

Lehigh University Lehigh Preserve

Fritz Laboratory Reports

Civil and Environmental Engineering

1980

Energy utilization and recovery at the allentown wastewater facility, December 1980.

Anthony G. Collins

Robert L. Johnson

Follow this and additional works at: <http://preserve.lehigh.edu/engr-civil-environmental-fritz-lab-reports>

Recommended Citation

Collins, Anthony G. and Johnson, Robert L., "Energy utilization and recovery at the allentown wastewater facility, December 1980." (1980). *Fritz Laboratory Reports*. Paper 2237.
<http://preserve.lehigh.edu/engr-civil-environmental-fritz-lab-reports/2237>

This Technical Report is brought to you for free and open access by the Civil and Environmental Engineering at Lehigh Preserve. It has been accepted for inclusion in Fritz Laboratory Reports by an authorized administrator of Lehigh Preserve. For more information, please contact preserve@lehigh.edu.

ENERGY UTILIZATION AND RECOVERY
AT THE
ALLENTOWN WASTEWATER FACILITY

ANTHONY G. COLLINS, Graduate Student
ROBERT L. JOHNSON, Professor of Civil Engineering

LEHIGH UNIVERSITY

PREPARED UNDER THE SUPPORT OF THE
CITY OF ALLENTOWN, PENNSYLVANIA, URBAN OBSERVATORY

DECEMBER 1980

TABLE OF CONTENTS

| | <u>Page</u> |
|--|-------------|
| LIST OF TABLES | iii |
| LIST OF FIGURES | iv |
| ABSTRACT | 1 |
| 1. INTRODUCTION | 2 |
| 2. WASTEWATER TREATMENT PROCESS DESCRIPTION | 3 |
| 2.1 General Wastewater Process Concepts | 3 |
| 2.1.1 Wastewater Solids Processing | 5 |
| 2.2 Allentown Kline's Island Wastewater Treatment Plant Prior to Recent (1978-79 Expansion) | 7 |
| 2.3 Current Allentown Wastewater Treatment Plant | 8 |
| 3. PRESENT AND FUTURE DIGESTER GAS PRODUCTION | 12 |
| 3.1 Gas Production Data | 12 |
| 3.2 Sludge Production Data | 15 |
| 3.3 Theoretical Model Projection | 24 |
| 4. DIGESTER GAS UTILIZATION SCHEMES | 27 |
| 4.1 Potential Electric Power Generation Capacity | 27 |
| 4.2 Heat Recovery Systems | 28 |
| 4.2.1 Heat Pumps | 31 |
| 5. ECONOMIC ANALYSIS OF POWER GENERATION | 33 |
| 5.1 Present Electricity Costs | 33 |
| 5.2 Estimated Costs for Generating Capacity | 34 |
| 5.3 Economic Comparison | 36 |
| 6. DISCUSSION AND RECOMMENDATIONS | 38 |
| 7. REFERENCES CITED | 41 |
| APPENDIX A - THEORETICAL SRT ANALYSIS | 42 |
| APPENDIX B - DIGESTER GAS ANALYSIS | 44 |
| APPENDIX C - SPACE HEATING REQUIREMENTS | 45 |

LIST OF TABLES

| <u>Table</u> | | <u>Page</u> |
|--------------|--|-------------|
| 1 | PROJECTED SLUDGE AND DIGESTER GAS PRODUCTION | 24 |
| 2 | PROJECTED THEORETICAL DIGESTER GAS PRODUCTION | 26 |
| 3 | FUTURE DIGESTER GAS PRODUCTION | 26 |
| 4 | ESTIMATED HEAT PUMP OUTPUT | 32 |
| 5 | COSTS FOR DIGESTER GAS ENGINE-GENERATOR SYSTEMS | 36 |
| 6 | ANNUAL COSTS FOR ON-SITE POWER GENERATING ALTERNATIVES | 37 |
| 7 | ESTIMATE OF COEFFICIENT K | 46 |
| 8 | DIGESTER AND SPACE HEATING REQUIREMENTS | 47 |

LIST OF FIGURES

| <u>Figure</u> | | <u>Page</u> |
|---------------|--|-------------|
| 1 | Cumulative Wastewater Flow and Digester Gas Production | 10 |
| 2 | Cumulative Wastewater Flow and Electricity Use | 11 |
| 3 | Cumulative Digester Gas Production | 13 |
| 4 | Monthly Gas Production | 14 |
| 5 | Total and Volatile Solids to Digester | 16 |
| 6 | Digester Gas Production and Solids to Digester | 17 |
| 7 | Total Sludge Solids Production | 18 |
| 8 | Volatile Sludge Solids Production | 19 |
| 9 | Digester Gas Production and Solids Destroyed | 20 |
| 10 | Digester Gas Production per Unit Solids Destroyed | 21 |
| 11 | Monthly Sludge Volume Production | 23 |
| 12 | Projected Treatment Plant Wastewater Flow | 25 |
| 13 | Energy Schematic for Engine Generator Set | 30 |
| 14 | Comparative Annual Electric Energy Costs with On-Site Generation | 35 |

ABSTRACT

Based on the 1970-1977 operating data, projections were made for future gas production ranging from 130,000 cubic feet/day for a no-growth condition up to 309,000 cubic feet/day on a theoretical basis for the year 2000. Digester gas analyses confirmed the heat value of the digester gas at approximately 600 BTU/ft³.

Potential electric power generation capacity would be 285 KW to 720 KW depending upon the projected digester gas production value. An economic analysis showed a potential gross savings of \$233/year/KW installed. Further economic analysis showed a gross cost of \$206 to \$161/year/KW for the installation of IC-generator equipment depending upon the size selected.

Thus, a net savings of \$27 to \$72/KW is possible based on a 10 year, 12% interest payback condition.

Further energy recovery from digester gas IC-generators is possible. A large fraction, approximately 60% or more of the thermal needs for anaerobic digester operation and for space heating could be met from IC engine heat recovery systems.

1. INTRODUCTION

The 1978-79 upgrade and expansion of the regional Allentown Kline's Island Wastewater Treatment Facility has had a profound impact, not only on the quality of the final effluent from the plant, but also on the amount of electrical energy required to operate the new facility. The increased energy use coupled with the rising cost of energy made the City of Allentown interested in energy conservation and recovery at the new facility.

There has been a long history and experience with heat recovery from burning the digester gas at the treatment plant. Recognizing the high costs involved with the expanded wastewater facility, it seemed desirable to investigate an even greater recovery of energy from the digester gas.

In early 1979, it was proposed to study the feasibility of electric power production at the Kline's Island Treatment Facility on a co-generation basis. The study was to address not only the capacity potential but also the economic benefit, if any, to be derived from this scheme. The electricity generated would be utilized in the treatment facility, primarily for the pump motors which are the largest electric power use.

Coupled with the electric power generation study was an investigation of heat recovery not only from the engine-generator sets, but also from the wastewater flow itself, via heat pump, thus incorporating a total energy concept approach to the study. Also incorporated into the study were investigations of possible operating and design modifications to further enhance the energy recovery at this facility.

2. WASTEWATER TREATMENT PROCESS DESCRIPTION

This chapter is written in three sections. The first deals with general aspects of wastewater treatment, the second with the Allentown Wastewater Treatment plant prior to the recent expansion and the third deals with the current plant design and facilities. This organization provides an explanation of terms together with alternative design and operating concepts.

The historical data upon which many of the projections in this report are based pertain to the wastewater treatment facility prior to the recent expansion. The current plant is also described to form a basis for discussion of modifications to advance the basic aim of this study.

2.1 General Wastewater Process Concepts

The natural self-purification processes in a stream can be compressed in time and space into a series of wastewater treatment unit processes (1). The processes typically involved are settling, bio-oxidation of the non-settleable and dissolved organic material, and anaerobic decomposition of the settled and separated solids (2). In wastewater treatment facilities these processes are accelerated, monitored, controlled and supplemented to meet the desired effluent quality for protecting the receiving water body.

Where sewers collect both sanitary sewage and perhaps storm water, grit removal is required. Grit chambers are used for removal of sand and grit in a short detention settling channel or tank which allows the subsidence of coarse sand and grit particles. The purpose of grit removal is to protect pumps and other equipment plus preventing the accumulation of inert grit in sludge lines and digesters. Bar racks intercept rags and

debris in sewage as it enters the plant. To minimize handling, automatic scrapers are often fitted to the intercepting racks, which carry the screenings to a grinder or for removal by burial or burning. The grindings are usually returned to the wastewater stream.

The first major unit process that the wastewater flows through is sedimentation. Sedimentation is simple gravitational settling, and when applied to raw wastewater is termed primary settling. The settled material (sludge) and any floating solids or scum are removed for continuous or periodic pumping to a digester or other sludge process.

Bio-oxidation is the same phenomena as aerobic stabilization in a stream. The two most widely used processes are trickling filters and activated sludge. There are two steps associated with the processes. First, there is the sorption of the organic nutrients into the biological mass. Second, there is the utilization of the organic material in the presence of sufficient oxygen. In trickling filters, the sorption and biological utilization appear to be concurrent, with the biological mass attached to a rock or plastic media bed. In activated sludge, the system is a more delicate arrangement. The recycled activated sludge provides the seed to the entering wastewater. The organic nutrient sorption and subsequent utilization occurs in an aeration tank. The product of the biological activity is new biological cells (activated sludge), which is a floc that is separated in a settling basin for subsequent recycle. Both trickling filters and activated sludge processes require a sequential settling step (secondary sedimentation). These separate either the activated sludge floc or the new biological cell mass generated by the trickling filters for return in the process or for subsequent treatment.

Disinfection by chlorination is a final main-stream process which is used to maintain the bacteriological quality of the receiving water. The receiving water may subsequently be utilized as a drinking water source.

2.1.1 Wastewater Solids Processing - The sludge collected from the primary and secondary clarifiers forms a separate waste stream, distinct from the main-stream effluent. The waste sludge flow must also be treated. The sludge consists of organic and inorganic solids present in the raw wastewater and removed in the primary clarifier, plus organic solids generated in the bio-oxidation steps and removed in the secondary clarifier. The sludge will contain a greater or lesser amount of water depending in part on the processes involved. The sludge ranges from less than 1% solids to 10% solids.

The moisture associated with the waste sludge is in part free, and separable by sedimentation; in part trapped in the interstices of floc particles, and separable by mechanical dewatering; in part held by capillary action, and separable by compaction; and in part chemically bound within or around the bacterial cell, and separable only by destruction of the cell. The effect of moisture content upon sludge volume is appreciable, and sludge handling techniques are directed toward reducing the moisture content, and thereby the volume of sludge as well as reducing the pathogenic and obnoxious character of the sludge solids.

Sludge conditioning includes a variety of processes, some biological, some chemical, and some physical, which may be applied to favorably alter the characteristics of sludge and improve its dewaterability. The biological processes also provide up to about 35% decrease in total solids

content because of gas production from organic solids. Conditioning processes include sludge digestion (both aerobic and anaerobic), chemical coagulation, and heat treatment.

The most common waste sludge process and the one of particular interest to this study is anaerobic digestion (3,4). Anaerobic digestion is a two-step biological process in which the complex organic material in the waste solids are first broken down to simpler compounds - notably the short chain volatile fatty acids. In the second step, these intermediate compounds are further reduced (gasified) by a separate group of bacteria to methane and carbon dioxide.

The time required for the biological destruction (gasification) of the organic sludge solids is quite long at ambient temperatures. For both biological and economic reasons, the sludge digestion process is usually operated at elevated temperatures, usually around 95°F (35°C). The process can also be operated at even higher temperatures near 120°F (50°C).

