Accurate Incineration Control: An Interesting and Important Engineering Challenge

C. J. GARRETT
Fischer & Porter Company
Warminster, Pennsylvania

ABSTRACT
Increasingly rigid pollution laws and the increase in the total volume of both industrial and municipal refuse have resulted in rapid expansion of enclosed incineration. In order for incinerator designers to meet the requirements for volume reduction and to stay within the boundaries established by pollution-control laws, emphasis on accurately controlling incinerators must be given increased importance early in the design stage.

This paper explores the requirements for control-system design in light of the many human, legal, and technical factors that should be considered. The requirements for such systems and methods of measurement are discussed as well as the selection of hardware.

A number of suggested control systems are presented to illustrate the possible avenues that the designer may elect to pursue. The considerations, advantages, and disadvantages of these systems are explored in detail.

INTRODUCTION
At present, incinerators are emerging from their status as "skeletons in the municipal and industrial closets," and those of the future should certainly be prime examples of the latest fuel-burning technology and materials-handling engineering.

Modern, functionally designed buildings, attractively landscaped, are replacing the old eyesores of open-pit burning and of the early enclosed incinerators. In order to assure efficient and smokeless operation, these new plants must be equipped with adequate instrumentation for monitoring and control.

The question of what constitutes adequate monitoring and control is the subject of considerable disagreement among incinerator designers. It is generally agreed, however, that the simplest systems will be inadequate for modern, high-capacity incinerators. The earliest designs utilized little more than a few temperature points for monitoring and alarming of gas temperatures. Under the conditions existing at the time, these few operator aids were assumed to be adequate. Since the requirements have changed, it is doubtful that these rudimentary systems will any longer suffice.

More recently, incinerators have been coupled with boilers for gas cooling. In some cases, the steam generated is utilized in power generation. The heat available in municipal refuse is not insignificant. It has been postulated that up to 3 lb of steam can be generated per pound of refuse fired. This output would depend on the quality of the refuse as well as proper boiler and control-system design. If only part of this potential were to be realized, an incinerator could still generate enough electricity to handle all its own power requirements, have enough to supply an associated sewage treatment plant, and still have a power reserve to feed back into utility lines. In this case, proper control of the combustion process and water side of the boiler is essential to assure dependable power generation.
In the following discussion, we have suggested a number of control systems to meet the requirements of the incineration industry. Some of these may be inadequate for specific applications, and others may be unnecessarily complicated. It is not intended that any of these systems be taken as a general recommendation for controlling all incinerators. Rather, it is intended to demonstrate the technology available and where additional development is necessary.

Application of any control system should be on the basis of an individual situation to assure that the unique requirements of any installation are met.

CONTROL-SYSTEM REQUIREMENTS

The operational requirements of low particulate emission and efficient volume reduction dictate the basic system-design aims. Refuse consist, sizing, plant location, storage facilities, and duty cycle all combine to define the complexity and flexibility required to accomplish the basic operational requirements.

Maintenance and human requirements should also weigh heavily in system-design decisions. Unless the plant will be staffed by adequate maintenance personnel properly trained, a system that requires periodic maintenance and calibration could be a liability no matter how well it is otherwise conceived. On the other hand, it is not realistic to provide a system that will require a high degree of operator involvement and/or skill. Operating personnel are generally not expected to exhibit the high degree of skill of for instance a machine tool operator. High turnover, lack of time for extensive training, and salary structures are a few of the influences which preclude extensive operator involvement. Obviously these two requirements are at cross purposes. The availability of good, well-trained operators is hard to predict.

Somewhat more sophisticated control systems with rugged, reliable hardware must be developed. If truly automatic, these systems should relieve the operator of most of the actual control. At the same time, recalibration and scheduled maintenance can be at intervals of many months. In order to accomplish this degree of reliability, all components, including sensors, transmitters, and controls, must be rugged, first-class process instrumentation. At present these instruments would be pneumatic. However, modern electronic technology is developing rapidly, and electronic instrumentation and control is finding wider and wider application. Within the foreseeable future, electronic instrumentation for incinerator plants will be economically justified. Solid state hardware and integrated circuitry markedly increases the dependability of electronic equipment while keeping costs at a minimum. Modular construction simplifies electronic maintenance procedures.

INCINERATOR CONTROL SYSTEMS

Combustion and Stoker Control Systems

To date, most stoker-speed or bed-height control systems have been manual. The factors that may affect the required fuel rate are fuel characteristics, such as moisture, Btu content, and burning rate, the requirements for volume reduction and residue quality, or possibly requirements for waste heat/steam production.

