ENERGY RECOVERY FROM SLUDGE WASTE

CALVIN R. BRUNNER and GARY R. RICHARDSON
Malcolm Pirnie, Inc.
White Plains, New York

Although the Dry Creek Wastewater Treatment Plant utilizes an energy-intensive system to condition sludge for dewatering prior to incineration, steam is generated from the incinerator off-gas to provide the energy required for sludge conditioning. The sludge incinerator is also utilized for odor destruction, yielding additional savings in energy that would otherwise be required for a fume incinerator. The potential annual savings in fuel resulting from incinerator operation amounts to hundreds of thousands of dollars, a significant portion of the plant operating cost.

INTRODUCTION

The Dry Creek Wastewater Treatment plant was built in a depression in the rolling hills of northern Kentucky, a few hundred yards south of the Ohio River. It serves Northern Kentucky and its service area is primarily suburban. The population relies heavily on the business generated by the City of Cincinnati, which is located immediately north of the Ohio river, and the Cincinnati environs.

The Dry Creek Wastewater Treatment plant was designed for 30 mgd (million gallons per day) (1.31 m³/sec), a flow roughly equivalent to wastewater generated by a population of 270,000 people, the estimated population of the service area in the year 2,000. It went into operation in the spring of 1979, replacing the old and worn Bromley Treatment Plant located near Ludlow, Kentucky, on the south bank of the Ohio river.

The effluent of the new plant discharges into the Ohio River. Sewage solids other than sludge, such as grit, skimmings and screenings, are hauled to landfill. Sludge is dewatered and incinerated on site with the incinerator exiting flue gas generating steam, through a waste heat boiler, to process the sludge load.

WASTEWATER TREATMENT

The Dry Creek plant provides secondary treatment of wastewater. Sewage is pumped to the plant from the surrounding area through force mains, with grit and screenings removed from the influent flow before it enters the primary tanks. After primary settling, during which skimmings are removed from the surface of the influent and sludge is pumped from the bottom of the tanks, the discharge enters secondary treatment tanks. Secondary treatment consists of violent agitation
of the flow under action of air bubbles. Flow is retained in relatively deep (25 ft deep) (7.62 m) tanks and air is injected into piping at the bottom of these tanks. The air is introduced at sufficient pressure to overcome the 25 ft (7.62 m) head of water and produces bubbles which agitate the water and promote high turbulence. Organisms within the flow undergo increased biological activity because of the presence of these air bubbles and the turbulent condition within the tanks. This biological activity produces a floc, or fibrous mass, which is removed in the next stage of the treatment process, final clarification. In the clarifiers the flow remains relatively quiescent for a period of time during which floc settles to the bottom of the tank while overflow is chlorinated and discharged as plant effluent.

Sludge is collected from the primary tanks at approximately 4 percent solids content. Floc is collected as a sludge from the clarifiers, less than 1½ percent solids content.

**SLUDGE TREATMENT**

Sludge collected from the primary and secondary processes is mixed and pumped to a sludge holding tank. Although it will ultimately be incinerated, its solids content must first be increased, since at 4 percent solids it would fare little better than pure water in any burning process.

Sewage sludge is a colloidal gel comprised of particles contained within "sheaths". The sheath contains a high proportion of water and the matter within the sheath, or bound by it, is predominantly water. Because solids content must be increased from 4 percent, that of the raw sludge, to 25 to 30 percent for incineration, the bound water must be released within the sludge particle. Of the methods available for attacking the sheath, such as polymer treatment and metal salt action, heat treatment was chosen at Dry Creek. Raw sludge is heated to approximately 370 F (461 K) and maintained at this temperature for 15 to 30 min, after which the sheath dissolves and bound water is released.

With the release of bound water, solids can be extracted, or concentrated. Vacuum filters used to dewater the sludge produce a sludge filter cake containing in excess of 25 percent solids.

