SEWAGE SLUDGE INCINERATION AT THE MANCHESTER, NEW HAMPSHIRE WATER POLLUTION CONTROL FACILITY

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ABSTRACT

This paper documents the evolution of sewage sludge incineration at the Manchester, New Hampshire Water Pollution Control Facility (WPCF) from the original multiple hearth furnaces (MHFs) to the recently installed fluid bed incineration system. Specifically the paper presents: the performance and operating problems experienced with the original MHFs; the furnace modifications made to improve the performance and stability of the MHFs; the feasibility studies performed to evaluate alternative combustion systems; the decision to install a hot windbox fluid bed incinerator to replace the MHFs; and design features of the new fluid bed incinerator.

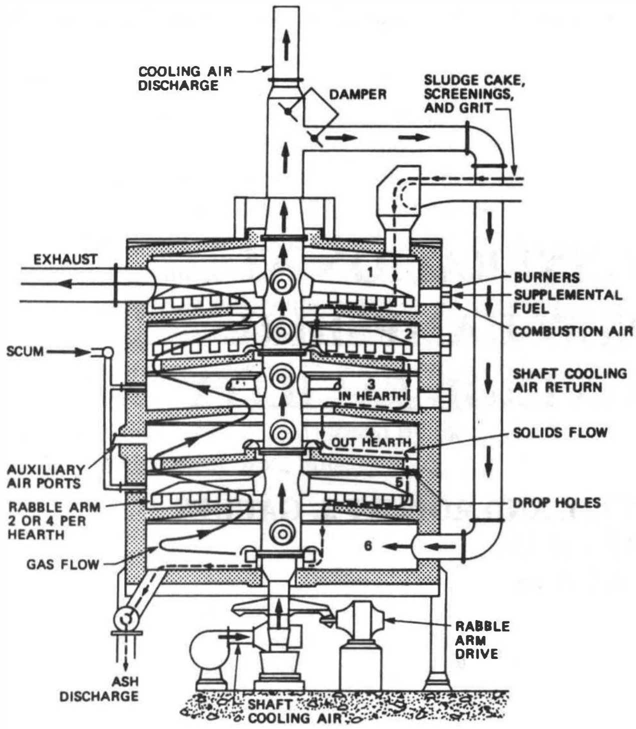
BACKGROUND

The City of Manchester, New Hampshire at their Brown Avenue WPCF has two, six hearth, 22.25 ft (6.78 m)-outside-diameter multiple hearth furnaces, manufactured by Envirotech, BSP Thermal Systems. The furnaces were originally started up in 1976 and have been in intermittent operation since then till 1994. The furnaces are equipped with the following auxiliary equipment:

- Emergency bypass stack
- Provision for center shaft cooling air recycle to furnace or exhaust to stack
- Precooler
- Venturi scrubber with automatically adjustable throat
- Three tray impingement tray subcooler
- Induced Draft (ID) fan
- Steel stack discharging 10 ft (3.05 m) above incinerator building roof.

Each MHF consists of a vertical, circular, refractory-lined, steel shell surrounding six refractory hearths and a central rotating shaft to which rabble arms are attached. A cross sectional view of a typical six hearth MHF is shown in Figure 1. The sludge feed enters the top of the furnace and is moved by the rabble arms across the hearths. Drop holes located at the inner and outer periphery of alternate hearths allow the sludge to fall from hearth to hearth as it moves through the furnace. The combustion gases flow countercurrent to the flow of sludge and exit the top of the furnace, through a side breaching. Conceptually, the furnace has three zones which serve the following functions: sludge drying; burning of volatile matter; and ash cooling. These zones (or hearth areas) are not fixed but rather variable areas which can expand or contract depending on the feed moisture and volatile solids content. The combustion zone in particular can rise or fall in the furnace depending on the feed sludge characteristics.

One of the primary disadvantages of the MHF is that the furnace gases after performing their drying function on the upper hearths exit the furnace at 900°F (482°C). Since there is no afterburning of the exiting gas, this gas stream can contain significant levels of hydrocarbons and odiferous compounds. As explained in the following sections, emission of odors became a primary concern at the Manchester, NH, WPCF.



SOURCE: U.S. EPA PROCESS DESIGN MANUAL FOR SLUDGE TREATMENT AND DISPOSAL EPA 625/1-79-011

FIG. 1 CROSS SECTION OF A MULTIPLE-HEARTH FURNACE

ORIGINAL DESIGN CRITERIA

Two MHFs were provided: one operating and one standby. Each furnace was originally specified to burn dewatered sludge, grit, grease and scum with the following quantities and characteristics:

Sludge Cake:	11,500 wet lb/hr (5,216 wet kg/hr) 15% solids 0.70 lb volatile solid/lb dry solid 10,000 Btu/lb volatile solid (23,260 kJ/kg vol. solid)
Grit:	500 wet lb/hr (227 wet kg/hr) 20%–50% solids 0.30–0.50 lb volatile solid/lb dry solid 10,000 Btu/lb volatile solid (23,260 kJ/kg vol. solid)
Grease and Scum:	500 wet lb/hr (227 wet kg/hr) 50% solids 0.90 lb volatile solid/lb dry solid 16,670 Btu/lb volatile solid (38,770 kJ/kg vol. solid)

The future sludge production for the year 2005 is 28 DTPD (25.4 DMTPD) or 11,670 wet lb/hr (5293 wet kg/hr) at 20% solids. Thus, the MHFs would appear to have adequate capacity to meet the future sludge production. However, the capacity of an incineration system is also determined by its air pollution control train and whether it can meet present-day emission standards. As explained in the following sections, these factors severely limited the capacity of the MHFs.