No system has yet been devised that can properly weigh all of these factors and combine them in such a manner that the fuel rate could be left on automatic control during all the permutations and combinations of these factors.

Fuel characteristics and residue quality are the major problem areas. Systems to establish required stoker speeds based on volume-reduction needs or heat requirements can be readily designed as long as the fuel characteristics remain constant. Minute-to-minute evaluations of residue quality are dependent on operator judgement.

Importance of Burning Rate

Btu content would not be such a problem if the burning rate could be increased as the Btu content declined. For example, in an incinerator associated with a waste heat boiler, boiler pressure or steam-flow could be maintained by varying stoker speed. With a fuel such as gas, oil, wood, or coal, the fuel rate can be increased in response to heat requirements. In those cases, the burning rate increases with increased fuel input up to the capacity of the equipment. If Btu content falls off with one of these fuels, the feed rate is increased, resulting in an increase in both burning rate and heat-release rate. More simply put, with conventional fuels, all the fuel put in the combustion chamber burns up at the rate it is being fed. With refuse firing, however, moisture and sizing of a given refuse consist limits the burning rate. If the stoker is being fired so that the refuse-retention time in the furnace is at or near the critical time necessary to dry and burn it properly, an increase in fuel rate will not result in an increase burning rate. Such an increase may result in
a decreased burning rate due to the shorter furnace-retention time. Drying and burning rates are thereby decreased, resulting in decreased heat-release rates. Incinerator systems have been set up to maintain steamflow or pressure by varying fuel input. Unfortunately, when very wet refuse is fired, all of these systems must be put on manual control, or the stoker would go at its maximum speed and put the fire out. Actually, the fuel rate should be decreased to allow more time for drying and proper burning with wet refuse.

Associated with the requirements for reduced fuel rates with high-moisture refuse is a requirement for increased undergrate airflow for drying. In this case, airflow demand should be counter to fuel rate if the fuel rate is decreased. All of these requirements could be built into a control system except that, unfortunately, refuse sometimes is dry and acts like a normal fuel. In that case, the system must act in exactly the opposite way.

In order to make a completely automatic system, some means to measure inferentially Btu and moisture continuously must be devised. At this time, no system exists that can accomplish this measurement reliably over the entire range of refuse consists, sizing, and moisture content.

**MEASUREMENT OF OXYGEN**

Oxygen measurement provides the most readily available check on Btu content. If this measurement is used to trim airflow to maintain constant oxygen, then the relationship between airflow and fuel rate is a direct indication of Btu content.

For example, assume stoker speed in one case is 50 percent and airflow is at 50 percent. In the second case, for the same 50 percent stoker speed, the airflow is only 40 percent with the same oxygen content in the flue gas. Obviously the Btu content of the refuse in the second case is some 20 percent lower than in the first case.

Figure 1 shows two arrangements in which an oxygen controller is used to maintain the proper relationship between fuel and air by maintaining $O_2$ at the value set by the operator.

In the top sketch, a demand is established by the incinerator master. This could be a manually established demand as set by the operator or one from an automatic controller maintaining steam pressure or flow. This demand is fed in parallel to the stoker-speed changer and forced-draft fan-inlet vanes. The oxygen measurement is compared to the designated setpoint in the oxygen controller. The oxygen controller through proportional and reset action changes the stoker demand in the multiplier by changing the gain of the signal from the incinerator master to the stoker-speed drive.

In the lower sketch, the required oxygen content is obtained by changing the demand for airflow in the multiplier, which changes the gain of the signal to the forced-draft fan-inlet vane drive.

In both cases, the relationship between the measured airflow and stoker speed as determined in the divider is a true indication of relative Btu content. Note that in this example we are assuming that the demand signal to the stoker drive is linear with stoker speed. If the linkage and variable speed mechanism is such that this is not true, the actual stoker speed must be used.

The basic difference between the two systems shown in Fig. 1 is that in the upper sketch the demand for refuse is compensated by oxygen to become an actual Btu demand. In the lower sketch, the airflow demand is compensated by oxygen to match the actual Btu input. Which system to use depends on the actual installation.

