MEASUREMENT OF THERMAL PROPERTIES

Lecture 07

PFE-2.4.5

By:
ER. K. R. Jethva
Assistant Professor,
PFE Department, CAET, Godhra

Measurement of Thermal Conductivity

(i) Steady state (ii) Unsteady state methods

STEADY STATE VS. UNSTEADY STATE HEAT CONDUCTION

Steady state	Unsteady state
1) Temp. constant with time.	1) Temp. varies with time.
2) No variation of rate of heat transfer.	2) Variation of rate of heat transfer .
3) The change of internal energy in a given time interval will be zero.	3) The change of internal energy in a given interval will not be zero.

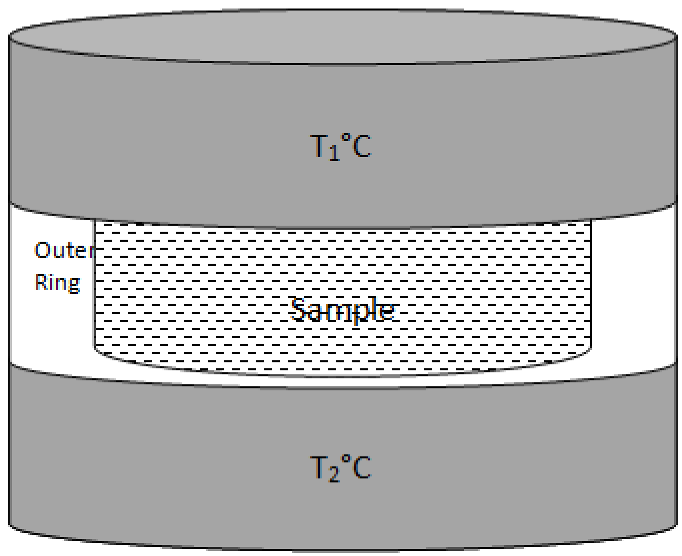
Measurement of Thermal Conductivity

<u>Steady state methods</u>

- **simplicity in the mathematical processing**
- **high precision in the results**
- **long time is required**
- **definite geometry**
- **large sample size**

Longitudinal Heat Flow Method

Guarded hot plate method - dry homogeneous materials in slab forms

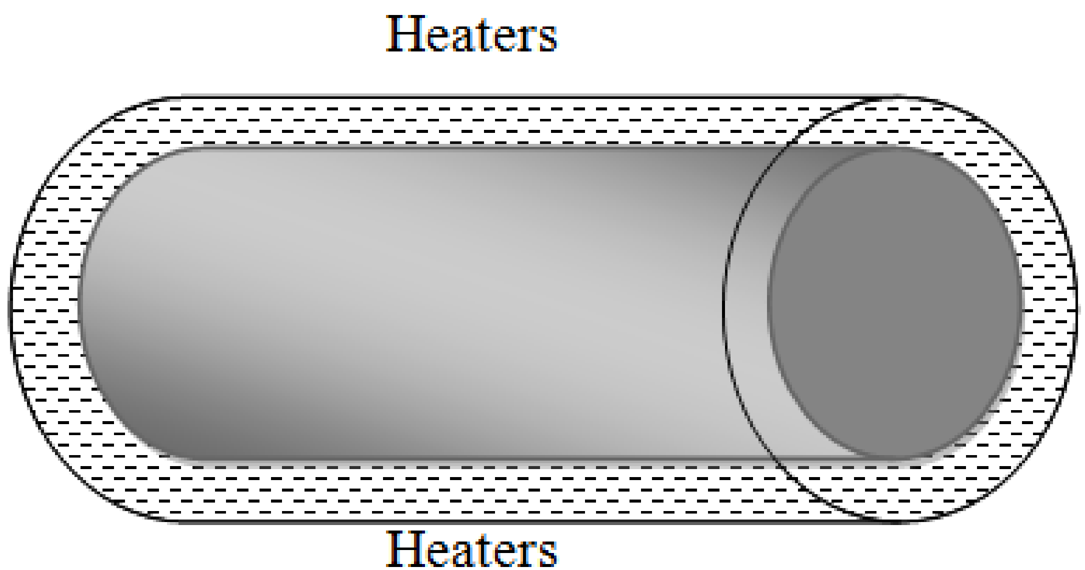


$$Q = -k\,A\,\frac{T_1 - T_2}{\Delta x}$$

Radial Heat Flow Methods

Concentric Cylinder Method:

- The sample is placed between two concentric cylinders.
- This method is preferable for liquid samples.