Even with elevated temperatures, the time required for sludge solids destruction is quite long. Minimum detention periods of 10-14 days are required with 20-30 days being more typical of the design and operating conditions in normal practice. Because of the long detention period required, it is desirable to reasonably minimize the water content of the sludge feed to the anaerobic digesters, thus reducing both the required volume of the digester and the energy required to heat and maintain the sludge at the higher operating temperatures.

The digester gas (methane plus carbon dioxide) produced by the destruction of the organic solids has a moderately high energy content

(600 BTU/ft³) and has been used beneficially in wastewater plant design and operation for many years (2). In small to moderate sized facilities, the digester gas is almost universally used to help maintain the elevated temperature required for sludge digestion, and perhaps space heating in the buildings.

Many moderate to large sized wastewater treatment facilities utilize the digester gas for on-site power generation or for direct prime movers of pumps and other equipment, partially meeting the energy needs of the treatment plant. Heat recovery systems incorporated with the prime mover uses or on-site power generating capability allow a very high recovery of the total energy content in the digester gas.

2.2 Allentown Kline's Island Wastewater Treatment Plant

Prior to Recent (1978-79) Expansion

The Allentown Wastewater Treatment Plant prior (5) to the recent expansion consisted of the following unit processes:

- mechanically-cleaned bar racks
- pumping station
- detritus (grit) removal and dewatering facilities
- primary settling
- trickling filter (fixed nozzle)
- secondary (final) settling
- disinfection
- sludge thickening
- sludge digestion (primary and secondary)
- elutriation
- sludge dewatering facilities.

Detailed plant records are available (6), and the period 1970 through 1977 form the data base used in this report. Records from 1978 to the present were not considered representative due to the influence of the construction period and the expansion start-up.

Figure 1 shows a plot of cumulative digester gas production and wastewater flow for the 1970-77 data base period. Figure 2 is a similar plot showing cumulative wastewater flow and electrical use during the same data base period.

The digester gas produced by the destruction of the organic solids (total volatile solids-TVS) in the wastewater sludge was used primarily to heat and maintain the digester tanks at 90-95°F (32-35°C). The dual fuel hot water boilers used for this purpose also provided space heating for the buildings. Excess digester gas was burned in the waste gas burner.

2.3 Current Allentown Wastewater Treatment Plant

The major additions and modifications of the Allentown Wastewater Treatment Plant (5) were:

- an auxiliary pumping station
- new aerated grit chamber
- new primary settling
- new plastic media trickling filters
- conversion of existing primary settling to intermediate settling
- use of existing trickling filters for nitrification
- additional final settling
- additional primary sludge digestion
- an additional vacuum sludge filter.

Associated with the additional digester, more hot water boiler capacity was installed. New meters were also installed to provide more accurate monitoring of the digester gas production. Although intended primarily for operational control purposes, the new metering capability will provide better data for digester gas utilization.

Figure 1 Cumulative Wastewater Flow and Digester Gas Production

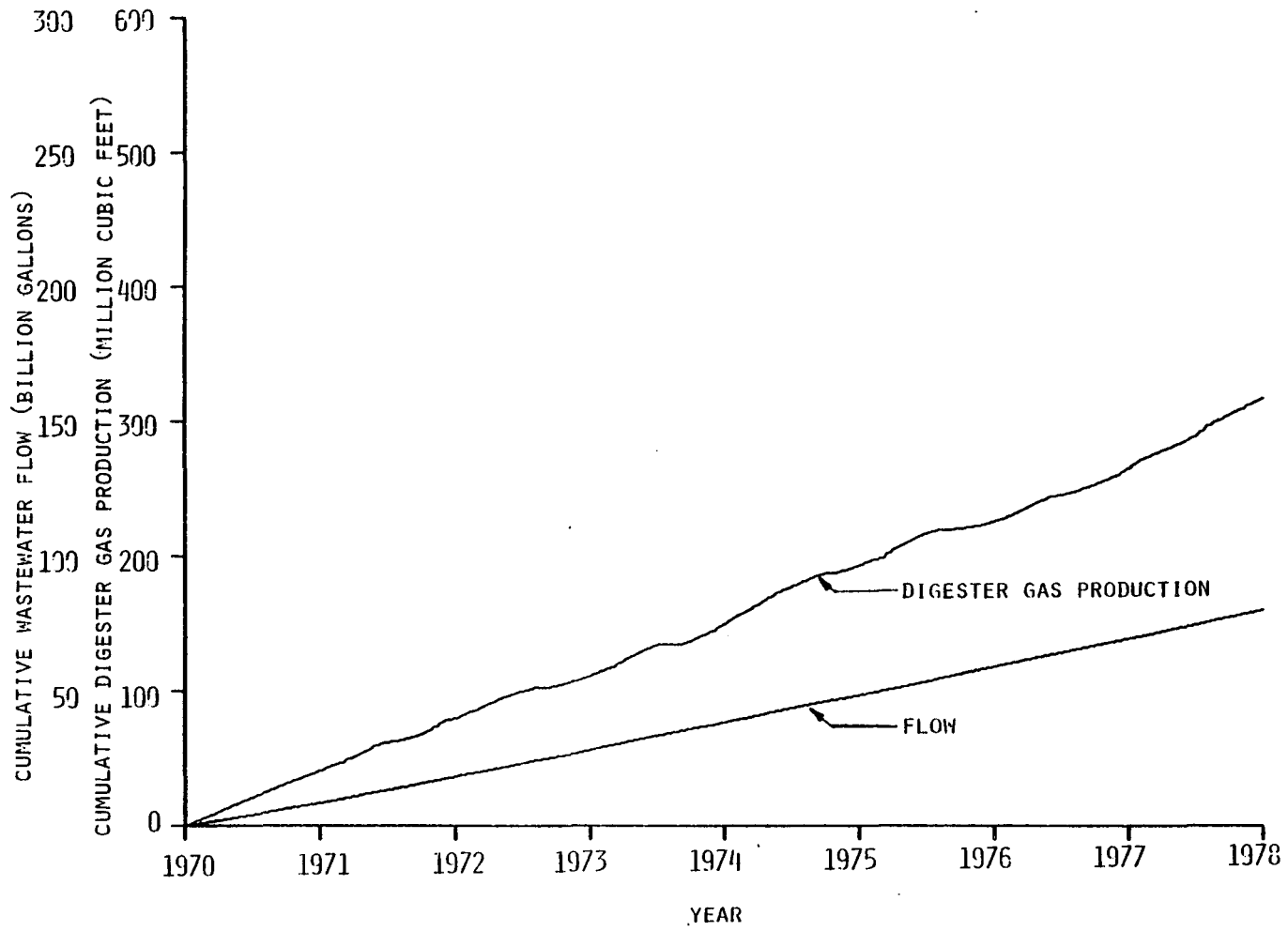
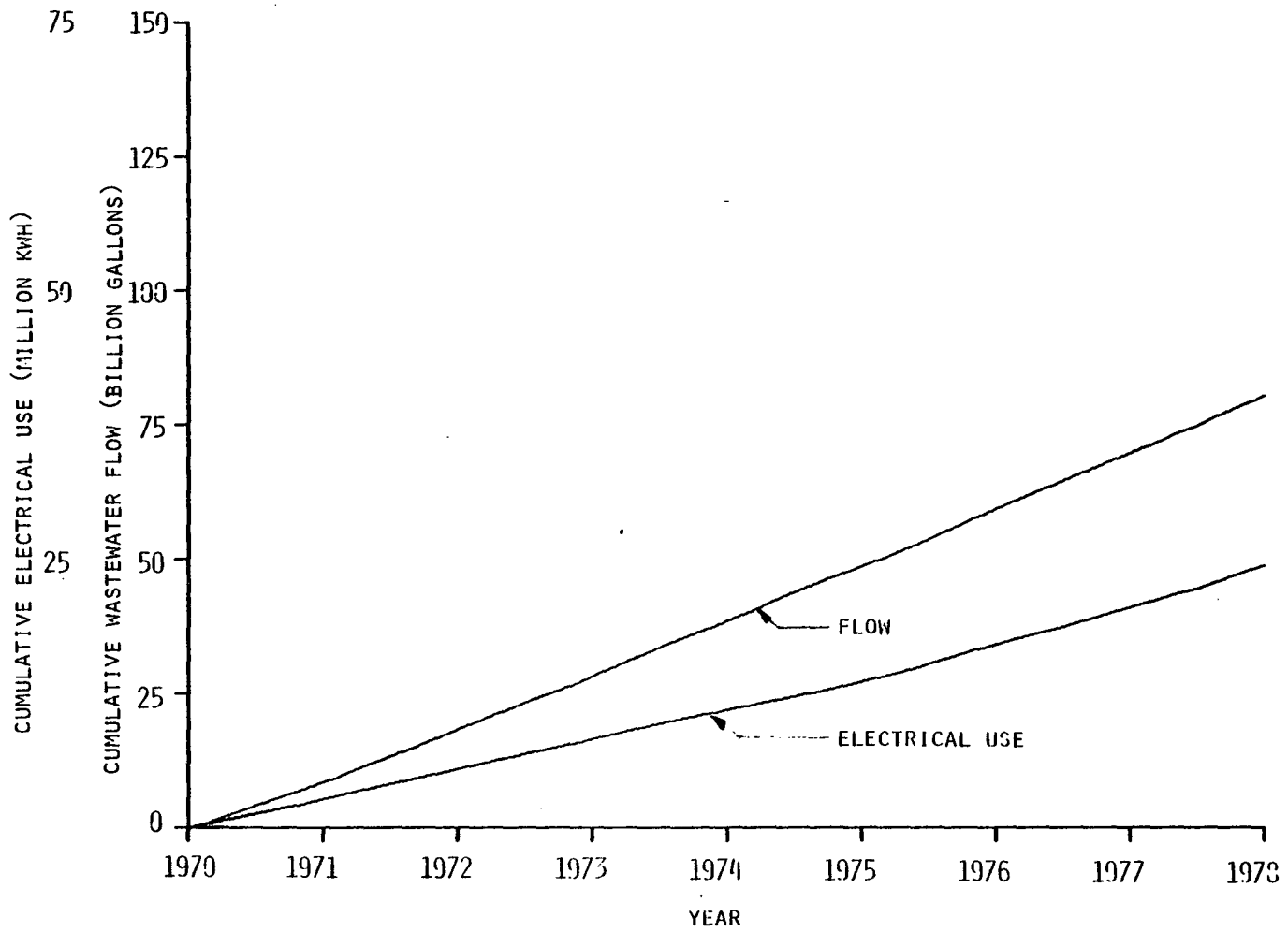


Figure 2 Cumulative Wastewater Flow and Electricity Use



3. PRESENT AND FUTURE DIGESTER GAS PRODUCTION

This chapter deals with estimating the digester gas production value for 1980 (the base year) from the historical data and then projecting gas production for future years 1990 and 2000 using several methods. The historical data reflect the operation of the plant without the current expansion. Therefore the values extracted as the base of projecting future conditions are considered to be quite conservative.

Three methods were used to obtain the digester gas production figures. Results from all methods are compared at the end of the chapter.

3.1 Gas Production Data

A linear extrapolation based on past digester gas production data is shown in Fig. 3 to estimate the future cumulative digester gas production. This projected amount of gas production translates into an average daily rate of 130,000 ft³/day. The actual daily digester gas production will vary considerably. Figure 4 shows the observed monthly gas production during the 1970-77 base data period. The highly variable production rate is due to many factors, most of which are beyond control at the present time. The data strongly emphasize the need for gas storage such as the existing digester gas dome cover to ensure a uniform supply of gas for effective use at the plant.

No allowance for increased gas production was made using this technique, thus the values estimated are low and can be considered an ultraconservative "no growth" condition.

