In complex pollution problems the end of one form of pollution may be the start of another. Today’s sewage must be cleaned and as a result of the treatment process, waste solids are generated which must be disposed of in a manner compatible with the total environment. An economical, environmentally compatible, method of destroying waste sludges is by incineration in the multiple hearth furnace.

It is important to note that many of the advanced waste water treatment systems used to limit pollution, such as lime coagulation and adsorption with granular activated carbon, rely upon regeneration and reuse of these materials by thermally processing these chemicals for their subsequent reuse in the treatment process. It is essential that the thermal processing equipment used for this purpose be functionally reliable and limiting of air pollution.

Advanced multiple hearth technology today limits atmospheric emissions and optimizes combustion conditions, through proper temperature distribution, and control of oxygen within the furnace. These improvements, combined with the characteristics of flexibility and rugged construction, have enabled the multiple hearth to increase its role in the important function of sludge incineration as well as lime recalcining and carbon regeneration. At this time there are over 175 multiple hearth installations in various types of waste treatment plants.

Process Description

The multiple hearth furnace is a cylindrical, refractory lined, steel shell containing a series of horizontal refractory hearths located one above the other. These hearths, having alternate in-feed and out-feed direction cause the sludge to move completely across each hearth as it drops from one level to another. These hearths have the effect of creating the multi-chamber effect and induce a true countercurrent flow of wet sludge cake and hot gases of combustion. Mechanical stoking is provided by a motor driven, revolving, insulated central shaft to which are attached radial arms, called “rabble” arms. To these arms are attached “rabble” teeth similar to the ploughs of a circular clarifier which move the material across the hearth to the peripheral of central openings through which they drop to the next hearth. The central shaft and arms are cooled by air supplied in a regulated quantity and pressure from a blower discharging into a housing at the bottom of the central shaft [1].

The return to the furnace of the hot air from the cooling air system into the combustion zone of the furnace precludes the necessity of the expensive and troublesome preheating of the combustion air. The heated combustion air, returned from the central shaft, has been raised from ambient temperature to approximately 400 F.

When incinerating sludge the multiple hearth furnace can be characterized as being divided into three distinct operating zones. The first zone, the Drying Zone, consists of the upper hearths, where a major portion of the free moisture is evaporated; the second zone, the Burning Zone (or Combustion Zone) is where the material to be destroyed is burned, at temperatures generally in the range between 1400 F to 1700 F; and the third zone, the Cooling Zone, which serves to cool
the ash prior to its discharge into the ash quenching facilities or ash hopper, consists of the lowest hearths. The sequence of these zones always remain the same; the instantaneous position varies as the characteristics of the sludge feed change. The size of the furnace will also dictate the particular number of hearths which will be utilized for any one zone at the particular time of operation.

If the sludge is high in volatile content, auxiliary fuel will not be required. If it is required, the multiple hearth furnace can operate on any normal type of fuel available to the community, e.g., natural gas, fuel oil or digester gas. Pilots can be automatically electrically ignited or can be manually ignited.

The hot gases from the combustion zone of the furnace give up heat to the cold sludge as they sweep upward and pass the sludge inflow, evaporating an important percentage of the cake moisture. As the sludge particles are rabbled across the hearth they are constantly agitated by the rabbles and are reduced to small particle size. This rabbling insures that the maximum sludge surface is exposed to the passing hot furnace gases which induces rapid drying and burning of the sludge. The movement and direction of the gases across the sludge provides an important exchange of energy which enables the gases to leave the furnace at temperatures ranging from 500 F to 1600 F. This actual exit gas temperature is dependent upon the moisture and organic feed of the incoming sludge. In general, the wetter the feed, the lower the gas outlet temperature.

Generally, an off gas temperature of 500 F to 600 F indicates that auxiliary fuel is required. Gas outlet temperatures of 800 F to 1600 F indicate that sludge with excess calorific values are being burned. In the latter case additional excess air is brought into the furnace to stabilize the burning operation. Inasmuch as these operations are very efficient, particularly for wet sludges, the need for expensive external air pre-heaters is eliminated.

