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Heat Treatment/Low Pressure Oxidation Systems:

Design and Operational Considerations

HEAT TREATMENT/LOW PRESSURE OXIDATION SYSTEMS: DESIGN AND OPERATIONAL CONSIDERATIONS

by

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This document is condensed from an EPA research report entitled "Improving Design and Operation of Heat Treatment/Low Pressure Oxidation Systems", which will be available in late 1985. That report has been subjected to the United States Environmental Protection Agency's peer review. This document has undergone an EPA administrative review and has been found to be consistent with the EPA research report referenced above. The information in this document is made available for the use of the technical community. The information contained herein does not constitute EPA policy, guidance or directive. Design engineers, municipal officials, and others are cautioned to exercise care in applying this general information to particular circumstances of individual wastewater treatment facilities. EPA assumes no responsibility for use of this information in a particular situation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The construction grants program of the U.S. Environmental Protection Agency (EPA) has provided financial assistance to many municipalities to construct new and expanded wastewater treatment facilities. As more municipal wastewaters are treated to higher levels, there has been an accompanying increase in the amount of sewage sludge that must be treated and disposed. This has stimulated the search for improved technologies to treat these sludges in a cost-effective way.

Thermal conditioning of sludge to improve dewaterability was first used in municipal wastewater treatment facilities in the late 1960s. Over the years, however, thermal conditioning processes have experienced a variety of serious design and operational problems that have compromised process performance and raised questions as to the suitability for use in municipal wastewater treatment facilities. EPA's Water Engineering Research Laboratory in Cincinnati, Ohio has undertaken a study of thermal conditioning processes to identify the nature and extent of these problems, to identify possible problem solutions, and to determine the applicability of the process for use as part of a sludge treatment system in a municipal wastewater treatment facility.

This summary document is based on that EPA study and is intended to provide a basic understanding of thermal conditioning processes, as well as concise information on design considerations, operational characteristics, and process and equipment problems and possible solutions. The document will be useful to design engineers, governmental agency review personnel, municipal officials, operators, and others who are considering using thermal conditioning in a sludge treatment train, or who are concerned with optimizing the performance of an existing thermal conditioning system. Whether for design or operating decisions, the information in this summary will supplement detailed guidance available elsewhere. As in all comparative analyses, process applicability to a particular wastewater and effective integration into a total treatment system should be considered, along with the associated costs, before any thermal conditioning process is selected.

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SECTION 1

INTRODUCTION

In recent years the quantities of sludge produced in wastewater treatment plants have increased substantially as a result of improved treatment efficiency. As the volume of sludge production has increased, the need for more efficient means of dewatering sludges has become a growing concern. Wastewater sludges are difficult to dewater, at best. Both the rate and extent of sludge dewatering may be enhanced by thermal conditioning of the sludge before the dewatering process.

PURPOSE

This design information summary report presents data and best practices relating to the design and operation of thermal sludge conditioning systems. It is based on an investigation which evaluated the causes for operations and maintenance problems experienced with thermal sludge conditioning systems. The data contained in the report were obtained from technical literature, discussions with manufacturers, and telephone inquiries and site visits to municipal wastewater treatment plants. This document presents process and equipment descriptions, operational characteristics, process selection and application information, common problems and solutions, and design and operational considerations relative to heat treatment and low pressure oxidation of sludge.

The purpose of this report is to concisely summarize available thermal conditioning design and operational information, thereby providing a general understanding of the thermal sludge conditioning process as well as its proper application in a sludge handling system. The report is not intended as a detailed design guide or as a replacement for other design guides available from manufacturers or technical information contained in published literature. Detailed discussions of particular topics are contained in the original investigation document (1) and in the references cited within the text.

BACKGROUND

Thermal sludge conditioning is a continuous flow process in which sludge is heated to temperatures in the range between 350°F and 400°F in a reactor under pressures of 250 to 400 psig for 15 to 40 minutes. There are two basic modifications of the thermal conditioning process employed in wastewater treatment. One modification, Heat Treatment (HT), does not include the addition of air to the process. In the other modification, Low Pressure Oxidation (LPO), air is added to the process. Both thermal conditioning processes produce a biologically stable sludge with excellent dewatering characteristics.

Heat Treatment

The heat treatment process was developed by William K. Porteous in England during the period of 1932 to 1953. The process went through several design modifications during this period and ultimately was patented by the firm Norstel & Templewood Hawksley as a continuous flow process using steam injection. Norstel & Templewood Hawksley (N.T.H.) continued to develop this technology in the early 1960's and installed several continuous flow systems in Europe. The Envirotech Corporation, through their BSP Division, acquired an exclusive license from N.T.H. to market the Porteous process in the United States. The first full-scale Porteous process heat treatment system in the U.S. went into operation in 1969 at Colorado Springs, Colorado. The heat treatment product line was sold to the Lurgi Corporation in 1980.

Approximately 31 wastewater treatment plants in the United States have heat treatment facilities. Of these, 13 facilities are reported to be operating, 9 facilities are reported not operating, and the operating status of the remaining 9 facilities is unknown. Of the 13 operating HT facilities, 8 incinerate the thermally conditioned sludge after dewatering using either multiple-hearth or fluid bed furnace incineration. The startup dates for the operating HT facilities are from 1971 through 1977. The sludge processing capacity of these facilities ranges from 25 to 150 gallons per minute at plants with capacities ranging from 2.1 to 50 million gallons per day (mgd), respectively (1).

Low Pressure Oxidation

The low pressure oxidation system, along with intermediate and high pressure systems, was developed by Fred J. Zimmerman and his associates at Rothschild, Wisconsin. The business organization established to develop and sell commercial applications of these processes was called Zimpro, Inc. The first LPO system was installed in Levittown, Pennsylvania in 1967. Prior to 1967, thermal oxidation systems were limited to intermediate and high pressure oxidation installations.

Seventy eight municipal wastewater treatment plants nationwide are known to have low pressure oxidation facilities. Of these, 75 facilities are reported to be operating, and 3 are reported not operating. Of the known operating LPO facilities, 32 facilities incinerate the thermally conditioned sludge after dewatering. Startup dates are from 1969 to 1980. Sludge processing capacities range from 6 to 280 gallons per minute at plants with capacities from 1.5 to 200 mgd, respectively (1).

PROCESS PROBLEMS

Although thermal conditioning of sludge is an established and proven process, these systems have had problems in the areas of design and operation that have limited successful and cost-effective operation. Design problems have related primarily to sizing of thermal conditioning and support systems, materials of construction, odor control, and treatment of sidestreams generated by use of the process. Operational problems have included excessive energy consumption, insufficient operator training or skills, and high maintenance requirements.

In some cases, these problems have been serious enough to cause abandonment of the process. In general, thermal conditioning systems have been shut down as a result of high energy costs. These costs can be directly related to improper design and/or to improper operation of the thermal conditioning systems.

The potential for operational problems, the ability to minimize or avoid these problems through proper design features or operational controls, and a careful analysis of operation and maintenance costs associated with the specialized requirements of a thermal conditioning system should all be considered before the process is selected over other sludge conditioning alternatives. Both the benefits and the potential problems attributed to thermal conditioning systems, as well as side benefits such as the potential for gas production by anaerobic digestion of decant liquors, should all be included in such considerations.

SECTION 2

PROCESS AND EQUIPMENT

The thermal conditioning process enhances the dewatering characteristics of sludge through simultaneous application of heat and pressure. This process is one step in a total sludge handling system in which sludge is conditioned, stabilized, and thickened by thermal conditioning before dewatering and ultimate disposal. How the process conditions and stabilizes sludge and the equipment that comprises a thermal conditioning system are described in this section. Operational characteristics and guidelines for process selection and application are also discussed.

PROCESS DESCRIPTION

Thermal Conditioning

Wastewater sludge contains water and cellular and inert solids which form a gel-like structure. The water portion consists of bound water, which surrounds each solids particle, and water of hydration, which is inside the cellular solids. Thermal conditioning improves sludge dewaterability by subjecting the sludge to elevated temperature and pressure in a confined reactor vessel to coagulate solids and break down the gel-like structure of the sludge. As the temperature and pressure are increased, particle collisions increase. These collisions result in the breakdown of the gel-like structure, allowing the bound water to separate from the solids particles. In addition, hydrolysis of protein material in the sludge occurs. Cells break down and water is released, resulting in coalescence of solids particles. In its conditioned state, the sludge is readily dewatered on most commonly used dewatering devices to 30 to 50 percent solids without the addition of chemicals.

A portion of the volatile suspended solids (VSS) in sludge is solubilized as a result of the breakdown of the sludge structure. The solubilization of VSS increases its biodegradability. Although this solubilization does not change the total organic carbon content of the sludge, it does result in an increase in the 5-day biochemical oxygen demand (BOD_5). The BOD_5 produced is of primary concern in the recycle of sidestreams, as discussed in Section 3. The solubilization of

VSS and resultant BOD_5 production for HT systems may be estimated as follows (2):

$$VSS = 0.1\ PS + 0.4\ WAS$$

$$BOD_5 = 0.07\ PS + 0.3\ WAS$$

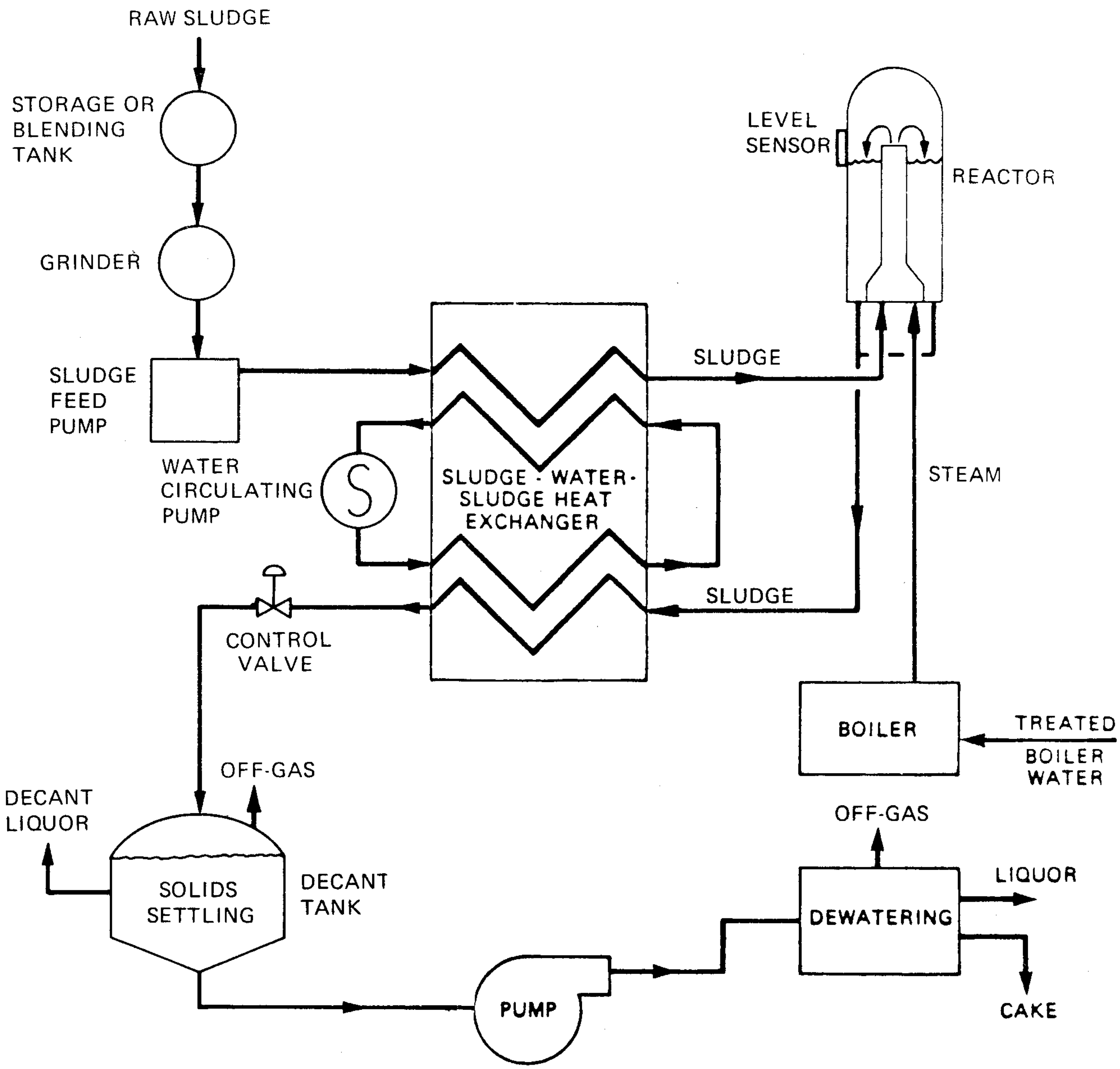
where:
- VSS = Volatile suspended solids solubilized, dry lb
- PS = Primary sludge, dry lb
- WAS = Waste activated sludge, dry lb
- BOD_5 = 5-day biochemical oxygen demand produced by VSS solubilization, lb