Figure 3 Cumulative Digester Gas Production

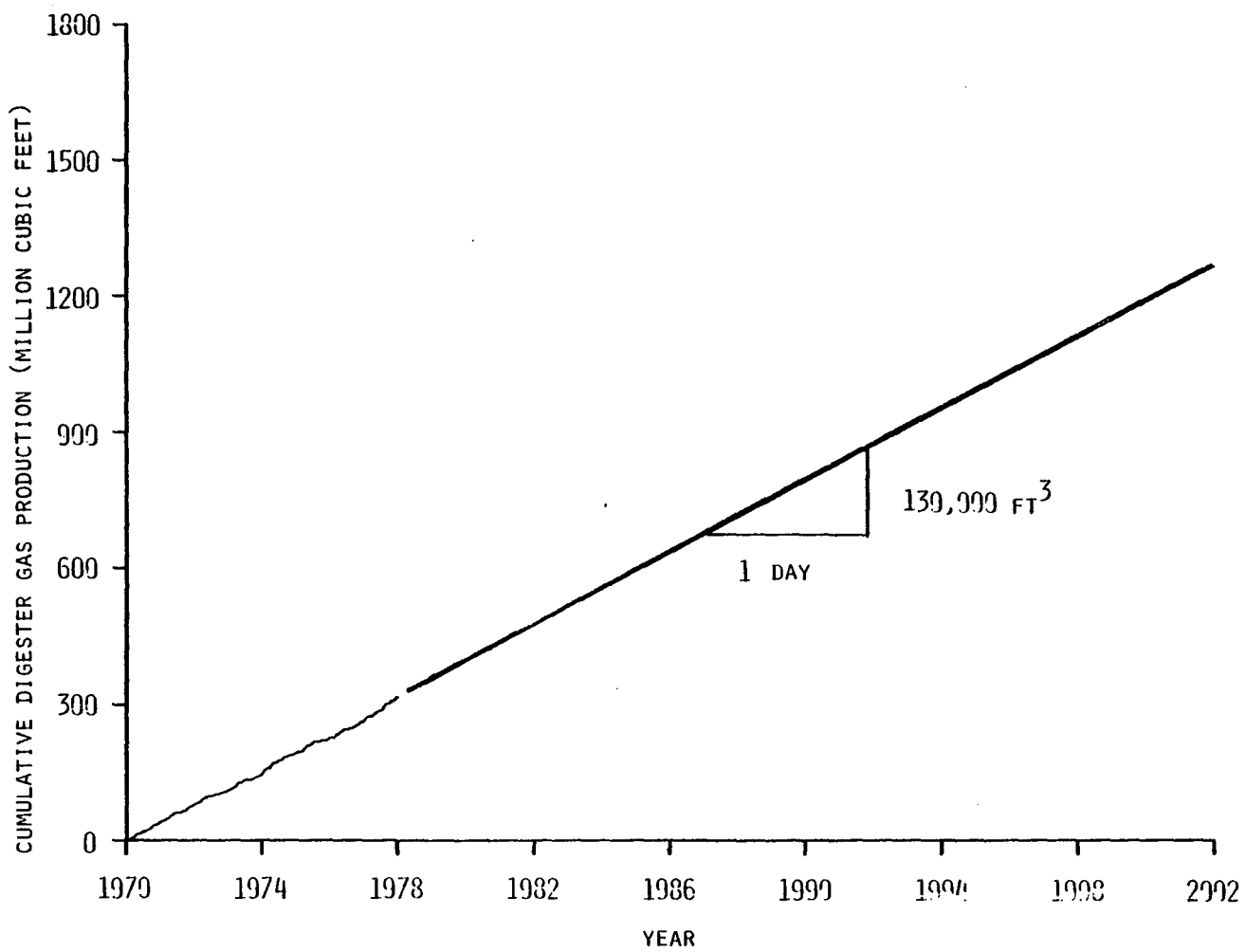
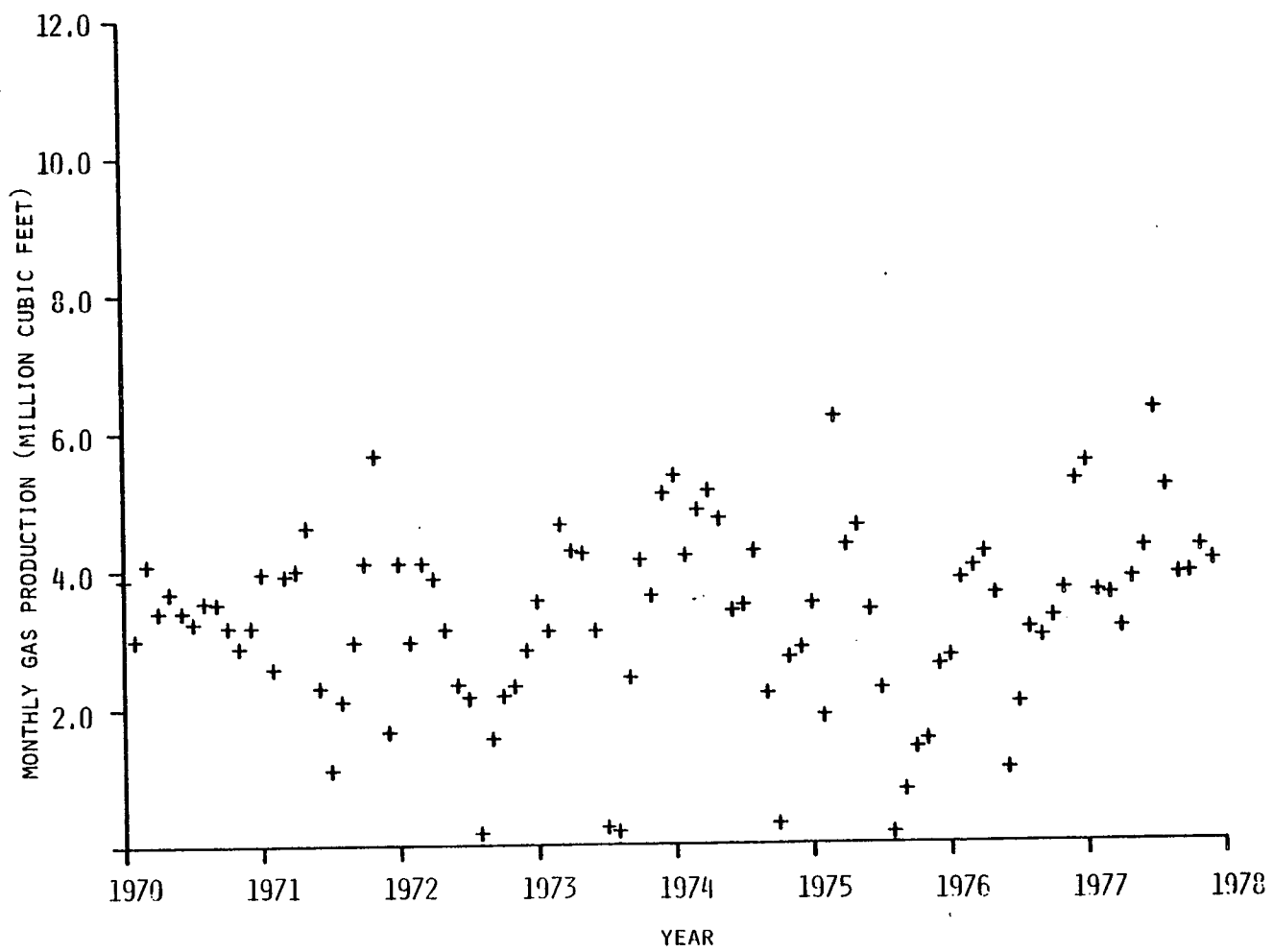


Figure 4 Monthly Gas Production



3.2 Sludge Production Data

The second method employed to project future gas production was based on an estimate of the future sludge solids production coupled with the digester gas production per unit sludge. The organic sludge solids are the actual "foodstuff" which are biologically metalolized (digested) to produce the digester gas. These foodstuff solids are termed the "volatile solids" due to analytical techniques used in analysis of the sludge and not due to the character of the sludge since it is not really volatile in any aspect except perhaps odor.

The cumulative total and volatile (organic) sludge solids that were fed to the digesters during the 1970-77 base data period are shown in Fig. 5 and Fig. 6 along with the total wastewater flow and digester gas produced. This information was the souce of data for projection of future sludge and digester gas production.

The extrapolation used to estimate the future total and volatile solids production as shown in Fig. 7 and Fig. 8 was essentially linear. It should be noted that a six (6) month moving average was used to smooth the variability in the data.

Since the digester gas is produced by the destruction of the volatile (organic) sludge solids, it is important to consider not just the sludge production, but also the fraction that is converted into the usable digester gas. Figure 9 shows the sludge solids destroyed together with the digester gas produced during the 1970-77 base data period.

The monthly unit digester gas production for the 1970-77 base data period is shown in Fig.10. There is appreciable variation in this data.

