Abstract

The object of this paper is to describe and discuss the various methods currently available for temperature measurement, with particular emphasis on those applicable to incinerators. It will also indicate the various special conditions, commonly found in incinerators, which these instruments must meet. The scope of this paper will be confined to the temperature sensors, their characteristics and application requirements, such as location and protection, which are “peculiar to incinerators”.

How – Temperature Measuring Devices

There are several types of sensors or temperature measuring devices available for use in an incinerator. Temperature sensing elements for application in incinerators fall into two general classifications, the electrical type, and the filled-bulb type. The selection of the element to be used for a specific application is usually influenced by the maximum temperature to be measured, environmental conditions at the measurement location, accuracy, and the desired temperature span. Other considerations which may or may not be important, depending upon application, include cost, speed of response, and linearity of the sensing device.

The first type, under the electrical category of sensors, is the thermocouple. It and its associated forms, such as the thermopile (a number of thermocouples arranged in series to produce a higher output signal than a single thermocouple) is the most widely used and accepted device for measuring temperature in incinerators. The thermocouple develops a dc signal proportional to temperature changes between the junction point of two dissimilar metals and a cold, or reference, junction. This signal is then received, amplified, and used for recording, control, or both. A Chromel-Alumel Thermocouple has an effective range to 2000°F, with the upper limit approximately 2300°F for very short periods of time.

A second type of electrical sensor is the radiation pyrometer. This instrument detects the level of radiant energy emitted from a hot object and, in conjunction with an electrical receiver for the voltage output, converts the radiation measurements into temperature measurements. It has an effective range from 1000°F to 3000°F, but can be used for temperatures as high as 4000°F. This is the only device which could properly measure the actual fire temperature in the primary combustion chamber of an incinerator.

Another general type of electrical sensor is the resistance type temperature detector. This device functions by using the principle that the resistance of a platinum wire varies along a known curve in accordance with the temperature variation. The current output from a resistance temperature detector is used in an electrical circuit in a manner such that a voltage proportional to temperature is produced. The applicable range is from -400°F to 1000°F.

The second general category of temperature measuring devices includes the filled-bulb system. This system consists of a bulb connected through small
diameter capillary tubing to a pressure sensing element such as a bourdon tube, capsule, or bellows. The bourdon tube, because of its small volume, is the most widely used pressure sensing element.

The bulb, capillary tubing, and bourdon tube are filled with a substance which expands or contracts when subjected to a change in temperature. This change is transmitted through the capillary tubing to the bourdon tube to produce a motion in the bourdon tube. The system may be filled with liquid, vapor, gas or mercury.

Filled systems generally offer two types of sensing bulbs: the straight bulb, often used with a protecting well, and a coiled bulb. The coiled bulb is designed to measure the average temperature in a large pipe or duct, and is stretched completely across the duct to eliminate stratification problems. However, unusual conditions of corrosion, erosion, and the deposition of material on the bulb will generally preclude the use of a coiled bulb in incinerators. The various types of filled systems are generally suited for a maximum continuous temperature up to 1200°F.

Quite often it is impossible to immerse the bare thermal bulb directly into the measured media because of high pressure or the corrosive effect of the media on the bulb. The latter is most often a factor in incinerator applications. A protecting well must then be used.

Protecting wells, or sockets, are installed in pipe lines or ducts when required to protect the temperature sensing element. The wells may either be welded or threaded into the pipe. They are available in a number of wall thicknesses and alloy materials, depending upon the severity of the environment which they must withstand. However, the use of a well greatly reduces the speed of response of the system, and should only be used when absolutely necessary.

There are many factors which affect the ability of the sensing element to quickly detect temperature changes. The detection of any temperature change by a sensing device requires some heat transfer, either from the medium to the sensing device, or from the device to the medium. A number of resistances to this heat transfer are always present, and should be analyzed as to their ultimate effect on the performance of the temperature measuring device.

The nature of the medium itself plays a part in the over-all response of the measuring device. Since it is usually easier to transfer heat from a liquid to metal than it is from a gas to metal, we would generally find a slower response from a sensing device in air than from one in water.

As the velocity of the medium passing over the sensing element increases, the heat transfer coefficient rises and the rate with which the heat is transferred increases. This is due to the faster rate at which the flowing medium in direct contact with the element, or protecting well, is removed from the element. This emphasizes the importance of locating any detecting element properly, avoiding stagnant areas, so that the increased speed of response, brought about by increased velocity, can be fully used to indicate a more truly representative temperature.

Since the majority of sensing elements must be inserted in a protecting well, this additional mass and thickness of metal must be considered in the over-all response factor. As the wall thickness of the well increases, the response time also increases.

Finally, the internal time constant, involving the time to transfer the heat from the protecting well metal to the sensing element itself, will affect the over-all response factor. The small mass of electric detecting units gives them some advantage over the more massive requirements of the filled bulb systems. Proper transmission of the heat is essential in both cases, and every effort should be made to insure sufficient metal to metal contact.

