DESIGN CRITERIA TO ACHIEVE INDUSTRIAL POWER PLANT RELIABILITY IN SOLID WASTE PROCESSING PLANTS WITH ENERGY RECOVERY

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ABSTRACT

During the past few years many new attempts to introduce innovative solid waste processing systems, including energy recovery capabilities, have run into difficulties.

The outstanding performance of the well established system of mass burning with energy and resource recovery is described in this paper, with special reference to important design criteria.

The latest criteria for optimum combustion chamber design, to minimize superheater and boiler tube corrosion and erosion, and criteria for improved stoker performance reliability to obtain a total on stream availability of nearly 90 percent, including scheduled down-time, are the main topics of this presentation.

INTRODUCTION

Many disappointing experiences with incinerators during the past 10 years have shown that innovative designs cannot be developed from scaled-up pilot units or from theoretical concepts without many years of actual field performance.

This raises the question as to whether actual continuous availability of solid waste-fired boilers, as required with utility boilers, is actually attainable. The answer is an unequivocal “YES,” as a result of many years of performance, experience, research, development and redesign.

It can be said without hesitation that solid waste fired steam generating equipment is available “TODAY” and can perform to extremely strict performance specifications.

There is no “magic” to such an assertion. If a certain fuel is to be burned, whether it be lignite, bark, black liquor or sewage, each case requires a specific design. Solid waste, whether industrial or residential, is extremely heterogeneous and its combustion requirements are, therefore, exceedingly sensitive to variations in design criteria.

Breakdown of unreliable firing equipment, waterwall and superheater corrosion, boiler tube erosion and many other disheartening experiences have made many municipal authorities consider a return to landfill operations.

This paper is written to dispel such concern, and makes reference to actual performance records showing that full utility boiler operation with solid waste as a fuel is presently and continuously being carried out in many of the world’s countries.

The minimum requirements for efficient and most economical performance should include the following guarantees:

1. Be capable of accepting most municipal refuse as received, without special front-end separation except for bulky waste.
2. Costly and difficult to maintain shredding equipment not required.
4. Continuous uniform and clean burn-out of
the fuel, to the specified limit of organic matter.
5. Minimum boiler tube corrosion and erosion, to specified maximum allowable rates.
7. Uninterrupted stoker and boiler operation of more than 4000 hr semiannually.
8. Assurance of a total availability of 85 to 90 percent of annual operating time.
9. Extended average efficiency for 6 months of continuous operation.
10. Full compliance with environmental rules and regulations.

When preparing specifications for equipment, compromises must be avoided. The equipment selected must, without question, meet the requirements outlined in the Request For Proposals.

If, for example, long years of performance have shown that certain design criteria are of critical importance, values must not be adjusted to permit an unknown supplier to bid. Critical data items include furnace heat release rate, stoker width, heat input, superheater operating temperature and wall thickness, and stoker reliability records.

RECOVERED ENERGY OR DISPOSED WASTE?

Energy recovered from solid waste can be measured in terms of heat units. The efficiency of the recovery is:

\[
\% H \text{ recovered} = \frac{H_{\text{input}} - H_{\text{loss}}}{H_{\text{input}}} \times 100
\]

From the waste management viewpoint, it may be desirable to measure the solid waste tonnage disposed per day, per week or per year, but the energy or heat quantity per ton of waste processed will vary widely from season to season and is also subjected to wide fluctuations depending on the district from where it is collected and even the time of the day at which the collection takes place. For example, household waste with a low heat value may be delivered early in the morning and industrial waste with exceedingly high heat values may not come in until later in the afternoon.

SEASONAL HEAT VALUE VARIATIONS

During January, shortly after the holiday season, while paper and packaging material is being discarded, the heat value of the waste can be very high. During the month of May when grass clippings and other waste from the garden clean-up appears, the heat value of the waste may decrease to an extreme low. In former years, the rainy seasons also had a considerable influence on the waste’s heat content, but since the presently widespread use of plastic bags by the householders, the moisture content has become more stabilized and the burnability of the solid waste has improved markedly.

As a result, the influence of inclement weather conditions has been reduced but the seasonal variation of the waste heat value can still affect its burnability.

