DETERMINE PROPER SHEATH MATERIAL

Information is located in each product section throughout the catalog in regards to the sheath materials available. In surface or air heating, operating at high temperatures can cause oxidation and scaling of the sheath. This impedes the transfer of heat from the element, resulting in over-heating and failure. It is always safe to specify Incoloy in these situations. The additional cost of the element will be recovered by providing longer service. In the direct heating of liquids and gasses, corrosion will be an important consideration in the selection of an immersion heater. An extensive Corrosion Resistance of Sheath Materials guideline (24T) is provided later in this section. Besides the information there, note the following:

- The effects of the solution concentration.
- As heat is a catalyst in a chemical reaction, lowering the watt density and in effect the sheath temperature will prolong the life of the element(s).
- Mineral deposits contained in a water supply can build-up on the elements, reducing the transfer of heat. Sheath temperatures can elevate to the point of failure. Stainless Steel or Incoloy sheath material will not attract the deposits as copper will and can operate at higher element temperatures should the build-up occur. This provides longer heater life.

In essence, the sheath material selected must be compatible with the process environment and the heat requirement.

Depending upon the design, many heaters have the potential to produce sheath temperatures exceeding 1400°F. This is where the heat transfer path from the element to the material becomes so important. The more efficient the heat transfer, the less the temperature difference between the heater and the process. The medium plays a key role in the design of a thermal system, as seen in more detail later. Calculating the wattage requirement, the selection of the watt density, sheath material and the heater type are integral in the decision as to how to apply the heat to a process. **OGDEN** has been instrumental in providing information and assisting in the design of thousands of process heat and control applications. If the information for a particular application is not included here, contact **OGDEN**. With over 50 years of expeience on file, **OGDEN** may already have solved the problem.

THERMAL SYSTEM DESIGN

In industrial processes, temperature is often the most important variable to control. Temperature variations cause changes in the chemical or physical state of most substances, resulting in changes in flow, viscosity, pressure, level or humidity. An arrangement of components designed to supply controlled heat is a Thermal System. The most sensitive control will not provide acceptable results if careful consideration is not given to the entire system design. As technology has focused increasingly on the application of electronics, control systems can be required to collect and retrieve data and communicate with computers or other controls. Even as industry moves toward the completely automated factory, process temperature control utilizes the same principles and theories whether accomplished by microprocessor or mechanically actuated thermostat.

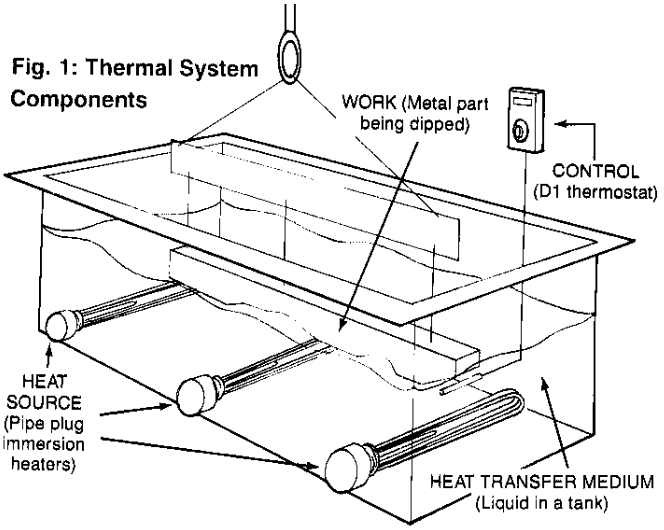
THERMAL SYSTEM COMPONENTS

The four elements comprising a thermal system are:

1.) The work or load.
2.) The heat source.
3.) The heat transfer medium.
4.) The control system.

1.) The work is the material or product being processed. The heat demand may be steady, meaning that the material must be maintained at a constant temperature for a specified period of time. A bacteria culture in an incubating oven is an example of a steady system.

Fig. 1: Thermal System Components



Often the heat demand is variable and cyclic. In this dynamic system, cold material enters the system for processing, absorbs heat, is removed, then replaced in the system by more cold material. An example of a variable or dynamic system is plastic injection molding equipment. The mold receives plastic material, heats, forms, cures then ejects the finished part. The process is repeated again and again.

2.) The heat source is the device that provides heat to the system. The source may be electric heaters, oil or gas fired systems, steam, or the process may be exothermic in that the system generates its own heat.

