CONVENTIONAL REFRACTORY LINED INCINERATOR UPGRADING TO MEET THE REQUIREMENTS OF THE 1990s
CASE HISTORY: NEW YORK CITY DEPARTMENT OF SANITATION, SOUTHWEST BROOKLYN INCINERATOR

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ABSTRACT

Recent concerns over the emissions of trace organic compounds from municipal solid waste incinerators have resulted in proposed and recently enacted government regulations which affect the design and operation of existing incinerators. Most of these regulations emphasize the use of “good combustion practices” to minimize the emission of organic compounds. Many of the conventional refractory-lined stoker grate incinerator systems built before these regulations came into effect were not designed to use these “good combustion practices” in their operation.

This paper presents a case history of the efforts to modify the design and operating conditions of an older refractory-lined municipal waste incinerator system located at the New York City Department of Sanitation, Southwest Brooklyn, Incinerator. Included in this paper are test data and descriptions of recent modifications in the design and operating conditions which affect incinerator system stoker grate performance. Discussed are the aspects of a new integrated control system; underfire, overfire and wall cooling air systems; and the reciprocating grate stoker and furnace enclosure.

INTRODUCTION

Early incinerator engineering designs centered primarily around the size and shape of incinerator furnaces enclosure, i.e., long and narrow, box-shaped, high-arched, low-arched or other configurations considered as controlling factors by the designer. Until recently, during existing facility upgrades, little consideration was given to the improvement of the total incinerator concept as single package, whereby the incinerator is comprised of a combustion air supply and distribution systems, solid waste transport, control system and furnace enclosure. In the past, designers have centered efforts about the mechanical refuse agitation and transport, along with furnace chamber sizing and configuration.

This paper presents a case history of the integration of a new combustion control system which modulates
the operation of the refuse stoker and utilizes an existing combustion air system, while the existing furnace enclosure remains unchanged. This case history details the modifications and results of (4) 250 TPD replacement reciprocating stokers installed at the New York City Department of Sanitation (NYCDOS) Southwest Brooklyn Incinerator, located at Southwest Brooklyn, New York.

The NYCDOS Southwest Brooklyn Incinerator was constructed during the 1950s and completed about 1957. Figure 1 presents the general arrangement of the original traveling grate stoker systems for that facility. The facility’s four (4) stoker systems were each rated at 250 TPD, for a total of 1000 TPD. Combustion intensity and temperature were controlled by the combustion air supply with combustion air fan control based as either on or off. Combustion chamber temperature sensing was achieved by the placement of the thermocouple at the midpoint of the combustion arch and the boundary between the secondary and settling chambers. These temperature indications were used for recording the temperature history and management control. No automation or automatic controls were provided in the original design.

The traveling grate stoker system consisted of two (2) independent sections: an inclined drying grate and a horizontal burn section. The combined length of both grates was about 40 ft, and were 8 ft wide. This resulted in an aspect ratio of 5 to 1.

Primary combustion air was provided by a manually set vortex inlet damper to the underfire fan. Auxiliary overfire was provided to limit furnace enclosure temperature. Fixed wall cooling air was provided for the hollow silicon carbide walls.

Typical combustion chamber design for a vintage 1950s refractory lined incinerator was employed; it consisted of a high arch combustion zone, an ignition arch, and was followed by an outlet restrictor to the secondary chamber, which exhausted to a 200 ft stack.

Underfire combustion air was ducted to three (3) fixed flow wind boxes below the inclined drying stoker grate surface and nine (9) fixed flow wind boxes below the horizontal burning stoker. Air distribution was established during cold balance conditions. Wall cooling air entered the combustion chamber through outlet nozzles approximately 5.5 ft above the grate line, starting at a point adjacent to the charging chute along the drying stoker and continuing along the burn stoker and ending six (6) ft before the residue drop off. Overfire combustion air would only be utilized when the sensed temperature at the center of the combustion zone or at the exit pass of the secondary chamber exceeded 1800°F.