Radial Heat Flow Methods

Concentric Cylinder Comparative Method:

- This method uses a central heater followed by a cylindrical sample and a cylindrical standard.
- The temperatures T_1 and T_2 at radii r_1 and r_2 of the sample, respectively, and temperature T_3 and T_4 at radii r_3 and r_4 of the standard, respectively, are measured.

Sphere with Central Heating Source

- In this method, the sample is placed between the central heater which has a radius r_1 and the outer radius of sphere, r_2. The sample completely encloses the heating source so that end losses are eliminated.
- This is the most sensitive method among the steady-state methods because the error due to heat losses can be practically eliminated.

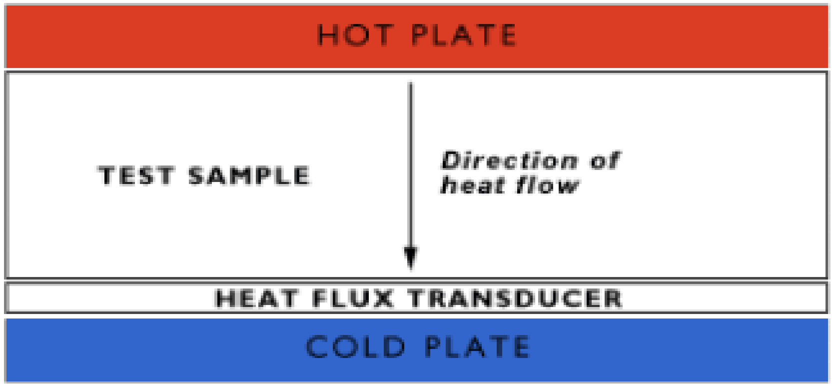
Heat of Vaporization Method

- a small test sample is put between two silver plates, one of which is in contact with a liquid A at its boiling point and the other one is in contact with liquid B. Heat transferred through the sample vaporizes some of the liquid B, which has a lower boiling point. Since the time necessary to vaporize a unit mass of liquid B is known, the thermal conductivity of the sample is calculated.

$$Q = -k\,A\,\frac{\Delta t}{\Delta x} = m\,\lambda$$

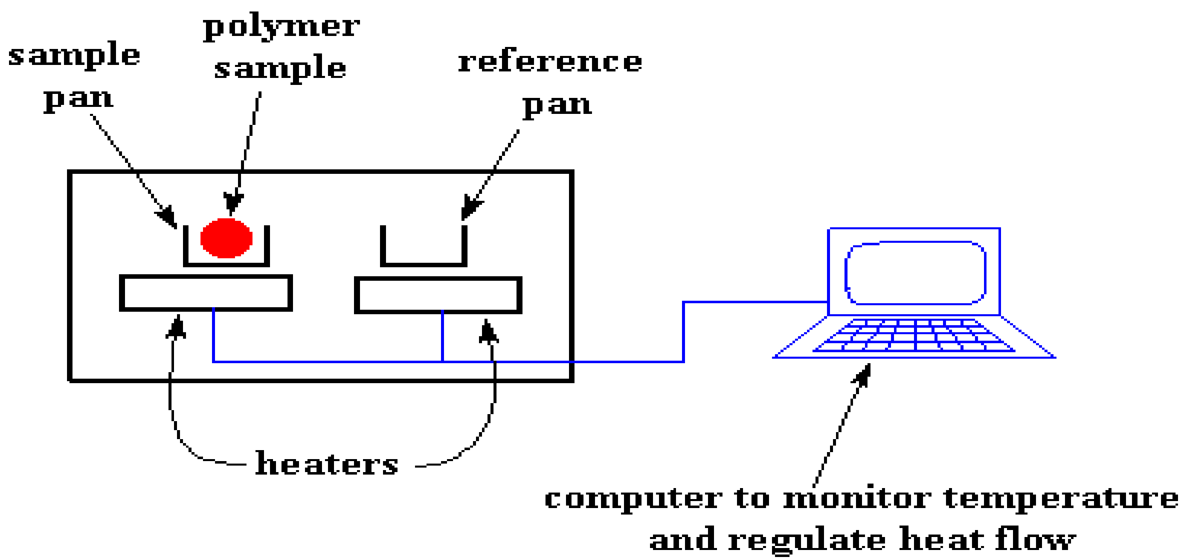
Heat Flux Method

- The heat flow meter is a device for measuring heat flux. In this technique, a heat flux sensor is attached to the inner surface of the wall with a very thin layer of high thermal conductivity adhesive. A temperature difference of 5 to 7°C is maintained within the system and the thermal conductivity is evaluated at the arithmetic mean temperature.