The location of the oxygen-sampling probes is most critical. Stratification of the gasflows can result in totally misleading sample collection. The ducts should be traversed to assure proper probe locations. Probably a minimum of five probes is necessary to assure a representative sample. There are two basic types of sampling systems, wet and dry. In either case, they require a systematic scheduled maintenance program to assure reliable operation.

Both the catalytic combustion type and the paramagnetic type of analyzers work well when properly calibrated and maintained and when supplied with a clean, dry, representative gas sample from a properly maintained sampling system.

**MOISTURE MEASUREMENT**

The other disadvantage to automatic $O_2$ compensation is that variations in refuse moisture content are ignored. Although higher moisture content requires additional air for drying the refuse, there is no good way of automatically measuring the moisture content of the refuse. The operator can visually observe moisture content, of course, and change the oxygen setpoint to compensate.

Some means to measure moisture content of the refuse continuously during operation is required to assure adequate drying of the refuse.
Perhaps a better way of accomplishing this measurement than operator observation is to design a system to dry the refuse automatically. Figure 2 illustrates such a system. In this system, refuse drying is done by recirculated gas on the drying grate. The temperature of the gas leaving the drying section is controlled to assure proper drying. As moisture content increases, this temperature will decrease. The drying controller compares this value with the setpoint temperature and increases the gas recirculation as necessary to restore the temperature to the setpoint. Since the recirculated gas is low in oxygen content, burning is still confined to the burning grates. In addition, gas recirculation results in lower furnace temperatures, thereby reducing the potential for damage to the masonry lining.

**STEAM FLOW AS AIR INDEX**

Historically, one of the most reliable methods of maintaining proper fuel/air relationships in boiler plants is by relating airflow to measured steamflow. The logic underlying this method is that steamflow represents a good measurement of the amount of Btu absorbed in the boiler and that this is a relatively constant percentage of the amount of Btu fired. The airflow required to burn the refuse properly is directly proportional to the amount of Btu being fired. Hence, a constant steamflow/airflow relationship results in a stable excess air and O\textsubscript{2} content.

When a refuse incinerator is associated with a boiler, the steamflow measurement can be used to trim the airflow demand in the same way as an oxygen measurement with much the same results.

Figure 3 shows two arrangements utilizing a steamflow/airflow ratio controller to compensate for Btu changes. In the upper sketch, the corrective action is applied to the demand for fuel, rendering the master controller output a Btu demand. In the lower sketch, the corrective action is applied to the multiplier in the airflow demand. This approach makes the airflow track Btu input as Btu content of

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**FIG. 2**
the refuse varies. Note the similarity to Fig. 1. These systems will accomplish nearly the same thing for an incinerator associated with a boiler as the systems shown in Fig. 1 for a refractory-lined incinerator.

An additional feature of the systems shown on Fig. 3 is the high selector in the airflow demand. This device selects the higher of the two, steamflow or air demand, as the signal to position the forced-draft fan-inlet vanes. This insures that adequate airflow is maintained to burn the fuel remaining on the grate from the previous firing rate. If the rate of refuse input were decreased, the airflow would otherwise be decreased proportionally even though the grate would remain at the previous level of refuse until it burns down. With this system, however, as long as the refuse continues to burn at the old rate, producing steam, the airflow will not be decreased.

**UNDERGRATE AIR**

The amount of undergrate air required depends on many factors. The air required for combustion is a function of the burning rate; however, other variables such as moisture content also influence this requirement. In the section on combustion controls, these factors were investigated in relation to total airflow required.

A method is required to determine the amount of undergrate air in relationship to secondary or overfire air. Basically, the more refuse on the grate, the more air is required under it.

The system shown in Fig. 4 illustrates a very simple system that positions the undergrate-air damper in proportion to the bed height of the refuse on the stoker. Total airflow is maintained by a combustion-control system similar perhaps to one of those shown in Figs. 1 or 3. The system shown in Fig. 4 therefore changes the relationship between secondary or overfire air and undergrate air. This assumes that the air for the two systems is being supplied by the same fan.

In order to make the system shown on Fig. 4 work, the two pressure drops $\Delta P_1$ and $\Delta P_2$ are gained to appear equal with a clean grate. The divider then indicates unity with a clean grate, and this value (1) is subtracted from the signal in the bias station. At this point, the bed height is zero, and this is the signal level below the bias station. As refuse builds on the grate, the signal level

![Diagram of undergrate air system](image)
below the bias station is proportional to the bed height. The ratio station allows the operator to vary the damper opening relationship to compensate for difference in compacting, moisture, or noncombustibles in the refuse. The damper drive is characterized to provide a somewhat linear relationship between signal level and airflow.