ENERGY RECOVERY

However, when burning solid waste, the goal remains optimum energy recovery, generally in the form of superheated steam for conversion into electricity by means of an extraction, backpressure or condensing turbo-generator set, depending entirely on whether a fraction of the steam can be used for process or heating purposes. Multipurpose use of the steam may result in higher heat utilization than by condensing alone.

From the energy recovery viewpoint, the solid waste cannot be regarded as a weight quantity to be disposed of in tons per day, as delivered by a community or industry, but becomes strictly a fuel to be fed to the steam generating equipment. The feed rate should be controlled only by the energy demand, while making provision for any fluctuations in heat values of the waste.

SOLID WASTE INPUT CONTROL

The crane operator’s duty remains to feed as uniform a charge of waste as possible to the hopper by skillfully blending dry waste from the upper strata with moist waste from lower levels in the storage pit. All he can do from there on is to maintain a predetermined level of waste in the hopper and watch the mass slowly drop through the feed chute as fed to the fuel bed by the mechanical stoker feeding equipment. He should pick out occasional bulky pieces of waste such as tree stumps, large pieces of metal, or white goods for collection in a separate area of the storage pit. He is not at all aware of what happens to the waste, which has now become a fuel to generate steam and energy in the waterwalled furnace and boiler. The weight of the waste charge as now introduced into each furnace hopper should be automatically recorded to-
gether with the related steam quantity generated. The ratio of steam generated to waste burned is a positive indication of the heating value of the waste consumed.

ENERGY INPUT AND OUTPUT CONTROL

The steam output or energy demand becomes the factor to control the firing rate; however, the waste input is also of prime importance as a desired quantity must be consumed daily. Wide load swings should not be permitted for this reason. In other words, the steam output of the boiler should be utilized as a base load only, for as constant a load as possible.

Figure 1 shows that a constant heat input over a wide range of waste input is possible even though heating value fluctuations exist. Only the extreme ends of this range limit the heat recovery to a reduced value.

As the moisture content rises, the heat input drops off abruptly as a result of the quenching effect of its water content. Present day solid waste heating values lie generally between 4500 and 6000 Btu/lb (10.467 and 13.956 MJ/kg). Figure 1 indicates that the heat input varies only 7 percent over this range if throughput rates are varied as shown. If one considers that the steam flow remains essentially constant, it is not difficult to regulate the waste feed rate accordingly.

CONTROL SYSTEM

As the heat input should be kept constant and the mass input varies with its heat value, it is obvious that the latter becomes the controlling factor to maintain a constant steam flow. With a constant air flow and varying heat value the furnace temperature will rise and fall correspondingly. Averaging thermocouples placed at strategic locations in the furnace area will sense instantaneously any fluctuations in heat input. See Figure 2. The resulting furnace temperature signal, together with a steam flow signal, can be used to regulate the hydraulic system operation for both the solid waste input feeder and the stoker agitating equipment.

![Diagram](image)

FIG. 1
In this manner it is possible to keep the furnace temperature within very close limits and simultaneously maintain the steam flow rate within a reasonable range. The normal load range should be kept within 75 to 105 percent of rated heat input.

SOLID WASTE FEEDING AND COMBUSTION AIR DISTRIBUTION
(See Fig. 3)

To obtain optimum combustion performance and steam generator efficiency it is essential that the refuse feeding and stoker grate agitating equipment be designed for rapid response to heat load changes, whether resulting from changes in heat value of the fuel (solid waste) or steam demand in response to signals from the control equipment outlined above. To satisfy these requirements the feeder and stoker must be designed to perform as follows:

1. The stoker must be designed for positive air distribution under the incoming waste load whether consisting of loose paper, matted material, rugs, metal or grass clippings.

2. For this purpose, it is important to limit the undergrate air supply ports to 2 percent of the total grate area maximum.

3. The reduced size of the air openings requires a higher pressure air supply, enabling penetration of more matted combustible material.

