SUPPLEMENT FOR
PLAN NO. 858

ANAEROBIC DIGESTION SYSTEM AND
COGENERATION FOR DAIRY FARMS

By

R. W. Guest
R. K. Koelsch

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Summary: This publication provides supplemental information for plan no. 858. Some unique conditions involved with anaerobic digestion require special design features and material selection. This supplement details these unique conditions.
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INTRODUCTION

This supplement provides additional explanation of those concepts that relate to unique considerations due to anaerobic digestion technology. General considerations including safety, applicable codes, and material selection are discussed. This information is followed by a sheet by sheet description of applicable design, material, and safety considerations unique to an anaerobic digester.

Plan No. 858 is designed for a dairy located in a climate comparable to upstate New York that will supply the manure from 250 to 400 cow equivalents. A biogas production level of 17,000 to 30,000 cubic feet per day can be anticipated depending on herd size. If the current or planned number of cow equivalents does not fall between 250 and 400, modifications in the digester would need to be made that consider such concerns as manure retention time, heating requirements, digester cover size, etc. Consultation with professionals familiar with this technology is critical before modifications are made to Plan No. 858 to accommodate a dairy size for which this plan was not intended.

A digester should provide an average retention time of 20 to 30 days. The digester in this design has an approximate manure volume of 13,700 cubic feet. Table 1 details the approximate retention time of the digester illustrated in the attached plans assuming a daily manure production of 1.8 cubic feet per cow equivalent (1300 pound lactating cow).

<table>
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<tr>
<th>Cow Equivalents</th>
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<tr>
<td>200</td>
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<td>250</td>
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The plug flow digester illustrated in Plan No. 858 is designed to handle manure that is near to its original state as produced by the cow (all feces and urine mixed). Substantial additions of long hay or straw bedding will cause problems for a plug flow design. Dilution of the manure with water or milking parlor wastes also creates problems for a plug flow digester. If the manure entering the manure handling system is substantially altered from its original state as produced by a cow, consult with a competent professional as to the advisable use of a plug flow digester. The terminology related to this technology has not been standardized and may not be familiar to many contractors and farmers. Figure 1 illustrates the terminology used to describe various structural components of a plug flow anaerobic digestion system.
SAFETY

The anaerobic digester and cogenerator pose several safety concerns not common with other agricultural structures. The biogas contains 60% methane (primary constituent of natural gas), 40% carbon dioxide, and less than 1/2% hydrogen sulfide. Methane is flammable when mixed with air. Its lower flammability level in air is 5% by volume. Thus, one cubic foot of methane (or natural gas) mixed with 20 cubic feet of air can burn or explode. One cubic foot of biogas mixed with 12 cubic feet of air will also burn or explode. The greatest concern for a potential explosion is in a confined space such as the cogeneration building. Since methane is lighter than air, a continuous ridge vent in the cogeneration building is necessary to prevent accumulation of methane due to a possible gas leak. Monitoring equipment should also be installed near the roof of the equipment room of the cogeneration building to alert the operator of a methane accumulation exceeding a level of 1% by volume.

Hydrogen sulfide is immediately dangerous to life and health during exposures to 300 ppm (0.03%) for 30 minutes. At 50 ppm, anosmia, anoxia, headache, nausea, dizziness, vomiting, confusion, weakness, ataxia, irritability, and insomnia may occur. Rhinitis, pharyngitis, coughing, bronchitis, and pneumonitis are also possible. At 500-1000 ppm, coma, convulsions, and death may occur within 30 minutes. At extremely high concentrations, respiratory paralysis and death from asphyxia may be immediate. OSHA has established a maximum limit of 20 ppm for hydrogen sulfide in a working environment. A monitor of hydrogen sulfide designed to alert the operator of concentrations in excess of 20 ppm should be installed in the equipment room of the
cogeneration building. Since hydrogen sulfide is heavier than air, the gas sensor should be located near the floor.

