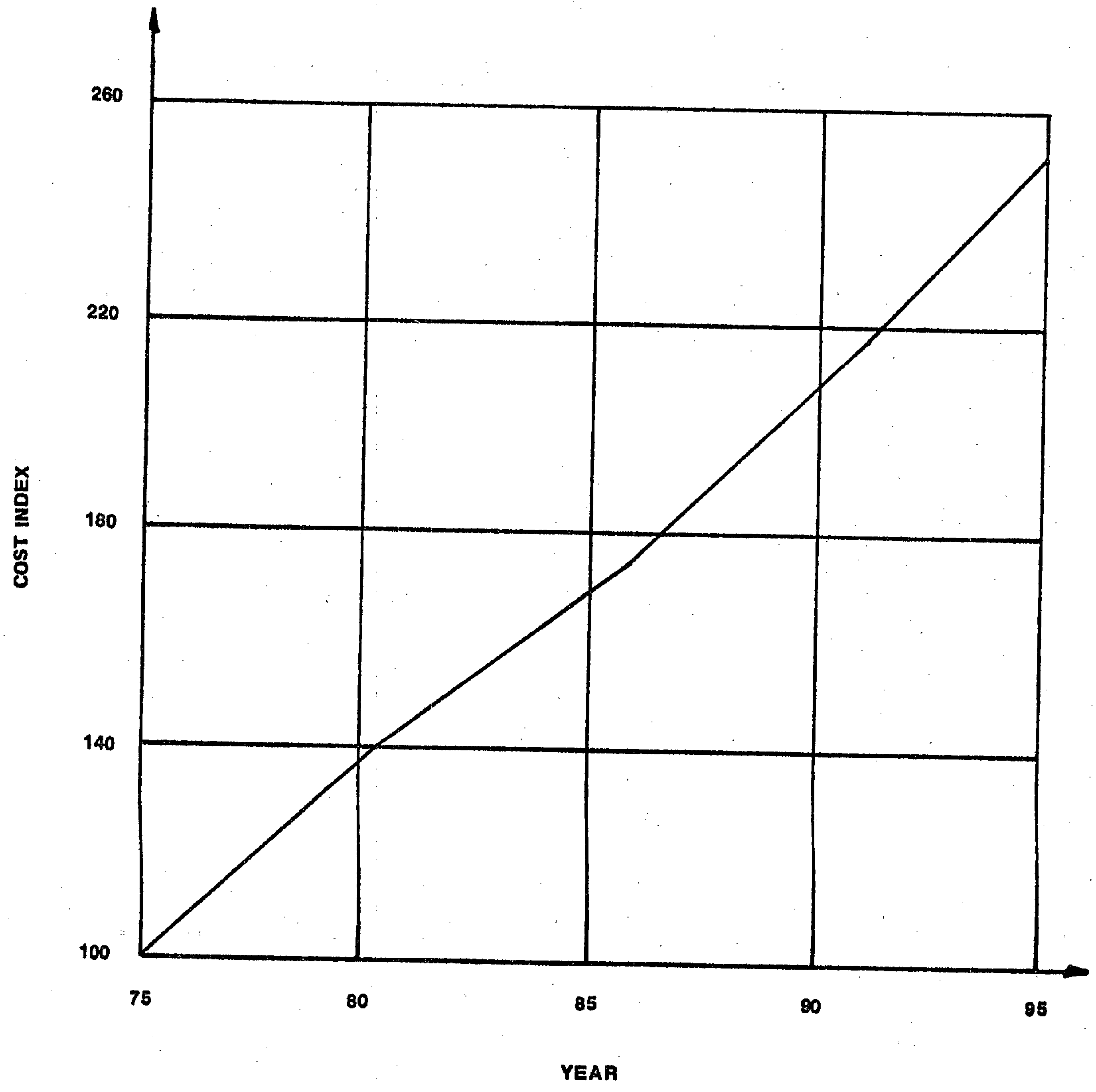
NATIONAL WHOLESALE COST OF POWER
(Data from Reference 2)

FIGURE 8–1



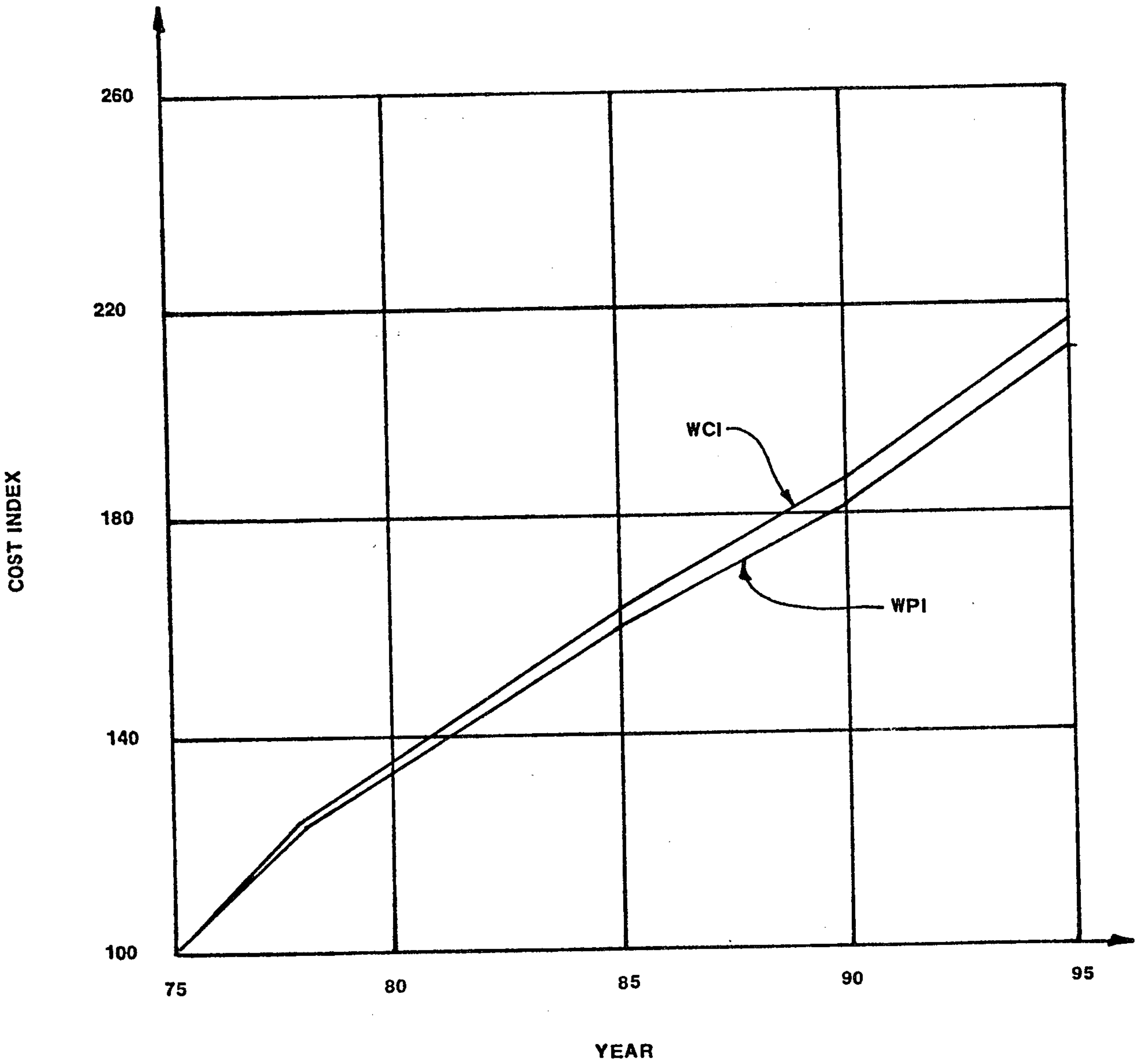
NATIONAL UNIT LABOR COST
(Data from Reference 2)

FIGURE 8-2



NATIONAL CONSTRUCTION COST
(Adapted from information in Reference 4)

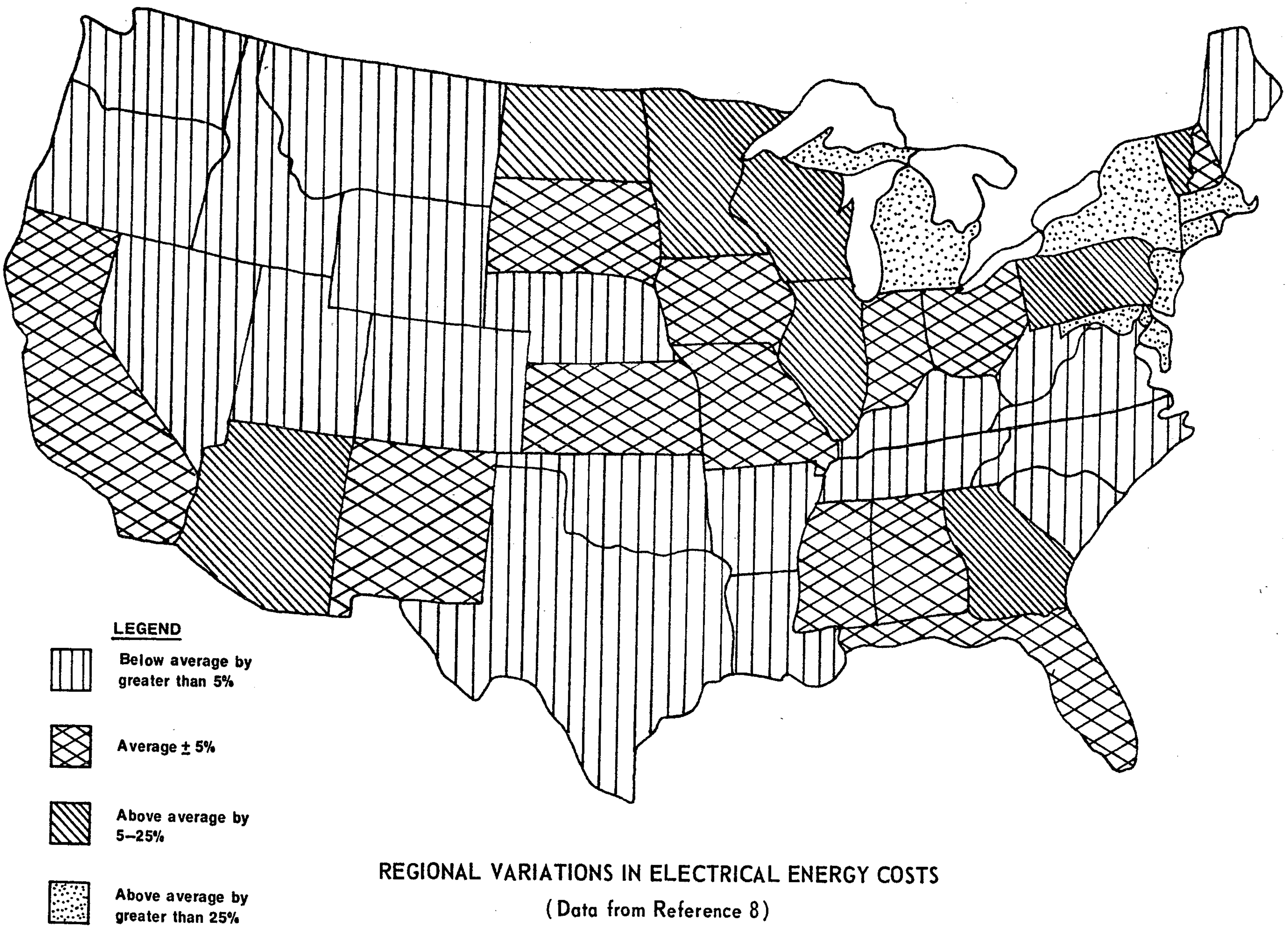
FIGURE 8-3



NATIONAL WHOLESALE CHEMICAL INDEX (WCI) AND WHOLESALE PRICE INDEX(WPI)

(Adapted from information in References 2 and 7)

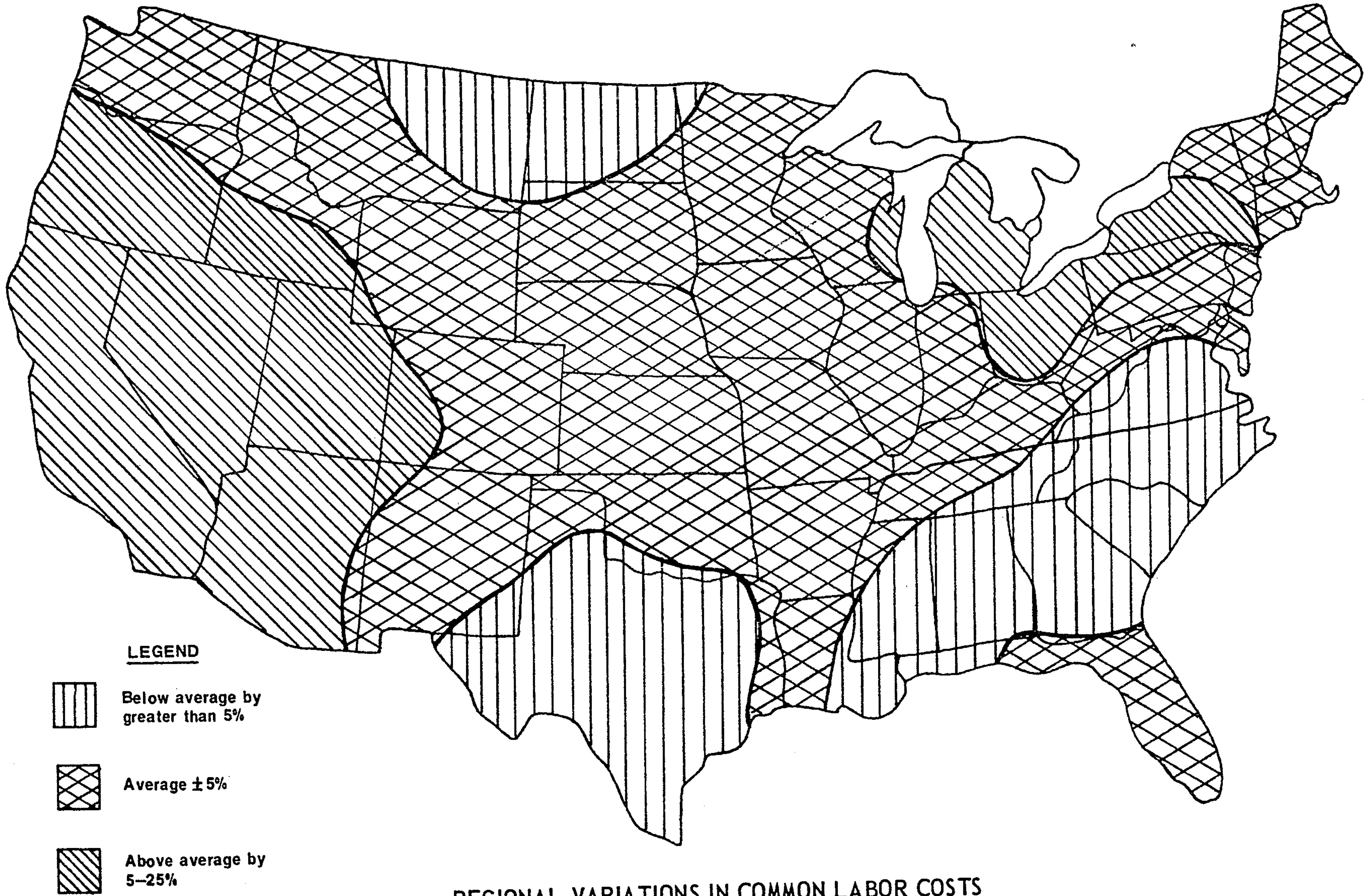
FIGURE 8-4



REGIONAL VARIATIONS IN ELECTRICAL ENERGY COSTS

(Data from Reference 8)