MHF OPERATION

The furnaces were originally designed to incinerate 15%–20% solids sludge dewatered by centrifuges, as well as thickened scum and grit. The centrifuges were removed and two 2-meter belt filter presses were installed in 1983. The belt filter presses produced drier cake of approximately 18% to 24% solids. Also the incineration of scum and grit was discontinued due to furnace combustion control and maintenance problems.

The MHF operating records from May 1984 through September 1985 were evaluated and are summarized in Table 1. The data show that the furnaces were operated intermittently. On the average the MHFs were incinerating sludge only 228 hours per month (10 days/month) and were in either a heat up or cool down mode 88 hours per month. The intermittent operation was the result of the low generation of sludge at the treatment plant, approximately 8.6 DTPD (7.8 DMTPD). The plant was receiving wastewater from only about one third of its future (2005) service area.

At that time sludge processing consisted of storing primary and waste activated sludge in gravity thickeners for several days and then dewatering and incinerating the sludge in continuous runs, lasting approximately 5 days out of each 2 week period. The MHF loading rate of 9,370 wet lb/hr (4250 wet kg/hr) at 23.3% solids was governed by the belt press feed rate since the belt presses experienced tracking problems at feed rates lower than this value. The intermittent mode of operation resulted in the furnaces going through frequent heat-up and cool down cycles which required a considerable amount of fuel. As shown in Table 1, the fuel usage per hour was greater for heating-up and cooling down than for incinerating sludge. Also the furnaces experienced considerable damage to refractories due to the frequent start-ups and shut downs.

OPERATING PROBLEMS

The dewatered sludge cake produced at the Manchester, NH WPCF is subject to wide variation in both cake solids and volatile content which result in difficult to control operation of the MHFs. The variability in dewatered sludge characteristics is caused by limitations in the plant's thickening operation. Both primary and secondary waste sludges are stored in gravity thickeners prior to dewatering. Prolonged storage and subsequent stratification of the sludges results in layers of sludges with markedly different composition and dewatering character-

TABLE 1 SUMMARY OF INCINERATOR OPERATING DATA MAY 1984 THROUGH SEPTEMBER 1985

PARAMETER	U.S. Units	S.I. Units
SLUDGE INCINERATED IN 17 MONTH PERIOD	4,367 dry tons	3,962 dry metric tons
OPERATING TIME		
Incinerating	228 hr/month	228 hr/month
Heating-up and cooling-down	88 hr/month	88 hr/month
FURNACE LOADING RATES		
Dry solids	2,184 lb/hr	974 kg/hr
Wet solids	9,370 lb/hr	4,250 kg/hr
AVERAGE CAKE SOLIDS	23.3%	23.3%
FUEL OIL USE		
Incinerating	21.2 gal/hr	80.3 l/hr
Heating-up and cooling-down	25.9 gal/hr	98.0 l/hr
Total per hour incinerating	31.1 gal/hr	118 l/hr
FUEL OIL USE		
Incinerating	19 gal/ton dry	79 l/dry metric ton
Heating-up and cooling-down	9 gal/ton dry	38 l/dry metric ton
Total per dry ton	28 gal/ton dry	117 l/dry metric ton

istics. In addition, wet weather flows to the WPCF cause a greater proportion of primary sludge which dewaters more readily than secondary (waste activated) sludge. At times, the belt presses have produced cake with solids levels as high as 50% versus the typical solids level of 22%. Also the heating value of just primary sludge can approach 9,500 Btu/dry lb (22,100 kJ/kg) versus a typical heating value of 7,500 Btu/dry lb (17,400 kJ/kg) for secondary sludge.

Such variations in sludge feed made it impossible to achieve steady, uniform combustion in the MHFs. The high solids and high volatile content sludge caused preignition of volatiles on the upper hearths of the furnace and the release of smokey and odorous emissions to the atmosphere. Due to the large number of odor complaints received at the treatment plant, elimination of odorous emissions became a primary objective in the MHF improvement program.

SHORT-TERM IMPROVEMENTS

In May 1986, to eliminate the periodic emission of smoke and odors from the MHFs, the top hearths of both of furnaces were converted to "zero-hearth" afterburners. This conversion was accomplished by changing the sludge feed point such that the sludge would drop directly on to the second hearth. The first hearth is then used only as a gas residence chamber to complete the combustion of unburned particulate and volatile organics. In addition, a refractory baffle wall encompassing 210 degrees of the center drop hole was constructed. The baffle wall prevented flue gases from shortcircuiting from the drop hole to the furnace outlet breaching. Also one of the existing top hearth burners was relocated such that the two burners

