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ENERGY REQUIREMENTS FOR SMALL FLOW WASTEWATER TREATMENT SYSTEMS

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This report summarizes energy requirements for small wastewater treatment systems (0.05 - 5 million gallons per day) applicable to military installations It compares various treatment combinations, and presents the energy requirements for the most viable alternatives in tabular form. It also presents energy requirements for various components of wastewater treatment systems in a format making it convenient to calculate the energy requirements for many combinations of the components. In addition, it summarizes briefly energy

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20. Abstract continued

estimates made by others. The report compares typical combinations of unit operations and processes used to produce various quality effluents on the basis of energy consumption. It concludes that land application systems are the most energy-efficient wastewater treatment systems and that they are capable of producing an equivalent or higher quality effluent than any other treatment system.

PREFACE

This report was prepared by E. Joe Middlebrooks and Charlotte H. Middlebrooks, both of Middlebrooks and Associates, Logan Utah.

The study was performed for the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) and was funded under DA Project 4A762720A896, Environmental Quality for Construction and Operation of Military Facilities; Task 02, Pollution Abatement Systems; Work Unit 004, Wastewater Treatment Techniques in Cold Regions.

The final scope of study was defined by Sherwood C. Reed of CRREL. He served as technical monitor during the course of the study and his efforts in this regard contributed significantly to the successful completion of this report.

Technical review of this report was performed by Sherwood C. Reed, Robert S. Sletten, C. James Martel, and Edward F. Lobacz of CRREL.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To Obtain
inch	25.4*	millimeter
inch	2.54	centimeter
foot	0.3048*	meter
yard^2	0.8361274	meter^2
foot^3	0.02831685	meter^3
yard^3	0.764549	meter^3
gallon	0.003785412	meter^3
pound	453.6	gram
pound/inch^2	6894.757	pascal
pound/foot^3	16.01846	kilogram/meter^3
kilowatt-hour	3.600×10^6	joule
horsepower-hour	2.6845×10^6	joule
watt	1.000	joule/second
watt	0.0013410	horsepower
Btu	1054.85	joule
BTu	0.000293	kilowatt-hour
standard feet^3 of air/minute	0.47195	standard meter^3 of air/minute

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*Exact

SUMMARY

With increasing energy costs, energy consumption is assuming a greater proportion of the annual cost of operating wastewater treatment facilities of all sizes, and because of this trend, it is likely that energy costs will become the predominant factor in the selection of cost-effective small-flow wastewater treatment systems.

Where suitable land and groundwater conditions exist, a facultative pond followed by rapid infiltration is the most energy-efficient system described in this report. Where surface discharge is necessary and impermeable soils exist, a facultative pond followed by overland flow is the second most energy-efficient system described. Facultative ponds, followed by slow or intermittent sand filters, are the third most energy-efficient systems discussed, and are not limited by local soil or groundwater conditions.

INTRODUCTION

General

The concern for energy use at wastewater treatment facilities has developed well after many of the plans were made for the management of water pollution in the United States. This is true in military as well as in civilian installations. With changing standards and technology, information on energy requirements for small (0.05 to 5 mgd) wastewater treatment systems is needed to avoid future errors and to provide information to assist in designing and planning. Several estimates have been made for large systems, usually in the range of 5 to 100 mgd, but because hundreds of small systems are being used by military installations, it is imperative that information be gathered on energy requirements for wastewater treatment for small systems.

This report summarizes the energy requirements for all viable alternatives presently available to military installations for the treatment of small flow rates (0.05 - 5 mgd) of wastewater. It compares various treatment combinations, and presents in tabular form the energy requirements for the most viable alternatives. The data can be combined to produce an estimate of the energy requirements for all currently available unit operations and processes.

Other Studies

Only one comprehensive study of the energy requirements associated with wastewater treatment has been performed. Wesner et al. (1978) presented a detailed analysis of energy requirements by unit operations and unit processes employed in wastewater treatment. The results of this study were presented in graphical form with accompanying tables outlining the design considerations employed in developing the graphs. Energy requirements were presented in terms of the design flow rate of the treatment system in most cases, but when a wide choice of loading rates was applicable, the graphs were presented in terms of surface area or the flow rate applied to the component of the system. Portions of the Wesner et al. (1978) results are presented in detail in Appendix A in this report

Culp (1978) has presented an analysis of alternatives for future wastewater treatment at South Tahoe, California. This illustrates the increasing sensitivity of energy costs. When the original advanced wastewater treatment system was constructed in the late 1960's, energy was not costly and was not usually a significant factor in concept selection and design. Table 1 illustrates the energy required for alternatives compared with the original design. It is anticipated that the final product

Table 1. Energy requirements 7.5 mgd, Lake Tahoe Wastewater Treatment system (Culp and Culp, 1971; Culp, 1978).

Alternative	Total energy[a] (electricity and fuel expressed as equivalent 1000 kwh/yr)
Original system complete secondary treatment, AWT system, effluent export to Indian Creek Reservoir	64,500
1978 Alternatives Continue secondary, nitrification, effluent export to Indian Creek Reservoir	39,400
Continue secondary, nitrogen removal (ion exchange) effluent export to I.C.R.	40,244
Continue secondary on site, flood irrigation land treatment in Carson River Basin	25,000

[a] Does not include secondary energy requirements for chemical manufacture.

from the flood irrigation land treatment alternative will be at least equal in quality to the original design effluent.

Energy requirements for four wastewater treatment systems, including sludge processing, that are capable of achieving secondary effluent quality and complete sludge treatment and disposal were presented by Wesner and Burris (1978). Estimated energy requirements were presented for 1) trickling filter with anaerobic digestion, 2) activated sludge with anaerobic digestion, 3) activated sludge with sludge incineration, and 4) independent physical-chemical treatment with sludge incineration using 5 and 30 mgd capacities. A comparison of energy requirements for the four systems treating 30 mgd is shown in Figure 1. The potential for solar energy as a method of heating the digester and control building was discussed. Heat recovery from sewage effluents using heat pumps to heat digesters and buildings was considered.

Zarnett (1976, 1977, and undated) has examined the energy requirements for water and wastewater treatment plants and has presented the requirements by unit operations employed. The results were presented by unit operation to make it convenient to assess any treatment system on the basis of total energy consumption. By combining various flow configurations, a system capable of producing a given effluent quality can be assembled and the energy requirements compared. Zarnett cautions

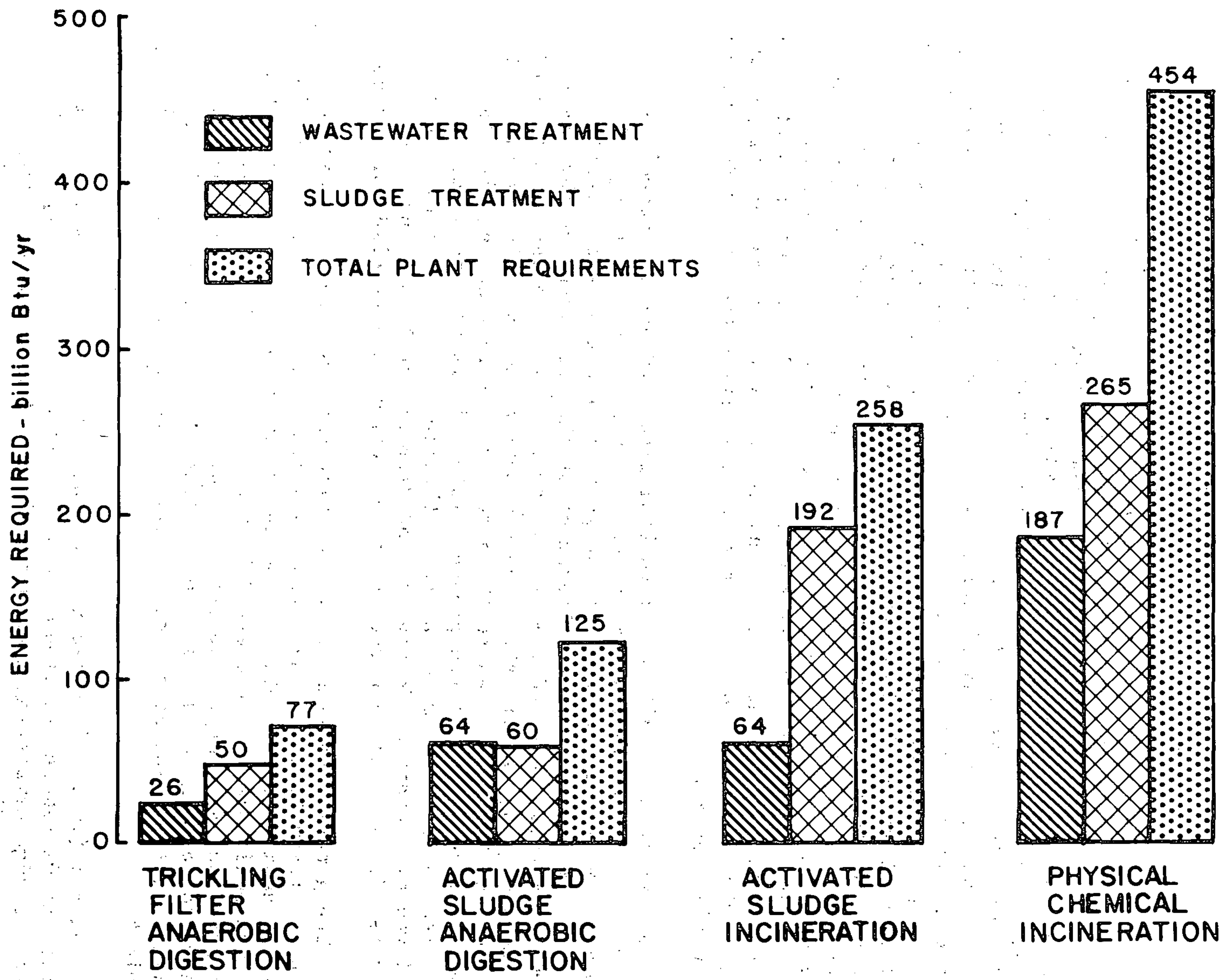


Figure 1. Energy requirements for 30 mgd secondary treatment plants (Wesner and Burris, 1978). Courtesy of Journal Water Pollution Control Federation, Washington, D.C.

that the data were presented for comparative purposes and should not be used as absolute values.

Energy requirements for various types of wastewater treatment plants were presented by Hagan and Roberts (1976). In addition to the discussion of conventional secondary and tertiary treatment systems, land treatment systems were considered. Tradeoffs between pollutants removed from wastewater and pollutants added to the environment by energy use were discussed. It was pointed out that decreasing returns are obtained as the level of treatment increases, and it is possible to add more contamination to the environment by increased energy consumption than is removed from the wastewater. Comparisons of energy requirements for a 100 mgd capacity system employing conventional secondary, advanced wastewater treatment and land treatment systems were presented. Energy implications with regard to wastewater reuse were considered, and it was shown that in many instances the reuse of wastewater can conserve energy. The savings are related to the degree of treatment required before reuse. Table 2 is a summary of total energy requirements for various wastewater treatment systems assumed by Hagan and Roberts for direct discharge of the wastewater, employed for various reuse purposes, and the energy requirements for alternative sources of fresh water. Their assumptions include unnecessarily stringent preapplication treatment requirements for the general case of irrigation reuse. Current EPA guidance on the topic is presented in the Results and Discussion section.

Garber et al. (1975) compared biological and physical-chemical processes to treat wastewater in the Los Angeles area. Biological processes were found to be more energy efficient and less stressful on the overall environment. Treatment of the wastewater by physical-chemical methods required almost five times as much energy as activated sludge including nitrification and phosphorus removal. Solids disposal by pumping 90 to 100 miles to the desert to drying beds required 16 times as much energy as the present system of discharging screened digested solids seven miles at sea. Chemical treatment of the sludge followed by mechanical dewatering and disposal at local landfills required 35 times as much energy as the current sludge disposal system.

The general problems associated with small wastewater treatment plants, alternative treatment processes available to small plants, important design considerations, and an economic comparison of the alternatives available were presented by Benjes (1978). Table 3 presents the estimated annual energy required alternative wastewater treatment processes for a range of design flows. Tchobanoglous (1974) conducted a similar analysis and cost factors derived from his work are shown in Table 4.

Jacobs (1977) discussed various ways to more effectively utilize energy at wastewater treatment plants. Use of different types of pumps, sludge dewatering equipment, plant modification and energy recovery from digester gas and incineration of sludge were discussed.

Table 2. Examples of systems to be considered in evaluating energy implications of wastewater reuse (Hagan and Roberts, 1976).[a]

	Total Energy Required for 100 mgd kwh/day
Treatment assumed for discharge	
1. Activated sludge (with chlorination, sludge digestion and landfill disposal)	93,000
2. Biological-chemical (activated sludge with alum treatment, nitrification/denitrification, sludge digestion and landfill disposal)	235,000
3. Tertiary (activated sludge, coagulation/filtration, carbon adsorption, zeolite ion-exchange, recalcination)	1,137,000
Type of reuse	
1. Local irrigation (assume 100-ft head for conveyance)	57,000
2. Distant irrigation (assume 1,500-ft head for conveyance)	615,000
3. Industrial (assume 100-ft head)	57,000
4. Unrestricted (assume 500-ft head)	216,000
Treatment assumed prior to reuse	
For irrigation reuse:	
activated sludge	93,000
biological-chemical	235,000
For industrial reuse:	
biological-chemical	235,000
biological-chemical & desalting	695,000
tertiary	1,137,000
tertiary & desalting	1,597,000
For unrestricted reuse:	
tertiary	1,137,000
tertiary & desalting	1,597,000
Alternative sources of fresh water	
1. Local supplies	57,000
2. Imported	938,000
3. Desalted seawater	6,661,000

[a] Courtesy of Water and Sewage Works, Chicago, Illinois.

Table 3. Estimated energy (electricity and fuel) for alternative treatment processes (Benjes, 1978).

Process[a]	Energy (1000 kwh/yr) Plant capacity (mgd)			
	0.1	0.5	1.0	2.0
Prefabricated extended aeration	139	-	-	-
Prefabricated contact stabilization	95	447	886	-
Custom design, extended aeration	197	857	1,901	-
Oxidation ditch	134	647	1,288	2,571
Activated sludge, anaerobic digestion	119	387	764	1,525
Activated sludge, nitrification, anaerobic digestion	251	650	922	2,576
Trickling filter, anaerobic digestion	31	126	246	485
RBC, anaerobic digestion	65	276	566	1,105
RBC, nitrification, anaerobic digestion	113	496	1,026	2,005

[a] All with aerated grit chamber, chlorination and sludge drying beds.

A comparison of energy requirements and costs for sludge dewatering equipment is shown in Table 5. Energy requirements and costs for biological treatment systems are presented in Table 6.

Mills and Tchobanoglous (1974) presented detailed methods for calculating the energy consumption by the unit operations and processes used in wastewater treatment. Use of the equations and graphs presented in the paper is illustrated by examples using two alternative flow schemes. Detailed results are presented in tabular form and are easily compared between processes and systems.

Smith (1973) estimated the electrical power consumption by most conventional and advanced processes used to treat municipal wastewater on a unit processes basis. Electrical power consumption for complete plants was estimated by adding the power consumption for the individual processes. A comparison of electrical power consumption by wastewater treatment systems was made with other uses.

Estimates of recoverable energy in digester gases were made by Wesner and Clarke (1978). A discussion of the variation in gas production with the type sludge was presented.

Table 4. Estimated total annual and unit costs for alternative treatment processes with a design flow of 1.0 mgd (Tchobanoglous, 1974).[a]

Process	Initial capital cost dollars[b]	Annual cost, dollars[b]			Unit cost cents/ 1000 gal[b]
		Capital[c]	O & M	Total	
Imhoff tank	380,000	41,720	15,550	57,270	15.7
Rotating biological disks	800,000	87,832	57,680	145,512	39.9
Trickling filter processes	900,000	98,811	58,480	157,291	43.1
Activated sludge processes					
With external digestion	1,000,000	109,790	74,410	184,200	50.5
With internal digestion	500,000	54,895	48,800	103,695	28.4
Stabilization pond processes	250,000	27,447	23,680	51,127	14.0
Land treatment processes					
Slow rate					
Basic system	340,000	37,328	41,540	28,859	21.6
With primary treatment	940,000	103,302	81,540	184,742	50.6
With activated sludge	1,240,000	136,139	115,950	252,089	69.1
With stabilization pond	590,000	64,775	65,220	129,996	35.6
Rapid infiltration					
Basic system	200,000	21,958	25,100	47,058	12.9
With primary treatment	800,000	87,832	65,100	152,932	41.9
With activated sludge	1,000,000	109,790	99,510	209,300	57.3
With stabilization ponds	450,000	49,405	48,780	98,185	26.9

[a] Courtesy of Public Works Journal Corporation, Ridgewood, New Jersey.

[b] Based on an ENRCC index of 1900.

[c] Capital recovery factor = 0.10979 (15 years at 7 percent).

Table 5. Energy comparison of sludge dewatering equipment (Jacobs, 1977).[a]

	kw Demand cost/mo.	kwh Usage cost/mo.	Monthly cost	Annual cost
Belt press filters	40.0 kw	6105 kwh		
	$112.00	$153.85	$265.85	$3190.20
Vacuum filter	75.5 kw	8750 kwh		
	$210.00	$220.50	$430.50	$5166.00
Centrifuges	108.0 kw	13,700 kwh		
	$299.60	$313.05	$612.65	$7351.80

Notes:
1. Based on dewatering 75,000 lb/week of waste activated sludge at 3 percent feed, and approximately 20 percent cake solids concentration.
2. Costs based on varying rate schedule.

[a] Courtesy of Water and Sewage Works, Chicago, Illinois.

Table 6. Energy comparison of biological treatment systems[a,b,c] (Jacobs, 1977).[f]

	Completely mixed AS[e]	Extended aeration AS[d,e]	Carousel extended aeration AS[d,e]	Pure oxygen AS	Bio-Disk
kw demand	550	540	525	525	425
Cost	$ 1,070	$ 1,053	$ 1,053	$ 1,020	$ 800
kwh usage	230,000	236,000	218,000	216,000	188,000
Cost	$ 3,423	$ 3,498	$ 3,282	$ 3,247	$ 2,701
Monthly cost	$ 4,498	$ 4,542	$ 4,335	$ 4,076	$ 3,501
Annual cost	$53,976	$54,504	$52,020	$48,804	$42,012

[a] Comparison based on entire plant energy consumption.

[b] Includes consideration of differences in sludge quantity and characteristics.

[c] Costs based on varying rate schedule.

[d] Result in higher effluent quality.

[e] Activated sludge.

[f] Courtesy of Water and Sewage Works, Chicago, Illinois.

METHODS AND PROCEDURES

Equation Development

The graphs presented by Wesner et al. (1978) were converted to lines of best fit at the lower design flow rates (0.1 - 5.0 mgd) and used to calculate the energy requirements for small systems such as those employed at military installations. Least-squares fits of the linear and curvilinear lines were employed. A power function was used to fit the linear lines on the log-log plots and a polynomial equation was used to fit the curvilinear lines. The forms of the two functions are shown below.

$$\log Y = a + b\,(\log X) + c\,(\log X)^2 + d\,(\log X)^3$$

Polynomial function

$$Y = a\,X^b$$ Power function

Various combinations of the unit operations and processes were selected to form the most commonly used wastewater treatment systems. Energy requirements for each component of the system for various design flow rates were estimated using the equations of best fit. These results were tabulated for easy comparison between various types of treatment systems.

Design Parameters

Design parameters for all of the unit operations and processes are shown with the energy equations for each operation or process in Appendix A. Additional detail can be obtained by referring to the report by Wesner et al. (1978). The energy relationships for the conventional and advanced wastewater treatment processes are unmodified, but it was necessary to modify the land application energy relationships to conform to accepted practice in cold regions. The slow rate and overland flow application seasons were modified from five months per year to 250 days per year to more realistically reflect actual practice. Rapid infiltration application seasons extend over 365 days per year and not five months per year as shown in the Wesner et al. (1978) report.

Wastewater Characteristics

Raw wastewater and sludge characteristics used to develop the energy relationships are presented in Appendixes B and C, respectively.

Energy Recovery

The potential energy available in digester gas was estimated using a figure of 6.5 million Btu/million gallons of wastewater treated. This value is based upon a mixture of primary and waste activated sludge, and the value will vary with the type of sludge and must be adjusted when better data are available. However, a value of 6.5 million Btu/million gallons of wastewater is satisfactory for estimating purposes and will yield a conservative estimate for net energy consumption.

Btu available in digester gas can be converted to electricity, and a conversion factor of 11,400 Btu per kwh can be used to estimate the electricity generated. The conversion factor assumes an electrical generation efficiency of 30 percent. The gas utilization system also requires energy and this must be considered when comparing systems.