STOKER WIDTH AND FUEL BED DEPTH
(See Figs. 4-7)

The feeder and stoker equipment must be designed for "thin layer distribution" of the incoming waste to assure ample aeration for rapid and intensive burning. Experience has shown that the best burn-out results are obtained by limiting the heat input to approximately 10.0 million Btu/hr/ft (34.466 GJ/m) of stoker width. With an incoming waste density of 400 lb/ 3 (237.31 kg/m 3 ) and an assumed heat value of 6000 Btu/lb (13.956 MJ/kg) the resulting mass input per foot is:

\[
\frac{10,000,000}{6,000} = 1667 \text{ lb/ft-hr} (2,481.44 \text{ kg/m-h})
\]

or

\[
\frac{1667 	imes 27}{400} = 113 \text{ ft}^3/\text{hr/ft} (10.4517 \text{ m}^3/\text{m-h})
\]

and with a solid waste feed velocity of 1.0 ft/min at stoker front approximate fuel bed depth is:

SCHEMATIC OF COMBUSTION LOAD CONTROL EQUIPMENT

FIG. 2
Deeper fuel beds will retard the combustion intensity and prolong the burning process on the grate length. A short intensive burn-out on the grate will reduce the rate of CO generation to zero.

**PREVENTION OF FURNACE TUBE CORROSION**

The basic cause of furnace tube corrosion is incomplete combustion which generally causes the generation of large quantities of carbon monoxide (CO). The resulting reducing atmosphere in the furnace is oxygen starved and observation of such a fire shows long tongues of fire actually searching for oxygen. Wherever such a flame licks the furnace tubes or superheater area metal, oxidation can be anticipated. The rate of metal wastage will increase proportionately with the waterwall, or superheater-metal temperature. For this reason the saturated water temperature should be kept below 500 F (260 C).

**OVERFIRE AIR SUPPLY**

(See Fig. 8)

It is important to install closely spaced overfire air nozzles at the front and back of the furnace throat area to obtain a maximum air jet penetration for maximum flame turbulence. Any attempt to introduce overfire air through the sidewalls can have a detrimental effect on the solid waste burn-out as the side air pressure will tend to push the flames toward the furnace center and may result in severe flame stratification with a resultant poorer burn-out.

**WATERWALL PROTECTION**

(See Fig. 8)

The waterwalls in the area above the grate should be protected by a high alumina castable refractory about ⅛ in. (19.1 mm) thick applied to closely spaced steel studs to support the coating. The use of silicon carbide is not very satisfactory.

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FIG. 4. FIVE SECTION STOKER WIDTH
unless it is bonded ceramically to the waterwall at 1200 to 1400 F, (649 to 760 C), a temperature which cannot be attained in a welded waterwall boiler, where the metal temperature does not exceed the saturated water temperature.

This protective coating should extend approximately 25 to 30 ft (7.6 m to 9.14 m) above the grate level. Visible luminous combustion will normally not exist above this height. For waste fuels with a high moisture content, preheated under-grate and overfire air will contribute greatly to accelerated combustion within the designated combustion zone.

HEAT RELEASE IN THE PRIMARY FURNACE CHAMBER

The primary furnace consists basically of two distinct volumetric sections:

1. The luminous combustion zone where visible combustion takes place should not exceed half of the furnace height.

2. The incandescent furnace zone with exposed bare tube walls for maximum radiant heat absorption to assure that the gas temperature is reduced to less than 1500 F (816 C) before entering the second boiler pass.

Both these zones together constitute the total furnace volume, which should be dimensioned to limit the heat release to less than 10,000 Btu/ft³hr (371.93 MJ/m³h).

BURN-OUT OF HYDROCARBON GASES
(See Figs. 9 and 10)

It is important to provide a relatively low, suspended watercooled arch, protected with a refractory coating over the rear section of the grates. In this area, smoldering volatile gases (hydrocarbon) from the ash and clinker bed are still being released. These gases travel forward under the arch into the high intensity combustion zone on the forward section of the stoker grate for completion of burn-out.
FIG. 6. GRATE BAR DETAIL

FIG. 7

HEAT INPUT
MILLION BTU/HR-FT STOKER WIDTH

STOKER WIDTH FT. (w)

RECOMMENDED HEAT INPUT LIMIT
BTU/HR-FT OF STOKER WIDTH
○ = EXISTING INSTALLATIONS

434
FIG. 8. REAR FURNACE WALL WITH OVERFIRE AIR NOZZLES
FIG. 9. FURNACE THROAT DESIGN

FIG. 10. STOKER WITH REAR ARCH
AGITATION OF THE FUEL BED

Thin layer fuel feeding to the grate is not sufficient to assure a rapid and intense waste fuel burn-out. A slow and thorough bed agitation with stoker action to turn the fuel bed many times over the stoker grate length will assure burn-out from the bottom up and result in an optimum burn-out over the shortest travel distance. On this type of stoker, the basic 90 percent burn-out is usually completed in the first half of the grate length while the final, much slower burn-out of the still smoldering ash bed is completed on the balance of the grate length. In this way there is rarely any burning material falling off the end of the grate. A clinker roll which regulates the depth of the residue layer on the grate should be provided as part of the stoker, and is located at the residue discharge of the unit.