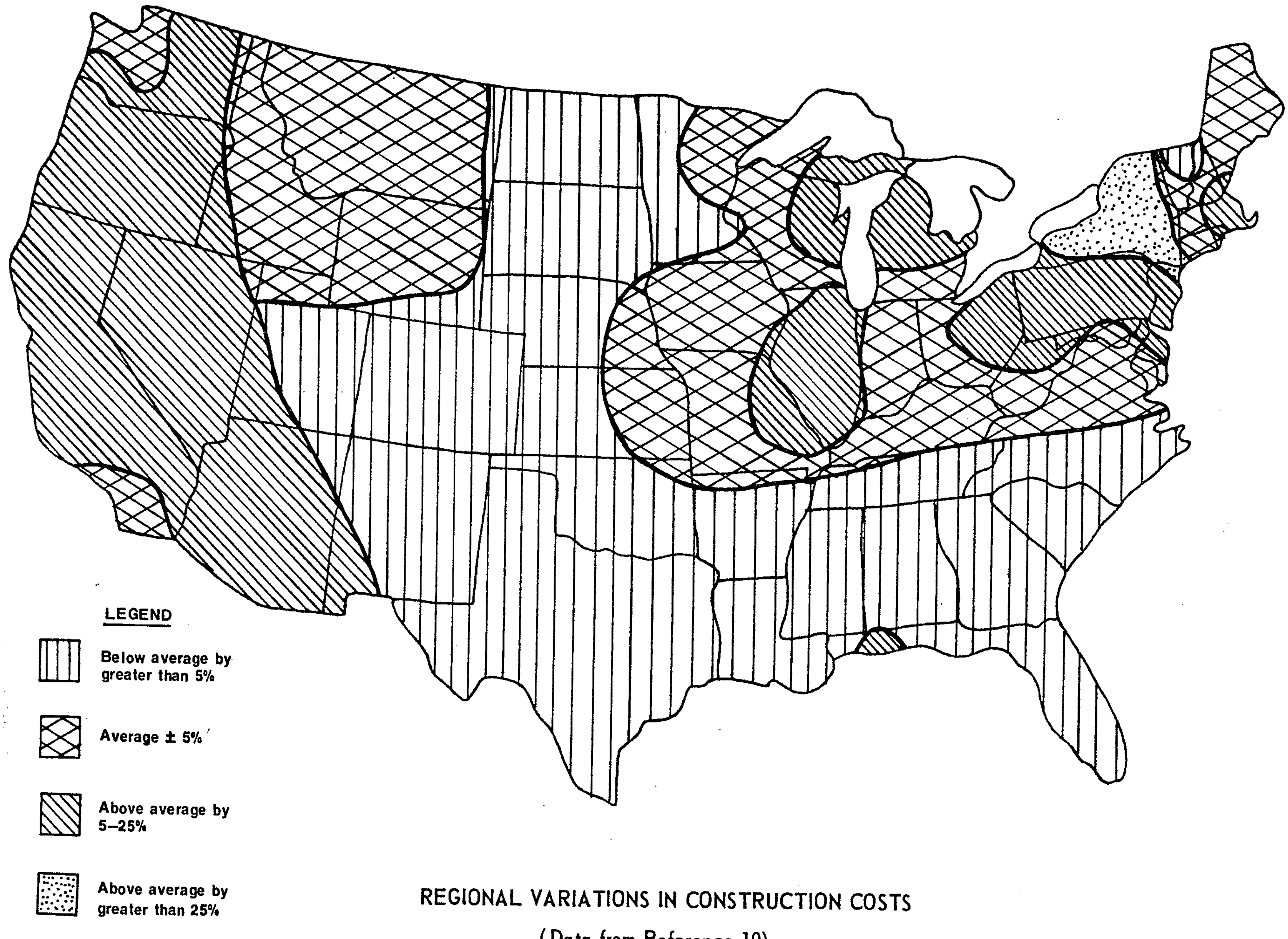
FIGURE 8–5



REGIONAL VARIATIONS IN COMMON LABOR COSTS

(Source: EPA Treatment Facility labor costs, for 50 mgd and 5 mgd in 50 cities, 2nd Quarter, 1976)

FIGURE 8–6



REGIONAL VARIATIONS IN CONSTRUCTION COSTS

(Data from Reference 10)

FIGURE 8–7

TABLE 8-1

ELECTRICAL ENERGY COSTS BY STATES

DATA FOR INDUSTRIAL USERS

(Data From Reference 8)

State	Bill* (dollars)	Deviation (percent)	State	Bill* (dollars)	Deviation (percent)
Wash.	1868	- 57	Ind.	4092	- 5
Ore.	2396	- 45	Ky.	3648	- 16
Cal.	4261	- 1	Tenn.	3407	- 21
Idaho	2720	- 37	Ala.	4225	- 2
Nev.	3964	- 8	Mich.	5464	+ 27
Mont.	3226	- 25	Ohio	4408	+ 2
Utah	3279	- 24	Fla.	4513	+ 5
Ariz.	4640	+ 7	Ga.	4712	+ 9
Wyo.	2907	- 33	S.C.	3465	- 20
Colo.	3697	- 14	N.C.	3318	- 23
New Mex.	4327	0	Va.	4073	- 6
Tex.	3277	- 24	W.Va.	3562	- 18
N.D.	4730	+ 10	Pa.	5207	+ 21
S.D.	4305	0	N.Y.	10374	+ 140
Nebr.	3310	- 23	Md.	5403	+ 25
Kansas	4088	- 5	Del.	5542	+ 28
Okla.	3222	- 25	Wash. D.C.	5839	+ 35
Minn.	4560	+ 6	N.J.	5309	+ 23
Iowa	4192	- 3	Conn.	5649	+ 31
Missouri	4468	+ 3	Mass.	5921	+ 37
Ark.	4038	- 7	R.I.	5713	+ 32
La.	3731	- 14	Vt.	4835	+ 12
Wisc.	4591	+ 6	N.H.	4478	+ 4
Ill.	4606	+ 7	Maine	3930	- 9
Miss.	4174	- 3			

*1974 Data - Average = $4,320

TABLE 8-2

REGIONAL VARIATIONS IN LABOR COSTS FOR LARGE CITIES

City	1976 Wage Rate Manhours/$1000	Variation (percent)
Atlanta, Ga.	39.36	-8.0
Baltimore, Md.	37.10	-2.0
Birmingham, Ala.	40.19	-9.0
Boston, Mass	37.31	-2.0
Charlotte, N.C.	50.94	-29.0
Chicago, Ill.	36.14	+1
Cincinnati, Ohio	34.25	+6
Cleveland, Ohio	34.09	+7
Dallas, Texas	37.93	-7
Denver, Colo.	35.10	+4
Detroit, Mich	33.14	+10
Houston, Texas	36.55	0
Kansas City, Mo.	34.82	+ 5
Los Angeles, CA	32.52	+12
Miami, Fla.	35.98	+1
Milwaukee, Wis.	34.19	+6
Minneapolis, Minn.	36.51	0
New Orleans, La.	39.85	-9
New York, N.Y.	33.27	+9
Philadelphia, PA	35.17	+3
Pittsburgh, PA	36.72	-1
St. Louis, MO	37.50	-3
San Francisco, CA	30.77	+18
Seattle, Wash.	35.57	+2
Trenton, New Jersey	34.87	+4
Average	36.39	

TABLE 8-3

REGIONAL VARIATIONS IN LABOR COSTS FOR SMALL CITIES

City	1976 Wage Rate Manhours/$1000	Variation (percent)
Bakersfield, CA	29.49	+18
Bismark, N. D.	37.53	- 7
Burlington, VT	36.33	- 4
Casper, Wyo.	33.07	+ 5
Charlestown, S.C.	48.01	-28
Cumberland, MD	35.43	- 2
Duluth, Minn	34.19	+ 2
Eugene, Oregon	30.95	+12
Gainesville, FLA	35.59	- 2
Green Bay, Wis.	35.66	- 3
Harrisburg, PA	32.44	+ 7
Las Vegas, Nevada	29.81	+16
Mobile, Alabama	36.80	- 6
Muncie, Indiana	33.99	+ 2
Pocatello, Idaho	31.81	+ 9
Pueblo, Colo	31.74	+ 9
Rapid City, S. D.	35.40	- 2
Roanoke, Virginia	39.10	-11
Saginaw, Michigan	32.35	+ 7
St. Joseph, Missouri	34.16	+ 2
Sioux City, Iowa	34.06	+ 2
Syracuse, N.Y.	33.21	+ 5
Tulsa, Oklahoma	33.59	+ 3
Waco, Texas	38.76	-10
Wheeling, West Virginia	34.48	+ 1
Average	34.72	

TABLE 8-4
REGIONAL VARIATIONS 50 mgd PLANT COSTS
EPA INDEXES

City	1976 Index*	Variation (percent)
Atlanta, Ga	100	- 16.7
Baltimore, Md	122	+ 1.6
Birmingham, Ala	99	- 17.5
Boston, Mass	136	+ 13.3
Charlotte, NC	75	- 37.5
Chicago, Ill	140	+ 16.7
Cincinnati, Ohio	124	+ 3.3
Cleveland, Ohio	129	+ 7.5
Dallas, Texas	95	- 20.8
Denver, Colo	105	- 12.5
Detroit, Mich	121	+ 0.8
Houston, Texas	104	- 13.3
Kansas City, Kan	120	0
Los Angeles, Cal	126	+ 5.0
Miami, Fla	106	- 11.6
Milwaukee, Wisc	125	+ 4.2
Minneapolis, Minn	109	- 9.1
New Orleans, La	113	- 5.8
New York, NY	160	+ 33.3
Philadelphia, Pa	142	+ 18.3
Pittsburgh, Pa	126	+ 5.0
St. Louis, Mo	139	+ 15.8
San Francisco, Cal	134	+ 11.7
Seattle, Wash	124	+ 3.3
Trenton, NJ	130	+ 8.3
Average	120	

*Base year, 1973

TABLE 8-5

REGIONAL VARIATIONS 5 mgd PLANT COSTS

NEW EPA INDEXES

City	1976 Index*	Variation (percent)
Bakersfield, Ca	119	+ 8.1
Bismarck, ND	100	- 9.1
Burlington, Vt	102	- 7.3
Casper, Wyo	105	- 4.5
Charleston, SC	77	- 30.0
Cumberland, Md	128	+ 16.4
Duluth, Minn	109	- 0.9
Eugene, Oregon	122	+ 10.9
Gainesville, Fla	98	- 10.9
Green Bay, Wisc	121	+ 10.0
Harrisburg, Pa	129	+ 19.0
Las Vegas, Nev	127	+ 15.4
Mobile, Ala	120	+ 8.2
Muncie, Indiana	113	+ 1.8
Pocatello, Idaho	108	- 1.8
Pueblo, Colo	99	- 10.0
Rapid City, SD	95	- 13.6
Roanoke, Virginia	105	- 4.5
Saginaw, Mich	118	+ 7.3
St. Joseph, Missouri	113	+ 1.8
Sioux City, Iowa	107	- 2.7
Syracuse, NY	139	+ 26.4
Tulsa, Okla	98	- 10.9
Waco, Texas	88	- 20.0
Wheeling, West Virginia	122	+ 10.9
Average	110	

* Base year, 1973

TABLE 8-6

REGIONAL VARIATION IN CONSUMER PRICE INDEX

City	1976 Index*	Variation (percent)
Chicago, Ill	159.6	- 2.4
Detroit, Mich	162.9	- 0.4
Los Angeles, Ca	160.4	- 2.0
New York, NY	169.3	+ 3.5
Philadelphia, Pa	166.9	+ 2.0
Boston, Mass	163.0	- 0.4
Houston, Texas	165.8	+ 1.3
Minneapolis, Minn	161.9	- 1.0
Pittsburg, Pa	161.7	- 1.2
Buffalo, NY	163.5	- 0.1
Cleveland, Ohio	162.4	- 0.7
Dallas, Texas	160.6	- 1.8
Milwaukee, Wisc	159.2	- 2.7
San Diego, Ca	162.5	- 0.7
Seattle, Wash	157.3	- 3.9
Washington	163.4	- 0.1
Atlanta, Georgia	164.7	+ 0.7
Baltimore, Md	167.6	+ 2.4
Cincinnati, Ohio	163.9	+ 0.2
Kansas City, Kan	160.2	- 2.1
St. Louis, Mo.	158.9	- 2.9
San Francisco, Ca	161.5	- 1.3
Average	163.6	

*Base year, 1967

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7. "Wholesale Price Indexes," Supplement 1975 to data for 1974, Bureau of Labor Statistics.
8. "Typical Electric Bills," Federal Power Commission, 1974.

CHAPTER 9

ENERGY EFFECTIVENESS AND COST EFFECTIVENESS

INTRODUCTION

The purpose of this chapter is to discuss the relationships between energy effectiveness and cost effectiveness through the use of three examples. Each of the examples compares two alternative 5 and 25 mgd treatment systems for meeting a specified effluent standard:

> Example 1 compares trickling filter and activated sludge systems to meet secondary effluent standards of BOD = 30 mg/l and SS = 30 mg/l.

> Example 2 compares independent physical-chemical treatment (IPC) with activated sludge, followed by chemical clarification and filtration to meet higher than secondary effluent standards of BOD = 10 to 20 mg/l, SS = 5 mg/l and total phosphorus = 1 mg/l.