Secondary Energy

Secondary energy requirements are the amounts of energy needed to produce consumable materials used in a wastewater treatment system. Disinfectants, coagulants, sludge conditioning chemicals and regeneration of activated carbon and ion exchange resins require energy in their production, and this energy must be considered when comparing the energy efficiency of various systems.

Methods of construction, materials of construction, seasonal variations and other factors also influence the energy budget for a treatment system, but to a lesser degree than the primary factors such as direct energy consumption on a daily basis. Only the direct energy consumption and the secondary energy requirements are considered in this report.

RESULTS AND DISCUSSION

Energy Equations

The equations of the lines of best fit for the energy requirements of the unit operations and processes used in wastewater treatment based on the graphs reported by Wesner et al. (1978) are presented in Appendix A. Design conditions and assumptions used in developing the graphs are presented along with each equation. Details about the conditions imposed upon the equations can be obtained from the Wesner et al. (1978) report. Each equation is cross referenced to the Wesner et al. report. The equation number used in Appendix A coincides with the figure number in the Wesner et al. report; i.e., Equation 3-15 corresponds to Figure 3-15. Only the portions of the curves below a flow rate of 5 mgd were used to determine the line of best fit. This was done to obtain a better trend at the lower flow rates of interest rather than introduce the influence of the higher flow rates. All equations for the linear lines have a correlation coefficient of 0.999 or better.

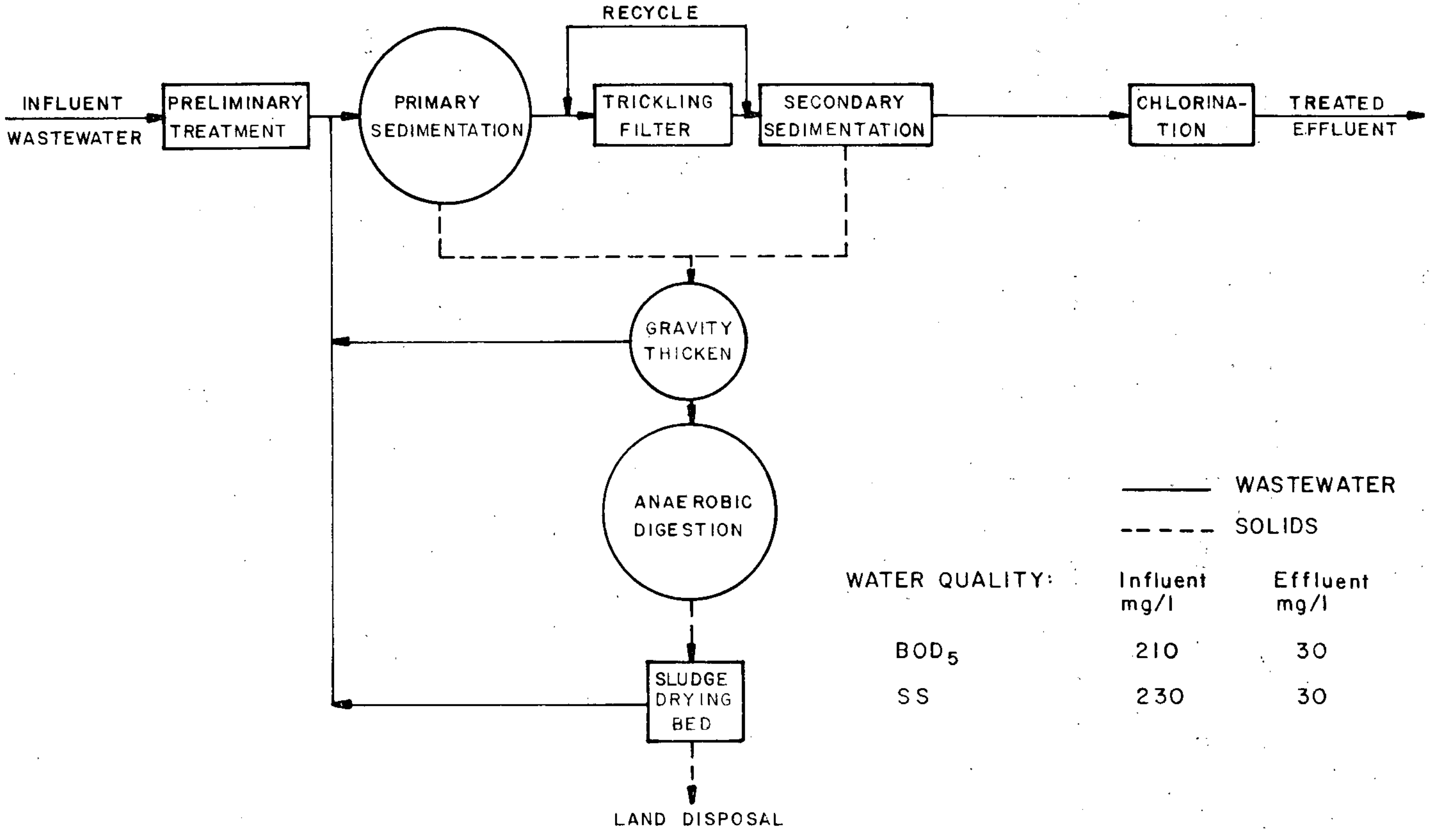
Treatment Systems

Flow diagrams of the wastewater treatment systems commonly employed are shown in Figures 2 through 12. The flow diagrams for land applications systems were selected utilizing the preapplication treatment guidelines shown in Table 7. The biological and physical treatment systems shown in Figures 2, 3, 4, 7, 8, 9, 10, and 11 are most often employed in small systems; however, the activated sludge process with sludge incineration (Figure 5), physical-chemical treatment (Figure 6), and the advanced treatment following secondary treatment (Figure 12) have been employed in special cases. These 11 systems can be modified by adding various processes in the treatment train to produce almost any quality effluent desired. Also, a very wide range of energy consumption can be experienced with these basic systems and their modifications.

The raw wastewater characteristics and the expected effluent quality from each of the systems are shown on the figures. The raw water characteristics are also summarized in Appendix B. Sludge characteristics used to develop the energy relationships in Wesner et al. (1978) and this report are presented in Appendix C.

Energy Consumption

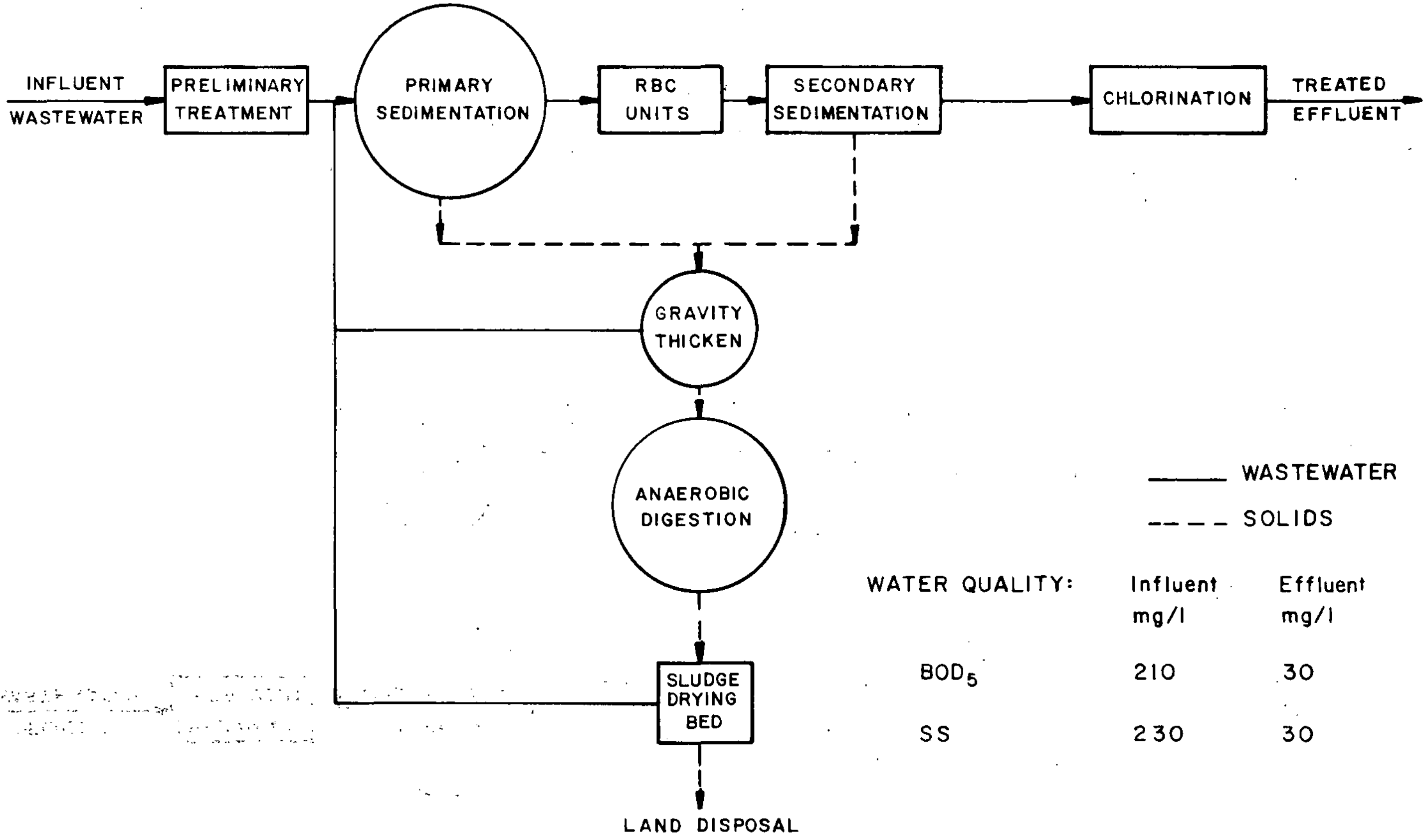
Energy requirements for the components of the treatment systems shown in Figures 2 through 12 for various flow rates of wastewater treated by the systems are presented in Tables 8 through 19. The table



WATER QUALITY:

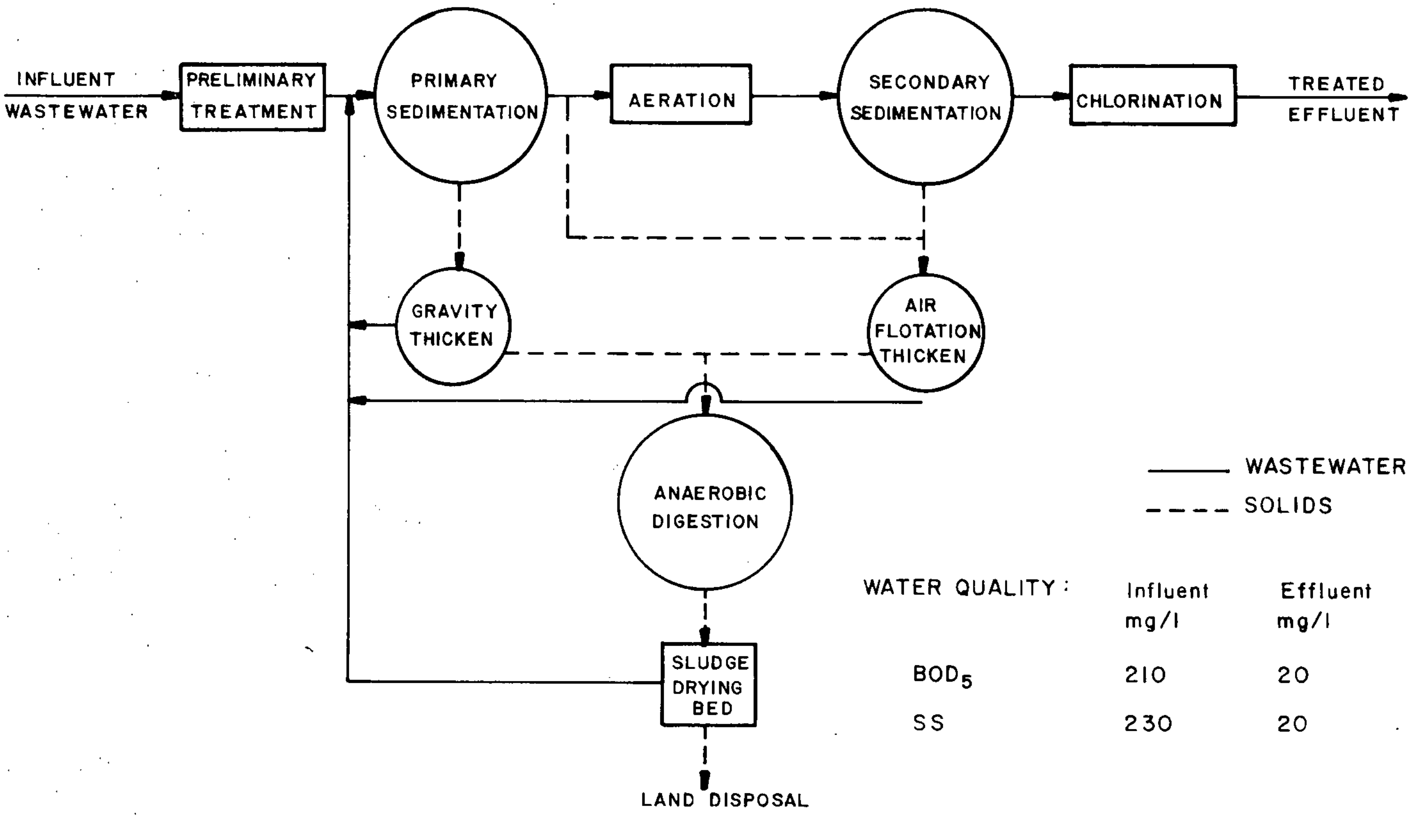
	Influent mg/l	Effluent mg/l
BOD_5	210	30
SS	230	30

Figure 2. Trickling filter treatment with anaerobic digestion (BOD_5 = 5-day, 20°C biochemical oxygen demand; SS = suspended solids).



WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	30
SS	230	30

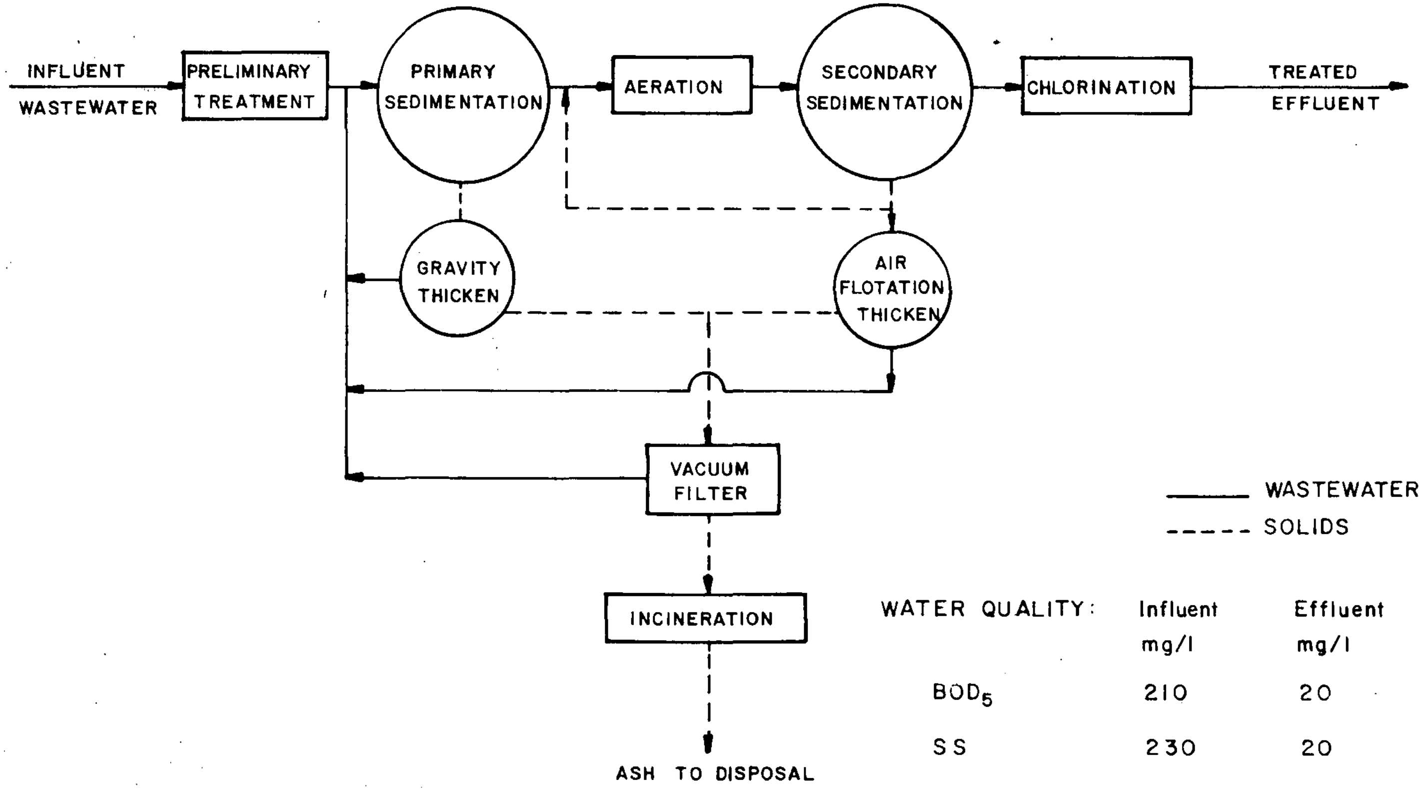
Figure 3. Rotating biological contactor treatment with anaerobic digestion.



WATER QUALITY:

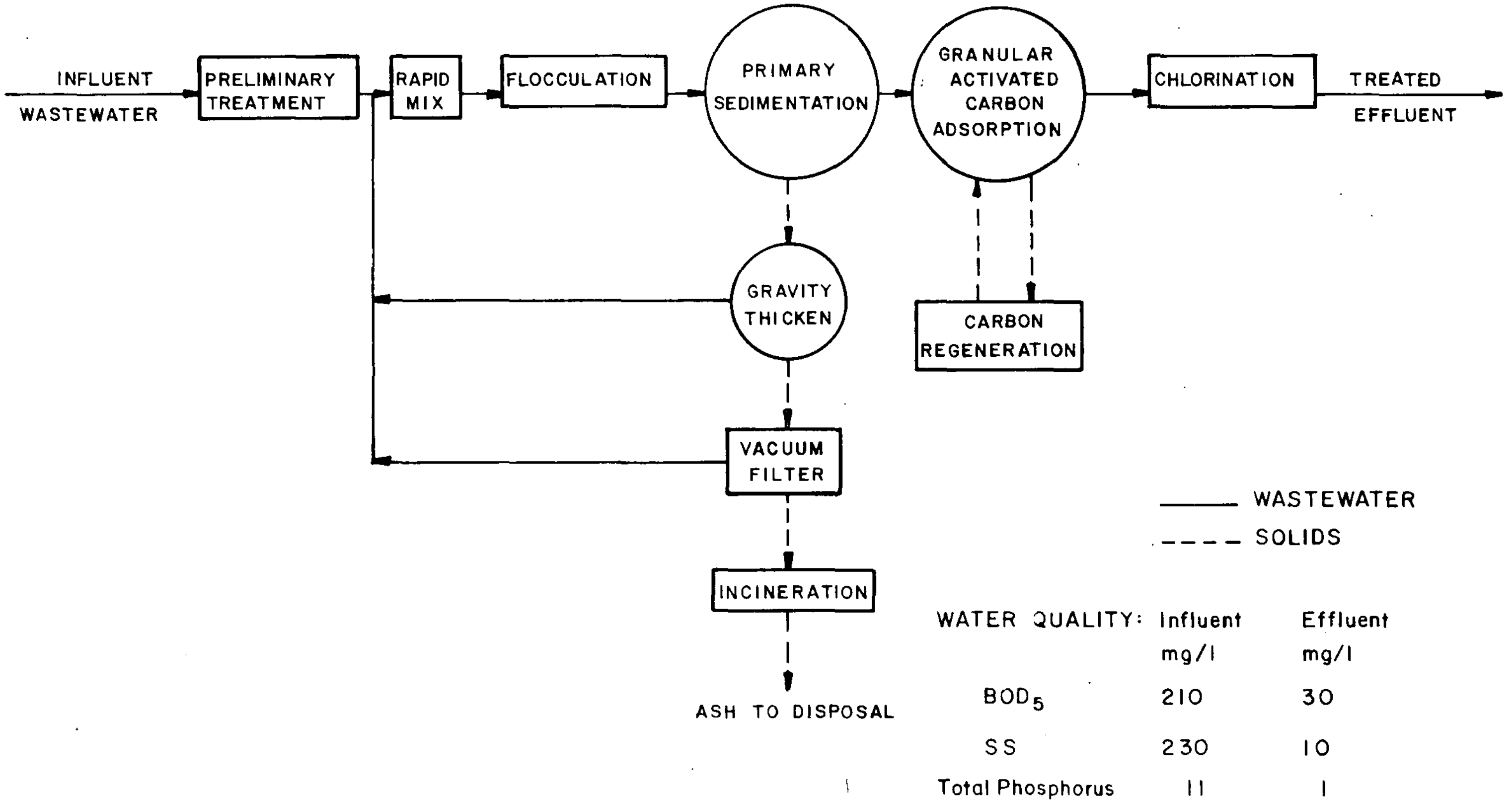
	Influent mg/l	Effluent mg/l
BOD_5	210	20
SS	230	20

Figure 4. Activated sludge treatment with anaerobic digestion.