RESIDUE QUENCH, DRYING AND DISCHARGE

(See Fig. 11)

After completion of the waste burn-out, residue at a temperature of approximately 650 to 700 F (343 to 371 C) plunges into a quenching device. This equipment should form a seal against air infiltration. In the unit shown the residue is moved by means of a hydraulically operated ram to a drying chamber where the excess quench water is drained off, and the partially dried residue is eventually discharged onto a vibrating or belt conveyor. The drying chamber should be designed to provide a residence time of 30 to 45 min, which will reduce the moisture content of the residue by approximately 85 percent.

Good design will minimize or eliminate overflow of contaminated water from the quench bath. Its water level can be maintained by utilization of the continuous boiler blow-down or by use of other process water wastes. If carefully controlled, the discharge of any polluted streams to the sewer will not be required except when quench equipment is drained for maintenance.

RECOMMENDED BOILER OPERATING PRESSURE AND TEMPERATURE

For the most efficient energy recovery operation without excessive maintenance the superheater out-
let pressure and temperature of a boiler fired with a heterogeneous fuel such as solid waste should not exceed 600 psig (4136.90 MPa) and 750 F (399 C). This will still keep the steam rate of the turbo-generator down to 10.5 lb/kWh (4.76 kg/kWh). It is also advisable to limit the saturation temperature in the waterwalls to 500 F (260 C) or a maximum drum pressure of 665 psig (4585.01 MPa). This allows a 65 psi (448.16 MPa) pressure drop through the superheater and attemperator.

**TWO DRUM BOILER DESIGN**

WITH SUPERHEATER INSTALLED AT CONVECTION SECTION OUTLET

FIG. 12
THE SUPERHEATER
(See Fig. 12)

A superheater in a waste fired boiler is subjected to much larger dust quantities with generally lower fusion temperatures and a continuously varying composition of the chemicals in the flue gases compared with the operation of a coal-fired boiler. This may result in severe metal wastage unless specific precautions are included in the boiler design. One solution to this problem is to locate the superheater away from the radiant furnace zones and in an area of greatly reduced gas temperatures, not to exceed 1100°F (593°C) to 1200°F (649°C), where particle abrasion or slagging will no longer attack the protective oxide coating on the superheater tube wall. Such a superheater location does not demand the most exotic tube metal alloys but, as a result of the lower temperature differential between the gas stream and the superheated steam, an increased heating surface will be required. The end result assures, however, an indefinite life of the superheater for which a full guarantee can be given, provided that the equipment is properly operated and maintained as recommended. Continuous operating experience of 35,000 hr without any sign of tube metal wastage is on record.*

BOILER DESIGN CONSIDERATIONS FOR HANDLING OF SOLID WASTE FLY ASH

Solid waste with a heating value of 6000 Btu/lb (13,929 kJ/kg) normally has an ash content in the order of 16.0 percent compared to, for example, Kentucky coal with 12,100 Btu/lb (28,099 kJ/kg) and an ash content of 9.0 percent. On an equal heat input basis the comparable ash quantity is:

1. for solid waste = \( \frac{1,000,000}{6,000} \times 0.16 = 26.67 \) lb ash/million Btu (12.09 kg ash/million kJ)

2. for coal = \( \frac{1,000,000}{12,100} \times 0.09 = 7.44 \) lb ash/million Btu (3.37 kg ash/million kJ)

Tests show that the fraction of fly ash to bottom ash for underfired solid waste stokers is practically identical and equals approximately 25 percent. Solid waste burning therefore creates 26.67 lb ash = 3.6 times more ashes by weight for the same heat input as compared with coal firing.