**OVERFIRE AIR**

Overfire air can be divided into two basic categories: (1) secondary air basically for combustion and (2) tempering or cooling air for the control of furnace temperature.

Secondary air must penetrate into the area over the grate in order to mix properly with any gaseous
or particulate fuel for efficient combustion. Proper penetration depends on nozzle design and location and air pressure. There are two ways that adequate air pressure can be accomplished, either by providing separate high head fans for secondary air or by directly controlling the secondary-air plenum chamber pressure.

Figure 5 shows a suggested system to maintain secondary-air plenum pressure for a unit with three elevations of secondary air. As plenum pressure falls off, due to decreased secondary airflow, the dampers close sequentially in order to maintain the proper pressure for penetration. The operator biases each elevation in order to establish the sequence that best suits the combustion requirements. A typical sequence is shown in the sketch at the bottom of Fig. 5. At low secondary airflows, all secondary airflow is through the lower nozzle elevations. As flow increases, the second elevation comes in and, finally, the upper elevation. The operator can change the sequence and/or break points at will by varying the amount of bias at each elevation.

On a unit that does not use a separate fan for secondary air, the secondary-air plenum pressure will vary with the amount of under grate airflow. As under grate airflow increases, plenum pressure decreases, resulting in decreased pressure drop across all the secondary-air nozzles. This reduces the penetration of all of the nozzles. With the system described above, however, only those nozzles on the elevation controlling plenum pressure have a reduced flow and pressure drop. The remaining nozzles have full flow, full pressure drop, and full penetration.

**FURNACE DRAFT**

As with most systems associated with fuel burning, furnace draft controls can range from simple, single-loop arrangements to cascaded types with feed forward from steam- or airflow.

Figure 6 illustrates these two extremes. In the upper system, a measurement of furnace pressure is compared against the setpoint in the controller. The controller positions the induced-draft fan-inlet vanes or changes the fan speed as necessary to maintain the furnace draft at setpoint. In the lower system, the basic control is accomplished by maintaining the induced-draft fan-suction pressure. The setpoint for induced-draft fan-suction is established by the furnace pressure controller, which compares a measurement of furnace pressure with its setpoint. By proportional and reset action, the proper induced-draft fan-suction setpoint pressure is established, which will maintain the proper furnace draft.

The advantage of the more complicated system is that it is very responsive to firing-rate changes while not being overactive in response to a noisy furnace pressure signal. The feed-forward airflow signal provides a rapid initial response to load changes and gives dynamic stability to the entire process/control loop by reducing the integral duty in the induced-draft fan-suction pressure controller.

**TEMPERING AIR AND SUPPLEMENTARY FUEL**

Tempering air, used to prevent excessive furnace temperature, and supplementary fuel, used to start up and stabilize refuse ignition, are both initiated from furnace temperature.

Historically, the tempering air has been an on/off type of system with perhaps two or more air inlets sequenced open or closed as furnace temperatures fluctuated. This type of system puts a severe strain on furnace-draft-control systems due to the rapid flow changes from these dampers opening and closing in response to furnace-temperature fluctuations. Furthermore, such on/off action results in rapidly varying furnace temperatures, which contribute to refractory damage.

Figure 7 illustrates a very simple control system that will regulate tempering air as necessary to maintain the proper furnace temperature during normal operation. In addition, the same system will operate the supplementary-fuel valve and air damper at low loads and startup, to assure adequate, minimum furnace temperatures for igniting and proper combustion. Note that the supplementary-fuel air damper is positioned in proportion to the valve position to insure adequate combustion air at all times that supplementary fuel is being fired.

Measurement of gas temperature for this system is difficult due to the stratification of the gas in the ducts. This makes the location of thermocouples critical to assure measurement of the maximum temperature. The best way to locate the thermocouples is to traverse the ducts. This should be done at several different ratings since stratification patterns tend to change with gasflow. It may be necessary to locate three or more couples to assure a representative measurement.