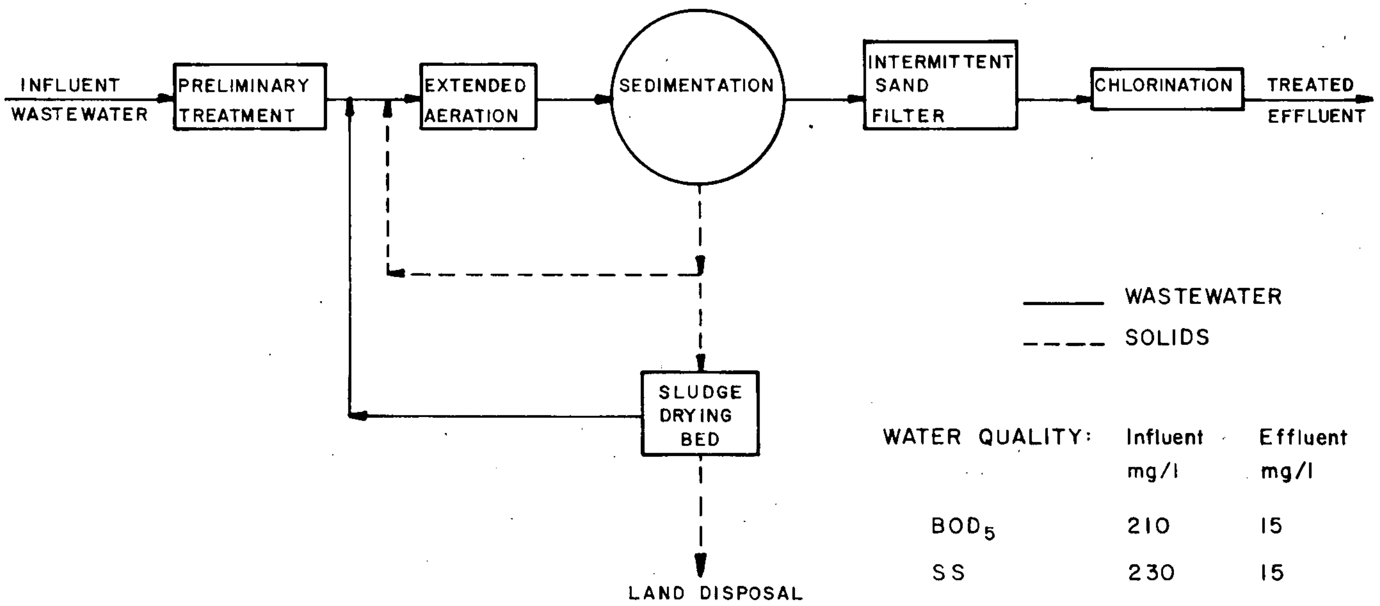
WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	20
SS	230	20

Figure 5. Activated sludge treatment with sludge incineration.



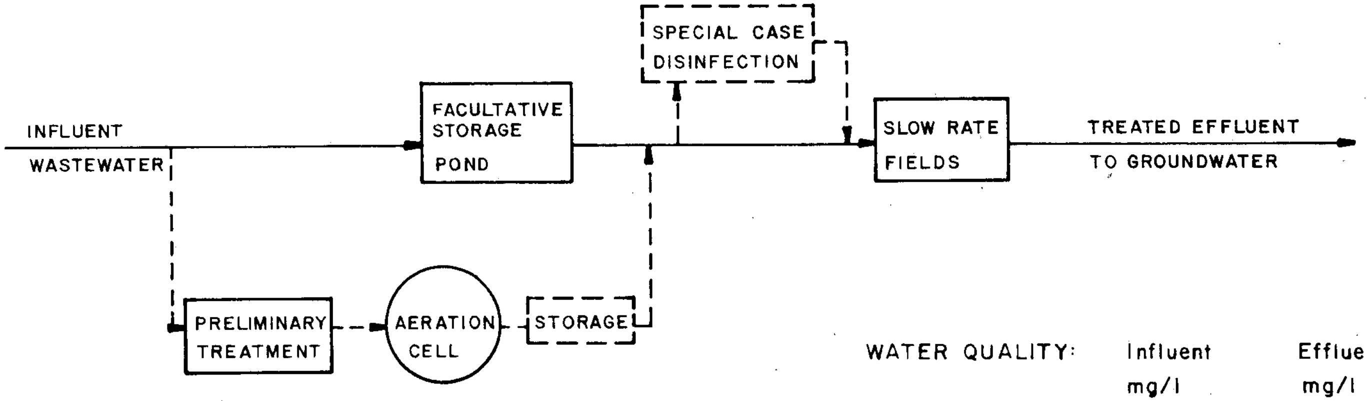
WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	30
SS	230	10
Total Phosphorus	11	1

Figure 6. Physical-chemical advanced secondary treatment.



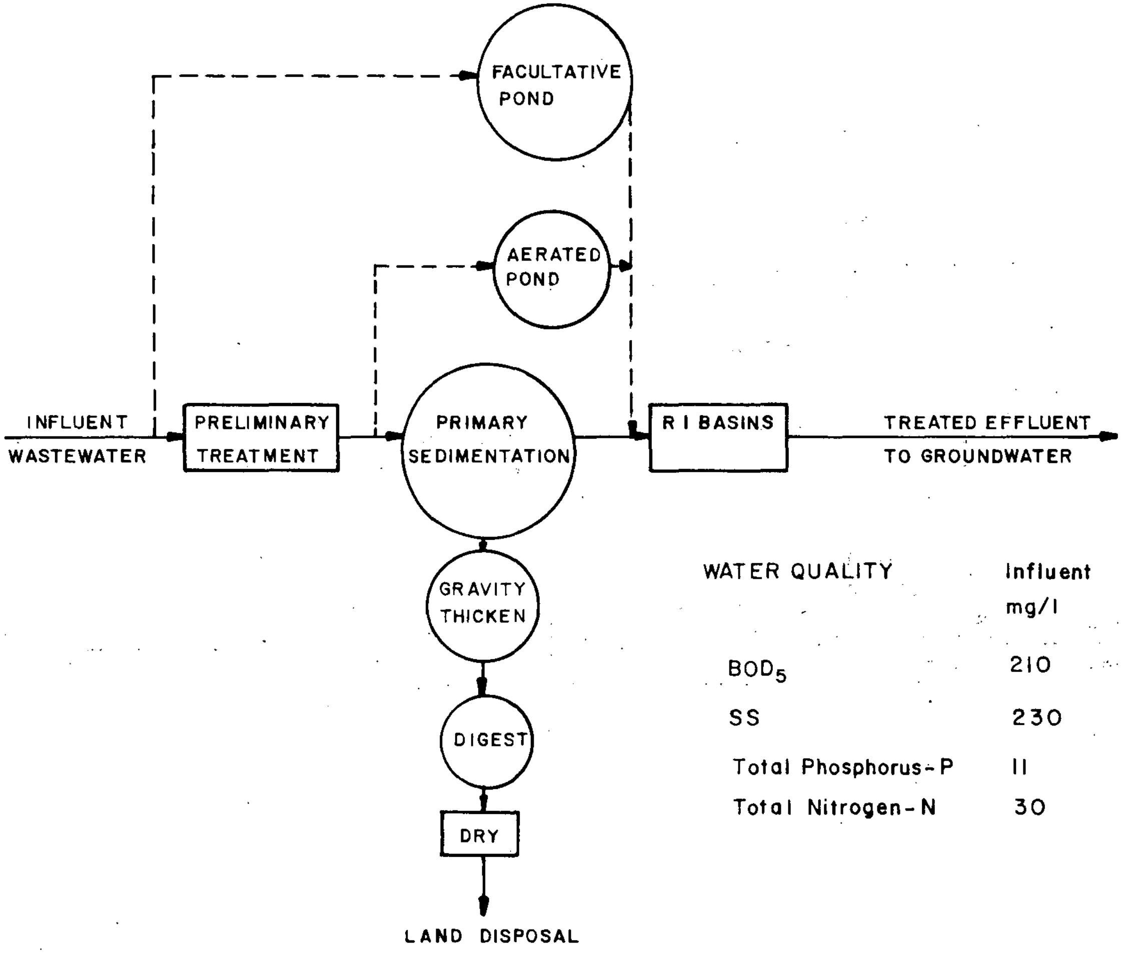
WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	15
SS	230	15

Figure 7. Extended aeration with intermittent sand filter.



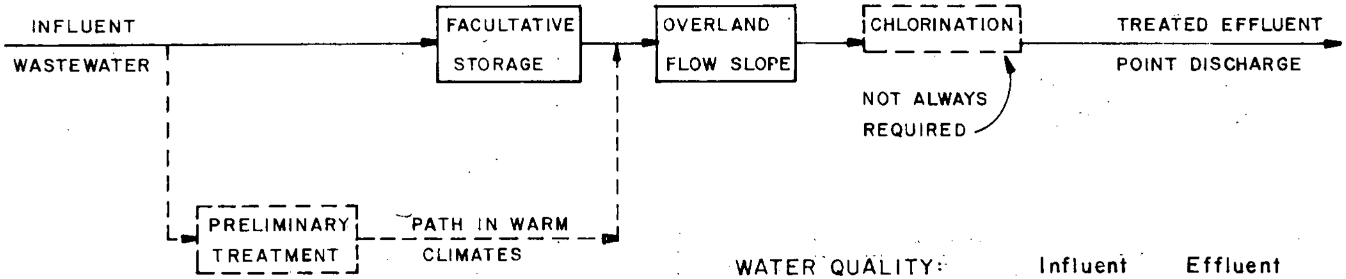
WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	1
SS	230	1
Total Phosphorus-P	11	0 1
Total Nitrogen-N	30	3

Figure 8. Slow rate irrigation.



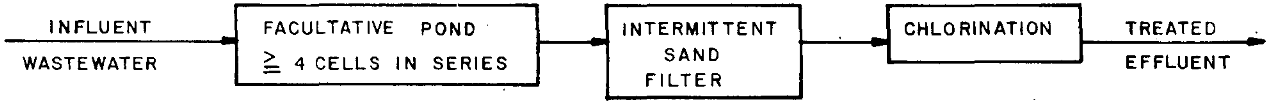
WATER QUALITY	Influent mg/l	Effluent mg/l
BOD_5	210	5
SS	230	1
Total Phosphorus-P	11	2
Total Nitrogen-N	30	10

Figure 9. Rapid infiltration.



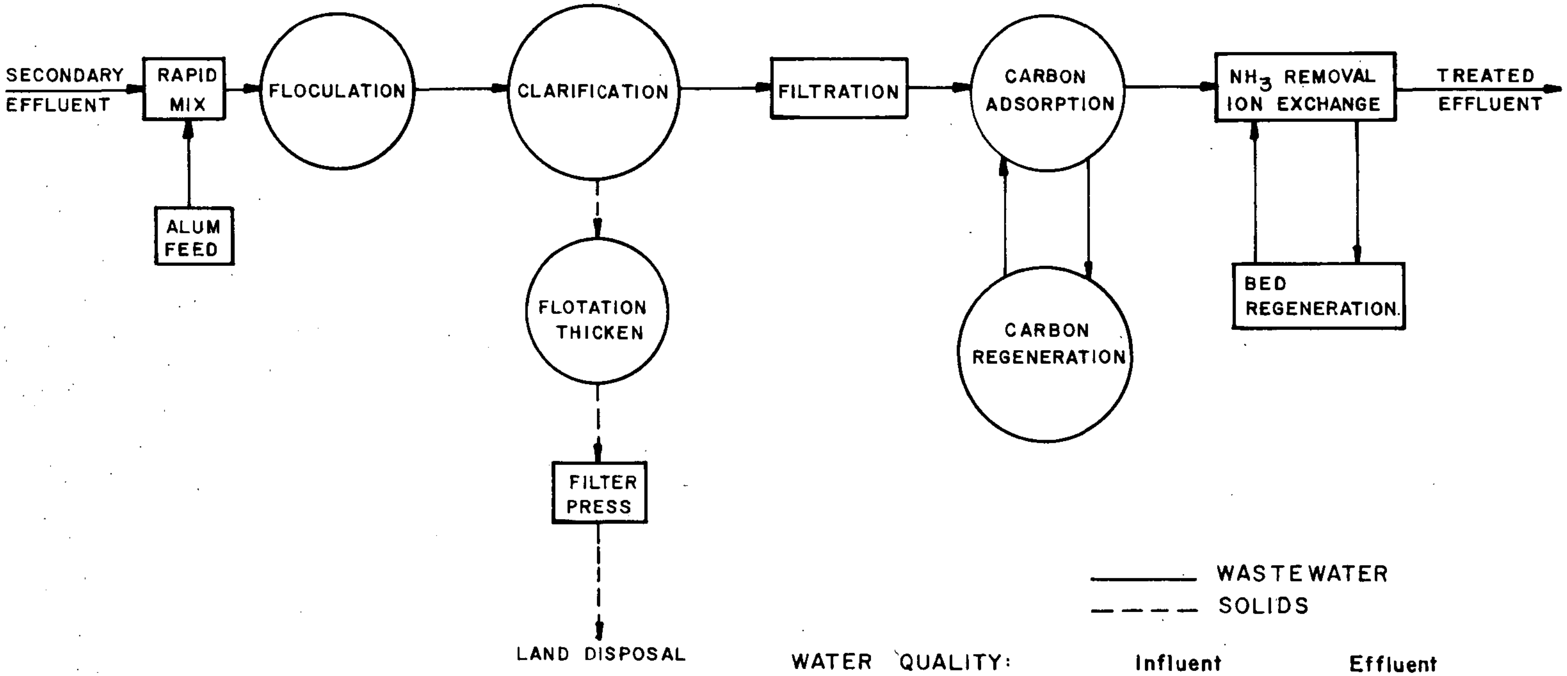
WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	5
SS	230	5
Total Phosphorus-P	11	5
Total Nitrogen-N	30	3

Figure 10. Overland flow.



WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	15
SS	230	15

Figure 11. Facultative lagoon-intermittent sand filter treatment.



WATER QUALITY:	Influent mg/l	Effluent mg/l
BOD_5	210	<10
SS	230	5
Total Phosphorus-P	11	<1
NH_3-N	15	<1

Figure 12. Advanced wastewater treatment.

Table 7. Guidance for assessing level of preapplication treatment for land treatment systems (EPA, 1978).

I. Slow-rate systems (reference sources include Water Quality Criteria 1972, EPA-R3-73-003, Water Quality Criteria EPA 1976, and various state guidelines).

  A. Primary treatment - acceptable for isolated locations with restricted public access and when limited to crops not for direct human consumption.

  B. Biological treatment by lagoons or inplant processes plus control of fecal coliform count to less than 1,000 MPN/100 ml[a] acceptable for controlled agricultural irrigation except for human food crops to be eaten raw.

  C. Biological treatment by lagoons or inplant processes with additional BOD or SS control as needed for aesthetics plus disinfection to log mean of 200/100 ml (EPA fecal coliform criteria for bathing waters) - acceptable for application in public access areas such as parks and golf courses.

II. Rapid-infiltration systems

  A. Primary treatment - acceptable for isolated locations with restricted public access.

  B. Biological treatment by lagoons or inplant processes - acceptable for urban locations with controlled public access.

III. Overland-flow systems

  A. Screening or comminution - acceptable for isolated sites with no public access.

  B. Screening or comminution plus aeration to control odors during storage or application - acceptable for urban locations with no public access.

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[a] Most probable number of coliform bacteria per 100 ml of sample.

number corresponds to the figure number; i.e., Table 8 is a listing of the energy requirements for a trickling filter treatment system with anaerobic digestion (Figure 2). The last column in each table lists the equations used to calculate the values (Appendix A).

Table 20 shows the energy requirements for components frequently appended to secondary treatment systems to produce a better quality effluent. By modifying the basic systems shown in Figures 2 through 12, it is possible to develop the energy requirements for almost any

Table 8. Energy requirements for components of trickling filter system with anaerobic digestion in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Elec- tricity, kwh/yr	Fuel, Million Btu/yr	Elec- tricity, kwh/yr	Fuel, Million Btu/yr	Elec- tricity, kwh/yr	Fuel, Million Btu/yr	Elec- tricity, kwh/yr	Fuel, Million Btu/yr	Elec- tricity, kwh/yr	Fuel, Million Btu/yr	Elec- tricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH[a] = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Non Aerated	260		305		450		530		690		780			3-10
Primary Sedimentation	2,530		3,190		5,420		6,820		9,970		11,990		Circular Tanks	3-12
Trickling Filter (Rock Media Recirculation 2:1)	3,670		7,200		31,950		61,300		172,200		278,300			3-16
Secondary Sedimentation	3,130		3,750		5,810		7,230		10,920		13,720			3-13
Disinfection														
Primary energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary energy	(8)		(17)		(83)		(165)		(495)		(825)		(Secondary Energy Requirements)	4-5
Sub-Total	13,793		20,802		63,363		110,655		285,875		452,235			
Sludge Treatment														
Gravity Thickening	35		69		316		610		1,730		2,730			3-85
Anaerobic Digestion High Rate	1,220	62	2,435	124	12,180	632	24,354	1,270	73,060	3,860	121,760	6,460	Detention Time = 20 days Mixing = 1/2 HP/1000 ft^3	3-105
Drying Beds	17	0.2	32	0.4	145	2	282	4	833	13	1,395	21		3-98
Hauling-Truck		13		26		128		256		767		1,278		3-100
Landfill Disposal		1.6		3.3		16		33		99		164		3-104
Sub-Total	1,272	77	2,536	154	12,641	778	25,246	1,563	75,623	4,739	125,885	7,923		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	15,264	225	23,582	335	76,462	1,098	136,547	1,996	362,726	5,484	579,846	8,911		
Digester Gas Utilization System	10,070	10	14,480	25	34,980	159	52,350	315	102,950	864	143,540	1,358		5-18
Total with Gas Utilization	25,334	235	38,062	360	111,442	1,257	188,897	2,311	465,676	6,348	723,386	10,269		
Energy Recovered-Digester Gas		119		237		1,187		2,373		7,119		11,865		

[a] TDH = total dynamic head.