Few opportunities exist for an explosive situation to occur within the digester. During the first few days of startup of a digester, air and biogas will both be present under the gas bag cover. During start up, vent all biogas from the digester for one week after the digester temperature reaches 80°F. Another situation for concern is when the gas bag is partially opened after the digester has operated. Be certain the gas bag and digester are well ventilated with air before working in the digester. The toxic effects of hydrogen sulfide during work inside a recently operated digester can linger even though sufficient air has ventilated the digester to prevent an explosion. Extreme caution should always be used when working in a digester.

There are many manufacturers of combustible and toxic gas detectors. Examples of manufacturers include:

1. Gas Detection Sales Group, Bacharach Instruments, 301 Alpha Drive, Pittsburgh, PA 15238, (412) 782-3500.
2. Sensidyne, Inc., 12345 Starkey Road, Suite E, Largo, FL 33543, (813) 530-3602.
3. GFG America, 8269 Brentwood Ind. Ct., St. Louis, MO 63144, (314) 781-2233.

Industrial safety equipment suppliers market gas detection equipment and can be found in most major cities.

**APPLICABLE CODES, REGULATIONS AND STANDARDS**

Chapter 5, Special Occupancies, of the National Electric Code should be reviewed by the electrical contractor. The cogenerator building would be considered a Class 1, Division 2 occupancy where "flammable gases are handled, processed, or used, but in which ... gases will normally be confined within closed containers, or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment; ...". Article 501 of this chapter describes electrical components appropriate for this application. Reference: National Electric Code 1987, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA 58, Storage and Handling of Liquefied Petroleum Gasses and NFPA 54, National Fuel Gas Code cover the requirements relative to handling, storage, and use of gaseous fuels. NFPA 54 does not apply to installations of farm equipment but it does provide the best available recommendations relative to handling gaseous fuels similar to biogas. The address for obtaining NFPA 54 and NFPA 58 is the same as that for the National Electric Code.

The New York State Uniform Fire Prevention and Building Code contains several sections discussing appropriate codes. Articles 10 and 11 of Chapter B address issues relative to heating, ventilation and air conditioning requirements, and electrical requirements addresses some topics appropriate for the cogenerator building. Chapter C on Fire Prevention should also be reviewed. The NYS Uniform Fire Prevention and Building Code is available from Division of Housing and Community Renewal, 2 World Trade Center, New York, NY 10047.
Article 21-106, New York State Energy Law, describes safety standards for controlling access to the cogeneration building and digester. These standards can be met if the building can be secured, an appropriate fence encloses the digester, and entrances to the cogeneration building are posted with a sign bearing the legend:

CAUTION: POTENTIALLY DANGEROUS EQUIPMENT
ADMITTANCE TO
AUTHORIZED PERSONNEL ONLY

These regulations can be obtained from the New York State Energy Office, Bureau of Codes and Standards, Two Rockefeller Plaza, Albany, NY 12223.

CONSTRUCTION MATERIALS

Materials used with the anaerobic digester and cogeneration building are subject to certain unique conditions. Any components exposed to the biogas (e.g. gas handling system, parts of the preheat chamber, digester and effluent chamber above manure level) are subject to highly corrosive conditions. Biogas contains hydrogen sulfide and water vapor which combine to produce a dilute sulfuric acid. Iron and steel products corrode rapidly in this environment. Substitutes for metal fasteners, iron piping, and steel supports are suggested where practical. PVC is suggested for gas plumbing that is below ground. Codes require steel gas piping above ground due to its ability to withstand mechanical damage.

The high humidity in the space above the manure also can cause deterioration of wooden products. A foundation of marine grade plywood and pressure treated lumber should be used for the panels covering the preheat chamber and the cover of the effluent chamber. The inorganic arsenicals (e.g. copper chromate arsenate) are the only recommended preservatives. Creosote and pentachlorophenol are not recommended due to their potential for entering the food chain. Paints and adhesives should also be selected that will withstand constant exposure to moisture.

Below the surface of the manure, the corrosive effects of biogas have not been observed. Black iron piping for heat grids and standard steel products for grid supports or other applications are acceptable. When two metals are in contact, select similar materials to avoid galvanic action. PVC and pressure treated wood have also proved acceptable for use below the surface.