> Example 3 compares a total AWT system with land treatment by spray irrigation to meet effluent standards of BOD = 1 mg/l, SS = 1 mg/l, P = 0.1 mg/l and N(total) = 3 mg/l.

Primary energy requirements used in these examples are from the curves in Chapter 3 and secondary requirements from Table 4-1.

Construction costs are based on the authors' experience and include all site work, equipment, installation, engineering and administrative costs, interest during construction and other costs normally required for a complete and operable facility. The EPA Treatment Plant Index at the time of these estimates was 257.8. The cost estimates are considered representative of a typical installation and do not include allowances for any unusual local conditions. The estimates are based on generalized cost data and are for illustrative purposes only.

Operating and maintenance cost estimates are based on the following unit prices.

Labor	$7.00/hr
Electricity	$0.025/kwh
Natural Gas	$1.50/million Btu
Alum	$70/ton
Activated Carbon	$1,000/ton
Chlorine	$220/ton
Lime	$37/ton
Polymer (wastewater)	$0.30/lb
Polymer (sludge conditioning)	$2.00/lb

Total operating and maintenance costs in the examples include costs for primary and secondary energy, labor, material, supplies and chemicals.

EXAMPLE 1 - SECONDARY TREATMENT

Flow diagrams for the trickling filter and activated sludge alternates in this example are shown in Figure 9-1. The following requirements and cost estimates are summarized from the energy data in Tables 9-1 and 9-2 and the cost data in Table 9-3.

	Treatment System and Capacity			
	5 mgd		25 mgd	
	Trickling Filter	Activated Sludge	Trickling Filter	Activated Sludge
Total Primary and Secondary Energy				
Thousand kwh/yr	1,117	2,066	5,207	9,502
Million Btu/yr	5,713	25,908	28,332	135,570

Costs	Treatment System and Capacity 5 mgd Trickling Filter	5 mgd Activated Sludge	25 mgd Trickling Filter	25 mgd Activated Sludge
Construction, $1,000	4,935	6,990	16,210	18,505
Primary Energy, $1,000/yr	29	83	135	402
Total O & M, $1,000/yr	200	351	606	1,312
Total Annual, $1,000/yr				
6-1/8% - 20 yr	635	966	2,034	2,942
7% - 20 yr	666	1,011	2,136	3,059
10% - 20 yr	780	1,172	2,510	3,486

These estimates indicate that activated sludge plants are more costly than trickling filter facilities. However, most of the cost difference between these two alternatives is in the sludge treatment processes as shown in Table 9-3. The thickening, vacuum filtration and incineration processes used in the activated sludge alternative are more costly to construct and operate than thickening and anaerobic digestion in the trickling filter alternative. Of course, anaerobic digestion can be used for sludge treatment in activated sludge plants as well as in trickling filter facilities.

Energy requirements for fuel are almost all for sludge treatment; building heating and secondary requirements are a small percentage of the total. Fuel requirements for incineration remain nearly constant for any location and climate, but requirements for digester heating vary with sludge and outside air temperatures. Digester heat requirements in this example are based on an influent sludge temperature of 60^0F in a plant located in the Southern U.S.

Primary electrical energy use is higher for the activated sludge alternative because of the aeration requirements. Secondary electrical energy requirements for chlorine production are the same in both alternatives.

The cost and energy estimates for these two alternatives demonstrate that a careful evaluation must be conducted for a specific application since the differences are not conclusive for all potential plant sites.

EXAMPLE 2 - HIGHER THAN SECONDARY TREATMENT

Flow diagrams for activated sludge treatment, plus chemical clarification and filtration, and IPC treatment alternatives are shown in Figure 9-2. These alternatives may not be directly comparable for some applications because it may be difficult to achieve the effluent quality goal of 10 to 20 mg/l BOD for a particular wastewater. A combination of biological and physical-chemical treatment systems is almost always more efficient than either system alone.

The following energy and cost estimates are summarized from energy data in Tables 9-4 and 9-5 and cost data in Table 9-6.

	Treatment System and Capacity			
	5 mgd		25 mgd	
	IPC	Act. Sludge + AWT	IPC	Act. Sludge + AWT
Primary Energy				
Thousand kwh/yr	1,476	1,996	6,945	8,847
Million Btu/yr	55,438	24,238	292,692	125,592
Secondary Energy				
Thousand kwh/yr	305	305	1,525	1,525
Million Btu/yr	17,309	2,040	86,545	10,200
Costs				
Construction, $1,000	9,112	8,935	27,051	26,114
Primary Energy, $1,000/yr	120	86	613	409
Total O & M, $1,000/yr	573	518	2,304	1,931
Total Annual, $1,000/yr				
6-1/8% - 20 yr	1,377	1,305	4,687	4,231
7% - 20 yr	1,434	1,361	4,858	4,396
10% - 20 yr	1,645	1,568	5,482	4,998

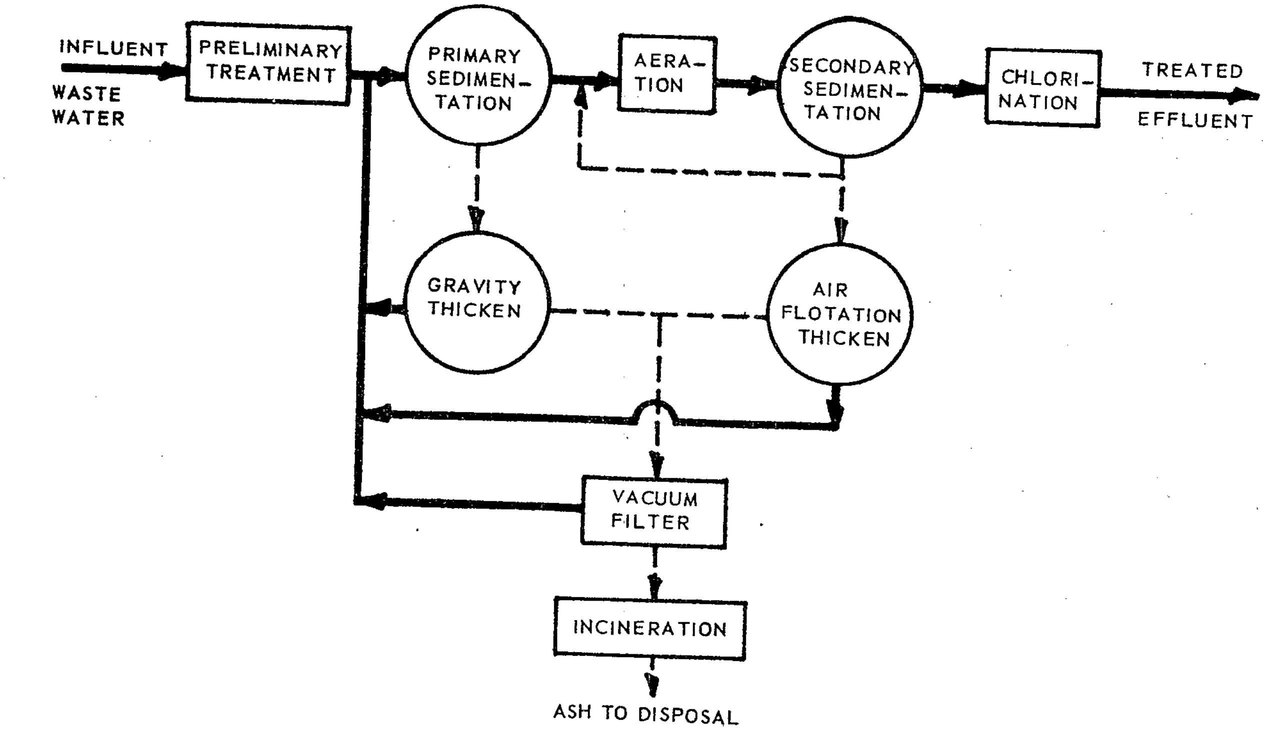
The estimated construction costs for the two alternatives are nearly identical well within the accuracy of the estimates. The total operation and maintenance costs are also close (less than 10 percent difference) for the two alternatives. The most significant difference is the higher secondary energy requirements for IPC treatment. This secondary energy requirements difference is reflected in the higher cost for chemicals. The IPC system is, therefore, more susceptible to chemical price increases and energy curtailments resulting in chemical shortages than the activated sludge system.

EXAMPLE 3 - HIGHER THAN SECONDARY TREATMENT

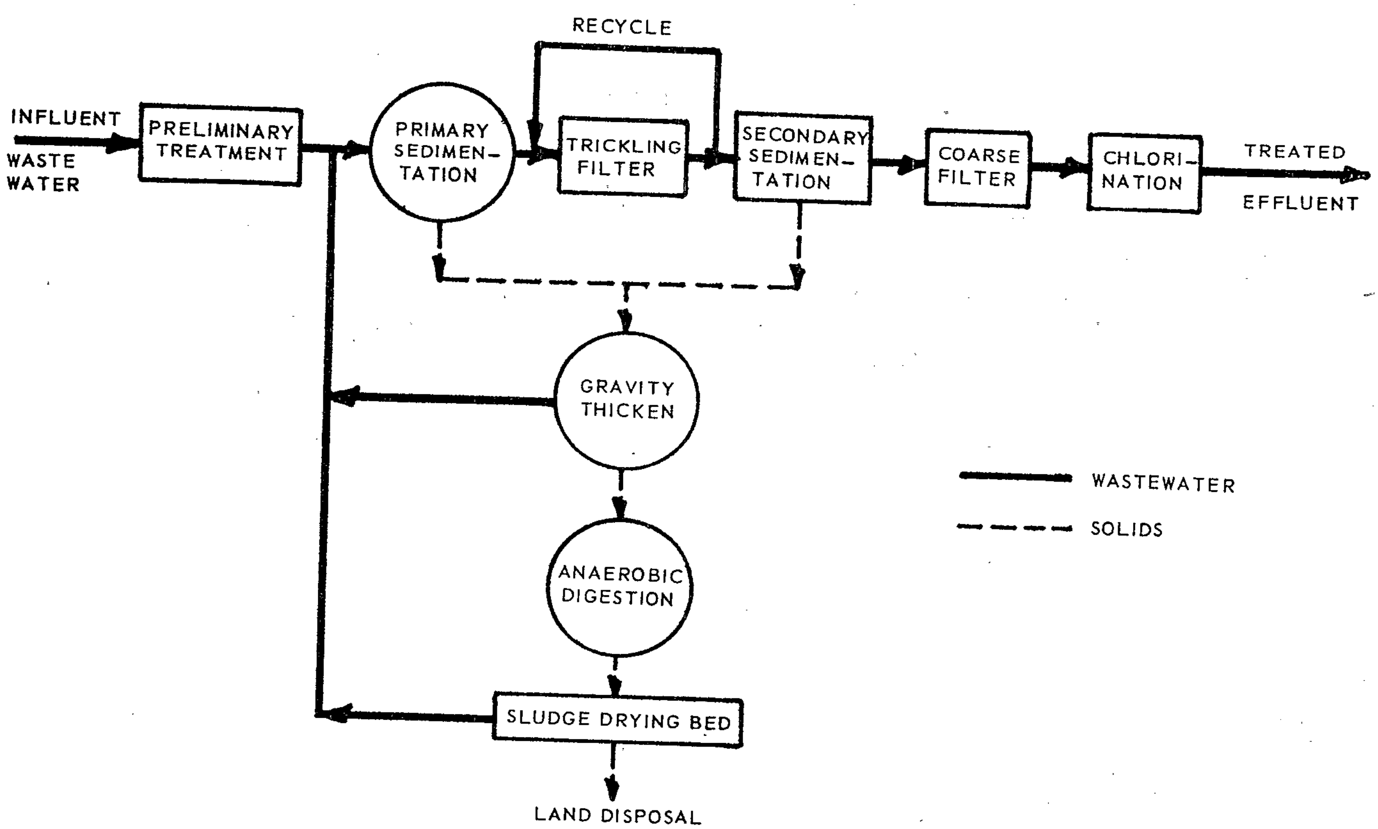
This example compares two systems that are capable of producing an extremely high quality effluent (BOD = 1 mg/l, SS = 1 mg/l, P = 0.1 mg/l and N (total) = 3 mg/l). In order to achieve this quality effluent, nitrification and denitrification have been added to the AWT system in Example 2. This system was compared to the land treatment system shown in Example 14 of Chapter 6. Costs and energy requirements are based on solid set sprinklers operating under the conditions listed in Figure 3-79. The following tabulation summarizes the energy and cost estimates.

	Treatment System and Capacity			
	5 mgd		25 mgd	
	Land Treatment	Total AWT	Land Treatment	Total AWT
Primary Energy				
Thousand kwh/yr	2,701	3,172	12,433	14,697
Million Btu/yr	0	24,230	0	125,592
Secondary Energy				
Thousand kwh/yr	0	305	0	1,525
Million Btu/yr	0	24,200	0	120,900
Costs				
Construction, $1,000	9,600	12,061	40,000	35,393
Primary Energy, $1,000/yr	68	116	311	555
Total O & M, $1,000/yr	210	624	700	2,294
Total Annual, $1,000/yr				
6-1/8% - 20 yr	1,056	1,687	4,224	5,412
7% - 20 yr	1,116	1,763	4,475	5,635
10% - 20 yr	1,337	2,041	5,396	6,453

Land costs are included in the construction costs and crop revenues (negative costs) are included in the total annual costs of the land treatment system. The electrical energy requirements for the total AWT system are approximately 15 percent greater than those of the land treatment system, which requires zero primary fuel input. The secondary energy fuel requirements for the total AWT system are extremely high due to the energy requirements for the production of methanol (36×10^6 Btu/ton). A review of the costs shows that the O & M cost of a land treatment system is 58 percent of the total AWT system. The impact of the scale on construction costs is reflected in the total annual cost of the system.