On the other hand the bulk density of fly ash from solid waste is only 20 lb/ft³ (320 kg/m³) compared with 45 lb/ft³ (720 kg/m³) for fly ash from coal. This establishes a volumetric ratio of:

\[ \frac{\text{solid waste fly ash}}{\text{coal fly ash}} = 3.6 \times \frac{45}{20} = 8.10:1 \]

It is this much larger ash content of the waste, which is reflected in the quantity of fly ash, that poses a much greater slagging and fouling problem than in the ordinary coal fired boiler. For this reason, wider tube spacing and more sootblowers are required to keep a waste-fired boiler on the line for 6 months without intermediate shutdown for internal surface washing.

SOOTBLOWER OPERATION

The sootblowers serve to keep the boiler heating surfaces clean over prolonged operating periods. They are generally placed at locations selected to assure dislodgement of fly ash and scale deposits, even from corners with poor gas circulation.

Fly ash resulting from burning of solid waste is usually light in weight with a low ash softening temperature. On the other hand the ash is extremely abrasive due to the glass particles carried along with ordinary ash from burning of organic matter, paper, textiles, rubber, etc. Tube deposits of this nature are normally cleaned at least once during an 8 hr shift to assure a minimum increase of fouling over many months of uninterrupted operation.

RETRACTABLE VS STATIONARY ROTARY SOOTBLOWERS
(See Figs. 13 and 14)

The type of sootblower used is also very important. Sootblowers for solid waste fired boilers must clear out almost four times as much potential fly ash at relatively lower gas temperatures than for coal fired boilers and must therefore be activated more frequently.

Retractable sootblowers will always cross the face of adjacent tubes on their way into a tube bank and back. Such direct impingement on the
Fig. 13. Erosion effect of retractable sootblower on boiler tubes

Elimination of direct steam jet impingement of boiler tubes

Fig. 14. Stationary rotary sootblower
tube face laden with very abrasive fly ash will not only sandblast the tubes but will penetrate through the protective oxide layer and expose the bare metal to the corrosive action of CO or other chemicals in the gas stream.

To avoid damage from direct impingement on the tubes, either high alloy shields should be applied in the endangered zones, or better still, direct impingement on the tube face should be avoided. This can be done by using stationary rotary sootblowers which operate in a fixed position and blast only into the clear lanes of in-line tubes. Wide tube spacing is, of course, important to assure deep penetration of the steam jet to clear the ash deposits from the more remote tube surfaces.

The stationary sootblower has a shorter life span than the retractable sootblower, where its element is normally withdrawn from the hot boiler passes and subjected to the higher gas temperatures only during the sootblowing cycle of relatively few minutes duration per shift. However, the lower ambient gas temperature in the solid waste fired boiler with much higher excess air rates (80-100 percent), assures a reasonable life expectancy of the sootblower alloy element even near the furnace zones. It is naturally less expensive to replace a sootblower element than to repair a superheater or convection tube bank which requires a complete shutdown for repair and loss of valuable operational time, whereas a sootblower element can, in most cases, be replaced while the boiler continues to operate.

**COLLECTION OF FLY ASH**

It is not necessary to burden the electrostatic precipitator with the entire fly ash quantity. For this reason the boiler should be of the multipass design with gas flow reversal hoppers under the open pass before entering the convection section as well as under the economizer. Up to 35 percent of the coarser fly ash is collected at these pockets and is discharged through rotary valves (to prevent air infiltration) into the screw-type conveyors which transport the ash to the residue collection chamber. The fly ash should be moistened before being discharged into the residue collection chamber or elsewhere to avoid environmental dust problems.

**SUMMARY AND CONCLUSIONS**

The importance of proper coordination of all individual design details for the complete solid waste incineration train, from feed chute to and including the stack by one responsible and thoroughly experienced engineering organization cannot be over-emphasized.

In the author's opinion, too many compromises, resulting from vague requests for proposals, have been accepted due to limited field experience by the purchaser or the specifying engineers. Very stringent rules for selection of acceptable equipment must be applied to insure that a low bidder accepts the full responsibility for design, construction and long-term performance of the equipment submitted.

There is no doubt that an uncompromising attitude by the specifying engineer will lead to higher initial plant cost, but unquestionably this will, in the long run, result in the specified reliability, reduced maintenance cost, and the fullest satisfaction and benefit to the purchaser.