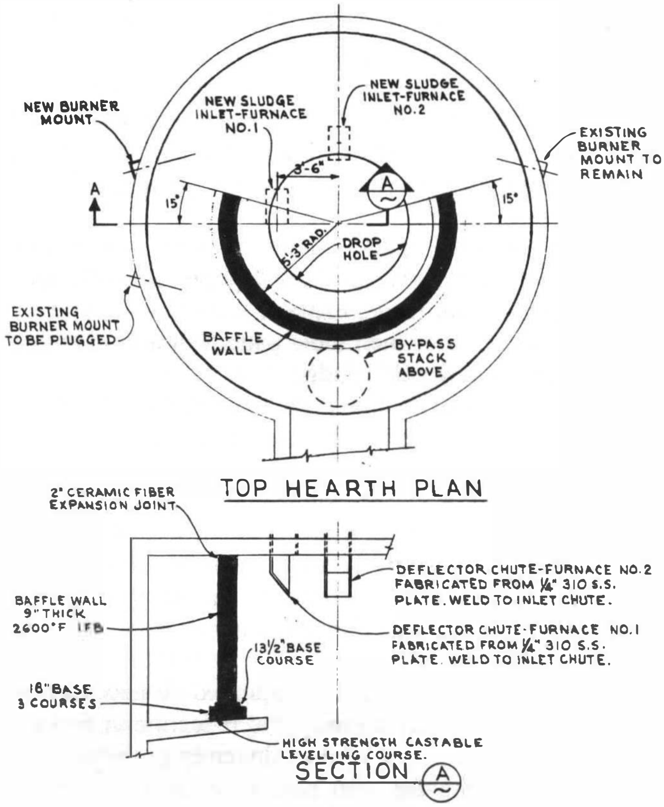


FIG. 2 ZERO HEARTH AFTERBURNER-PLAN AND SECTION

on this hearth would form a flame screen through which the flue gases would have to pass before exiting the furnace. Plan and section views of the "zero-hearth" afterburner are shown in Figure 2.

In general, the zero hearth conversion was effective in controlling smokey and odorous emissions. Reportedly, the zero hearth conversion resulted in the elimination of odor complaints attributable to the MHFs. Visible emissions from the stack were also eliminated even during periods when "difficult to dewater" sludge (received from a neighboring wastewater treatment plant — WWTP) was incinerated. In the past incineration of this imported sludge resulted in emission violations and numerous odor complaints.

With one less hearth on which to incinerate sludge, it was thought that the furnace rating would be reduced to approximately 5/6 of its former capacity or to 9,700 wet lb/hr (4,400 wet kg/hr) assuming a 20% solids feed. However, due to operation problems (mostly clinker formation) this feed rate could not be attained. It appears that clinkers were formed by ash fusion on the hot rabble teeth of Hearth No. 2. The clinkers would break off the rabble teeth and get rabbled through the furnace. The large clinkers caused blockage of the ash screw conveyor and resulted in shutdown of the incineration system. The clinker problem was attributed to the "difficult to dewater" sludge and the excessive amount of auxiliary fuel firing which caused hot spots along the rabble arms and teeth.

Another reason for the reduced furnace capacity was to prevent the discharge of excessively hot ash out the bottom of the furnace. This problem was caused by the lowering of the burning zone to Hearths 4 and 5, leaving only one hearth for ash cooling.

During the three month operating period with zero hearth afterburners, several other equipment and operational changes were made, namely:

(*1*) Modification of the rabble pattern to accommodate the "difficult-to-dewater" sludge.

(*2*) Elimination of the use of the large burners on Hearth No. 2 which had been causing hot spots on the rabble arms and which was an inefficient use of auxiliary fuel.

(*3*) Applying heat lower in the furnace to lower the combustion zone and get more efficient use of the heat for drying the sludge on the upper hearths. This was accomplished by returning the center shaft air to the lower hearths and by sparingly firing the burners on the lower hearths when necessary.

These changes significantly improved furnace performance as evidenced by a substantial reduction in fuel use and essential elimination of the clinkering problem.

However, during the zero hearth test period, a maximum, consistent feed rate of only 8,300 wet lb/hr (3,800 wet kg/hr) was attained which was lower than the expected feed rate of 9,700 wet lb/hr (4,400 wet kg/hr). Due to the reduced furnace capacity, the City decided to eliminate the zero hearth afterburners and in September 1986 converted both MHFs to their original configuration with sludge feed to the top hearths.

PARTICULATE EMISSIONS

In addition to problems with smoke and odorous emissions, the MHFs were not able to meet the EPA particulate emission criteria. MHF, Unit 1, was tested for particulate emissions on July 27, 1987. The furnace had a particulate emission rate of 1.515 pounds of particulate per dry ton of sludge incinerated (lb/dry ton) (0.7575 kg/dry metric ton) and thus was not able to pass the EPA New Source Performance Standard (NSPS) of 1.3 lb/dry ton (0.65 kg/dry metric ton). (The sludge feed during the test averaged approximately 8,875 wet pounds per hour (4,026 wet kg/hr) at 16% solids.

The MHF, Unit 1, was retested on June 22, 1988 and achieved a particulate emission rate of 1.22 lb/dry ton (0.61 kg/dry metric ton), thus passing the NSPS criteria. However, the sludge feed rate to the furnace had to be dropped to 7,073 wet lb/hr (3,208 wet kg/hr) at 19.4% solids, corresponding to a hearth loading rate of 4.48 wet lb/hr-ft^2 (21.9 wet kg/hr-m^2). Thus, the furnaces had to be significantly derated in order to meet the NSPS particulate emission standard. The above sludge feed rate corresponded to 1,372 dry lb/hr (622 dry kg/hr) or 16.5 DTPD (15.0 DMTPD) which was less than the year 2005 sludge production of 28 DTPD (25.4 DMTPD). Thus, the existing MHFs could not meet the year 2005 sludge production and still have a standby unit.