Figure 5 Total and Volatile Solids to Digester

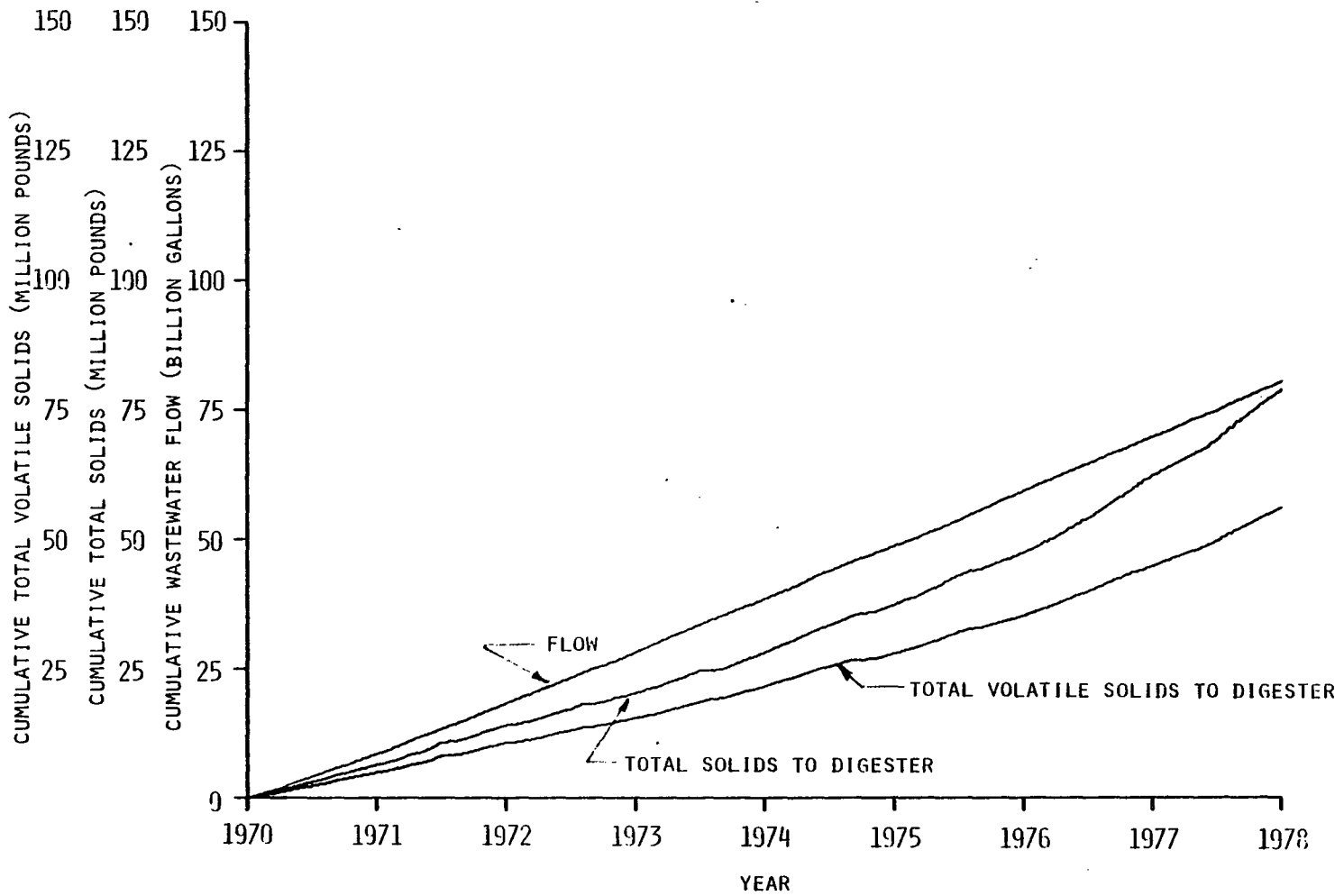


Figure 6 Digester Gas Production and Solids to Digester

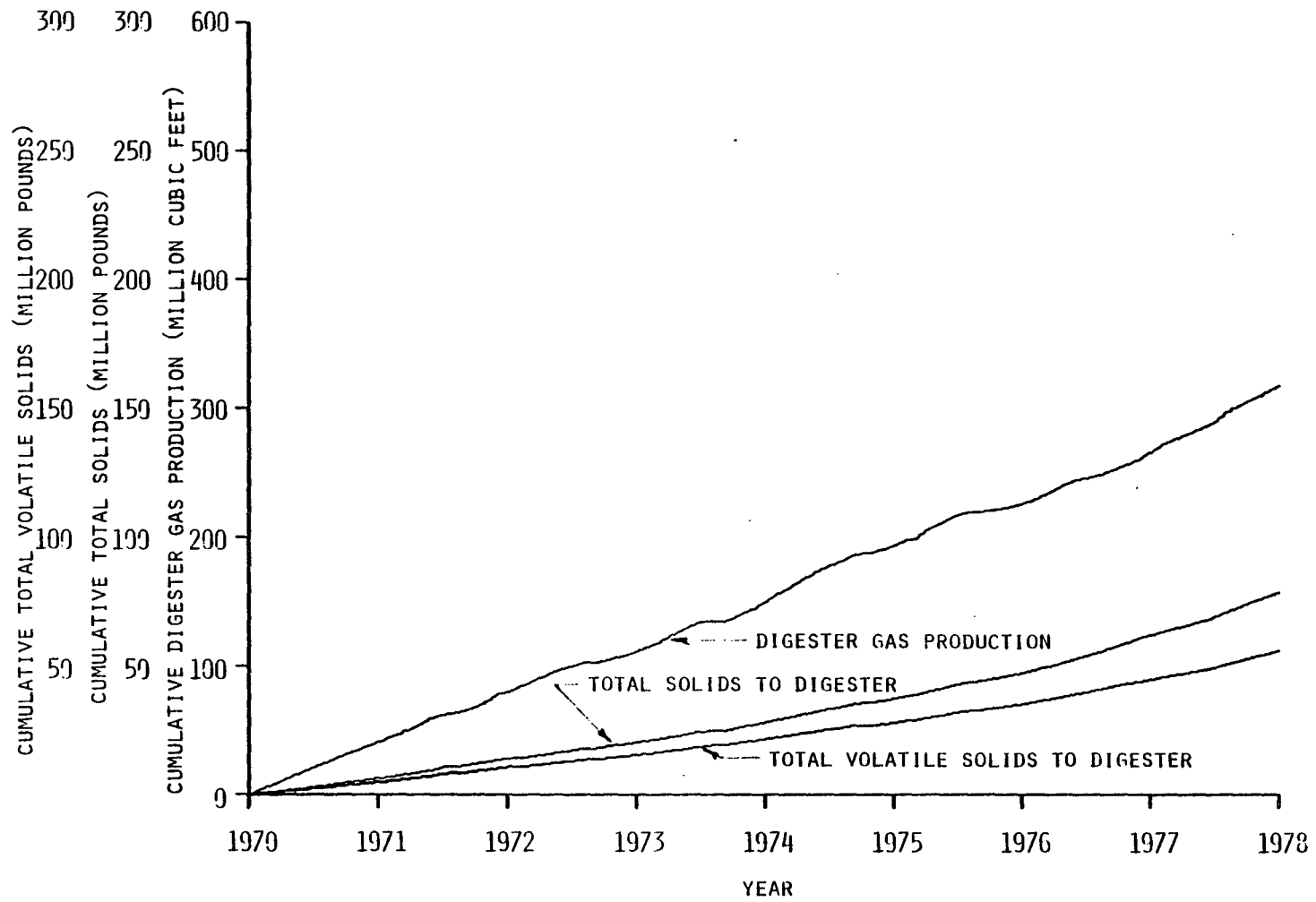


Figure 7 Total Sludge Solids Production

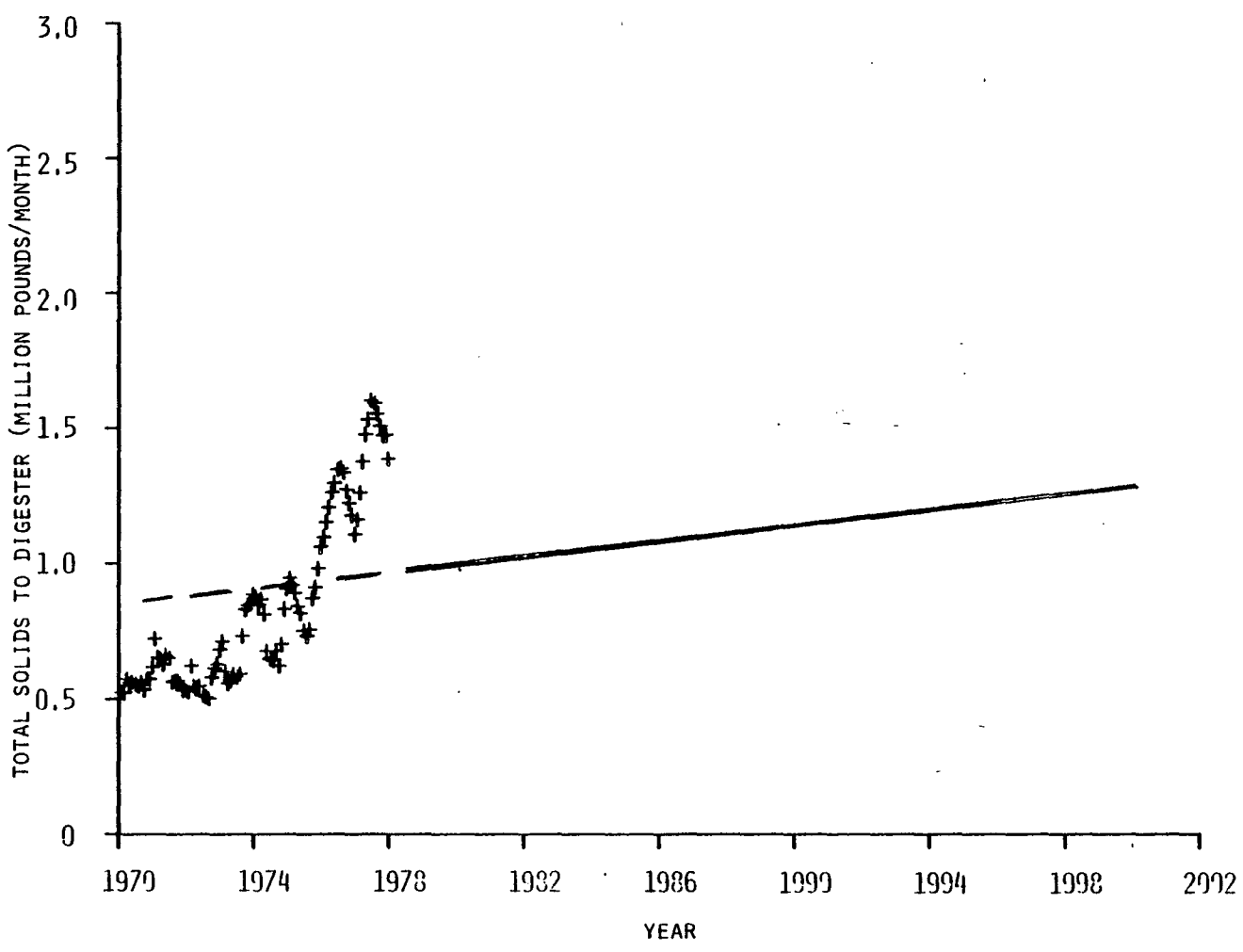


Figure 8 Volatile Sludge Solids Production

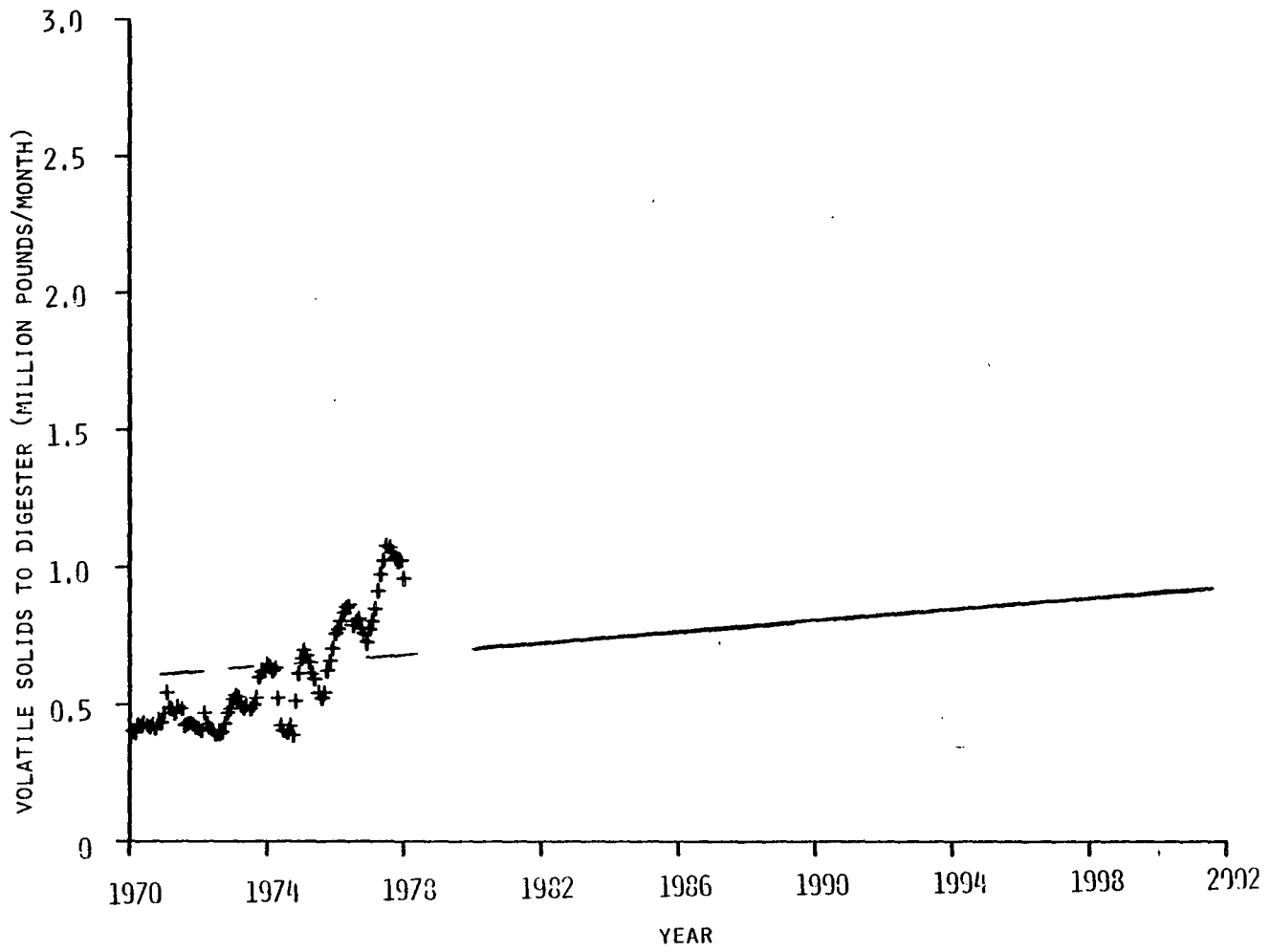


Figure 9 Digester Gas Production and Solids Destroyed

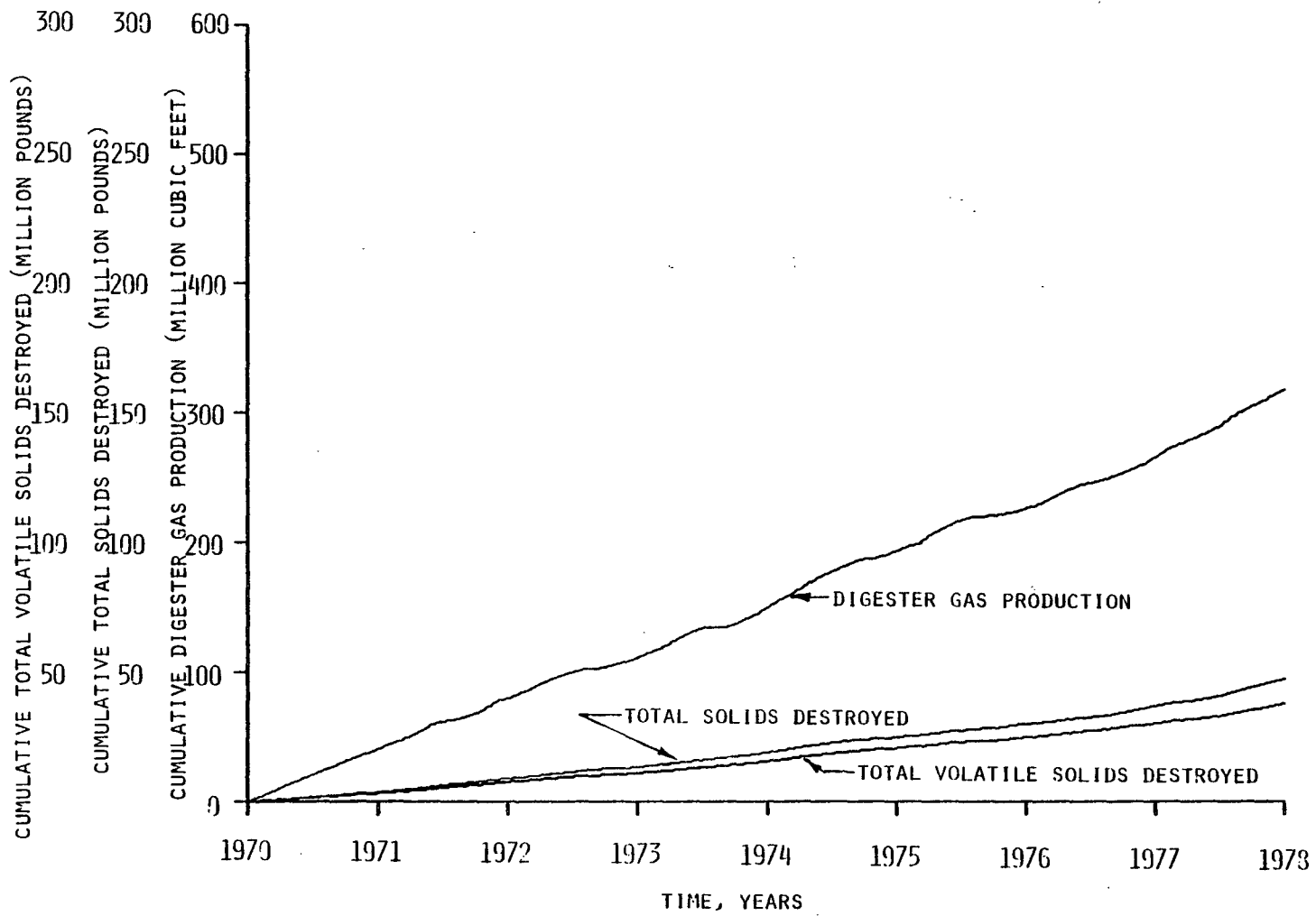
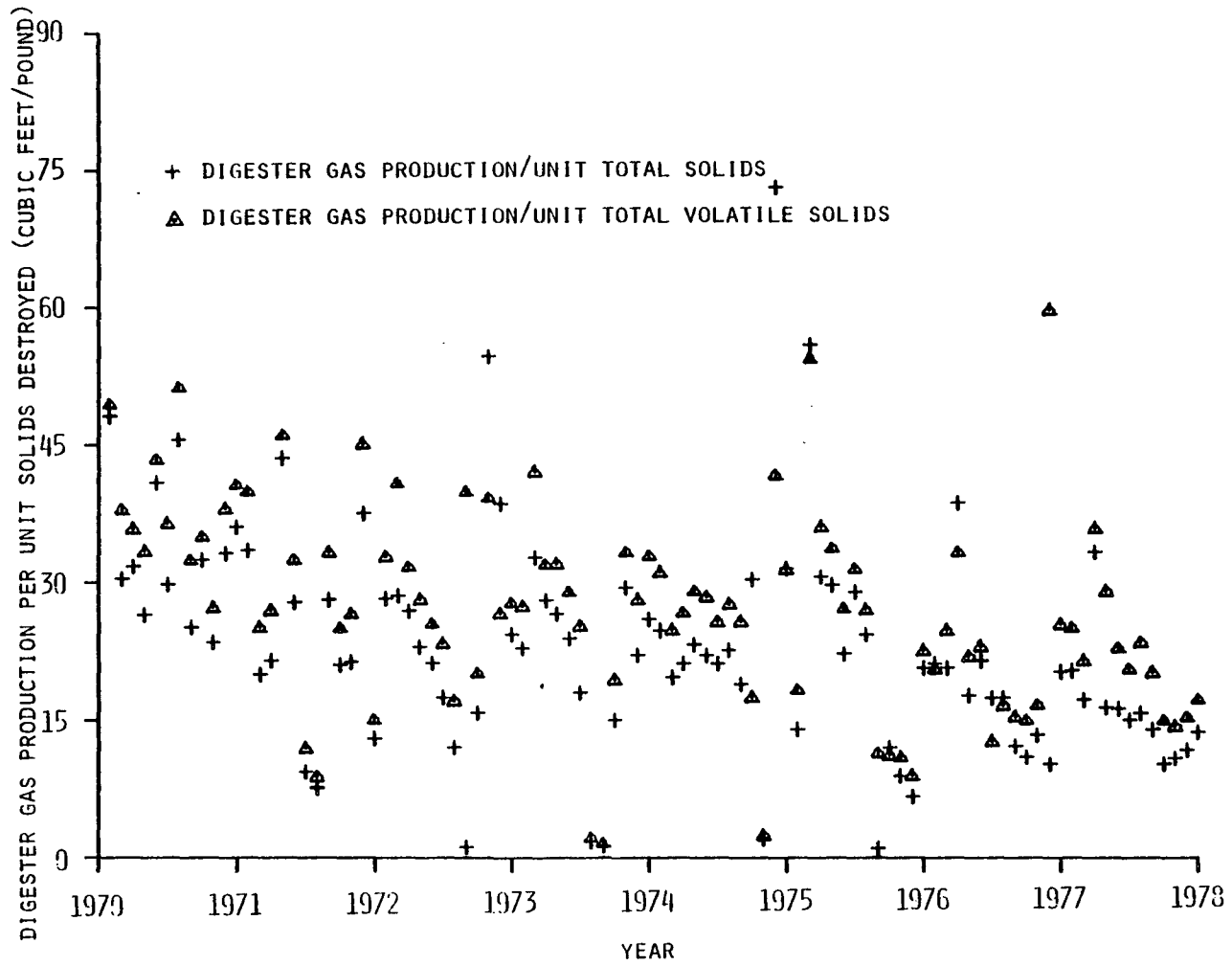


Figure 10 Digester Gas Production per Unit Solids Destroyed



However, the average value over the eight (8) year base data period is 8.5 cubic feet digester gas/pound volatile solids destroyed. The value of 8.5 ft³/lb volatile solids destroyed is quite low compared to normal values in the range of 12 to 18 ft³ gas/lb volatile solids destroyed (2). Digester gas production is a function of many variables, primarily the sludge characteristics and the two major digester operating parameters of temperature and detention time previously discussed.

Since the digester volume is fixed, the detention time depends on the volume of sludge sent to the digesters. Figure 11 shows the monthly sludge volume produced over the 1970-1977 base data period using a six month moving average to smooth variations. The sludge volume appears to have increased rather dramatically over the 1975-77 period, while the mass of wastewater solids sent to the digesters has not increased proportionately. This would cause shorter detention time in the digesters with the resulting lower unit gas production. This probably corresponds to a period when industrial waste loads (Schaeffer and Kraft) from Lehigh County Authority increased and also when the sludge thickeners ahead of the digesters were overloaded, a condition that was addressed and hopefully corrected by the recent plant expansion.

From the projected future sludge solids shown in Fig. 8 and assuming a typical value of 2/3 destruction of the volatile (organic) solids, the 1990 and 2000 gas production was estimated. A slightly increased unit value of 12 cubic feet digester gas/lb volatile solids destroyed was used in this projection. The results of these extrapolations and projections are shown in Table 1.