The cogeneration building will also be exposed to slightly more corrosive conditions than other farm structures. Wood construction is acceptable. Aluminum siding and roofing will likely last longer than steel products. Copper components will corrode. Copper plumbing should be avoided. Electrical contacts, wiring, and motors will all show signs of corrosion on copper components and should be protected as much as possible. This is part of the reason for moving electrical components into the control room and the use of constant positive ventilation. Gas tight electrical boxes are recommended by the National Electric Code for the equipment room and might be considered for all electrical installations associated with the digester.

SHEET 1: PLAN AND SECTION VIEWS OF ANAEROBIC DIGESTER

Digester bypass: It is essential to provide an alternative means of moving the manure from the barn to the manure storage. The inflow pipe should be equipped with a "Y" and two bypass control valves appropriately placed to provide for bypassing the manure during
"down" periods and draining the preheat chamber. Draining of the preheat chamber can be accomplished by allowing manure to flow backward through the entrance pipe and then through the bypass pipe. Elevation or location of the "Y" or the choice of smaller diameter manure piping may prevent preheat chamber emptying. Alternative arrangements will be necessary to allow for draining the preheat chamber.

Preheat chamber: An external preheat chamber (see sheet 2) and an alternative internal preheat chamber (see sheet 10) designs are provided. Locating this chamber completely outside of the gas collecting chamber allows for easy cleaning and repair without the need to uncover the main digester and shut down gas production. An internal preheat chamber provides a shorter structure, and possibly a less expensive alternative, but is less accessible for repair and cleaning. Manure with even slight amounts of inorganics such as sand, dirt, or gravel will require occasional removal of these materials from the preheat chamber. Heat exchanger pipes may also require occasional cleaning.

Heating: Three inch diameter black iron pipe (see Construction Materials Section) serves as the heat exchanger to heat and maintain the manure at 100°F. Water is moved between the equipment building and digester by 2 inch black iron pipe. To promote even heating of the manure, the hottest water entering the preheat chamber should be directed to the side opposite the hottest water entering the digester heating grid. This design utilizes full 21 foot lengths of pipe for all heating grids, thus minimizing field cutting and threading of the large pipe. Rubber hose bends (180°) would be desirable if they can be obtained. If not, street L's can be used at each end of the pipe and appropriately connected with a straight hose section and stainless steel hose clamps. Two 90° rubber bends with connector nipple are also acceptable. Rubber connections are desirable for ease of installation and maintaining flexible joints. A pressure leak test using 15 psi should be conducted before charging the digester with manure.

Gas collection pipe: A three inch PVC must be anchored to the digester wall (see Detail B, Sheet 6). It is intended that this pipe exit the digester wall in the same proximity as the heat exchanger pipes.

**SHEET 2: PREHEAT CHAMBER**

The purpose of the preheat chamber is to heat manure from ambient temperature to about 80° F by circulating hot water through 24 full lengths of three inch black iron pipe. Note that the bottom two pipes of the two middle vertical grids have been shortened to allow greater clearance at the manure inlet pipe. If the manure inlet pipe is at any other point, (e.g. near corner or at a 90° angle to the chamber) the vertical grid closest to the entry point should be shortened. Note both entrance and exit heat exchange pipes exit through the wall at the same proximity.

The manure surface height in the preheat chamber will generally be controlled by the height of the internal block wall near the exit of the preheat chamber. It must be sufficiently high to maintain a manure level above the heating pipe. However, due to the manure surface gradient that can result during loading of cold manure, a minimum of two feet of clearance between the top of the internal block wall and the top of the preheat chamber exterior walls is suggested to prevent manure spills near the entrance of the preheat chamber.

If manure cannot flow from the preheat chamber to the digester as rapidly as it enters the preheat chamber, the potential for a manure spill exists. The elevation difference between the preheat chamber and the digester, as well as maintenance of the manure level within the digester at the prescribed level, provide the necessary head difference for moving manure.
The size of the opening between the preheat chamber and digester is also important for insuring sufficient flow.