Using these rule-of-thumb procedures, one would estimate 22 pounds of VSS solubilization and 16.2 pounds of BOD_5 production by heat treatment of 100 pounds of a typical mixture of 60 percent primary and 40 percent waste activated sludge. In LPO systems, VSS solubilization and BOD_5 production are expected to be 10 and 5 percent greater, respectively, than the above estimates for HT systems.

Thermally conditioned sludge can be dewatered on vacuum filters, belt filter presses, recessed plate filter presses, centrifuges, or sand drying beds. Ultimate disposal of dewatered solids can be by incineration, landfill, or other land application methods.

Heat Treatment

A schematic diagram of a typical HT system is shown in Figure 1. In this continuous process, raw sludge is ground to reduce particle size to less than 1/4 inch and is then pumped through a heat exchanger and into a reactor. Normal discharge pressure from the sludge feed pump is approximately 250 psig. In the heat exchanger, the temperature of the sludge is raised from ambient to between 300°F and 350°F. The heated sludge exits the heat exchanger and enters a reactor feed standpipe where steam is injected through a nozzle and the sludge is turbulently mixed. The steam and sludge proceed upward through the standpipe and enter the reactor at the top. The hot sludge (between 350°F and 400°F) is retained for a period of time in the reactor and is subsequently returned through the heat exchanger to be cooled to approximately 120°F (about 60°F greater than the incoming sludge). From the discharge side of the heat exchanger, the conditioned sludge flows through a control valve, which controls reactor sludge level and pressure, and into a decant tank. The decant tank permits rapid settling and compaction of the sludge particles and the release of gas. The settled sludge is pumped to a dewatering device. Process off-gases can be treated by various odor control methods as discussed in Chapter 3.



SOURCE: EPA PROCESS DESIGN MANUAL: SLUDGE TREATMENT AND DISPOSAL, EPA 625/1-79-011, SEPT. 1979 (MODIFIED)

FIGURE 1. HEAT TREATMENT PROCESS FLOW DIAGRAM

Low Pressure Oxidation

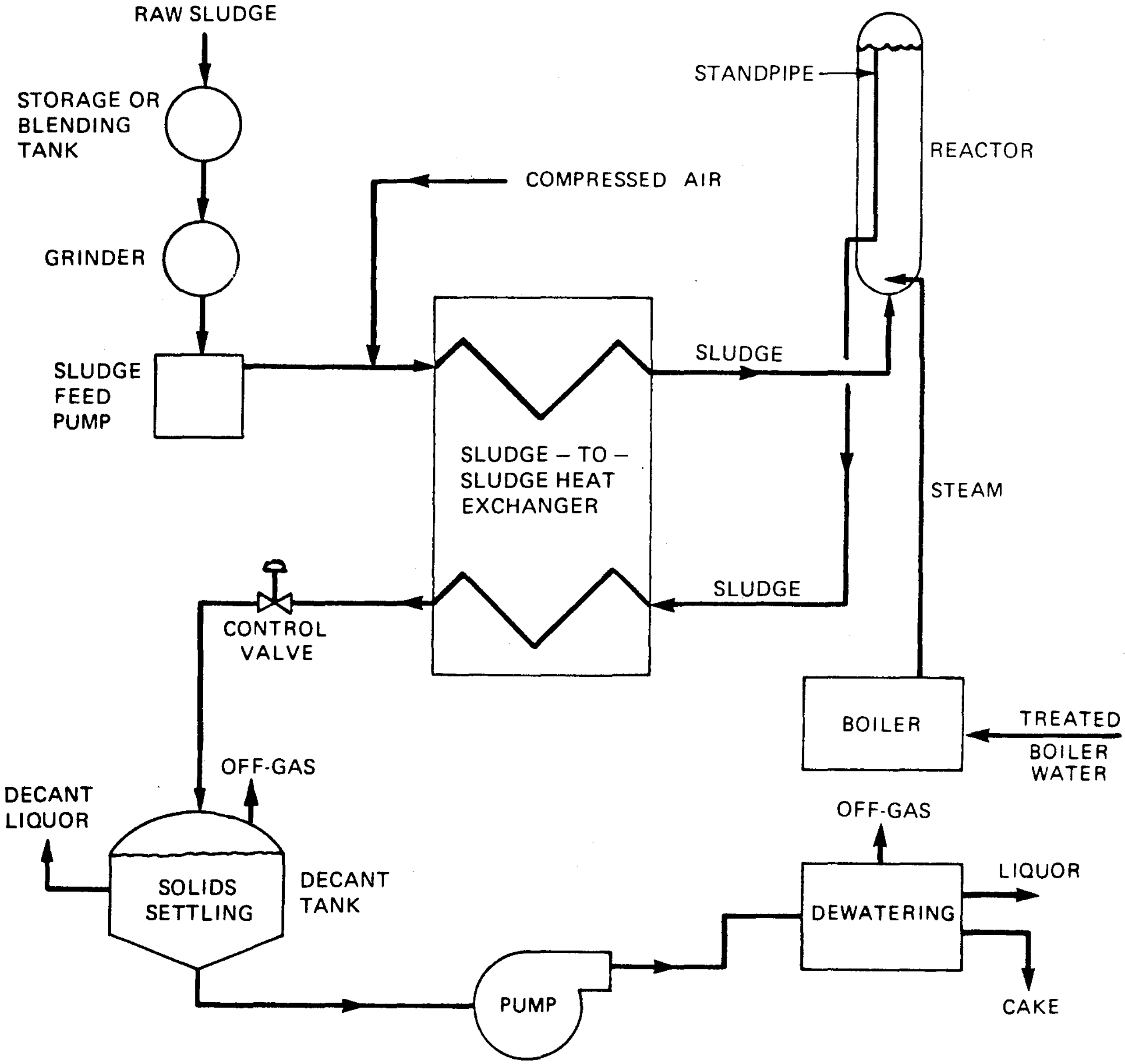
A schematic diagram of the LPO system is shown in Figure 2. Raw sludge is first passed through a grinder where particles are reduced to less than 1/4 inch. The ground sludge is then pumped at approximately 400 psi through a heat exchanger followed by an LPO reactor. High pressure air from the system air compressor is introduced into the sludge flow upstream of the heat exchanger. The air improves heat transfer and converts sulfur products in the sludge to sulfate, slightly reducing odors from off-gases. The resulting turbulent flow of sludge and air proceeds through the heat exchanger where the sludge is preheated by processed sludge returning from the LPO reactor. The sludge and air mixture enters the reactor at a temperature between 300°F and 320°F. Steam is injected directly into the reactor to increase the sludge/air mixture temperature to between 330°F and 350°F. The combined products rise slowly in the reactor and a slight heat of reaction or oxidation occurs producing a small amount of heat. From the reactor midpoint to the reactor outlet, the sludge temperature increases approximately 10°F due to the heat of reaction of the sludge, contributing to an overall temperature increase from reactor inlet to reactor outlet of approximately 40°F. Detention time or "cook time" in the reactor is based on the volume of the reactor, by the height of the discharge pipe (standpipe or downcomer line), and is controlled by the air, steam, and sludge flow rates to the reactor.

After leaving the LPO reactor, the partially oxidized product flows back through the heat exchanger and releases heat to the incoming sludge/air mixture. When the partially oxidized product reaches the control valve, the temperature ranges between 110°F and 130°F. This valve controls the pressure in the reactor. From the valve, the thermally conditioned sludge and exhaust gases flow to the decant tank where the sludge settles and exhaust gases are released. The settled solids are then pumped to a dewatering device prior to final disposal. Process off-gases from the LPO system also can be treated by various odor control methods as discussed in Chapter 3.

EQUIPMENT DESCRIPTION

The equipment for both types of thermal conditioning processes is similar. Both processes include a grinder, high pressure pump, heat exchanger, reactor, boiler system, and decant tank. HT/LPO systems should also have a blending tank to mix sludges prior to thermal conditioning.

In addition to the above equipment, the HT system includes a circulating water system for its heat exchanger, and the LPO system includes a compressed air system for process air supply. Descriptions of this equipment and differences in equipment between the HT and LPO systems are presented in this section.



SOURCE: EPA PROCESS DESIGN MANUAL: SLUDGE TREATMENT AND DISPOSAL, EPA 625/1-79-011, SEPT. 1979 (MODIFIED)

FIGURE 2. LOW PRESSURE OXIDATION PROCESS FLOW DIAGRAM

Figure 3 is an illustration of a typical LPO system which shows most of this equipment and its relative location within a thermal conditioning facility. This general arrangement may also be utilized for a HT system, except that space must be provided for a horizontal heat exchanger.

Blending Tank

A blending tank should be provided to receive and blend primary and waste activated sludges. The tank can also act as a storage unit before the sludge is released into the HT/LPO system for processing. It should have a paddle-type mixing mechanism that creates sufficient agitation to blend the dissimilar sludges into a homogeneous feed without entraining air in the mixture.

Grinder

Sludge from the blending tank passes through a grinder which shreds foreign objects to a particle size of approximately 1/4 inch. This prevents objects from plugging the high pressure pump, the heat exchanger piping, and the control valve.

