High Temperature Heat Transfer Equipment[1]

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Abstract

Various alternative methods of high temperature heat transfer in the range of 300 to 750 F, such as direct firing, forced circulation of heat transfer fluids such as water, oil, Therminol, Dowtherm and other fluids are outlined. Advantages and disadvantages of each are discussed. Important considerations include design of heaters, temperature uniformity, heat transfer rates, safety precautions, hardware required, control sequences, fluid degradation and velocities.

Introduction

Selecting a high temperature heater is different from selecting a steamboiler. In the case of a steamboiler, it is simply a matter of determining how many pounds of steam are needed per hour and the steam pressure needed. A typical job for which steam is needed requires 2 million BTUs at 300 F. Dividing 2 million BTUs by 33,479 BTUs per horsepower indicates 60 HP is required. Steam at 100 lb. pressure gives 338 F, which should be enough for the 300 degree job.

Suppose the job for which heat is needed requires 2 million BTUs at 600 F. More or less standard heaters which will deliver 2 million BTUs at 600 F are available but the high temperature heater really must be matched carefully to the job to be done. The best heater in the world can be a dismal failure it it is not matched to the job.

Discussion

Two broad types of heaters are on the market: liquid phase and vapor phase. Discussion of why one is better than the other can be left to the manufacturers of the various mediums themselves. Sometimes the application itself dictates this.

Liquid Phase Units

The liquid tube units can be of either natural circulation or forced circulation types. When a liquid system is used, it consists of the heater itself, the heat user, a pump to circulate the heating medium through the heater and heat user, a control valve, an expansion tank and the connecting piping. The liquid leaves the heater and goes into the heat user at a given temperature and leaves the heat user at a given temperature. If the heating medium enters the user at, e.g., 600 F and leaves at 550 F, it has given up 50 degrees to the product. If the specific heat of the heating medium is, e.g., 0.33 or ⅓ that of water, each pound that is circulated gives up 16⅔ BTUs to the product. Dividing that into the total BTUs required will give the number of pounds of heating medium that needs to be pumped per hour through the system. There are forced circulation liquid tube heaters available in capacities of 500,000 BTUs per hour and up. There are such units in use with outputs as high as 400,000,000 BTUs/hr. Some are of the helical coil type, others are of the serpentine type. All are available in vertical or horizontal designs. They are of one pass or two pass design. Temperatures range up to 1000 F. They are equipped with gas or oil or combination and oil burners.

Vapor Phase Units

For vapor phase heating both fire tube and liquid tube units are available. Here again, both vertical and horizontal units can be had. The firetube units are made for capacities of 60,000 BTUs/hr up to 10,000,000 BTU/hr and temperatures up to 700 F. When a vapor system is used a heating medium such as Dowtherm, Ucon or Paracyme, etc., which has a definite boiling point at a given pressure is used. The system then consists of the heater itself (but now it is called a Vaporizer), and the heat user, connecting piping and controls, or pump if required.

As the heating medium is heated, vapor is generated, just as steam is generated when water is the medium. This vapor, like steam, contains the latent heat of evaporation; as the vapor is condensed, as its heat is transferred to the product being heated, it gives up this heat and the resulting condensate either drains back to the heater or vaporizer by gravity or is pumped back. This vapor is piped to the heat using equipment.

Before getting into specific details and to provide a little background for what follows, we may ask what the most important thing about a high temperature installation is.

The one most important point in the whole process of selecting and designing a heater is the maximum temperature to which the heating medium will be subjected. A word of caution is due. This does not refer to the bulk temperature or the outlet temperature. The temperature of the heating medium right next to the heating surface commonly known as film temperature, which is always higher than the bulk temperature or the outlet temperature, is the concern. A heating medium manufacturer sets a maximum temperature to which he wants his fluids subjected, and that is what the rest of this exercise will be devoted to.

Assume that it is decided to use a liquid phase system, and that the size of the unit needed (BTU output), the temperatures, and the fuel or fuels to be used are known.