The quality of the residue burnout at the end of the burning stoker would be varied by changing the stoker’s retention time, i.e., increasing or decreasing the stoker speeds. No other adjustments were required of this system.

This system originally operated without any Air Pollution Control (APC) devices or an induced draft fan; federal mandates in the 1970s prompted the NYCDOS to install APC systems. APC systems were installed in the 1970s and included gas conditioning towers (water sprays), single field ESPs and induced draft fans, while the existing stacks remained intact.

By 1978, the original two-section traveling grate stokers were replaced with four reciprocating stokers and new controls at a cost of approximately $5,000,000. The modified facility was still rated at 1000 TPD, and included new combustion controls to automate the temperature regulation of the combustion process.

The reciprocating stoker consisted of alternate rows of stationary and mechanical grates. The alternate rows of mechanical grates move simultaneously in opposite directions, forming at the end of a 14 in. stroke a 15 in. step about each stationary row of grates. The reciprocating grate was installed in a plane declined approximately 14 deg. towards the ash drop-off.

The entire stoker assembly consisted of four separate and independently controlled sections. The grate speed of each of the four sections (top, upper middle, lower middle, and bottom) was adjusted independently to fit the combustion characteristics of refuse incinerated.

The stoker drive mechanism consisted of two front trunion mounted, hydraulic cylinders per each of the four sections. Continued grate motion is achieved through end of stroke reversing limit switches. Grate speed of each stoker section was controlled by a pressure compensated flow control valve with adjustable settings with a range of 0-10. The “10” setting equals the fastest grate speed (about 30 sec per stroke).

The stoker consisted of four (4) separate sections: (a) charging and dry; (b) upper middle burning; (c) lower middle burning; (d) ash residue burnout. All but the first section received underfire air supplied from the original fan system installed in 1950s. The vortex inlet damper of the fan was mechanically connected to a high torque 90 deg. electric actuator with positional feedback, all electrically connected to the new control system.

A new overfire air fan was installed with an electric inlet damper control, similar to the installation for the underfire system. The overfire air was ducted into the combustion chamber by eight (8) side wall connections on both sides, for a total of sixteen (16) on the incline parallel to the grate surface at an elevation $Ha$ [1].
GENERAL ARRANGEMENT OF ORIGINAL TRAVELING GRATE STOKER SYSTEM

FIG. 1  LONGITUDINAL ELEVATION
\[
Ha = \frac{4}{3} (Ag)^{4/11}
\]

where

\(Ha\) = overfire nozzle height ft,

\(Ag\) = grate area ft\(^2\)

The original design intent of \(Ha\) was for furnace enclosure height above the grate line. In this facility \(Ha\) was used to locate the overfire air injection location with the furnace roof at a height equal to twice \(Ha\).

Fixed wall cooling for the silicon carbide walls entered along each side wall at (9) points, for a total of eighteen (18) at a height of five (5) ft above the grate surface.

A new thermocouple T1 was installed at the center position of the combustion arch roof and connected to the adjustable overfire temperature controller. The overfire controller transmitted an analog (1–5 V DC signal) proportional to an internal calculation of the set point deviation. This signal was sent to the slave underfire temperature set point adjustable controller. The outputs of the two controllers would attempt to regulate each supply fan flow rate by positioning the inlet dampers.

The control system was designed to operate at a 1600°F setpoint. Temperature sensed by T1 above 1600°F would signal the overfire fan damper to open and the controller would transmit an analog scale signal to the underfire controller to reduce the damper opening. T1 temperatures sensed below 1600°F would reverse the process. The original control scheme philosophy was to use a constant quantity of combustion air to maintain a fixed temperature. The system controlled temperatures by the distribution of the fixed total combustion air of sections [2, 3].