**SHEET 3: DIGESTER**

The heating grid in the digester is designed to heat manure from 80°F to a final temperature of 100°F and hold the manure near this temperature. Twenty-four lengths of three inch black iron pipe provide the necessary heating surface.

Three control joints have been placed on the digester's long walls at 22 foot intervals. Each joint is supported with a pilaster (also see Detail C, sheet 6). The number and spacing of these joints can be increased for convenience of pouring concrete. Fewer than three joints per wall is not suggested.

**SHEET 4: DIGESTER WALL SECTION**

Concrete walls are designed to utilize standard eight inch wall forms. *Inward forces on the wall will increase and the reinforcing schedule will need to be modified if*:

1. the ground water is not drained from the earthen backfill;
2. backfill exceeds the height shown;
3. the gas bag is not allowed to rise at least six feet above the top of the wall;
4. gas pressure is allowed to exceed 12 inches H₂O; or
5. digester width is increased.

Special effort will be necessary when pouring the wall to obtain a "true - flat" surface upon which to lay the 1/2 inch high density rubber strip (e.g. cow mat material). Additionally, placement of anchor bolts and their alignment with holes in the channel iron for clamping down the gas bag will require special attention as the concrete is poured. Note that anchor bolt spacings are detailed on sheet 7. Anchor bolts can be placed as shown or turned 90° in line with the wall. A 1.5 inch concrete covering of all anchor bolts and rebar is suggested.

The gas bag is designated as a 30 oz. Shelter-Rite XR-5 (8130), a product of the Seaman Corporation (Box 331, Millersburg, Ohio) or equivalent. Fabric must have a minimum tensile strength of 100 pounds per inch of fabric length. It should also be resistant to ozone, moderately acidic conditions, and high humidity or constant submersion in liquid. If exposed to sunlight for extended periods ultraviolet resistance is also desired. Seams must run from side to side (the short dimension). Outside plastic cover (10 mil - PVC) is not gas tight, it is only for mechanical and weather protection of the insulation and gas bag. This cover must be resistant to ultraviolet light and ozone. Placement of fiberglass blanket insulation and the weather cover should not be attempted until after the gas bag has been inflated.

**SHEET 5: EFFLUENT CHAMBER**

The effluent chamber can be constructed from concrete blocks as shown or poured as an integral part of the end wall. If blocks are used, at least two layers of dura-wall reinforcing should be used in the top half of the chamber wall. The effluent chamber can be used as a pumping chamber if gravity out-flow is not possible. Check the size of the pump to be used and make dimension changes in the effluent chamber if necessary.
Digester drain: A commercial or fabricated guillotine valve (12 inch diameter minimum) can be used for draining the digester. Since operation of this valve will be infrequent, a hand operated lever action is suggested. After a long period of inoperation, the valve should be opened carefully in small increments to insure closability. It is suggested that a 1/2 inch polycarbonate (plastic) plate be used in place of steel for the guillotine to reduce the corrosive bonding between sliding parts.

Effluent chamber trap wall height: The trap wall in the effluent chamber should not exceed the height of the digester discharge hole by more than 12 inches. This height differential acts as a safety release valve that will not allow the gas pressure to exceed 12 inches of water pressure.

Discharge wall height: The discharge wall in the digester controls the level of manure in the digester. It is desirable to maintain the manure height above the joint between the exterior concrete walls and the flexible gas bag. This will insure a "wet seal" minimizing the likelihood of a gas leak at this location. Leaks will appear as a visible manure leak. The two side walls of the digester trap shall be at least two inches above the digester's exterior walls. The front wall of the discharge should be an additional two inches higher than the side discharge walls to encourage manure flow from the sides which will minimize short circuiting of manure flow within the digester. These features will insure a manure depth of at least two inches above the concrete wall/gas bag joint at the effluent end of the digester. Due to manure's viscosity, the influent end of the digester will have a manure depth about one foot greater than the effluent end.