Table 9. Energy requirements for components of a rotating biological contactor treatment system with anaerobic digestion located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Non Aerated	260		305		450		530		690		780			3-10
Primary Sedimentation	2,530		3,190		5,420		6,820		9,970		11,990			3-12
RBC Units	3,650		7,300		36,500		73,000		219,000		365,000		Dense Media	3-20
Secondary Sedimentation	3,130		3,750		5,810		7,230		10,920		13,720			3-13
Disinfection (Cl_2)														
Primary energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary energy	8		17		83		165		495		825			4-5
Sub-Total	13,773		20,902		67,913		122,355		332,675		538,935			
Sludge Treatment														
Gravity Thickening	35		69		316		610		1,730		2,730			3-85
Anaerobic Digestion High Rate	1,220	62	2,435	124	12,180	632	24,354	1,270	73,060	3,860	121,760	6,460		3-105
Drying Beds	17	0.2	32	0.4	145	2	282	4	833	13	1,395	21		3-98
Hauling-Truck		13		26		128		256		767		1,278		3-100
Landfill Disposal		1.6		3.3		16		33		99		164		3-104
Sub-Total	1,272	77	2,536	154	12,641	778	25,246	1,563	75,623	4,739	125,885	7,923		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	15,244	225	23,682	335	81,012	1,098	148,247	1,996	409,526	5,484	666,546	8,911		
Digester Gas Utilization System	10,070	10	14,480	25	34,980	159	52,350	315	102,950	864	143,540	1,358		5-18
Total with Gas Utilization	25,314	235	38,162	360	115,992	1,257	200,597	2,311	512,476	6,348	810,086	10,269		
Energy Recovered-Digester Gas		119		237		1,187		2,373		7,119		11,865		

Table 10. Energy requirements for components of activated sludge system with anaerobic digestion in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Aerated	10,610		11,400		12,290		13,270		17,800		22,670			3-9
Primary Sedimentation	2,530		3,190		5,420		6,820		9,970		11,990		Circular Tanks	3-12
Aeration-Mechanical	8,000		16,000		80,000		160,000		480,000		800,000		Complete Mix	3-28
Secondary Sedimentation	4,470		5,010		10,390		16,400		37,030		54,870			3-13
Disinfection (Cl_2)														
Primary energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary energy	8		17		83		165		495		825			4-5
Sub-Total	29,813		41,957		127,833		231,265		636,895		1,036,975			
Sludge Treatment														
Gravity Thickening	35		69		316		610		1,730		2,730			3-85
Air Flotation Thickening	4,340		7,940		32,170		58,800		152,900		238,450			3-86
Anaerobic Digestion	1,220	52	2,435	104	12,180	518	24,354	1,040	70,060	3,110	121,760	5,180	Mixing - 1/2 HP/1000ft^3	3-105
													Detention Time = 20 days	3-105
Drying Beds	17	0.2	32	0.4	145	2	282	4	833	13	1,395	21		3-98
Hauling-Truck		12		24		120		240		720		1,200		3-100
Landfill Disposal		1.5		3.1		15.4		31		93		154		3-104
Sub-Total	5,612	66	10,476	132	44,811	655	84,046	1,315	225,523	3,936	364,335	6,555		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	35,624	214	52,677	313	173,102	975	315,957	1,748	863,646	4,681	1,403,036	7,543		
Digester Gas Utilization System	10,070	10	14,480	25	34,980	159	52,350	315	102,950	864	143,540	1,358		5-18
Total With Gas Utilization	45,694	224	67,157	338	208,082	1,134	368,307	2,063	966,596	5,545	1,546,576	8,901		
Energy Recovered-Digester Gas		119		237		1,187		2,373		7,119		11,865		

Table 11. Energy requirements for components of activated sludge system with sludge incineration in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Aerated	10,610		11,400		12,290		13,270		17,800		22,670			3-9
Primary Sedimentation	2,530		3,190		5,420		6,820		9,970		11,990		Circular Tanks	3-12
Aeration-Mechanical	8,000		16,000		80,000		160,000		480,000		800,000		Complete Mix	3-28
Secondary Sedimentation	4,470		5,010		10,390		16,400		37,030		54,870			3-13
Disinfection (Cl_2)														
Primary energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary energy	8		17		83		165		495		825			4-5
Sub-Total	29,813		41,957		127,833		231,265		636,895		1,036,975			
Sludge Treatment														
Gravity Thickening	35		69		316		610		1,730		2,730			3-85
Air Flotation Thickening	4,340		7,940		32,170		58,800		152,900		238,450			3-86
Vacuum Filter	13,198		13,320		18,950		25,190		45,460		63,020			3-95
Incineration	2,250	145	3,870	287	12,350	1,440	20,630	2,880	46,520	8,630	67,900	14,390		3-111, 3-112 3-113
Ash Hauling		11		22		109		217		651		1,085	20 miles round grip	3-100
Landfill Disposal		1.4		2.8		14		28		84		140		3-104
Sub-Total	19,823	157	25,199	312	63,786	1,563	105,230	3,125	246,610	9,365	372,100	15,615		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	49,835	305	67,400	493	192,077	1,883	337,141	3,558	884,733	10,110	1,410,801	16,603		

Table 12. Energy requirements for components of a physical-chemical advanced secondary wastewater treatment system located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Aerated	10,610		11,400		12,290		13,270		17,800		22,670			3-9
Chemical Clarification-$FeCl_3$													Dosage = 200 mg/1	
Primary Energy	8,580		8,950		14,900		21,850		48,500		75,570			3-57
Secondary Energy	35		70		350		700		2,100		3,500			4-6
Activated Carbon														
Adsorption	3,100		6,200		31,000		62,000		186,000		310,000		Upflow Expanded Bed	3-66
Regeneration	1,900	200	3,800	400	19,000	2,000	38,000	4,000	114,000	12,000	190,000	20,000		3-67
Disinfection (Cl_2)														
Primary Energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/1	3-74
Secondary Energy	8		17		83		165		495		825			4-5
Sub-Total	28,428	200	36,777	400	97,273	2,000	170,595	4,000	460,495	12,000	749,185	20,000		
Sludge Treatment														
Gravity Thickening	35		69		316		610		1,730		2,730			3-85
Vacuum Filter	14,000		16,310		31,400		45,650		96,400		142,300			3-95
Incineration	3,870	400	6,460	800	21,000	3,930	34,860	7,800	78,800	23,470	114,960	39,140		3-111,3-112, 3-113
Ash Hauling		24		50		220		450		1,400		2,300	20 mile round trip	3-100
Landfill Disposal		10		20		95		200		550		1,000		3-104
Sub-Total	17,905	434	22,839	870	52,716	4,245	81,120	8,450	176,930	25,420	259,990	42,440		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	46,532	782	59,860	1,451	150,447	6,565	252,361	12,883	638,653	38,165	1,010,901	63,428		

Table 13. Energy requirements for components of an extended aeration system with slow sand filter located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Aerated	10,610		11,400		12,290		13,270		17,800		22,670			3-9
Aeration	17,500		35,000		175,000		350,000		1,050,000		1,750,000		Mechanical	3-28
Secondary Sedimentation	4,470		5,010		10,390		16,400		37,030		54,870			3-13
Intermittent or Slow Sand Filter	596	2.5	1,135	5	5,070	25	9,660	50	26,830	151	43,150	252	TDH = 5 ft; Diesel Powered Truck & Cleaning Equipment. Hydraulic Loading Rate = 0.4 mgad[a] 12 hr operation of truck and cleaning equipment/acre 6 cleanings/yr. Two gallons of fuel/hr. 1 gal. = 140,000 Btu.	
Disinfection (Cl_2)														
Primary Energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary Energy	8		17		83		165		495		825			4-5
Sub-Total	37,379	2.5	58,902	5	222,483	25	424,105	50	1,223,755	151	2,018,135	252		
Sludge Treatment														
Drying Beds	64	0.2	121	0.3	570	1.7	1,140	3.3	3,530	9.9	6,040	16.5		3-98
Hauling-Truck		12		24		120		240		720		1,200		3-100
Landfill Disposal		1.5		3.1		15.4		31		93		154		3-104
Sub-Total	64	14	121	27	570	137	1,140	274	3,530	823	6,040	1,371		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	37,642	164	59,267	213	223,511	482	425,891	757	1,228,513	1,719	2,025,901	2,611		

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[a] Million gallons per acre per day.

Table 14. Energy requirements for components of slow rate (irrigation) land treatment system located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Aerated Pond	13,000		26,000		130,000		260,000		780,000		1,300,000			3-32
Sub-Total	16,365		31,100		144,950		285.280		842,430		1,397,100			
Spray Irrigation														
Solid Set	8,970		17,570		83,720		164,000		476,050		781,350			3-79
Center Pivot	13,500		27,000		135,000		270,000		810,000		1,350,000			3-79
Ridge & Furrow Flooding	1,400	1	2,800	2	14,000	10	28,000	20	84,000	60	140,000	100		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System-Aerated Ponds														
Solid Set	25,534	148	48,914	181	229,128	320	449,926	433	1,319,708	745	2,180,176	988		
Center Pivot	30,064	148	58,344	181	280,408	320	555,926	433	1,653,658	745	2,748,826	988		
Ridge & Furrow-Flooding	17,964	149	34,144	183	159,408	330	313,926	453	927,658	805	1,538,826	1,088		
Total for Treatment System-Facultative Ponds														
Solid Set	10,369	148	20,094	181	94,378	320	184,046	433	531,178	745	869,776	988		
Center Pivot	14,899	148	29,524	181	145,658	320	290,046	433	865,128	745	1,438,426	988		
Ridge & Furrow-Flooding	2,799	149	5,324	183	24,658	330	48,046	453	139,128	805	228,426	1,088		

Table 15. Energy requirements for components of a primary wastewater treatment plant followed by rapid infiltration land treatment systems located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel. Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Grit Removal-Non Aerated	260		305		450		530		690		780			3-10
Primary Sedimentation	2,530		3,190		5,420		6,820		9,970		11,990		Circular Tank	3-12
Sub-Total	6,155		8,595		20,820		32,630		73,090		109,870			
Rapid Infiltration														
Flooding	141		287		1,480		3,000		9,200		15,490			3-81
Sludge Treatment														
Gravity Thickening	35		69		316		610		1,730		2,730			3-85
Anaerobic Digestion-High Rate	1,220	62	2,435	124	12,180	632	24,354	1,270	73,060	3,860	121,760	6,460		3-105
Drying Beds	17	0.2	32	0.4	145	2	282	4	833	13	1,395	21		3-98
Hauling-Truck		13		26		128		256		767		1,278		3-100
Landfill Disposal		1.6		3.3		16		33		99		164		3-104
Sub-Total	1,272	77	2,536	154	12,641	778	25,246	1,563	75,623	4,739	125,885	7,923		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	7,767	225	11,662	335	35,399	1,098	61,522	1,996	159,141	5,484	252,971	8,911		

Table 16. Energy requirements for components of rapid infiltration land treatment systems located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Aerated Pond	13,000		26,000		130,000		260,000		780,000		1,300,000			3-32
Sub-Total	16,365		31,100		144,950		285,280		842,430		1,397,100			
Rapid Infiltration														
Flooding	141		287		1,480		3,000		9,200		15,490			3-81
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System-Aerated Ponds														
Flooding	16,705	148	31,631	181	146,888	320	288,926	433	852,858	745	1,414,316	988		
Total for Treatment System-Facultative Ponds														
Flooding	1,540	148	2,811	181	12,138	320	23,046	433	64,328	745	103,916	988		

Table 17. Energy requirements for components of overland flow land treatment systems located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.01 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft	3-1
Preliminary Treatment														
Bar Screen	465		640		1,050		1,200		1,450		1,590			3-7
Comminutor	1,700		2,180		3,700		4,680		7,080		8,810			3-8
Aerated Pond	13,000		26,000		130,000		260,000		780,000		1,300,000			3-32
Sub-Total	16,365		31,100		144,950		285,280		842,430		1,397,100			
Overland Flow														
Flooding	460		920		4,600		9,200		27,600		46,000			3-81
Solid Set Sprinklers	8,500		17,000		85,000		170,000		510,000		850,000			3-82
Disinfection (Cl_2)														
Primary Energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary Energy	8		17		83		165		495		825			4-5
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System-Aerated Ponds														
Flooding	17,862	148	33,521	181	154,791	320	304,621	433	900,923	745	1,495,171	988		
Solid Set Sprinklers	25,902	148	49,601	181	235,191	320	465,421	433	1,383,323	745	2,299,171	988		
Total for Treatment System-Facultative Ponds														
Flooding	2,697	148	4,701	181	20,041	320	38,741	433	112,393	745	184,771	988		
Solid Set Sprinklers	10,737	148	20,781	181	100,441	320	199,541	433	594,793	745	988,771	988		

Table 18. Energy requirements for components of a facultative lagoon-intermittent sand filter system located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Wastewater Treatment														
Raw Sewage Pumping	1,200		2,280		10,200		19,400		53,900		86,700		TDH = 10 ft.	3-1
Intermittent Sand Filter	596	2.5	1,135	5	5,070	25	9,660	50	26,830	151	43,150	252		
Disinfection (Cl_2)														
Primary Energy	830		1,240		4,700		9,330		29,170		49,520			3-74
Secondary Energy	8		17		83		165		495		825			4-5
Sub-Total	2,634		4,672		20,053		38,555		110,395		180,195			
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	2,833	150	4,916	186	20,511	345	39,201	483	111,623	896	181,921	1,240		

Table 19. Energy requirements for components of an advanced wastewater treatment system processing secondary effluent located in the intermountain area of the USA.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Secondary Effluent Treatment														
Chemical Clarification (Alum)														
Primary Energy	10,430		10,620		17,380		25,680		58,110		91,730			3-57
Secondary Energy	200		401		2,005		4,011		12,032		20,054		Zarnett, 1977	
Filtration	1,100		2,200		11,000		22,000		66,000		110,000		Gravity Filters	3-63
Activated Carbon														
Adsorption	3,100		6,200		31,000		62,000		186,000		310,000		Upflow Expanded Bed	3-66
Regeneration	1,900	200	3,800	400	19,000	2,000	38,000	4,000	114,000	12,000	190,000	20,000		3-67
Ammonia-N Removal														
Ion Exchange	1,100		2,200		11,000		22,000		66,000		110,000		Gravity	3-68
Regeneration														
Primary Energy	100		200		1,000		2,000		6,000		10,000		Regeneration with 2% NaCl	3-69
Secondary Energy	1		2		10		20		60		100			
Disinfection (Cl_2)														
Primary Energy	830		1,240		4,700		9,330		29,170		49,520		Dosage = 10 mg/l	3-74
Secondary Energy	8		17		83		165		495		825			4-5
Sub-Total	18,769	200	26,880	400	97,178	2,000	185,206	4,000	537,867	12,000	892,229	20,000		
Sludge Treatment														
Air Flotation Thickening	15,030		26,470		107,360		195,480		509,040		794,080			3-86
Filter Press	910		1,490		4,720		8,190		16,890		24,280			3-96
Hauling-Truck		3		5		25		50		150		250		3-100
Landfill Disposal		0.3		0.6		3		6		19		32		3-104
Sub-Total	15,940	3	27,960	6	112,080	28	203,670	56	525,930	169	818,360	282		
Other														
Building Heating		148		181		320		433		745		988		3-83
Building Cooling	199		244		458		646		1,228		1,726			3-84
Total for Treatment System	34,908	351	55,084	587	209,716	2,348	389,522	4,489	1,065,025	12,914	1,712,315	21,270		

Table 20. Energy requirements for components frequently appended to secondary wastewater treatment plants.

Operation or Process	Capacity of Wastewater Treatment Facility												Comments	
	0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd			
	Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements		Energy Requirements			
	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr		
Filtration-Gravity	1,100		2,200		11,000		22,000		66,000		110,000			3-63
Filtration-Pressure	1,500		3,030		15,390		31,000		94,030		157,510			3-63
Intermittent Sand Filters and Slow Sand Filters	596	2.5	1,135	5	5,070	25	9,660	50	26,830	151	43,150	252		
Microscreens - 23μ Screen	6,097		10,540		37,590		65,000		154,800		231,800			3-62
35μ Screen	4,005		6,930		24,700		42,700		101,700		152,300			3-62
Ammonia-N Removal														
Ion Exchange	1,100		2,200		11,000		22,000		66,000		110,000		Gravity	3-68
Regeneration														
Primary	100		200		1,000		2,000		6,000		10,000		Regeneration with 2% NaCl	3-69
Secondary	1		2		10		20		60		100			
Breakpoint Chlorination + Dechlorination	74,460		78,650		98,760		114,600		156,200		186,600		Dechlorination with Sulfur Dioxide	3-73
Nitrification-Suspended Growth	7,000		14,000		70,000		140,000		420,000		700,000		Mechanical Aeration	

system applicable to the treatment of small flows of wastewater. For combinations not shown in the tables, energy requirements can be calculated using the equations in Appendix A.

Carbon and Ion Exchange Regeneration

Energy requirements for the regeneration of carbon and ion exchange materials for very low flow systems (0.05 - 0.1 mgd) are shown in Tables 12, 19, and 20 only for comparative purposes. In most cases activated carbon would be replaced rather than regenerated and the energy requirements would be reduced accordingly. The regeneration of ion exchange resins would probably be justified, but depending upon local conditions it may be less expensive to replace ion exchange resins on a fixed schedule rather than to regenerate them.

Energy requirements for carbon regeneration represent greater than 10 percent of the electricity and 93 percent of the fuel consumed in the components of an advanced treatment system following secondary treatment at a flow rate of 5 mgd. At a flow rate of 0.05 mgd, the energy requirements for carbon regeneration have been reduced to 5 percent of the electricity and 57 percent of the fuel requirements. However, the inconvenience of operating additional equipment and the need for highly skilled operation would probably rule out the use of carbon regeneration at very small (< 0.5 mgd) wastewater treatment systems.

Gas Utilization

Although the energy required and produced by gas utilization is presented in the examples summarized in Tables 8, 9, and 10, gas utilization in small flow systems, particularly at the lower flow rates of less than 0.5 mgd, may not be advisable. The increased operating expense caused by the need for a more skilled operator and more sophisticated equipment will likely offset any savings from gas utilization. However, this is a decision that must be made on an individual basis.

Effluent Quality and Energy Requirements

Table 21 shows the expected effluent quality and the energy requirements for various combinations of the operations and processes shown in Figures 2 through 12 and Tables 8 through 20. Energy requirements and effluent quality are not directly related. Utilizing facultative lagoons and land application techniques, it is possible to obtain an excellent quality effluent and expend small quantities of energy. Although one system may be more energy efficient, the selection of a wastewater treatment facility must be based upon a complete economic analysis. However, with rising energy costs, energy requirements are assuming a greater proportion of the annual cost of operating a wastewater treatment facility, and it is likely that energy costs will

Table 21. Expected effluent quality and total energy requirements for various sizes and types of wastewater treatment plants located in the intermountain area of the USA.

Treatment System	Effluent Quality mg/l				Total Energy Requirements at Various Flow Rates												Comments
					0.05 mgd		0.1 mgd		0.5 mgd		1.0 mgd		3.0 mgd		5.0 mgd		
	BOD_5	SS	Total Phos. as P	Total Nitrogen as N	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	Electricity, kwh/yr	Fuel, Million Btu/yr	
Trickling Filter with Anaerobic Digestion	30	30	-	-	15,300	225	23,600	335	76,500	1,100	137,000	2,000	363,000	5,490	580,000	8,910	See Figure 2 No Energy Recovery
Rotating Biological Contactor with Anaerobic Digestion	30	30	-	-	15,200	225	23,700	335	81,000	1,100	148,000	2,000	409,000	5,490	667,000	8,910	See Figure 3 No Energy Recovery
Facultative Pond + Microscreens 23μ	30	30	-	15	8,330	148	14,300	181	53,000	320	94,500	433	239,000	745	371,000	988	
Physical-Chemical Advanced Secondary Treatment	30	10	1	-	46,500	782	59,900	1,451	150,000	6,570	252,000	12,900	639,000	38,200	1,010,000	63,400	See Figure 6
Activated Sludge With Anaerobic Digestion	20	20	-	-	35,600	214	52,700	313	173,000	975	316,000	1,750	864,000	4,680	1,400,000	7,540	See Figure 4 No Energy Recovery
Activated Sludge with Sludge Incineration	20	20	-	-	49,800	305	67,400	493	192,000	1,880	337,000	3,560	885,000	10,100	1,410,000	16,600	Theoretically Could Recover Enough Heat To Generate All Need Elect. See Figure 5
Extended Aeration with Sludge Drying Beds	20	20	-	-	37,000	161	58,100	208	218,000	457	416,000	707	1,200,000	1,570	1,980,000	2,360	See Figure 7
Trickling Filter + Granular Media Gravity Filtration.	20	10	-	-	16,400	225	25,800	335	87,500	1,100	159,000	2,000	429,000	5,480	690,000	8,910	
Trickling Filter + N-Removal (Ion Exchange) + Gran. Media Filt.	20	10	-	5	17,600	225	28,200	335	99,500	1,100	183,000	2,000	501,000	5,480	810,000	8,910	
Facultative Pond + Intermittent Sand Filter	15	15	-	10	2,830	150	4,920	186	20,500	345	39,200	483	112,000	896	182,000	1,240	See Figure 11
Aerated Pond + Intermittent Sand Filter	15	15	-	20	18,000	151	33,700	186	155,000	345	305,000	483	900,000	896	1,490,000	1,240	
Extended Aeration + Intermittent Sand Filter	15	15	-	-	37,600	164	59,300	213	223,000	482	426,000	757	1,230,000	1,720	2,030,000	2,610	See Figure 7
Activated Sludge (A.D.) + Gran. Media Gravity Filt.	15	10	-	-	36,700	214	54,900	313	184,000	975	338,000	1,750	930,000	4,680	1,510,000	7,540	
Activated Sludge + Nitrification + Gran. Media Gravity Filt.	15	10			43,700	214	68,900	313	254,000	975	478,000	1,750	1,350,000	4,680	2,210,000	7,540	
Overland Flow-Facultative Pond Flooding	5	5	5	3	2,700	148	4,700	181	20,000	320	38,700	433	112,000	745	185,000	988	See Figure 10
Rapid Infiltration-Facultative Pond Flooding	5	1	2	10	2,380	148	4,070	181	16,900	320	32,500	433	94,000	745	154,000	988	See Figure 9
Slow Rate (Irrigation)-Fac. Pond-Ridge & Furrow Flooding	1	1	0.1	3	3,640	149	6,580	183	29,400	330	57,500	453	169,000	805	280,000	1,090	See Figure 8
Activated Sludge + Advanced Treatment	<10	5	<1	<1	70,500	565	108,000	900	383,000	3,320	705,000	6,240	1,930,000	17,600	3,110,000	28,900	See Figure 12

become the predominant factor in the selection of small flow treatment systems. Operation and maintenance requirements, and consequently costs, are frequently kept to a minimum at small installations because of the limited resources and operator skills normally available. This favors the selection of systems employing units with low energy requirements. It is very likely that all future wastewater treatment systems at small installations in isolated areas will be designed employing low energy consuming units and simple operation and maintenance. The only exceptions to this will be in areas with limited space or construction materials, or where surplus energy is available.