The following presents the rated fan capacities [4]:

<table>
<thead>
<tr>
<th>AIR SYSTEM</th>
<th>FLOW CFM @ 70 °F</th>
<th>STATIC PRESSURE IN. H2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underfire</td>
<td>27,000</td>
<td>2.5</td>
</tr>
<tr>
<td>Overfire</td>
<td>22,550</td>
<td>3.0</td>
</tr>
<tr>
<td>Wall cooling</td>
<td>8,500</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Additional facility modifications included revisions to the combustion chamber enclosure. These revisions consisted of increasing the elevation of the high arch to 20 ft, an additional 4 ft over the original design. Slopes of the forward ignition and rear reflective arches were changed to provide for increased radiant heat transfer and increased combustion chamber volume. Figure 2 presents the revised furnace cross section.

The analog overfire and underfire damper controllers potentiometer where adjusted for rate, reset, and proportional gain. Dead Band was factory set.

After stoker commissioning and thermal dry out, long term automatic control of the combustion process at the 1600°F set point proved to be unsuccessful. Various combinations of rate, reset and proportional gain adjustments where set into the equipment, without achieving long term consistent automatic controlled operation. When control system calibration was performed with a relatively constant quality refuse mixture, temperature stability could be maintained for periods up to two (2) or three (3) days. When refuse quality control varied (i.e., wet, dry, heating value), control system over compensation constantly repositioned combustion dampers between their respective full open and closed limits. This control action caused wild temperature fluctuations ranging from 1300°F to 2000°F. Positive draft conditions occurred, forcing furnace gases into the operating floor area.

The following presents typical operating problems which occurred at the facility:

(a) Positive pressure above the grate line forced hot combustion gases through the refuse, and penetrated the grate line, causing the frame support assembly to warp, sag and fail.

(b) Positive pressure in the arch of the combustion chamber forced hot gas into overfire ducts and burnt them out. This eliminated any form of controllable overfire air and permitted the stoker to operate with excess air.

(c) Brick delamination occurred due to the large fluctuations of unbalanced air.

Between 1978 and 1980, several attempts were made to correct facility operating problems. The following presents several control system modifications which were unsuccessfully implemented:

(a) Set underfire air damper at a fixed position and operate overfire air in the automatic mode.

(b) Set overfire air damper at a fixed position and operate underfire air automatically.

(c) Balance both overfire and underfire dampers to open to exactly the same mechanical positions.

After 15 years of operation and continued maintenance, the stoker and combustion chamber were in very poor condition. Service and maintenance was very costly; units had to be taken out of service before their scheduled maintenance for major repairs. Repeated clean out of the secondary and lower settling chambers was required after short operating periods due to particulate carryover caused by excess air.

**RECENT MODIFICATIONS**

In 1986, at a cost of some three million dollars, the stokers installed during the 1970s were replaced with
FIG. 2 FURNACE CROSS SECTION OF RECIPROCATING GRATE INSTALLATION
another reciprocating stoker of the same style. From all outward appearances the stoker resembled the earlier version, except for improved structural integrity, but in reality these two stoker systems are completely different. The differences center about the integrated control system which operates the stoker’s hydroelectric actuation in reference to the sensed combustion temperatures. The new integrated control system utilizes a closed loop stoker control system that is completely automated to control:

(a) Feed stoker speed (i.e., stoker section 1, feed rate of refuse).

(b) Temperature (the ability to change operating temperature set points without recalibration).

(c) The ability to effectively change the useable length of the stoker (i.e., location of wall-of-flame).

(d) Provide a stoker control system which operates effectively over a wide range of tonnage through-puts (i.e., turn down ratio).

Since commissioning in 1986, this integrated control system has worked with no control system downtime. The system has varied stoker operation to accommodate feed refuse from any source within the City of New York. This has been accomplished using the original long and narrow structure originally installed in 1957, modified during the 1970s and now reused for the 1990s.

The overfire and wall cooling air injection nozzles were reused at locations established for the 1970s configuration without the reoccurrence of structural failure as in the past. Underfire was modified from the 1970s distribution pattern.

Figure 2 presents the configuration of the 1970 installation as well as the installation for the 1986 modifications. The underfire air duct work modification consisted of installation of a connecting duct between stoker Section 1 and 2. By adding the bleed duct with a volume damper from the stoker plenum No. 2, it now adds positive underfire air to the underside of stoker plenum No. 1 hopper. This prevents positive high temperature gas from penetrating through the refuse and grate, thus eliminating the failures that occurred to the 1970 stoker undercarriage. The bleed duct volume damper is adjusted to provide sufficient undercarriage pressure to balance the positive pressure above the grate line, due to refuse combustion, without causing blow back up the charging chute.