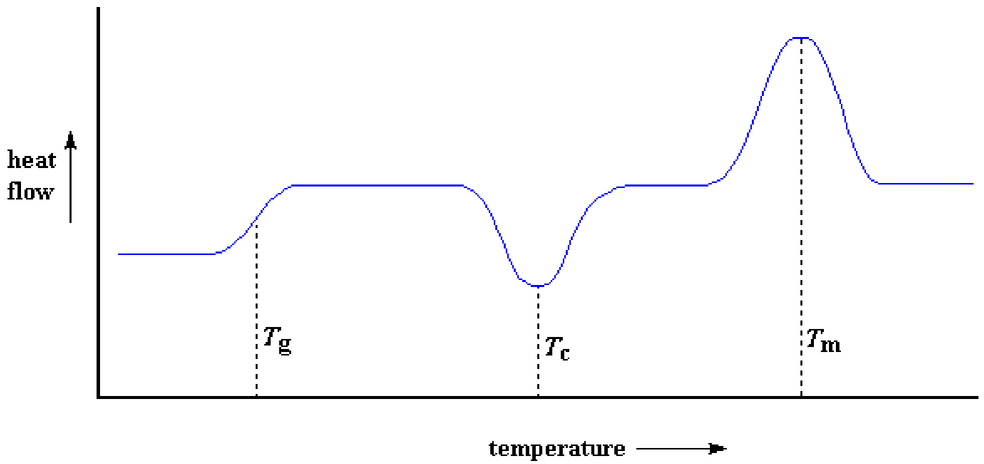


Differential Scanning Calorimeter

- Differential scanning calorimetry or DSC is a thermoanalytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. Both the sample and reference are maintained at nearly the same temperature throughout the experiment.



Differential Scanning Calorimeter



The entire DSC plot, right before your very eyes!

$$k = \left(\frac{L}{\Delta Q}\right)\left(\frac{A}{\Delta T_2 - \Delta T_1}\right)$$

Using D.S.C based on steady state method.

L= sample length,

ΔQ =difference in energy required to maintain pan temperature (W)

A= sample area perpendicular to flow (m^2)

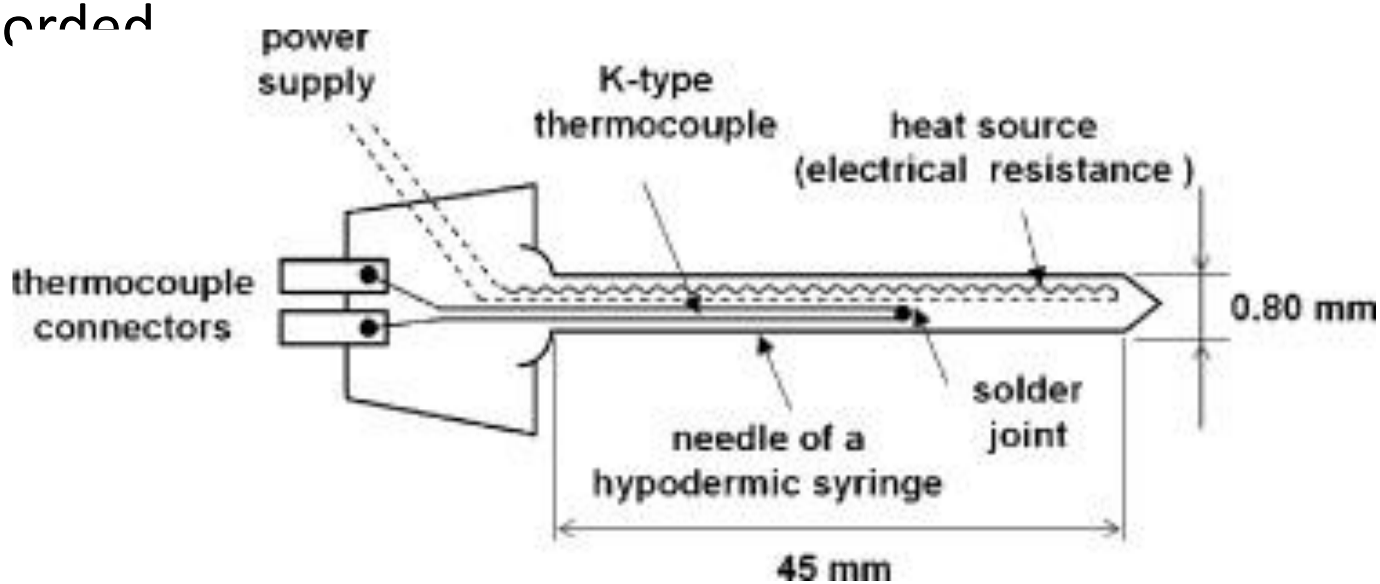
$\Delta T_2 =$ Final temperature difference between DSC heating pan & sample (k)