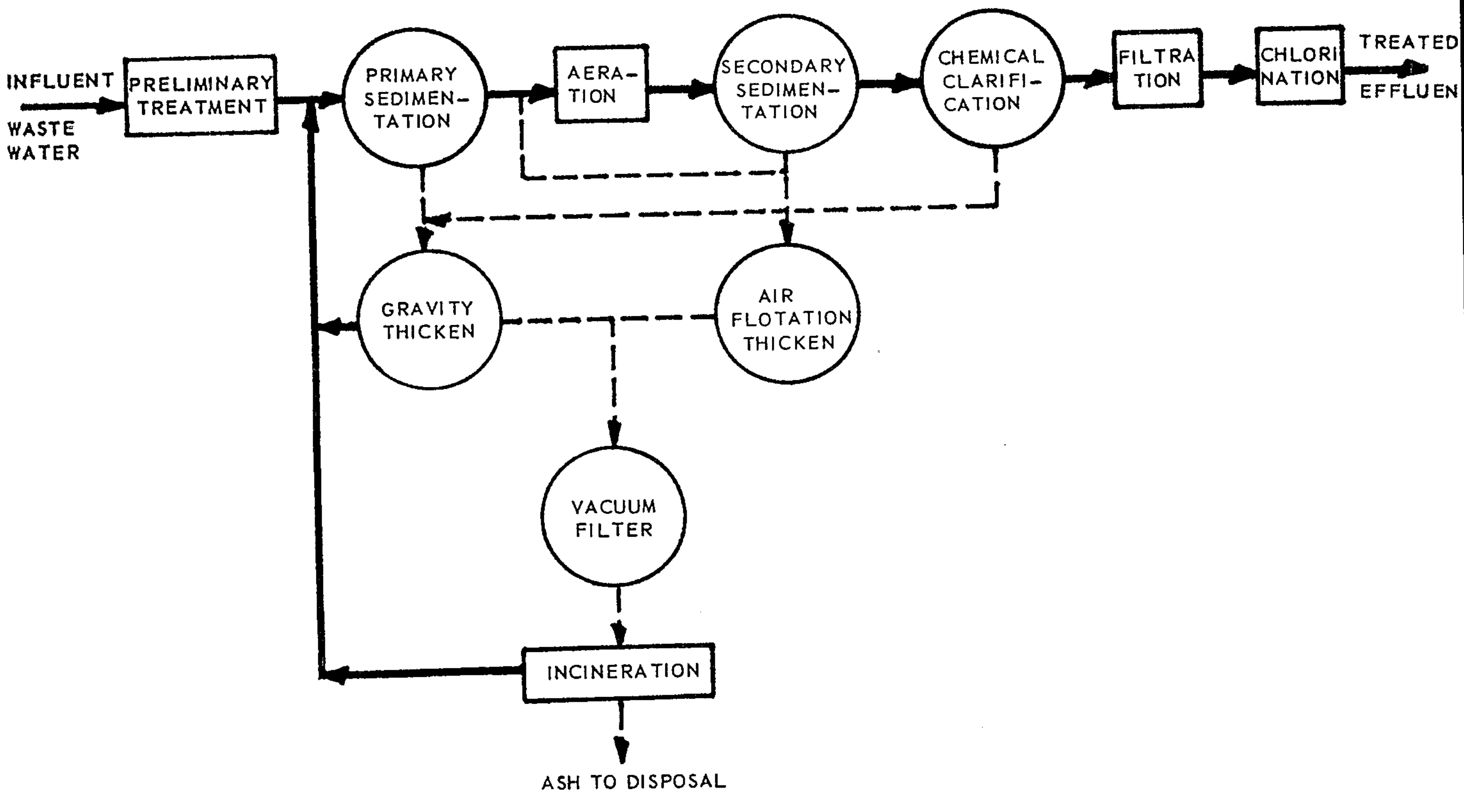
ACTIVATED SLUDGE



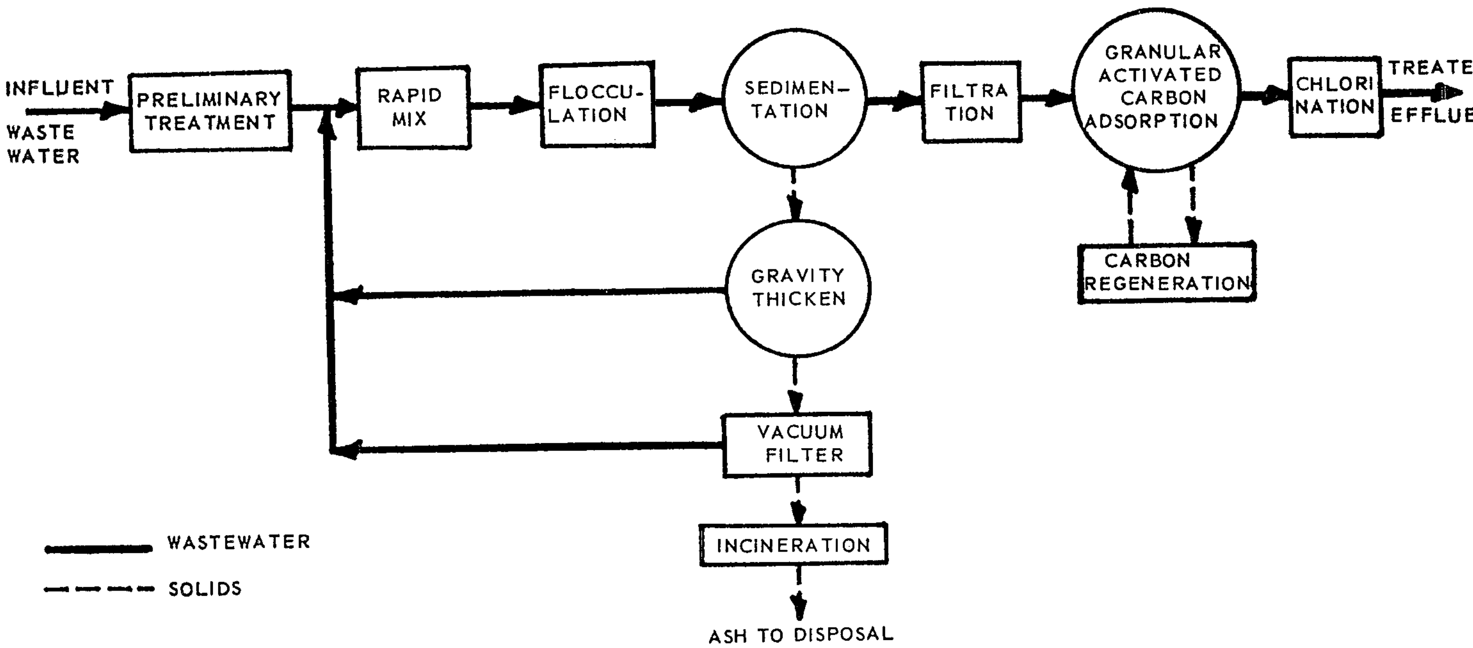
TRICKLING FILTER

FIGURE 9–1

EXAMPLE 1
SECONDARY TREATMENT



ACTIVATED SLUDGE AND AWT



INDEPENDENT PHYSICAL CHEMICAL

EXAMPLE 2

HIGHER THAN SECONDARY TREATMENT

FIGURE 9–2

TABLE 9-1

ENERGY REQUIREMENTS
ACTIVATED SLUDGE - SECONDARY TREATMENT
(FLOW DIAGRAM FIGURE 9-1)

PROCESS	Figure No.	5 mgd Plant Energy Requirements Thousand kwh/yr	5 mgd Plant Energy Requirements Million Btu/yr	25 mgd Plant Energy Requirements Thousand kwh/yr	25 mgd Plant Energy Requirements Million Btu/yr
Primary Energy					
Raw Sewage Pumping	3-1	90		410	
Preliminary Treatment		34		92	
Bar Screen	3-7				
Comminutor	3-8				
Grit Removal	3-9				
Primary Sedimentation	3-12	11		28	
Aeration-Mechanical	3-28	800		4,000	
Secondary Sedimentation	3-13	50		220	
Chlorination	3-74	55		250	
Sub Total		1,040		5,000	
Gravity Thicken	3-85	1		7	
Air Flotation Thicken	3-86	210		1,100	
Vacuum Filter	3-95	130		580	
Incineration	3-111/112/113	350	25,600	1,200	130,800
Ash Disposal			100		100
Sub Total		691	25,700	2,887	130,900
Building Heating	3-83		160		430
Building Cooling	3-84	30		90	
Sub Total		30		90	430
Total Primary Energy		1,761	25,860	7,977	135,330
Secondary Energy (Table 4-1)					
Chlorine		305		1,525	
Polymer			48		240
Total Secondary Energy		305	48	1,525	240
Total Primary + Secondary Energy		2,066	25,908	9,502	135,570

TABLE 9-2

ENERGY REQUIREMENTS

TRICKLING FILTER - SECONDARY TREATMENT
(FLOW DIAGRAM FIGURE 9-1)

PROCESS	Figure No.	5 mgd Plant Energy Requirements Thousand kwh/yr	5 mgd Plant Energy Requirements Million Btu/yr	25 mgd Plant Energy Requirements Thousand kwh/hr	25 mgd Plant Energy Requirements Million Btu/yr
Primary Energy					
Raw Sewage Pumping	3-1	90		410	
Preliminary Treatment		11		23	
Bar Screen	3-7				
Comminutor	3-8				
Grit Removal	3-10				
Primary Sedimentation	3-12	11		28	
Trickling Filter - High Rate, Rock Media	3-16	290		1,250	
Secondary Sedimentation	3-13	12		30	
Coarse Filter	3-63	150		750	
Chlorination	3-74	55		250	
Sub Total		619		2,741	
Gravity Thicken	3-85	1		7	
Anaerobic Digestion	3-105/5-45	160	5,293	830	26,462
Drying Bed	3-98	2	20	14	140
Land Disposal - Truck	3-100		240		1,300
Sub Total		163	5,553	851	27,902
Building Heating	3-83		160		430
Building Cooling	3-84	30		90	
Sub Total		30	160	90	430
Total Primary Energy		812	5,713	3,682	28,332
Secondary Energy					
Chlorine	4-5	305		1,525	
Total Secondary Energy		305		1,525	
Total Primary + Secondary Energy		1,117	5,713	5,207	28,332

TABLE 9-3

COST ESTIMATES

ACTIVATED SLUDGE AND TRICKLING FILTER
SECONDARY TREATMENT
(FLOW DIAGRAM FIGURE 9-1)

	5 mgd		25 mgd	
	Trickling Filter	Activated Sludge	Trickling Filter	Activated Sludge
Construction, $1,000				
Wastewater Treatment	4,035	3,582	12,829	13,155
Sludge Treatment	900	3,408	3,381	5,350
Total	4,935	6,990	16,210	18,505
Operation and Maintenance $1,000/yr				
Labor	122	136	297	364
Material	32	51	90	140
Electricity	20	44	92	199
Fuel	9	39	43	203
Chemicals	17	81	84	406
Total	200	351	606	1,312

TABLE 9-4

ENERGY REQUIREMENTS
ACTIVATED SLUDGE WITH CHEMICAL CLARIFICATION AND FILTRATION
HIGHER THAN SECONDARY TREATMENT
(FLOW DIAGRAM FIGURE 9-2)

PROCESS	Figure No.	5 mgd Plant Energy Requirements		25 mgd Plant Energy Requirements	
		Thousand kwh/yr	Million Btu/yr	Thousand kwh/yr	Million Btu/yr
Raw Sewage Pumping	3-1	90		410	
Preliminary Treatment		34		92	
Bar Screen	3-7				
Comminutor	3-8				
Grit Removal	3-9				
Primary Sedimentation	3-12	16		46	
Aeration - Mechanical	3-28	800		4,000	
Secondary Sedimentation	3-13	50		220	
Chemical Clarification (Alum)	3-57	90		450	
Chlorination	3-74	55		250	
Filtration	3-63	120		600	
Sub Total		1,255		6,068	
Gravity Thicken	3-85	4		13	
Flotation Thicken	3-86	195		800	
Vacuum Filter	3-95	190		760	
Incineration	3-111/112/113	350	23,600	1,200	124,100
Ash Disposal			18		92
Sub Total		739	23,618	2,773	124,192
Building Heating	3-83		620		1,400
Building Cooling	3-84	2		6	
Sub Total		2	620	6	1,400
Total Primary Energy		1,996	24,238	8,847	125,592
Secondary Energy					
Alum			1,972		9,860
Polymer			68		340
Chlorine		305		1,525	
Total Secondary Energy		305	2,040	1,525	10,200
Total Primary + Secondary Energy		2,301	26,278	10,372	135,792

TABLE 9-5

ENERGY REQUIREMENTS
INDEPENDENT PHYSICAL CHEMICAL
HIGHER THAN SECONDARY TREATMENT
(FLOW DIAGRAM FIGURE 9-2)

PROCESS	Figure No.	5 mgd Plant Energy Requirements Thousand kwh/yr	5 mgd Plant Energy Requirements Million Btu/yr	25 mgd Plant Energy Requirements Thousand kwh/yr	25 mgd Plant Energy Requirements Million Btu/yr
Raw Sewage Pumping	3-1	90		410	
Preliminary Treatment		34		92	
Bar Screen	3-7				
Comminutor	3-8				
Grit Removal	3-9				
Chemical Clarification (Alum)	3-57	90		450	
Filtration	3-63	120		600	
Carbon Adsorption	3-66	320		1,600	
Carbon Regeneration	3-67	140	16,000	820	93,000
Chlorination	3-73	55		250	
Sub Total		849	16,000	4,222	93,000
Thicken - Chemical Sludge	3-85	5		22	
Vacuum Filter	3-95	170		695	
Incineration	3-111/112/113	450	38,800	2,000	198,200
Ash Disposal			18		92
Sub Total		625	38,818	2,717	198,292
Building Heating	3-83		620		1,400
Building Cooling	3-84	2		6	
Sub Total		2	620	6	1,400
Total Primary Energy		1,476	55,438	6,945	292,692
Secondary Energy					
Alum			1,972		9,860
Activated Carbon			11,118		55,590
Polymer			6		30
Lime			4,213		21,065
Chlorine		305		1,525	
Total Secondary Energy		305	17,309	1,525	86,545
Total Primary + Secondary Energy		1,781	72,747	8,470	379,237

TABLE 9-6

COST ESTIMATES

ACTIVATED SLUDGE AND INDEPENDENT PHYSICAL CHEMICAL

HIGHER THAN SECONDARY TREATMENT

(FLOW DIAGRAM FIGURE 9-2)

	5 mgd		25 mgd	
	IPC	Activated Sludge	IPC	Activated Sludge
Construction, $1,000	9,112	8,935	27,051	26,114
Operation and Maintenance $1,000/yr				
Labor	178	198	418	486
Material	53	64	161	185
Electricity	37	50	174	221
Fuel	83	36	439	188
Chemicals	222	170	1,112	851
Total	573	518	2,304	1,931

CHAPTER 10

ENERGY IMPLICATIONS OF SEPARATE AND COMBINED SEWERS AND INFILTRATION/INFLOW

INTRODUCTION

Energy requirement curves are presented in this chapter for the treatment of storm and combined flows and infiltration/inflow for POTW sizes from 5 to 200 mgd. Power requirements, based on unit process design parameters, were determined for the following processes:

1. Swirl concentrator
2. Screens
   a. Stationary
   b. Horizontal shaft
   c. Vertical shaft
3. Air flotation
4. High rate filtration
5. Flow equalization
   a. Storage
   b. Sedimentation
   c. Sludge removal
6. Chlorination
   a. High intensity mixing
   b. Chlorine gas
   c. Chlorine dioxide
   d. Hypochlorite
   e. Dechlorination

Design criteria were selected in order to show energy requirements for various plant capacities. These design criteria are variable for specific local circumstances or flow characteristics, in terms of quantity variations (unit hydrograph) and quality variations (seasonal and during-storm).

