Lecture 36: Temperatue Measurements

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Key Words: Thermocouple, Seeback Effect, Furnace, emf

### Principle of Thermocouples

When two dissimilar metals such a iron and copper are gained to form a closed circuit, current flow when one junction is at higher temperature and the other one is at lower temperature as shown in the figure.
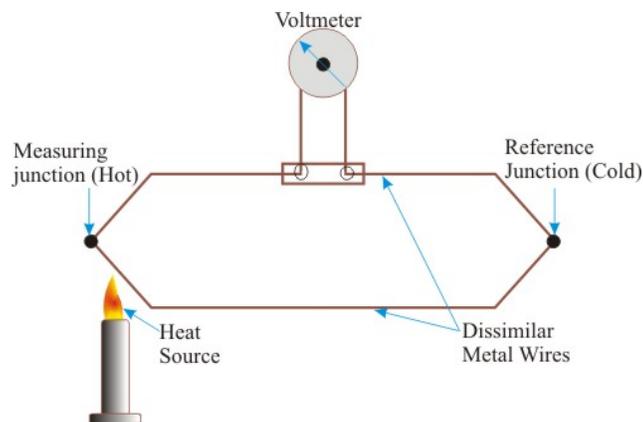
Figure 36.1: Principle of measurement of temperature by a thermocouple

The emf driving the current is called a thermoelectric emf and the phenomenon is known as thermoelectric effect or Seeback effect.

Usually a thermoelectric emf is very small. A pair of dissimilar metals welded together at their junction forms what is called a thermocouple. When several thermocouples are arranged in series, the emf is added together to give an appreciable output, this arrangement is called thermopile as shown in the figure.
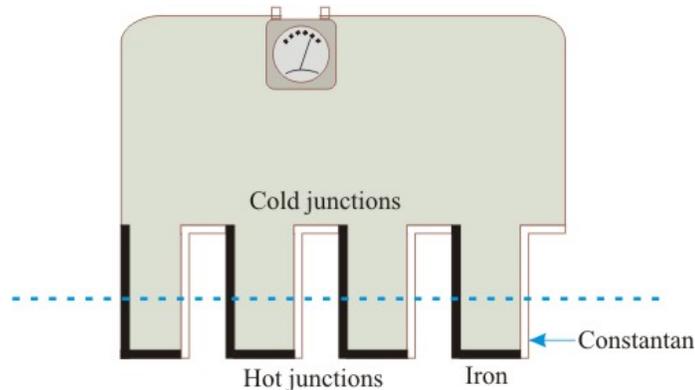
Figure 36.2: Arrangement of thermocouple to form a thermopile

When two dissimilar metals are joined together, the free electrons move randomly across the junction. Because of the different atomic structure of each metal, electrons pass more readily across the boundary in one direction than in other. This results in displacement of charges, making one metal positive and other negative.

Materials for thermocouple:

1. Melting point of thermocouple materials must be higher than the measuring temperature.
2. The dissimilar materials on joining should be able to produce large emf for accuracy of measurements.
3. Temperature is determined indirectly i.e. through calibrations of emf with temperature. As for as possible, the linear variation of emf with temperature is desired.
4. Thermocouple materials should be resistant to atmospheres in furnaces.
   Available thermocouples.

Type	Positive wire (+ve)	Negative wire (-ve)	Maximum temperature ($°C$)	Suitable under
T	Cu	$Ni_{45}Cu_{55}$	$370°C$.	Oxidizing & reducing
S	$Pt_{90}Rh_{10}$	Pt	$1700°C$.	Oxidizing & inert
N	$Ni_{85}Cr_{14}Si_{1.5}$	$Ni_{95.5} Si_{1.5} Mn_{0.4}$	$1260°C$.	Oxidizing & inert

K	$Ni_{90}Cr_{10}$	$Ni_{95}Mn_2 At_2 Si_1$	1260°C.	Oxidizing &inert
J	Fe	$Ni_{45} Cu_{55}$	760°C.	Oxidizing and reducing
B	$Pr_{70}Rh_{30}$	$Pt_{94}Rh_6$	1750°C.	Oxidizing, inert & vacuum

Cold junction compensation

Application of see back effect to thermocouple requires that one end of the junction (cold) must be at constant temperature.