$\Delta T_1 =$ Initial temperature difference between DSC heating pan & sample (k)

Unsteady-State Methods

(a) Thermal Conductivity Probe Method

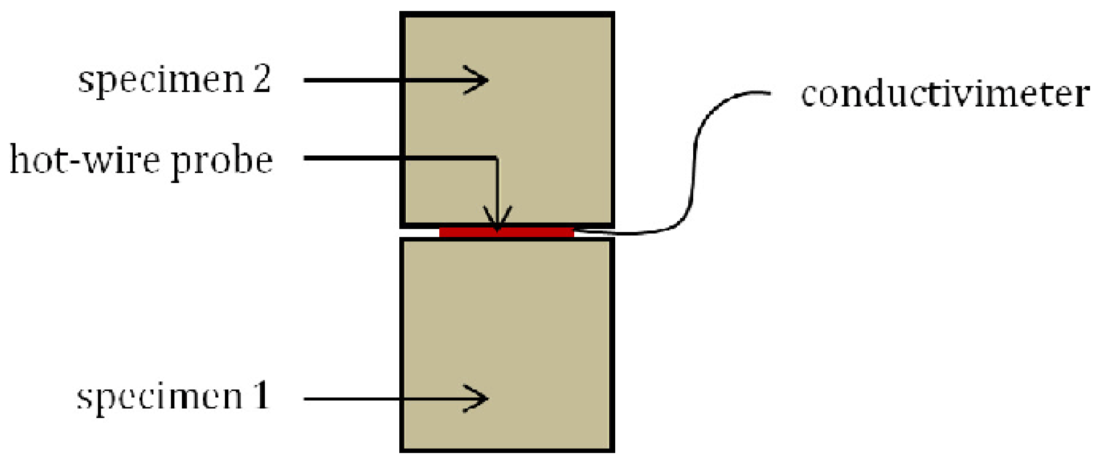
- The container is filled with sample and the line heat **source probe is inserted at the center of the container.**
- The container is placed in a constant temperature bath and equilibrated at room temperature.
- Time versus temperature adjacent to the line heat source is recorded



Unsteady-State Methods

(b) Transient Hot Wire Method

- The hot wire is located at the interface between the sample and a reference of known thermal conductivity
- the temperature rise T at a point located on the interface between the two materials at a distance x from the heater wire may are calculated.



Modified Fitch Method

- The Fitch method consists of a heat source or a sink in the form of a vessel filled with constant temperature liquid, and a sink or a source in the form of a copper plug insulated on all sides except one face through which heat transfer occurs.

Point Heat Source Method

- This method involves a point heat source, which is heated for a period of time followed by monitoring of its temperature as the heat dissipates through the sample.
- The typical device used for this purpose is a **thermistor** that serves as both a heating element and a temperature sensor.

Comparative Method

- This method involves cooling of two spheres side by side in a well stirred ice/water bath.
- One sphere contains the sample and the other contains a reference of known thermal conductivity.
- The thermal conductivity of the sample is calculated from the **time–temperature data** of the cooling spheres.
- It is based on the analytical solution for the center temperature of a sphere being cooled with convection boundary conditions.

Specific heat & Measurement

- For M.C above 8% only

$$C_p = \left(\frac{m}{100}\right)C_W + \left(\frac{100-m}{100}\right)C_d$$ kcal/kg˚C

$$C_p = \left(\frac{m}{100}\right) + \left(\frac{100-m}{100}\right)C_d$$

- C_d= Sp. of bone dry material, C_w of water = kcal
- m= m.c content in wet basis

Mixture method

- One unknown sp. heat of the specimen is then computed using a heat balance between the heat gained by or lost by the water or liquid & calorimeter & the heat cost or gained by the specimen.