LONG-TERM IMPROVEMENTS

Long-term improvements to the sludge incineration systems were evaluated in the WPCF Final Facilities Plan, completed in November 1987. Four alternative conversions of the MHFs were evaluated, namely:

(*1*) Installation of Zero Hearth Afterburners
(*2*) Installation of External Afterburners
(*3*) Conversion of MHFs to Pyrolysis Mode
(*4*) Conversion of MHFs to Cyclo-Hearth^{TM} Mode

The main objective of this evaluation was to increase sludge incineration capacity while eliminating the previously cited problems of smokey and odorous emissions. Each of the alternatives is briefly described below.

Installation of Zero Hearth Afterburners

This alternative, described previously, had two disadvantages. First, the afterburner configuration was less than optimal since it provided for a 1.25 second gas residence time at 1400°F (760°C). Sawyer (1) has shown that an afterburning temperature of 1400°F (760°C) is sufficient to ensure elimination of odors. However, some air pollution regulatory agencies have required minimum afterburning temperatures of 1500°F (816°C) or greater to ensure destruction of odorous emissions.

Although no odor complaints were received during its use, it is not known exactly how effective the zero hearth afterburner was in consistently controlling odors since no odor measurements were taken during its use. Second, the zero hearth afterburner significantly reduced incineration capacity.

Installation of External Afterburners

This alternative would involve the construction of two free-standing, external afterburners, one located downstream of each MHF outlet breaching. Each afterburner would consist of a vertical refractory-lined chamber, 6 feet (1.83m) square in cross section and 50 feet (15.2m) long, with a burner mounted on top at the inlet end. The chamber would provide approximately 2.4 seconds of gas residence time at 1500°F (816°C). The installation of the afterburners would require extensive modification of the existing incinerators including reinforcing of the existing basement slab, and relocation of the existing venturi scrubbers.

Conversion of MHFs to Pyrolysis Mode

In the pyrolysis or starved-air mode, combustion occurs in two stages. In the first stage which occurs in the MHF, the supply of air is controlled so that partial oxidation occurs. The products of this starved-air combustion are a carbonaceous char and an offgas consisting primarily of products of combustion but containing enough combustible gases (CO, H2 and low molecular weight hydrocarbons) to have a heating value of 20 to 80 Btu/cubic foot (745 to 2980 kJ/cubic meter).

The combustible gas is then delivered to the second stage of the combustion system, an afterburner, where the pyrolytic gas is burned with a minimum of excess air (10 to 15 percent) to achieve the 1400°F (760°C) temperature needed for deodorization and burnout of greases and soot. The main advantage of pyrolysis over incineration is that the pyrolysis afterburner can generally rely on the heating value of the pyrolysis gas to achieve the required 1400°F (760°C) without use of auxiliary fuel. In the pyrolysis mode, only 40 percent excess air is needed for complete combustion, including combustion of the furnace off-gases in the afterburner.

The pyrolysis process has limited operating history. Although pyrolysis of wastewater sludges has been demonstrated successfully in a few pilot-scale and full-scale tests, there is still a need for greater experience to confirm that the pyrolysis mode can be sustained continuously in a full-scale plant.

Conversion to MHFs to Cyclo-Hearth™ Mode

The Cyclo-Hearth™ system is a proprietary product of Zimpro Environmental Inc., designed to alleviate the problems associated with autogenous or self-sustaining combustion. These problems include excessive emission of hydrocarbons and products of incomplete combustion (PICs) due to poor gas mixing and poor temperature control. A Cyclo-Hearth™ system is usually used when the sludge feed has such a high solids and volatile content that pre-ignition and flashing occur on the top hearths of a furnace. In a CycloHearth™ furnace, the sludge feed is dropped to the second or third hearths to keep the combustion zone in the middle of the furnace. Also, the system uses tangentially-fired auxiliary fuel burners and high velocity mixing jets to improve combustion efficiency and temperature control. The turbulence from the mixing jets assures that there are no hearth areas starved for oxygen and hence PICs are not formed. The auxiliary fuel and mixing jet systems allow the operators to respond to rapid changes in feed solids and composition.

At the Manchester, NH WPCF, the characteristics of the dewatered sludge fluctuate significantly. Variable sludge cake characteristics cause fluctuations in the furnace temperature and periodic flashing of sludge volatiles. Conversion to the Cyclo-Hearth™ mode would primarily provide better control of the combustion process. In addition, it was thought that the high velocity mixing jets would provide a more turbulent combustion zone and hence minimize emissions of odors and PICs.

Recommendation from Final Facility Plan

The above four alternatives were technically and economically evaluated in the Final Facilities Plan. The result of this evaluation was that Alternative 2 (Installation of External Afterburners) was recommended as the most cost-effective upgrade to the MHFs. However, an independent Value Engineering (VE) Study was conducted (as required by the EPA) at the conclusion of the Final Facilities Plan, and its recommendation was to abandon the existing MHFs and install two new fluid bed incinerators. After review and analysis of the VE recommendations, the City finally decided to construct one fluid bed incinerator and a new incineration building. The existing MHFs were at first to be maintained as standby units, but the City has since decided that it is not worth the expense to maintain these furnaces as standby units and hence both units will be abandoned. During outage of the fluid bed incinerator, the dewatered sludge will be either hauled to regional landfills or else hauled away by a private sludge processing company.