Figure 11 Monthly Sludge Volume Production

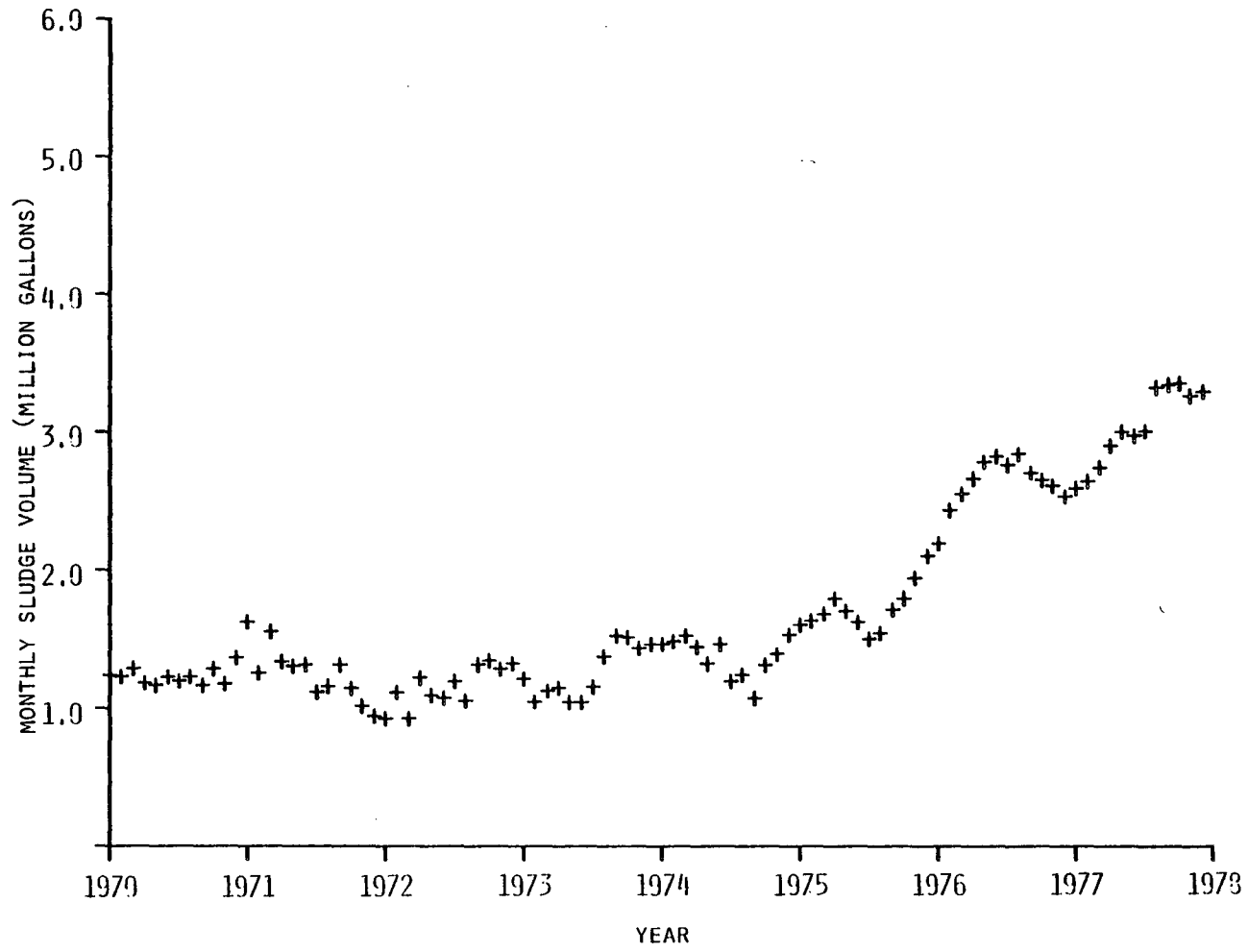


Table 1
PROJECTED SLUDGE AND DIGESTER GAS PRODUCTION

| Year | Sludge Solids Production (pounds/day) | | Digester Gas Production ^a (cubic feet/day) |
|------|--|----------|--|
| | Total | Volatile | |
| 1980 | 31,800 | 22,500 | 180,000 |
| 1990 | 36,500 | 25,800 | 206,000 |
| 2000 | 42,000 | 29,700 | 238,000 |

^aBased on 2/3 destruction of volatile solids and 12 ft³ gas per lb volatile solids destroyed.

3.3 Theoretical Model Projection

The third procedure used to estimate the future gas production uses a biological SRT model applied to the future estimated influent biochemical oxygen demand (BOD). The BOD is a measure of the organic foodstuff available for digestion and gas production.

Future wastewater flow to the treatment plant was estimated using the linear extrapolations shown in Fig. 12. Using the average influent BOD concentration for 1978 and the future flow rates, the SRT model (Appendix A) was used to estimate the future gas production. The results of this approach are shown in Table 2.

Figure 12 Projected Treatment Plant Wastewater Flow

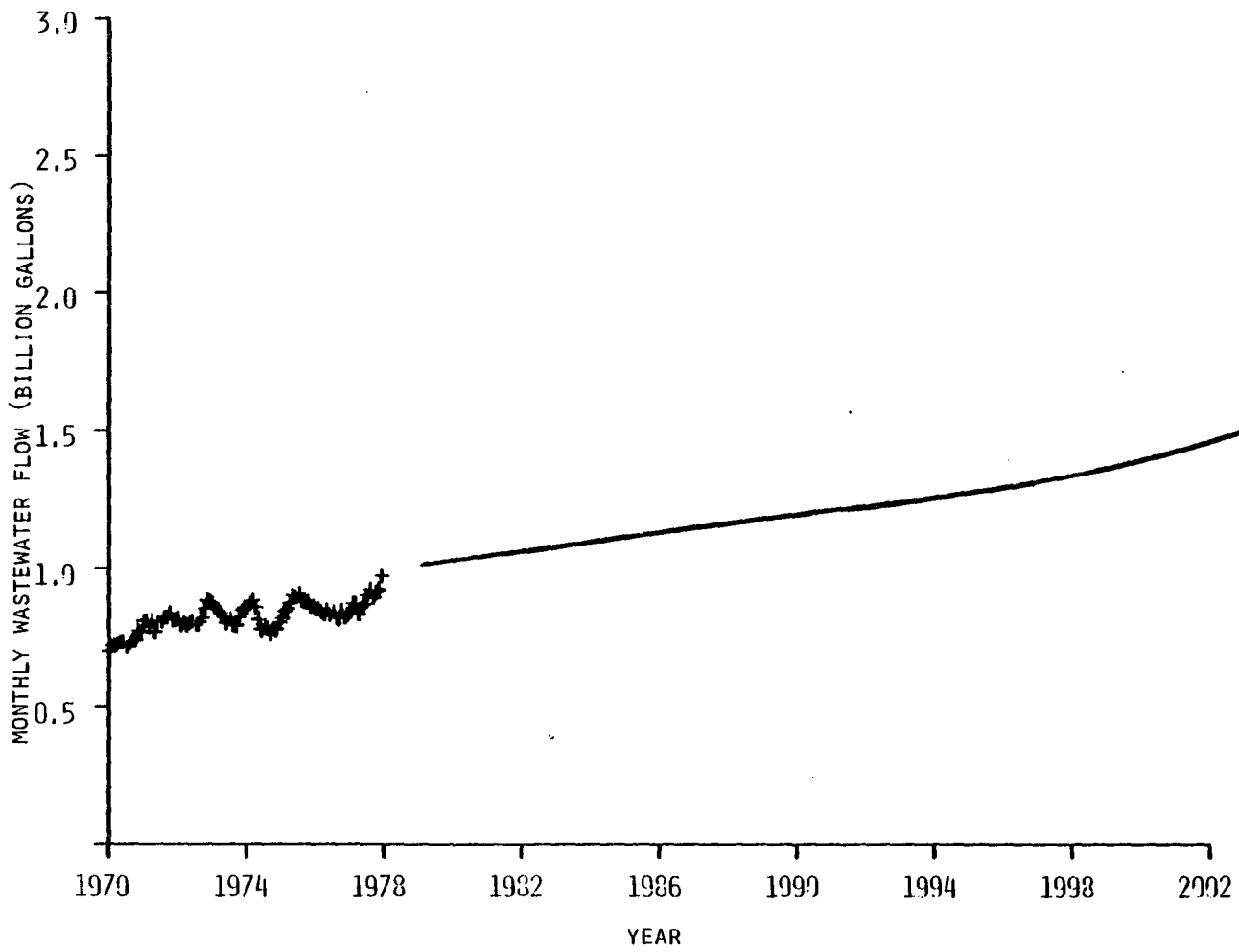


Table 2
PROJECTED THEORETICAL DIGESTER GAS PRODUCTION^a

| <u>Year</u> | <u>Flow Rate MGD</u> | <u>Digester Gas Production (cubic feet/day)</u> |
|-------------|--------------------------|---|
| 1980 | 33 | 217,000 |
| 1990 | 40 | 263,000 |
| 2000 | 47 | 309,000 |

^aSee Appendix A

Table 3 summarizes the results from all three techniques used to predict the future digester gas production.

Table 3
FUTURE DIGESTER GAS PRODUCTION

| Estimated Digester Gas Production (cubic feet/day) | | | |
|---|---|---|--|
| <u>Year</u> | <u>From Past Gas Production^a</u> | <u>From Projected Sludge Production</u> | <u>Theoretical^b SRT Model</u> |
| 1980 | 130,000 | 180,000 | 217,000 |
| 1990 | 130,000 | 206,000 | 263,000 |
| 2000 | 130,000 | 238,000 | 309,000 |

^a"No growth"

^bSee Appendix A

4. DIGESTER GAS UTILIZATION SCHEMES

There is a wide variety of methods to utilize the energy content in digester gas, ranging from complete waste burning of the gas to complex power and heat recovery schemes. Some methods that have been employed are listed below.

- Fired in hot water or low pressure steam boilers for digester and/or space heating. This is presently the method used in the Allentown Wastewater Treatment Facility.
- Fuel for on-site internal combustion engines with or without heat recovery systems to drive:
 - Pumps
 - Air compressors and blowers
 - Electric generators
- Clean, purify and compress the digester gas for:
 - Input to gas pipeline systems
 - Stationary internal combustion engines used as above
 - Cars, trucks and other mobile internal combustion engines.

Since this study was based on investigating electric power co-generation, the other possible uses were not studied further, however, it is advisable to keep some of these other potential uses in mind.

4.1 Potential Electric Power Generation Capacity

Internal combustion (IC) engines are available in numerous sizes, shapes and configurations. A fairly normal range of efficiencies that can be obtained is from 25 to 40%. Modern low-speed IC engines will commonly provide 35% efficiency.

A recent technical report by the U.S. Environmental Protection Agency (8) provides some generalized data for IC engine-generator sets. Based on this report, the input energy consumption is estimated at 11,400 BTU/KWH. Using 600 BTU/ft³ energy value for digester gas (Appendix B) the gas consumption would be 19 ft³/KWH. These figures are based on an input gas to output wire efficiency of 30%, comparable to the normal range of values to be expected (8).

Using the projected digester gas production values from Table 3, the potential power generation capacity at Allentown varies from 285 KW for current conditions (no growth) to year 2000 values of 522 KW (from sludge projection) or 720 KW (theoretical SRT projection). If generators were operated only during the peak demand charge period (7 AM to 7 PM), the potential capacity would be twice these values, assuming adequate gas storage capacity.

For comparison purposes, this study investigated an installed capacity range from 100 KW to 1000 KW, operating either 12 hour daytime periods or 24 hours continuously. In all cases, it was assumed that heat recovery systems would also be provided for digester and space heating needs.

4.2 Heat Recovery Systems

One of the major energy needs at a wastewater facility is the heat required for the anaerobic digester. Since all IC engines require a cooling system to dissipate the heat generated, it is possible to incorporate heat recovery systems that allow the heat rejected from the engine to be used to heat the digesters or other needs such as space heating. Heat recovery systems thus increase the overall energy recovery from the

digester gas fuel used in the IC engine. Figure 13 shows a general schematic of energy use and heat rejection in an IC engine-generator set (7,8).

The EPA report previously mentioned (8) considers 25% of the input digester gas energy as recoverable for heating purposes. As Fig. 13 shows, this is very conservative and a value of 30 to 40% is probably more realistic.

To provide a basis for comparison the heating requirements for 1977 were estimated from the operating data. The results of this relatively crude analysis is shown in Appendix C. The total heating requirements, both for the digester operation and space heating were estimated at 1.936×10^{10} BTU/year. This estimated value is quite conservative and probably would not change greatly over the years.

Based on the projected gas production values shown in Table 3 for the theoretical gas production the overall heat recovery system of an IC-generator system would need to function at 40% thermal energy recovery to satisfy the digester and space heating requirements. A thermal recovery of 68% would be required from the quantity of gas produced under the "no-growth" condition to satisfy the same heating needs. It will be necessary to properly define the actual heat requirements by design calculations, however it appears that the recovery of the heat rejected by IC-generator systems will be very close to satisfying all thermal needs in addition to the benefit from the electric power generated.