Some heating mediums can be used in almost any type of heater; others require a specific design for optimum results. Some heating mediums are usable in the liquid phase only and some are usable in both vapor and liquid phases. Generalizations are dangerous but, in general, those mediums which are usable in the liquid phase only require units of the liquid tube type and those mediums which are good for both liquid and vapor phase can be used in firetube or liquid tube design units.

No heating medium is indestructible and no heater is indestructible, but properly engineered they can be considered indestructible from a practical standpoint. A heater must be matched to the process.

The best way to come to grips with this entire topic is to explain the designing of a liquid phase heater. Determine how many BTUs are needed, the outlet temperature of the heating medium, and the desired difference between the temperature of the heating medium entering the heat user or users and the temperature of the heating medium leaving the heat user or users. Then multiply this temperature difference by the specific heat of the particular heating medium being used. This gives the BTUs each pound of heating medium that will transfer to the process. Divide that into the output of the heater. This gives the quantity in pounds of heating medium that must be circulated throughout the heater per hour.

Make a preliminary selection of a heater which is believed to be in a range which might be usable, and from the above figures calculate the velocity in which the above flow rate would result in the heater selected. If this is between 4 and 10 ft/sec continue, if not, pick a different heater to get one which will give the desired velocity range. From this velocity, determine the amount of heat transfer from 1 ft^2 of surface in the heater per degree difference per hour to the flowing heat transfer fluid. This figure multiplied by the total square feet of transfer surface in the particular heater gives the BTUs which can be transferred per degree temperature difference between the tube metal temperature and the temperature of the fluid. This figure divided into the output of the heater gives the average temperature difference required to transfer the total amount of the BTUs involved.

This figure in turn is added to the outlet temperature, which is a start toward the figure looked for—the all-important film temperature. If it is more than the heating medium the manufacturer says is safe, the operation should be started all over again, another heater should be selected,

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and the same process should be repeated. This gives a beginning toward computing the film temperature, which is the average temperature. The maximum film temperature occurs in an area of the radiant section of the heater; it involves lengthy and complicated calculations (1).

The most serious thing that can go wrong on a high temperature unit which is not properly designed is degradation of the heating medium itself. If the film temperature is too high in any part of the system the fluid tends to polymerize or carbonize. Some fluids are flammable and can break down into carbon, causing a vicious cycle of local overheating, eventual leaking of fluid into the combustion area, resulting in uncontrolled burning of the heat transfer fluid itself. Some fluids are nonflammable, but here polymerization causes thickening of the fluid reducing the pumping rate leading to excessive tube wall temperatures and resulting in possible collapse of the tubes.

On controls, the general practice is to use a two-way electric or pneumatic valve in the liquid line with a relief valve in a bypass line, or a three-way valve to shunt the flowing heating medium back to the heater. It is mandatory that full circulation of the heating medium go through the heater when it is in use whether the process is taking heat or not. If the flow of heating medium through the heater is cut off, or reduced, the film temperature may go up leading to difficulties mentioned above.

The higher the outlet temperature the more important the circulation rate becomes. The reason for this is obvious. If the maximum film temperature the heating medium manufacturer has set is 640 F, and the heater outlet is 600 F, the heating medium must flow at a rate fast enough to keep the tube metal below 640 F and there is only a 40 degree allowable differential with which to work. If the outlet temperature is 400 F, there is a 240 degree differential with which to work. Obviously a lower flow rate will keep the tube wall temperatures below the prescribed 640 F maximum.

It is extremely important to insure full flow through the heater at all times. Flow controls should be used to instantly and automatically cut off the fuel if the flow should drop to a certain point. If there is power failure, or pump motor failure, the circulating pump would stop, stagnating the liquid, and the fuel would be instantly cut off. The design should be such that there is no refractory in the radiant zone and the insulation in the convection zone is a lightweight refractory which has very little heat stored up and its temperature is low.

Tests have been made to determine the amount of temperature build-up which occurs at failure of circulation and cut-off of fuel. These tests were made on units which had been running at full load for a long period of time so that the entire unit was at maximum heat. There was no measurable build-up in liquid film temperature although thermocouples were placed in many spots in the heater.

These high temperature mediums are excellent tools and enable faster production and better quality of products. With properly designed and operated systems there is no fear of the dire picture which may seem to have been painted.