The effluent quality expected with each of the treatment systems and the energy requirements shown in Table 21 are presented in the order of decreasing BOD_5 concentration in the effluent. The other parameters (suspended solids, Total P, and Total N) do not necessarily decrease in the same manner because most treatment facilities are designed to remove BOD_5, but in general there is a trend in overall improvement in effluent quality as one reads down the table. As shown in Table 21, there are many systems available to produce an effluent that will satisfy EPA secondary or advanced effluent standards; however, energy requirements for the various systems are varied and can differ by a factor of greater than 10 to produce the same quality effluent.

For purposes of comparison the total energy (electricity plus fuel) for a typical 1 mgd system has been extracted from Table 21 and listed in Table 22 in order of increasing energy requirements. It is quite apparent from Table 22 that increasing energy expenditures do not necessarily produce increasing water quality benefits. The four systems at the top of the list, requiring the least energy, produce effluents comparable to the bottom four that require the most. Three of the top four are land treatment systems, and their adoption will depend on local site conditions. The facultative pond followed by intermittent sand filter and surface discharge to receiving waters is less constrained by local soil and groundwater conditions.

Conventional Versus Land Treatment

A comparison of the energy requirements for a conventional wastewater treatment system consisting of a trickling filter system followed by nitrogen removal, granular media filtration and disinfection with a facultative pond followed by overland flow and disinfection is shown in Figure 13. This comparison is made because of the approximately equivalent quality effluents produced by the two systems (Table 21). The relationships in Figure 13 clearly show that there are significant electricity and fuel savings with the land application system. Similar comparisons for modifications of the two systems can be made by referring to Tables 8, 17, and 20 and selecting combinations to produce equivalent effluents.

Figure 14 shows a comparison of the energy requirements for an activated sludge plant producing a nitrified effluent, followed by

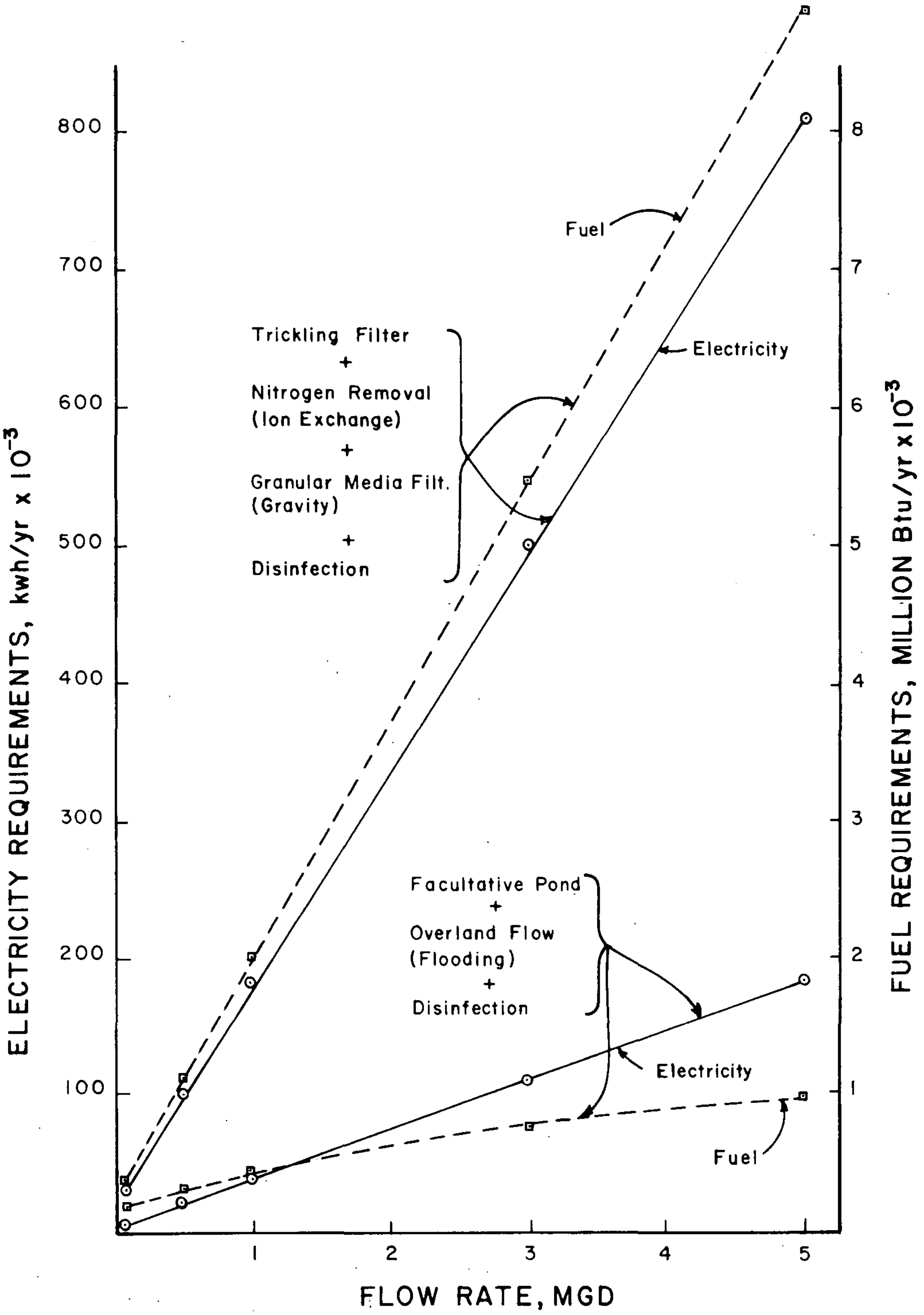

Figure 13. Comparison of energy requirements for trickling filter effluent treated for nitrogen removal and filtered versus facultative pond effluent followed by overland flow treatment.

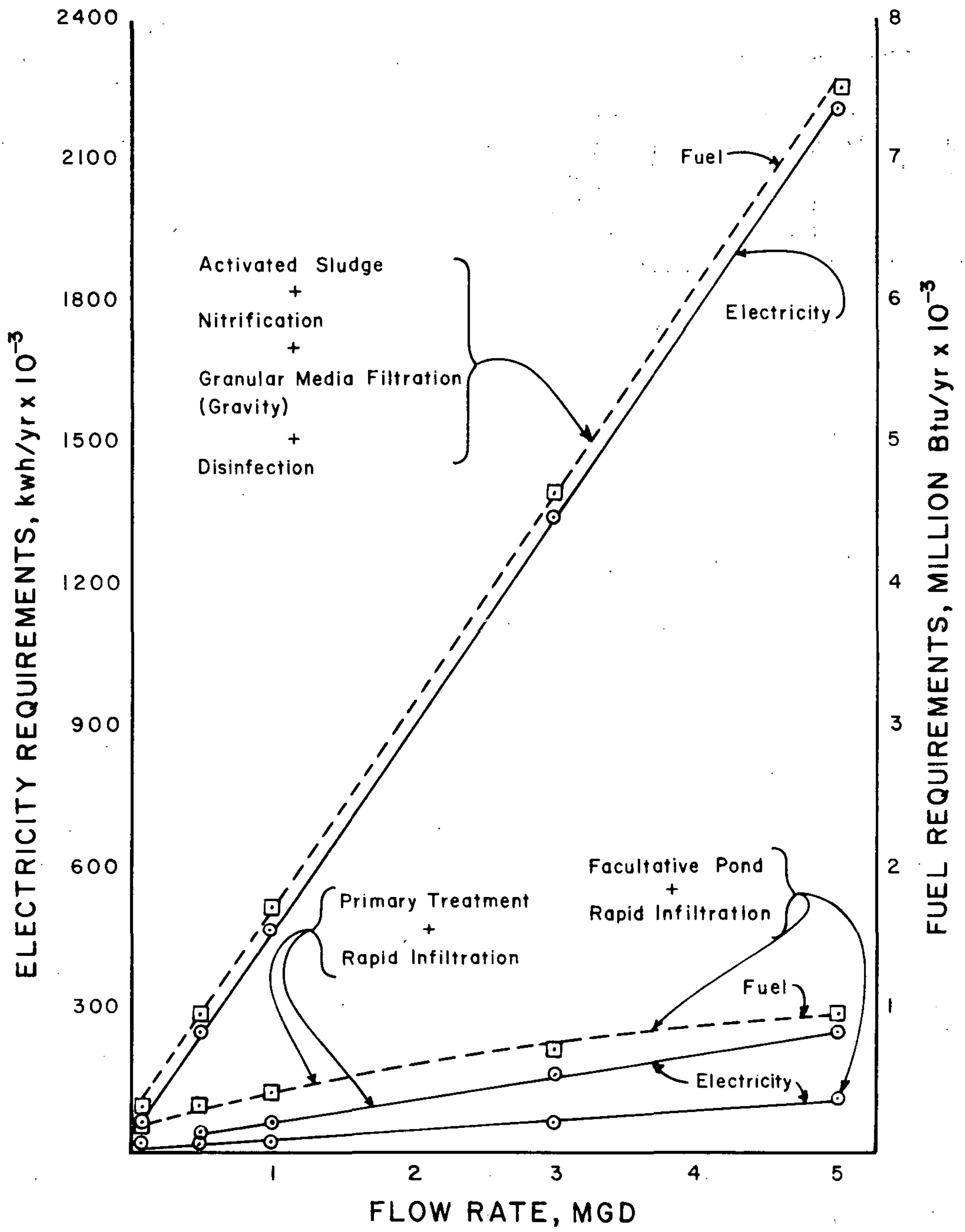

Figure 14. Comparison of energy requirements for activated sludge, nitrification, filtration and disinfection versus facultative pond effluent followed by rapid infiltration and primary treatment followed by rapid infiltration.

Table 22. Total annual energy for typical 1 mgd system (electrical plus fuel, expressed as 1000 kwh/yr).

Treatment system	Effluent quality BOD	SS	P	N	Energy 1000 kwh/yr
Rapid infiltration (facultative pond)	5	1	2	10	159
Overland flow (facultative pond)	5	5	5	3	165
Facultative pond + interm. filter	15	15	-	10	181
Slow rate, ridge + furrow (fac. pond)	1	1	0.1	3	190
Facultative pond + microscreens	30	30	-	15	221
Aerated pond + interm. filter	15	15	-	20	446
Extended aeration + sludge drying	20	20	-	-	623
Extended aeration + interm. filter	15	15	-	-	648
Trickling filter + anaerobic digestion	30	30	-	-	723
RBC + anaerobic digestion	30	30	-	-	734
Trickling filter + gravity filtration	20	10	-	-	745
Trickling filter + N removal + filter	20	10	-	5	769
Activated sludge + anaerobic digestion	20	20	-	-	828
Activated sludge + an. dig. + filter	15	10	-	-	850
Activated sludge + nitrification + filter	15	10	-	-	990
Activated sludge + sludge incineration	20	20	-	-	1,379
Activated sludge + AWT	<10	5	<1	<1	2,532
Physical chemical advanced secondary	30	10	1	-	4,029

granular media filtration and disinfection; a facultative pond followed by rapid infiltration land treatment, and primary treatment followed by rapid infiltration land treatment. The facultative pond system followed by rapid infiltration land treatment is the most energy-efficient wastewater treatment system, but it is closely followed in energy efficiency by the primary treatment and rapid infiltration system. The energy requirements for both of the rapid infiltration land treatment alternatives are less than 10 percent of the energy required for the activated sludge system.

In Figure 15, energy requirements for slow rate land application systems using ridge and furrow and center pivot systems to distribute facultative pond effluent are compared with the energy requirements for an activated sludge plant practicing nitrogen and phosphorus removal, granular media filtration of the effluent, and disinfection prior to discharge. Both the activated sludge and advanced treatment system and the facultative pond and slow rate systems produce approximately equivalent quality effluents. The ridge and furrow flooding technique of land treatment requires less than 10 percent of the energy required by the advanced treatment scheme. Utilizing a center pivot mechanism to distribute the facultative pond effluent increases the energy requirements by a

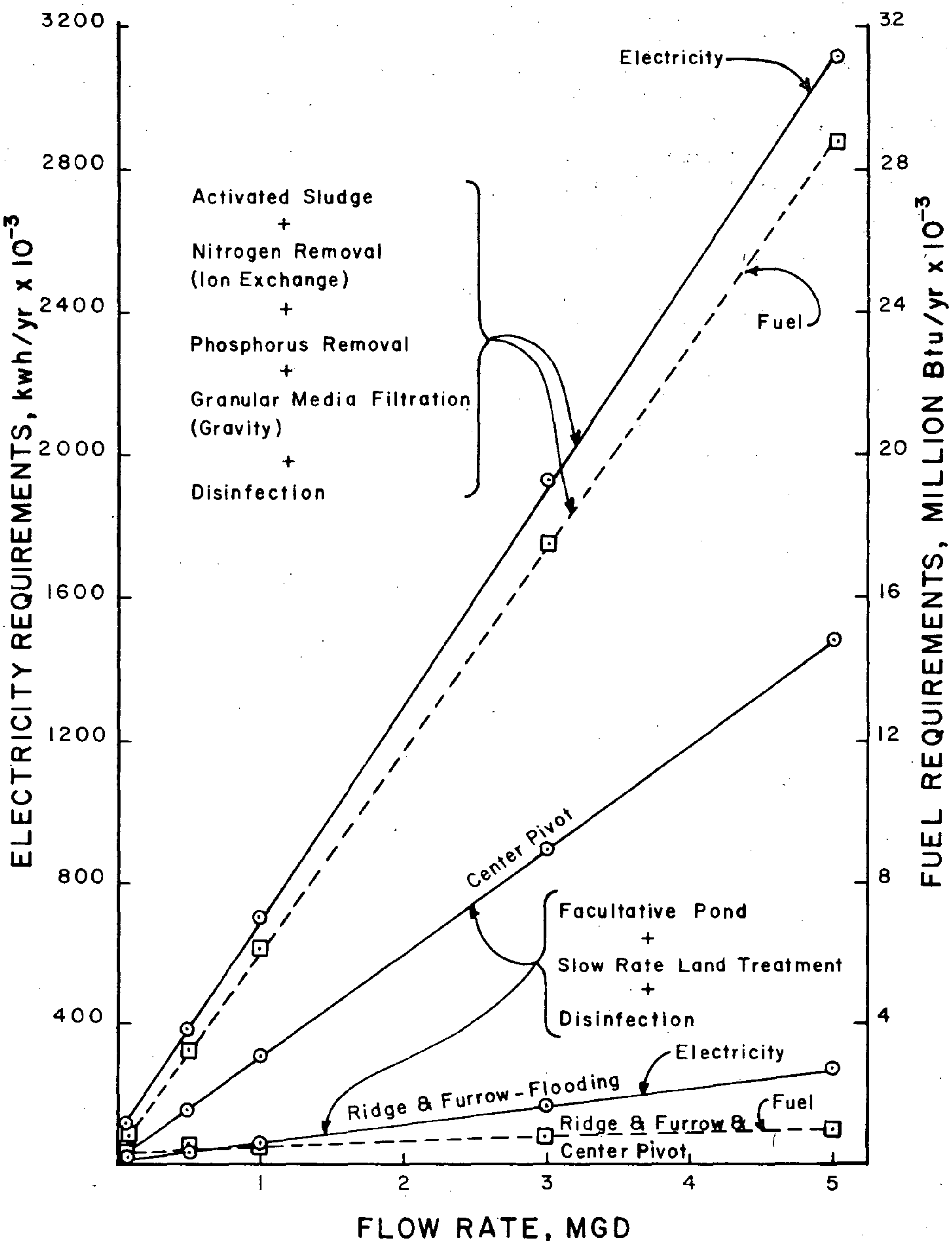

Figure 15. Comparison of energy requirements for secondary treatment followed by advanced treatment versus facultative pond effluent followed by slow rate land treatment.

factor of five compared with the ridge and furrow flooding technique, but the energy requirements for the center pivot system are less than one-half the energy requirements for the advanced treatment system.

In an energy conscious environment, the land application techniques of treating wastewater have a distinct advantage over the more conventional wastewater treatment systems. When land is available at a reasonable cost, the lower energy requirements for land application systems will likely result in a more cost effective as well as more energy effective system of wastewater treatment.

CONCLUSIONS

Based upon the results of the analyses presented in this report, the following conclusions are made.

1. With increasing energy costs, energy consumption is assuming a greater proportion of the annual cost of operating wastewater treatment facilities of all sizes, and because of this trend, it is likely that energy costs will become the predominant factor in the selection of cost-effective small-flow wastewater treatment systems.

2. Small-flow wastewater treatment systems are frequently designed to minimize operation and maintenance, and as energy costs increase, design engineers will tend to select low-energy-consuming systems.

3. Low-energy consuming wastewater treatment systems are generally easier to operate and maintain than energy intensive systems, making the low-energy-consuming systems even more attractive because of the desire to minimize highly skilled operation at small facilities.

4. Where suitable land and groundwater conditions exist, a facultative pond followed by rapid infiltration is the most energy-efficient system described in this report.

5. When surface discharge is necessary and impermeable soils exist, a facultative pond followed by overland flow is the second most energy-efficient system described in this report.

6. Facultative ponds, followed by slow or intermittent sand filters, are the third most energy-efficient systems discussed, and are not limited by local soil or groundwater conditions.

7. Physical-chemical advanced secondary treatment systems utilize the most energy of the conventional methods of producing an effluent meeting the federal secondary effluent standard of 30 mg/1 of BOD_5 and suspended solids.

8. Slow rate land application systems following facultative ponds are more energy efficient than most forms of mechanical secondary treatment systems, while also providing benefits of nutrient removal, recovery and reuse.

9. Advanced physical-chemical treatment following conventional secondary treatment consumes approximately 13 times as much electrical energy and 26 times as much fuel as slow rate land treatment to produce an equivalent effluent.

10. Land application wastewater treatment systems following storage ponds (aerated or facultative), preliminary treatment (bar screens, comminutors, and grit removal), or primary treatment are by far the most energy-efficient systems capable of producing secondary effluent quality or better.

11. This study did not consider the energy requirements for production of all materials consumed in the treatment process, but it is not believed that inclusion of such factors would significantly change the relative ranking of the systems discussed. Such inclusion would rather make the differences between simple biological processes and mechanical systems even more dramatic.

APPENDIX A

EQUATIONS DESCRIBING ENERGY REQUIREMENTS

Figure Number From EPA 430/9-77-011[a]	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-1	Raw Sewage Pumping (Constant Speed) $Y = 197{,}000\,X^{0.93}$ TDH = 100 ft $Y = 123{,}000\,X^{0.93}$ TDH = 60 ft $Y = 61{,}100\,X^{0.93}$ TDH = 30 ft $Y = 19{,}400\,X^{0.93}$ TDH = 10 ft $Y = 9{,}660\,X^{0.93}$ TDH = 5 ft Y = Electrical Energy Required, kwh/yr X = Flow, mgd	Design Assumptions: Effeciencies for typical centrifugal pumps (varies with flow) Variable level wet well TDH is total dynamic head Type of Energy Required: Electrical
3-2	Raw Sewage Pumping (Variable Speed) $Y = 69{,}000\,X^{0.94}$ TDH = 30 ft $Y = 24{,}100\,X^{0.94}$ TDH = 10 ft $Y = 10{,}800\,X^{0.96}$ TDH = 5 ft Y = Electrical Energy Required, kwh/yr X = Flow, mgd	Design Assumptions: Efficiencies for typical centrifugal pumps (varies with flow) Wound rotar variable speed Variable level wet well Type of Energy Required: Electrical
3-3	Raw Sewage Pumping (Variable Speed) $Y = 229{,}000\,X^{0.94}$ TDH = 100 ft $Y = 152{,}000\,X^{0.95}$ TDH = 60 ft Y = Electrical Energy Required, kwh/yr X = Flow, mgd	Design Assumptions: Efficiencies for typical centrifugal pumps (varies with flow) Wound rotor variable speed Varible level wet well Type of Energy Required: Electrical
3-4	Lime Sludge Pumping $\log Y = 3.4788 + 0.7475\,(\log X) + 0.1906\,(\log X)^2 - 0.0101\,(\log X)^3$ - Raw Sewage, Low Lime $\log Y = 3.4448 + 0.7273\,(\log X) + 0.1714\,(\log X)^2 - 0.0515\,(\log X)^3$ - Raw Sewage, High Lime $\log Y = 3.3983 + 0.7173\,(\log X) + 0.1872\,(\log X)^2 - 0.0532\,(\log X)^3$ - Secondary Effluent, Low Lime $\log Y = 3.4676 + 0.7619\,(\log X) + 0.1842\,(\log X)^2 - 0.0614\,(\log X)^3$ - Secondary Effluent, High Lime Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-5	Alum Sludge Pumping $Y = 4{,}000\,X^{0.95}$ (Secondary Effluent) $Y = 6{,}330\,X^{0.96}$ (Raw Sewage) Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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

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[a] See Wesner et al., 1978.