The thermal treatment process, as shown in Fig. 1, requires a supply of heat, which is necessary for conditioning, and compressed air, which serves two basic purposes. First, it creates turbulence in the
sludge within the heat exchangers, increasing the heat transfer rate between the entering sludge and the conditioned sludge. Secondly, as the sludge sheath dissolves, gases are released as well as bound water. The injected air provides the released gases with a degree of oxidation, decreasing their odor and reactivity.

The operating pressure of the entire system is controlled by back pressure, i.e., the setting of the pressure control valve is adjusted to provide 175 psig (1.20 × 10^6 Pa gage) within the reactor, that pressure necessary to maintain the required reactor temperature, 370 F (460 K). Steam is injected from the steam header into the reactor and the reactor pressure, therefore, determines the steam header pressure. The header pressure, nominally 425 psig (2.93 × 10^6 Pa gage), will vary from 390 psig (2.68 × 10^6 Pa gage) to 450 psig (3.10 × 10^6 Pa gage). Valving between the header and the reactor accounts for the pressure drop of the steam, from the 425 psig (2.93 × 10^6 Pa gage) header to the 175 psig (1.20 × 10^6 Pa gage) of the reactor.

**STEAM GENERATION**

A waste heat boiler extracts heat from the incinerator flue gas to produce steam. It is rated at 7,200 lb/hr (0.91 kg/sec) of 450 psig (3.10 × 10^7 Pa gauge) steam, dry and saturated. In addition, two identical packaged boilers have been provided with the thermal conditioning system for back-up, one designed for use and the other a spare. Each boiler is rated at 200 hp (149 kW) and produces a maximum of 6,900 lb/hr (0.87 kg/sec) of steam while consuming approximately 61 gph (6.71 × 10^-5 m³/sec) of #2 fuel oil. Boiler controls are adjusted to fire continuously on a low firing rate. A decrease in header pressure to below 400 psig (2.75 × 10^6 Pa gage) switches the boiler to its high firing rate; this continues until pressure rises to 440 psig, (3.03 × 10^6 Pa gage) at which point a low firing rate is resumed.

The thermal conditioning process requires an average of 3,000 lb/hr (0.38 kg/sec) of steam for normal operation. During start-up, when feed to the reactor is at ambient temperature, steam consumption more than doubles for the few hours required to reach operating temperature. During this time water is circulated, but sludge is not introduced into the reactor until the reactor temperature exceeds 300 F (422 K). During normal operation, raw sludge enters the first heat exchanger at approximately 80 F (300 K), and is heated to 300 F (422 K) before entering the reactor. Leaving the reactor at 370 F (461 K), the thermally conditioned sludge exits the last of the three heat exchangers at 125 F (325 K).

When the waste heat boilers are producing steam, the packaged boiler is kept on standby. It is maintained in an unfired condition until line pressure drops below a preset value, whereupon it fires automatically.

**FLOATING HEADER**

The steam system operates on a floating header design when the waste heat boiler is firing. If the waste heat boiler is producing more steam than the thermal conditioning system needs, the header pressure will increase. When it rises above 450 psig (3.10 × 10^6 Pa gage), one of the two water-cooled steam condensers opens, wasting the excess steam. Upon a drop to 430 psig (2.96 × 10^6 Pa gage) the condenser steam valve will close. If, after one condenser is admitting steam, the steam header pressure continues to rise, the second condenser comes on line. The condensers are sized to waste the entire generation capacity of the waste heat boiler, rated at 7,200 lb/hr (0.91 kg/sec) of steam, if necessary.

If the thermal conditioning system requires more steam than the waste heat boiler is producing, the header pressure will drop. When the header pressure drops below 400 psig (2.75 × 10^6 Pa gage), the packaged boiler starts firing and continues firing, until the header pressure reaches 440 psig (3.03 × 10^6 Pa gage), when the boiler ceases firing.