**SPRAY-CHAMBER CONTROL**

Sprays used to cool the hot gases before they enter the electrostatic-precipitator section have been
mostly off/on, or at best, sequenced through two or more valves. Control of spray-chamber temperature by modulating the spray valves, again in sequence, to increase turndown ratio is relatively simple. The off/on method produces rapid temperature changes and varying moisture content in the flue gases and contributes to unstable furnace-pressure control. Figure 8 illustrates a simple control system that will open the three spray valves in sequence, modulating each as necessary to maintain the spray-chamber temperature at a safe value for the electrostatic precipitator. Practically, the turndown ratio through any given valve is limited by the spray-nozzle characteristics. At low flows across the nozzle, there is inadequate pressure drop to assure proper atomization and dispersion of the moisture in the hot gases. Consequently, the valve sequencing has to be done with overlap and backing off the wider open valve to maintain a smooth spray-flow characteristic.

**BOILER-CONTROL SYSTEMS**

The addition of a boiler to the incinerator requires the addition of controls for the water side of the unit. Combustion, air distribution, and furnace-draft controls must be provided in any event. The gas temperature, tempering air, and spray-chamber-control systems, may be eliminated however. Therefore, control costs for an incinerator with or without a boiler are not significantly different.

The additional controls required with a boiler are feedwater control and some type of boiler-pressure control. Feedwater control is the same as for any industrial boiler. The system shown in Fig. 9, a standard two element system, will be adequate for almost all installations. The steamflow signal provides the basic demand signal for positioning the feedwater valve. The drum-level controller provides the vernier adjustment to maintain drum level at setpoint.
Boiler pressure should be controlled by a back-pressure valve except in cases where the refuse is relatively consistent in Btu and moisture content. Incinerators firing mostly wastepaper, bark, or scrap wood could use a standard combustion-control system, wherein firing rate is modulated to maintain pressure. A detailed discussion of this is made in the discussion of Combustion Control.

Figure 10 illustrates the simple, single-loop back-pressure-control system that will maintain boiler pressure by modulating the back-pressure valve.

**BOARD-MOUNTED-INSTRUMENTATION REQUIREMENTS**

Individual control panels are located adjacent to the incinerators right on the firing aisle. In addition to these operating panels, however, remotely or centrally located monitoring panels are coming into use. The local panels contain all the indicators, recorders, alarms, lights, and switches necessary to operate the individual units. The monitoring panels record and indicate only the most critical values from each of the individual incinerators where a supervisor can monitor the overall operation of the plant. In addition, certain pumps, fans, conveyors, and other equipment common to the entire incinerator plant can be controlled and monitored from this central panel.

On refractory units, the monitoring and recording requirements for the incinerator proper are quite simple. Tempering air and sprays are used along the gas path to protect refractory, ductwork, and dust collectors from excessive temperatures. For this portion, a multiple-point temperature recorder provides a record and indication of trends. This, coupled with position-indicating lights for the various dampers and spray valves, provides adequate information of conditions and a check on the operation of the automatic tempering-air dampers and spray valves. In the event that the tempering air is modulated, rather than just open or closed, a position indicator is required for each damper drive.

Overfire air, when used primarily as secondary-combustion air, should be flow controlled. This is also true of undergrate air. In these cases, these flows should be recorded as operator aids.

The following indications should be provided:

1. Furnace pressure,
2. Tempering-air plenum pressure,
3. Secondary-air plenum pressure,
4. Undergrate-air pressure,
5. Spray-water pressure,
6. Auxiliary-fuel pressure, and
7. Auxiliary-fuel flow.

Of considerable legal importance as well as a valuable operator aid is a smoke-density indicator and recorder. This may be supplemented by or supplemented with an oxygen recorder.

Alarms must be provided to alert the operators to abnormal and dangerous conditions. Specific among these are alarms for abnormally high temperatures in the furnace, spray chamber, dust-collector inlet, and the stack. Low air-plenum chamber pressures and low spray-water pressures should also be alarmed.

On boiler-type incinerators, certain other indications are necessary. Feedwater flow and drum level are frequently recorded; feedwater pressure and steam pressure, indicated; and high and low drum level and low feedwater pressure, alarmed. In addition, softeners, demineralizers, and deaerators associated with the feedwater train must be monitored.

**CONCLUSIONS**

Modern incinerators will require more sophisticated control systems in order to meet stringent performance and operational requirements. Modern process-instrumentation hardware and system-design engineers are ready to meet the challenge. In many cases, existing systems from other industries can adequately handle the requirements for incinerators. In other cases, especially designed new systems must be developed. Each new incinerator project should be carefully analyzed to provide the best-engineered control system for that specific unit. The best system is not necessarily the most automated; rather, it is the one that adequately meets the operational and performance requirements for the best, overall initial and operating cost.