Data collected at various treatment plants by Owen [2] indicate that the temperature of the sludge varies only slightly during its retention and travel across the upper drying hearths towards the combustion zone, and generally does not exceed 160 F. Further, the moisture content of the sludge during its travel across the upper hearths to the high temperature combustion zone does not fall below between 40 and 50 percent from a high of about 70 to 80 percent. It would appear, therefore, that the evaporation of the moisture is a factor in maintaining low sludge temperatures on the upper hearths. Since the multiple hearth furnace design is unlike any other, it is not unreasonable to expect its operation would be unlike any other combustion device. Surprisingly, the exhaust gas temperature range stated did not produce noxious odours under normal operating conditions. This was so contrary to experience gained with single chamber incinerators that investigation was undertaken in 1932 to determine the reasons for this phenomenon.

In the summary of a paper by W. Rudolfs and Wm. H. Baumgartner, it was stated, “Distillation of volatile matter from sludge containing 75 percent moisture did not occur until 80 to 90 percent of this moisture had been driven off, regardless of the temperature. In drying operations with subsequent incineration, a moisture content of the (feed) sludge from 20 to 30 percent would probably prevent nearly all odour trouble and reduce heat required in the combustion step” [3].

Further investigation has proved that the sludge cake readily ignites in a multiple hearth furnace when the moisture content has been reduced to approximately 48 percent, thus, staying within the researched ranges. It is not uncommon, in fact, to see sludge burning vigorously in the middle of a hearth and, immediately adjacent to the hot coals, filter cake from which steam vapor is being evaporated. The average temperature of this zone would be 1400 F to 1500 F.

This phenomenon of the sewage sludge existing for only a very short time in the distillation range of temperatures is known as the “thermal jump”. It is thermal jump that allows the process to bypass the zone where offensive smelling vapors are generated that gives the multiple hearth furnaces the ability to burn the sewage solids effectively and without the production of obnoxious odours even though the gas outlet temperatures are between the 800 F and 1600 F range, as previously stated [4].

Multiple hearth incinerators designed for sludges containing 50 to 70 percent moisture generally produce exhaust gases in the 1200 F to 1600 F range. Furnaces for this application are designed to accept feed material at the second or third hearth level to ensure adequate combustion volume is provided to ensure complete destruction of combustible gases. The drying zone in this instance rarely exceeds more than one hearth due to the rapid transfer of heat from the combustion gases and shaft speed.

The furnace construction previously described varies from the basic design only in that refractory and casting qualities have improved considerably over the years. However, other design considerations and the development of excellent auxiliary support systems today provides total process control and elimination of problems experienced during the period prior to the 1960's.

**Historical Development of the System**

The multiple hearth sludge incinerator of the 1930's
generally was provided with an oil-fired fuel system without combustion safeguards, radial brick stack, guillotine damper for draft control, and a bare minimum of draft gauges and temperature recording strip charts. No process control truly existed and the furnace operator generally was provided with an oil-fired fuel system with gauges and temperature recording strip charts. No manually adjusted burners, dampers and doors to control operation. Manual operation made it mandatory to process feed sludge at a 5 to 6 lb/ft²/h rate.

**Air Pollution Control Development**

It was not until the 1950's that some combustion safeguard equipment was added to the auxiliary fuel system and crude spray chambers and induced draft fan systems were added in an effort to increase capacity and eliminate air pollution problems. It was not, however, until 1962 when the Detroit Water Board purchased a 60,000 cfm cyclonic type wet scrubber directly from a scrubber manufacturer that true air pollution control systems were applied to multiple hearth sludge incinerators. The use of the first scrubber systems significantly enhanced the operation of the furnace because they produced a continuous stable draft and were designed with considerable excess capacity. Simply because the scrubber and induced draft fan were oversized it was determined that furnace ratings could be increased, depending upon the size of the furnace, to approximately 15 lb/ft²/h of wet feed.