FLUID BED INCINERATION SYSTEM

Technical specifications and design drawings for the incineration facility were prepared in 1990–91, and the project was bid as part of the overall WPCF Upgrade and Expansion in May 1991. Zimpro Environmental Inc. was selected as the supplier of the Fluid Bed Incineration System (FBIS). As of January 1994, construction of the FBIS was complete and testing was underway.

General Description of a Fluid Bed Incinerator

A fluid bed incinerator or reactor consists of a vertical, cylindrical, refractory-lined vessel containing a bed of sand in its lower tapered section. Sludge and fuel, if necessary, are fed into the bed and fluidizing air is blown into the bottom of the sand bed to create a turbulent suspension of sand, sludge and gases. In the hot suspension, 1400°–1500°F (760°–816°C), water in the sludge is rapidly evaporated and volatile matter in the sludge is quickly combusted. Unlike the MHF, in a fluid bed, drying and combustion take place concurrently in the same zone at temperatures of 1400°–1500°F (760°–816°C). Also good mixing in the bed allows for low excess air levels of 30%–45%. The sand in the bed serves several purposes. It promotes thorough and rapid mixing of the sludge and the combustion air; it acts as a thermal sink, storing heat and insuring uniform temperatures; and it acts

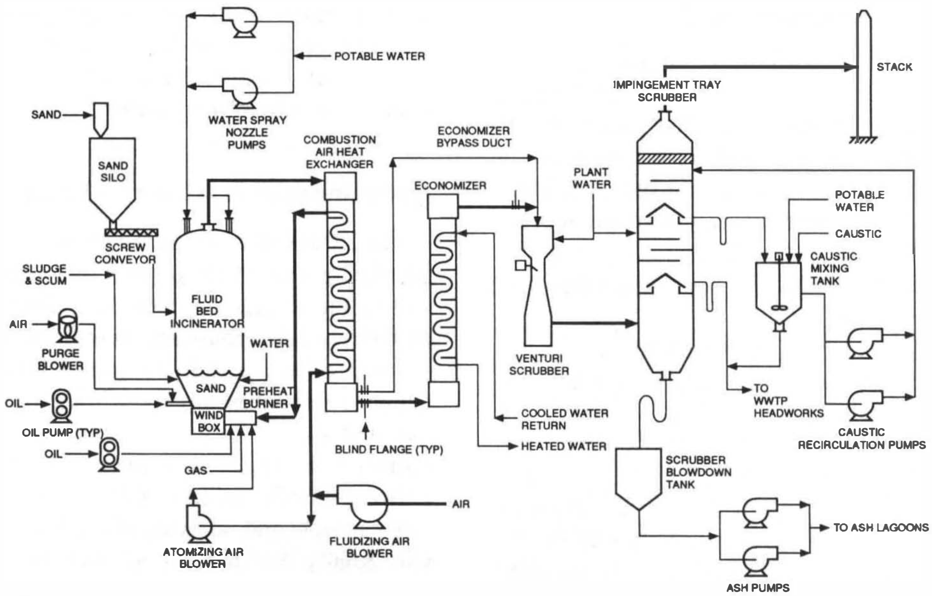


FIG. 3 PROCESS FLOW DIAGRAM OF FLUID BED INCINERATION SYSTEM

as a very efficient heat transfer medium that rapidly heats up the incoming sludge.

The hot combustion gases flow out of the bed into the freeboard which is a large open air space above the bed. In the freeboard the velocity of the combustion gases is reduced to allow the sand to disengage from the upward moving gas stream and fall back into the bed. The freeboard also acts like an afterburner, providing approximately 5 to 6 seconds of gas residence time at 1550°F (843°C), thus insuring essentially complete combustion of volatile matter.

Since the flue gas exits the reactor at 1550°F (843°C), the sensible heat loss from the reactor is very high, and thus fuel usage would be high. This deficiency has been overcome by the use of a combustion air heat exchanger which is capable of preheating combustion air to approximately 1200°F (649°C) while cooling the flue gas to about 1050°F (566°C). In Manchester's case, the combustion air heat exchanger makes it possible to burn a low, 22% solids sludge cake with a minimal fuel use of 2.4 gal/hr (9.1 l/hr). Whereas without the combustion air heat exchanger, the fuel usage would be 162 gal/hr (613 l/hr), nearly 70 times higher. A fluid bed incinerator with a combustion air heat exchanger is called a hot windbox design, versus a cold windbox without the heat exchanger. In a hot windbox fluid bed, the windbox is refractory-lined so it can receive hot preheated combustion air.

It should be noted that all the inert material in the feed streams and some of the bed material leaves the reactor as flyash entrained in the exiting flue gases. Fortunately, the flyash resembles a fine grain sand, not tacky or sooty, and is collected relatively easily in a high pressure drop venturi scrubber. Electrostatic precipitators have also been successfully used at a few installations.