SHEET 6: GRID SUPPORT, WALL PILASTER, AND PREHEAT CHAMBER COVER DETAILS

The plywood cover panels are commercially available but special attention must be given to their construction. With the design shown, either side can be subject to the manure surface and the saturated air in the preheat chamber. Do not cover the panels with a sheet of plastic, as this will trap moisture above the panels and will not allow them to dry on the top side. Wood doweling of joints is preferable to nailing. Turning these cover panels over periodically should increase their life.

SHEET 7: DIGESTER COVER INSTALLATION

Support for the cover is necessary as it is being moved into place and clamped down. If installed during the summer, the digester may be filled with manure to give support to the cover. This method is not advisable for cold weather installation of the cover due to the high heating requirements for attaining operating temperature. A temporary support structure that can be removed after the gas bag is clamped to the side and end walls, but prior to clamping to the corners, will be needed.

SHEET 8: EQUIPMENT BUILDING

Interior wall: Noise, heat, and, air contaminants in the equipment room should be isolated as much as possible from the control room. The purpose of the interior wall is to physically separate the equipment room from a clean control room. The use of pressure ventilation in the control room and natural ventilation in the equipment room with continuous open ridge vent will minimize air contaminants in the control room. An open
ridge is also desirable for preventing an accumulation of methane gas and excess heat in the equipment room.

Wood construction is preferred because of the corrosive effect of ammonia and H2S on steel and many other metals. The control room should be fully insulated on all sides for acoustical reasons and heat control. Insulation of the equipment room is optional.

Electrical systems: Air contaminants resulting from a gas leak, engine exhaust, and nearby manure storage can cause rapid corrosion of electrical components (especially copper components). For this reason the control room will provide a more suitable location for electrical systems and engine controls than the equipment room.

COGENERATOR SELECTION

The selection of the engine generator set (called cogenerator) for converting biogas to useful electric and heat energy is a critical decision. When selecting a cogeneration system, consider the following three key issues:

1. Unit durability. The engine generator will accumulate in excess of 8,000 hours each year (equivalent to about 400,000 miles on an auto engine).
2. Electrical energy efficiency. Small increases in the efficiency of converting biogas to electricity will substantially improve the financial return of the total biogas system. For this reason, the selection of the engine-generator set that will operate above 75% of capacity continually is desired.
3. Availability of service. Local availability of parts and repair personnel is critical to minimizing down time.

The following discussion is a brief summary of the important features to be considered for each of the four major components of the cogenerator.

Engine: The engine should be a heavy duty industrial engine designed for continuous operation. It should include a large oil sump with the ability to add oil on the go. The key problem related to the use of biogas in an engine has been the accumulation of sulfur and moisture in engine oil causing corrosive conditions. This concern will be controlled both by selection of the engine and management of the engine’s lubrication program.

The desired compression ratio for most efficient operation is between 11 and 16 to 1. Commercial units with a compression ratio of 10 to 1 (units designed for LP-gas and natural gas) are more readily available. A gas carburetor similar to systems used for natural gas is required. The carburetor should have sufficient capacity to deliver adequate gas containing 540 BTU per cubic foot at six inches of water pressure (operating pressure of the digester). Approximately 30 cubic feet per hour of biogas must be delivered to the engine per kilowatt of cogenerator capacity. This requires that the carburetor deliver almost twice the volume of fuel to the engine as would be required for natural gas operation. It is recommended that carburetion capacity be oversized rather than boosting gas pressure with mechanical compression. Filtering of the biogas for particulate matter is also suggested.

Generator: Paralleling with the utility requires the use of an induction generator. This allows for the purchase of electricity during peak farm power requirements and provides a market for electricity when farm use is minimal. These units cannot be operated as a standby generator similar to more standard synchronous generators.

Utility personnel should be involved from the initial stages of planning for any engine generator to be operated in parallel with a utility power grid. A clear understanding of their
safety requirements is essential. Utilities will commonly require a lockable disconnect switch constantly accessible to utility personnel and protection relays on the generator for over-voltage, under-voltage, over-frequency, under-frequency, and a synchronism check relay.

Heat recovery: Heat should be recovered from the engine water cooling system and the engine exhaust with commercially available heat exchangers. Oil coolers can also be added but their contribution to the heat recovery is modest.