Although application of cyclonic and venturi type wet scrubbers did reduce particulate matter, corrosion problems arose in carbon steel ductwork and induced draft fans due to the presence of chlorides released from ferric chloride conventionally used with polymers to condition the sewage sludge. In order to overcome the corrosion problems, stainless steel was used, however, even with this, induced draft fan impellers failed due to stress corrosion.

In an effort to overcome these maintenance problems the 36 in. venturi scrubber system, furnished to the city of Orangetown, N.Y., with a 16ft-9in. O.D. six hearth multiple hearth furnace, was provided with a 6 in. deep flooded packed bed section to reduce the normal scrubber discharge adiabatic saturation temperature from approximately 178 F to 115 F. It was determined during an extensive test period that at any temperature below 135 F stress corrosion problems and particulate buildup on the induced draft fan blades was eliminated. A further benefit from this sensible cooling technique was the production of a stack condensate with a pH of 6 or above. This contrasted greatly to the 1.5 to 3.0 range pH typical of scrubbers operating at saturated temperatures of approximately 175 F [5].

In 1967 three-stage impingement type scrubbers selected to cool the scrubber exhaust gases to 110 F were provided with both the lime recalcining multiple hearth furnace and the sludge incinerator at the South Tahoe Public Utility District Advanced Waste Water Plant. Of concern at this facility was the fact that the stack gases would be compressed and used to recarbonate the effluent from the nitrogen stripping tower. It was therefore critical that the gas volume be reduced as much as possible and that any corrosive characteristics be eliminated. It is also interesting to note that since the subcooling technique has been applied at Tahoe and other installations, induced draft fan failures have been eliminated.

The plume normally associated with wet scrubbers is readily dissipated and eliminated by mixing hot air from the furnace shaft in the induced draft fan discharge duct. Other techniques for plume suppression require additional equipment, such as condensers, heat exchangers, auxiliary firing devices, fans and cooling towers [6].

**Burner Development**

Other improvements to the system besides air pollution control include burner and automation development. The Tahoe furnace design also incorporated a new burner design to overcome slagging problems that had occurred in many earlier installations. A detailed study of several relatively new operating installations showed that the burners used at that time produced a flame that on occasion would either impinge directly upon the burning material in the combustion zone of the furnace, or would reflect off the end of the rabble arm, thereby hitting the hearth and fusing ash which eventually hardened to form a clinker. To overcome this characteristic heights between hearths of the furnace were increased and burners positioned to fire directly above the arms, thus eliminating all burner flame impingement. Additionally, tiles were extended to the interior furnace firebrick wall, thus eliminating a ledge where flyash accumulated and eventually slagged. These improvements, coupled with the addition of air introduction ports on each hearth, first added in 1963 to prevent individual hearths from overheating, have completely prevented the formation of slag in the furnaces. This is particularly important as lime calcining furnaces for advanced waste water treatment systems operate at temperatures in excess of 1800 F. See Fig. 1 [7].

**Automated Control System Developments**

Along with burners and air pollution control, automation control systems have been developed. Automatic operation has now been achieved to the extent that the
TABLE 1