Mixture method

Placing a hot metal into a cup of cool water will cause the metal to cool and the water to increase in temperature. A final uniform temperature will be reached. Knowing the masses involved, the specific heat of water, and the temperatures involved will allow one to calculate the specific heat (C_{sample}) of the metal. For a perfectly insulated system, the change in the thermal energy of the system will be zero ($\Delta Q_{total} = 0$), and using $Q = mC\Delta T$, an equation can be derived to find C_{sample}:

$$C_{sample} = -(m_w C_w + m_{cup} C_{cup})(\Delta T_w) / (m_{sample} \Delta T_{sample})$$

Where m_w is the mass of the water, C_w the specific heat of water (1 cal/g°C), m_{cup} is the mass of the cup, C_{cup} is the specific heat of the cup, ΔT_w is the change in temperature of the water, m_{sample} is the mass of the sample metal, and ΔT_{sample} is the change in temperature of the sample metal. For this lab, all masses should be measured in grams and all temperatures should be measured in °C.

Before the specific heat of the sample metal can be found, the specific heat of the cup must be determined. This will be done by using two samples of water held at different temperatures and then mixed together. Assuming another perfectly insulated system, $\Delta Q = 0$, and using $Q = mC\Delta t$, then C_{cup} can be found from:

$$C_{cup} = -(C_w / m_{cup}) [(m_{HW} \Delta T_{HW} / \Delta T_{CW}) + m_{CW}]$$

Where m_{HW} is the mass of the hot water, ΔT_{HW} is the change in temperature of the hot water, ΔT_{CW} is the change in temperature of the cold water, and m_{CW} is the mass of the cold water.

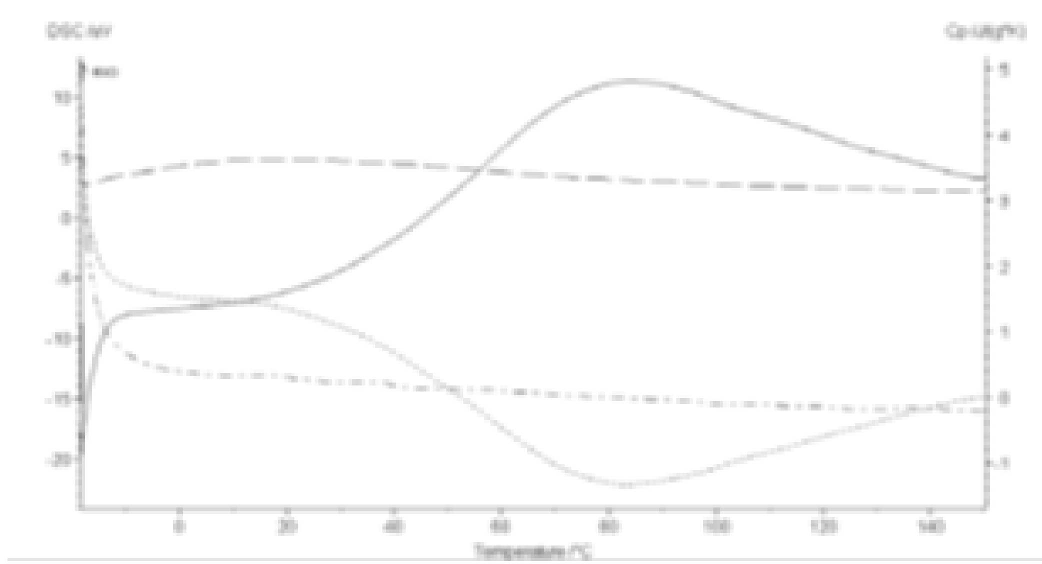
Specific heat measurement by DSC:

- To find out the specific heat of the food sample usually a reference sample of known specific heat is carried out prior to running the test for the food sample.
- The reference samples are usually a sapphire disc or distilled water.
- The sample of uniform cross section (possibly cylindrical) is placed in the sample pan, the opposite end of which is in contact with a heat sink at constant temperature. Initially, the sample is maintained at a constant temperature.

Specific heat measurement by DSC:

- At a predetermined time, the pan temperature is immediately increased to a predetermined higher value.
- A new steady state is reached in a few minutes and the heat flow into the DSC pan levels off.
- The difference in heat flow between the two states is recorded from the thermogram.


Tc 353.31 °C
Φ 0.227 mW


10
5
0
-5
-10
-15
-20
0
20
40
60
80
100
120
140
5
4
3
2
1
0
-1

Thermal properties of food constituent at approximately 20°C

Component	**Sp. Heat, kJ/kg°C**	**Thermal conductivity, W/m °C**
Water	4.18	0.60
Carbohydrate	1.42	0.58
Protein	1.55	0.20
Fat	1.67	0.18
Air	0.96	0.25
Steam	2.01(110°C)	-
Inorganic minerals	0.84	-
Metals	0.05-1.0	50-400