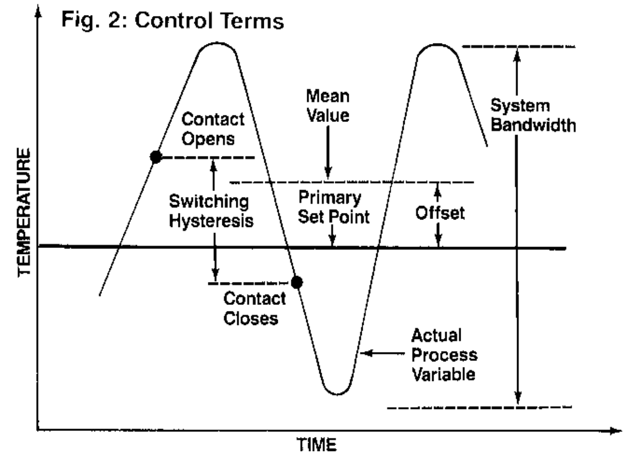
3.) The heat transfer medium is a solid, liquid or gas which transmits the heat generated from the heat source to the work. The transfer characteristics or conductivity of the material are significant in determining how fast temperature changes travel through the system, and thus, how close the system can be controlled.

4.) The control system includes the instrument that directs whether heat is on or off, depending on the difference between the desired temperature or control set point and the actual temperature.

FACTORS AFFECTING SYSTEM ACCURACY

A product within acceptable quality tolerances with lowest possible scrap levels are the ultimate measures of system accuracy. Generally, a constant mean temperature and the system bandwidth determine accuracy. The system bandwidth is the temperature variance measured at the work *(Fig. 2)*. Several factors affect the accuracy of the system.

Fig. 2: Control Terms



Thermal Lag is the time delay for a temperature change in one part of the system to be recognized in another part of the system. As power is applied to the heat source, a temperature rise will occur in the transfer medium in the area of the heat source, and then flow to other parts of the system. The Temperature Gradient is the range of temperatures at different locations in the system measured at the same time. Both thermal lag and temperature gradients are influenced by the conductivity of the transfer medium. Conductivity is the measure of the rate at which heat travels through a medium. See Chart 11T.

Cost considerations, thermal properties, availability and the application determine what material is most practical for use as a heat transfer medium.

The application will also determine what method of heat transfer is most practical. Conduction takes place in solids, liquids and gases, and is the transfer of heat from one material, at a given temperature, to another material at a lower temperature while in direct contact with each other.

Natural convection occurs in a liquid or a gas when heat is generated from the source causing the surrounding mass to become warm and expand. The mass decreases in density (becomes lighter), mixes with and warms the cooler mass. Forced convection can be produced by mechanically mixing the warm with the cool mass.

The transfer of heat from one body to another by emitting and absorbing radiant energy is the third method of heat transfer. No transfer medium is required, for an electromagnetic wave phenomena similar to light carries energy from a radiant heat source, passes some distance through the surrounding space to the work. The work absorbs the radiant energy and converts it to molecular-vibration heat energy. An oven utilizing tubular heaters may receive heat by all three methods. See section on Process Infrared Heating, pages 244-247. The following heat transfer medium comparison list is in order of descending preference:

Well agitated liquids
Rapidly moving gases
High conductivity metals
Low conductivity metals
Stagnant gas
Stagnant liquid

Temperature gradients can be observed by measuring the temperature at different points in the thermal system at the same time. Starting at the heat source, the temperature would decrease progressively as you move to the edge. Every thermal system has a gradient at all times because of heat source cycling and heat losses. These changes are not transmitted or compensated for immediately throughout the system. Some gradient is necessary for heat flow, since heat can only be conducted, convected or radiated to areas lower in temperature.