The stoker drive actuating mechanism includes two side drives in parallel per each section. This eliminated the racking to the sectional frames when powered by the original single center located cylinder. Now, if a single cylinder fails, the system may operate off one cylinder, preventing unnecessary shut downs. Another benefit of side drives is the elimination of structural interference caused by the original cylinder installation to the flow of underfire air. Obstructions that cause unequal distribution of underfire air will promote blow torching and loss of underside grate cooling.

Outlet diffusers and balance splitters were added to the original underfire air ducts installed in 1970s. At each outlet face of the stoker plenum, combustion air was directed downward towards the bottom of the sifting hoppers. Pressure now builds from the bottom up towards the grate underside.

Figure 3 presents the basic stoker combustion air and control system schematic for the 1986 modifications. Figure 4 presents the combustion air and sectional stoker control block diagrams which are all components of the integrated control system. T1 is located in the center of the high arch combustion chamber parallel to the feed’s two separate independent processors that drive overfire and underfire damper motors independently while the fan speed is fixed. Processors are equipped with normal settings rate, reset, proportional gain, dead band, load line, set point, and feedback. Each of the respective controllers’ menus are linearized along a sloped load line to the rate of combustion.

Another control system thermocouple, T2, is located above the sloping throat of the exit ventui after the combustion chamber. Its position was located by testing to provide a true indication of combustion chamber exit temperature. The thermocouple senses combustion chamber exit gas temperatures, which indicates if complete combustion of the gases is occurring within the combustion chamber enclosure.

The control system process function of (T1–T2) produces a processor error signal when the function is less than or exceeds 250°F. This function indicates the position on the stoker of the wall of flame. The error signal is adjustable between 0°F and 2000°F, and effectively changes the useable length of a stoker by varying the stoker section speeds. The resultant error signal feeds a rotary servo valve as shown in Fig. 4. Stoker speed variation is accomplished by the adjustment of oil flow from the hydraulic pumps to the cylinders, which drive each of the independent sections. With this configuration, we have achieved changes of 0.001 gpm to accurately regulate the total flow. This small rate of reciprocation per section is not perceived by the naked eye, but is sensed by the (T1–T2) process function.

In order for this system to work effectively, the excess air provided by the 1970 installation had to be eliminated from the damper scale factor per degree Fahrenheit of error of the desired set point value. Based on a design point of 250 TPD and 3.89 lb air per pound of refuse (dry), the total combustion air required for 20%
FIGURE 3

LEGEND
OFFM = OVERFIRE FAN MOTOR
F = FAN BLADE
OFD = OVERFIRE DAMPER
OFDM = OVERFIRE DAMPER MOTOR
BG = BLAST GATE ADJUSTMENT
UFFM = UNDERFIRE FAN MOTOR
UFD = UNDERFIRE DAMPER
VD = VOLUME DAMPER
IVD = INLET VOLUME DAMPER
SEC = STOKER SECTION
HYD = HYDRAULIC CYLINDER
S = SHAFT
T1 = COMBUSTION TEMPERATURE THERMOCOUPLE
T2 = EXHAUST TEMPERATURE THERMOCOUPLE
WC = WALL COOLING NOZZLES
Z = WALL OF FLAME MEASURE POINT
FIGURE 4

**LEGEND**

- IVD = INLET VOLUME DAMPER
- SEC = STOKER SECTION
- HYD = HYDRAULIC CYLINDER
- S = SHAFT
- T₁ = COMBUSTION TEMPERATURE THERMOCOUPLE
- T₂ = EXHAUST TEMPERATURE THERMOCOUPLE

