Thermal Conductivity

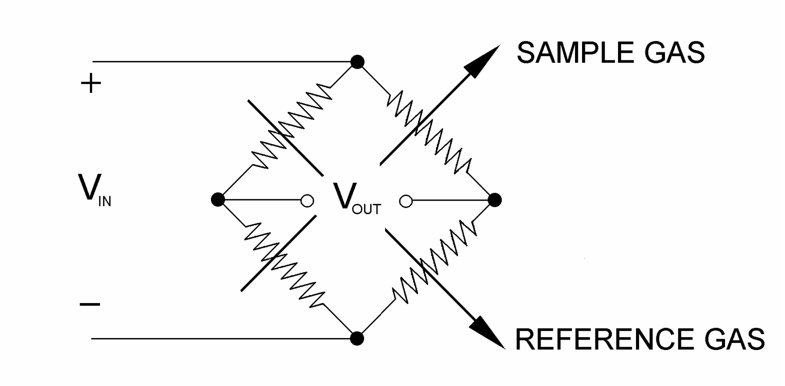
Each gas has a known thermal conductivity, that is how well heat transfers through it. This property can be measured. Thermal conductivity is measured with a sensor that employs four matched filaments that change resistance according to the thermal conductivity of the gas passing over it. The thermal conductivities of some gases can be found in Table A below.

GAS	THERMAL CONDUCTIVITY
ACETYLENE	4.400
AMMONIA	5.135
ARGON	3.880
CARBON DIOXIDE	3.393
CARBON MONOXIDE	5.425
CHLORINE	1.829
ETHANE	4.303
ETHYLENE	4.020
HELIUM	33.60
HYDROGEN	39.60
HYDROGEN SULPHIDE	3.045
METHANE	7.200
NEON	10.87
NITRIC OXIDE	5.550
NITROGEN	5.680
NITROUS OXIDE	3.515
OXYGEN	5.700
SULPHUR DIOXIDE	1.950

Table A. Thermal conductivities of common gases.

Theory & Principle of Operation

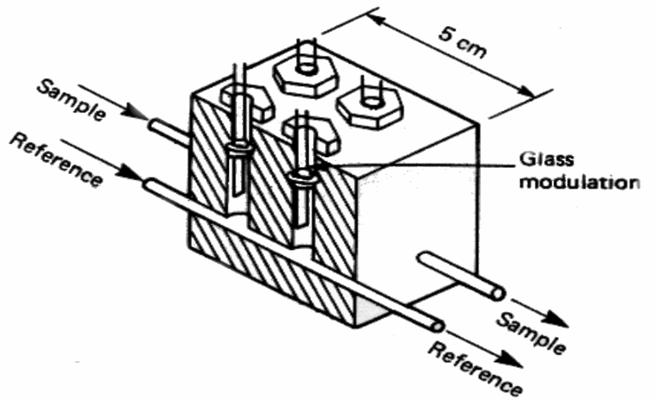
The sensor uses four matched filaments that change resistance according to the thermal conductivity of the gas passing over it. These four filaments are connected in a Wheatstone Bridge configuration as shown below in Figure 1.



(Figure 1. Wheatstone Bridge of the thermal conductivity detector.)

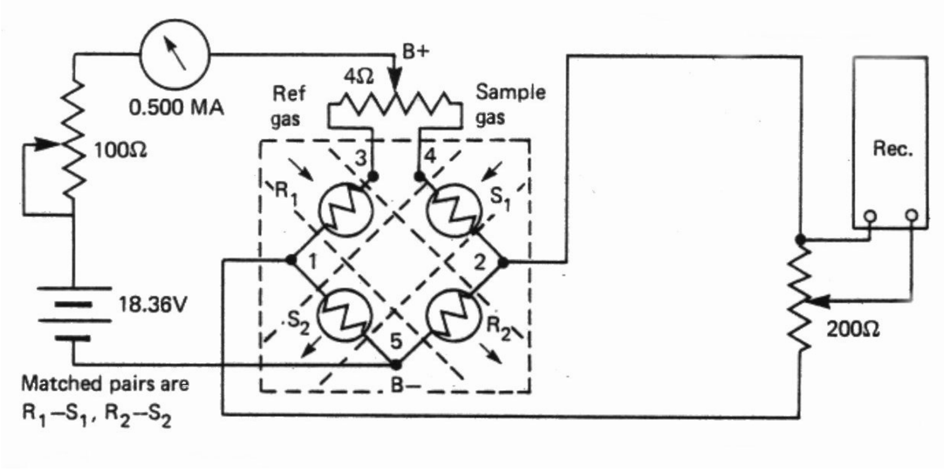
When all four resistances are the same, V_{OUT} is zero and the bridge is considered balanced. When zeroing, the reference gas is passed over all the filaments, the resistances will be the same (because filaments are matched) and the bridge is balanced. When the sample gas is passed over half of the bridge, then V_{OUT}'s value correlates to the content of the sample gas in the reference.