Minneapolis-Saint Paul Sanitary District

Cost of Operation and Maintenance of Sludge Disposal System

<table>
<thead>
<tr>
<th>Year</th>
<th>Dry Sludge Solids Tons</th>
<th>Cost of Vacuum Filtration &amp; Disposal Cost Per Ton Dry Solids</th>
<th>Cost of Incineration &amp; Disposal Cost Per Ton Dry Solids</th>
<th>Total Sludge Disposal Cost Per Ton Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>1939</td>
<td>35,028</td>
<td>$99,448.39</td>
<td>$37,367.04</td>
<td>$1.06</td>
</tr>
<tr>
<td>1940</td>
<td>37,091</td>
<td>81,874.93</td>
<td>50,222.47</td>
<td>1.36</td>
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<tr>
<td>1941</td>
<td>33,993</td>
<td>77,589.64</td>
<td>44,227.43</td>
<td>1.23</td>
</tr>
<tr>
<td>1942</td>
<td>33,838</td>
<td>71,129.03</td>
<td>39,579.34</td>
<td>1.17</td>
</tr>
<tr>
<td>1943</td>
<td>32,955</td>
<td>70,473.10</td>
<td>45,862.71</td>
<td>1.39</td>
</tr>
<tr>
<td>1944</td>
<td>33,758</td>
<td>69,719.27</td>
<td>42,812.66</td>
<td>1.27</td>
</tr>
<tr>
<td>1945</td>
<td>32,428</td>
<td>68,593.08</td>
<td>44,894.57</td>
<td>1.38</td>
</tr>
<tr>
<td>1946</td>
<td>33,381</td>
<td>88,655.30</td>
<td>51,536.86</td>
<td>1.54</td>
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<tr>
<td>1947</td>
<td>36,633</td>
<td>121,489.22</td>
<td>52,334.63</td>
<td>1.42</td>
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<tr>
<td>1948</td>
<td>34,349</td>
<td>124,202.24</td>
<td>61,863.44</td>
<td>1.79</td>
</tr>
<tr>
<td>1949</td>
<td>34,992</td>
<td>121,651.05</td>
<td>60,530.50</td>
<td>1.73</td>
</tr>
<tr>
<td>1950</td>
<td>33,637</td>
<td>133,545.97</td>
<td>63,362.76</td>
<td>1.78</td>
</tr>
<tr>
<td>1951</td>
<td>34,929</td>
<td>143,279.83</td>
<td>71,414.76</td>
<td>2.05</td>
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<td>1952</td>
<td>32,529</td>
<td>156,298.86</td>
<td>72,306.34</td>
<td>2.23</td>
</tr>
<tr>
<td>1953</td>
<td>37,637</td>
<td>179,837.25</td>
<td>76,727.61</td>
<td>2.04</td>
</tr>
<tr>
<td>1954</td>
<td>40,907</td>
<td>186,104.97</td>
<td>106,250.30*</td>
<td>2.60*</td>
</tr>
<tr>
<td>1955</td>
<td>44,126</td>
<td>171,266.98</td>
<td>93,162.84</td>
<td>2.11</td>
</tr>
<tr>
<td>1956</td>
<td>42,558</td>
<td>159,327.74</td>
<td>101,430.19</td>
<td>2.39</td>
</tr>
<tr>
<td>1957</td>
<td>44,617</td>
<td>181,445.56</td>
<td>95,735.22</td>
<td>2.14</td>
</tr>
<tr>
<td>1958</td>
<td>42,750</td>
<td>171,837.56</td>
<td>90,691.03</td>
<td>2.13</td>
</tr>
<tr>
<td>1959</td>
<td>47,390</td>
<td>171,563.07</td>
<td>92,723.42</td>
<td>1.97</td>
</tr>
<tr>
<td>1960</td>
<td>46,738</td>
<td>175,433.03</td>
<td>112,884.54</td>
<td>2.42</td>
</tr>
<tr>
<td>1961</td>
<td>46,141</td>
<td>190,905.85</td>
<td>97,424.98</td>
<td>2.11</td>
</tr>
<tr>
<td>1962</td>
<td>44,938</td>
<td>212,502.53</td>
<td>105,373.33</td>
<td>2.34</td>
</tr>
<tr>
<td>1963</td>
<td>50,290</td>
<td>203,231.71</td>
<td>103,125.64</td>
<td>2.05</td>
</tr>
<tr>
<td>1964</td>
<td>51,929</td>
<td>256,044.96</td>
<td>138,906.75</td>
<td>2.71</td>
</tr>
</tbody>
</table>

* The first major hearth rebuilding work in 16 years of operation accounted for about two-thirds of the increased incineration cost in 1954.
SLUDGE FURNACE vs. AUTOMOBILE

HYDROCARBON EMISSIONS

PER PERSON PER DAY

1970 ACTUAL 1972 STANDARDS 1975 STANDARDS FURNACE EMISSIONS
Grams per mile x 12 miles* Grams per day **
66.2 grams 49.5 grams 8.5 grams 0.5 grams
Based on 1.3 million per day
Based on 0.9 lbs. dry sludge solids per day per person
EPA 6/13/71 average of 68 U.S. auto producers.