**Micro Processor**
- SET POINT - 5°F DESIRED
  - R = 0
  - R₃ = 0

**Micro Processor**
- SET POINT + 5°F DESIRED
  - R = 0
  - R₃ = 0

**Damper Motor**
- 0 TO 90°
  - 0° = 20% MAX
  - 90° = MAX

**SPOOL Valve**

**Rotary Servo**

**Cylinder**

**Typical Per Section**

**Figure 4 Diagram**

T₁ - T₂ = 250°F
Facility Operating Results and Test Data

Performance testing was performed on the facilities Unit #2, during July 1989 [5]. The testing was performed almost two years after original commissioning of the unit. The test program consisted of several days of pretest preparation and monitoring of the following:

(a) Continuous emission monitoring of flue gases for CO₂, O₂, and CO.
(b) Combustion air flow rates to each stoker section.
(c) Total wall cooling and overfire flow rates.
(d) Thermocouple temperatures T1 and T2.

excess air is 36,000 SCFM. This required a combustion air fan flow rate reduction of 10,000 SCFM from the original combustion air system.

### TABLE 1  RESULTS OF PERFORMANCE TESTING AND MONITORING THE SOUTHWEST BROOKLYN INCINERATOR

<table>
<thead>
<tr>
<th>TEST RUN NO.</th>
<th>AVERAGE UNIT THRU-PUT (TPD)</th>
<th>(1) % EXCESS AIR MEASURED</th>
<th>(1) % EXCESS AIR THEORETICAL</th>
<th>(2) AVERAGE FURNACE TEMP (°F)</th>
<th>AVERAGE PROCESS FUNCTION VALUE (°F)</th>
<th>(3) AVERAGE LOCATION OF WALL-OF-FLAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>293</td>
<td>151</td>
<td>162</td>
<td>1910</td>
<td>257</td>
<td>+0.8</td>
</tr>
<tr>
<td>2</td>
<td>257</td>
<td>171</td>
<td>181</td>
<td>1860</td>
<td>267</td>
<td>-0.1</td>
</tr>
<tr>
<td>3</td>
<td>307</td>
<td>214</td>
<td>125</td>
<td>1924</td>
<td>-60</td>
<td>-4.3</td>
</tr>
<tr>
<td>4</td>
<td>288</td>
<td>145</td>
<td>160</td>
<td>1923</td>
<td>135</td>
<td>-4.4</td>
</tr>
</tbody>
</table>

### INCINERATOR PERFORMANCE TEST RESULTS

<table>
<thead>
<tr>
<th>TEST RUN NO.</th>
<th>AVERAGE T1 TEMPERATURE (°F)</th>
<th>(4) AVERAGE MONOXIDE EMISSION (PPMdry @ 7 % O₂)</th>
<th>(5) FURNACE RETENTION TIME (SEC'S)</th>
<th>RESIDUE COMBUSTIBLES %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,773</td>
<td>45</td>
<td>3.81</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>1,766</td>
<td>75</td>
<td>4.25</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>1.772</td>
<td>112</td>
<td>3.18</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>1.821</td>
<td>64</td>
<td>3.17</td>
<td>1.1</td>
</tr>
</tbody>
</table>

NOTES:  
(1) Excess air comparison based on the calculated measurement of flue gas composition at the secondary chamber exit 5, the theoretical determination based on the total combustion air flow from underfire, overfire and wall cooling system and the average unit thru-put for the test.
(2) Based on the average of the temperature of mid point of the wall-of-flame and the average YT1 temperature during the test run.
(3) Datum point for the wall-of-flame is the end of stoker section 3, beginning of stoker section 4, (see figure 2)
(4) Flue gas monitoring performed at exit of secondary chamber
(5) Furnace retention time based on total combustion chamber volume minus refuse on grate volume divided by the average outlet flow rate of the combustion chamber at the average furnace temperature.
TABLE 2 RESULTS OF PERFORMANCE TESTING AND MONITORING THE SOUTHWEST BROOKLYN INCINERATOR

<table>
<thead>
<tr>
<th>UNIT #4 TESTING PERFORMED ON 11/28/89</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST RUN #</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Average Facility thru-put during testing 264TPD
(1) Excess air and carbon monoxide determination based on the calculated measurement of flue gas composition at the secondary chamber exit
(2) Datum point for wall-of-flame is the end of stoker section 3, beginning of stoker section 4, (see figure 2).