The unit processes may be used individually or in combination with others. For example, a screening device may be provided ahead of a dissolved air flotation unit. The choice of unit process combinations will depend on local circumstances. Generalized storm water characteristics were developed by Metcalf and Eddy[7] and include the following:

	BOD, mg/l	Suspended Solids, mg/l	Total Coliform MPN/100 ml	Total Nitrogen, mg/l as N	Total Phosphorus, mg/l as P
Combined Sewage	115	410	5×10^6	11	4
Surface Runoff	30	630	4×10^5	3	1

The energy required to operate a storm water treatment facility is composed of the process equipment which is active only during the overflow period and heating and lighting of enclosed spaces. The cost associated with the power may basically be a demand charge since the power use is so low compared to the maximum demand; however, many water utilities have rate schedules which incorporate the demand into other utility facilities locations which tends to average demand charges across the system. The rates for a specific location should be investigated prior to assigning a unit charge.

Energy requirements are presented in terms of kwh/yr and Btu/yr for varying time of operation. The average energy usage will be a function of a flow somewhat less than the peak recorded flow. The rated plant capacity must be equal to the peak storm event. Most storm overflows will not cause treatment plants to operate at full capacity; review of typical storm hydrographs show that plants will operate at peak flow only for a portion of time. The flow selected for estimating the energy requirements will be a function of variation in storm flows and of the unit hydrographs which are a function of the collection system and each individual storm. For this report, the flow rate for average energy consumption was assumed to be 45 percent of the rated capacity of the treatment plant.

SWIRL CONCENTRATOR

A swirl concentrator requires no energy except that needed to recover hydraulic headlosses through the system. These headlosses would depend on the particular system design. Generally, this process headloss would be similar to a sedimentation tank headloss of 2 to 6 feet.[9]

SCREENS

Stationary

A stationary screen requires no energy except that needed to recover hydraulic headlosses through the system. As with swirl concentrators, headlosses depend on the particular system design. The stationary screen headloss will normally be 3 to 8 feet.[4,5]

Horizontal Shaft Rotary Screen (Microscreen)

The wastewater enters the interior of a slowly rotating drum and discharges through the screen into a collection chamber. Screen submergence typically varies from 74 to 83 percent and is sized based on loadings in gpm/sq ft. The power required to operate the screen includes the screen rotation drive, washwater supply pump, and instrument air compressor. Power required for each of these functions is as follows:

Screen Surface Area sq ft	Rotational Drive, hp	Washwater Supply Pump, hp	Instrumentation Air, hp	Electrical Energy Use kwh/day
315	5	5	1	195
630	7.5	7.5	2	303
1,260	15	15	4	605
2,520	30	30	8	1,210
5.040	60	60	16	2,419

Exact design criteria are difficult to establish. Work in the Philadelphia area[3] showed successful operation for a loading range of 35 to 45 gpm/sq ft. A second study[7] shows a wide range of values on reported facilities, but recommends 5 to 10 gpm/sq ft for low rate and 20 to 50 gpm/sq ft for high rate screens. Based on this information, and assuming a high rate system, 35 gpm/sq ft is the loading rate shown in Figure 10-1.

Vertical Shaft Rotary Screens

Energy requirements are based on the use of the SWECO centrifuge wastewater concentrator. Each unit is driven by a 5 hp motor and requires 10 gpm at 80 psi backspray. The horsepower required for the backspray is about 0.75 hp per screen unit.

Additional energy is required to heat the backspray water from an assumed 60^0F to 160^0F. Each unit requires 100,000 Btu/hr of operation. Instrument air compressor requirements are about 0.25 hp. The resulting energy requirement is 6 hp per operating screen or 2.7 hp avg/screen/hr of overflow. The 100,000 Btu/hr avg per screen for heating the backwash water results in an average of 45,000 Btu/hr/screen. Figures 10-2 and 10-3 show energy requirements for vertical shaft rotary screens.

A design loading rate of 80 gpm/sq ft of screen surface area is shown in Figures 10-2 and 10-3. The design was determined based on the manufacturer's rating of the unit and expressing that loading in terms of gpm/sq ft.

AIR FLOTATION

The power to operate an air flotation unit varies with the manufacturer. The two major manufacturers of air flotation equipment use a different recycle ratio and thereby require different power utilization. Energy required is approximately 0.10 kwh/sq ft for units with surface areas larger than 2,000 sq ft.

Design loading rates for dissolved air flotation units have been reported from 1,530 to 5,690 gpd/sq ft.[1,2,6,8] These reported units were preceded by screening devices. The design loading rate is dependent on the influent waste characteristics and the type or size of screening device preceding the flotation unit. A typical loading rate of 3,500 gpd/sq ft is shown in Figure 10-4.

HIGH RATE FILTRATION

The direct power requirements for filtration are backwash and surface wash pumping and instrumentation. Backwash and surface washwater normally require 5 percent of the average flow rate at 25 ft TDH. For an average flow of 45 percent of the flow capacity of the facility, the energy requirements are about 8 hp-hr/mil gal. Assuming 0.67 hp/filter for instrumentation, the total energy requirements are as shown in Figure 10-5.

Gravity filters are assumed for this application and main stream pumping may or may not be required depending on site conditions. Pumping energy requirements are shown in Chapter 3 for varying pumping heads.

Design loadings have been reported from 8 to 40 gpm/sq ft.[7] A design loading rate of 15 gpm/sq ft and no main stream pumping is used for the energy requirements shown in Figure 10-5. This loading rate is applicable when high rate filtration units are preceded by a screening device.

FLOW EQUALIZATION

Storage

Storage reservoirs may be lined earthen or concrete, open or covered. Several other concepts have been proposed such as collapsible bladders, deep underground reservoirs, and short term flooding of open spaces. The energy requirement shown in Figure 10-6 is for a spray system to wash the reservoir walls and floor to remove deposited solids. The spray water quantity is 3 gpm for 10 min/sq ft of reservoir wall and floor area and the pressure is 60 psi.

The plant capacities shown in Figure 10-6 were determined by assuming a 12 hr detention time. This criterion will vary considerably depending on the treatment method and/or effluent standard.

Sedimentation

Energy required for sedimentation basins equipped with mechanical sludge removal mechanisms is shown in Figure 10-7. Sludge pumping is not included in this figure. Sedimentation energy requirements are presented in Chapter 3. Sedimentation basin sizing is based on 1,000 gpd/sq ft surface loading rate at 45 percent of design flow capacity or 2,222 gpd/sq ft surface loading rate at design flow.

Sludge Removal

Energy requirements for sludge pumping are based on the use of positive displacement pumps (efficiency = 40 percent) and intermittent pumping (10 min each hr). A 25 ft TDH was used to develop the energy requirements shown in Figure 10-8.

The sizing of the sludge pumps is based on removal of 2,200 lb/mil gal at 45 percent of design flow capacity (assume sludge can be stored in sedimentation tank if quantity of solids temporarily exceed pumping capacity).

CHLORINATION

Chlorine dosages are highly variable depending on the storm water quality and type of unit process applied. A dosage of 10 mg/l is used for the energy requirements presented in this chapter.

High Intensity Mixing

Energy requirements for high intensity mixing are based on a G value of 300 sec^{-1} and water temperature of 15°C. Energy requirements are shown in Figure 10-9. Plant capacities shown in this figure are based on a 1 min detention time.

Chlorine Gas

Power requirements for chlorine feed equipment are small but increase substantially where evaporators are used to convert liquid chlorine to the gaseous form. Standard size chlorinators are rated at 400, 2,000 and 8,000 lb/day. If a 2,000 lb/day or 8,000 lb/day unit is required, then an evaporator is normally used. Therefore, the total energy requirement is 135 Btu of chlorine evaporated and is applicable when the dosage exceeds 400 lb/day. Energy requirements shown in Figure 10-10 are applicable for dosages greater than 4 tons/yr for a 20 day occurrence, 8 tons/yr for a 40 day occurrence, etc. The top abscissa shows plant capacity for 20 days operation/yr. For more frequent operation the scale would shift to the right but the plotted line would not change.

Chlorine Dioxide

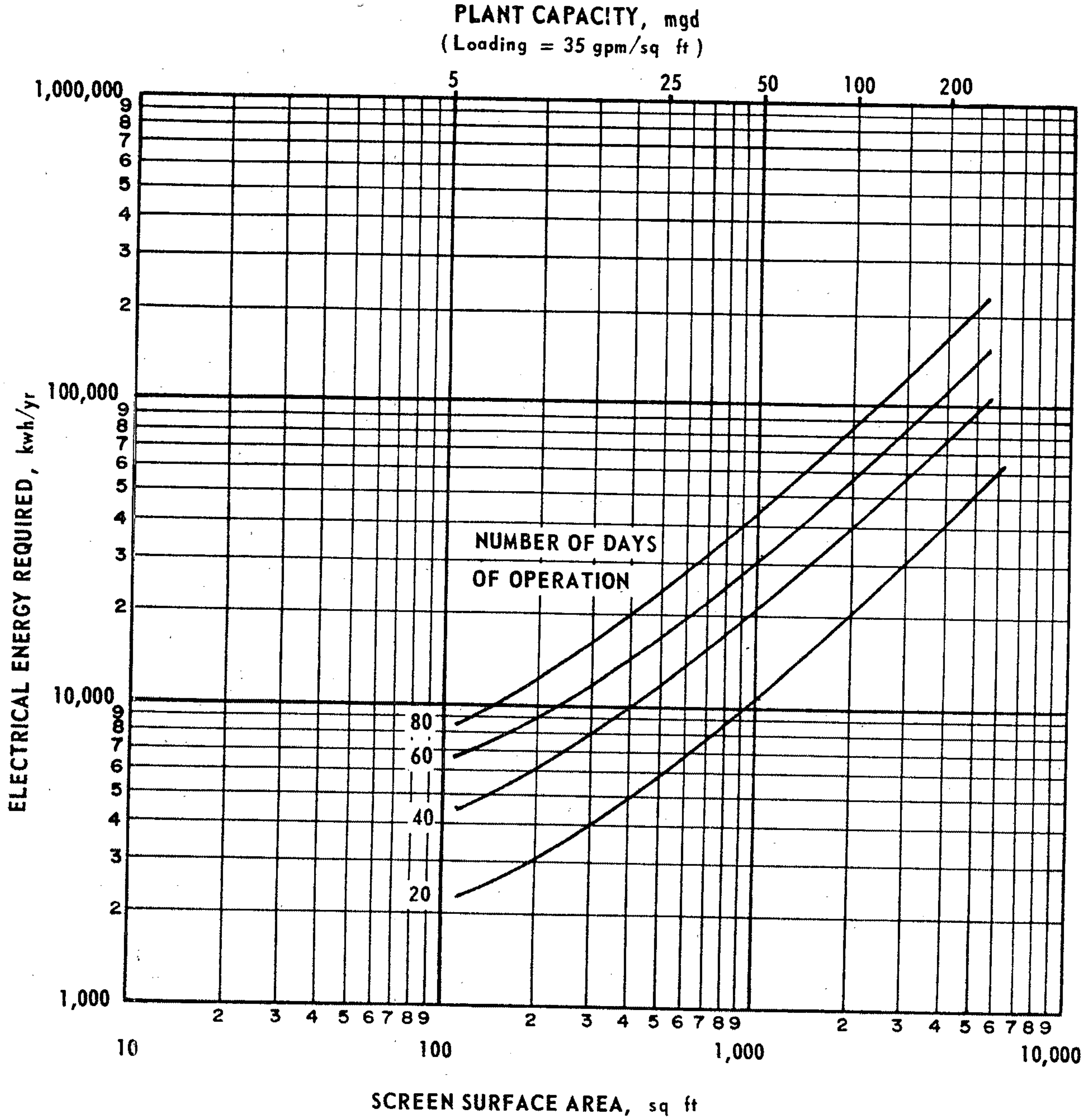
Power for chlorine dioxide systems consists of chlorinator, sodium chlorite mixer and diaphragm feed pump requirements. The chlorinator feed requirement is 1.68 times the desired chlorine dioxide feed rate.[10] Energy requirements shown in Figure 10-11 are based on a line pressure of 10 psi and pumping efficiency of 40 percent. Plant capacities shown in Figure 10-11 are based on a feed concentration of 1.2 mg/l.

Hypochlorite

Energy requirements for hypochlorite generators vary between equipment manufacturers. A typical energy requirement for on-site generation of sodium hypochlorite is 2.5 kwh/lb of chlorine equivalent. Energy requirements shown in Figure 10-12 are for 20 days of overflow.

Dechlorination

Assuming dechlorination by addition of sulfur dioxide the energy requirements per pound will be identical to that needed per pound of chlorine additions. Evaporator energy is the most significant power requirement. The latent heat of vaporization for sulfur dioxide is 150 Btu/lb at 70^{0}F. The dosages for sulfur dioxide will be less than the chlorine dosage. This difference depends on the demand of the water treated. The amount of sulfur dioxide dosage is nearly equal to the chlorine residual (0.9:1.0). Therefore, the energy required is determined by multiplying the chlorine feed energy requirement (Figure 10-10) by the ratio of sulfur dioxide dosage to chlorine dosage.