1970 COMPARATIVE RATIO 1975 COMPARATIVE RATIO
2900:1 250:1

Fig. 2

SLUDGE FURNACE vs. AUTOMOBILE

CARBON MONOXIDE EMISSIONS

PER PERSON PER DAY

1970 ACTUAL 1972 STANDARDS 1975 STANDARDS FURNACE EMISSIONS
Grams per mile x 12 miles* Grams per day **
565 grams 484 grams 49.5 grams 0.5 grams
Based on 1.3 million per day
Based on 0.9 lbs. dry sludge solids per day per person
EPA 6/13/71 average of 68 U.S. auto producers.

1970 COMPARATIVE RATIO 1975 COMPARATIVE RATIO
19,000:1 700:1

SLUDGE FURNACE vs. AUTOMOBILE

NITROGEN OXIDE EMISSIONS

PER PERSON PER DAY

1970 ACTUAL 1972 STANDARDS 1975 STANDARDS FURNACE EMISSIONS
Grams per mile x 12 miles* Grams per day **
63.3 grams 35.5 grams 4.5 grams 0.5 grams
Based on 1.3 million per day
Based on 0.9 lbs. dry sludge solids per day per person
EPA 6/13/71 average of 68 U.S. auto producers.

1970 COMPARATIVE RATIO 1975 COMPARATIVE RATIO
170:1 10:1

Fig. 2
operator can attend to other functions within the incinera-
tor area and the unit will respond to reasonable fluctua-
tions in feed (± 20 percent) without any manual
manipulations of controls.

The control system includes individual temperature
indicating controllers, proportional fuel burners provided
with electric ignition, ultraviolet scanners, and motor-
ized valves in air headers; automatic draft control, air
inlet openings and most importantly an oxygen analyzer/
controlling unit. (Figs. 3 and 4). Although the first fully
automated multiple hearth incinerator purchased in 1963
by the East Bay Municipal Utilities District of Oakland,
California, for burning of grease, screenings, and grit,
including oxygen control, it was not until 1971 that
automated operation with a constant volume of oxygen
in the exhaust gases was achieved. This was due partially
to the fact that the response of oxygen analyzer control-
ler units was slow and the circuitry concepts were not
fully developed or unknown. Resolution of this single
design problem has enabled full achievement of our goal
of automated operation.

To minimize operating problems, solid state circuitry
has been effectively used in the burner combustion
control systems to eliminate the necessity for the plant
electrician to repair malfunctions.

Air Emission Characteristics of Multiple Hearth System

The combination of improved burner design, high
performance scrubbers and automated control have had
a highly favorable impact on exhaust gas quality and
appearance. Tables 3 and 4 [8] list emissions and local
air pollution regulations as tested at San Mateo and
South Lake Tahoe, California installations. This
emission control performance is consistent with increas-
ingly restrictive air pollution code requirements for
stationary emission sources. While awaiting a broad
technological breakthrough to control automobile emis-
sions, the major source of air pollution in urban America,
the fullest use of available technology is being used to
limit stationary sources. The success of this effort is
evident in a comparison between the per capita emissions
of sewage sludge incinerators and the automobile.

The data for automobile exhausts is a combination of
proposed emission standards of the Federal Government
and actual test averages on late model cars. These auto
emissions are given in terms of weight of pollutant per
mile driven. The sources of the data are indicated by the
notes in Fig. 2, a, c and e. By using the national average
of 12 miles per car per day, the daily emissions per car
result. Now the pollutants from both the auto and
incinerator sources per capita can be directly compared
on a daily basis.