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-6	Ferric Chloride Sludge Pumping $\log Y = 3.6192 + 0.8308 (\log X) + 0.1364 (\log X)^2 - 0.0356 (\log X)^3$ – Secondary Effluent $\log Y = 3.6051 + 0.8078 (\log X) + 0.1301 (\log X)^2 - 0.0047 (\log X)^3$ – Raw Sewage Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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) = 2% Sludge concentration (tertiary) = 1% Operating Parameters: Ferric Chloride addition = 85 mg/l Type of Energy Required: Electrical
3-7	Mechanically Cleaned Screens $\log Y = 3.0803 + 0.1838 (\log X) - 0.0467 (\log X)^2 + 0.0428 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Flow, mgd	Design Assumptions: Normal run times are 10 min total time per hr except 0.1 mgd (5 min) and 100 mgd (15 min) Bar Spacing is 3/4 in Worm gear drive, 50% efficiency Type of Energy Required: Electrical
3-8	Comminutors $\log Y = 3.6704 + 0.3493 (\log X) + 0.0437 (\log X)^2 + 0.0267 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Flow, mgd	Type of Energy Required: Electrical
3-9	Grit Removal (Aerated) $\log Y = 4.1229 + 0.1582 (\log X) + 0.1849 (\log X)^2 + 0.0927 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Water Quality: Removal of 90% of material with a specific gravity of greater than 2.65 Design Assumptions: Grit removal 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
3-10	Grit Removal (non-Aerated) $Y = 530 X^{0.24}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Water Quality: Removal of 90% of material with specific gravity greater than 2.65 Design Assumptions: Grit removal to a holding facility by screw pump Size based on peaking factor of 2 Square tank Smallest volume is 117 cu ft 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
3-11	Pre-Aeration $\log Y = 4.5195 + 0.7785 (\log X) + 0.3618 (\log X)^2 - 0.0496 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumption: Detention time is 20 min Operating Parameter: Air supply is 0.15 cu ft/gal Type of Energy Required: Electrical

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-12	Primary Sedimentation $\log Y = 3.8564 + 0.3781 (\log X) + 0.1880 (\log X)^2 + 0.0213 (\log X)^3$ - Rectangular $\log Y = 3.8339 + 0.3362 (\log X) + 0.0148 (\log X)^2 + 0.0081 (\log X)^3$ - Circular Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-13	Secondary Sedimentation $\log Y = 4.2149 + 0.6998 (\log X) + 0.1184 (\log X)^2 - 0.0660 (\log X)^3$ - Activated Sludge $\log Y = 3.8591 + 0.3349 (\log X) + 0.0735 (\log X)^2 + 0.0238 (\log X)^3$ - Trickling Filter Y = Electricity Required, kwh/yr X = Plant Capacity, mgd	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 system 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
3-14	Chemical Treatment Sedimentation Alum or Ferric Chloride $\log Y = 3.5364 + 0.0743 (\log X) + 0.0290 (\log X)^2 - 0.0144 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Coagulant: alum or ferric chloride Operating Parameter: Overflow rate = 700 gpd/sq ft Type of Energy Required: Electrical
3-15	Chemical Treatment Sedimentation Lime $\log Y = 3.5144 + 0.0172 (\log X) + 0.0942 (\log X)^2 + 0.0905 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Coagulant: Lime Overflow rate, Avg = 1,000 gpd/sq ft Type of Energy Required: Electrical
3-16	High Rate Trickling Filter (Rock Media) $Y = 61,300 X^{0.94}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-17	Low Rate Trickling Filter (Rock Media) $Y = 93{,}600\ X^{0.94}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-18	High Rate Trickling Filter (Plastic Media) $Y = 161{,}000\ X^{0.95}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-19	Super - High Rate Trickling Filter (Plastic Media) $Y = 224{,}000\ X^{0.93}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-20	Rotating Biological Disk $Y = 110{,}000\ X^{1.02}$ - Standard Media $Y = 73{,}000\ X^{1.00}$ - Dense Media Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-21	Activated Biofilter $Y = 210{,}000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-22	Brush Aeration (Oxidation Ditch) $Y = 430{,}000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-23	Oxygen Activated Sludge - Uncovered Reactor With Cryogenic Oxygen Generation $Y = 201,000\ X^{1.00}$ Unstaged, plug flow O_2 activated sludge and complete mix O_2 activated sludge Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-24	Oxygen Activated Sludge - Covered Reactor With Cryogenic Oxygen Generation $Y = 170,000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Type of Energy Required: Electrical
3-25	Oxygen Activated Sludge - Covered Reactor With PSA Oxygen Generation $Y = 230,000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-26	Activated Sludge - Coarse Bubble Diffusion $Y = 290,000\ X^{1.00}$ Conventional activated sludge (complete mix) $Y = 600,000\ X^{1.00}$ Extended aeration $Y = 350,000\ X^{1.00}$ Contact stabilization Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-27	Activated Sludge - Fine Bubble Diffusion $Y = 230,000\ X^{1.00}$ Conventional activated sludge (complete mix) $Y = 440,000\ X^{1.00}$ Extended aeration $Y = 240,000\ X^{1.00}$ Contact stabilization Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 aeration Type of Energy Required: Electrical
3-28	Activated Sludge Treatment - Mechanical Aeration $Y = 160,000\ X^{1.00}$ Conventional activated sludge (complete mix) $Y = 350,000\ X^{1.00}$ Extended aeration $Y = 180,000\ X^{1.00}$ Contact stabilization Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Type of Energy Required: Electrical
3-29	Activated Sludge - Turbine Sparger $Y = 215,000\ X^{1.00}$ Conventional activated sludge (complete mix) $Y = 430,000\ X^{1.00}$ Extended aeration $Y = 250,000\ X^{1.00}$ Contact stabilization Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-30	Activated Sludge - Static Mixer $Y = 250,000\ X^{1.00}$ Conventional activated sludge (complete mix) $Y = 500,000\ X^{1.00}$ Extended aeration $Y = 300,000\ X^{1.00}$ Contact stabilization Y = Electrical Energy Required, kwh/yr X = Plant capacities, mgd	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-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
3-31	Activated Sludge - Jet Diffuser $Y = 170,000\ X^{1.00}$ Conventional activated sludge (complete mix) $Y = 340,000\ X^{1.00}$ Extended aeration $Y = 210,000\ X^{1.00}$ Contact stabilization Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-32	Aerated Ponds $Y = 260,000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 - 1st 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
3-33	Nitrification - Suspended Growth $Y = 180,000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-34	Nitrification, Fixed Film Reactor $Y = 133{,}000\ X^{0.92}$ Recycle = 0.5:1 $Y = 151{,}000\ X^{0.92}$ Recycle = 1:1 $Y = 226{,}000\ X^{0.92}$ Recycle = 2:1 Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-35	Denitrification - Suspended Growth (Overall) (Includes Methanol addition, reaction, sedimentation and sludge recycle) $\log Y = 5.0043 + 0.9495 (\log X) + 0.0248 (\log X)^2 - 0.0332 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 in EPA 430/9-77-011 Denitrification Reactor, Figure 3-36 Reaeration, Figure 3-37 Sedimentation and Sludge Recycle, Figure 3-38 Type of Energy Required: Electrical
3-36	Denitrification - Suspended Growth Reactor $Y = 72{,}500\ X^{0.99}$, Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-37	Denitrification, Aerated Stabilization Reactor $Y = 32{,}000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Detention time = 50 min Mechanical aeration = 1 hp/1000 cu ft Type of Energy Required: Electrical
3-38	Denitrification, Sedimentation and Sludge Recycle $\log Y = 4.1171 + 0.7596 (\log X) + 0.1607 (\log X)^2 - 0.0389 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Surface loading = 700 gpd/sq ft Sludge recycle = 50% @ 15 ft TDH Type of Energy Required: Electrical
3-39	Denitrification - Fixed Film, Pressure $\log Y = 4.4238 + 0.8657 (\log X) + 0.0840 (\log X)^2 + 0.0097 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-40	Denitrification - Fixed Film, Gravity $\log Y = 3.9344 + 0.7310 (\log X) + 0.1803 (\log X)^2 - 0.0453 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-41	Denitrification - Fixed Film, Upflow (Based on Experimental Data) $\log Y = 4.4935 + 0.8695 (\log X) + 0.0864 (\log X)^2 - 0.0012 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-42	Single Stage Carbonaceous, Nitrification, and Denitrification Without Methanol Addition, Pulsed Air $Y = 391{,}000\ X^{0.95}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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)
3-43	Separate Stage Carbonaceous, Nitrification and Denitrification Without Methanol Addition (Based on Experimental Data) $Y = 413{,}000\ X^{0.98}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-44	Single Stage Carbonaceous, Nitrification, and Denitrification Without Methanol Addition - Orbital Plants* (Based on Experimental Data) $Y = 436{,}000\ X^{0.99}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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)
3-45	Lime Feeding $Y = 6{,}700\ X^{0.75}$ Slaked lime, low lime $Y = 11{,}000\ X^{0.75}$ Slaked lime, high lime $Y = 7{,}600\ X^{0.81}$ Quicklime, low lime $Y = 13{,}300\ X^{0.81}$ Quicklime, high lime Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-46	Alum Feeding $\log Y = 3.4969 + 0.2487 (\log X) + 0.2711 (\log X)^2 + 0.1337 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Operating Parameters: Dosage - 150 mg/l as $Al_2(SO_4)3 - 14H_2O$ Type of Energy Required: Electrical
3-47	Ferric Chloride Feeding $\log Y = 3.4586 + 0.3358 (\log X) + 0.2082 (\log X)^2 + 0.0053 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Operating Parameter: Dosage - 85 mg/l as $FeCl_3$ Type of Energy Required: Electrical
3-48	Sulfuric Acid Feeding $\log Y = 3.1523 + 0.0204 (\log X) + 0.0270 (\log X)^2 + 0.0188 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Operating Parameter: Dosage = 450 mg/l (high lime system) Dosage = 225 mg/l (low lime system) Type of Energy Required: Electrical
3-49	Solids Contact Clarification - High Lime, Two Stage Recarbonation (Includes reactor clarifier, high lime feeding, sludge pumping, two stage recarbonation) $\log Y = 5.1077 + 0.8739 (\log X) + 0.1084 (\log X)^2 - 0.0549 (\log X)^3$ - Liquid CO_2 Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and primary effluent. Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 10 Phosphate as P 11.0 1.0 Water Quality: Influent Effluent (Treatment of Pri. Eff.) (mg/l) (mg/l) Suspended Solids 80 10.0 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011. 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
3-50	Solids Contact Clarification, High Lime, Sulfuric Acid Neutralization (Includes reactor clarifier, high lime feed, chemical sludge pumping, sulfuric acid feed) $\log Y = 4.5932 + 0.6333 (\log X) + 0.2024 (\log X)^2 \; 0.0208 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both primary and secondary effluents Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 10 Phosphate as P 11.0 1.0 Water Quality: Influent Effluent (Treatment of Sec. Eff.) (mg/l) (mg/l) Suspended Solids 30 10 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: Lime Feeding, Figure 3-45; Reactor Clarifier, 3-53; Sludge Pumping, 3-4; Sulfuric Acid Feeding, 3-48 Type of Energy Required: Electrical
3-51	Solids Contact Clarification Single Stage Low Lime With Sulfuric Acid Neutralization (Includes reactor clarifier, low lime feeding, sludge pumping, sulfuric acid feeding) $\log Y = 4.5447 + 0.6844 (\log X) + 0.1365 (\log X)^2 - 0.0461 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and primary effluents Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 20 Phosphate as P 11.0 2.0 Water Quality: Influent Effluent (Treatment of Pri. Eff.) (mg/l) (mg/l) Suspended Solids 30 20 Phosphate as P 11.0 2.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: Lime Feeding, Figure 3-45; Reactor Clarifier, 3-53; Sludge Pumping, 3-4; Sulfuric Acid Feeding, 3-48 Type of Energy Required: Electrical

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-52	Solids Contact Clarification, Alum or Ferric Chloride Addition (Includes chemical feeding, reactor clarifier, sludge pumping) $\log Y = 4.6237 + 0.6983 (\log X) + 0.1477 (\log X)^2 - 0.0470 (\log X)^3$ - Alum $\log Y = 4.5496 + 0.6894 (\log X) + 0.1645 (\log X)^2 - 0.0559 (\log X)^3$ - Ferric Chloride Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and primary effluent) Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 30 Phosphate as P 11.0 1.0 Water Quality: Influent Effluent (Treatment of Pri. Effl.) (mg/l) (mg/l) Suspended Solids 80 10 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: 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
3-53	Reactor Clarifier $\log Y = 4.3817 + 0.7223 (\log X) + 0.0947 (\log X)^2 - 0.0027 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-54	Separate Rapid Mixing, Flocculation, Sedimentation High Lime, Two Stage Recarbonation $\log Y = 5.0961 + 0.9484 (\log X) + 0.1979 (\log X)^2 - 0.0101 (\log X)^3$ - Liquid CO_2 Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and secondary effluent Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 10 Phosphate as P 11.0 1.0 Water Quality: Influent Effluent (Treatment of Sec. Eff.) (mg/l) (mg/l) Suspended Solids 30 10.0 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: 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
3-55	Separate Rapid Mixing, Flocculation, Sedimentation Single Stage High Lime, Neutralization With Sulfuric Acid $\log Y = 4.5919 + 0.6683 (\log X) + 0.1926 (\log X)^2 - 0.0432 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and secondary effluent Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 10 Phosphate as P 11.0 1.0 Water Quality: Influent Effluent (Treatment of Sec. Eff.) (mg/l) (mg/l) Suspended Solids 30 10 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: 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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-62	Microscreens $Y = 65,000\ X^{0.79}$ 23μ Screen $Y = 42,700\ X^{0.79}$ 35μ Screen Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Equation for 35μ screen applicable above 0.2 mgd. For flow rates <0.2 mgd energy requirements = 11,000 kwh/yr. Equation for 23μ screen applicable above 0.1 mgd. For flow rates <0.1 mgd energy requirements = 11,000 kwh/yr.
3-63	Pressure and Gravity Filtration $Y = 31\ X^{1.01}$ Pressure Filters $Y = 22\ X^{1.00}$ Gravity Filters Y = Electrical Energy Required, thousand kwh/yr X = Plant Capacity, mgd	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: 20 ft TDH Filtration rate (both filters): 5 gpm/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 back wash Surface wash pumping (both filters): 5 min. per back wash Type of Energy Required: Electrical
3-64	Granular Carbon Adsorption - Downflow Pressurized Contractor $Y = 74,000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 (average) Operating Parameters: Operate to 20 ft. head loss building before backwashing Backwash pumping: 15 min per backwash Type of Energy Required: Electrical
3-65	Granular Carbon Adsorption - Downflow Gravity Contactor $Y = 31,000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-56	Separate Rapid Mixing, Flocculation, Sedimentation Low Lime, Neutralization With Sulfuric Acid $\log Y = 4.4521 + 0.7260 (\log X) + 0.2292 (\log X)^2 - 0.0022 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and secondary effluent Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 10 Phosphate as P 11.0 1.0 Water Quality Influent Effluent (Treatment of Sec. Eff.) (mg/l) (mg/l) Suspended Solids 30 10 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: 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
3-57	Separate Rapid Mixing, Flocculation, Sedimentation Alum or Ferric Chloride Addition $\log Y = 4.4096 + 0.6351 (\log X) + 0.2349 (\log X)^2 - 0.0169 (\log X)^3$ - Alum $\log Y = 4.3395 + 0.6226 (\log X) + 0.2215 (\log X)^2 - 0.0133 (\log X)^3$ - Ferric Chloride Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	This curve is valid for chemical treatment of both raw sewage and secondary effluent Water Quality: Influent Effluent (Treatment of Raw Sewage) (mg/l) (mg/l) Suspended Solids 250 10 Phosphate as P 11.0 1.0 Water Quality: Influent Effluent (Treatment of Sec. Eff.) (mg/l) (mg/l) Suspended Solids 30 10.0 Phosphate as P 11.0 1.0 Design Assumptions and Operating Parameters are shown on the following curves in EPA 430/9-77-011: 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
3-58	Rapid Mixing $Y = 3{,}900\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Detention time = 30 seconds $G = 600\ \text{sec}^{-1}$ Temperature = 15°C Coagulant: lime or alum or ferric chloride Type of Energy Required: Electrical
3-59	Flocculation $Y = 9{,}840\ X^{0.98}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Detention time = 30 minutes $G = 110\ \text{sec}^{-1}$ Temperature = 15°C Coagulant: lime or alum or ferric chloride Type of Energy Required: Electrical
3-60	Recarbonation - Solution Feed of Liquid CO_2 Source $Y = 89{,}000\ X^{1.03}$ Low lime $Y = 141{,}000\ X^{1.03}$ High lime Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-61	Recarbonation - Stack Gas as CO_2 Source $Y = 50{,}000\ X^{1.00}$ Low lime $Y = 170{,}000\ X^{1.00}$ High lime Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-66	Granular Carbon Adsorption - Upflow Expanded Bed $Y = 62{,}000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-67	Granular Activated Carbon Regeneration $Y = 38{,}000\ X^{1.00}$ Clarified raw wastewater Electricity $Y = 4{,}000\ X^{1.00}$ Clarified raw wastewater Fuel - million Btu/yr $Y = 10{,}000\ X^{1.00}$ Clarified secondary effluent Electricity $Y = 1{,}100\ X^{1.00}$ Clarified secondary effluent Fuel - million Btu/yr Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-68	Ion Exchange for Ammonia Removal, Gravity and Pressure $Y = 310{,}000\ X^{1.00}$ Pressure $Y = 220{,}000\ X^{1.00}$ Gravity Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-69	Ion Exchange For Ammonia Removal - Regeneration $Y = 2{,}000\ X^{1.00}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-70	Ion Exchange for Ammonia Removal - Regenerant Renewal by Air Stripping $Y = 120{,}000\ X^{1.00}$ with NH_3 recovery $Y = 65{,}000\ X^{1.00}$ without NH_3 recovery Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 adsorption tower with H_2SO_4 Type of Energy Required: Electrical
3-71	Ion Exchange for Ammonia Removal, Regenerant Renewal by Steam Stripping $Y = 3{,}180\ X^{1.04}$ Electricity $Y = 6{,}150\ X^{1.03}$ Fuel-million Btu/yr Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-72	Ammonia Stripping $Y = 82,200\ X^{1.01}$ Pumping $Y = 510,000\ X^{1.01}$ Fans $Y = 610,000\ X^{1.01}$ Total Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-73	Breakpoint Chlorination With Dechlorination $\log Y = 5.1423 + 0.3092\ (\log X) + 0.1369\ (\log X)^2 + 0.0458\ (\log X)^3$ Dechlorination with Activated Carbon $\log Y = 5.0593 + 0.2396\ (\log X) + 0.0844\ (\log X)^2 + 0.0084\ (\log X)^3$ Dechlorination with Sulfur Dioxide Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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: Activated carbon pumping, TDH = 10 ft Type of Energy Required: Electrical
3-74	Chlorination and Dechlorination for Disinfection $\log Y = 4.0108 + 0.9289\ (\log X) + 0.0868\ (\log X)^2 + 0.0065\ (\log X)^3$ Chlorination with Dechlorination $\log Y = 3.9698 + 1.0172\ (\log X) + 0.0746\ (\log X)^2 - 0.0658\ (\log X)^3$ Chlorination Without Dechlorination Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Water Quality: Influent Effluent BOD_5, mg/l 20 20 Suspended Solids, mg/l 20 20 Coliform, no./100 ml >1000 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
3-75	Chlorine Dioxide Generation and Feeding $\log Y = 3.4604 + 0.3656\ (\log X) + 0.2171\ (\log X)^2 + 0.0541\ (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-76	Ozone Disinfection $Y = 150,000\ X^{1.00}$ Air Feed $Y = 57,000\ X^{1.00}$ Oxygen Feed Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-77	Ion Exchange for Demineralization, Gravity and Pressure $Y = 90,000\ X^{1.00}$ Gravity $Y = 120,000\ X^{1.00}$ Pressure Y = Electrical Energy Required, kwh/yr X Plant Capacity, mgd	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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-78	Reverse Osmosis $Y = 2{,}850{,}000\ X^{0.95}$ Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	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
3-79	Land Treatment by Spray Irrigation (Modified) $Y = 270{,}000\ X^{1.00}$ Center Pivot $Y = 164{,}000\ X^{1.00}$ Solid Set Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Irrigation season is 250 days/yr Center pivot, TDH = 196 ft Solid set, TDH = 175 ft Type of Energy Required: Electrical
3-80	Land Treatment by Ridge and Furrow Irrigation and Flooding (Modified) $Y = 20\ X^{1.00}$ Ridge and Furrow Fuel, million Btu/yr $Y = 16{,}000\ X^{1.00}$ Flooding Power $Y = 12{,}000\ X^{1.00}$ Ridge and Furrow Power Y = Electrical Energy Required, kwh/yr except for fuel X = Plant Capacity, mgd	Design Assumptions: Irrigation season is 250 days/yr Power includes runoff return pumping Fuel for annual leveling and ridge and furrow replacement Type of Energy Required: Electrical and Diesel Fuel
3-81	Infiltration/Percolation and Overland Flow by Flooding (Modified) $Y = 9{,}200\ X^{1.00}$ Overland Flow $Y = 3{,}000\ X^{1.02}$ Rapid Infiltration Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Infiltration/percolation, TDH = 5 ft Overland flow, TDH = 10 ft Disposal time is 250 days/yr for Overland Flow Disposal time is 365 days for Rapid Infiltration Type of Energy Required: Electrical
3-82	Infiltration/Percolation and Overland Flow by Solid Set Sprinklers (Modified) $Y = 170{,}000\ X^{1.00}$ Overland Flow $Y = 75{,}000\ X^{1.00}$ Rapid Infiltration Y = Electrical Energy Required, kwh/yr X = Plant Capacity, mgd	Design Assumptions: Infiltration/percolation spray, TDH = 115 ft Overland flow spray, TDH = 175 ft Disposal time is 250 days/yr for Overland Flow Disposal time is 365 days/yr for Rapid Infiltration Type of Energy Required: Electrical
3-83	Wastewater Treatment Plant Building Heating Requirements $\log Y = 2.6362 + 0.4562\ (\log X) + 0.0795\ (\log X)^2 + 0.0026\ (\log X)^3$ Minneapolis $\log Y = 2.4485 + 0.4498\ (\log X) + 0.0483\ (\log X)^2 - 0.0345\ (\log X)^3$ New York $\log Y = 1.8742 + 0.4162\ (\log X) + 0.0732\ (\log X)^2 - 0.0118\ (\log X)^3$ Los Angeles Y = Building Heating Requirements, million Btu/yr X = Plant Capacity, mgd	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 in EPA 430/9-77-011