Fluid Bed Incineration System at Manchester, NH WPCF

The FBIS at Manchester, NH WPCF was designed for a feed rate of 43 DTPD (39 DMTPD) in order that the future (year 2005) sludge production of 28 DTPD (25.4 DMTPD) could be processed in a 16 hour (2 shift) work day. A process flow diagram of the FBIS is presented in Figure 3 and design criteria for the FBIS are listed in the Appendix. The FBIS consists of the following components:

- Hot Windbox Fluid Bed Incinerator
- Combustion Air Heat Exchanger
- Economizer With Heat Recovery System
- Venturi and Impingement Tray Scrubber

Hot Windbox Fluid Bed Incinerator. Feeds to the fluid bed consist of mixed primary and secondary sludges dewatered to 22% solids on the existing belt filter presses and scum thickened to 50% solids. The dewatered sludge and scum are fed to the FBIS using two high pressure piston pumps manufactured by Schwing Inc. The scum is mixed with the sludge in the inlet hopper of the piston pumps. The sludge and scum are fed directly into the fluid bed through four feed ports located low on the periphery of the bed. Fuel oil is pumped into the reactor through 4 fuel injection guns, or air-cooled lances, located low on the bed.

The fluid bed incinerator supplied by Zimpro has a unique air distribution system in the windbox section of the reactor. The system consists of a large refractory-lined duct from which risers feed horizontal air ducts lying on the floor of the bed. Tuyeres or cone-shaped nozzles are screwed into the horizontal air ducts and cover nearly the entire floor of the bed. The tuyeres have flat tops containing numerous slits through which the fluidizing air is introduced into the sand bed.

The reactor has inside diameters of 14 ft-0 in (4.27 m) at the bottom of the bed and 17 ft-0 in (5.18 m) at the freeboard. The superficial space velocity of the combustion gases in the freeboard at design conditions is approximately 3 ft/sec (0.914 m/sec) which is in agreement with recommended design criteria found in a sludge incineration manual (2).

The reactor has a large preheat burner located off the windbox capable of supplying 8.4 million Btu/hr (8860 MJ/hr). The preheat burner is used only during start ups to heat the bed from ambient to about 1200°F (649°C). Once the bed temperature has reached 1200°F (649°C), fuel oil can be injected directly into the bed to further increase the bed temperature.

The reactor is also equipped with six high pressure water spray nozzles located in the reactor dome, two emergency water spray guns located in the reactor side wall near the top of the sand bed, and two water injection guns located low in the bed. The dome sprays are provided to ensure that flue gas temperatures do not exceed 1700°F (927°C), since temperatures above 1700°F (927°C) can cause damage to the downstream combustion air heat exchanger. The bed sprays are automatically activated by the combustion control system when excessive bed temperatures occur.

Like most fluid bed sludge incinerators, the FBIS at the Manchester, NH WPCF is a push system; there is no ID fan. The fluidizing air blower pressurizes the entire system from blower discharge to stack. The fluidizing air blower is a multi-stage centrifugal machine capable of supplying 7,275 scfm (12,760 Nm^3/hr) at 7.5 psig (51.7 kN/m^2).

Combustion Air Heat Exchanger. As previously stated, the combustion air heat exchanger preheats the combustion air to 1200°F (649°C) while cooling the flue gas from 1550°F (843°C) to 1050°F (566°C). In doing so, approximately 8.8 million Btu/hr (9285 MJ/hr) of thermal energy is recovered from the flue gas and returned to the reactor to sustain the combustion process. The combustion air heat exchanger has a severe duty since it must recovery thermal energy from a dirty, corrosive flue gas, heavily-laden with particulate matter.

The combustion air heat exchanger was supplied by American Schack Company Inc. and consists of a vertical tube bundle with top and bottom refractory-lined plenums. The flue gas enters the top plenum and then flows vertically down through the tubes at velocities in the range of 6000–8000 ft/min (1829–2438 m/min) at the inlet end. The tubes are 3 inches (76 mm) in inside diameter to prevent plugging. The fine grain flyash in the flue gas helps to scour the inside surface of the tubes and prevent fouling.

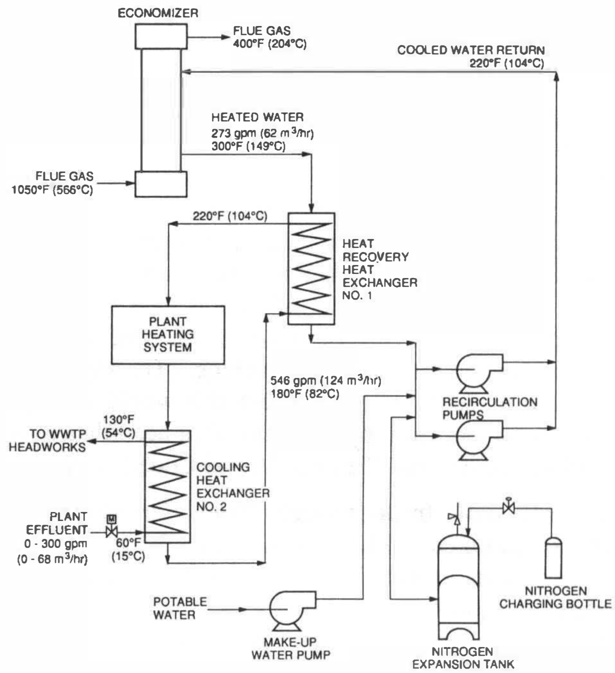


FIG. 4 PROCESS FLOW DIAGRAM OF HEAT RECOVERY SYSTEM

The combustion air is heated on the shell side of the heat exchanger. The tubes, tubesheets and expansion joints in the heat exchanger are constructed of a high nickel alloy (Alloy 625) to withstand the high temperature and corrosive attack from chlorides, estimated at 100 ppmdv in the flue gas.