Figure 2 illustrates the pressure profile for the steam header for ideal operation, which is where the steam generation exactly equals the steam use rate. The steam pressure floats (hence, Floating Header) between the pressure at which the package boiler fires and that at which a condenser comes on line. The waste heat boiler produces and continues to discharge steam into the header at a rate faster than the steam is consumed, causing the header pressure to rise. The peaks on the curve in Fig. 2 represent those points in time where the header pressure has risen to the pressure of the steam drum. A stop-check valve (boilers are required to have check valves at their steam exit to prevent backflow from the steam header) then closes. At the same time, make-up water is entering the boiler, at a lower temperature than the steam produced (feedwater is 220 F (378 K) while the steam temperature at 425 psig (2.93 × 10^6 Pa gage) is...
approximately 450 F (505 K) and the boiler drum temperature and pressure decreases.

While the cooler water in the boiler is being heated to steam, steam is discharging from the header, resulting in a decreasing header pressure. When the pressure of the steam produced in the waste heat boiler exceeds the steam header pressure the stop-check valve on the boiler steam exit opens, driving the header with steam. The bottom "peak" illustrates the point at which the header pressure has dropped below the steam pressure within the boiler drum and steam is admitted into the header.

**ACTUAL OPERATION**

The chart in Fig. 3 shows the flow profile of the waste heat boiler in actual operation. The peaks are analogous to the peaks shown in Fig. 1. The steam flow follows the header pressure, i.e., the flow increases as the pressure increases and, likewise, decreases when the pressure drops.

**INCINERATION**

A multiple-hearth sludge incinerator is used for destruction of the filter cake, as shown in Fig. 4. This incinerator is 18 ft 9 in. (5.72 m) in diameter, and 40 ft (12.19 m) high, with a 13½-in. (0.34 m) inner lining of refractory. The center shaft is hollow, and cooling air circulates through it, reaching temperatures as high as 450 F (505 K) at its exit.
The center shaft rotates, at from \( \frac{1}{2} \) to \( 1 \frac{1}{2} \) rpm, with its rabbler arms sweeping sludge along the furnace hearth surface. Enough room was allocated within the incinerator building for installation of a second incinerator in the future.

Seven hearths are provided in this incinerator. Sludge cake is rabbled across one hearth to a drop hole where it falls to the hearth below, is rabbled across to its drop hole and so on.

A total of ten burners are included for start-up and to provide supplemental heat. They fire #2 fuel oil.

Air is provided at a number of areas within the furnace for combustion of the sludge cake. Shaft cooling air, which has been heated to from 300 F (422 K) to 450 F (505 K), can be recycled for use as combustion air. Its heat is, therefore, utilized, as preheated air. This air supply can also be used to heat the exhaust gas before discharging to the atmosphere. Heating the gas will convert much of exhaust gas moisture to colorless moisture vapor, reducing or eliminating the stack plume.

The forced draft air supply can be taken from outside the building or it can exhaust specific enclosed areas. The exhaust from the thermally conditioned sludge storage tank and spent ventilation air from the vacuum filter floor can be used as sludge combustion air for the incinerator.

The organic compounds found within a treatment plant will fully incinerate (fully oxidize) and odor will likewise be destroyed at temperatures below 1,400 F (1,033 K) at a corresponding residence time of 0.5 sec. Odors occur where active organic compounds exist and completely oxidizing these compounds will destroy the associated odor.

Until the incinerator reaches operating temperatures, outside air is used for combustion; however, when temperatures in excess of 1,400 F (1,033 K) are obtained, combustion air is taken from within the building. Scrubbers using permanganate solution are provided for odor control during those times when the incinerator is not at operating temperature.

The filter cake is dropped by gravity from the top of the incinerator, whereas air/gas flow is from bottom to top. The incinerator is designed to dry incoming sludge on the top two hearths, reducing the hot gas temperature to approximately 800 F (700 K). The sludge cake starts to burn on hearth 3 (third from the top) and continues burning on hearths 4 and 5. The gas temperatures above these hearths range from 1,300 F (978 K) to 1,700 F (1,200 K).