There are several aspects of the anaerobic digester design and operating that would warrant further investigation. First would be reduction of heat loss by more insulation, particularly in the digester floating covers. The second aspect would be to reduce the digester operating temperature slightly

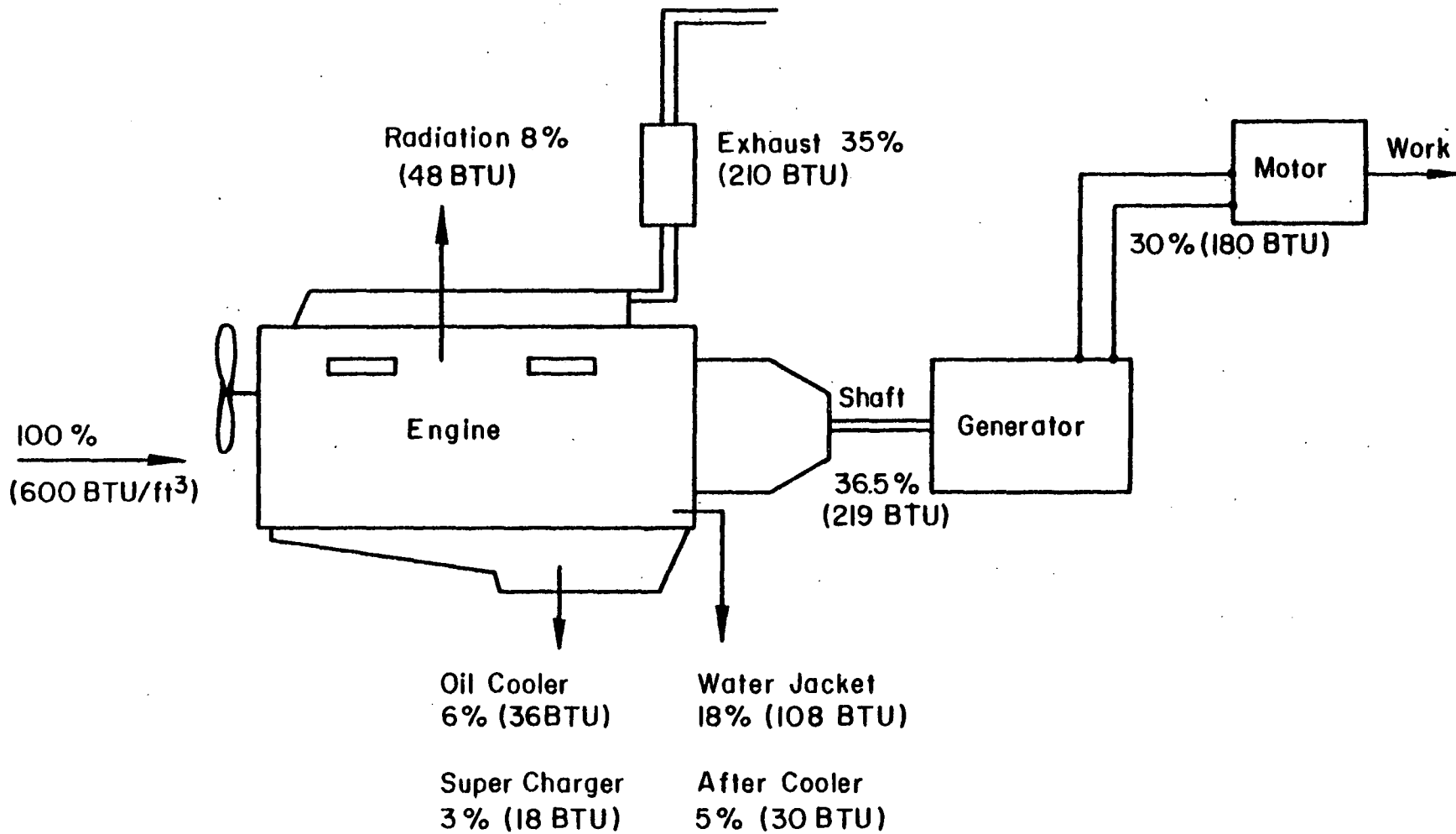


Figure 13 Energy Schematic for Engine Generator Set

during the coldest parts of the season. For a short two to four week period, this would have little impact on the efficiency of the digesters.

4.2.1 Heat Pumps - In addition to the heat recovery systems that could be incorporated into the IC-generator systems, another source of thermal energy to be considered is the actual heat content of the wastewater itself. Although information on design or practical operation of such systems is limited, the EPA report (8) does provide some information and guidelines from theoretical calculations and from the proposed installation at Wilton, Maine.

A heat pump operates on a refrigeration cycle so its components and circuit diagram are similar to a conventional refrigeration system. A refrigeration system operates in a cycle with the net result being the absorption of some heat at a low temperature (at the evaporator), the rejection of a larger amount at a higher temperature (at the condenser). A heat pump provides relatively cool temperatures at the evaporator (less than 45°F) and relatively warm temperatures at the condenser (greater than 90°F). The heat rejected at the condenser is available for either space heating or for digester heating. Work is done on the refrigerant by the compressor but there is a net energy gain by the system.

Based on the operating conditions outlined in the EPA report (8) for Wilton, Maine, estimates were made of potential water to water heat pump output at Allentown for the 1977 conditions. The results are summarized in Table 4.

Table 4
ESTIMATED HEAT PUMP OUTPUT^a

| <u>Month</u> | <u>Wastewater Temperature (°F)</u> | <u>Output (million BTU)</u> |
|--------------|--|---------------------------------|
| Jan | 61 | 180 |
| Feb | 59 | 177 |
| Mar | 59 | 177 |
| Apr | 60 | 179 |
| May | 61 | 180 |
| Jun | 65 | 184 |
| Jul | 68 | 190 |
| Aug | 69 | 191 |
| Sep | 69 | 191 |
| Oct | 67 | 189 |
| Nov | 66 | 187 |
| Dec | 62 | 182 |
| Total | | 2082 |

^aBased on 1977 conditions

The thermal energy to be derived from the wastewater is small compared to potential from the digester gas, however it is an additional source that should be incorporated into the overall energy consideration.

5. ECONOMIC ANALYSIS OF POWER GENERATION

This chapter evaluates the economic feasibility of electric power generation by using digester gas in IC engine-generator sets.

5.1 Present Electricity Costs

The cost of electricity supplied to the Allentown Wastewater Treatment Facility by Pennsylvania Power and Light (PP&L) is a fairly complex function dependent upon both the maximum 15 minute power demand (KW) and the total electrical energy use (KWH). The particular electric rate schedule used is termed LP4. A computer program (LP4) to calculate the monthly charge was obtained from PP&L personnel. The following input to the LP4 program was used:

Energy Charge - A value, adjusted monthly depending on PP&L generating capacity; zero (0.000) was used for this comparative study

Pennsylvania Tax Surcharge - 0.0737

Deferred Fuel Expense - \$0.001047/KWH

Tax Exemption - 0.06

Peak 15 minute power demand (KW) in billing period

Total energy use (KWH) in billing period.

The 15 minute power demand values (KW) for the Allentown Wastewater Treatment Facility were obtained from PP&L for the period April 1979 to March 1980. A separate computer program was written to analyze this raw data and to determine the required input values for the LP4 rate computation program, namely, peak (adjusted) 15 minute power demand (KW) and total energy use (KWH) over the monthly billing period. The LP4 program was then used to calculate the monthly charges and subsequently the annual electrical

cost to the City of Allentown was determined. Since no attempt was made to use the particular value for energy charge (LP4 input figure) each month, the results of this computation are comparative only. However, they are quite close to the actual billed electrical costs that Allentown had during this time period.

Both computer programs were used to calculate the cost benefit of on-site electric power generation. Different scenarios used generating capacities of 200, 400, 600, 800 and 1000 KW during the 12 hour daytime peak period (7 AM to 7 PM), and 100, 200, 300, 400 and 500 KW over the entire 24 hour period. In all cases, synchronized co-generation conditions were assumed.

The potential results of using these different sizes of generating units are shown in Fig. 14. There are two important aspects shown in Fig. 14. First, the benefit of extra electric power generation during the daytime period (when the peak 15 minute KW demand is more costly) is negligible compared to generating over the 24-hour period. The same amount of electrical energy (KWH) supplied over the 24 hour period would provide a similar cost reduction, yet require only one-half the installed generating capacity. Secondly, the relationship between annual electrical cost and on-site electric power generation is linear.

On-site electrical generating capacity operating continuously over the 24 hour period would save \$233/KW/year in operating costs.

5.2 Estimated Costs for Generating Capacity

The EPA technical report (8) previously mentioned provides some conservative cost figures for digester gas fuel IC engine-generator

**ONSITE
ELECTRICITY
GENERATION
CAPACITY , KW**

**12 hr.
Peak
Period**

**24 hr.
Period**

1000

500

800

400

600

300

400

200

200

100

0

0

100

150

200

250

300

ANNUAL ELECTRIC ENERGY COST , 1000 \$

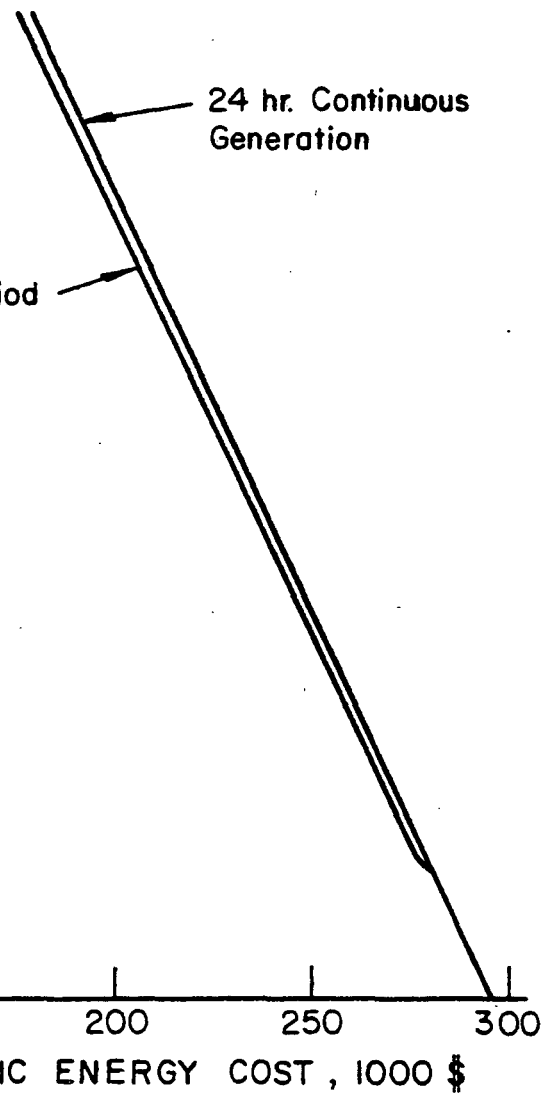


Figure 14 Comparative Annual Electric Energy Costs with On-Site Generation

installations. Estimated costs for 300, 600 and 1000 KW installed capacity are summarized in Table 5.

Table 5
COSTS FOR DIGESTER GAS ENGINE-GENERATOR SYSTEMS^a

| <u>Capacity (KW)</u> | <u>First Cost (\$)</u> | <u>Annual Operating and Maintenance Costs (\$/year)</u> |
|--------------------------|----------------------------|---|
| 300 | 300,000 | \$ 8,800 |
| 600 | 500,000 | 17,000 |
| 1000 | 790,000 | 21,000 |

^aBased on 600 rpm IC engine-generator sets with heat recovery and alternate fuel system, and gas storage using existing digester covers domes.

In addition to the costs shown in Table 5 taken from the EPA generalized data, a budget quotation was obtained from the American MAN Corporation. The quotation was for six co-generation units with an installed capacity of 1038 KW at a cost of DM 885, 000 (\$508,620). This reduces to an initial capital cost of \$490 per kilowatt installed capacity. This would indicate that the cost estimates based on the EPA data (\$790/KW to \$1000/KW) are reasonably valid and conservative.