Review of the performance test results for Unit #2 indicated the incinerator's ability to operate under "good combustion practices" with an average furnace enclosure temperature of 1900°F and an average retention time of 2.2 sec.

Figure 5 presents graphically the turndown ratio for the stoker throughout. The refuse density lines (in lb/ft$^2$ of refuse) depicts the required hydraulic flow for feed section No. 1 as a function of moisture, density and other factors which affect compacting of the refuse. By manually setting the initial flow rate in gpm, the number of shear strokes cut into the column of refuse below the feed chute is increased or decreased to vary the refuse feed rate into the furnace. Automatic variation of the initial flow by the parallel hydraulic trim of the T1–T2 process function changes the flow above or below the 2.72 gpm design point. If T1–T2 varies above or below the 250°F reference, it repositions the location of the wall-of-flame by changing the stoker retention time.

Location of wall-of-flame data shows the auto variation of the grate speed control as the wall of flame moves back. While the T1–T2 process function became
FIG. 5 FEED STOKER SPEED GPM VS THROUGHPUT (TPD)

LEGEND

M = MANUAL SET POINT OF HYDRAULIC FLOW (BASIC FLOW)

Sf MIN = BASIC FLOW MINUS REDUCED FLOW
BY ROTARY SERVO CONTROLLER OPENING

Sf MAX = BASIC FLOW PLUS ADDITIONAL FLOW
BY ROTARY SERVO CONTROLLER OPENING
significant, control signals increase the stoker speeds to bring material forward. Passing the control process function boundary reverses the process, causing the wall of flame to move back towards the boundary (i.e., highly volatile, high moisture content, etc.). This process repeats on a regular cycle with unstable material. Stable material will not cause any speed variation to the stoker transport process.

Changes in the ambient air relative humidity at particular times affects the flame temperature of the combustion process according to investigations by R. H. Essenhigh [7]. Changes in the rate of refuse combustion effects the refuse retention time vs stoker speed thereby forcing the T1–T2 process function to readjust stoker control hydraulic flow along the load line with no rate or reset in any of the microprocessors. The linerized evaluation of the combustion process along load lines measuring the efficiency of the rate of reduction simplifies the control requirements.

CONCLUSION

The test data, obtained from stoker Unit #2 in 1989 after 2 years of operation and from Unit #4 after commission in 1989, presents data which represents reliable and consistent operating conditions which are the result of facility modifications which included the integration of a stoker and combustion air control system with an existing reciprocating stoker and furnace enclosure. Overfire and underfire fan damper microprocessors and hydraulic servo valve microprocessors were all calibrated in 1986 and 1989 for Unit #2 and in 1989 for Unit #4 with identical menus. Test data from both stoker units is repetitive, and long term visual observations all indicate these stoker systems operate as twins. Test data shown in this paper mentions Units #2 and #4. Actually, there are three units working at this plant. Units #2, #3 and #4 are all operating in an identical manner and are all calibrated with the same menu. Unit #1 does not have a A.P.C. system to treat flue gases and remains shut down.

Test data from Unit #2 shows the control system regulates combustion air flow and stoker speed to a sufficient degree in order for the unit to operate under recommended "good combustion practices".

Using the $T_1 - T_2 = T_{reg}$, it is conceivable to operate any other servo arrangement to control a prime mover of refuse stoker mechanics.

The overall cost of the control system modification was less than 8% of the stoker replacement costs at the Southwest Brooklyn Incinerator. A number of control spinoffs are possible using this control scheme in combination with:

(a) Predetermining extremes of refuse moisture within charging hopper columns.
(b) Trim adjustment of intermediate points along the grate line.
(c) Trim and modulation control of air injection at points after the flame wall are now possible.
(d) Trim and modulation of combustion air based on flue gas oxygen content.

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REFERENCES