**ACKNOWLEDGMENTS**

The author wishes to express his appreciation to Messrs. W. J. Martin and H. Weiand of the Josef Martin Company for their cooperation in furnishing actual performance information.

**Key Words**

- Air
- Boiler
- Burning
- Chicago
- Combustible
- Control
- Corrosion
- Europe

- Flyash
- Furnace
- Heat
- Incineration
- Pennsylvania
- Refuse
- Waterwall
In his paper Mr. Stabenow has presented us with interesting data on a system for refuse disposal, namely, one for the conversion of refuse into electric power. The system was developed and perfected in Europe where considerable field experience was apparently obtained on several installations. The public or government ownership of both the electric supply system and of the refuse disposal facilities greatly simplified the problem connected with merging the two functions involved in the construction of a small refuse fueled generating plant. In the USA, the financial feasibility of such a facility must be proven to the management of a privately owned utility before they would permit it to be connected to their grid.

To compare the Northwest Incinerator plant of the City of Chicago to the type of facility described in this paper would most likely be unfair to Mr. Stabenow. Our incinerator plant has been in operation for seven years while the equipment and plant design are ten to eleven years old. Obviously many modifications and design improvements have been made and applied to new installations in the intervening years. Northwest Incinerator is not an electric generating plant. It was built to bum household refuse. Steam generation was used as a means of cooling the combustion gases to permit use of electrostatic precipitators, the steam being wasted in large air cooled condensers. At the planning stage, steam sales was not a significant consideration. The plant has no superheaters. It also lacks underfire air preheaters which constitute a serious handicap when confronted with dripping wet garbage. Preheated air could evaporate the excess moisture and burning could perhaps be continued at a reduced rate. Without preheating great care is needed not to quench the fire. Unlike Mr. Stabenow, with plastic bags and all, we still find soaking wet refuse an annoying problem.

The prime purpose of our plant is to dispose of refuse and we cannot curtail throughput to meet steam or electric demand. The refuse that arrives in the pit must be burned.

We are impressed by the uniformity of the steam output shown by Mr. Stabenow, an achievement we have not been able to even approach. Even with the help of the "Black box" controls furnished by Martin, our steam output rate fluctuates considerably.

Mr. Stabenow speaks of refuse with a higher heating value of 5000 to 6500 Btu/lb. In Chicago a higher heating value falls in the range of 4500 Btu/lb. We wonder if Mr. Stabenow's values are based on European refuse? Looking at Fig. 1 of Mr. Stabenow's paper we wonder if this difference in heating value accounts for the steam output fluctuations we experience.

A few other items of Mr. Stabenow's we would like to question. Starting with his list of minimum requirements in the introduction, we have found equipment availability to be in the range of 75 to 85 percent of the time rather than 85 to 90 percent. We generally plan on the basis of 3 out of 4 furnaces being in service, the 4th being down for maintenance.

We fully concur concerning the importance of clear and concise specifications. For us, as for many other government agencies, competitive bidding is required by law. The only way to exclude inferior products is through carefully written, stringent specifications. We agree wholeheartedly with the concept that all engineering design, construction and performance should be under one responsibility, but what happens when the one responsible contractor or consultant has run out of money and the job is but half done?

**Question 1**

The question of combustion control and steady steam output is a difficult one. Garrett stated that no system has yet been devised which properly weighs calorific value, moisture and ash content and combines these operating variables in such a way that the refuse feeding rate can be left on automatic control, and the required heat demand, steady combustion and a good residue quality be attained [1]. Akaji [2] attempted to quantify burning conditions of refuse on a grate as a pre-requisite to automatic control. The transfer function relating the output to the input variables has been determined experimentally at the Stuttgart
incinerator, on both a Martin and a VKW grate [3]. The large backmixing effect of the Martin grate was thus demonstrated experimentally and it was also shown that on the Martin grate temperature could be controlled by varying the feeder frequency exclusively, where as the air factor could be controlled by means of the over-pressure of the air under the grate. The other grate required more elaborate controllers [3]. In my opinion I feel that this previous work should have been mentioned in this context, especially since it shows some control advantages of the grate marketed by your company. My question really is whether the work of Braun [3] and Akaji [2] has been continued and whether you can add new data to the ones already published.

Question 2

Do you think that heat accumulators, as proposed by Farkas [4] can help to solve the problem of a constant steam output?