The chief objection to direct flame on a heat sensitive product is the extreme hazard of disastrous fires caused by decomposition of the product into carbon which can cause carburizing or embrittlement of the product vessel and dump flammables into the hot combustion chamber. Another objection is that the product itself can be locally overheated and scorched reducing its quality or rendering it completely unsalable. Or, at best, it is practically impossible to process two batches alike, sacrificing uniformity of product. Another disadvantage is the inefficiency of direct fired applications. When indirect heat transfer is used, all of these objections are nonexistent—the fire hazard is eliminated in the processing area. If necessary, the heat source (Therminol or Dowtherm or hot oil) can be located some distance away from the processing area, piping the hot liquid to the process vessels. There was a case where direct firing was used on a large process involving vegetable oils and there were frequent small fires in the production area. One day one of these small fires completely destroyed the plant. When the plant was rebuilt, indirect high temperature units were installed outside and the hot liquid was piped in. That was 15 years ago; since then there have been no fires and the company is producing more goods of uniform quality at lower fuel cost.

The heat transfer from indirect heat transfer mediums to products per degree temperature difference is greater than from fire to product; this is perhaps the single most important reason for indirect heat transfer systems. It means that production is faster and products are not overheated. Actually, it is possible to transfer more heat per degree temperature difference with indirect heat transfer fluids than with an atomic or hydrogen bomb. It is preferable to use vapor to liquid phase, but there are many applications which either cannot be done with vapor, or which would involve rather complex equipment, and in such cases the liquid phase is preferable. Liquid phase is more flexible than vapor phase, particularly as far as temperatures are concerned. Liquid is good for the entire range from melting point to maximum. Vapor, at the lower temperatures, would be under such a high vacuum as to render it unusable.

A big advantage of most liquid phase mediums is that they operate at high temperatures with no pressure, which is not true of vapor phase mediums. Thus schedule 40 piping and 150 pound valving is acceptable on such mediums while mediums at higher pressures may require schedule 80 piping and 300 pound valving. Another advantage of some liquid phase mediums is that they are not flammable.

Indirect high temperature mediums are in wide use. Typical applications are vegetable oil and animal fat deodorizing, varnish making, asphalt melting, oil treating, gas dehydrating, deep fat frying and the myriad processes which America's fantastic chemical industries have spawned.

A suggestion that may be beneficial to all concerned is that after selecting a particular manufacturer's heater, a customer may feel inclined to ask the manufacturer to change this or that detail, such as the make of control, burner, blower, etc. The heater manufacturer has no doubt standardized on particular appurtenances for good and sufficient reasons. He must have determined that these result in the best integrated operating unit. If he is asked to use Brand X instead of his established standard, the customer gets a more or less mongrel piece of equipment with which no one is completely familiar, and the operating instructions have to be special.

Servicing of the unit becomes a little more difficult. Delivery takes longer. Spare parts are harder to get. And, worst of all, the cost goes up. The standard components are purchased in volume at lower cost than would be the case with one at a time purchases, and even if the cost of the items themselves were the same, the control sequence and wiring and piping would have to be reengineered, which is time-consuming and costly. Any time a customer departs from the standard, the cost goes up.

It is appreciated that a customer may have other equipment in his plant with Brand X controls, and would like to have Brand X controls on the heater. However, there may be some good reasons why Brand X will not do as good a job as the one the manufacturer uses as standard. And if the customer insists that the manufacturer use Brand X and the combination is unsatisfactory, a serviceman may give the customer some trouble because he did not get the standard equipment.

It is understandable that a customer might still want Brand X controls because he has other Brand X controls in his plant; no manufacturer will refuse to make substitutions, but it must be appreciated that such substitutions make an otherwise standard basic unit somewhat special, requiring special operating instructions, special handling, etc., all of which increases cost.

To some extent it is like asking General Motors to quote on a Cadillac with a Continental engine and a Chrysler transmission.

REFERENCES

1. Loso, W. E., and J. E. Evans, Trans. Amer. Inst. Chem. Eng. 35:743 (1939).

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