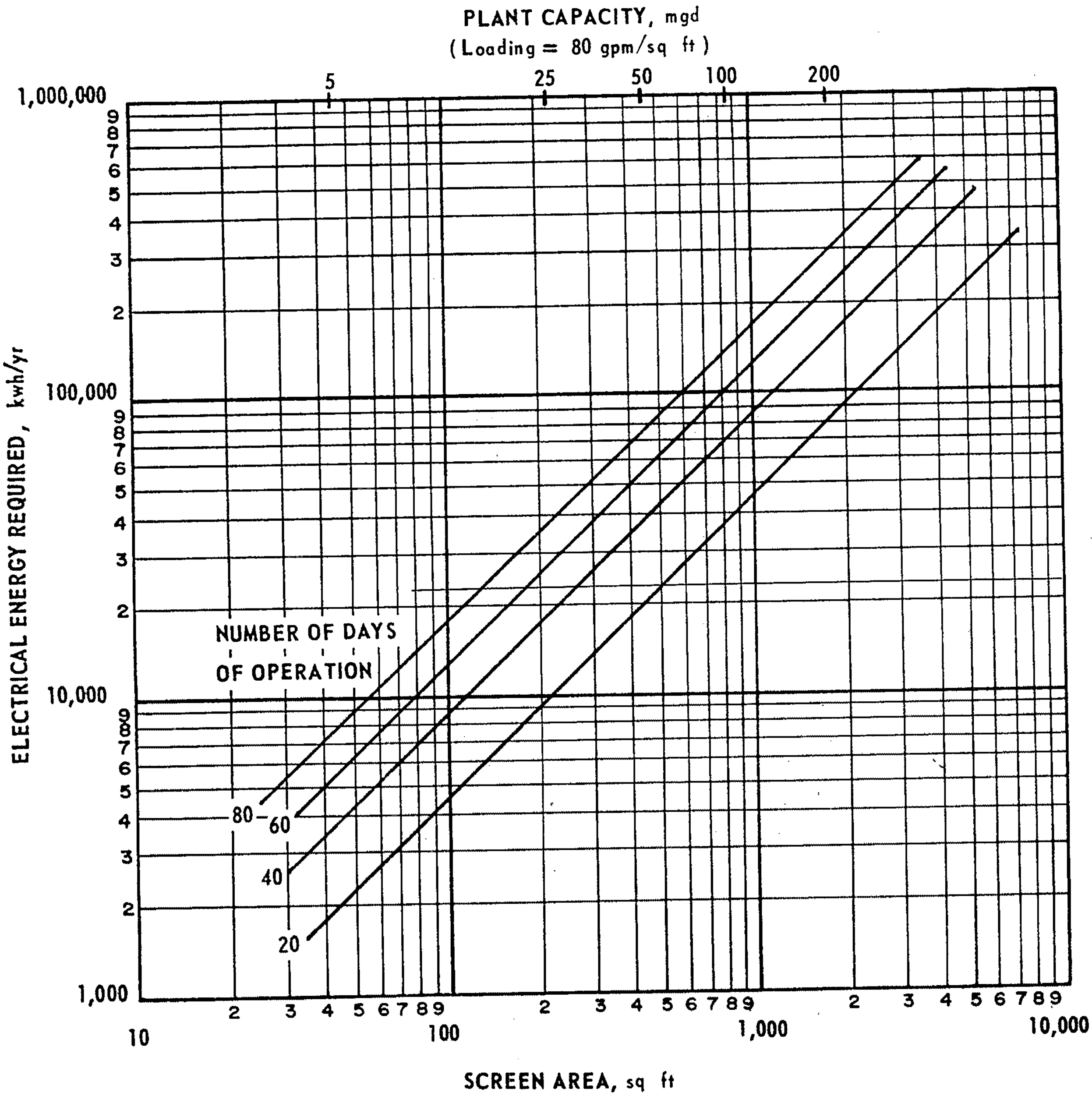
HORIZONTAL SHAFT ROTARY SCREEN

Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	410	50

Operating Parameters:
Loading = 35gpm/sq ft

Type of Energy Required: Electrical

FIGURE 10-1



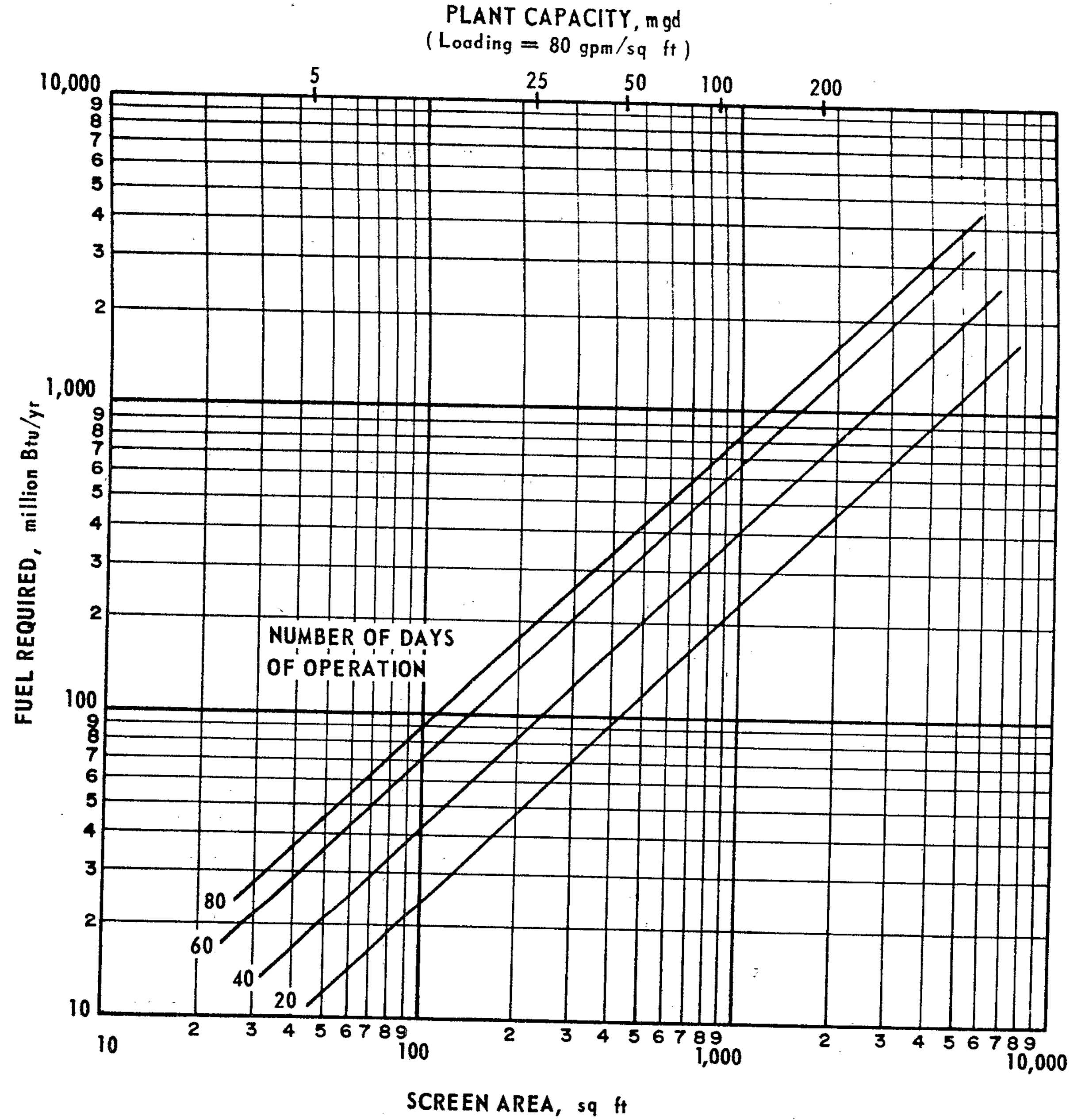
VERTICAL SHAFT ROTARY SCREEN

Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	410	75

Operating Parameter:
Loading = 80gpm/sq ft

Type of Energy Required: Electrical

FIGURE 10–2



VERTICAL SHAFT, ROTARY SCREEN

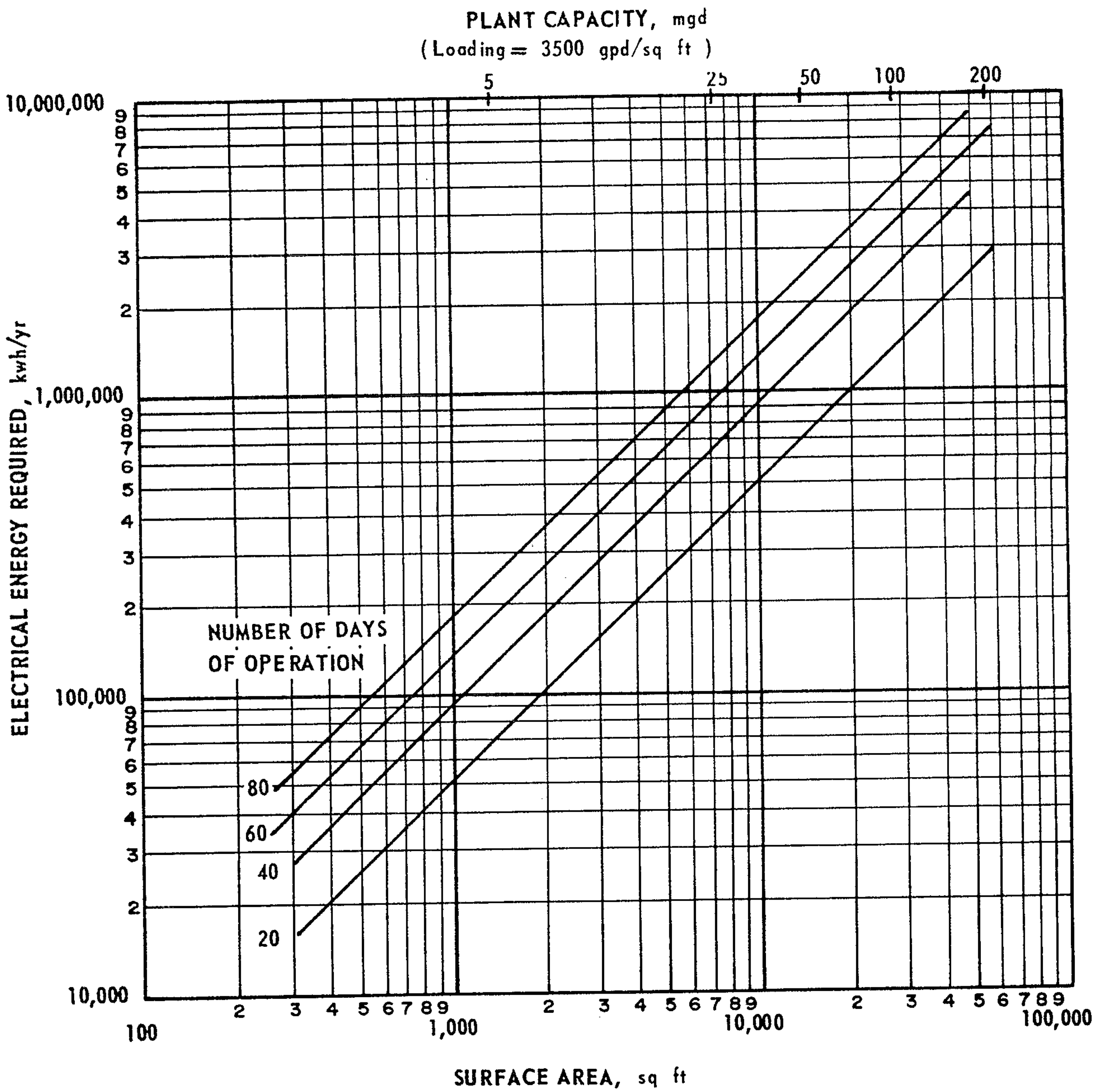
(Heating Backwash Water)

Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids:	410	75

Operating Parameters:
Loading = 80gpm/sq ft
Backwash = 10gpm @ 80psi, 160° F

Type of Energy Required: Natural Gas

FIGURE 10-3



AIR FLOTATION

Water Quality:

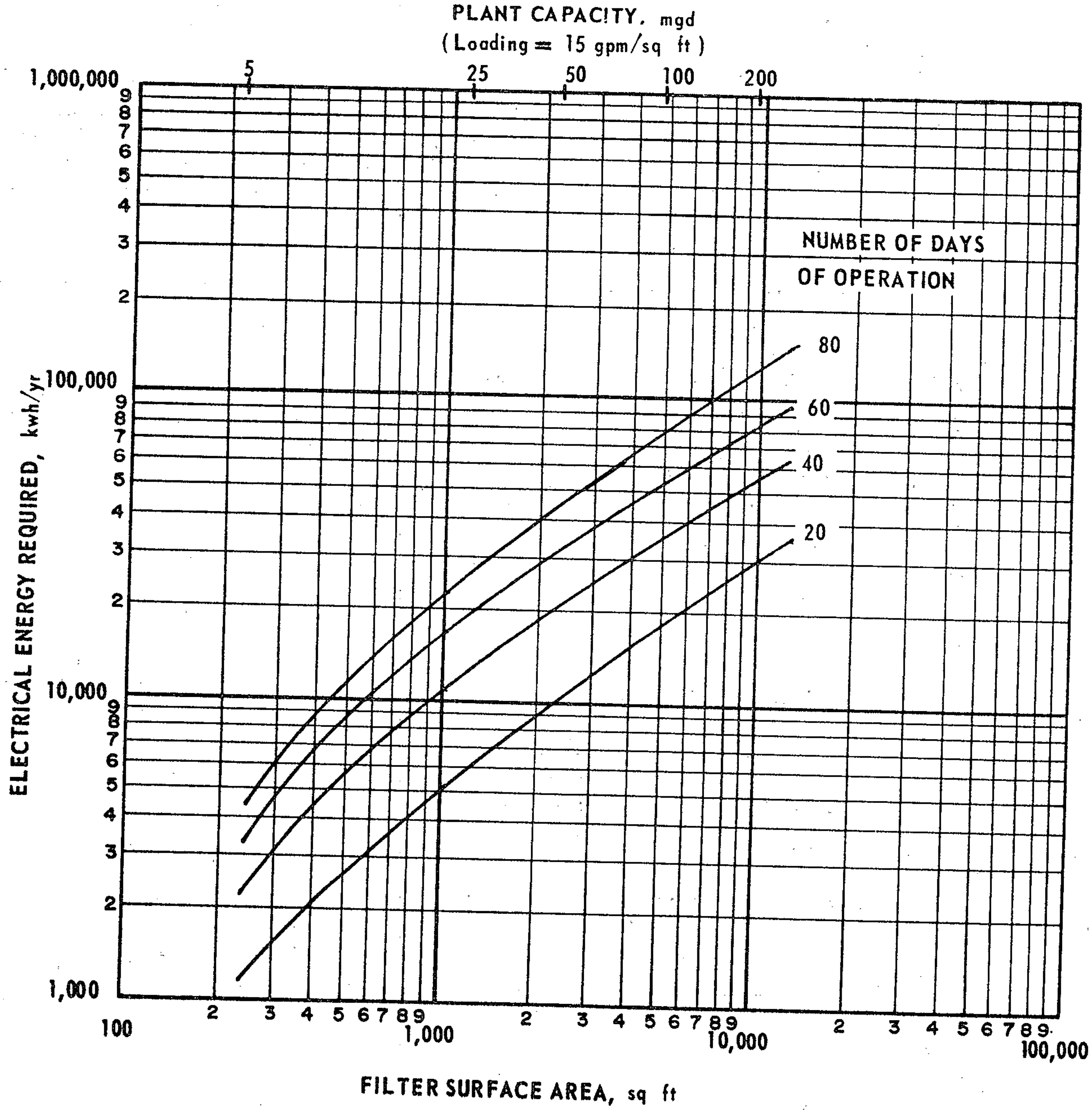
	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	150	30

Design Assumptions:
Preceeded by screening device.
Polymers are used.