On hearths 6 and 7 burn-out occurs. The sludge burns out to a fine powdery ash normally containing less than 2 percent fixed carbon. Ash at from 300 F (422 K) to 400 F (478 K) falls from the bottom hearth (hearth 7) into a series of air locks. It is then pneumatically conveyed to an ash silo and is eventually hauled to landfill, a sterile product of combustion only a small fraction of the original sludge volume.

**Burning Thermal Conditioned Sludge**

At the time of initial equipment design there was very little data available on the burning properties of thermally conditioned sludge cake. The incinerator design was conventional, with two drying hearths, three burning hearths and two hearths provided for ash burn-out. As data on burning this type of sludge cake was generated, it became evident that on an as-received basis the heat release of thermal conditioned sludge was higher than anticipated.

The original design was based on an as-received heating value from 1,800 \((4.19 \times 10^6 \text{ J/kg})\) to 2,200 Btu/lb \((5.12 \times 10^6 \text{ J/kg})\) with 60 percent to 70 percent moisture content. Two incinerator hearths were required to dry this cake, and reduce the moisture content to allow burning to occur (sustained burning will occur with a moisture content of approximately 30 percent). However, experience at other plants just coming on line indicated a heating value of 2,900 Btu/lb \((6.74 \times 10^6 \text{ J/kg})\) as received, with moisture in the order of 55 percent, could be expected. At this low moisture rate and high heating value the sludge cake would not require two hearths for drying. In fact, the cake could start burning on the first hearth.

Burning on the top hearth of a multiple-hearth incinerator is undesirable for a number of reasons, the most important of which is that there is insufficient residence time above the first hearth to properly burn out the products of combustion. Odor and small particulate size emissions could result which would be beyond the ability of the gas cleaning system to control. Odor and smoke could thus be discharged from the stack.

An additional disadvantage of top hearth burning is that burning may carry over into the discharge flues, where it would be uncontrolled with incomplete combustion occurring and attendant carbon (soot) deposition on flue refractory promoting corrosion and hastening flue refractory failure.
Although it became obvious that thermal conditioned cake burned “hotter” than anticipated, incinerator design had already been completed and construction had begun. Therefore, it was decided to modify the top hearth and make minor equipment changes which would allow the sludge filter cake to bypass the top hearth and feed either hearth 2 or hearth 3. The flue gas residence time above hearth 2 included that residence volume above hearth 1. If sludge cake were dropped directly onto hearth 2 and burning occurred, the volume above hearth 2 would provide the residence time needed for full combustion of the off-gas.

Similarly including provisions for dropping feed onto hearth 3 would make even more volume available for complete incineration.

The design changes that allowed discharging sludge filter cake to a lower hearth were as follows:

1. Placement of a plugged opening on hearth 1 under the sludge feed opening. With the plug (a high-temperature metal plate) in place, the incinerator operates in a conventional manner with filter cake dropping onto hearth 1. With the plug removed, filter cake drops through the opening on hearth 1, bypasses hearth 2, and comes to rest on hearth 3.

The filter cake bypasses hearth 2 because it is an “in hearth”, i.e., filter cake is rabbled in, towards the center of this hearth. A relatively large annular space in the center of this hearth allows the filter cake to fall to the hearth below, an “out hearth”, where the filter cake is rabbled out, towards the furnace shell. As shown in Fig. 4, when dropped through the opening on hearth 1, the filter cake will pass through the annular opening on hearth 2.

2. Provision of a second incinerator sludge cake feed inlet. Use of this inlet will allow the sludge filter cake to fall through an opening on the top hearth, an out hearth, and come to rest on hearth 2.

3. Redesign of the sludge feed conveyor. This conveyor, a screw conveyor, was provided with an opening approximately halfway along its length for use when feeding hearth 2. When feeding hearth 1 or hearth 3 this conveyor opening is closed and filter cake is discharged in a conventional manner, at its end.