Fig. 2-a is a graphic illustration of the final analysis
for hydrocarbon emissions from autos and incinerators.
It is seen that one person is responsible each day for
0.019 grams of hydrocarbon emissions from a multiple
hearth furnace which is treating his sewage sludge.
Meanwhile, even when the 1975 auto exhaust standards
are in effect, there will be produced 4.8 grams of hydro-
carbons from the “daily” use of a car. Fig. 2-b shows
that the comparative ratio of auto to furnace emissions

Fig. 3  Oxygen analysis of stack gases from the San Mateo
plant, manual operation.
Fig. 4 Oxygen analysis of stack gases from the San Mateo plant, automatic control.

Table 2
New Orleans, Louisiana

18'-9" O.D. - Nine Hearth
Capacity - 13,000 Lbs./Hr.

ANNUAL MAINTENANCE COST

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractory</td>
<td>800</td>
</tr>
<tr>
<td>Ash pumps - rubber linings, ends, ceramic packing</td>
<td>500</td>
</tr>
<tr>
<td>Rabble Teeth</td>
<td>150</td>
</tr>
<tr>
<td>V-Belts</td>
<td>50</td>
</tr>
<tr>
<td>Lubricants</td>
<td>100</td>
</tr>
<tr>
<td>Damper Cables</td>
<td>50</td>
</tr>
<tr>
<td>Miscellaneous, Labor, etc.</td>
<td>700</td>
</tr>
</tbody>
</table>

$2,350

Unit commenced operation in 1966.
Unit burns sludge 48 hours/week.
is a remarkable 2900:1 for 1970 and a still high 250:1 for the clean air standards of 1975.

Likewise, carbon monoxide emissions are compared in Figs. 2-c and 2-d. Here the furnace performance is even more impressive by having a comparative ratio of 10,000:1 for 1970 and 700:1 for 1975. Nitrogen oxide emissions are a very difficult problem in any air pollution control program. Yet as seen in Figs. 2-e and 2-f the multiple hearth furnace even has a decided edge over autos for nitrogen oxide contributions to the atmosphere. By 1976 the furnace will still have 16 times less emissions than automobile standards will allow.

All of the furnace emission data is based on currently operating furnace performance. Thus while the future auto emission standards assume technological improvement, the projected furnace operating in 1976 is the same one in use today. These comparative ratios take on added significance and will even more heavily favor the furnace if it is rightly assumed that furnaces will also be subject to technological advancements.

In the final analysis per capita air impact of the operation of a sewage incinerator is equivalent to a person driving a 1972 automobile approximately 120 yards by consuming less than 1 oz. of gasoline.

By comparing the operation of sludge incineration furnaces and automobiles in equal terms it is fair to say that sludge incineration has relatively little impact on the atmospheric environment. Moreover, sludge incineration allows the reuse of valuable treatment chemicals and provides gases needed in the recarbonization of effluents treated by advanced methods. It is clear that present multiple hearth furnaces of advanced design will continue for the foreseeable future to have a relatively minute influence on the continuing urban air quality problem [9].

**Future Developments**

Despite the fact that the multiple hearth furnace does provide unique operating economies to the user, the recommendation of the Environmental Protection Agency for destruction of insecticides and polychlorinated biphenals may mandate that all incinerators operate with a 1600 F exhaust gas temperature and with a residence time of 2 sec. [10]. This requirement can be achieved through the multiple hearth unit by feeding sludge to the second or third hearth of the unit and altering the furnace temperature profile and excess air distribution. To maintain economical fuel operation and conserve energy resources it will be necessary to either preheat combustion air and/or recover heat in waste heat recovery units for building environmental control or provide heat for the thermal conditioning of sewage sludges. Substantially all of the extra heat required to attain the extended 1600 F temperature condition can be obtained from sludge cake production from heat treatment systems or with filter presses and conditioning chemicals. It is anticipated that solids disposal systems of the future may well incorporate these systems since the capitol