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-84	Wastewater Treatment Plant Building Cooling Requirements $\log Y = 4.0520 + 0.5279 (\log X) + 0.0856 (\log X)^2 - 0.0168 (\log X)^3$ Miami $\log Y = 2.8103 + 0.5304 (\log X) + 0.1114 (\log X)^2 - 0.0044 (\log X)^3$ Minneapolis $\log Y = 2.9050 + 0.5226 (\log X) + 0.0692 (\log X)^2 - 0.0325 (\log X)^3$ New York Y = Building Cooling Requirements, kwh/yr X = Plant Capacity, mgd	Note: See chapter 5, pages 5-8 to 5-10 in EPA 430/9-77-011
3-85	Gravity Thickening $Y = 6.72 X^{0.95}$ Lime Sludge and Other Sludge for Thickener and <2,200 ft^2 $Y = 174 X^{0.53}$ Other Sludge from 2,200 to 9,000 ft^2 of Thickener Area $Y = 1.70 X^{1.03}$ Other Sludge for Thickener Area >9,000 ft^2 Y = Electrical Energy Required, kwh/hr X = Thickener Area, sq ft	See Table 3-4 in EPA 430/9-77-011 for design assumptions and operating parameters. Lime curve based on tertiary system at 60 lb/sq ft/day Type of Energy Required: Electrical
3-86	Air Flotation Thickening $Y = 1,730 X^{0.87}$ Y = Electrical Energy Required, kwh/yr X = Surface Area, sq ft	See Table 3-5 for design assumptions and operating parameters in EPA 430/9-77-011. 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
3-87	Basket Centrifuge $Y = 1,070 X^{0.72}$ <800 ft^3/day of dewatered solids $Y = 160 X^{1.00}$ >800 ft^3/day of dewatered solids Y = Electrical Energy Required, kwh/yr X = Dewatered Solids Capacity, cu ft/day	Design Assumptions: Operating hp is .375 times rated hp See Table 3-6 for specific sludge characteristics in EPA 430/9-77-011. Multiple units required above 800 cu ft/day capacity 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
3-88	Elutriation $Y = 1,660 X^{0.94}$ Digested Primary $Y = 3,100 X^{0.97}$ Digested Primary + Waste Activated Sludge and Digested Primary + Waste Activated Sludges with $FeCl_3$ Y = Electrical Energy Required, kwh/yr X = Sludge Quantity, ton/day (dry solids)	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 and settling tanks Wash water to sludge ratio = 4:1 Type of Energy Required: Electrical
3-89	Heat Treatment $\log Y = 1.5710 + 0.3158 (\log X) + 0.1754 (\log X) + 0.0914 (\log X)^3$ Low Oxidation (Air Addition) $\log Y = 1.4801 + 0.1952 (\log X) + 2.2864 (\log X)^2 + 0.2512 (\log X)^3$ Thermal Conditioning (No Air) Y = Electrical Energy Required, thousand kwh/yr X = Thermal Treatment Capacity, gpm	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 in EPA 430/9-77-011 Curve includes: Pressurization pumps Sludge grinders Post-thickener drives Boiler feed pumps Air compressors Type of Energy Required: Electrical

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-90	Heat Treatment - Without Air Addition $Y = 500\ X^{1.00}$ Y = Fuel Required, million Btu/yr X = Thermal Treatment Capacity, gpm	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 of Chapter 5 in EPA 430/9-77-011 Curve includes: Fuel to produce steam necessary to raise reactor contents to operating temperature Type of Energy Required: Fuel
3-91	Heat Treatment - With Air Addition $Y = 260\ X^{1.00}$ Primary + W.A.S. $Y = 320\ X^{1.00}$ W.A.S. $Y = 370\ X^{1.00}$ Primary (+ $FeCl_3$) + W.A.S. and Primary + W.A.S. (+$FeCl_3$) $Y = 420\ X^{1.00}$ Tertiary Alum Y = Fuel Required, million Btu/yr X = Thermal Treatment Capacity, gpm	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 of Chapter 5 in EPA 430/9-77-011 Curve includes: Fuel to produce steam necessary to raise reactor contents to operating temperature Type of Energy Required: Fuel
3-92	Heat Treatment - With Air Addition $Y = 280\ X^{1.00}$ Primary $Y = 310\ X^{1.00}$ Dig. Primary $Y = 360\ X^{1.00}$ Dig. Primary + W.A.S. and Primary + W.A.S. (+$FeCl_3$) $Y = 400\ X^{1.00}$ Dig. Primary + W.A.S. (+$FeCl_3$) Y = Fuel Required, million Btu/yr X = Thermal Treatment Capacity, gpm	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 of Chapter 5 in EPA 430/9-77-011 Curve includes: Fuel to produce steam necessary to raise reactor contents to operating temperature Type of Energy Required: Fuel
3-93	Chemical Addition (Digested Sludges) $\log Y = 3.6422 + 0.3834 (\log X) + 0.2290 (\log X)^2$ Digested Primary $\log Y = 3.5314 + 0.3664 (\log X) + 0.2808 (\log X)^2$ $0.1057 (\log X)^3$ Digested Primary + Waste Activated and Digested Primary + Waste Activated with $FeCl_3$ Y = Electrical Energy, kwh/yr X = Sludge Quantity, ton/day (dry solids)	Design Assumptions: See Table 3-8 preceding Figure 3-96 for chemical quantities in EPA 430/9-77-01 Pumping head = 10 ft TDH Curves include: Chemical feeding and handling Sludge pumping Sludge-chemical mixing Type of Energy Required: Electrical
3-94	Chemical Addition (Undigested Sludges) $\log Y = 3.5641 + 0.3108 (\log X) + 0.2344 (\log X)^2$ $+ 0.0007 (\log X)^3$ Waste Activated $\log Y = 3.5174 + 0.2951 (\log X) + 0.3228 (\log X)^2$ $- 0.1381 (\log X)^3$ Primary + Waste Activated $\log Y = 3.4817 + 0.2803 (\log X) + 0.2350 (\log X)^2$ $+ 0.0292 (\log X)^3$ Primary Y = Electrical Energy, kwh/yr X = Sludge Quantity, ton/day (dry solids)	Design Assumptions: Pumping head = 10 ft TDH Curves Include: Chemical feeding and handling Sludge pumping Sludge-chemical mixing Type of Energy Required: Electrical
3-95	Vacuum Filtration $\log Y = 4.1245 + 0.0840 (\log X) + 0.2186 (\log X)^2$ $- 0.0177 (\log X)^3$ Y = Electrical Energy Required, kwh/yr X = Vacuum Filtration Area, sq ft	See Table 3-7 for design assumptions in EPA 430/9-77-011 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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-96	Filter Pressing $Y = 6{,}980\ X^{0.58}$ Influent solids = 8% $Y = 7{,}810\ X^{0.60}$ Influent solids = 6% $Y = 6{,}710\ X^{0.71}$ Influent solids = 4% Y = Electrical Energy Required, kwh/yr X = Filter Press Volume, cu ft	See Table 3-8 for design assumptions in EPA 430/9-77-011 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
3-97	Centrifuging $Y = 4{,}000\ X^{1.00}$ Lime sludge classification $Y = 1{,}940\ X^{1.02}$ Dewatering Y = Electrical Energy Required, kwh/yr X = Flow, gpm	Operating Conditions: Power consumption based on continuous operation Dewatering accomplished with low speed centrifuge, $G = 700\ \text{sec}^{-1}$ 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
3-98	Sand Drying Beds $\log Y = 2.1785 + 0.9543(\log X) + 0.0285\ (\log X)^2 + 0.0020\ (\log X)^3$ Power Consumption $Y = 4.0\ X^{1.02}$ Fuel Consumption @ 7.5% solids pumped, million Btu/yr $Y = 2.1\ X^{1.02}$ Fuel Consumption @ 5.0% solids pumped, million Btu/yr $Y = 1.2\ X^{1.00}$ Fuel Consumption @ 2.5% solids pumped, million Btu/yr $Y = 0.42\ X^{1.00}$ Fuel Consumption @ 1.0% solids pumped, million Btu/yr Y = Fuel Required, million Btu/yr except Power Consumption Which is kwh/yr X = Sludge Quantity, gpm	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 in EPA 430/9-77-011 Type of Energy Required: Electrical and Fuel
3-99	Sludge Pumping $\log Y = 2.6558 + 1.4926\ (\log X) - 0.2455\ (\log X)^2 + 0.0065\ (\log X)^3$ Y = Electrical Energy Required, kwh/yr per mile X = Annual Sludge Volume, mil gal	Design Assumptions: 4% solids maximum (Dilute to 4% if greater) 4 inch pipeline minimum, design velocity 3 fps 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 in EPA 430/9-77-011 Type of Energy Required: Electrical
3-100	Dewatered Sludge Haul by Truck $Y = 7.0\ X^{1.00}$ Truck Capacity = 10 yd^3 $Y = 4.6\ X^{1.00}$ Truck Capacity = 15 yd^3 $Y = 2.6\ X^{1.00}$ Truck Capacity = 30 yd^3 Y = Fuel Required, million Btu/one way mile/yr X = Annual Sludge Volume, 1,000 cu yd	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 in EPA 430/9-77-011 Type of Energy Required: #2 Diesel fuel

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-101	Liquid Sludge Hauling by Barge $Y = 5.6\ X^{0.97}$ Barge Capacity = 2 MG $Y = 11.0\ X^{0.97}$ Barge Capacity = 1 MG $Y = 12.0\ X^{0.97}$ Barge Capacity = 0.85 MG $Y = 14.7\ X^{0.97}$ Barge Capacity = 0.5 MG $Y = 26.9\ X^{0.97}$ Barge Capacity = 0.3 MG Y = Fuel Required, million Btu/one way mile/yr X = Annual Sludge Volume, 1,000 cu yd	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 in EPA 430/9-77-011 Type of Energy Required: Marine diesel fuel
3-102	Liquid Sludge Hauling by Truck $Y = 14.9\ X^{0.98}$ Truck Capacity = 5,500 gallons $Y = 25.3\ X^{1.01}$ Truck Capacity = 2,500 gallons $Y = 53.2\ X^{1.02}$ Truck Capacity = 1,200 gallons Y = Fuel Required, million Btu/one way mile/yr X = Annual Sludge Volume, mil gal	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 in EPA 430/9-77-011 Type of Energy Required: #2 Diesel fuel
3-103	Utilization of Liquid Sludge $Y = 180\ X^{1.00}$ Land spreading Y = Fuel Required, million Btu/yr X = Annual Sludge Volume, mil gal	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 in EPA 430/9-77-011 Type of Energy Required: #2 Diesel fuel
3-104	Utilization of Dewatered Sludge $Y = 18\ X^{1.00}$ Landfill $Y = 71\ X^{1.00}$ Land Spreading Y = Fuel Required, million Btu/yr X = Annual Sludge Volume, 1,000 cu yd	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 in EPA 430/9-77-011 Type of Energy Required: #2 Diesel fuel
3-105	Mixing - Anaerobic Digester - High Rate $Y = 1.8\ X^{1.00}$ Mechanical Mixing - 1/4 HP/1000 ft^3 $Y = 3.3\ X^{1.00}$ Mechanical Mixing - 1/2 HP/1000 ft^3 $Y = 6.8\ X^{1.00}$ Mechanical Mixing - 1 HP/1000 ft^3 $\log Y = 3.8094 + 0.1464 (\log X) - 0.0721 (\log X)^2 + 0.0209 (\log X)^3$ Gas Mixing - 5 scfm/1000 ft^3 $\log Y = 12.6028 - 6.3342 (\log X) + 1.5075 (\log X)^2 - 0.1036 (\log X)^3$ Gas Mixing - 10 scfm/1000 ft^3 $\log Y = 6.3722 - 1.9562 (\log X) + 0.5249 (\log X)^2 - 0.0301 (\log X)^3$ Gas Mixing - 20 scfm/1000 ft^3 Y = Electrical Energy Required, kwh/yr X = Digester Volume, cu ft	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 in EPA 430/9-77-011.

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-106	Thermophilic Anaerobic Digestion $Y = 0.7\ X^{1.00}$ Primary + High Lime Sludge $Y = 0.8\ X^{1.00}$ Primary + (W.A.S. + $FeCl_3$) $Y = 0.9\ X^{1.00}$ Primary + $FeCl_3$, Primary + W.A.S., and (Primary + $FeCl_3$) + W.A.S. $Y = 1.03\ X^{1.01}$ Primary, and Primary + Low Lime $Y = 1.19\ X^{1.01}$ Waste Activated Sludge Y = Fuel Required, million Btu/yr X = Solids, lb/day	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 103°F See Figure 3-105 for mixing energy in EPA 430/9-77-011 See Table 3-3 for sludge characteristics in EPA 430/9-77-011 Type of Energy Required: Fuel or Natural Gas
3-107	Aerobic Digestion $Y = 157\ X^{1.01}$ Mechanical Aeration - Detention Time = 8 days $Y = 200\ X^{1.00}$ Mechanical Aeration - Detention Time = 16 days $Y = 230\ X^{1.00}$ Mechanical Aeration - Detention Time = 24 days $Y = 300\ X^{1.00}$ Diffused Air - Detention Time = 8 days $Y = 360\ X^{1.00}$ Diffused Air - Detention Time = 16 days $Y = 400\ X^{1.00}$ Diffused Air - Detention Time = 24 days Y = Electrical Energy Required, kwh/yr X = BOD_{IN} - lb/day	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
3-108	Thermophilic Aerobic Digestion $Y = 125\ X^{1.00}$ 200 lb $BOD_5/1000\ ft^3$/day $Y = 157\ X^{1.02}$ 100 lb $BOD_5/1000\ ft^3$/day Y = Electrical Energy Required, kwh/yr X = BOD_{IN} - lb/day	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
3-109	Chlorine Stabilization of Sludge $Y = 2,190\ X^{0.96}$ Y = Electrical Energy Required, kwh/yr X = Sludge Flow, gpm	Design Assumptions: Operating pressure = 35 psi Recirculation ratio = 5:1 Chlorine feed = 4 lbs/1,000 gal Type of Energy Required: Electrical
3-110	Lime Stabilization of Sludges $Y = 7.50\ X^{0.72}$ Lime Dosage = 200 lb/ton as $Ca(OH)_2$ $Y = 12.25\ X^{0.70}$ Lime Dosage = 400 lb/ton as $Ca(OH)_2$ $Y = 17.97\ X^{0.70}$ Lime Dosage = 800 lb/ton as $Ca(OH)_2$ $Y = 30.71\ X^{0.68}$ Lime Dosage = 1,000 lb/ton as $Ca(OH)_2$ Y = Electrical Energy Required, kwh/yr X = Sludge Quantity, lb dry solids/day	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 in EPA 430/9-77-011 if pumping required) Type of Energy Required: Electrical
3-111	Multiple Hearth Furnace Incineration (See Figure 3-112 in EPA 430/9-77-011 for Start-up Fuel) $Y = 14.00\ X^{1.00}$ Primary Sludge $Y = 16.00\ X^{1.00}$ Primary + Low Lime Sludge $Y = 22.30\ X^{1.00}$ Digested Primary Sludge $Y = 40.00\ X^{1.00}$ Primary + (W.A.S. + $FeCl_3$) Sludge $Y = 60.00\ X^{1.00}$ (Primary + $FeCl_3$) + W.A.S., (Primary + $FeCl_3$) + W.A.S., and W.A.S. $Y = 66.67\ X^{1.00}$ Primary + $FeCl_3$ and W.A.S. + $FeCl_3$ Y = Fuel Required, million Btu/yr X = Dry Sludge Feed, lb/hr	See Table 3-10 for design assumptions in EPA 430/9-77-011 Operating Parameters: Incoming sludge 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 Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
3-112	Multiple Hearth Furnace Incineration Start-Up Fuel $Y = 0.00194 X$ Y = Fuel Required, million Btu/hr X = Effective Hearth Area, sq ft	Design Assumptions: Use in conjunction with Figure 3-111 in EPA 430/9-77-011 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
3-113	Multiple Hearth Furnace Incineration $Y = 3870 X^{0.74}$ Y = Electrical Energy Required, kwh/yr X = Effective Hearth Area, sq ft	Design Assumptions: Solids Concentration, % — Loading Rates, lb/hr/sq ft (wet sludge): Small Plants <25 mgd — Large Plants >25 mgd 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.
3-114	Fluidized Bed Furnace Incineration $Y = 10.3 X^{1.00}$ Primary Sludge, Rate - 14 lb/ft^2/hr $Y = 12.5 X^{1.00}$ Primary + Low Lime Sludge, Rate - 18 lb/ft^2/hr $Y = 15.6 X^{1.01}$ Digested Primary Sludge, Rate - 14 lb/ft^2/hr $Y = 31.0 X^{1.00}$ Primary + (W.A.S. + $FeCl_3$), Rate - 8.4 lb/ft^2/hr $Y = 45.0 X^{1.00}$ Primary + W.A.S., (Primary + $FeCl_3$) + W.A.S., and W.A.S., Rate - 6.8 lb/ft^2/hr $Y = 51.0 X^{1.00}$ Primary + $FeCl_3$ and W.A.S. + $FeCl_3$, Rate - 6.8 lb/ft^2/hr Y = Fuel Required, million Btu/yr X = Dry Sludge Feed, lb/hr	Design Assumptions: Heat value of volatile solids is 10,000 Btu/lb See Table 3-10 preceding Figure 3-111 for more design assumptions in EPA 430/9-77-011. 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
3-115	Fluidized Bed Furnace Incineration $Y = 47{,}400 X^{0.93}$ Y = Electrical Energy Required, kwh/yr X = Bed Area, sq ft	See Table 3-10 preceding Figure 3-111 for design assumptions in EPA 430/9-77-011 Operating Parameters: Full time operation Type of Energy Required: Electrical
3-116	Sludge Drying $Y = 10 X^{1.0}$ Fuel 30% Input Solids Concentration, million Btu/yr $Y = 16.5 X^{1.0}$ Fuel 20% Input Solids Concentration, million Btu/yr $Y = 200 X^{1.0}$ Electricity 30% Input Solids Concentration $Y = 234 X^{1.02}$ Electricity 20% Input Solids Concentration $Y = 32.4 X^{1.02}$ Fuel 8% Input Solids Concentration, million Btu/yr $Y = 277 X^{1.01}$ Electricity 8% Input Solids Concentration $Y = 71.0 X^{1.01}$ Fuel 4% Input Solids Concentration, million Btu/yr $Y = 1154 X^{1.02}$ Electricity 4% Input Solids Concentration	Design Assumptions: Continuous operation Dryer Efficiency 72% Product moisture content 10% Power includes blowers, fans, conveyors Type of Energy Required, Fuel and Electricity