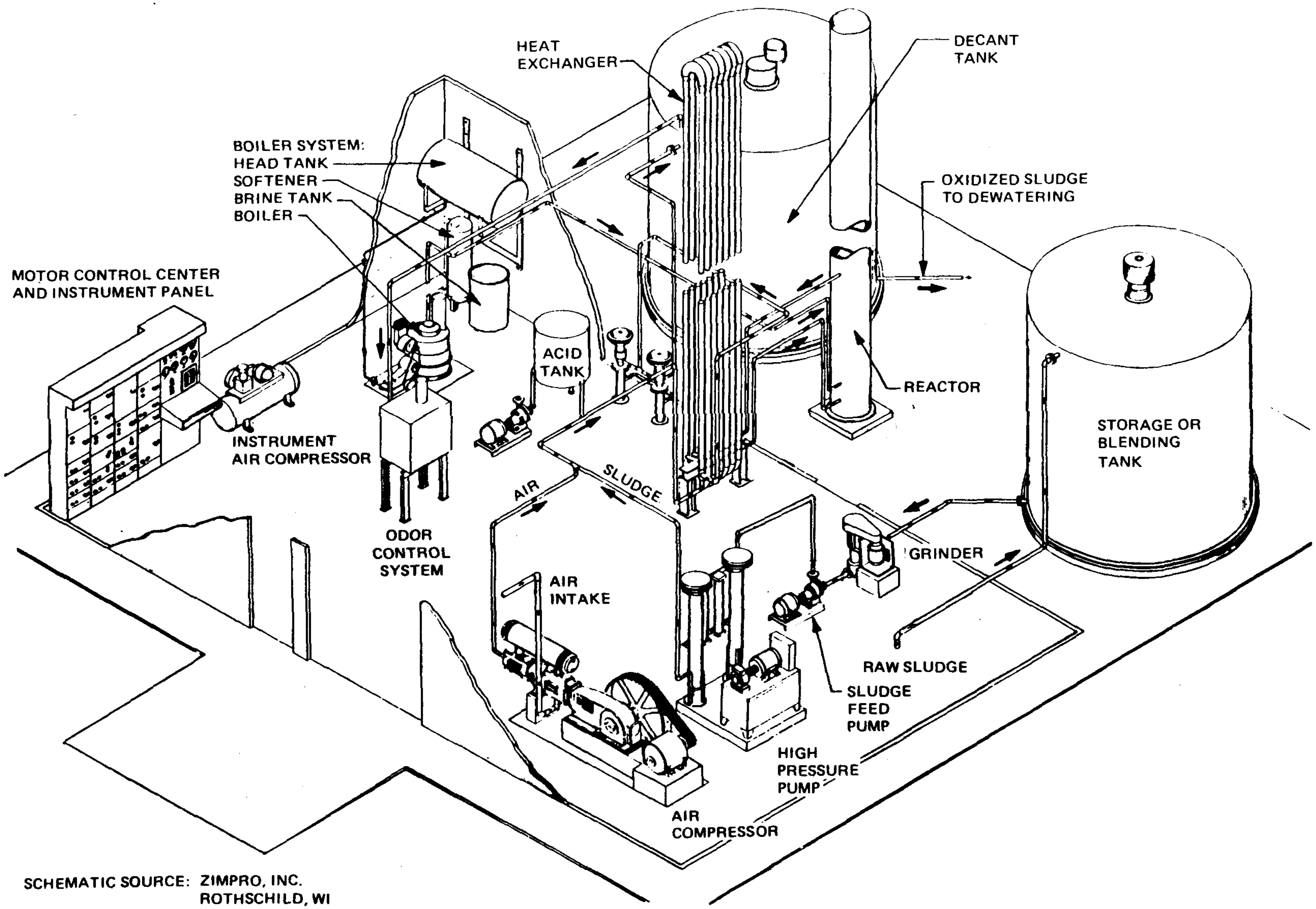
High Pressure Pump

After grinding, the sludge is brought up to system pressure using a high pressure pump. Positive displacement pumps such as piston pumps or progressive cavity pumps are normally used for this purpose. A hydraulic exchange "bag" pump, illustrated in Figure 4, has been specifically developed for LPO systems and is often found in these systems.

The hydraulic exchange pump is unique to LPO systems, and has been operated successfully in this rigorous application. The pump forms part of a pumping system that consists of a conventional type feed pump (either positive displacement or centrifugal) and the hydraulic exchange pump. The hydraulic exchange pump itself is a hydraulically operated positive displacement diaphragm pump. The hydraulic exchange pump utilizes hydraulic fluid for power. The fluid is pumped through a hydraulic system to diaphragm bags inside pressure vessels. The hydraulic fluid is completely isolated from the sludge by the diaphragm bag and the stroke control cylinder.

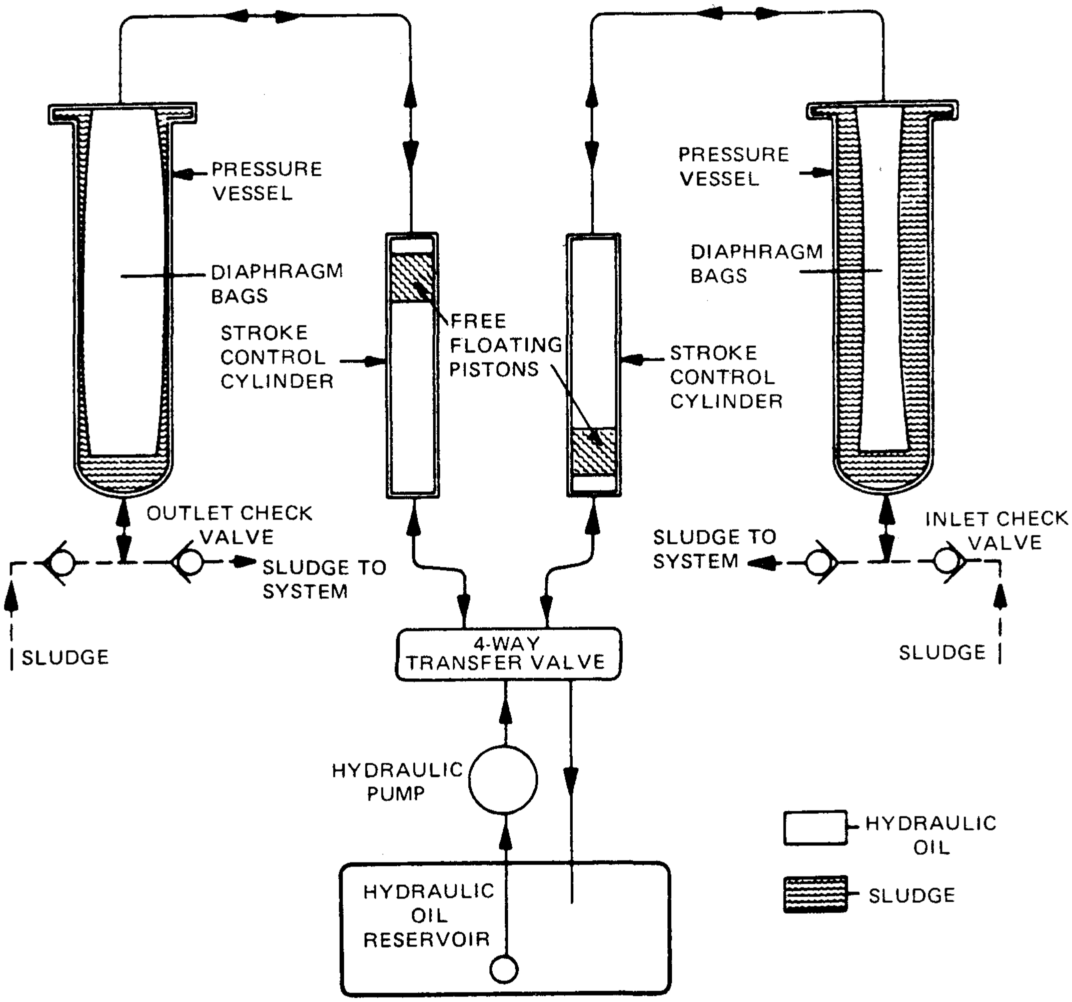
Heat Exchanger

A heat exchanger is used to preheat feed sludge with heat recovered from the treated sludge. Double-pipe heat exchangers are used for both HT and LPO processes. In this type of heat exchanger, two pipes are mounted concentrically, one inside the other. The inner pipe is often referred to as the tube, and the



SCHEMATIC SOURCE: ZIMPRO, INC.
ROTHSCHILD, WI

FIGURE 3. LOW PRESSURE OXIDATION SYSTEM CONFIGURATION



SOURCE: ZIMPRO, INC.
ROTHSCHILD, WI.
(MODIFIED)

FIGURE 4. HYDRAULIC EXCHANGE PUMP

outer pipe as the shell. In the wastewater treatment field, the double-pipe heat exchanger is termed a tube-in-shell exchanger, although in the heat exchange field this term is reserved for another common type of exchanger where an entire bundle of tubes is placed inside one large cylindrical vessel, commonly termed the shell.

The HT system normally uses a horizontal sludge-water-sludge double-pipe heat exchanger with a water circulation loop. The sludge flows through the inner tube, while the water to heat and cool the sludge flows through the annular space between the tube and shell. In different sections of the exchanger, heat is transferred from the hot treated sludge to the water, and then from the water to the feed sludge. The water circulates in a closed loop. Although sludge-water-sludge heat exchangers are used in the majority of HT installations, sludge-to-sludge exchangers, described below, have also been used in the HT process.

The LPO system always uses a vertical sludge-to-sludge double-pipe heat exchanger. In this type of exchanger, the thermally conditioned sludge flows in the annular space, while the cool feed sludge flows in the inside tube. Heat is transferred directly from the thermally conditioned sludge to preheat the feed sludge.

Sludge velocities through the heat exchanger are designed to be high enough to maintain a scouring action sufficient to move debris through the system, yet not so high as to induce damage from grit and loose scale from mineral deposits at the 180 degree upper turns in the LPO system. The combination of cavitation caused by gas release, and abrasion from coarse particulate material at these upper bends can result in rapid wear. Normal design velocities are:

inside tube inlet	6 to 8 feet per second
inside tube outlet	10 to 12 feet per second
annular space inlet	12 to 14 feet per second
annular space outlet	8 to 9 feet per second.

Processed sludge temperature should be between 120°F and 130°F in order to assure proper settling and reduce odor potential. Should a processed sludge temperature of less than 120°F be required, an aftercooler section may be added to the heat exchanger. An aftercooler is a separate heat exchanger in which nonpotable water is utilized for cooling.

Circulation Water System

In sludge-water-sludge heat exchangers, the circulation water system circulates water through the heat exchanger, transferring heat from treated to raw sludge. In this system, water is pumped through a closed, pressurized circulation loop in the heat exchanger. The circulating water tank is pressurized to 100 psig by compressed nitrogen. The tank has a safety pressure relief valve, a vent valve, a pressure indicator, and a level indicator. Treated boiler feed water is used in the circulating water system as initial fill and as makeup water when needed.