What - The Incineration Process

A brief description of the conditions existing in an incinerator, tracing the gas passage from the primary combustion chamber to the stack, will be presented prior to describing the application of these instruments.

Inside the primary combustion chamber of the incinerator, the actual fire temperature is approximately 2400°F. The combustion chamber exit temperature is between 1800°F and 2000°F. Normally, this temperature is the one used as the master indication for furnace operation. If care is not exercised in the mixing of refuse in the pits, this temperature can become as high as 2200 or 2300°F in a very short time, due to the ignition of a charge of high Btu refuse. A load of sawdust in a charge, for example, could increase the normal operating temperature of 1800°F to over 2000°F in approximately 15 seconds. This effect is similar to lighting off an oil burner from hot refractory. While this temperature fluctuation may be most prevalent in batch feed furnaces, it also exists in continuous feed furnaces.

The expression “Furnace Temperature” is commonly used by operators and others to mean combustion chamber exit temperature. The actual flame temperature is very seldom measured. It is evident that when using the phrase “Furnace Temperature”, one should always state where the measurement was taken. Otherwise, the phrase is not definite.

After leaving the combustion chamber, the gases enter the secondary flues. These are the flues entering
the waste heat boiler, if one is provided, or the spray and fly ash removal facilities. In this area, the temperature ranges from 1400 to 1800 F. If a waste heat boiler is provided, the temperature in the flue between the boiler and the fly ash removal facilities ranges from 500 to 700 F.

The gases leaving the fly ash removal facilities enter the chimney flue and are discharged out the stack. The temperature expected in this area is usually less than 1000 F, depending on the equipment upstream from the point of measurement.

The environment existing in the gas passage of an incinerator is a very important consideration when choosing the temperature sensing element to be used. The environment at the combustion chamber exit contains many substances which tend to contaminate the sensing element. Among these are slag, which is primarily a glass containing major amounts of silica and alumina, with amounts of iron oxide, manganese oxide, lime and titaania also present. Slag tends to build up on the protecting wells, mechanically gripping them. When the temperature changes, differential expansion will break these wells. Other problems existing at this point include the abrasive action of fly ash, and the corrosive and contaminating action of gases containing metal vapor and other substances produced in the furnace.

The environment in the secondary flues is very likely to contain slag, while contaminating gases and vapors, as well as fly ash, may also be present. The fly ash at this point is most abrasive, since it has cooled somewhat and hardened.

After the waste heat boiler and fly ash separators, or the spray and fly ash removal facilities, a stucco-like gray coating may exist. This coating may be deposited on the Induced Draft Fan, the stack, and over any openings. It is very difficult to remove and in some incinerators, a periodic lye bath is used, in order to prevent excessive build-up. Slag generally does not present a problem at this point. Fly ash abrasion, in proportion to the fly ash not removed by the fly ash removal facilities, still exists. However, since the velocities and concentrations are usually much lower than those previously encountered, abrasion from fly ash is not considered a problem at this point in the gas passage.

Where – Application to Incinerators

The application of the various temperature measuring devices described above to an incinerator plant requires that consideration be given to the environment of the area where the measurement is to be made, the proper location of the sensor, and the use to be made of the measurement.

First, we will consider the actual fire, or flame, temperature. As stated previously, the temperature range of the actual fire is of the order of 2400 F, which is above the practical limit of a Chromel-Alumel Thermocouple. The radiation pyrometer is the only practical measuring device with which to properly obtain this temperature. The sighting tube of the pyrometer might best be located in the crown, or roof, of the furnace, sighting down on the fire. These devices generally are provided with an air purge to aid in cooling. The air purge keeps the sighting tube clear, and relatively cool, but does not affect the temperature reading, since the pyrometer responds to the level of radiant energy emitted by the hot target object. The location in the furnace crown is recommended to minimize slagging and its effect upon the reading, and this location may also provide the clearest sighting path to the flame. Experience to date has shown that the greatest problem with the crown installation is one of wear, or erosion, due to the abrasive action of fly ash caught up in the furnace gas turbulence. The temperature of the actual fire is seldom measured, however, due to the relatively high cost of the sensing system required. As the relation between flame temperature and refractory life and proper combustion becomes better understood, the radiation pyrometer, and the flame temperature measurement may become part of the instrumentation in new plants.

The next area to be considered is the primary combustion chamber. The primary combustion chamber temperature is approximately 1800 F, and, in fact, incinerator control systems are generally based upon controlling this temperature at a relatively constant 1800 F. A Chromel-Alumel Thermocouple can be considered for this measuring sensor, as it has an effective range between 100 F and 2000 F, with an upper limit of approximately 2300 F for short periods of time.