5.3 Economic Comparison

The figures from this study show a potential reduction in operating costs of \$233/KW/year if the digester gas were used for on-site power generation. However, in order to obtain these savings, it will be necessary to invest in electric power generating capacity, not only first costs but also operation

and maintenance costs. Any savings in total plant operating costs must be adequate to pay off the additional investment required within a reasonable time period, certainly some time less than the physical life of the equipment.

The total annual costs for the different alternatives are shown in Table 6.

Table 6
ANNUAL COSTS FOR ON-SITE POWER GENERATING ALTERNATIVES

| Capacity (KW) | First Cost Debt Repayment ^a (\$/year) | O&M ^b (\$/year) | Total Annual Costs (\$/year) (\$/KW) | |
|------------------|---|-------------------------------|---|-----|
| 300 | 53,100 | 8,800 | 61,900 | 206 |
| 600 | 88,500 | 17,000 | 105,500 | 176 |
| 1000 | 139,800 | 21,000 | 160,800 | 161 |

^a10-year period, 12% annual interest

^bsee Table 5

Since the total annual cost of on-site power generation is less than the \$233/KW/year potential savings previously developed, all of the different power generation capacity installations would be economically feasible. The gas production rate appears to be the limiting factor in selecting the size of the generating capacity. The net savings increase with the size of the generating capacity installed and used.

6. DISCUSSION AND RECOMMENDATIONS

Using the conditions and values of this study, electric power co-generation at the Allentown Wastewater Treatment Facility appears to be economically justified. Throughout the study, conservative conditions have been used and it is highly probable that the net savings to the City of Allentown would be even larger than projected. There are several operational and design aspects that have large impacts on the gas production and merit further consideration.

Since so much of the digester gas energy (or other source) is used to heat the raw sludge and maintain the elevated digester temperature, it would seem valuable to minimize the water that is carried along with the waste solids. More effective concentration of the sludge solids by the clarifier withdrawal system and sludge thickeners will reduce sludge heating requirements and increase the effective detention time that the organic sludge solids will undergo biological degradation in the digesters. Not only would this reduce heat and sludge handling requirements, but it would also increase the amount of digester gas produced in the existing units.

Even though a somewhat higher value of $12 \text{ ft}^3/\text{lb}$ volatile solids destroyed was used in the projection of future gas production, the value is considerably less than the normal range of $15\text{-}18 \text{ ft}^3/\text{lb}$ volatile solids destroyed. Certainly the observed value of $8.5 \text{ ft}^3/\text{lb}$ volatile solids destroyed is very low and warrants further investigation. If the expected values were achieved, the gas production would essentially double the current rate and be 50% higher than the projected values. This investigation into the nature of the Allentown sludge and the expected unit gas

production value should be started immediately to verify or even better, to increase the power production potential.

The digester gas production results from biological destruction of "foodstuff". Although the organic material in wastewater is the usual "food", there are other sources. In particular, the biodegradable portion of garbage and other solid wastes could be utilized for feed stock to the digesters. The economic advantages of on-site co-generation would seem to favor a greater food supply to the digesters. Of course, the primary purpose of the digesters for wastewater processing must be upheld. However, it would appear desirable to determine other sources and investigate the feasibility of incorporating these waste materials in an energy recovery process.

The potential power generation capacity ranges from 285 to 720 KW based on different gas production projections. The comments above point out some areas of even greater potential that need to be investigated.

There are strong economic advantages and it seems advisable to proceed with design and construction of on-site power generating capacity. Since the actual installed capacity will be a blend of economic potential and pragmatic limitations, it is advisable to incorporate expansion potential in the plans to provide for any positive results of the above suggested areas of investigation.

In summary, the specific recommendations from this study are

1. Initiate development of plans for on-site co-generation capacity.
2. Investigate means to improve raw sludge thickening.
3. Study the nature and digestability of the Allentown sludge to determine an accurate gas production value for future utilization.

4. Determine the accuracy and precision of the digester gas meters to allow proper future planning.

7. REFERENCES CITED

1. Tchobanoglous, G. (Ed.), Wastewater Engineering, 2nd ed., McGraw-Hill Book Co., 1979.
2. Water Pollution Control Federation, Wastewater Treatment Plant Design, Manual of Practice No. 8, 1977.
3. Water Pollution Control Federation, Anaerobic Sludge Digestion, Manual of Practice No. 16, 1968.
4. U.S. Environmental Protection Agency, Sludge Treatment and Disposal, Vol 1 and Vol 2, EPA-625/4-78-012, October 1978.
5. Metcalf and Eddy, Inc., Report to Allentown Authority on the Design for Increased Capacity and Tertiary Treatment at the Allentown Wastewater Treatment Plant, November 15, 1971.
6. Daily and Monthly Summary Operating Records, Kline's Island Wastewater Treatment Plant, City of Allentown, Pennsylvania, January 1970-December 1978.
7. Johnson, R. L., Seminar on Digester Gas Utilization, Pennsylvania Energy Extension Service, April 13, 1978.
8. U.S. Environmental Protection Agency, Energy Conservation in Municipal Wastewater Treatment, EPA-430/9-77-011, March 1978.

APPENDIX ATHEORETICAL SRT ANALYSISAssumptions:

1. Ultimate biochemical oxygen demand (BOD_L) is 1.5 times BOD_5 .
2. Sources of BOD_L in the sludge.
 - $\frac{1}{3}$ Influent BOD_L settles in primary clarifiers
 - $\frac{1}{2}$ remaining BOD_L ($\frac{2}{3}$ of influent BOD_L) converted to biological cells (sludge solids).
 - Plant effluent BOD_L considered to be $\frac{1}{2}$ soluble BOD_L and $\frac{1}{2}$ cell (sludge) BOD_L .
3. SRT model constants
 - $Y = 0.05$ lb biological cells/lb BOD_L utilized
 - $k_d = 0.03$ days⁻¹
 - $\theta_c = 25$ days
 - $e = 0.80$ (digester BOD_L removal efficiency)

Data (1978):

Average Plant Influent Flow = 28 MGD

Average Plant Influent $BOD_5 = 164$ mg/l

Average Plant Effluent $BOD_5 = 24$ mg/l

Calculations:

1. BOD Load to Digesters

$$\text{Primary Solids } BOD_L = \frac{1}{3} (164) \times 1.5 = 82.0 \text{ mg/l}$$

$$\text{Secondary Solids } BOD_L = \left[\frac{2}{3} (164) - 24 \right] \times 0.5 = 42.7 \text{ mg/l}$$

$$\text{Total Solids } BOD_L \text{ to Digester} = 82.0 + 42.7 = 124.7 \text{ mg/l}$$

$$\text{Total Solids } BOD_L \text{ to Digester} = (124.7 \text{ mg/l}) \times 28 \text{ MGD} \times \frac{8.34 \text{ lb}}{\text{mg/l MGD}} = 29,100 \frac{\text{lb}}{\text{day}}$$

2. Digester Biological Solids Production:

$$\frac{dX}{dt} = \frac{Y \frac{dF}{dt}}{1 + k_d \theta_c}$$

where $\frac{dX}{dt}$ = net growth rate, lb/day

Y = growth-yield coefficient, lb/lb

$\frac{dF}{dt}$ = e (BOD_L) = rate of substrate utilization, lb/day

k_d = decay coefficient, days⁻¹

θ_c = mean cell residence time (SRT), days

The growth and decay coefficients are quite variable and should be determined experimentally. The growth coefficient can range from 0.054 for fatty acids to 0.240 for carbohydrates. Conservative values were selected for this evaluation

Hence:

$$\frac{dX}{dt} = \frac{0.05 \cdot 0.80 \cdot 29,100}{1 + 0.03 \cdot 25} = 665 \text{ lb/day}$$

3. Volume of Methane and Digester Gas Produced

The volume of methane produced by anaerobic digestion of the solids BOD_L can be evaluated from

$$C = 5.62(e \cdot \text{BOD}_L - 1.42 \frac{dX}{dt})$$

Hence:

$$C = 5.62(0.80 \cdot 29100 - 1.42 \cdot 665)$$

$$C = 125,500 \text{ ft}^3/\text{day}$$

The Allentown digester gas was found to be 65% methane (Appendix B) which fits the normal range of 60-70% methane.

Hence the total theoretical digester gas produced is:

$$\text{Digester Gas Production} = 125,500/0.65 = 193,100 \text{ ft}^3/\text{day}$$

APPENDIX BDIGESTER GAS ANALYSES

Gas samples were taken from the primary digester gas outlet on October 12 and on October 29, 1979. Both samples were analyzed for methane (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) in the Department of Chemistry GC/MS Laboratory at Lehigh University. The results were virtually identical and showed the digester gas to be 64.8% CH_4 , 35.2% CO_2 with H_2S less than 0.1%.

Based on stoichiometric oxidation of the methane (CH_4) in the saturated digester gas, the net heat value would be in excess of 600 BTU/cubic foot at standard temperature and pressure.

APPENDIX CSPACE HEATING REQUIREMENTS

A very rough estimate was made of the space heating requirements using the following.

$$H_D = 8.34 V_S (T_D - T_S) + K(T_D - T_A) \quad (1)$$

where: H_D = Digester heat requirements, BTU

T_D = Digester operating temperature, °F

T_S = Raw sludge temperature, °F

T_A = Ambient air temperature, °F

V_S = Raw sludge volume, gallons

The first term in Eq. 1 is the heat required to raise the raw sludge temperature up to the digester temperature. The second term in Eq. 1 is the heat loss from the digester to the ambient surroundings, both air and soil. The factor K is an overall coefficient incorporating digester volume, heat loss characteristics and all other factors.

The total heat requirements at the treatment plant are

$$H_T = H_D + H_S \quad (2)$$

where: H_T = Total plant heating requirements

H_D = Digester heat requirements

H_S = Plant space heat requirements

During the months of May through September, the space heat requirements are zero and since all information in Eq. 1 is known, except K, we can estimate the value of K. This value can be used in Eq. 1 and in Eq. 2 for the space heating season to estimate H_S , the space heat requirements.

Using the 1977 monthly operating data, together with the climatic data from the ABE Weather Observation Station, the various heating values were estimated. The results are summarized in Tables 7 and 8.

Table 7
ESTIMATE OF COEFFICIENT K
(1977 Data)

| <u>Month</u> | $H_D = H_T^a$ (million BTU) | K (million BTU/°F) |
|--------------|--------------------------------|-----------------------|
| May | 1220 | 9.26 |
| June | 1343 | 11.41 |
| July | 1191 | 14.00 |
| August | 776 | 2.81 |
| September | 1085 | 8.18 |
| Average | - | 9.13 |

^aBased on 600 BTU/ft³ x Digester gas used in boilers

Table 8

DIGESTER AND SPACE HEATING REQUIREMENTS
(1977 Data)

| Month | H_T (million BTU) | H_D^a (million BTU) | $H_S = H_T - H_D^a$ (million BTU) |
|-----------|------------------------|--------------------------|--------------------------------------|
| January | 3185 | 1645 | 1540 |
| February | 2185 | 1508 | 677 |
| March | 2155 | 1397 | 758 |
| April | 1788 | 1025 | 763 |
| May | 1220 | 1220 | 0 |
| June | 1343 | 1343 | 0 |
| July | 1191 | 1191 | 0 |
| August | 776 | 776 | 0 |
| September | 1085 | 1085 | 0 |
| October | 1501 | 1401 | 100 |
| November | 1342 | 1342 | 0 |
| December | 1691 | 1691 | 0 |
| Total | 19362 | 15524 | 3838 |

^aBased on $H_T = 600 \text{ BTU/ft}^3 \times \text{Digester gas used in boilers}$ and H_D taken from Eq. 1.