The detector is a four element Katharometer having two elements situated in the reference gas and two elements in the sample gas shown in Figure 2 below.



(Figure 2. Cut-away view of the thermal conductivity sensor.)

The four elements are electronically connected in a bridge circuit and a constant current is passed through the bridge to heat the elements. If each element is surrounded by the same gas, then the temperature, and hence the resistance, of each element will be similar and the bridge circuit will be balanced.



(Figure 3. Electrical diagram of the thermal conductivity sensor.)

When the gas to be measured is introduced into the sample gas stream, the two Katharometer elements in this gas stream will be cooled to a greater extent than the two elements in the reference gas. The bridge circuit will be unbalanced, producing a signal voltage related to the measure gas content of the sample gas. This relationship is non-linear. As a result, the 542 is calibrated at zero, mid-span, and high span and the software mathematically linearises the curve.

The equation for the bridge voltage output, E, is:

$$E = I^3 R_o^2 a \left[\frac{1}{l_{ref}} - \frac{1}{l_{sample}} \right] \qquad (1)$$

where:

∝ = temperature coefficient of resistance of the wire
R_o = resistance of wire
λ_{ref} = temperature coefficient of reference gas
λ_{sample} = temperature coefficient of sample gas

and the relative thermal conductivity can be calculated by:

$$\lambda = \frac{\lambda_2}{\lambda_1} \qquad (2)$$

where:

λ_2 = thermal conductivity of reference gas
λ_1 = thermal conductivity of measured gas

The thermal conductivity of a mixture of gases can be calculated as follows:

$$l_{sample} = \frac{l_1}{1 + A_{12}\dfrac{x}{(1-x)}} + \frac{l_2}{1 + A_{21}\dfrac{(1-x)}{x}} \qquad (3)$$

A_{12} and A_{21} are constants and are calculated by:

$$A_{12} = \frac{1}{\sqrt{2}} \left[\frac{d_1 + d_2}{2d_1} \right]^2 \sqrt{\frac{m_1 + m_2}{m_2}}$$

$$A_{21} = \frac{1}{\sqrt{2}} \left[\frac{d_1 + d_2}{2d_2} \right]^2 \sqrt{\frac{m_1 + m_2}{m_1}}$$

where:

d_1 = molecular diameter of reference gas
d_2 = molecular diameter of measured gas
m_1 = molecular mass of reference gas
m_2 = molecular mass of measured gas

Assuming a constant current, we can combine equations 1, 2, and 3 to get:

$$E = \frac{K}{C_n} \left[\frac{(l - A_{12}A_{21}) + (lA_{12} - A_{12})\dfrac{x}{(1-x)}}{(l + 1) + A_{21}\dfrac{(1-x)}{x} + lA_{12}\dfrac{x}{(1-x)}} \right]$$

where K and C_n are constants calculated during calibration.

Because the measuring technique relies on the different thermal conductivities of the two gases, the highest resolution occurs between two gases that have a large thermal conductivity differential (such as hydrogen and nitrogen).

Applications

Measure the sample content of a sample/reference mixture by comparing the thermal conductivity of the mixture with that of a reference.

For example, hydrogen has a thermal conductivity which is approximately seven times greater than that of nitrogen, so small changes are readily detected. All other common gases have conductivities similar to nitrogen so the method of measurement is fairly selective.

Helium is the only other gas with a thermal conductivity comparable with that of hydrogen.

Other gases that may be measured using this technique are:

- Carbon Dioxide
- Oxygen
- Argon
- Methane
- Sulphur Dioxide
- Ammonia

WARNING: Many sensors may not be used to measure gas/air or gas/oxygen mixtures which are capable of ignition.

Typical companies using such Instruments include industrial gas companies, metal heat treating companies, and furnace manufacturers.

Applications range from high purity gas production to furnace atmospheres.