When considering the use of a thermocouple to measure primary combustion chamber temperature, the existing environmental conditions play a major role. The Chromel-Alumel Thermocouple is attacked and contaminated by the gases present in the combustion chamber. Therefore, a protecting well is required. Protecting wells presently available, constructed of stainless steel, or other adequate alloy, all will resist the gases, but are subject to corrosion from slag. Hence, a protecting tube, or sheath, is required over the protecting well. The Silicon-Carbide protecting tube is recommended as the best available at the present time. This tube will resist slag and fly ash, but is porous to gases. Therefore, to effectively withstand the various conditions existing at this location, the best protection would be afforded by a Silicon-carbide-
eventually, the Chromel-Alumel thermocouple will disintegrate from oxidation. The Chromel wire will disintegrate first, followed closely by failure of the Alumel wire. A swaged, magnesia packed, sheathed thermocouple is generally recommended to protect the thermocouple from oxidation and extend its service life. A 14-gage thermocouple in a 3/8-in. diameter, 1/32-in. wall stainless steel protecting well has recently been introduced in incinerators to take the place of the widely used bare 8-gage wire couple. It is the heaviest thermocouple presently available, and is expected to extend the service life period over the bare 8-gage type. To minimize the effects of chunks of slag breaking off and dropping on the thermocouple, a vertical installation in the furnace roof, or crown, is the recommended location.

It is recognized that stratification is a major problem in the location of a temperature sensor. The optimum solution is to take a temperature traverse, under various load conditions, to determine a correct, representative location. The installation of the temperature transmitting device may be made, but the location of the thermocouple should be withheld until a traverse is made. This is expensive, but may be justified in large plants where refractory maintenance, due to improper temperature control resulting from an incorrect sensor location, may run into many thousands of dollars.

If the above recommendation cannot be economically justified, an alternate would be the installing of the thermocouple, with provision being made for various openings. A traverse should be made later through the openings provided, with the calibration of the instrument set up to reflect the average temperature conditions, as determined by this traverse.

The next area to be considered is the combustion chamber outlet, or secondary flues. The temperature ranges from 1400°F to 1800°F in this area, and a Chromel-Alumel thermocouple is again recommended, since this expected temperature is above the upper operating limits of either resistance temperature detectors or filled systems. Basically the same environmental conditions encountered in the primary combustion chamber will be found here, and it is again recommended that the thermocouple be installed vertically through the crown. Since slag is still likely in this area, and since fly ash is most abrasive at this point, having cooled and hardened, a Silicon-Carbide protecting tube and alloy protecting well are also recommended.

The final areas under consideration are the flues between the waste heat boiler and the fly ash removal facilities, the chimney flue and the stack. In these areas, since the maximum temperature expected is 1000°F, a resistance temperature detector or a filled system is recommended. A thermocouple could also be used in these areas. From the point of view of obtaining the correct average temperature in the duct, a coiled-bulb filled system is best. However, serious questions concerning corrosion, erosion and deposition of matter on the bulb have been raised by designers and plant personnel. Recalling that a stucco-like gray coating, tending to coat all exposed areas and openings, exist at this point, it is expected that this build-up would cause a gradual lagging of the bulb, with correspondingly lower readings. It would, however, be easier to remove this coating from a protecting well, during periodic maintenance, than it would be from a coiled bulb stretched completely across the duct.

The resistance temperature detector would offer greater accuracy over the thermocouple at a higher cost. If this measurement were to be used in a control system to provide low temperatures to protect the Induced Draft Fan, this detector could be economically justified. If the measurement is only of secondary interest, a thermocouple would suffice.

A stainless steel or alloy protecting well is sufficient to protect the detector, thermocouple, or filled system bulb to provide satisfactory service for a year or longer. The sensor could be installed vertically or in a convenient side location in the gas stream. Here, too, several temperature traverses may be required to obtain a representative location in the gas stream.

Aside from the physical factors, such as temperature range desired, gases, slag, etc. which affect the sensor and its protection device, we must consider the operation and maintenance capabilities of each incinerator. Which personnel in the plant will be responsible for maintaining the instrumentation equipment? In many cases, the instrumentation maintenance capabilities of a plant consist merely of the replacement of a thermocouple and protecting well, quickly and simply done by means of a quick disconnect polarized plug and receptacle. Because of this lack of properly trained maintenance men, particularly in the smaller and medium sized plants, a simple, rugged system, while not as accurate and informative, may be preferred over more complex, and therefore more delicate, instrumentation. However, as greater automatic control of the incinerator process is desired, as the "state of the art" improves, more complex systems will be needed. This will necessitate better trained personnel, and an effective, conscientiously applied program of preventative maintenance.
Conclusion

An attempt has been made in this paper to suggest the proper type of instrumentation and the best location for the various temperature measurements to be taken in the incinerator system. We have seen that the range desired and the physical effects of slag, gases, etc. must be considered when selecting types and locations of the various available sensors. Another important factor which should also be considered is the capability of the personnel of the particular incinerator to maintain the equipment.