The heat recovery system should also include a means of dumping heat. A radiator and fan sized to dissipate all coolant and exhaust heat is suggested. The additional heat from the exhaust will require a radiator that is about 50% larger than would normally be matched with an engine. For summer operation, it is desirable to bypass the exhaust heat exchanger and thus minimize the run time of the radiator fan, unless the heat is being utilized.

Controls: An adequately designed control package should try to anticipate all potential hazards occurring during unattended operation. It should also be possible for the operator to easily check each control for proper functioning. Common engine controls will shut the unit down due to high coolant temperature, low coolant level, low oil pressure, low oil level, low gas pressure, and engine over-speed. Several of the generator control requirements were discussed previously. The generator should also be protected against reverse power (induction generators can act as induction motors), over current, and ground faults.

In addition, controls are needed that will match engine generator load with digester gas production. Control packages are available that will automatically adjust throttle position with changes in gas pressure. Some systems also include controls that will shut the engine down at preset low gas pressures and restart it automatically at higher gas pressures. However, it is preferable to run the engine continuously.

Sizing of the cogeneration unit to the digester's gas production is critical to maintaining efficient operation. Over-sizing a unit will reduce income. Sizing to allow around-the-clock operation is also suggested to minimize the corrosive effects of the sulfur in the biogas and to eliminate the need for gas storage equipment. A rule of thumb of one kilowatt of cogenerator capacity per 10 lactating cows is a reasonable starting point. If potential gas production has been estimated, the cogenerator should have one kilowatt of capacity per 600 to 650 cubic feet of daily raw biogas.

To help maintain efficient operation, the system should include meters for gas consumption by the engine and electricity production by the generator. A comparison of these two numbers represents critical information for the management of the cogeneration unit.

Finally, it will be important to establish contact with a local mechanic and involve this individual in the installation of the cogenerator. Cogeneration equipment designed for biogas systems is available from only a few suppliers. Because of the regularity at which major overhauls and other maintenance will occur on an engine operating 8,000+ hours per year, knowledge of a system by a local mechanic is highly recommended.

BACK UP BOILER SELECTION

A back up boiler is necessary for initially heating the digester and maintaining the digester when the engine is down. It is desirable to have a boiler that will burn both LP-gas and biogas. Operation on biogas should only be for short periods of time due to the highly corrosive effects of hydrogen sulfide on boiler heat exchangers. Biogas has only about
25% of the energy per unit volume as does LP-gas (540 vs. 2,280 BTU per cubic foot). If the same gas orifice is used for both fuels, the boiler, when burning biogas, will deliver only 25% of its rated heat output for LP-gas operation. The boiler should be capable of delivering a minimum of 150,000 BTU per hour. If the same orifice is used for both fuels, a boiler rated at 600,000 BTU/hr on LP-gas is required.

**INSTRUMENTATION SELECTION**

Knowledge of key performance parameters is critical for safe and efficient operation of the digester and cogenerator. Monitoring equipment should perform the following functions:

1. alert operator to the accumulation of methane and hydrogen sulfide in the engine room (see safety discussion);
2. measure gas production by the digester and gas consumption by the engine;
3. measure electrical production by the cogenerator;
4. measure digester operating temperature;
5. measure heating system water temperature;
6. measure biogas CO₂ content; and
7. measure water flow.

Gas volume measurements should be made of digester biogas production and the cogenerator biogas consumption. Under some circumstances, these two measurements will differ and thus both measurements are recommended. Biogas contains moisture, particulate matter, and hydrogen sulfide which will render most gas meters inoperative within a short period of time.

A positive displacement, rotary type Roots TM gas meter or comparable meter has been successfully used with this application. It is critical that the specifications for a gas meter detail the presence of hydrogen sulfide (2,000 to 6,000 ppm) and condensate in the biogas. The meter should be capable of handling gas flow rates of up to 1500 cubic feet per hour at atmospheric pressure. Other features such as temperature and pressure compensation are generally not needed unless pressurized biogas (greater than one psi or 28 inches of water column) is being measured or biogas is being sold. Roots gas flow meters can be purchased from Dresser Industries, Inc., P.O. Box 42176, Houston, Texas 77242, 713/972-5000.

