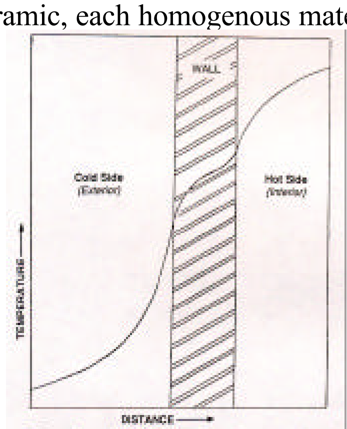
NANMAC NOTES

SUBJECT: TEMPERATURE GRADIENTS AND SENSORS

In order to design temperature sensors accurately one must have a basic knowledge of the temperature profile both within the wall and the adjacent gas or liquid. One must also be aware of the factors that influence this profile. The temperature sensor must measure the desired temperature without disturbing this temperature by its very existence. The sensor must also have sufficiently fast response time to follow temperature changes accurately.

Let us examine the case of a hot gas or liquid on one side of a wall and ambient temperature on the other side at the wall. The wall can be that of a chamber such as a furnace or a pipe through which a hot gas or liquid is flowing. At a given instant of time, the temperature profile within the wall will be as follows:

The schematic above illustrates the case wherein the wall is made of one homogenous material such as steel or ceramic. In the case where the wall contains several materials; ie steel, insulation, plus graphite or ceramic, each homogenous material will have its own temperature profile across it.



There are several observations one can make from this graph:

Heat is always flowing from the hotter medium to the cooler medium.

(2) Heat energy is continuously being absorbed by the wall at its hot side and liberated at the cold side to the cooling medium (ie air, water, etc.) Under steady state conditions the heat absorbed must be equal to the heat liberated or the wall will begin to melt.

(3) The temperature profile at each interface approaches exponential conditions.

(4) There is no region where temperature is constant over a given cross-section. Constant temperature zones are called isotherms. Isotherms appear at right angles or normal to the plane of heat flow.

In theory one molecule of the wall adjacent to the hot gas is at the same temperature of an adjacent molecule of gas. In practice this may not be the case. Adjacent to the hot wall there is a laminar layer of gases which tend to inhibit the heat flow and acts as an insulator. Imagine that this laminar layer is a layer of heat insulating tape. Thus this tape acts as another material which has its own inherent thermal properties and therefore it has its own temperature profile across it.

There are five distinct areas for temperature measurement in the above example.
(1) The exterior surface temperature of the wall (cold side)
(2) Interior temperature of the wall at a specific point.
(3) Surface temperature of the wall (hot side).
(4) Local gas/liquid temperature at the interior surface of the wall (hot side).
(5) Gas temperatures on the hot side of the laminar layer.

Each of these areas of temperature measurement is discussed below together with sensor requirements.

(1) Exterior Surface Temperature:

The temperature sensor must be in intimate thermal contact with the wall. Also, the thickness of the sensor must be small in relation to the wall's thickness. Ideally a flat two-dimensional sensor is best for this application.

(2) Interior temperature of the wall:

The temperature sensor must have the same thermal properties (thermal conductivity and thermal diffusivity) as that of the wall. Also it must be accurately located within the wall and it must make good thermal contact with the bottom of the blind hole. And finally, the sensor hardware such as the protection sheath, mounting hardware, etc; must not introduce large conductive paths for heat transfer to occur. Spring-loaded thermocouples are use for this type of application. For shallow depth applications wherein the stem effect is greatest, we recommend a spring-loaded bayonet thermocouple with ribbon elements.

Finally, for extremely accurate in-wall temperatures, we recommend the use of our "Eroding thermocouples". These sensors have a two-dimensional sensing surface and can be located with a precision of +/- .001 inch. Also these sensors can be manufactured from any machinable material thus duplicating precisely the wall's thermal properties. Examples include stainless steel, carbon steel, copper, graphite, wood, tantalum etc., etc.

(3) Hot Side Surface Temperatures:

There are two distinct temperatures that one can measure at the hot wall surface. These are:

(a) Hot Side Surface Temperature of the Walt.

In this instance we need a two-dimensional surface temperature sensor with fast response times and thermal properties identical to that of the wall. These conditions are met very accurately with the NANMAC "Eroding Thermocouple".

(b) Local gas or liquid temperature at the surface of the wall.

In this instance, the temperature sensor must be an adiabatic sensor, ie; it must reach equilibrum temperature with the local gas without conducting any heat away from the sensing tip via the wires, insulation, sheath, etc. Since this ideal sensor is not possible we have designed a two-dimensional surface thermocouple with very small mass and thermally isolated from the body of the sensor.

Thus, minimum heat losses are encountered and the sensor measures the local gas or liquid temperature. We use a high temperature hard fired oxide to thermally isolate the thermocouple junction. When ordering these "adiabatic" sensors simply add the letter (u) to the part number.

(c) Gas Temperature

The true gas region begins from the hot side of the laminar layer and extends to the opposite wall. The gas temperature as a function of distance from the wall generally follows a bell-shaped profile. It is coolest near the wall and reaches a maximum at the center of the distance between the walls of the chamber or the pipeline. In order for a temperature sensor to measure the gas temperature, it must protrude through the laminar layer. This layer may be as thin as 0.010 inch in gases and as much as 0.050 inch thick in plastics. Since the "Stem Effect" (conduction errors caused by the thermowell, wires, insulation, etc.) can cause large errors in the observed temperatures, special emphasis must be paid to both the design and orientation of the sensor with respect to the isotherms within the gas. (See NANMAC Bulletin No. 92-4). If response time and length of immersion are not a factor, then one can use a conventional style of thermocouple probe provided it meets the conditions outlined in Bulletin No. 92-4.

In instances where the length of immersion into the gas is limited, the conditions of Bulletin 92-4 can be met with a specially designed ribbon thermocouple. Examples of these applications include industrial mixers and blenders with steam or water jacketed walls. Other examples include gas and liquids flowing in small pipelines. NANMAC has designed special sensors for these applications

In instances where there are extremely high velocity gases or high viscosity fluids such as wind tunnels, plastics extrusion and injection molding, NANMAC has developed special temperature sensors for these applications.

Finally on the subject of gas temperatures, there are many special situations which require unique solutions. These include radiation shields, total temperatures, Free-stream temperatures, etc. If you have requirements in these areas, we suggest that you speak to our Engineering Staff. We are available to assist you.