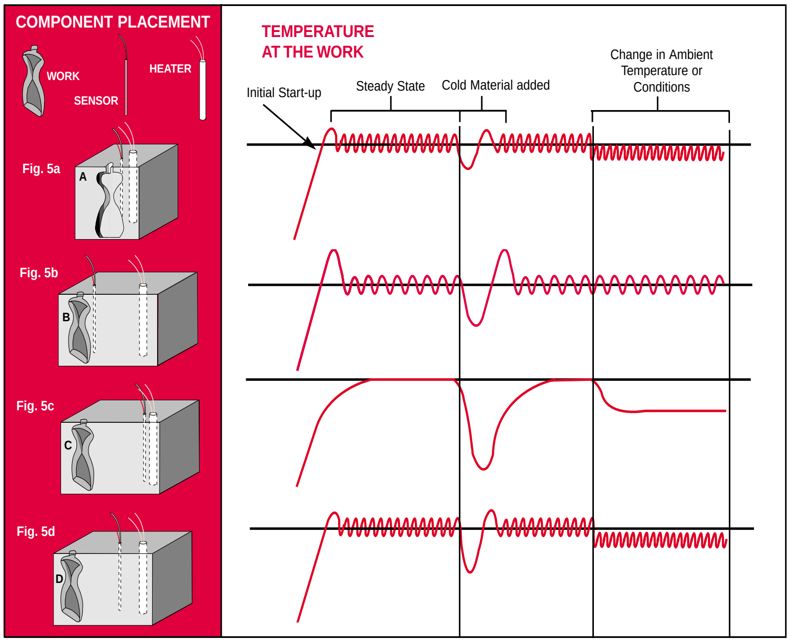
Also inevitable in every system is the delay in the distribution of heat. Thermal Lag is influenced by the distance between the heat source and the work and the heat conduction capacity of the transfer medium. Thermal Lag delays information about temperature changes in the system to the control. This delay can prevent the control from sensing a need for heat soon enough, resulting in temperature undershoot. Thermal Lag can also delay the arrival of heat at the work long enough to where the heat source has produced more than what is required, producing temperature overshoot. Both overshoot and undershoot can create too large a system bandwidth, and unsatisfactory control.

Temperature gradients and thermal lag exist and are necessary to an extent as stated, but can be reduced for more accurate control. Applying as much insulation as practical to reduce heat losses from the system is the first step.

The location of the heat source and control sensor relative to the work can produce a wide range of accuracies. It is ideal to group these components in a compact area. The short distance from the heat source and control sensor to the work would enable heat requirements to be detected and responded to quickly producing the ultimate system bandwidth and a constant mean temperature *(Fig. 5a)*. As this placement is often not practical due to the size of a system, a compromise in the placement of the component is necessary.

Maintaining a narrow bandwidth may be important in processes which are being heated close to decomposition, vaporization or other critical points. A narrow bandwidth does not guarantee perfect control, however, since the mean temperature can drift (offset or droop) *(Fig. 2)*.

Where the heat demand is variable, the best results can be achieved by placing the control sensor closer to the work. The difference between the heat source and the control sensor is significant, causing thermal lag and sizable temper-



ature overshoot at the work. The control selected should have compensating features (PID) for this situation *(Fig. 5b)*.

Where the heat demand is steady, the sensor should be placed closer to the heat source. The short distance between the heat source and control sensor will allow minimal thermal lag and reduced potential for temperature overshoot and undershoot. Temperature changes are quickly detected *(Fig. 5c)*.

When a system is both steady and variable, placing the sensor mid-way between the heat source and the work will reduce thermal lag. Some overshoot and undershoot will occur. For this arrangement, the control should also have compensating features (PID) *(Fig. 5d)*.

Matching the wattage requirement of the system with the capacity of the heat source will also help to achieve the best possible temperature control *(Fig. 6)*. When the desired operating temperature (set point) is reached, the heat source should be on 50% of the time. Heat loss from the thermal system, voltage fluctuations, changes in ambient temperatures, and other process upsets can also affect heat balance. Allowances need to be made for these factors when determining wattage requirements and the heat source.