Operating Parameters:
Loading = 3500gpd/sq ft
Pressurized Flow = 15%

Type of Energy Required: Electrical

FIGURE 10–4



HIGH RATE FILTRATION

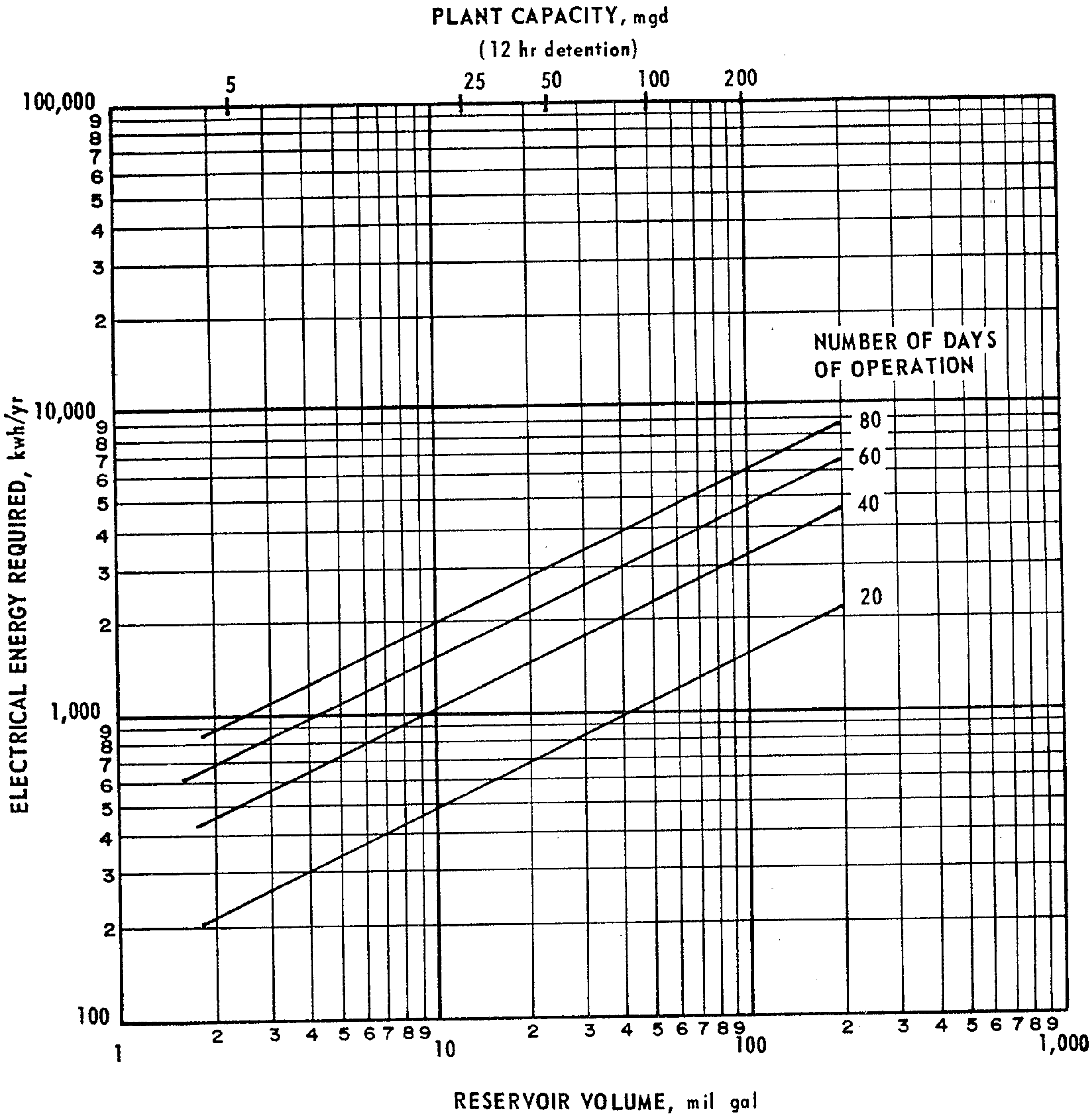
Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	50	10

Design Assumptions:
Mixed Media
Preceeded by Microscreen

Operating Parameters:
Loading = 15gpm/sq ft
Backwash rate = 20gpm/sq ft

Type of Energy Required: Electrical

FIGURE 10-5



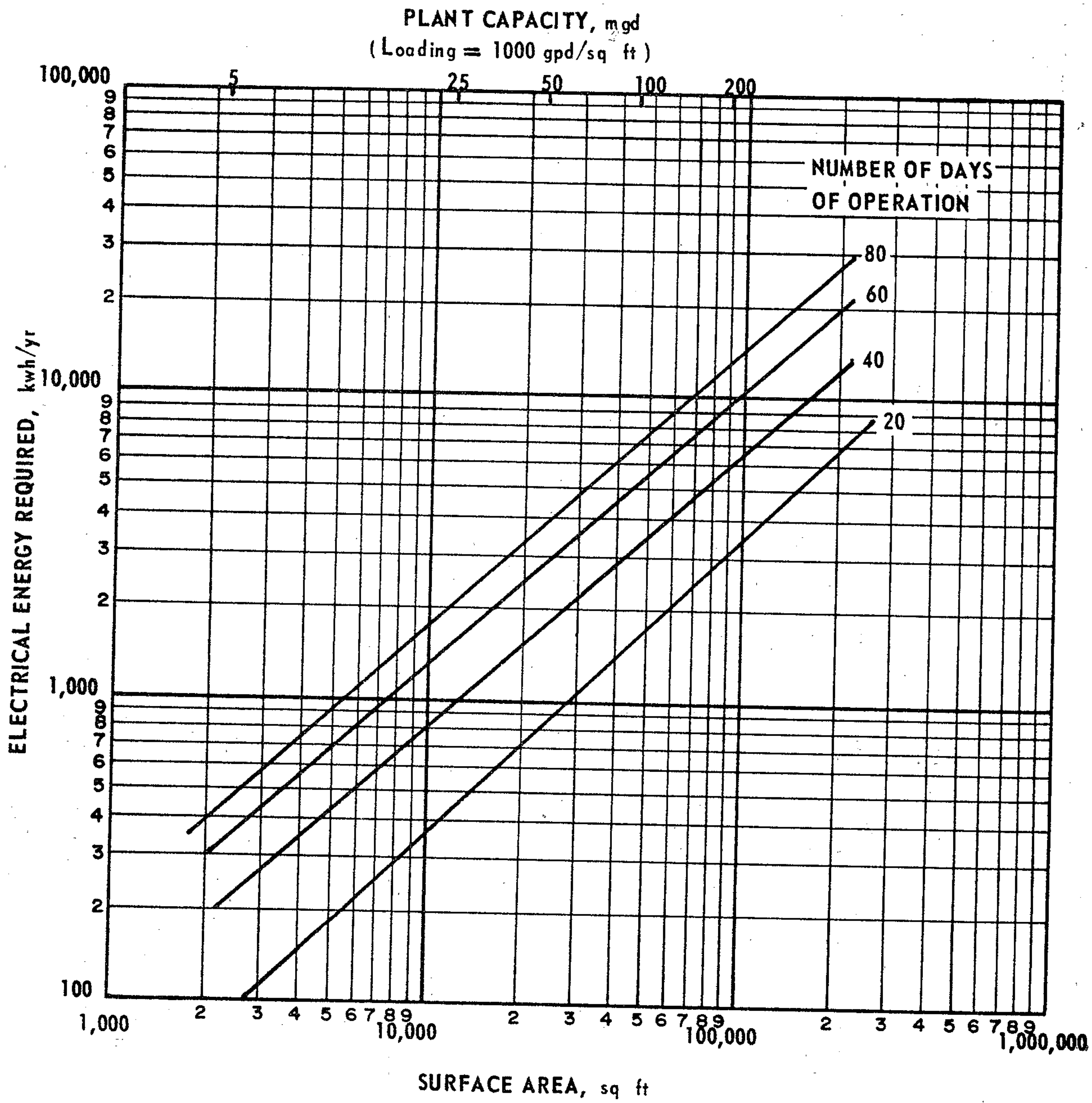
STORAGE RESERVOIRS

Operating Parameters:
  Detention time = 12 hours
  Spray Water = 3gpm/10min/sq ft of reservoir wall

Water Pressure: 60psi

Type of Energy Required: Electrical

FIGURE 10-6



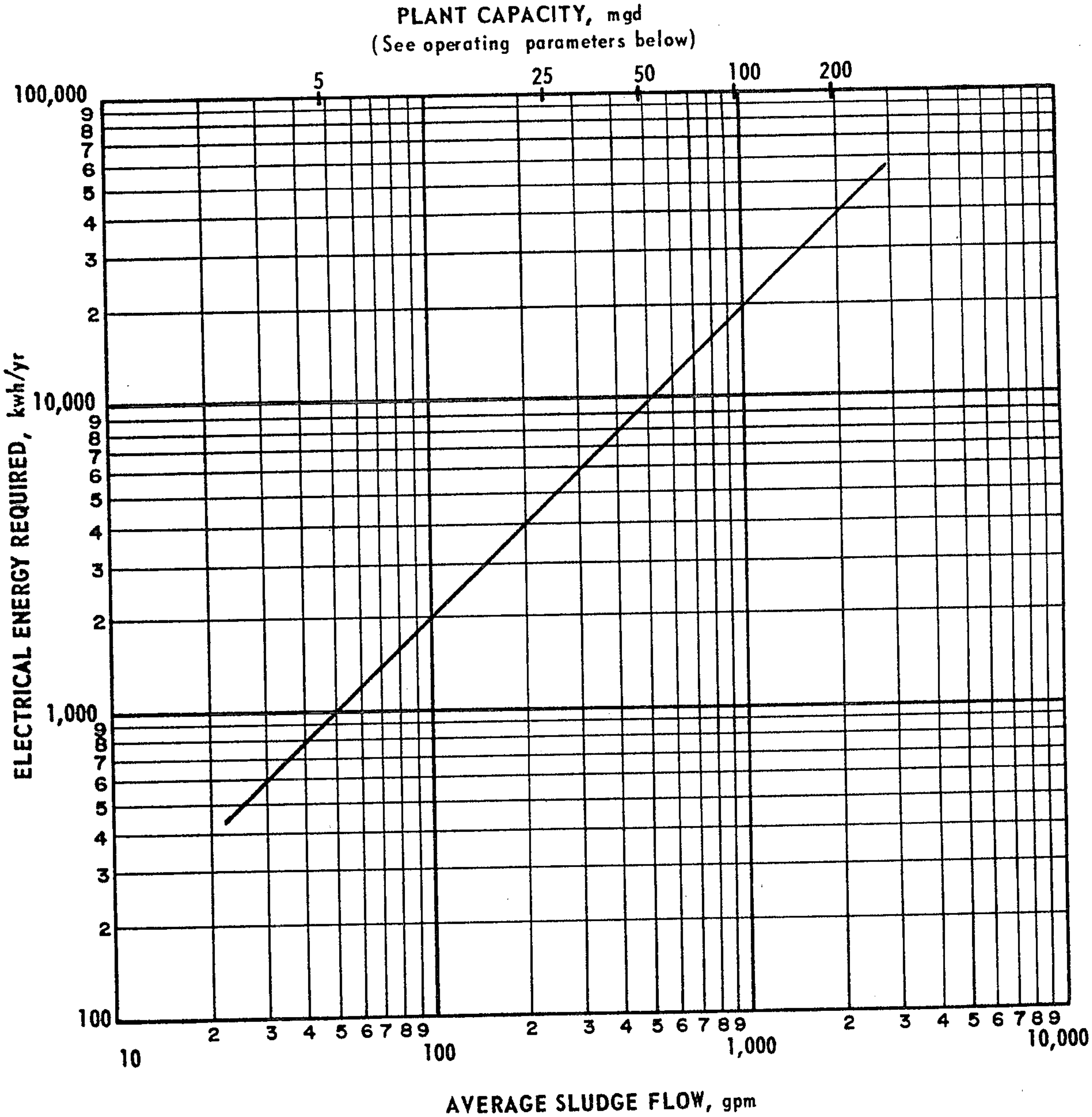
SEDIMENTATION BASINS

Water Quality:	Influent (mg/l)	Effluent (mg/l)
Suspended Solids	410	145

Operating Parameter:
Hydraulic loading = 1,000gpd/sq ft

Type of Energy Required: Electrical

FIGURE 10–7



WASTE SLUDGE PUMPING

Design Assumptions:

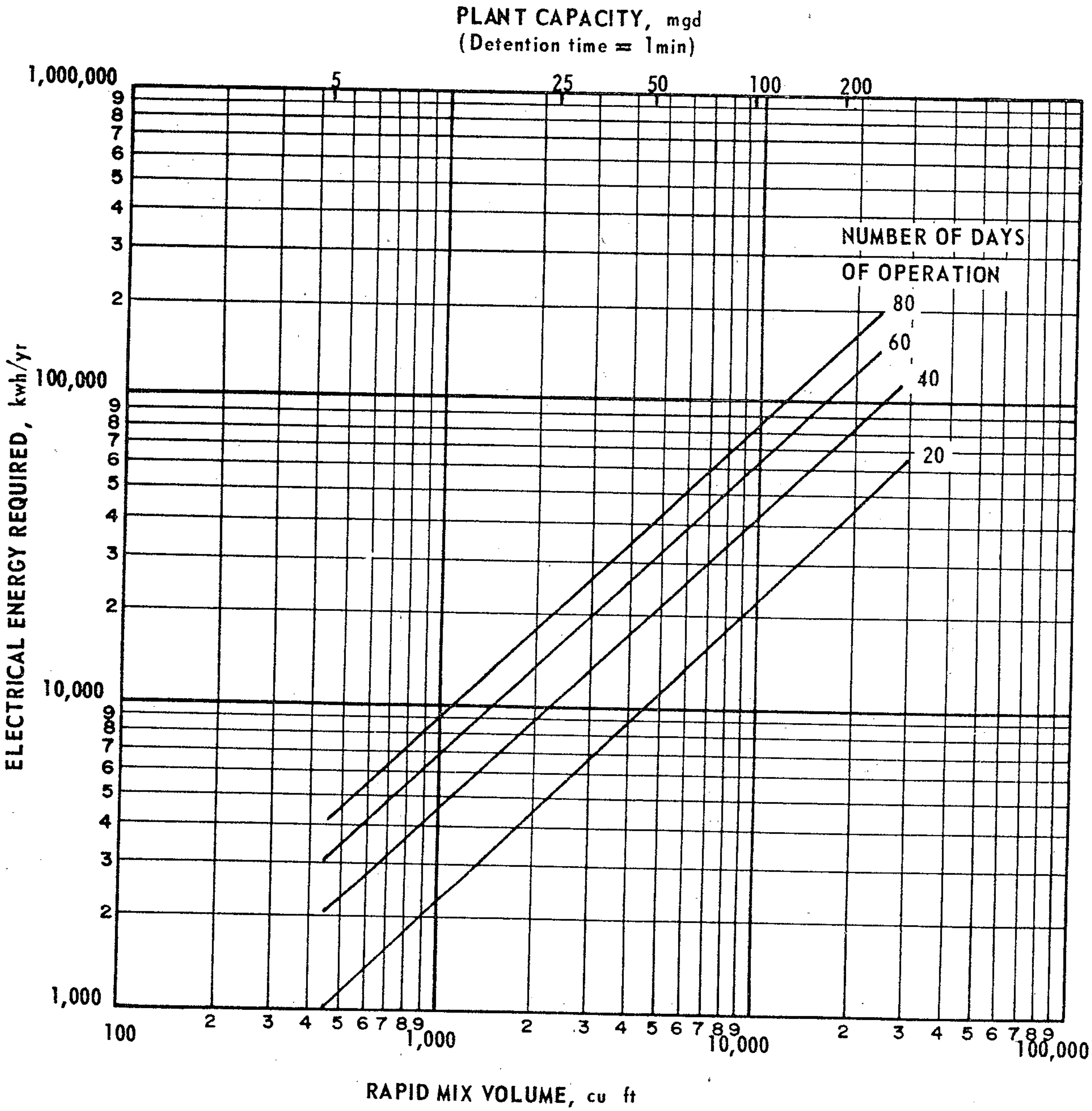
- Pumps are run 10 min, each hour.
- Sludge concentration is 5%.
- Pumping efficiency is 40%.