<table>
<tr><th>Figure Number From EPA 430/9-77-011</th><th>Operation, Process, and Equation Describing Energy Requirements</th><th>Design Conditions, Assumptions and Effluent Quality</th></tr>
<tr><td>3-116
(Continued)</td><td>$Y = 150\ X^{1.00}$ Fuel 2% Input Solids Concentration, million Btu/yr
$Y = 2650\ X^{1.00}$ Electricity 2% Input Solids Concentration
$Y = 300\ X^{1.00}$ Fuel 1% Input Solids Concentration, million Btu/yr
$Y = 5100\ X^{1.00}$ Electricity 1% Input Solids Concentration
Y = Electrical Energy Required, kwh/yr except fuel required
X = Annual Dry Solids Product, ton/yr</td><td></td></tr>
<tr><td>3-117</td><td>Wet Air Oxidation
$\log Y = 2.2518 + 0.6392\ (\log X) + 0.1259\ (\log X)^2 - 0.0108\ (\log X)^3$ Primary + W.A.S.
$\log Y = 2.1561 + 0.5493\ (\log X) + 0.1772\ (\log X)^2 - 0.0205\ (\log X)^3$ W.A.S.
Y = Electricity Required, thousands kwh/yr
X = Treatment Capacity, gpm</td><td>Design Assumptions:
Reactor pressure
Primary + W.A.S. = 1700 psig
W.A.S. = 1800 psig
Continuous operation
See Table 5-9 for sludge description and text in Chapter 5 in EPA 430/9-77-011
Curve Includes:
Pressurization pumps
Boiler feed pumps
Sludge grinders
Air compressors
Decant tank drives
Type of Energy Required: Electrical
Note: Fuel is required only at start-up</td></tr>
<tr><td>3-118</td><td>Lime Recalcining - Multiple Hearth Furnace
$Y = 1544\ X^{0.51}$ Fuel - Primary, 2 stage high lime, million Btu/yr
$Y = 2094\ X^{0.51}$ Fuel - Tertiary, low lime, million Btu/yr
$Y = 2290\ X^{0.51}$ Fuel - Tertiary, 2 stage high lime, million Btu/yr
$Y = 18{,}650\ X^{0.48}$ Power, kwh/yr
Y = Electrical Energy Required, kwh/hr
X = Hearth Area, sq ft</td><td>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
<table>
<tr><th>Sludge Composition:</th><th>$CaCO_3$</th><th>$Mg(OH)_2$</th><th>Other Inerts</th><th>Combustibles</th></tr>
<tr><td>Primary, 2 stage high lime</td><td>65%</td><td>2%</td><td>13%</td><td>20%</td></tr>
<tr><td>Tertiary, low lime</td><td>71</td><td>10</td><td>16</td><td>3</td></tr>
<tr><td>Tertiary, 2 stage high lime</td><td>86.1</td><td>4.3</td><td>6.1</td><td>3.5</td></tr>
</table>Type of Energy Required: Fuel and Electrical</td></tr>
<tr><td>4-1</td><td>Activated Carbon Secondary Energy Requirements
$Y = 1.05\ X^{1.00}$ 400 lb/mil gal Tertiary granular Carbon treatment, million Btu
$Y = 17.5\ X^{1.00}$ 2,500 lb/mil gal, IPC Powered Carbon treatment, million Btu
Y = Production Energy, million Btu
X = Plant Capacity, mgd</td><td></td></tr>
<tr><td>4-3</td><td>Ammonium Hydroxide Secondary Energy Requirements
$Y = 73\ X^{1.04}$ 4,175 lb/mil gal, million Btu
Y = Production Energy, million Btu
X = Plant Capacity, mgd</td><td></td></tr>
</table>

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
4-4	Carbon Dioxide Secondary Energy Requirements $Y = 1.5\ X^{1.0}$ 200 mg/l, million Btu $Y = 3.2\ X^{1.0}$ 300 mg/l, million Btu Y = Production Energy, million Btu X = Plant Capacity, mgd	
4-5	Chlorine Secondary Energy Requirements $Y = 165\ X^{1.00}$ 10 mg/l, kwh $Y = 1800\ X^{1.00}$ 135 mg/l, kwh Y = Production Energy, kwh X = Plant Capacity, mgd	
4-6	Ferric Chloride Secondary Energy Requirements $Y = 200\ X^{1.00}$ 50 mg/l, kwh $Y = 700\ X^{1.00}$ 200 mg/l, kwh Y = Production Energy, kwh X = Plant Capacity, mgd	
4-7	Lime (Calcium Oxide) Secondary Energy Requirements $Y = 6.2\ X^{1.0}$ 300 mg/l, million Btu $Y = 8.3\ X^{1.0}$ 400 mg/l, million Btu Y = Production Energy, million Btu X = Plant Capacity, mgd	
4-8	Methanol Secondary Energy Requirements $Y = 7.9\ X^{1.0}$ 60 mg/l, million Btu Y = Production Energy, million Btu X = Plant Capacity, mgd	
4-9	Oxygen Secondary Energy Requirements $Y = 345\ X^{1.0}$ 200 mg/l, kwh Y = Production Energy, kwh X = Plant Capacity, mgd	
4-10	Polymer Secondary Energy Requirements $Y = 1950\ X^{1.0}$, 1.4 #/mil. gal., Btu Y = Production Energy, Btu X = Plant Capacity, mgd	
4-11	Sodium Chloride Secondary Energy Requirements $Y = 25\ X^{1.0}$ Rock and Solar, 1200 lb/mil. gal. $Y = 20\ X^{1.0}$ Evaporated, 1200 lb/mil. gal. Y = Production Energy, kwh X = Plant Capacity, mgd	
4-12	Sodium Hydroxide Secondary Energy Requirements $Y = 550\ X^{1.0}$ 375 lb/mil. gal., kwh $Y = 7100\ X^{1.0}$ 4760 lb/mil. gal., kwh Y = Production Energy, kwh X = Plant Capacity, mgd	
4-13	Sulfur Dioxide Secondary Energy Requirements $Y = 0.35\ X^{1.0}$ 2 mg/l, kwh Y = Production Energy, kwh X = Plant Capacity, mgd	
4-14	Sulfuric Acid Secondary Energy Requirements $Y = 1500\ X^{1.0}$ 250 mg/l, million Btu $Y = 2600\ X^{1.0}$ 450 mg/l, million Btu Y = Production Energy, million Btu X = Plant Capacity, mgd	

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
5-1	Estimated Heat Requirements 1000 sq ft Building $Y = 1.7000 + 31.7402 X - 0.7765 X^2$ Case A: Uninsulated $Y = 0.3000 + 17,1750 X - 0.3750 X^2$ Case B: Added Wall and Ceiling Insulation With Storm Windows $Y = 0.0491 + 12.3386 X - 0.2538 X^2$ Case C: Wall and Ceiling Insulation Double Glazed Windows and Floor Insulation Y = Heat Required, million Btu/yr X = Thousand, deg day/yr	
5-2	Estimated Floor Area for Wastewater Treatment Plants $\log Y = 3.1801 + 0.1789 (\log X) + 0.4170 (\log X)^2 - 0.1074 (\log X)^3$ Total Floor Area $\log Y = 2.8073 + 0.4146 (\log X) + 0.1857 (\log X)^2 - 0.0332 (\log X)^3$ Laboratory and Administrative Area Y = Floor Area, sq ft X = Plant Capacity, mgd	
5-3	Anaerobic Digester Heat Requirements For Primary Sludge $Y = 3.20 - 0.0290 X$ South U.S. - Digestion Temp. = 95°F $Y = 3.43 - 0.0293 X$ Middle U.S. - Digestion Temp. = 95°F $Y = 4.03 - 0.0300 X$ North U.S. - Digestion Temp. = 95°F Y = Digester Heat Required, million Btu/mgd (0.05 lb VS/day/cu ft) X = Sludge Temperature to Digester, °F	
5-4	Anaerobic Digester Heat Requirements for Primary Plus Waste Activated Sludge $Y = 6.69 - 0.063 X$ South U.S. - Digester Loading = 0.05 lb VS/ft^3-day $Y = 7.14 - 0.063 X$ Middle U.S. - Digester Loading = 0.05 lb VS/ft^3-day $Y = 8.42 - 0.064 X$ North U.S. - Digester Loading = 0.05 lb VS/ft^3-day $Y = 6.11 - 0.062 X$ South U.S. - Digester Loading = 0.15 lb VS/ft^3-day $Y = 6.28 - 0.062 X$ Middle U.S. - Digester Loading = 0.15 lb VS/ft^3-day $Y = 6.67 - 0.062 X$ North U.S. - Digester Loading = 0.15 lb VS/ft^3-day Y = Digester Heat Required, million Btu/mgd X = Sludge Temperature to Digester, °F	
5-5	Heat Requirements Powered Activated Carbon Regeneration $Y = 0.0233 X^{0.88}$ Y = Fuel Required, million Btu/yr X = Powered Activated Carbon Regenerated, lb/day	

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
5-7	Digester Gas Cleaning and Storage Construction Costs $\log Y = 0.9701 + 0.8379 (\log X) - 0.1235 (\log X)^2 + 0.0218 (\log X)^3$ Total Clean Compress and Store $\log Y = 3.1972 - 1.7054 (\log X) + 0.6770 (\log X)^2 - 0.0642 (\log X)^3$ Clean and Compress $\log Y = -0.8547 + 1.7752 (\log X) - 0.3705 (\log X)^2 + 0.0521 (\log X)^3$ Store Y = Construction Cost, thousand dollars X = Digester Gas Cleaned and Compressed, scfm	
5-8	Digester Gas Cleaning and Storage O & M Labor Requirements $\log Y = 0.2605 + 1.3030 (\log X) + 0.0195 (\log X)^2 - 0.0247 (\log X)^3$ Y = O & M Labor, hr/yr X = Digester Gas Cleaned and Stored, scfm	
5-9	Digester Gas Cleaning and Storage Maintenance Material Costs $\log Y = -1.6763 + 0.9018 (\log X) + 0.2707 (\log X)^2 - 0.0653 (\log X)^3$ Y = Maintenance Material, thousand dollars/yr X = Digester Gas Cleaned and Stored, scfm	
5-10	Digester Gas Cleaning and Storage Energy Requirements $\log Y = 1.1149 + 0.4622 (\log X) + 0.0753 (\log X)^2 + 0.0024 (\log X)^3$ Y = Electricity Required, thousand kwh/yr X = Digester Gas Cleaned and Stored, scfm	
5-11	Internal Combustion Engine Construction Costs $\log Y = 5.2829 - 3.6573 (\log X) + 1.3169 (\log X)^2 - 0.1250 (\log X)^3$ Y = Construction Cost, thousand dollars X = IC Engine, hp	600 rpm engine with heat recovery and alternate fuel system
5-12	Internal Combustion Engine O & M Labor Requirements $\log Y = -1.1725 + 1.5611 (\log X) - 0.0273 (\log X)^2 - 0.0146 (\log X)^3$ Y = O & M Labor, hr/yr X = IC Engine, hp	600 rpm engine with heat recovery and alternate fuel system
5-13	Internal Combustion Engine Maintenance Material Costs $\log Y = -5.4676 + 4.3514 (\log X) - 1.1752 (\log X)^2 + 0.1337 (\log X)^3$ Y = Maintenance Material, thousand dollars/yr X = IC Engine, hp	600 rpm engine with heat recovery and alternate fuel system
5-14	Internal Combustion Engine Alternate Fuel Requirements $\log Y = -1.9249 + 3.5577 (\log X) - 0.7592 (\log X)^2 + 0.0736 (\log X)^3$ Y = Alternate Fuel Required, million Btu/yr X = IC Engine, hp	600 rpm engine with heat recovery and alternate fuel system

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
5-15	Digester Gas Utilization System Construction Costs $\log Y = 2.5404 - 0.4530 (\log X) + 0.6979 (\log X)^2 - 0.1318 (\log X)^3$ Y = Construction Cost, thousand dollars X = Plant Capacity, mgd	Complete electricity generation system as shown in Figure 5-6 EPA 430/9-77-011
5-16	Digester Gas Utilization System O&M Labor Requirements $\log Y = 1.8795 + 1.1374 (\log X) - 0.1063 (\log X)^2 + 0.0029 (\log X)^3$ Y = O & M Labor, hr/yr X = Plant Capacity, mgd	Complete system for electricity generation as shown in Figure 5-6 EPA 430/9-77-011
5-17	Digester Gas Utilization System Maintenance Material Costs $\log Y = 4.1712 - 8.2581 (\log X) + 6.1717 (\log X)^2 - 1.3289 (\log X)^3$ Y = Maintenance Material, thousand dollars/yr X = Plant Capacity, mgd	Complete system for electricity generation as shown in Figure 5-6 EPA 430/9-77-011
5-18	Digester Gas Utilization System Energy Requirements $\log Y = 2.4984 + 0.9564 (\log X) - 0.0985 (\log X)^2 + 0.0411 (\log X)^3$ Fuel $\log Y = 1.7189 + 0.5938 (\log X) - 0.0424 (\log X)^2 + 0.0068 (\log X)^3$ Electricity Y = Fuel Required, million Btu/yr X = Plant Capacity, mgd	Complete system for electrical generation as shown in Figure 5-6 EPA 430/9-77-011
5-19	Multiple Hearth Incineration Construction Cost $\log Y = 0.0606 + 0.5432 (\log X) + 0.4666 (\log X)^2 - 0.1592 (\log X)^3$ Y = Construction Cost, million dollars X = Plant Capacity, mgd	Design and Operation Assumptions: Loading rate = 6 lb/sq ft/hr Sludge: Primary + W.A.S. sludge = 16% solids
5-20	Multiple Hearth Incineration O & M Requirements $Y = 1600 X^{0.65}$ Y = O & M Labor, hr/yr X = Plant Capacity, mgd	Design and Operation Assumptions: Loading rate = 6 lb/sq ft/hr Sludge: Primary + W.A.S. sludge = 16% solids
5-21	Multiple Hearth Incineration Maintenance Material Costs $\log Y = 3.5505 + 0.0972 (\log X) + 0.3658 (\log X)^2 - 0.0539 (\log X)^3$ Y = Maintenance Material, dollars/yr X = Plant Capacity, mgd	Design and Operation Assumptions: Loading rate = 6 lb/sq ft/hr Sludge: Primary + W.A.S. sludge = 16% solids
5-22	Auxiliary Heat Required to Sustain Combustion of Sludge $Y = 4.09 - 0.165 X$ Primary, 60% VS $Y = 4 - 0.179 X$ Primary + W.A.S., 69% VS Y = Heat Required, million Btu/ton VS X = Sludge Solids, % by weight	Assumptions: 10,000 Btu/lb VS
5-23	Heat Recovered from Incineration of Sludge $Y = -2636.0 + 5.14 X - 0.0002 X^2$ Primary + W.A.S. $Y = -1195.4 + 2.06 X - 0.0006 X^2$ W.A.S. + $FeCl_3$ $Y = -820 + 1.71 X$ Primary Sludge Y = Initial Flue Gas Temperature, °F X = Heat Recovered, million Btu/yr/mgd	Assumptions: Final stack temp = 500°F 100% Excess air See table preceding Figure 3-111 for sludge characteristics in EPA 430/9-77-011
5-24	Impact of Excess Air on the Amount of Auxiliary Fuel for Sludge Incineration $Y = 0.41 + 0.0822 X$ Y = Auxiliary Fuel, million Btu/ton dry solids X = Excess Air, percent	Assumptions: Solids 30% Exhaust Temp. 1400°F Volatiles 70%

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
5-26	Energy Recovery Rotary Kiln Reactor Pyrolysis System $Y = 0.02\ X$ Net Energy Output, Btu/lb input $X =$ % Refuse % Sludge $= 100 - X$ $Y = 0.0 + 0.7150\ X - 0.0030\ X^2$ % Recovery of Energy Input $X =$ % Refuse % Sludge $= 100 - X$	
5-27	Energy Recovery Vertical Shaft Reactor Pure Oxygen Pyrolysis System $Y = 0.09 + 0.0291$ Net Energy Output $X =$ % Refuse % Sludge $= 100 - X$ $Y = 4.8750 + 0.9737X - 0.0041\ X^2$ % Recovery of Energy Input	
5-28	Heat Pump Output Based on Wilton Plant Design Operating Conditions for Various Effluent Temperatures $Y = -0.0714 + 1.9257\ X - 0.0109\ X^2$ Output, million Btu/yr/mgd $Y = 0.1529 + 0.0775\ X - 0.0005\ X^2$ Coefficient of Performance $X =$ Wastewater Temperature, $^{\circ}$F	
5-29	Air to Air Heat Pumps Typical Performance Curve $Y = 59 - 0.84\ X$ Typical Structure Heat Loss, thousand Btu/hr $X =$ Outside Temperature, $^{\circ}$F $Y = 11.5091 + 1.2769\ X - 0.0054\ X^2$ Heat Pump Capacity $Y = 0.8225 + 0.0519\ X - 0.0004\ X^2$ Coefficient of Performance	
5-30	Water to Water/Water to Air Heat Pumps Construction Cost $\log Y = 3.026 + 0.1483 (\log X) + 0.1530 (\log X)^2 - 0.0122 (\log X)^3$ $Y =$ Construction Cost, dollars $X =$ Heat Pump Capacity, thousand Btu/hr	
5-31	Water to Water/Water to Air Heat Pumps O & M Labor Requirements $\log Y = 0.2900 + 0.2924 (\log X) + 0.1916 (\log X)^2 - 0.0253 (\log X)^3$ $Y =$ O & M Labor, hr/yr $X =$ Heat Pump Capacity, thousand Btu/hr	
5-32	Water to Water/Water to Air Heat Pumps Maintenance Material Costs $\log Y = 0.4946 + 1.0205 (\log X) - 0.0819 (\log X)^2 + 0.0079 (\log X)^3$ $Y =$ Maintenance Material, dollars/yr $X =$ Heat Pump Capacity, thousand Btu/hr	
5-33	Water to Water/Water to Air Heat Pumps Energy Requirements $Y = 0.95\ X^{1.0}$ for 8,760 operating hr/yr $Y = 0.49\ X^{1.0}$ for 4,380 operating hr/yr $Y = 0.13\ X^{1.0}$ for 1,000 operating hr/yr $Y =$ Electricity Required, thousand kwh/yr $X =$ Heat Pump Capacity, thousand Btu/hr	Operating Conditions: COP = 2.8 Outside Temperature = 50°F

Figure Number From EPA 430/9-77-011	Operation, Process, and Equation Describing Energy Requirements	Design Conditions, Assumptions and Effluent Quality
5-34	Air to Air Heat Pumps Construction Cost $\log Y = -0.1984 + 0.3145 (\log X) + 0.1484 (\log X)^2 - 0.0143 (\log X)^3$ Y = Construction Cost, thousand dollars X = Heat Pump Capacity, thousand Btu/hr	
5-35	Air to Air Heat Pumps O&M Labor Requirements $\log Y = -0.0781 + 0.5929 (\log X) + 0.1290 (\log X)^2 - 0.0112 (\log X)^3$ Y = O & M Labor, hr/yr X = Heat Pump Capacity, thousand Btu/hr	
5-36	Air to Air Heat Pump Maintenance Material Costs $\log Y = 1.0960 + 0.4990 (\log X) + 0.0868 (\log X)^2 - 0.0072 (\log X)^3$ Y = Maintenance Material, dollars/yr X = Heat Pump Capacity, thousand Btu/hr	
5-37	Air to Air Heat Pump Energy Requirements $Y = 1.18 X^{0.98}$ for 8,760 operating hr/yr $Y = 0.53 X^{1.0}$ for 4,380 operating hr/yr $Y = 0.13 X^{1.0}$ for 1,000 operating hr/yr Y = Electricity Required, thousand kwh/yr X = Heat Pump Capacity, thousand Btu/hr	Operating Conditions: COP = 2.4 Outside Temperature = 45°F

APPENDIX B

RAW WASTEWATER CHARACTERISTICS (Wesner et al., 1978)

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

APPENDIX C

SLUDGE CHARACTERISTICS (Wesner et al., 1978)

Sludge Type	Total Solids (wt Percent of Sludge)	Sludge Solids (lb/mil gal)		Volatile Solids (wt Percent of Total Solids)	Sludge Volume (gal/mil gal)
		Total Solids	Volatile Solids		
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 + W.A.S.[a]	2	2096	1446	69	12,565
Primary + (W.A.S. + $FeCl_3$)	1.5	2685	1443	54	21,480
(Primary + $FeCl_3$) + W.A.S.	1.8	3144	1676	53	20,960
W.A.S.	1.0	945	756	80	11,330
W.A.S. + $FeCl_3$	1.0	1535	776	50	18,400
Digested Primary	8.0	806	345	43	1,210
Digested Primary + W.A.S.	4.0	1226	576	47	3,680
Digested Primary + W.A.S. + $FeCl_3$	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

[a] W.A.S. = Wasted activated sludge.

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