REFERENCES


Discussion by

J. T. Schroppe
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The author is to be commended for presenting in clear, concise terms the basic prerequisites for mass-burning refuse steam generators. I would also agree with his list of minimum requirements to provide efficient and economical performance with full consideration of the quality and nature of the "fuel".

It is also important that the coordinated effort for the plant take full advantage of the expertise and experience available by the major boiler manufacturers. We must not compromise on promises and unproven techniques.

The refuse steam generator industry in this country is relatively young, with the first installation in Norfolk, Virginia some 12 years ago. These units have provided excellent operation and service through the years. Others have experienced some pitfalls and problems when compromises and departures from basic operating experience were undertaken.

It should be remembered the objective is to consume refuse in an environmentally acceptable manner and save our dwindling national resources. Surely, this is a proven way to conserve energy and extend the life of our shrinking land-fill sites and can, in the not too distant future, eliminate unsightly land-fills.

AUTHOR'S REPLY

To Louis G. Kaplan

The questions raised in this discussion point out a number of problems experienced at the Chicago Northwest Incinerator.

First of all, air preheaters were not included in the original specifications based on the assumption by the authorities that the heating value of Chicago refuse would never fall below 5000 Btu/lb. Later it proved during test runs that the average heating value was merely 3900 Btu/lb instead of the higher value anticipated. Preheated air would naturally aid considerably to achieve a rapid burn-out and thus improve to level-off the steam generating rate. However, the best control system will not achieve the desired operating performance as long as the steam output is subjected to a widely fluctuating condensing system. In this case all excess steam flow, both high pressure and low pressure, are delivered to a large number of roof condensers each with its own cooling fan. Shortly after start-up it was soon learned that the mechanically operated louvres at the fan discharge side did not vary the air flow properly. As a consequence, the fans operated strictly on an "on" and "off" cycle which, of course, subjected the steam flow to a very erratic range. Freezing conditions have also raised havoc with many condenser tubes.

Presently a new agreement for sale of steam between the city and a neighboring industry has been consummated and the resulting steam demand will enable the City of Chicago to readjust their combustion and control system to achieve a similar performance as outlined in this paper.
To Professor A. Buekens

No further publications regarding automatic incinerator control systems other than the papers mentioned by Garrett, Akagi, Braun, and Farkas have been available to the author; however, diagram II in this paper represents the latest development in combustion control for incinerator furnace.

It is apparent that insufficient attention is being paid to the constantly changing combustion air demand which can vary from 670 to 750 lb of air per million Btu input depending on the momentary composition of the refuse (see Elmer Kaiser’s Paper, 1966 Proceedings, p. 84).

For this reason the furnace temperature controller alone cannot achieve optimum performance, but automated control of the O₂ contents in the stack gases should also be introduced to achieve closer control over the fluctuation in the steam flow. Another factor which makes perfect combustion control difficult is the continual variation in moisture content of the refuse.

At the present time a plus or minus 5 percent steam flow variation is about the optimum achievable. Additional research and development work will be necessary, but the heterogeneity of the refuse will always cause a variation of combustion efficiency whether the combustion process is by mass burning of unprocessed refuse or RDF.

To J. T. Schroppe

The performance achieved at the Norfolk installation with relatively low pressure steam generation shows that 12 years of reliable operation is not limited to European installations but can also be achieved in this country. Both the Chicago N. W. and Harrisburg incinerator plants respectively have now been 8 years and 6 years on the line and are proving excellent reliability of incinerator performance.

With worldwide experience gained in the meantime when operating at higher pressures and temperatures, it is now feasible to design refuse to energy plants up to 600 psig and 750 F for electric power generation. The information presented in this paper is based on the high reliability obtainable under such conditions.
EXHIBIT II-B - NO. 1 BOILER RECORDER CHART - STEAM-AIR-FEEDWATER FLOWS 0-150 M LB/HR
TEST DATE: JULY 25, 1975 (WITH "BLACK BOX" CONTROL)
EXHIBIT II-C – NO. 3 BOILER RECORDER CHART – STEAM-AIR-FEEDWATER FLOWS 0-150 M LB/HR
TEST DATE: JULY 30, 1975 (WITH "BLACK BOX" CONTROL)