Operating Parameters:

- Sludge removal = 65% of influent suspended solids at average flow
- Average flow = 45% of design flow

Type of Energy Required: Electrical

FIGURE 10-8

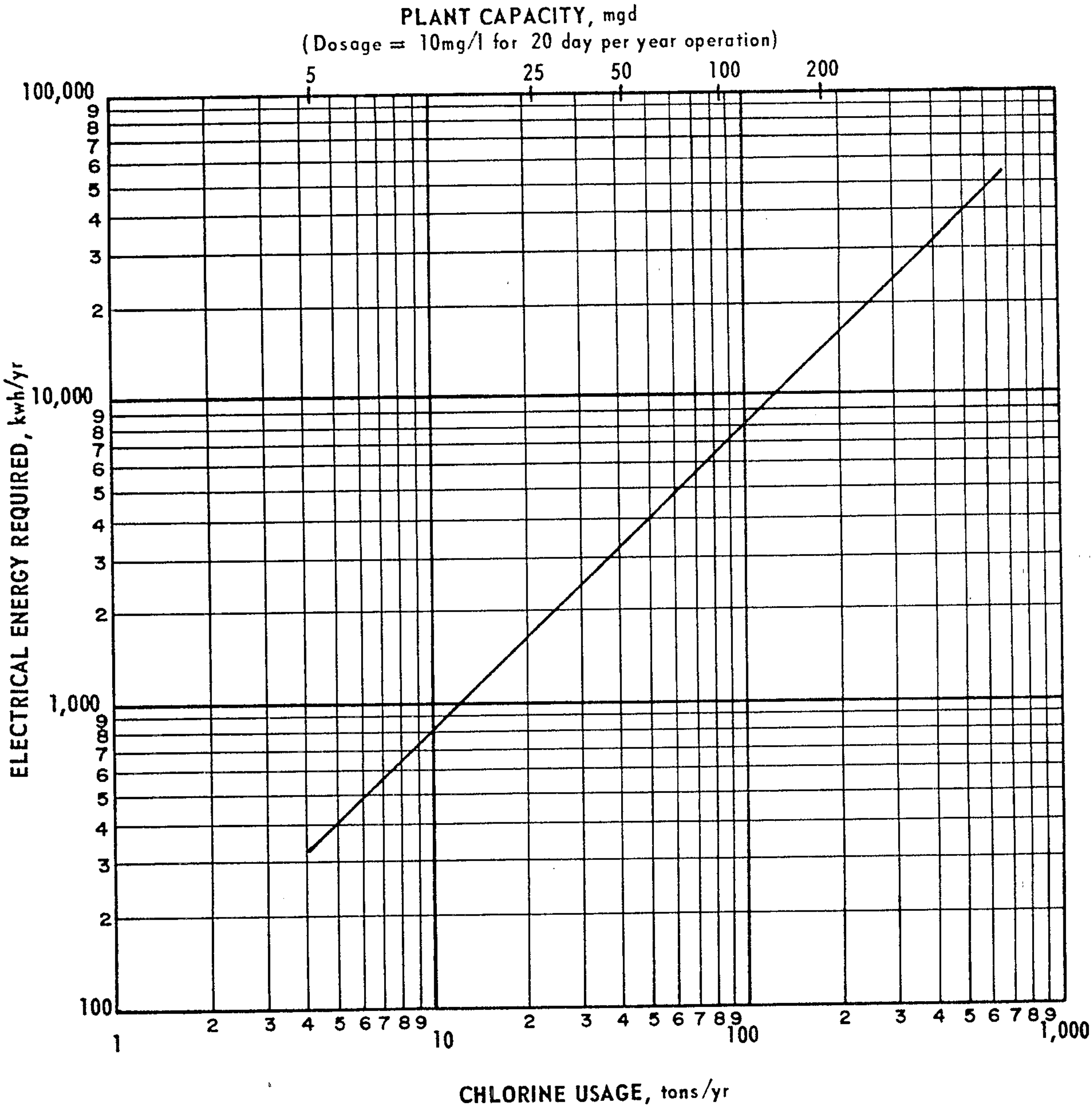


RAPID MIXING

Operating Parameters:
G = 300sec $^{-1}$
Temperature = 15°C
Detention Time = 1 min

Type of Energy Required: Electrical

FIGURE 10–9



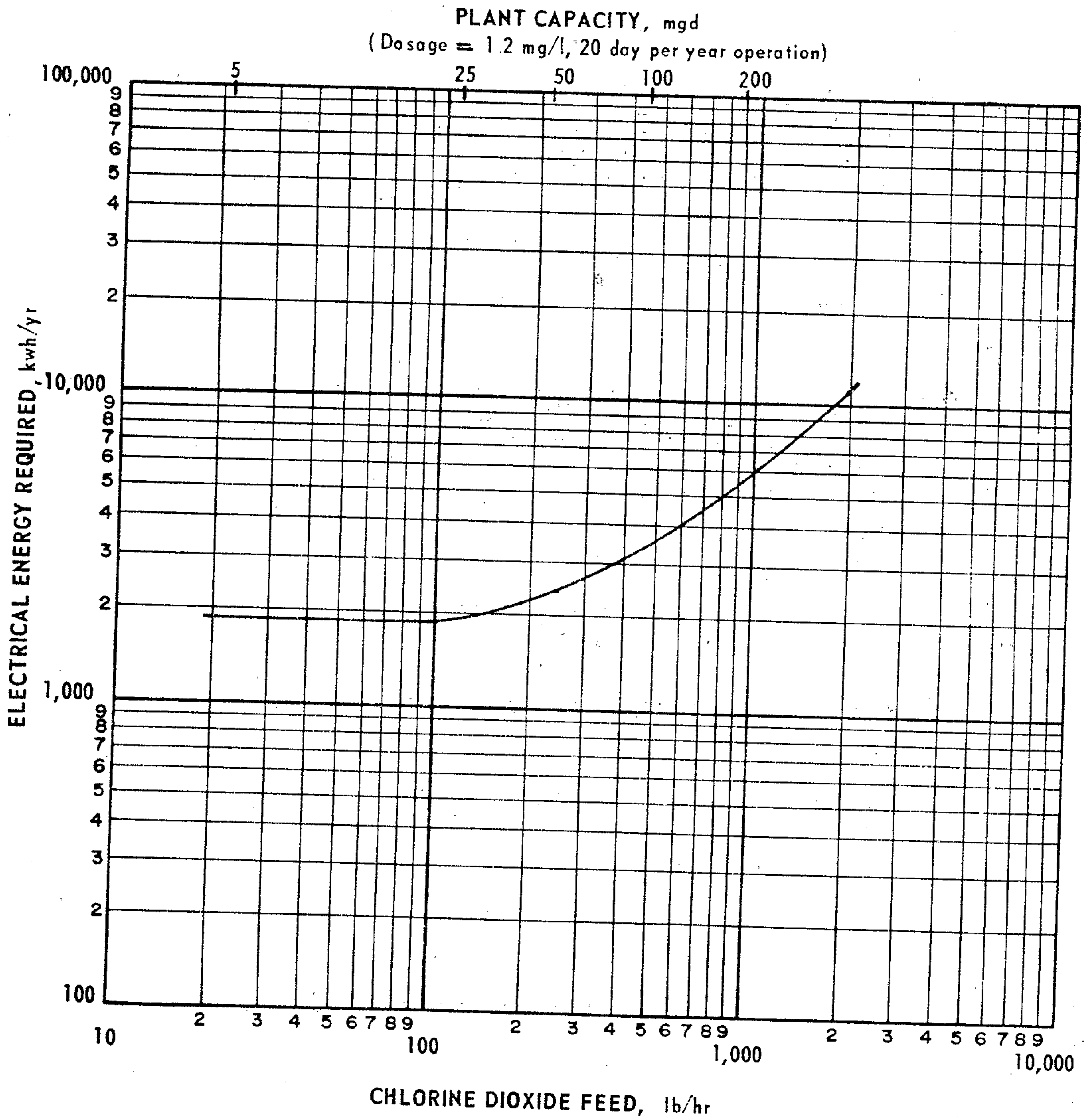
CHLORINE FEED (EVAPORATOR)

Design Assumptions:
Operation = 20 days/year
Average flow = 45% of design flow

Operating Parameter:
Dosage = 10 mg/l

Type of Energy Required: Electrical

FIGURE 10–10



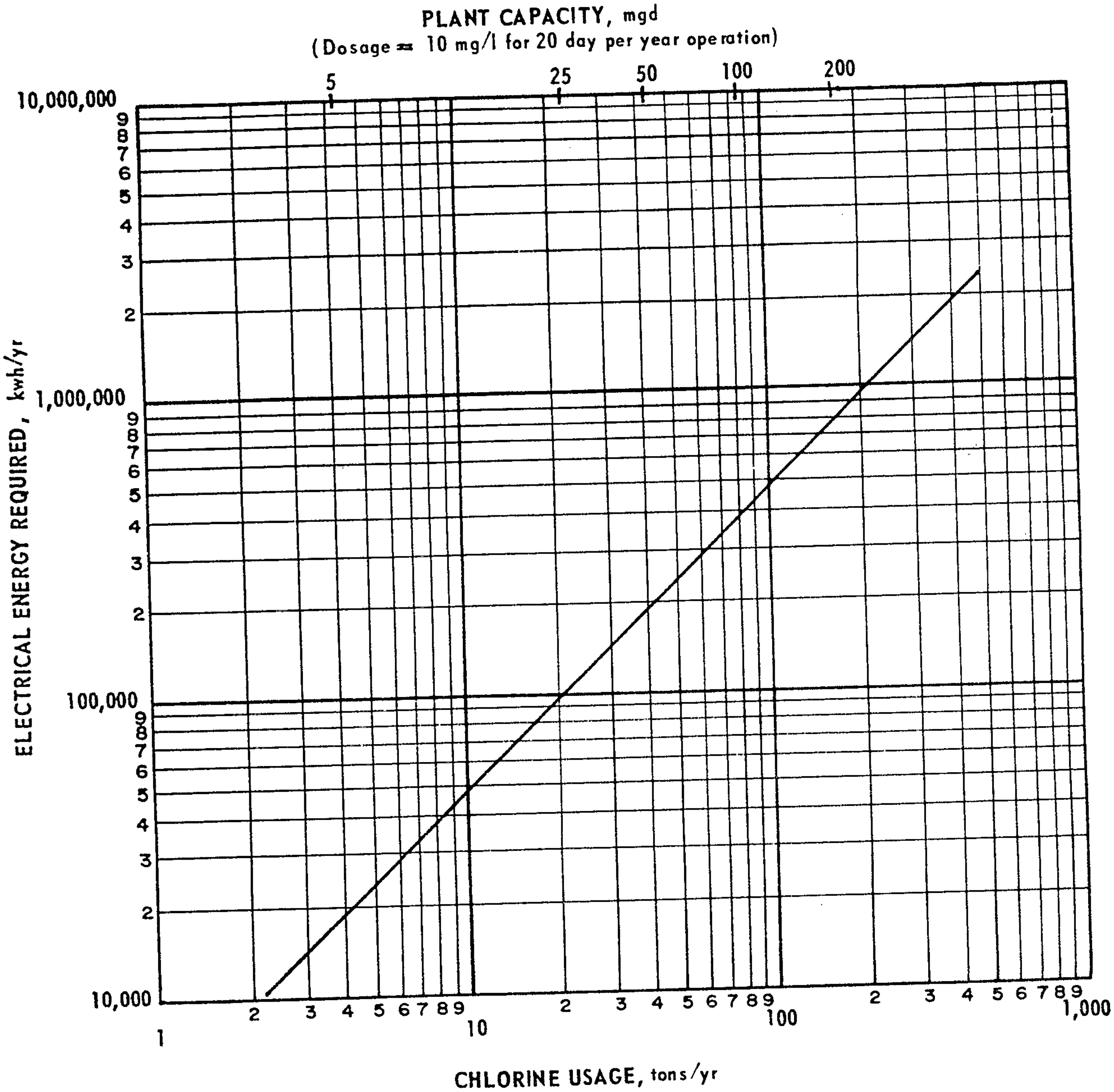
CHLORINE DIOXIDE GENERATION & FEED

Design Assumptions:
Operation = 20 days per year
Average flow = 45% of design flow

Operating Parameter:
Dosage = 1.2mg/l

Type of Energy Required: Electrical

FIGURE 10-11



HYPOCHLORITE GENERATION

Design Assumptions:
Operation = 20 days/year
Average flow = 45% of design flow

Operating Parameter:
Dosage = 10mg/l

Type of Energy Required: Electrical

FIGURE 10–12

REFERENCES - CHAPTER 10

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