Economizer with Heat Recovery System. The FBIS at Manchester, NH WPCF is distinctive in that it has an economizer with heat recovery system that can supply hot water to the plant heating system. A simplified flow diagram of the heat recovery system is presented in Figure 4. The system consists of an economizer, a heat recovery heat exchanger, a cooling heat exchanger, recirculation pumps and accessories. The economizer consists of a vertical tube bundle enclosed in an insulated steel shell. The flue gas flows vertically up through the tubes while high pressure water is heated on the shell side. The high pressure hot water is sent to the heat recovery heat exchanger which can transfer up to 10.44 million Btu/hr (11,020 MJ/hr) of thermal energy to a low temperature, low pressure hot water loop. Since the plant heating system will not need all the recovered heat during much of the year, a third heat exchanger (a cooling heat exchanger) is required. The cooling heat exchanger will take whatever heat that the plant heating system can not use and transfer it to the plant effluent. The flow of plant effluent to the cooling heat exchanger will vary from 0 to 300 gpm (0–68.1 m^3/hr) so that the constant flow of return water to the heat recovery heat exchanger is maintained at 180°F (82°C). Also since the primary high temperature loop is 220°F (104°C) to 300°F (149°C), this loop must be pressurized to prevent flashing of the water to steam. A nitrogen expansion tank and nitrogen charging bottle are provided to maintain a pressure of 118 psig (814 kN/m^2) in this loop. Note that a bypass duct around the economizer is provided so that the economizer and heat recovery system can be taken out of service in the warm weather months if the plant staff so chooses.

Based on the manufacturer's recommendation, the economizer tubes are constructed of carbon steel (rather than an austenitic stainless steel), since carbon steel will effectively prevent stress corrosion cracking. (The tubes could have been made of Alloy 625, but this would have prevented the vessel from being stamped in accordance with the ASME Boiler and Pressure Vessel Code.)

Venturi and Impingement Tray Scrubbers. The FBIS is supplied with a high pressure drop venturi scrubber as its primary particulate control device. The venturi is capable of providing a minimum pressure drop of 35 inches of water (8.7 kN/m^2) across the venturi. The pressure drop across the throat of the venturi is automatically controlled by a double damper blade in the throat section. The scrubber is designed to achieve an outlet particulate loading of 0.75 lb/ton (0.375 kg/metric ton) of dry sludge burned which will exceed the requirements of the EPA New Source Performance Standards (NSPS) for Municipal Sludge Incinerators. The venturi blowdown laden with incineration ash will be sent to two ash lagoons where the ash will settle and eventually be hauled to a landfill. The plant has been provided with two ash lagoons (i.e., below grade concrete basins), each capable of 3 months of ash storage.

The impingement tray scrubber is unique since it has two stages, each serving a different function. The lower stage, consisting of three impingement trays, is a subcooler in which a large quantity of water (plant effluent) is used to subcool the flue gas to 110°F (43°C). This is done to lower the humidity of the flue gases and thereby greatly reduce plume formation from the stack. The second stage, consisting of two impingement trays, is a caustic scrubber in which a 1% caustic (NaOH) solution is used to achieve 90% control of acid gases. The treated flue gas is sent to a 121.5 foot (37 m) stack with an outlet velocity of 65 ft/sec (19.8 m/sec). The blowdown from the subcooling trays and the caustic trays is sent to the headworks of the WPCF.

SUMMARY

The Manchester plant has had difficulty getting satisfactory performance from its MHFs largely due to the variability of the sludge feed which results from poor mixing and blending of the primary and secondary sludges prior to dewatering and from processing of difficult to dewater sludges from other WWTP's. Operating problems have included release of odorous and smokey emissions and reduced furnace capacity. The zero hearth afterburner, while successful in eliminating smoke and odors, reduced the incineration capacity to unacceptable levels and was discontinued by the plant staff. The long-range-planning studies eventually recommended that a fluid bed incinerator be installed to replace both MHFs. A state-of-the-art FBIS has been designed and constructed at the Manchester, NH WPCF, and it should be better able to handle the variable consistency of sludges encountered at this wastewater treatment plant.

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[2] Water Environment Federation. "Sludge Incineration: Thermal Destruction of Residues (Manual of Practice FD-19)." publ. by WEF, Alexandria, VA, 1992, pp. 171–173.