Total electrical production by the cogenerator should be measured to provide an indication of cogenerator performance. A kilowatt-hour electric meter compatible with the generator’s rating for voltage, amperage, and number of phases should be installed. Other meter features such as peak demand are not needed. Local utility representatives can recommend sources of a meter for this application.

Temperature measurements should be made at ten or more locations in the digester and water heating system. It is suggested that within the digester, temperature should be measured (see sheets 2 and 3):

1. near the manure entrance to the preheat chamber, (T1, and T2);
2. within the drop structure between the pre-heat chamber and the digester, (T3 and T4); and
3. near the end of the heating grid in the center of the digester, (T5 and T6).

Avoid locations within one foot of heating pipe. Duplicate (two) temperature probes should be used for each location within the digester.
Temperature probes should also be located within the supply and return lines (see sheet 9) of the:

1. domestic and farm water and space heating loop (T7 and T8);
2. preheat exchanger loop (T8 and T9); and
3. maintenance heat exchange loop (T9 and T10).

It is recommended that the temperature probes consist of a 20 gauge copper-constantan thermocouple wire with either polyvinyl chloride or Teflon insulation. The end of the thermocouple wire can be fashioned into a temperature probe by removing about 1/2 inch of insulation and coupling the two exposed wires with electrical solder. This point of contact between the two wires is the only point at which temperature is measured. The end of the wire with the soldered joint can be left exposed or placed into a short length of flexible copper tubing with both ends sealed with silicon seal. A six inch piece of copper tubing in conjunction with a compression brass fitting provides a temperature probe that can be placed into a water line. For measuring manure temperature, a 1/2 inch steel pipe can extend through the digester's wall three feet. The pipe should be sloped downward into the digester and the end in the manure capped. Fill the pipe with water. The thermocouple probe is inserted into the pipe for measuring manure temperature. It can also be easily removed for checking or replacement.

A digital thermocouple thermometer and a ten point or greater selector switch is recommended for reading temperatures. This device should be located in the control room. Products can be purchased from several suppliers such as Omega Engineering, Inc., P.O. Box 4047, Stamford, CT 06907-0047 (203/359-1660).

Gas quality should be checked for methane content regularly. Biogas is primarily carbon dioxide and methane. Carbon dioxide can be measured inexpensively and methane determined by subtraction (100% - % CO₂ = % methane). A small valve and connection for 1/2 inch plastic tube should be included in the gas piping in the engine room. A Bacharach Pyrite Gas Analyzer for measuring carbon dioxide or equivalent is available from Bacharach Instruments, 625 Alpha Drive, Pittsburgh, PA 15238 (412-963-2000).

Water flow should be measured at two locations. A flow meter in the water supply line for the heat distribution loop will provide an indication of water leaks. A second water meter in the heat distribution loop will give an indication of water flow rates through all heat exchangers since they are operated in series. Water meters can be obtained through plumbing suppliers.

**SHEET 9: SCHEMATIC OF GAS AND WATER PLUMBING AND ELECTRICAL SYSTEMS**

The gas system is designed to operate at six to eight inches of water pressure (12 inches maximum), which is sufficient to operate a properly carbureted engine without additional gas compression. The gas collection pipe must slope down to a drain located at all low points in the system. At these low points, locate a condensate drain. Two likely low point locations are: 1) where the gas collection pipe exits the digester wall, or 2) where it enters the engine-room. The low point water traps must be accessible and checked frequently. Gas is collected and transported to the cogeneration building via a three inch PVC pipe. Smaller (two inch) pipe can be used in the engine room. Black iron pipe should be used above ground in the cogeneration building to provide greater mechanical protection.
Inside the equipment room, a mechanism for controlling the maximum operating pressure for the gas system is suggested. The pressure regulated relief valve should vent biogas when pressure exceeds ten inches water column.