The standard calibration data for all thermocouples are based on 0°C cold junction temperature. In practice it may not be possible to keep cold junction at zero degree temperature. Hence standard data need to be corrected. One way is to add the environmental temperature to the value of temperature determined by thermocouple measurement.

In another method, thermistor may be put in the thermo-couple circuit. The voltage drop across thermistor depends on environmental temperature which then compensates for the error.

Compensating wires

Compensating wires are those wires which are connected from the thermocouple to the temperature indicator. Compensating wires should have same emf as that of thermocouples.

Compensating wires are color coded.

Positive wire	Color	Thermocouple
Fe	White	Fe-constantan
Ni Cr	Yellow	Chromel - alumel
Cu	Blue	Cu-NI base
Ni Cr	Purple	Chromel constantan
Ni - Cr - Si	Orange	Nicrosil / Nisil

The negative wires in all thermocouples are red.

Selection of thermocouples

1) Type of furnace;   whether batch or continuous and the frequency of measurement.

2) Furnace atmosphere: The furnace atmosphere may be oxidizing or reducing, inert or vacuum. Accordingly thermocouples are selected. For example Pt, Pt-Rh can be used in oxidizing and inert atmospheres up to 1480°C. Chromel -alumel thermocouples may be used in reducing atmosphere but at low temperatures.

3) Response of thermocouple to temperature difference is important. Normally thermocouples are inserted in a ceramic sheath. During temperature measurement, The hot junction of the thermocouple is heated by the transfer of heat from sheath. Also large diameter of wire requires sufficient time for heating.

Illustration of gas temperature correction

Consider the measurement of temperature of gas by a thermocouple. When a thermocouple in a protection tube is inserted in gas or liquid, the outer surface of the tube receives heat either by convection or by convection+radiation.

Consider a thermocouple with an emissivity 0.75 measures the temperature of gas flowing in a duct whose wall temperature is 593 K. A thermocouple indicates 833 K. The forced convective heat transfer coefficient between the gas and the thermocouple is $120 \, \text{Wm}^{-2} \, \text{K}^{-1}$. What would be the actual temperature of gas?

Solution

The temperature measured by the thermocouple is lower than that of gas because thermocouple radiates to the wall. Energy balance at steady state is

Radiant heat flow from the thermocouple to the wall =Convective heat flow form gas to thermocouple

$$A_1 \, F_{12} \, \varepsilon \, \sigma \, (T_1^4 - T_2^4) = h \, A_1 \, (T_f - T_1)$$

$A_1 = $ surface area of thermocouple

$\varepsilon = $ emissivity, $\sigma = $ Stefan's Boltzmann constant.

$T_1 = $ Temperature of thermocouple, and $T_2 = $ Temperature of duct wall and $T_f = $ temperature of fluid.

$$T_f - T_1 = \frac{F_{12} \, \epsilon \, \sigma \, (T_1{}^4 - T_2{}^4)}{h}$$

Substituting the values

$$T_f - T_1 = \frac{1 \times 0.75 \times 5.67 \left[\left(\frac{833}{100}\right)^4 - \left(\frac{593}{100}\right)^4 \right]}{120}$$

$$= \frac{1 \times 0.75 \times 5.67 \left[48150 - 1273 \right]}{120}$$

$$= 125.5 \text{ K}$$

$$T_f = 958.5 \text{ K}$$

One notes that there is an appreciable error and this must be taken into account. It should be recognized that in an oven or furnace gas temperature may not be equal to the temperature of the major source of radiation. This may lead to overheating of materials. Proper shielding of thermocouple would be necessary.