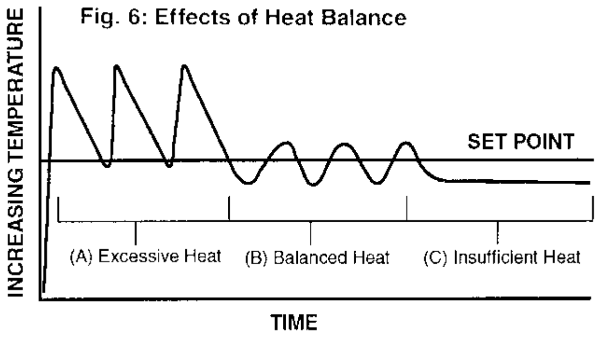
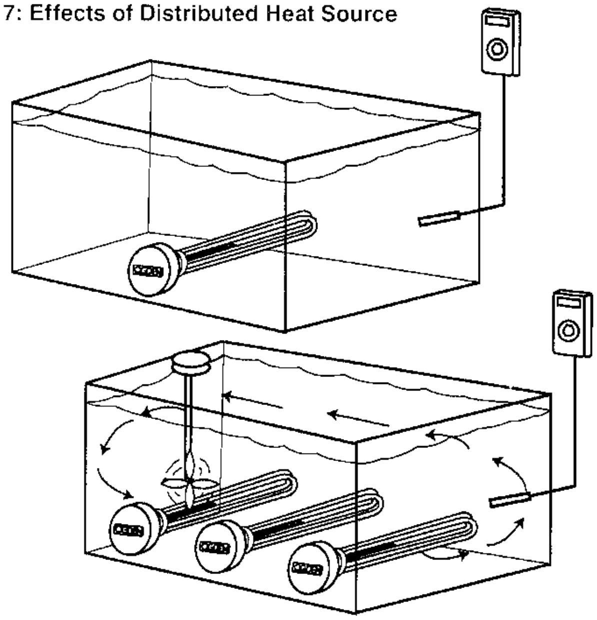


Fig. 6: Effects of Heat Balance

In general, if after system start-up the heat source is on more than 60% of the time, the wattage rating should be increased. If the heat source is on less than 40% of the time, the rating should be decreased. Heat conductivity is most efficient when good contact exists between the heat source and the material being heated. Rather than one large heater, several smaller rated heaters to better distribute heat throughout the system will further reduce temperature gradients *(Fig. 7)*.

Fig. 7: Effects of Distributed Heat Source



SELECTION OF TEMPERATURE CONTROL

The temperature control may be the first suspect if a system fails to perform to expectations. As can be seen, there are many factors to be considered in designing an accurately controlled thermal system. However, the control does have an exceptional responsibility in maintaining system accuracy and can compensate for inefficiencies and errors in other parts of the system.

Certain applications such as radiant heating can maintain adequate control with manual adjustments. An Open Loop temperature control system requires continual process monitoring by an operator.

An autotransformer or variac adjusts the voltage input from 0–100% to the heat source.

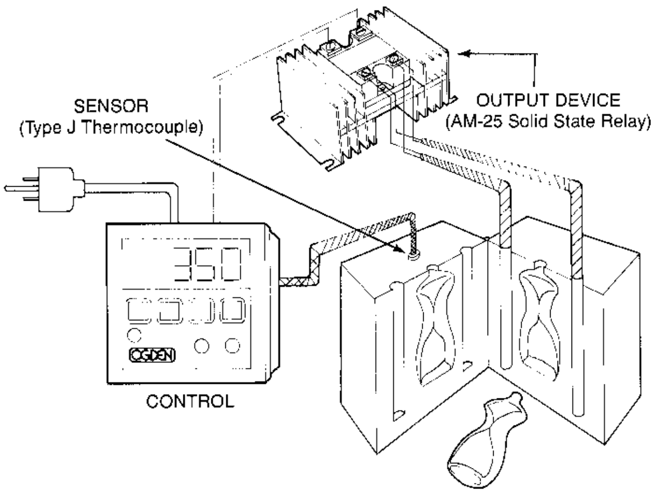
An infinite control or simmerstat provides a range of control from off to full heat by switching at short, definite time intervals.

Timers control direct current to the heat source based upon intervals of time.

A trial and error method, most process control requirements are too sophisticated for Open Loop systems.

A Closed Loop Control System utilizes a feedback sensor to automatically monitor the process temperature. The control interprets the signal from the sensor then directs the output device to switch power on or off to the heat source. The output device is either an electro mechanical relay, mercury displacement relay, solid state relay (SSR) or silicone controlled rectifier (SCR). The sensor in an electronic control system is a thermocouple, RTD or thermistor. See each catalog section for complete description.

Fig. 8: Closed Loop Control System



Control accuracy in the following discussion will refer to the control's capabilities, not including factors existing in the rest of the thermal system.

Resolution sensitivity is one measure of control accuracy. Expressed as a percentage of the controls temperature range, resolution sensitivity is the amount of temperature change that must occur before the control reacts.

Speed of response is the time needed for a temperature change occurring at the sensor to be translated into control action.

Indication and set point accuracy are expressed in degrees or percent of temperature range. Indication accuracy is the possible amount of error between the temperature displayed and the actual temperature. Set point accuracy is the possi-