4. Modification of the air supply. Sludge combustion air from the forced draft fan is provided at the third hearth. With burning occurring on the third or second hearth, providing air to that area increases local burning efficiency, i.e., burnout of combustion gases.

STEAM FROM SLUDGE

The waste heat boiler was designed specifically for use with the dirty, erosive gases exiting the incinerator. The flue gas velocity was limited to 40 ft (12.14 m) per second within the boiler, thus helping to reduce the erosive effect of ash traveling within the gas stream. No fins or protuberances of any kind were allowed on the boiler tubes, to reduce the possibility of plugging.

The airborne ash load, which can be as much as 30 percent of the ash component of the filter cake, is quite high, necessitating the above design features.

The waste heat boiler requires little maintenance and, besides a regular visual check of boiler water level, needs little operator attention. Once a day the three manual operated soot blowers are exercised, sample water tests are run and the blow-down is operated.

Depending on sludge filter cake loading and quality, which does vary, and off-gas temperature, which normally runs from 750 F (672 K) to 950 F (783 K), the steam quantity produced will vary. A portion of the generated steam is used for feedwater heating. The net steam available for thermal conditioning varies from 2000 (0.25 kg/sec) to 3500 lb/hr (0.44 kg/sec), a substantial portion of the thermal conditioning system steam requirement.

SAVINGS

The thermal conditioning system and the incinerator do not both operate at the same time. The conditioning system may operate for 24 hr without the incinerator in operation to start to build up a fresh inventory of sludge for the week. At the end of the week when the incinerator is in operation, burning sludge that was previously generated, the thermal conditioning system is not operating, having completed its weekly quota.

Calculating the fuel savings realized by use of the incinerator waste heat boiler requires some assumptions:

1. The thermal conditioning system and the incinerator operate concurrently three days a week, 48 weeks a year or a total of 148 days per year. This is the only time that steam generated by the incinerator can be used by the plant.

2. The thermal conditioning system requires in excess of 3000 lb of steam/hr (0.32 kg/sec).

3. The waste heat boiler generates 2500 lb of steam/hr (0.38 kg/sec).

4. The packaged boiler fires 27 \((2.97 \times 10^{-5})\)
Based upon the above assumptions, and realizing that there is no increase in feedwater treatment chemical used for a given total amount of steam, the cost savings using the waste heat boiler is calculated as follows:

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\frac{\text{148 days}}{\text{year}} \times \frac{24 \text{ hours}}{\text{day}} \times \frac{2500 \text{ lb steam}}{\text{hour}} \times \frac{27 \text{ gal #2 F.O.}}{3000 \text{ lb steam}} = \frac{80000 \text{ gallons #2 F.O.}}{\text{year}}
\]

\[
\frac{148 \text{ days}}{\text{year}} \times 8.64 \times 10^4 \frac{\text{sec}}{\text{day}} \times \frac{0.32 \text{ kg steam}}{\text{sec}} \times \frac{0.10 \text{ m}^3 \text{ #2}}{1360 \text{ kg steam}} = \frac{301 \text{ m}^3 \text{ #2 F.O.}}{\text{year}}
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Therefore, at a cost of $1.20/gal ($316.80/m^3) of #2 fuel oil, the savings in fuel oil is almost $100,000 per year. This does not include savings realized by not using the fume incinerator while the sludge incinerator is in operation.

**SUMMARY**

At this plant at today's fuel costs, an annual fuel savings of $100,000 can be realized, a figure that will increase with increasing fuel costs. As the surrounding community grows, increasing the wastewater load to the plant, the postulated 148 days per year operating credit will increase, further increasing fuel savings. Most important, the recapture of heat from sewage sludge is a viable and demonstrable technology.

**Key Words**

Boiler
Energy
Incineration
Pollution
Sludge
Steam