APPENDIX
DESIGN CRITERIA OF FLUID BED INCINERATION SYSTEM

	U.S. Units	S.I. Units
WWTP Solids Loading		
Initial Year:		
Sludge (dry) (7 day basis)	240, 100 lb/wk	108, 900 kg/wk
Scum (dry) (7 day basis)	440 lb/wk	200 kg/wk
Design Year:		
Sludge (dry) (7 day basis)	382, 900 lb/wk	173, 700 kg/wk
Scum (dry) (7 day basis)	700 lb/wk	317 kg/wk
Solids Feed to FBIS[1]		
Sludge:		
Solids, %	22	22
Moisture, %	78	78
Volatiles, %	76.8	76.8
Ash, % (dry basis)	23	23
Heat Content (dry basis)	8,622 Btu/lb	20,050 kJ/kg
Feed Rate (wet)	15,910 lb/hr	7,217 kg/hr
Feed Rate (dry)	3,500 lb/hr	1,588 kg/hr
Scum:		
Solids, %	50	50
Moisture, %	50	50
Volatiles, %	90	90
Ash, % (dry basis)	10	10
Heat Content (dry basis)	15,000 Btu/lb	35,000 kJ/kg
Feed Rate (wet)	220 lb/hr	100 kg/hr
Feed Rate (dry)	110 lb/hr	50 kg/hr
Hours of Combustion:		
Initial Year, hr/wk	68.6	
Design Year, hr/wk	109.4	
FBIS Operating Parameters		
Fluidizing Blower Discharge:		
Flowrate	7,275 scfm	12,360 N cu m/hr
Dry Gas	32,793 lb/hr	14,875 kg/hr
Water Vapor	246 lb/hr	112 kg/hr
Pressure	207 in of water	51.5 kN/sq m
Combustion Air Flowrate[2]	23,080 acfm	39,210 cu m/hr
Combustion Air Temperature	1,190°F	643°C
Excess Air, %	40	40

DESIGN CRITERIA OF FLUID BED INCINERATION SYSTEM

	U.S. Units	S.I. Units
Bed Temperature	1,350°F	732°C
Freeboard Temperature	1,550°F	843°C
Fluid Bed:		
Exit Flue Gas Flowrate	47,425 acfm	80,580 cu m/hr
Dry Gas	33,780 lb/hr	15,323 kg/hr
Water Vapor	14,812 lb/hr	6,719 kg/hr
Exit Flue Gas Temperature	1,550°F	843°C
Sand Loss (maximum)	40 lb/hr	18 kg/hr
Fuel Flowrate (@ 22% solids)		
#2 Fuel Oil	0.04 gpm	0.15 1/min
Annual Fuel Usage[3]		
#2 Fuel Oil	12,000 gal	45.4 cu m
Recuperator Exit Flue Gas:		
Flowrate	35,600 acfm	60,500 cu m/hr
Temperature	1,050°F	566°C
Economizer Exit:		
Flue Gas Flowrate	20,290 acfm	34,470 cu m/hr
Flue Gas Temperature	400°F	204°C
Water Temperature	300°F	149°C
Water Pressure	118 psig	814 kN/sq m
Water Flowrate	273 gpm	1,030 l/min
Economizer Available Heat	10.44 mm Btu/hr	11,020 MJ/hr
Heat Recovery Heat Exchanger, #1:		
Water Flowrate	546 gpm	124 cu m/hr
Water Inlet Temperature	180°F	82°C
Water Outlet Temperature	220°F	104°C
Cooling Heat Exchanger, #2:		
Water Flowrate	0-300 gpm	0-68 cu m/hr
Water Inlet Temperature	60°F	16°C
Water Outlet Temperature	130°F	54°C
Venturi Scrubber:		
Flue Gas Inlet Temperature	400°F	204°C
Pressure Drop (design)	35 in of water	8.71 kN/sq m
Water Flowrate	150 gpm	34.1 cu m/hr
Blowdown Flowrate	143 gpm	32.5 cu m/hr
Blowdown Temperature	175°F	79°C
Tray Scrubber:		
Flue Gas Exit Temperature	110°F	43°C
Water Flowrate	385 gpm	87.4 cu m/hr
Blowdown Flowrate	415 gpm	94.3 cu m/hr
Blowdown Temperature	140°F	60°C

APPENDIX - Continued

DESIGN CRITERIA OF FLUID BED INCINERATION SYSTEM

	U.S. Units	S.I. Units
Caustic Scrubber:		
Recirculation Flowrate	40 gpm	9.1 cu m/hr
Blowdown Flowrate	5.8 gpm	22 l/min
Caustic Make-up Flowrate	0.114 gpm	0.432 l/min
Water Make-up Flowrate	5.7 gpm	21.57 l/min
Stack Discharge Flue Gas:		
Flowrate	8,454 acfm	14,360 cu m/hr
Dry Gas	33,780 lb/hr	15,323 kg/hr
Water Vapor	1,892 lb/hr	858 kg/hr
Temperature	109°F	43°C
Stack:		
Exit Gas Velocity	65 ft/sec	20 m/sec
Diameter	1.67 ft	509 mm
Height (above grade)	121.5 ft	37.03 m
FBIS Ancillary Equipment		
Reactor Side Wall Water Spray Guns:		
Quantity	2	2
Capacity (each)	3 gpm	11.4 l/min
Discharge Pressure	20 psig	138 kN/sq m
Reactor Bed Water Injection Guns:		
Quantity	2	2
Capacity (each)	3 gpm	11.4 l/min
Discharge Pressure	20 psig	138 kN/sq m
Reactor Dome Water Spray Nozzles:		
Quantity	6	6
Capacity (each)	1 gpm	3.79 l/min
Discharge Pressure	300 psig	2,068 kN/sq m
Fuel Oil Guns:		
Quantity	4	4
Capacity (each)	0.3 gpm	1.14 l/min
Preheat Burner Capacity	8.4 mm Btu/hr	8,860 MJ/hr

Notes:

1. FBIS - Fluid Bed Incineration System
2. All actual gas flow rates in acfm are corrected for temperature but not pressure.
3. Annual fuel usage is based on initial year of operation and includes start-up and standby fuel.