<table>
<thead>
<tr>
<th>TEST</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Allowable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume SDCFM</td>
<td>4350</td>
<td>4450</td>
<td>5070</td>
<td></td>
</tr>
<tr>
<td>% H2O</td>
<td>5.0</td>
<td>4.7</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>% CO2</td>
<td>10.4</td>
<td>8.8</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>% O2 (dry)</td>
<td>8.0</td>
<td>8.1</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>CO - ppm</td>
<td>--</td>
<td>25</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbons, C2-C6 ppm*</td>
<td>0.7</td>
<td>2.2</td>
<td>0.4</td>
<td>25</td>
</tr>
<tr>
<td>Particulate-gr./SDCF*</td>
<td>.019</td>
<td>.021</td>
<td>.017</td>
<td>0.15</td>
</tr>
<tr>
<td>Carbonyls - ppm*</td>
<td>3.4</td>
<td>7.6</td>
<td>3.4</td>
<td>25</td>
</tr>
<tr>
<td>Ringleman Steam plume</td>
<td>Steam plume</td>
<td>Steam plume</td>
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<td></td>
</tr>
</tbody>
</table>

*Corrected to 6% oxygen and auxiliary fuel deleted.
TABLE 4
South Lake Tahoe, California

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<thead>
<tr>
<th>Volume SDCFM</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Allowable</th>
</tr>
</thead>
<tbody>
<tr>
<td>% H₂O</td>
<td>2.8</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% CO₂</td>
<td>5.2</td>
<td>7.7</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>% O₂ (dry)</td>
<td>10.4</td>
<td>9.6</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>CO - ppm</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbons, C₂ - C₆ ppm</td>
<td>11</td>
<td>28</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>Particulate - gr./SDCF</td>
<td>.011</td>
<td>.009</td>
<td>0.010</td>
<td>0.20</td>
</tr>
<tr>
<td>Carbonyls - ppm</td>
<td>6.1</td>
<td>6.7</td>
<td>7.4</td>
<td>50</td>
</tr>
<tr>
<td>Ringleman</td>
<td>0-3/4</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
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</table>

Sampling methods as described Regulation No. 2 and Source Test Methods of the Bay Area Air Pollution District (BAAPCD).

Particulate sampling train included glass sampling nozzle, followed by two glass wool packed glass tubes, three ice packed Greenburg Smith impingers in series, dry gas test meter and vacuum pump.

costs would be offset by substantial savings in fuel costs. Gases discharged at 1600 F from multiple hearth furnaces are particularly desirable for use in waste heat recovery systems as they carry a minimum of flyash and sand (less than 5 percent of the total ash) as compared to fluid bed or other parallel flow type incinerators. This is advantageous as ductwork and venturi throats are not worn out by significant loads of flyash and sand. In fact, multiple hearth sludge incinerators discharge less than 0.03 grains per standard dry cubic foot with an impingement scrubber operating at a pressure drop of 8-10 in. water column.

Operating Costs

Despite the fact that operating problems did occur in furnaces designed prior to 1967, the users of multiple hearth systems report the lowest operating cost for ultimate disposal of any method. Perhaps the longest and lowest cost record has been reported by Minneapolis-St. Paul Sanitary District. The District’s 27-year multiple hearth incineration record (Table 1) [11] shows incineration cost for the years 1960 to 1965 averaging $2.35/ton of dry solids and $4.44/ton of dry solids for dewatering. Furnace maintenance cost for the full term period since 1934 has averaged less than .50¢/ton of dry solids.

The list of expenditures for parts required by the New Orleans 18ft-9in. O.D. — nine hearth incinerator, operating since 1967. (Table 2) [12] is indicative of the reliability of a furnace that only operates forty eight hours per week and is therefore subjected to severe heating and cooling.

The 14ft-3in. O.D. — six hearth organic sludge and lime reclamation furnaces at the South Lake Tahoe plant have operated since February 1968 without refractory maintenance and with replacement of approximately $1,000 of rabble teeth.

We conclude from this and other installations operating with modern technology that maintenance
cost should be reduced despite cost of instrumentation servicing.

CONCLUSION

The developments in the multiple hearth system over the last four decades have brought such capability and versatility to the system that it seems likely to find increasing application and acceptance as more stringent disposal standards are applied to waste water and sludge.

REFERENCES