Reactor

The reactor for both the heat treatment and low pressure oxidation processes is a cylindrical pressure vessel that is sized to provide sufficient holding time to achieve the physical and chemical changes required for proper sludge conditioning. The operating pressure in the vessel can be varied depending on the characteristics of the sludge being treated. The differences between the HT and LPO reactors are described below and are shown in Figure 5.

Sludge enters the HT reactor through a central standpipe that runs to the top of the reactor. Steam is injected directly into the sludge at the base of the standpipe, heating the sludge between 350°F and 400°F. After exiting the standpipe, the sludge moves down through the reactor and is discharged from the bottom. The level in the reactor is controlled by a level control valve which is activated by a level sensor in the reactor. Reactor detention time of approximately 40 minutes is controlled by sludge flow rate.

In the LPO reactor, a mixture of sludge and air enters the bottom of the reactor. Steam is injected directly into the reactor to raise the sludge/air mixture temperature to between 330°F and 350°F. The mixture slowly rises in the reactor and is discharged through a standpipe or downcomer line. The detention time, which could vary between 15 to 40 minutes, is established by controlling the influent sludge flow rate.

Boiler System

Both HT and LPO systems have a boiler system that supplies steam to raise the temperature of the reactor feed sludge. The boiler system includes a deaerator which removes oxygen from the water, a water conditioning system, a single-pass steam generator, piping, and a pump. Feed water is first conditioned with sulfite and its pH is adjusted with caustic soda to prevent system corrosion. The water then passes into a deaerator which is a covered tank where the water is heated to 220°F at 5 to 10 psig. In the deaerator, dissolved oxygen is removed from the

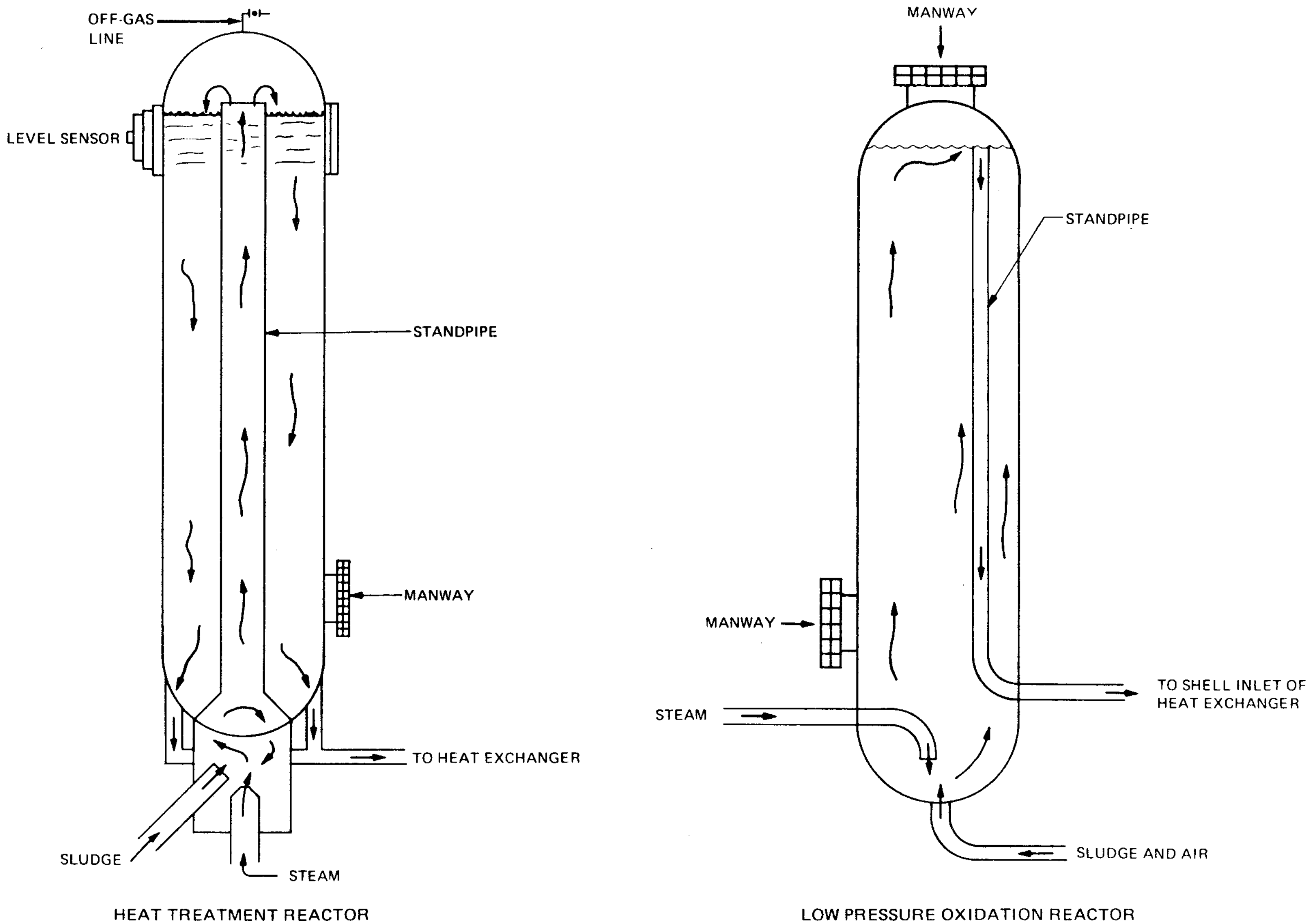


FIGURE 5. HEAT TREATMENT AND LOW PRESSURE OXIDATION REACTORS

water as it reacts with the sulfite conditioner to form sulfate. From the deaerator, the water is pumped to the boiler where the temperature is further raised, and steam is generated and injected into the sludge stream.

Decant Tank

In the decant tank, oxidized sludge is thickened to between 8 and 12 percent solids, water released as a result of the conditioning process is decanted, and gases produced in the process are released. The tank functions similarly to a gravity thickener and is similarly equipped. It is covered to prevent the escape of odorous gases. Thickened sludge is normally pumped to dewatering while decant liquor is either recycled to the mainstream processes or treated separately. As noted before, the gases released in the tank should be vented through the cover to an odor control system, as will be discussed in Section 3.

OPERATIONAL CHARACTERISTICS

The primary operating variables used to control the thermal conditioning process are sludge temperature and flow rate. In LPO systems, process air flow rate is also a key operating variable. Given a proper solids feed, monitoring and control of these variables will produce a stable, sterile (though easily reinoculated) end product that is easily thickened and dewatered. The process will also produce odorous gases and high strength sidestreams that must be treated.

The proper temperature for sludge conditioning is directly related to sludge dewatering characteristics and the fuel required to maintain "cook temperature". The optimum cook temperature is the lowest temperature in the recommended range (between 350°F and 400°F) that will allow acceptable dewatering. Dewaterability can be monitored by performing a Specific Filtration Resistance Analysis (3) on the solids entering the decant tank.

Since a few degrees difference in cook temperature can significantly affect sludge dewaterability and can have a major impact on boiler fuel consumption, it should be constantly monitored and adjusted. Lower cook temperatures result in savings through reduced fuel consumption and decreased solubilization and recycle of BOD.

In the HT process, changing the reactor outlet temperature can be achieved by two methods. One method is to increase or decrease the sludge feed rate by adjusting the speed of the high pressure feed pumps. The second method is to regulate the steam production rate by automatic adjustment from a temperature control setpoint in the reactor outlet.

Similarly, in the LPO process, the reaction temperature is controllable by increasing or decreasing the sludge feed and steam production rates. In addition, the process air flow rate affects the temperature and can be changed by using a needle valve on the air compressor system. Limiting the amount of process air also prevents slug flow and back surging in the heat exchanger. Process air flow rates greater than 0.15 pounds of air per gallon of sludge cause a back surging condition in which the sludge and air cannot flow through the piping at the same time. In order to prevent this condition, the process air flow rate should be controlled between 0.08 and 0.15 pounds of air per gallon of sludge.

The operational characteristics of the thermal conditioning process are not solely dependent on process design and operation. External influences that include the quality, characteristics, and particularly the continuity of the raw sludge feed can directly impact the operational characteristics of the process. The solids content of the feed sludge should be thickened to 3 to 5 percent solids in order to minimize fuel consumption. The proportion of waste activated sludge in the raw sludge feed will impact dewaterability, with higher percentages decreasing dewatered cake solids. These variables should be kept as stable as possible, and should be carefully monitored by the thermal conditioning system operator in order to fully assess process control needs.

PROCESS SELECTION AND APPLICATION

The thermal conditioning process can be successfully applied to nearly any combination of primary, waste activated, digested, or trickling filter sludges. Selection of the HT/LPO processes and their applicability in a particular treatment plant are largely dependent upon the plant process flow scheme and total system size and cost. The thermal conditioning process must be utilized as part of a treatment system designed to incorporate its operational characteristics and performance features. In addition, for effective performance of the treatment plant, allowances must be made for handling the high strength sidestreams and odorous gases produced in the process.

Plant Size and Costs

The increase in the cost of natural gas and fuel oil since the early 1970's has significantly changed the economic feasibility of new thermal conditioning systems for small plants. Larger installations (greater than 10 mgd) that utilize dewatering and incineration with energy recovery may determine that the addition of a thermal conditioning step would be an economic asset in their sludge train.

Several factors must be considered regarding the cost effectiveness of a thermal conditioning system as a function of plant size.

- Present-day energy costs dictate some form of resource recovery to make the thermal conditioning process competitive with other conditioning processes. In plants with waste heat recovery from incineration, energy costs for thermal conditioning can be greatly reduced. In general, thermal conditioning is more economical where waste heat recovery for steam generation is possible from sludge incineration.

- Thermal conditioning systems require well-trained and skilled supervisors and operators to optimize the operation and maintenance of the system. Maintenance and instrumentation personnel also must have specialized skills that are not normally present at small (1 to 5 mgd) plants.

- Both systems should be supported with a complete inventory of spare parts to reduce excessive downtime. Also, both systems require a thorough preventive maintenance program.

- The unit capital cost of thermal conditioning systems is in the range of $350 to $500 per dry ton of annual sludge production when processing over 10,000 dry tons per year (10 to 20 mgd of plant capacity) due to use of multiple treatment units and standby units rather than larger sized individual units (4). At lower loadings, processing costs increase significantly, and the comparatively high cost of support systems such as boilers, air compressors, and decant tanks, makes HT/LPO systems more costly to build than other sludge conditioning facilities.

System Comparison

Low pressure oxidation and heat treatment offer two alternative methods of thermally conditioning sludge. The major difference between the two processes is that air is added to the LPO system, offering a slight potential for reduced odor production. Both systems may be purchased today, although HT systems are not actively marketed.

Low pressure oxidation systems have been more widely utilized than HT systems. This wider use is probably the result of a more aggressive marketing strategy for the LPO system, and a perceived reduction in the odor production potential of this system. Aside from odor potential, neither system would appear to have any particular technical advantage over the other.

Advantages and Disadvantages of HT/LPO Conditioning

Previous literature on HT/LPO provides a summary of the advantages and disadvantages of using these processes to condition wastewater sludges (5).

Advantages cited include:

- Except for straight waste activated sludge, the process produces a sludge with excellent dewatering characteristics. Cake solids concentrations of 30 to 50 percent are obtained with conventional mechanical dewatering equipment.

- The processed sludge does not normally require chemical conditioning to dewater well on mechanical equipment.

- The process stabilizes the sludge and destroys all living organisms including pathogens.

- The process provides a sludge with a heating value of 11,000 to 13,000 Btu/lb of volatile solids, suitable for incineration or anaerobic digestion with energy recovery.

- The process is suitable for many types of sludges that cannot be stabilized biologically because of the presence of toxic materials.

- The process is effective on feed sludges with a broad range of characteristics and is relatively insensitive to changes in sludge characteristics.

- Continuous operation is not required as with incineration, since the system can easily be placed on standby.

Disadvantages cited include:

- The process has high capital cost due to mechanical complexity and the use of corrosion-resistant materials, such as stainless steel, in the heat exchangers.

- The process requires careful supervision, skilled operators, and a good preventive maintenance program.

- The process produces an odorous gas stream that must be collected and treated before release.

- The process produces darkly colored sidestreams with high concentrations of organics and ammonia nitrogen.

- Scale formation in heat exchangers, pipes, and reactor requires cleaning by difficult and/or hazardous procedures.

- Subsequent centrifugal dewatering may require continuous or intermittent polymer dosage to control recycle of fine particles.

- The daily sludge throughput of the process cannot be adjusted by a significant amount without incurring high energy and/or labor costs.

SECTION 3

COMMON PROBLEMS AND SOLUTIONS

The problems commonly associated with thermal sludge conditioning and some practical solutions to these problems are discussed in this section. The problems, as summarized in Table 1, can be grouped into three categories: design, equipment, and operations. They can inhibit operational efficiency, degrade performance, and increase the costs of thermal conditioning systems and the other associated treatment plant processes, as well as increase the safety risk to plant personnel. Solutions to these problems exist and have been successfully implemented in plants throughout the country. The solutions presented can be used as guidelines for designing and operating thermal conditioning systems, keeping in mind that specific solutions may have to be modified to fit a particular plant.

This information, gathered as part of a research study conducted for EPA, is drawn from a number of sources including telephone inquiries and site visits to wastewater treatment plants, and discussions with manufacturers and consultants.

DESIGN PROBLEMS

Design problems are those which affect the construction, sizing, and control of the thermal conditioning process.

Materials of Construction

The design of HT and LPO systems should avoid the use of dissimilar metals in heat exchangers and related process piping. Use of dissimilar metals provides a potential for corrosion due to galvanic action and increases the difficulty of acid washing the system. Galvanic action does not take place, however, between stainless steel and the more corrosion resistant nickel based alloys and titanium. Carbon steel heat exchangers are normally cleaned with hydrochloric acid that has an inhibitor added to prevent the acid solution from attacking the steel. Stainless steel heat exchangers are always cleaned using a 5 percent nitric acid solution heated to 180°F for greater solubilization of the sulfate scale. Because hydrochloric acid will pit stainless steel and nitric acid will destroy carbon

TABLE 1. SUMMARY OF COMMON PROBLEMS WITH THERMAL CONDITIONING SYSTEMS

Design Problems
Inappropriate materials of construction
Process sizing inconsistent with solids produced in the wastewater treatment train
Improper sizing of storage, blending, and decant tanks
Poor physical layout of the process
Inadequate or poorly located system control instrumentation
Under/oversizing of support systems such as boilers, circulation water pumps, and air compressors
Inadequate grit and rag handling or removal
Inadequate odor control provisions
Inadequate handling of high strength sidestreams
Equipment Problems
Loss of grinder seals
Wear of sludge feed pumps
Corrosion, plugging and scaling of heat exchangers
Unreliable level probes and off-gas control in reactors
Operations Problems
Lack of system understanding by senior management personnel
Poorly qualified O&M staff
Insufficient operator training
Improper process control operation and system maintenance

steel, a bimetallic (carbon steel/stainless steel) system cannot be descaled without damage to one of the metals.

The cleaning system for heat exchangers should be designed to accommodate the range of cleaning options normally used and should be constructed of materials compatible with those used in the HT and LPO systems. This criterion ensures compatibility between the acid and metals in the heat exchanger and related piping.

Selection of materials of construction is also constrained by the potential for corrosion in heat exchangers. The LPO system may require more corrosion-resistant metals than the HT system due to the possible production of more organic acids which lowers the pH, especially where primary sludge is processed.

Aftercooler sections of sludge-water-sludge double pipe heat exchangers with stainless steel tubes and carbon steel shells have experienced some corrosion and leakage problems due to use of effluent water as a cooling medium. Effluent water with fairly high levels of dissolved oxygen at elevated temperatures speeds up the rate of corrosion of metal.

Another corrosion concern applicable to both HT and LPO systems is the presence and concentration of chloride in the wastewater and sludge. High chloride concentrations have contributed to or caused corrosion of heat exchangers in numerous installations. Where chloride levels are expected to exceed 300 to 400 mg/L in the raw wastewater, the possibility of developing problems from chloride stress corrosion exists, and corrosion resistant metals should be used. Available material types include 316L stainless steel, nickel based alloys, higher alloyed iron based alloys, and titanium, in order of increasing corrosion resistance and cost. The capital cost for nickel based alloys and higher alloyed iron based alloys is about 5 to 7 percent greater than 316L stainless steel. The capital cost for titanium is about 15 percent greater than stainless steel. To keep costs as reasonable as possible, titanium or higher nickel based alloy construction only needs to be used in the heat exchanger bundle nearest the reactor where temperatures are highest and corrosion potential is greatest.

Process Sizing

The capacity of HT/LPO systems should be based on a careful estimate of sludge production rates. A low sludge production estimate will result in an undersized system that cannot process the total sludge produced without continuous operation, leaving no time for preventive maintenance. A high estimate leads to an oversized system that is only operated several hours a week, requiring a large amount of fuel to reheat the reactor contents. These sizing problems are due to insufficient or inadequate design data and to lack of consideration of operating conditions in the initial and design years.

To minimize the problem of over/undersizing, thermal conditioning systems should be designed with enough flexibility to accommodate initial, design, and future sludge production at minimum and maximum rates. These production rates can be estimated using existing sludge production data if available, mass balances using historical data and/or past treatment experience, or textbook values. Once sludge production rates are developed, system operation times should be established for average and peak conditions. In general, these systems should be designed with sufficient flexibility to satisfy initial year sludge production rates with a standby system in place to allow up to double the initial year solids loading, and sufficient floor space to install additional units to satisfy later year requirements.

Although installation of large units rather than multiple small units may involve a lower initial capital cost, larger units can require more effort to maintain due to the construction and size of the equipment. Larger units require the use of special rigging and hoisting equipment plus a considerably larger work area. The alternative, multiple small units with sufficient cross connections, should be considered and may be more cost-effective if full capacity is not needed within the near future.

Sludge Blending and Storage Tanks

To assure a homogeneous feed to the thermal conditioning process, the various sludges to be conditioned should be uniformly blended. To assure continuous operation of both the sludge generating and thermal conditioning systems, a storage tank should be provided to dampen surges in sludge flow. Where sludge production variations are not expected to be major, both of these functions can be accomplished in a single sludge blending tank. Where major variations in sludge flow are expected, off-line sludge storage in combination with a separate blending tank(s) may be preferable.

Sludge storage tanks hold peak sludge flows. Their volume must be large enough to store the peak flows yet minimize detention time to avoid septicity and odor problems. A recommended sizing criteria for an off-line storage tank is to provide a volume equal to three days average sludge production. Off-line storage tanks should be aerated to prevent septicity. Should the sludge become septic, thermal conditioning can cause the following operational problems: (1) poor thickening of the feed sludge, which increases the cost of conditioning due to a decrease in tons of solids processed per hour; (2) increased solubilization of VSS during the HT/LPO processes and resulting high levels of BOD in the sidestreams recycled to the plant; (3) decreased settleability of thermally conditioned sludge which also causes excessive recycle of BOD and suspended solids to the treatment plant; and (4) decreased dewaterability of thermally conditioned sludge which compounds solids backlog problems and also increases sidestream loadings to the treatment processes.

Sludge blending tanks should be sized to hold not less than 12 hours nor more than 24 hours of the HT/LPO system design capacity. Good design includes low level alarms and automatic low level pump shut off for the tank to prevent feed sludge pump damage. Blending tanks that hold less than 12 hours of design capacity are operator-intensive and there is a potential for the feed sludge pumps to run dry, causing considerable damage to the pumps. An oversized blending tank can result in septic sludge, increased energy costs for mixing the large volume, and increased maintenance costs for parts in these larger tanks.

Decant Tanks

In addition to thickening, a decant tank functions as a storage tank to permit the operating schedules or production rates of thermal conditioning and dewatering to differ. The sizing, septicity, and thickening problems in storage and blending tanks can also occur in decant tanks. If the decant tank holding time is too long or if the operator draws sludge from a tank on an infrequent basis, its contents can become reinoculated with bacteria. This condition can cause odor problems and will affect the dewaterability of the thickened sludge. The decant tank should be sized to be compatible with dewatering operations, such that the decant tank is empty when the dewatering operation shuts down at the end of the week or the thermal conditioning system is put on standby. Other decant tank design guidelines include:

- Solids loadings less than 40 $lb/ft^2/day$ for combined sludges
- Floor slopes greater than 2.75 inches per foot
- Proper access for maintenance
- Proper sealing of covers to minimize odors
- Continuous sludge withdrawal to prevent septic conditions.

The sludge depth in decant tanks should be monitored to assure proper thickening. Use of a portable gauge allows easy measurement of sludge depth. One improvement to the decant tank is installation of a 4-inch pipe that extends down through the roof of the tank to 4 to 5 inches below the liquid level. The pipe is extended below the liquid level to prevent the escape of gases. This improvement allows the operator to monitor the sludge level without opening roof hatches and allowing odors to escape. Installation of the pipe is not possible on tanks equipped with surface skimming arms. On these tanks, a hinged cap or valve can be placed on the pipe to prevent odors from escaping when sludge levels are not being measured and the end of the pipe can be located above the liquid level. Measurements are made after passage of the slowly rotating skimmer arms.

Physical Layout of the Process

For effective operation of thermal conditioning systems, operators should be able to monitor the total process easily. This is facilitated by installation of equipment on one level in one building. Installation of a HT/LPO system in a new or an existing building in a complex multifloor arrangement greatly increases the difficulty of system operation and maintenance. A multifloor arrangement substantially increases piping, wiring, foundation, rigging, erection, lighting, and building structure costs as well as creating operation and maintenance problems. This arrangement should be avoided if at all possible, because the initial capital savings in construction costs may soon be lost due to the increased cost of operation and maintenance or equipment replacement due to damage caused by inadequate operator attention to the system. Generally, a system that is spread over several floors and rooms of a building will not be monitored and maintained as well as a system that is contained on one level.

The placement and elevation of HT/LPO system tanks and sludge withdrawal pumps are also important considerations in the layout of the process. To avoid cavitation problems, the withdrawal pumps should be located below the liquid level in the tank. As an example, at one plant the vacuum filter feed pumps were several hundred feet removed and at a higher elevation than the decant tank water surface. Cavitation routinely occurred in these filter feed pumps due to the high suction lift created by elevation, friction losses, and the elevated temperature of the feed sludge.

Inadequate or Poorly Located System Instrumentation

The instrumentation for process control of thermal conditioning systems should be state-of-the-art, properly located, and adequate to provide needed process control information. Analyzers and other instrumentation must be placed where a true representation of process conditions can be obtained, with indicators located where operators can readily observe and respond to them. Otherwise, the instrumentation is of little use.

All mechanical gauges for high vibration areas should be anti-shock types, mounted on external gauge boards to avoid continual vibration. The gauges should have flexible connections to the monitoring elements. In one plant where this modification was made, the life expectancy of Bourdon tube type gauges is in excess of four years compared to a few weeks life expectancy when the gauges were mounted directly on pipes and components.

Adequate numbers of process monitoring points must be provided. The instrumentation listed in Table 2 should be built into the thermal conditioning system to provide the operator with

TABLE 2. RECOMMENDED HT AND LPO SYSTEM INSTRUMENTATION

Alarms - no local readout

- Reactor level, high and low
- Reactor pressure, high and low
- Sludge flow, low
- Circulation tank, water level
- Circulation tank, pressure
- Circulation water, flow
- Instrument air pressure, high and low
- Deaerator level, high and low
- Decant tank temperature, high (optional)

Recorded Instrument Readings

- Reactor pressure
- Sludge flow
- Steam flow
- Reactor level
- Steam pressure
- Reactor inlet and outlet temperature
- Circulation water crossover temperature (optional)
- Process air flow (LPO only)

Digital Readout and/or Recorder

- Sludge inlet temperature to heat exchanger
- Circulation water inlet and outlet temperature
- Heat exchanger, sludge outlet temperature
- Deaerator temperature

Additional

- Flow meter for reactor off-gas, for economic control to monitor steam losses from reactor (more critical on larger units)
- Reliable flow and density meters for feed sludge
- Needle valve assembly on air compressor (LPO only)

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the necessary information and/or control to operate the process effectively and efficiently. Additional instrumentation that could improve LPO systems is a process air flow meter, which allows the operator to monitor the proper ratio of air-to-sludge volume. A needle valve assembly should be provided on the air compressor discharge, prior to the airflow meter, to allow adjustment of the air-to-sludge ratio. This instrumentation/ control is needed because excessive air addition to the process can cause back surges in the heat exchanger and damage to the process air compressor safety valve.

The quality of control instrumentation must be carefully considered during design. The available data indicate that over the long run, sophisticated, heavy-duty control systems are more cost-effective and trouble-free than lighter-duty instrumentation. An HT/LPO system should have an integrated control system supplied by one manufacturer that can perform all required control functions. For the HT system, a 3-mode proportional-integral-derivative (proportional-reset-rate action) control loop should be supplied. For the LPO system, a 2-mode proportional-integral (proportional-reset) control loop should be supplied.

Sizing of Support Systems

HT/LPO system boilers should be sized to account for less than optimal heat exchanger efficiencies. In addition, single LPO system installations should have 100 percent standby capacity for the design steam production rate to the system. Scaling in the heat exchanger will lower heat transfer efficiency requiring a higher steam production rate to maintain system temperatures. An operator may discover that there is insufficient steam production to maintain system temperatures or to meet the total system needs when trying to recover from a process upset. A properly sized boiler and frequent cleaning of the heat exchanger to minimize scaling are recommended.

Insufficient potable water pressure to the boiler system may appear as a boiler sizing problem. The installation of potable water booster pumps should be considered and will benefit plants that experience large fluctuations in potable water pressure.

The size and location of boiler feed water pumps in relation to deaerators has caused problems. To avoid cavitation and ensure a flooded suction, boiler feed water pumps should be located close to and below the deaerator. Locating the boiler feed water pumps on a floor below the deaerator may be a good design in this case. The use of booster pumps between the deaerator and the boiler feed water pumps is another means to ensure that feed water pumps maintain a flooded suction. If booster pumps are used, the friction losses between the deaerator and boiler water feed pump must be carefully assessed to ensure that they do not limit the necessary flooded suction of the boiler feed water pumps. To avoid cavitation, feed water return should be to the deaerator and not to the suction side of the feed water pump.

When sizing the circulation water pumps in the heat exchanger circulation water system of HT systems, both minimum and maximum flow requirements should be considered and allowances should be made for loss of efficiency due to pump wear. As circulation pump efficiency drops, the cost of operation will increase because the HT system depends on a countercurrent (water-to-sludge) flow to transfer heat between processed and raw sludge using the water as an exchange medium. If the circulation water pressure is allowed to drop below the saturation point for the corresponding temperature in the heat exchanger, the water will flash to steam. This condition will cause water hammer that may in turn cause extensive damage to the heat exchanger piping. Proper pump sizing, along with attentive pump maintenance, can minimize these problems.

High pressure sludge feed pumps are one of the hardest worked pieces of equipment in the LPO system due to the various foreign materials contained in the sludge (rags, grit, plastics, etc.) and to the high pressure and vibrations produced by these units. Because these pumps require frequent maintenance and routine cleaning of ball check valves for rag removal, a full sized standby pump is necessary.

High pressure air compressors in the LPO system should have the capability to supply 0.08 to 0.15 pounds of air per gallon of sludge. If the air compressor output is much higher than 0.15 pounds per gallon, back surging will occur. If the air compressor output is too high, the compressor discharge pressure will increase until the safety valve actuates to release system pressure. The valve will close after the excess pressure is relieved and will reopen if pressure builds up again. This will continue until system operation is adjusted. To control the air-to-sludge ratio, the air compressor discharge should be equipped with a flow meter and needle valve bypass for diverting air away from the process.

Every LPO system is equipped with an acid cleaning system that should be capable of flushing the unit with a 5 percent nitric acid solution heated to 180°F. The intermittent use of this support system makes equipment duplication unnecessary. Normally, one system will be adequate for multiple LPO system installations.

Process control valves (PCV's) in LPO systems should be large enough to release the process byproducts through one valve. An additional valve of the same size should be provided as standby. Because these valves frequently become restricted with residue from the process, LPO systems cannot be operated reliably without a standby PCV.

Multiple LPO system installations may still require a certain amount of standby support system capacity. However, with adequate cross connection of equipment, much of the duplication can be avoided. In either single or multiple LPO unit installations, O&M personnel should not allow standby equipment to remain idle for long periods of time. Specifications should require that equipment O&M manuals correctly detail the frequency of rotation of support components.

Inadequate System for Grit and Rag Removal

Grit and rag removal from the feed sludge to the thermal conditioning system is essential to insure minimal plugging of the heat exchanger, pumps, and valves. Plugging due to grit, rags, or both can be so severe as to require frequent system shutdown to clean out these materials. These shutdowns are costly because they waste energy and cause unnecessary delays in processing sludge.

Grit and rags are less of a problem in the HT process than in the LPO process due to the design of the HT sludge-water-sludge heat exchanger. In this heat exchanger, sludge flows through a single pipe with no obstructions, and the design permits pigging of the sludge pipes to remove built-up deposits of sludge, grit and rags.

The configuration of the LPO heat exchanger can lead to plugging. The LPO system utilizes a concentric pipe sludge-to-sludge heat exchanger installed in a vertical position to facilitate the turbulent flow of sludge and air. Stabilizers are installed in the annulus between the two pipes to prevent vibration of the inner pipe. Rags and other foreign materials that have not been sufficiently ground up will accumulate on these stabilizers and lead to plugging problems.

In plants where rags pass through influent screens and comminuting devices and are left in the flow stream, the problem of plugged equipment is extremely severe. Shredded rags can reconstitute into long rope-like formations that are pumped with the sludge into the thermal conditioning system. Rags should be removed from the process flow stream to avoid the costly and time consuming process of later removing them from HT/LPO system pipes, valves and heat exchangers.

As with most wastewater treatment process equipment, the passage of grit through piping, pumps, valves and internal equipment components is never a good practice due to abrasion on these components. In the HT system, the abrasive grit problem is compounded by the high velocities experienced in some parts of the system. One of the areas most often affected is the 180 degree elbows on heat exchangers. If excessive amounts of grit are allowed to enter the thermal conditioning system, these elbows will wear away to the point where leakage occurs.

Careful consideration should be given to grit removal early in the design stage of wastewater treatment plants utilizing thermal conditioning systems to ensure that this removal process achieves maximum efficiency. The use of a grit removal system (e.g., cyclone separator) in the sludge flow stream in addition to a grit chamber may be warranted. Degritting of primary sludge, however, should be followed by thickening to keep primary sludge pumping and thermal conditioning operation costs low due to processing of higher solids feed sludge. The grit levels in feed sludge to HT/LPO systems should be monitored routinely and corrective actions taken if levels trend upward. These actions may include the use of a cyclone separator to handle increased grit levels during storm events, or because of seasonal variations. Redesign of the plant's grit chamber may be needed if the problem is chronic.

Odor Control

The odors associated with thermal conditioning of sludge are some of the most problematic found in wastewater treatment in terms of intensity and available control methods. The main odor producing or releasing areas are the decant tanks and dewatering areas. Odors in an LPO system may be less than in a HT system because the addition of air oxidizes hydrogen sulfide and other sulfur compounds to sulfate. However, this difference is not significant to the extent that odor control measures become unnecessary in an LPO system. Odor control must be addressed in the design of both processes and must include the collection of all gases in order to be effective. Treatment of these off-gases typically constitutes 5 to 10 percent of the total costs for thermal conditioning(6).

Many methods exist for handling these gases. One effective treatment method, if the option exists, is to collect the off-gases and include them with incinerator combustion air. As long as furnace temperatures remain above 1,400°F, good odor destruction will occur. Off-gases can also be collected and sparged into activated sludge aeration basins where the soluble odorous constituents are adsorbed and absorbed. A backup method is necessary for treatment of the collected gases when the primary process unit, such as an incinerator, is not in operation.

Other odor treatment methods include hypochlorite scrubbing or a multiple chemical system, which will consist of some combination of the following:

- Chlorinated water scrubbing (countercurrent)

- Sodium hydroxide (countercurrent)

- Potassium permanganate (countercurrent)

- Carbon columns (direct flow through)

- Fume incineration (flow through).

Other attempts to control odors using either ozone or a single chemical system have not been successful.

For plants under 10 mgd, total life cycle costs for odor control are generally the least for incineration and chemical scrubbing. As plant size increases, the total cost for incineration rapidly increases, and chemical scrubbing in conjunction with carbon columns becomes a more economical alternative. Detailed cost comparisons for odor control are given in the U.S. EPA publication entitled "Effects of Thermal Treatment of Sludge on Municipal Wastewater Treatment Costs" (6).

Odors generated during flushing and cooling of heat exchangers prior to temporary hot shutdown of the reactor (bottling) can be reduced through judicious selection of the cooling water source and piping design. Normally, nonchlorinated effluent water is used for flushing and cooling, because chlorinated effluent contains chlorine which interacts with the metal heat exchanger. However, the discharge of nonchlorinated water into the decant tank can result in contamination with sulfur reducing organisms and production of odors. To avoid this problem, flushing water piping should bypass the decant tank and direct all flushing water to the aeration basins or to the head of the plant. This piping can be installed between the process control valve and the inlet to the decant tank.

High Strength Sidestreams

The handling and treatment of sidestreams from thermal conditioning systems must be a major design consideration. These sidestreams include supernatant liquor from decant tanks, and liquors withdrawn from sludge in dewatering processes. Recycle liquor can increase plant influent BOD loading by 15 to 30 percent. If not properly accounted for in design, these loads can pass through the plant, causing permit violations. Treatment of these sidestreams will increase plant capital and operating costs. Total costs for treatment of thermal conditioning liquor will be a small percentage of total plant cost, but may be as much as 20 percent of the costs for thermal conditioning (6).

In general, the composition and strength of thermal conditioning liquor are a function of sludge type and age, volatile solids content, reactor detention time, and reactor temperature and pressure (5). These sidestreams have high levels of BOD and chemical oxygen demand (COD) as well as significant levels of total phosphorus and total nitrogen. As reported in the literature, the sidestream can have a BOD of 5,000 to 15,000 mg/L, suspended solids of 100 to 20,000 mg/L, and COD of 10,000 to 30,000 mg/L (5).

Assessment of the sidestream characteristics to use for design is difficult. At plants where sludge is available, sampling and testing for processed sludge filterability and recycle characteristics can be performed. Thermal conditioning pilot plants are available from system manufacturers and may be used to generate samples of conditioned sludge and recycle streams. Where sampling and testing are not feasible, ranges of sludge characteristics should be identified. A comparison with similar sludge conditioning experiences at other plants can provide a basis for design. Where no sludge is available for analysis, solids balances and a determination of the range of primary/waste activated sludge mixtures should be used in conjunction with data from past treatment experience. General characteristics of recycle streams from thermal conditioning are published in the U.S. EPA publication entitled "Process Design Manual for Sludge Treatment and Disposal" (5), and can be used as guidelines. These data indicate that the upper end of parameter concentration ranges for LPO sidestreams are higher than for HT. Addition of oxygen to the LPO process increases the production of organic acids and carbon dioxide, depressing the pH to about 4.5 to 5, compared to a pH of 5 to 6 with HT (7). This change in pH may add to the corrosiveness of the sludge and sidestreams.

Thermal conditioning sidestreams carry high levels of solubilized BOD caused by the breakdown of volatile matter. Factors that tend to increase the solubilization of BOD during thermal conditioning are:

- Septic feed sludge to the process
- A high proportion of waste activated sludge to primary sludge
- Improper control of cook temperature
- Excessive retention time in the decant tank.

Thermal conditioning liquors may be treated using several methods. Since the liquors are biodegradable, the preferred treatment methods utilize biological processes. The liquors may be treated by recycle to the treatment plant headworks, or to a biological process such as activated sludge, or by separate treatment. Recycle systems can either involve direct full time recycle, or can involve off-line storage with return feed during off-peak hours.

Where thermal conditioning liquors are recycled, mainstream processes must be sized accordingly. For example, where recycled to activated sludge systems, these sidestreams will require increased aeration tank size, air supply capabilities, and return and waste sludge pumpage. This will increase the capital cost of the aeration system, as well as increasing operating power and labor costs.

In order to minimize capital costs and peak power requirements, thermal conditioning liquors can be stored in a holding tank during the daytime when plant flows and loads are high, then returned to mainstream processes at night when the load is down.

Thermal conditioning liquors may also be separately treated. Biological systems have been exclusively used for this purpose. Although physical-chemical treatment may be possible, there are no known systems in use. One separate treatment alternative is to anaerobically digest the separated liquors while stabilizing the mixture and providing gas suitable for fueling the conditioning processes. The use of anaerobic filters has also been tested with apparent success (8).

The wastewater treatment facilities at San Mateo, California have been anaerobically digesting their LPO thickening tank supernatant and dewatering process filtrate for several years. The following data, taken from their June 1984 monthly log sheet (9), indicate an average reduction in sidestream BOD and COD loadings of 84 and 72 percent, respectively.

	Sidestream to Digesters			Supernatant			Percent Removal	
	pH	BOD, mg/L	COD mg/L	pH	BOD, mg/L	COD mg/L	BOD	COD
Maximum	4.6	6,660	14,640	7.12	1,110	4,590	83	80
Minimum	4.2	4,870	8,680	6.99	700	2,660	86	69
Average	4.4	5,883	11,171	7.06	930	3,145	84	72

The average feed to the anaerobic digester was between 50,000 and 60,000 gallons per day. Mixed liquors were between

1,200 and 1,500 mg/L. The mass was continuously circulated and no problems developed with accumulating bottom debris. Gas production was about 40,000 cubic feet per day.

The controlling factor for success at the plant is keeping the temperature of the sludge feed to the anaerobic digester at 102°F or less. This practice maintains the digestion process in the mesophilic temperature range, optimizing biological activity and gas production. This temperature is maintained by running the supernatant and filtrate piping from the LPO system through an aeration basin prior to discharge to the digester.

EQUIPMENT PROBLEMS

Equipment problems are associated with grinders, high pressure feed pumps, heat exchangers, and reactors.

Grinders

The major problem with grinders in the HT/LPO system is failure of the heavy duty internal upper and lower seals and bearings after only a few hundred hours of operation. The grinders can be modified by changing the factory installed internal seals to a less expensive external standard seal having a packing gland with a lantern ring and water seal. Although such a change requires modification of the grinder housing and relocation of the prime mover, it can greatly increase the life of the bearings and seals for these components.

High Pressure Feed Pumps

The most common problems experienced with piston pumps are high wear of the pistons and piston rods due to grit, internal recirculation of sludge within the pump due to failure of the cylinder liner seal, and breakage of oil lubrication system piping which can result from equipment vibration. Removal of grit in the headworks and, when necessary, from the sludge feed to a thermal conditioning system will minimize wear of pistons and piston rods.

Cylinder liner seal failure of piston pumps is of particular concern where a stroke counter is used instead of a sludge flow meter. With a stroke counter, the problem of sludge recirculation within the pump will go undetected for long periods due to the inability to detect loss of flow and/or pump efficiency. This flow reduction to the HT/LPO system can cause plugging problems in the heat exchanger. Although using a flow meter and recorder with a piston pump produces a flowchart of peaks and valleys reflecting pump pulsations, the record is useful in estimating average flow and in monitoring dropoff trends in flow rate.

The problem of breakage in the oil lubrication system piping can be solved by installing flexible tubing connections to pumps and by locating hard piping away from the pump which isolates it from equipment-generated vibrations.

The most common problem experienced with progressive cavity pumps is excessive wear of the rotor and stator due to high grit content of the feed sludge or the pump running dry. Removal of grit from the feed sludge is the best way to avoid rotor and stator wear. Stator life can be extended up to 50 percent by reversing the stator when pump efficiency begins to drop off. If grit wear occurs, the stator will wear out on the suction side first. By reversing the stator, the intact discharge side will deliver the required efficiency. Again, the use of flowmeters is a major benefit in early detection of stator wear. It should be emphasized that a progressive cavity pump should not be considered as a true positive displacement pump, and a pump revolutions meter, calibrated to cubic feet per minute, should not be used as a true indication of actual flow rate. If flowmeters are not installed, systematic and frequent sludge blending tank drawdown measurement should be employed to determine actual pump flow rates.

The hydraulic exchange pump does not have the problems observed with the positive displacement and the progressive cavity pumps. The design of the hydraulic exchange pump completely isolates the pump components and hydraulic system (except for inlet and outlet ball check valves) from the sludge being pumped by means of a positive mechanical seal and a flexible diaphragm. It was designed for and has been successfully used in LPO systems.

Heat Exchangers

Problems with heat exchangers include corrosion, clogging, and scaling. In some HT system heat exchangers with aftercoolers, corrosion and leakage in the outer tubes have occurred. These problems are caused by using effluent water as the cooling medium. One solution is to use noncorrosive materials in the aftercooler; however, the initial capital cost may be excessive. A more cost-effective solution may be to locate the aftercooler externally to the heat exchanger for easy access to the tube sections. The small aftercooler can be repaired without removing the massive insulation around the main heat exchanger.

High concentrations of grease, oil, polymers, tar, fibers, rags and metal particles may clog the heat exchanger in a relatively short period of time. Removal of scum and screenings prior to thermal conditioning (preferably from the liquid flow train) will reduce problems associated with these substances. Polymer dosages should be carefully monitored and controlled to minimize clogging associated with polymers. Cleaning methods for these substances include steam, polypigging, backflushing, alternating forward-back flushing, hot water or steam/cold water shock, acid cleaning, and combinations of these procedures, depending on the material of construction of the HT/LPO system. The specific cause of clogging must be identified in order to determine the cleaning procedure likely to be most effective.

Formation of hard calcium sulfate scale on heat exchangers is a problem reported in areas that have hard water or certain industrial contributions (5,7). The inverse solubility of calcium sulfate with temperature can be a serious problem with the thermal conditioning process. Sludge with high concentrations of calcium, sulfate and phosphate normally precipitates a scale over a relatively long period of time. Regular acid washing removes the scale and prevents its initial build-up (5). The acid wash solution used to clean the HT/LPO system is diluted with nonpotable water and bled back into the mainstream process.

Scale accumulation usually is a problem and is often a serious one in the LPO system. During the cool down cycle when conditioned sludge passes through the shell side of the heat exchanger, scale is deposited on the outer surface of the inner pipe (the tube). When the unit is put on standby or is shutdown, the cold effluent water fed through the heat exchanger for flushing loosens and fractures some of this scale from the surface of the tubes and is flushed out of the system. Some of the larger pieces of scale can become trapped in the tee sections at the shell bottom crossover. Prior to cleaning of the heat exchanger, this trapped scale should be removed from the shell by high pressure/high flow backflushing of the heat exchanger. After backflushing, the system should be flushed with acid to remove any scale deposits still on the tubes. Following the acid cleaning procedure, the operator should again backflush the annular space between the tube and shell of the heat exchanger to remove all remaining scale deposits.

The frequency of backflushing and acid and mechanical cleaning can vary from a few weeks to a few months, depending upon the sludge characteristics. Cleaning costs for scale have exceeded manufacturers estimates by several times in some facilities, resulting in reduced cleaning frequency or abandonment of the thermal conditioning process. A system-specific cleaning procedure and frequency should be developed for each plant by plant personnel in conjunction with the design engineer and system manufacturer. Operations personnel should be thoroughly trained prior to implementation of these procedures.

Reactors

Reactor problems are generally associated with the level control, steam injection, and off-gas systems. Use of capacitance probes for reactor level detection should be avoided due to the tendency of these probes to become clogged and to send false signals. A more dependable level control system is nuclear source level detection.

The steam injection system, in multi-unit systems where steam supply is controlled by a single manual valve, allows preferential steam loading to occur. To avoid this problem, the use of constant pressure regulators is recommended.

Plugging of the off-gas line in an HT reactor is an operational problem rather than a design or equipment problem. The solution to this problem is for the operator to use the steam clean-out system on the reactor as frequently as required to keep the off-gas line clear. The frequency of cleaning will vary depending on system and process conditions.

The installation of a flowmeter and throttling valve to the reactor off-gas system to limit the amount of hot gases released from the system would be an improvement. Manual throttling would assure sufficient steam injection to sustain treatment and limit the amount of energy wasted to the atmosphere.

OPERATIONS PROBLEMS

Problems associated with thermal conditioning system operations are in the areas of management, staffing, training, and process operation.

Management personnel should be aware of the technical complexities of HT/LPO systems. Management should have a knowledge of system O&M needs, including expected results, methods to evaluate performance, and a system of personnel accountability.

Because of the complexity of the thermal conditioning process, having an O&M staff with the right qualifications is an absolute necessity. This staff must have a working knowledge of the process, the ability to troubleshoot process problems, and be motivated to learn. Salaries commensurate with these qualifications are also needed to attract and retain highly skilled personnel.

Quality training is required for personnel who operate, maintain, and manage these systems. The training normally provided by the manufacturer during startup is, in most cases, not sufficient to ensure that long term personnel training needs are met. Specialized training is required and should include:

- Basic knowledge of routine system startup, shutdown and standby procedures
- Preventive maintenance requirements and procedures
- System process control theory and testing procedures
- Process troubleshooting techniques
- System economic considerations
- Process data collection, documentation, and evaluation
- Support system O&M, control, fine tuning, and troubleshooting.

A number of other problems associated with operation of thermal conditioning systems, and a number of potential solutions to the problems, were discussed under Design Problems and Equipment Problems in this section. Although many of these problems are related to the design of the system and the equipment provided, they can often be eliminated or at least mitigated by proper operation of the thermal conditioning process. In many instances, properly designed systems have functioned poorly due to improper operations. Areas in which improved operations can enhance system performance include:

- Control of sludge dewaterability through adjustment of cook temperatures
- Control of energy consumption through proper system maintenance and control of cook temperatures
- Control of clogging problems through scheduled, thorough cleaning of the system
- Control of odors and sidestream strengths through control of sludge feed characteristics and cook temperatures, and through proper system maintenance.

Thermal conditioning systems include a number of hazardous operations. Chief among these are system backwashing and acid cleaning. The use of concentrated acids in acid cleaning requires careful attention to safety precautions and should not be taken lightly by plant personnel.

SECTION 4

SUMMARY OF DESIGN AND OPERATIONAL CONSIDERATIONS

As with most processes in wastewater treatment facilities, the selection, design, and operation of a thermal conditioning system must take into account not only its integration into the overall treatment process, but also the complexities of the system. Failure to do this has led to many of the past and current problems that have plagued the thermal conditioning process. Under the right circumstances, it can be an effective part of the sludge processing train.

This section summarizes the more important design and operational factors to review when considering thermal conditioning as part of a new or upgraded treatment plant, or when optimizing the performance of an existing facility.

IMPROVING SYSTEM DESIGN

When planning a thermal conditioning system, the following process and equipment design factors should be considered:

- The characteristics of the feed sludge to the thermal conditioning process are extremely important. It should be a uniform 3 to 5 percent solids, contain a minimum of grit and rags, and be a homogeneous mixture of primary, waste activated, digested, or trickling filter sludges. Waste activated sludge alone does not condition well.

- The physical layout of the system should provide easy access to all equipment components, controls, and instrumentation. The installation of all system equipment on one floor of a single building is highly desirable.

- Equipment selection and sizing should be carefully matched to the rate and mass of sludge production expected from the mainstream treatment processes. Multiple and standby units should be provided where needed to allow efficient operation of the thermal conditioning system.

- Instrumentation that ensures continuous process monitoring and control should be carefully located and properly installed. Where vibrations are a problem, gauges should be remotely mounted, with flexible connections to the monitoring element, to extend instrument life.

- A blending tank with a mechanical mixing system should be provided to permit a uniform sludge mixture to be fed to the system.

- The materials of construction for the heat exchangers should be carefully selected in recognition of the characteristics of the sludge to be treated and the extreme operating conditions. Material selection should also be compatible with the cleaning system that will be used.

- Maximizing heat exchanger area, consistent with maintaining a reasonable pressure drop across the exchanger, should be considered. Increasing the effectiveness of heat transfer lowers energy consumption.

- The collection and treatment of odorous off-gases from decant tanks and dewatering areas must be included in all facility designs. The ability to control odors is an important consideration in the selection of a thermal conditioning system.

- Sidestreams must be fully characterized to evaluate accurately recycle and separate treatment alternatives. Pilot plant testing may be warranted. If sidestreams are returned to the mainstream treatment train, their impact on plant loading and capacity must be taken into account.

- Energy recovery systems to reduce plant-wide energy consumption should be incorporated into the solids handling system design where feasible.

IMPROVING EXISTING SYSTEMS

To improve the operation and increase the efficiency of an existing thermal conditioning system, the design factors discussed above should be used as a guide for determining needed plant modifications or operational changes. In addition, the following key factors should be given careful consideration as means to improve system effectiveness:

- Install equipment to improve grit and rag removal at the plant headworks and/or in the feed sludge flow to the thermal conditioning system. This will reduce problems of clogging and abrasive wear in the heat exchanger and high pressure pumps.

- Modify or replace existing sludge thickening equipment to provide a uniform feed sludge solids of 3 to 5 percent.

- Consider the installation of hydraulic exchange pumps in lieu of other high pressure feed pumps if pump wear is excessive.

- Upgrade system instrumentation to provide the proper number, types, and locations of analyzers, gauges, and other instrumentation to obtain representative process readings and to facilitate operator use. Where necessary, consider upgrading to provide two- or three-mode control loops.

- Undertake sampling and characterization of sidestreams to determine treatment alternatives. If necessary, perform pilot plant testing of treatment alternatives to determine improved sidestream treatment.

- Investigate the feasibility of energy recovery and reuse systems, such as using digester gas or waste heat from incineration for boiler heating, to decrease energy costs.

- Maintain the original heat transfer efficiency of the heat exchanger by establishing and implementing a routine mechanical or acid cleaning program.

DESIRABLE OPERATING CHARACTERISTICS

The key variables for achieving successful performance of HT/LPO systems include temperature, sludge feed, and, for the LPO system, process air. These parameters are an important consideration in designing a new system or in optimizing the performance of an operating facility.

- Sludge dewatering characteristics are directly related to the temperature to which the sludge is subjected in the reactor. This reaction temperature should be monitored by performing a Specific Filtration Resistance Analysis on the solids leaving the process. The cook temperature in the reactor should be kept between 350°F and 400°F, and as low as possible within this range, to reduce fuel consumption and the solubilizing of BOD.

- The reaction temperature can be controlled by changing the sludge feed rate or the boiler steam production rate. The specification of both variable speed sludge feed pumps and steam production rate controls with adequate operating ranges must be provided to properly control reactor temperatures.

- Process air rates in LPO systems should be between 0.08 and 0.15 pounds of air per gallon of sludge. A needle valve assembly on the compressor discharge will permit this control and prevent back surging in the heat exchanger.

IMPROVING PLANT OPERATION AND MAINTENANCE

As with any wastewater treatment process, efficient, safe, and cost-effective operation of a thermal conditioning system is dependent upon having well-qualified and trained personnel working within a well-managed system with adequate budget support. It must be recognized, however, that thermal conditioning is a complex process with very specialized equipment. These complexities demand that special attention be given to the staffing, training, and management of any thermal process to ensure safe and efficient operation.

Wastewater treatment plants with HT/LPO systems must also have an effective process control program to balance solids production with solids handling, conditioning, dewatering, and disposal operations. Such a program can minimize startups and shutdowns of the HT/LPO processes, decreasing operating costs for existing thermal conditioning systems by at least 10 to 20 percent of current costs.

Special attention should be given to the following areas:

- A thorough training program should be provided to operators of HT/LPO systems, with emphasis on hands-on training. Instructors should have practical, hands-on operating experience with thermal conditioning systems.

- The training emphasis should be on process control, special maintenance requirements, and safety.

- The training program should be routinely updated and presented to the operators to reinforce essential O&M concepts and to minimize the impact of personnel turnovers.

- All treatment plants with thermal conditioning systems should conduct a detailed evaluation of the complete solids handling train to identify areas where modifications can be made to improve the overall operation and reduce O&M costs.

REFERENCES

1. U.S. Environmental Protection Agency, "Improving Design and Operation of Heat Treatment/Low Pressure Oxidation Systems," EPA Contract No. 68-03-3208, In preparation.

2. Orris E. Albertson, Enviro Enterprises, Inc., Correspondence, March 12, 1985.

3. Adams Jr, Carl E., Davis L. Ford, and W. Wesley Eckenfelder Jr., Development of Design and Operational Criteria for Wastewater Treatment, Enviro Press, Inc., Nashville, TN, 1981.

4. U.S. Environmental Protection Agency, "Handbook for Estimating Sludge Management Costs," EPA/625/6-85/010, October 1985.

5. U.S. Environmental Protection Agency, "Process Design Manual for Sludge Treatment and Disposal," EPA-625/1-79-011, September 1979.

6. U.S. Environmental Protection Agency, "Effects of Thermal Treatment of Sludge on Municipal Wastewater Costs," EPA-600/2-78-073, June 1978.

7. U.S. Environmental Protection Agency, "Municipal Wastewater Treatment Plant Sludge and Liquid Sidestreams," EPA-430/9-76-007, June 1976, National Technical Information Service, Order No. PB 255-769.

8. Dague, Richard R., "Treatment of Recycle Streams from Thermal Sludge Conditioning," U.S. Department of Interior, Project A-073-LA, Iowa State Water Resources Research Institute, Ames, Iowa, March 1983.

9. San Mateo Water Quality Control Plant, San Mateo, California, June 1984 Monthly Log Sheet.

ENGLISH TO METRIC UNITS CONVERSION TABLE

English	Multiplier	Metric
British Thermal Unit, Btu	1.055	Kilojoule, kJ
British Thermal Unit, per pound, BTU/lb	2.326	Kilojoule per kilogram, kJ/kg
Cubic feet per day, cu ft/d	28.3	Liters per day, L/d
Degrees Fahrenheit, °F	0.555 (°F - 32)	Degrees Centigrade, °C
Feet per second, ft/sec	0.305	Meters per second, m/s
Foot, ft	0.305	Meter, m
Gallons per day, gpd	0.00379	Kiloliters per day, kL/d
Gallons per minute, gpm	0.063	Liters per day, L/d
Inch, in	25.40	Millimeter, mm
Million gallons per day, mgd	43,800	Milliliters per second, mL/s
Pound, lb	0.4536	Kilogram, kg
Pounds per gallon, lb/gal	0.119	Kilograms per liter, kg/L
Pounds per square foot per day, lb/sq ft/d	0.057	Grams per square meter per second, $g/m^2.S$
Pounds per square inch, psi	6895	Pascals, Pa
Ton, ton	907.2	Kilogram, kg

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