The gas line may collect organic solids and residues from iron piping degradation. It is recommended that hose connections to the gas pipe and a shut off valve be installed in the engine room and at the exit of the pipe from the digester for the purpose of flushing this line with water if such problems occur. Gas meter problems can often be corrected by flushing with water.

Filtering of the biogas prior to its use in an engine has limited value. A particulate filter (optional) would be of greatest value due to the level of particulate matter carried by the biogas. Filters similar to air filters on an engine should provide satisfactory filtration and reduce engine wear. Any particulate filter must be easily accessible to the operator due to the frequency of maintenance requirements. Several types of filters are also available for removal of various corrosive sulfur compounds from the biogas. Unless the biogas is to be burned regularly in a boiler or water heater, the value of filters for sulfur removal are questionable.

Water system: The circulating hot water system is designed to permit isolation of any individual loop without interference to the rest of the system. Two inch piping should be used in the control room and to and from the digester. The loop for domestic and farm space and water heating may be two to three inch pipe depending upon the distance between the equipment building and home or dairy. Insulate all heated water piping in the equipment building and lines to the digester, home, and dairy. Three inch black iron pipe is used inside the digester and preheat chamber. A flow rate of 20 gallons per minute should be considered a minimum. Table 2 indicates the estimated head loss (feet of water pressure) for sizing the required pumps.

Table 2. Estimated head loss in water piping for various heating loops associated with utilization of the cogenerator's waste heat.

<table>
<thead>
<tr>
<th>Heating Loop</th>
<th>Head Loss - Feet of Water Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 GPM</td>
</tr>
<tr>
<td>Maintenance Heat Loop¹</td>
<td>5.0</td>
</tr>
<tr>
<td>Preheat Chamber Loop¹</td>
<td>5.3</td>
</tr>
<tr>
<td>Domestic &amp; Dairy Loop</td>
<td></td>
</tr>
<tr>
<td>(3.0&quot;pipe)</td>
<td>0.6 + 0.005 x D</td>
</tr>
<tr>
<td>(2.5&quot;pipe)</td>
<td>1.6 + 0.020 x D</td>
</tr>
<tr>
<td>(2.0&quot;pipe)</td>
<td>3.9 + 0.039 x D</td>
</tr>
<tr>
<td>(D=distance in feet between cogeneration building and home or dairy)</td>
<td></td>
</tr>
</tbody>
</table>

¹Assume 75 feet between digester and cogeneration building.

Electrical system: The electric utility should be contacted for suggestions and review of all proposed electrical plans prior to construction. Plans shown are for an induction generator only. This type of generator cannot be used for stand-by power. An optional panel for connecting a stand-by generator is shown. The electrical circuit for the cogenerator should have a capacity to handle up to 50 KW at a power factor of 0.8. For a single phase 240
volt electrical service, a current of 260 amps can be expected. All electrical work should be performed by a licensed electrician.

SHEET 10: OPTIONAL PREHEAT AND EFFLUENT CHAMBER

The optional preheat chamber shown, would likely be more economical than the original design. However, the gas cover would need to be removed for maintenance and/or repair. Also because of configuration, all pipes would need to be cut and threaded. In this design the manure would simply flow over the wall between the preheat chamber and the digester.

The optional effluent chamber utilizes an eight foot length of conventional 18 or 24 inch concrete or PVC pipe. The horizontal section, elbow, and riser could be 18 or 24 inch PVC with an appropriate support. The top of the riser in the effluent chamber should be 12 inches above the top of the horizontal section so as to allow venting of the biogas if the pressure reaches 12 inches water pressure. The top of the concrete pipe in the digester should be two inches above the top of the wall.

REFERENCES

Partial Listing of Resource People:

1. Extension Agricultural Engineers at a Land Grant University. In New York, contact Richard Guest or Rick Koelsch, Department of Agricultural and Biological Engineering, Cornell University, Ithaca, NY 14853.
2. Mr. David Friederick and Dr. Richard Vettor, Product Manager, A. O. Smith Harvestore Products, Inc., 345 Harvestore Drive, Dekalb, IL 60115.
3. Dr. Stanley Weeks, Agway Research Farm, R. D. 2, Tully, NY 13159.

Selected References:
