SNS COLLEGE OF TECHNOLOGY
AN AUTONOMOUS INSTITUTION

Approved by AICTE New Delhi & Affiliated to Anna University Chennai
Accredited by NBA & Accredited by NAAC with A^+ Grade Recognized by UGC

DEPARTMENT OF FOOD TECHNOLOGY

COURSE CODE & NAME: 23AGT207 & ENGINEERING PROPERTIES OF AGRICULTURE PRODUCE

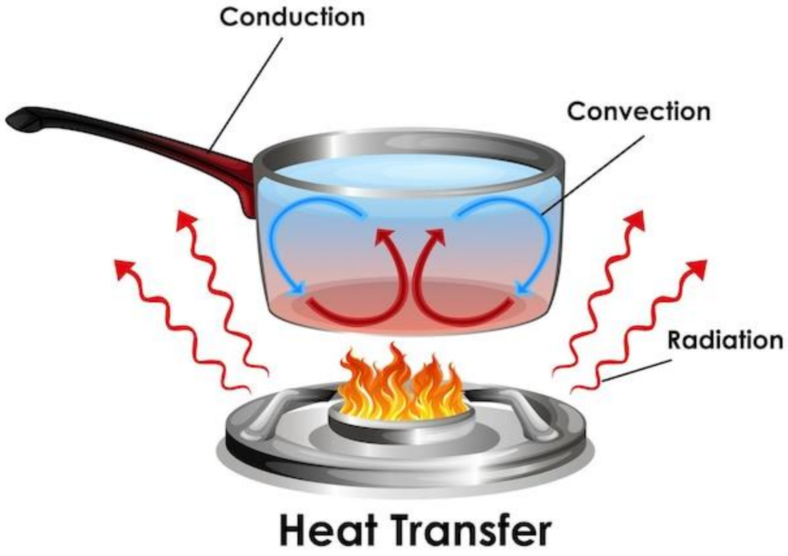
II YEAR / IV SEMESTER

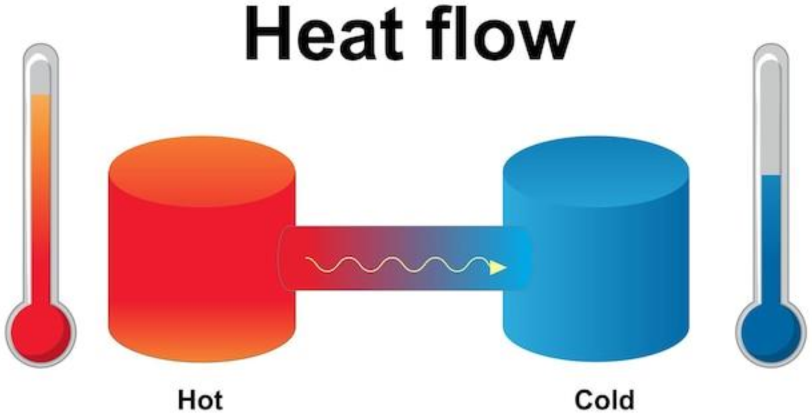
UNIT : III THERMAL PROPERTIES

TOPIC 1 : Thermal Properties- Co-efficient of Thermal Expansion

Heat Vs Temperature

Temperature is a relative measure, or indication of hotness or coldness





Heat transfer takes place between the system and the surrounding medium, until the body and the surrounding medium are at the same temperature.

What are the thermal Properties?

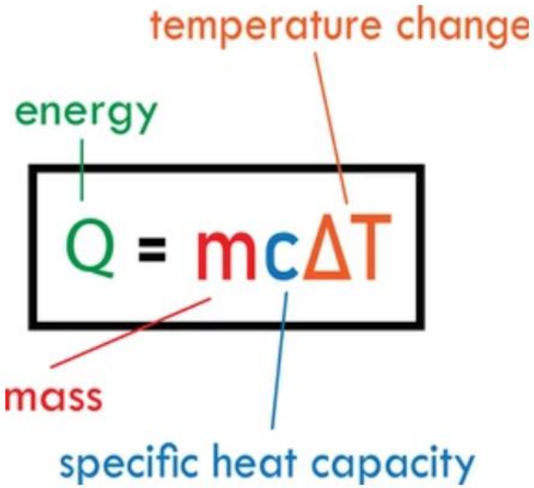
Specific Heat
Thermal Conductivity
Thermal Diffusivity

Specific Heat

The amount of heat that must be added to or removed from unit mass of a substance to change its temperature by unit degree.

The ratio of the heat supplied **Q to the corresponding temperature rise Δt is** defined as the heat capacity of a body.

Specific heat is the **mass heat capacity** defined as the **heat capacity of a body per unit mass of the body**

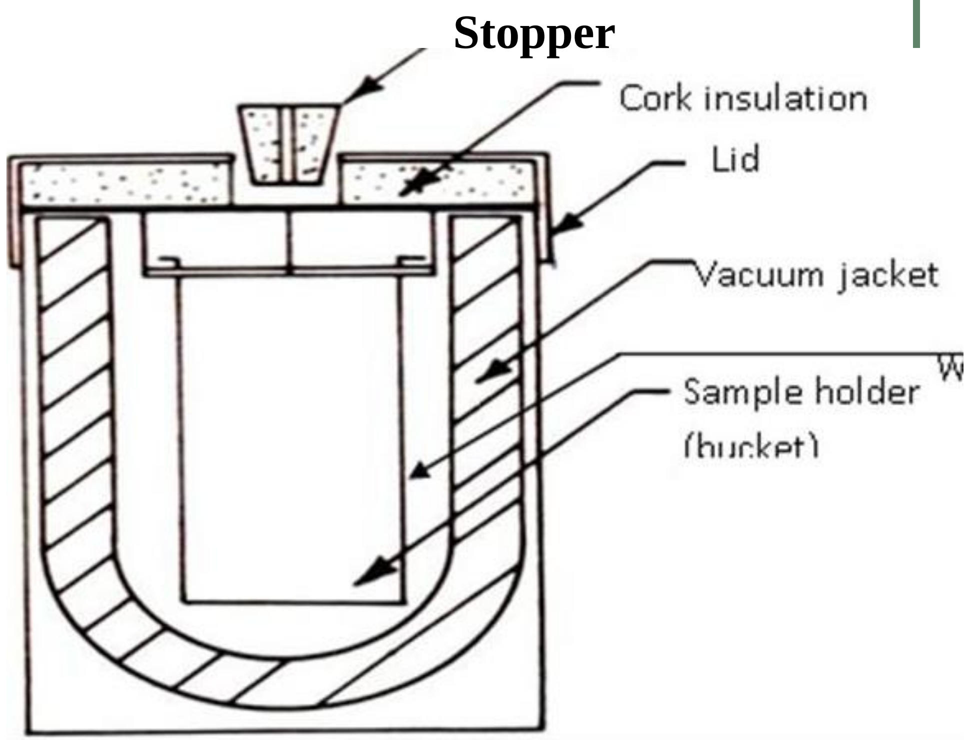


$$C = Q/(WV)\Delta T$$

C = specific heat in Kcal/kg ^{0}C,
w = specific weight in kg/m^3, and
V = the volume in m^3.
Q = Amount of heat, kcal

Measurement of Specific Heat

The specific heat of wet agricultural material is the sum of specific heats of bone dry material and its moisture content.
The specific heat of bone dry grain varies from 0.35 to 0.45 kcal/ kg °C
$Q = m\, C_p\, \Delta T$



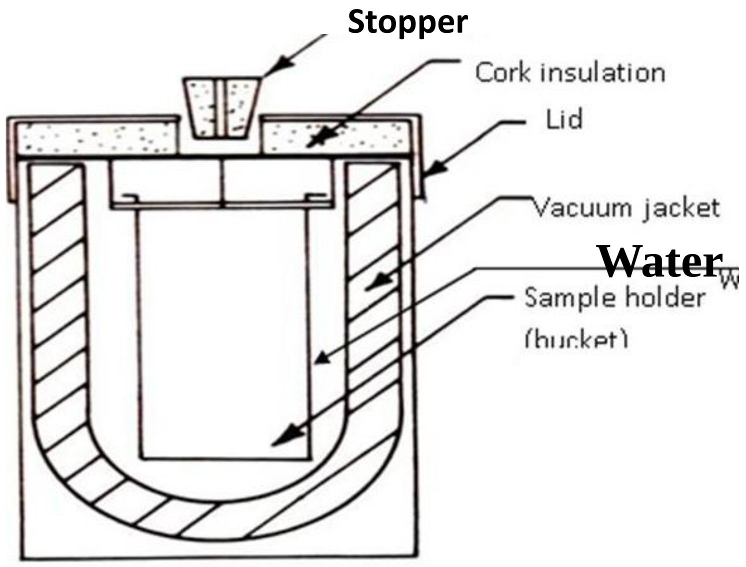
Vacuum jacketed calorimeter for specific heat measurement

Bone dry grain" refers to grain that has been dried to a point where it contains zero moisture. This is a theoretical state, as grains naturally absorb moisture from the air.

Measure Specific Heat - Procedure

Apparatus required : Vacuum jacket calorimeter, thermometer and thermocouple for temperature measurement, digital balance, grain and liquid food sample, water

Parts of a Vacuum Jacket Calorimeter

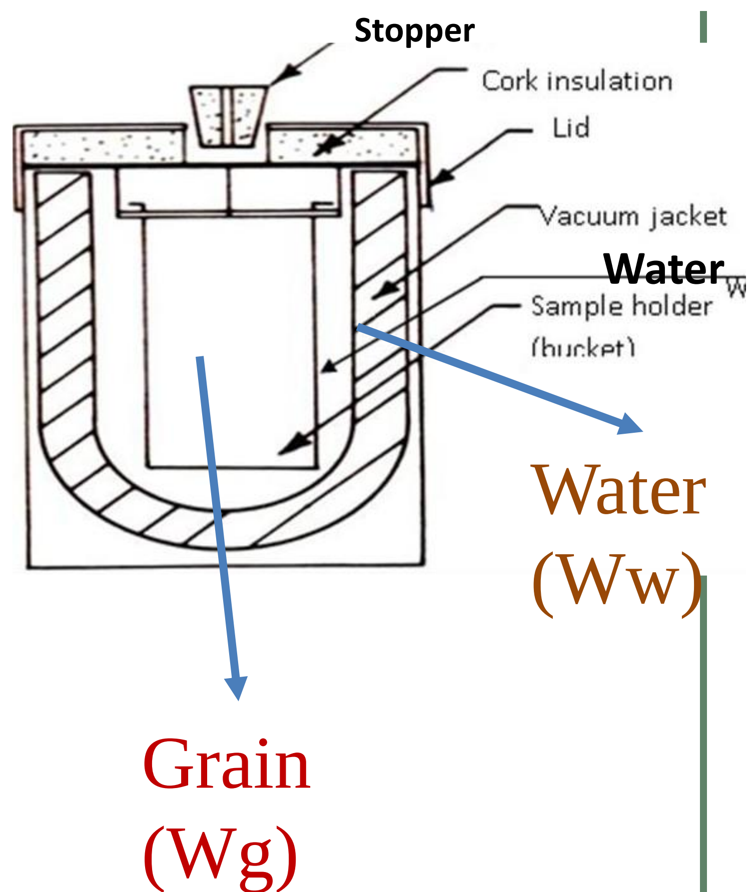


i) sample holder surrounded by water filled in annual space between the sample holder and a vacuum jacket.

ii) cork insulation is provided at top of the jacket to avoid the heat loss from the top.

iii) The thermocouples are inserted in the water and grain sample to measure the temperatures.

Measure the weight of calorimeter bucket (sample holder) (Wc).
Fill the grain of known weight (Wg) in sample holder (bucket).
Heat the bucket along with grain up to specific temperature level.
Place the heated bucket filled with grain sample of known weight and temperature into a calorimeter.
Fill the water of known weight (Ww) in calorimeter in the annular space between vacuum jacket and sample holder.
Seal the system from the top by cork insulation and record the initial temperature of bucket and grain sample (Ti) as well as .the temperature of water (Tw) using thermocouple.
Note down the temperature when the equilibrium is established between grain sample and water. This is the equilibrium temperature (Te).
Calculate the specific heat of grain as per the following heat balance equation.



Heat lost by grain and sample holder = Heat gain by water

Specific Heat Capacity - Definition

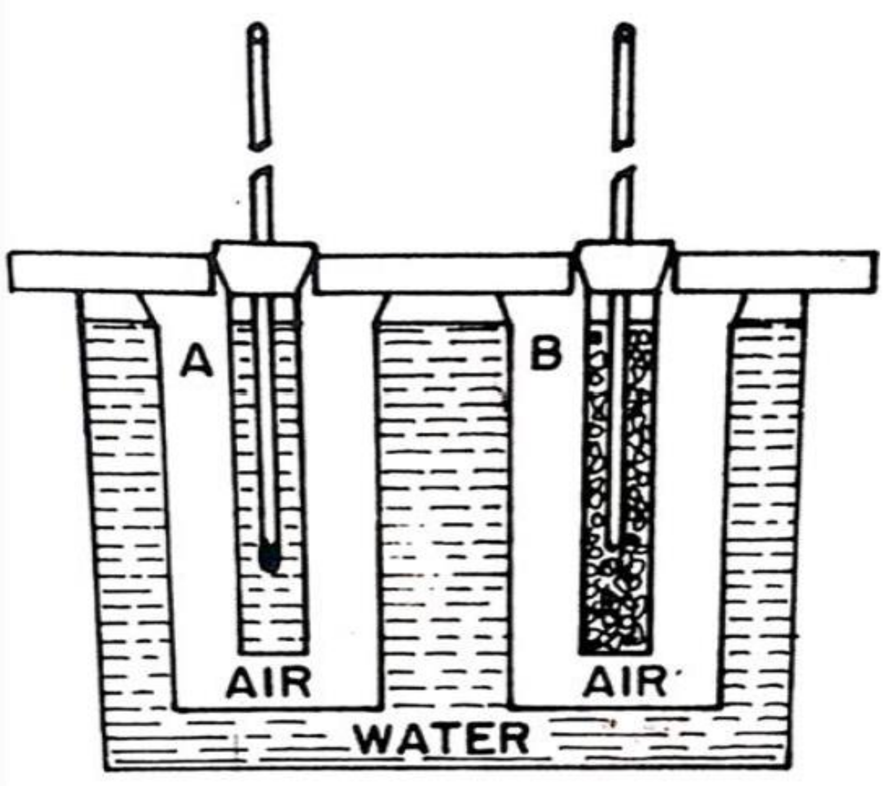
This is the amount of heat required to raise the temperature of 1 kg of a material by 1°C. It depends on the material's composition and moisture content.

$$C_c W_c (T_i - T_e) + C_g W_g (T_i - T_e) = C_w W_w (T_e - T_w)$$

C_W = Specific heat of water, kcal / kg °C
W_W = Weight of water, kg
T_e = Equilibrium temperature, °C
T_W = Initial water temperature, °C
T_i = Temperature of bucket and grain, °C
C_C = Specific heat of calorimeter bucket, kcal / kg °C
W_C = Weight of calorimeter bucket, kg
W_g = Weight of grain sample, kg

$$\text{Specific heat of grain}\,(C_g) = \frac{C_w W_w (T_e - T_w) - C_c W_c (T_i - T_e)}{W_g (T_i - T_e)}$$

Radiation type comparison calorimeter



used to determine the specific heat of liquid food materials

The area surrounding to the cups are to be filled with air and the remaining area in the calorimeter is to be filled with water.

Heat both cups to the same temperature (TA & TB) and then place in the calorimeter to cool down

Record the temperature of both the cups at 10 minutes time interval and plot the cooling curve between temperatures vs. time.

When the temperatures of both
the cups are become equal, their net rates of heat
losses are equal. In this condition, following relationship will be established.

$$\frac{\Delta Q_A}{\Delta \theta_A} = \frac{\Delta Q_B}{\Delta \theta_B}$$

If the temperature change of the cooling body is sufficiently small, the specific heats are constant and the rate of heat loss is equal to the rate of temperature change follows,

$$\frac{\Delta Q_A}{\Delta \theta_A} = (C_A W_A + C_W W_W)\frac{\Delta t}{\Delta \theta_B}$$

$$\frac{\Delta Q_B}{\Delta \theta_B} = (C_B W_B + C_S W_S)\frac{\Delta t}{\Delta \theta_B}$$

By putting the terms of Eq. 7 and 8 in the Eq. 6, we get,

$$(C_A W_A + C_W W_W)\frac{\Delta t}{\Delta \theta_B} = (C_B W_B + C_S W_S)\frac{\Delta t}{\Delta \theta_B}$$

$$C_s = \frac{(C_A W_A + C_W W_W)\Delta\theta_B - C_B W_B \Delta\theta_A}{W_S \Delta\theta_A}$$

Where,

C_S = Specific heat of liquid food sample filled in cup B, kcal/kg °C

C_A = Specific heat of cup A, kcal/kg °C

C_B = Specific heat of cup B, kcal/kg °C

C_W = Specific heat of water filled in cup A, kcal/kg °C

W_S = Weight of liquid food sample filled in cup B, kg

W_A = Weight of cup A, kg

W_B = Weight of cup B, kg

W_W = Weight of water filled in cup A, kg

$\Delta\theta_A$ = Time required for temp. drop (Δ_T) for water filled in cup A, s

$\Delta\theta_B$ = Time required for temp. drop (Δ_T) for liquid filled in cup B, s

Numerical Problem

Determine the specific heat of maize grains from the following observations

Temperature, °C				Weight, kg		
Grain, T_i	Bucket, T_i	Water, T_w	Equilibrium Temp., T_e	Water	Bucket	Grain
73	73	21	30	0.256	0.055	0.09

Specific heat of calorimeter bucket 0.226 kcal /kg °C

Solution:

$$\text{Specific heat of grain}\left(C_g\right) = \frac{C_w W_w (T_e - T_w) - C_c W_c (T_i - T_e)}{W_g (T_i - T_e)}$$

$$= \frac{1 \text{x} 0.256(30-21) - 0.226 \text{x} 0.055(73-30)}{0.09(73-30)}$$

$$= \frac{0.256 \text{ x } 9 - 0.0124 \text{ x } 43}{0.09 \text{ x } 43}$$

$$= 0.457 \text{ kcal/ kg } {}^{o}\text{C}$$

Thermal conductivity (k)

Knowledge of thermal conductivity for biological materials – analyzing heat during heat and mass transfer.

The quantity of heat that flows through the grains – depends on the thermal conductivity of the grains.

- **Thermal Conductivity (k):** This determines how quickly heat transfers through a material. It's influenced by factors like moisture content and temperature.

Liquids – heat transmissions as longitudinal vibration
Gases and vapors – molecular diffusion of kinetic energy (Low conductivities)
In foods, thermal conductivity depends mostly on composition – heat flow path

Void spaces,
shape,
Size and arrangement of void spaces,
homogeneity,
Orientation of fibers

1.Temperature

Biological material – conductivity depends on cellular structure, density and moisture ; effect of temperature is limited

Engineering materials – range of temperature

. If k is nonlinear function of temperature, a mean conductivity can be determined by taking.

$$K = \frac{1}{t2-t1}\int_{t1}^{t2} kt\, dt$$

Where, kt is the nonlinear function of conductivity versus temperature.

Moisture

Moisture migration affects thermal conductivity

$Q = K\,A\,\Delta T$, Where,
Q - Amount of heat flow, kcal
K - Thermal conductivity, kcal/m h°C
A - Area, m^2
ΔT - Temperature difference in the direction of heat flow,°C

Thermal conductivity of single grain ranges between 0 3 to 0 6 kcal/m h .°C and bulk grain varies from 0 1 to 0 15 kcal/m h.°C Thermal conductivity of air is 0 02 kcal/ m h °C

Measurement of Thermal Conductivity

Steady- state method
Transient –state method

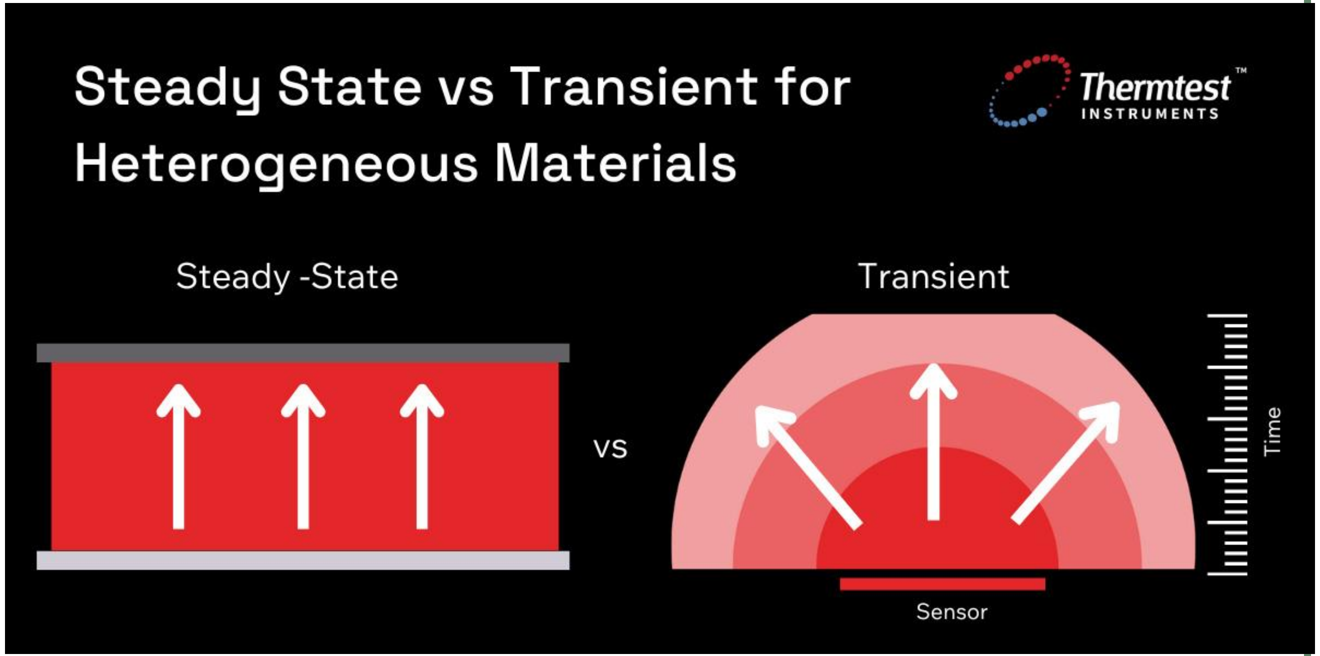
1. Steady- state method – Constant Heat flow

Merits
- Simple,
- ease of control
- Precise

Demerits
- The moisture migration and the necessity to prevent heat losses to the environment during
- this long measurement time
- In addition, these methods require definite
- geometry of the sample and relatively large sample size

2. Transient State Method

Transient methods for measuring thermal conductivity involve analyzing a material's response to a short heat pulse or periodic heat source, focusing on the time-dependent energy dissipation process



Steady-state method

Longitudinal Heat Flow Method
Radial Heat Flow Methods
Concentric Cylinder Method

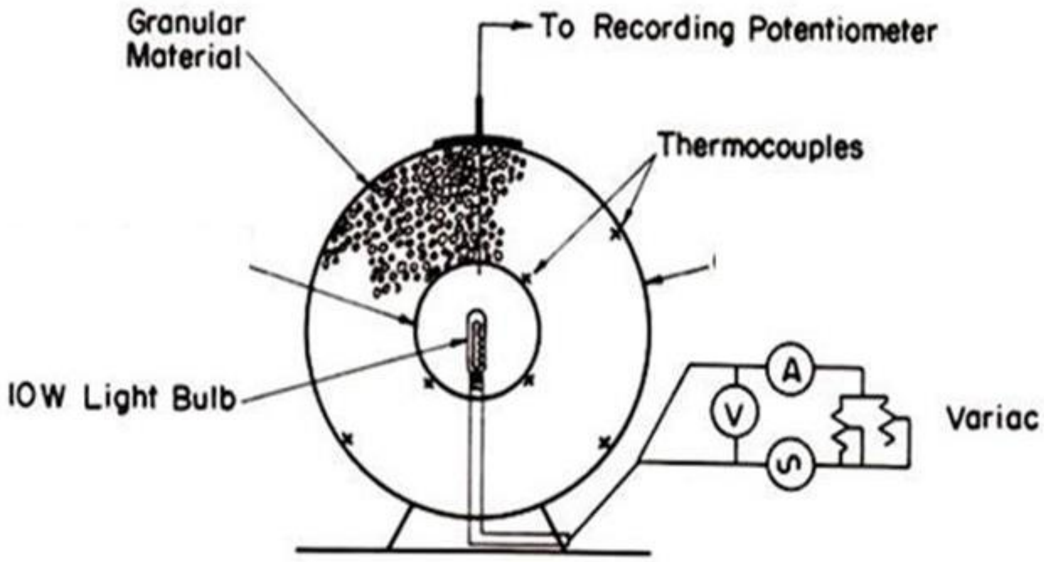
Cylinder without end guards

Cylinder with end guards

- **Sphere with central heating source**
- **Heat of vaporization methods**

Sphere with central heating capacity

Two concentric thin spheres of different diameters (di ammeter 9 75 cm, do 29 8 cm) made of copper material
thermocouples are fixed at different locations of the inner and outer sphere to record the temperature
The electric heater attached with the voltage and ampere meter is placed inside the small inner sphere
The whole apparatus is placed inside an insulated box with a fan circulating the air around the apparatus



Procedure

- Fill the grain sample of known moisture content in the annular space between outer sphere and inner sphere
- Tap the sphere to pack the grain down to a density of approximately the same as in the storage bin
- The inner sphere is heated electrically through electrical heater fitted inside the inner sphere
- Measure the current in Ampere (and voltage)
- Measure the temperature at four different locations on outer surface of the small inner sphere at half hour interval
- Similarly, measure the temperature at six different locations on inner surface of the large outer sphere at half hour interval

At steady state – change of temperature with time is zero, i e $dT/dt = 0$

Take the average of four temperatures (readings on outer surface of the small inner sphere and average of six temperatures (readings on inner surface of the large outer sphere

Then, the following equation can be used to calculate thermal conductivity of the sample

Thermal conductivity $K = q(r2 - r1) / 4\pi(r2 \ x \ r1)(Ti - To)$

Where, K - Thermal conductivity of test sample, kCal /h m C

q - The quantity of heat generated, kCal /h = 0 86 x I x V)

[I Electrical current, Amperes V Voltage, volt]

r 2 , r 1 the outer and inner sphere radius, respectively in cm

Ti ,To - the average temperature of outer surface of inner sphere and inner surface of outer sphere, respectively in ^{o}C

Activity

Determine the thermal conductivity of wheat grains at 12.2 % m.c. is packed in to the large sphere at a density of 726 kg/m3. An electric heater inside the small sphere is activated by adjusting the voltage and current to 70 Volt and 0.059 Amperes. After 14 hours, the steady state condition is reached showing constant average temperature of 65.8 ^{o}C outside the small sphere (ri = 4.87 cm) and 35.2 ^{o}C inside the large sphere (ro = 14.9 cm).

A batch of rice grains is stored in a cylindrical container. The thermal conductivity (kkk) of rice grains is **0.12 W/m·K**. Suppose heat is conducted through a **5 cm thick** layer of rice grains, and the temperature difference between the inner and outer surface of the layer is **10°C**. If the cross-sectional area through which heat is conducted is **0.2 m²**, calculate the heat transfer rate (Q) using Fourier's law of heat conduction

Step 1: Use Fourier's Law of Heat Conduction

The rate of heat transfer by conduction is given by:

$$Q = \frac{kA\Delta T}{L}$$

where:

- Q = heat transfer rate (W)
- k = thermal conductivity of rice grains = **0.12 W/m·K**
- A = cross-sectional area = **0.2 m^2**
- ΔT = temperature difference = **10°C**
- L = thickness of the layer = **5 cm = 0.05 m**

Step 2: Substitute the Values

$$Q = \frac{(0.12)(0.2)(10)}{0.05}$$

$$Q = \frac{0.24}{0.05}$$

$$Q = 4.8W$$

Thermal Diffusivity

- Thermal diffusivity is a quantity which measures the rate of temperature changes (speed of heat propagation) and indicates the speed at which temperature equilibriums will be reached.
- It is important in determination of heat transfer rates in solid food materials of any shape.
- The higher the thermal diffusivity, the faster is the heat propagation.
- In order to calculate the temperature change in grain bin due to fluctuations in external or internal temperature and predict the heat transfer in the food grains, it is essential to determine thermal diffusivity of food grains.
- thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure

Heating and cooling of agricultural materials involve the unsteady state or transient heat conduction.

Fourier’s general law of heat conduction

The temperature distribution in a body for the unsteady state condition is given by in the form of a partial differential equation as follows

$$\frac{dt}{d\theta} = \alpha \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right)$$

Where t is the temperature at any point given by the coordinated x, y, and z, is time in hours, and the coefficient α is thermal diffusivity with units of m^2/h.

Measurement of thermal diffusivity

Calculate from experimentally measured values of thermal conductivity, specific heat and mass density.

$$(\alpha) = \frac{K}{\rho Cp}$$

Where,

α = Thermal diffusivity of grain sample, m_2/h

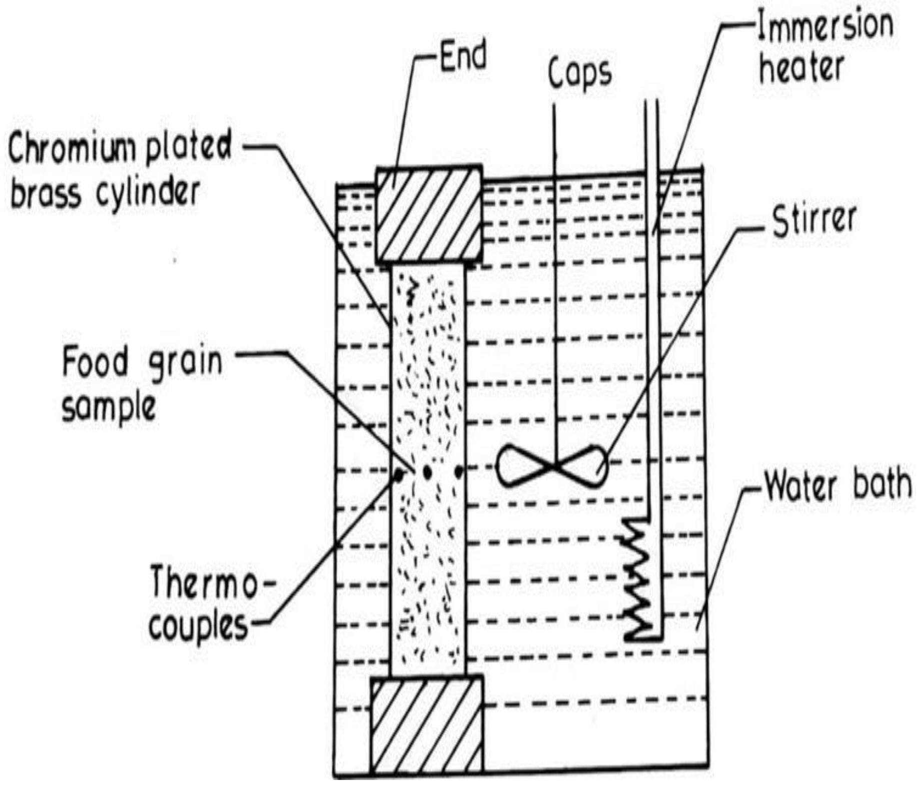
K = Thermal conductivity of grain sample, kCal/m.h.°C

ρ = Density of grain sample, kg/m^3

Cp = Specific heat of grain sample, kCal/kg °C

2. Thermal diffusivity apparatus

- Thermal diffusivity apparatus can be used to determine the thermal diffusivity.
- It consists of a chromium plated brass cylinder also known as thermal diffusivity tube.
- One thermocouple is fixed at the center of cylinder and another two thermocouples are fixed at the inside surface of cylinder opposite to each other.
- Whole assembly is placed in an insulated and well-stirred water bath of 25 liter capacity



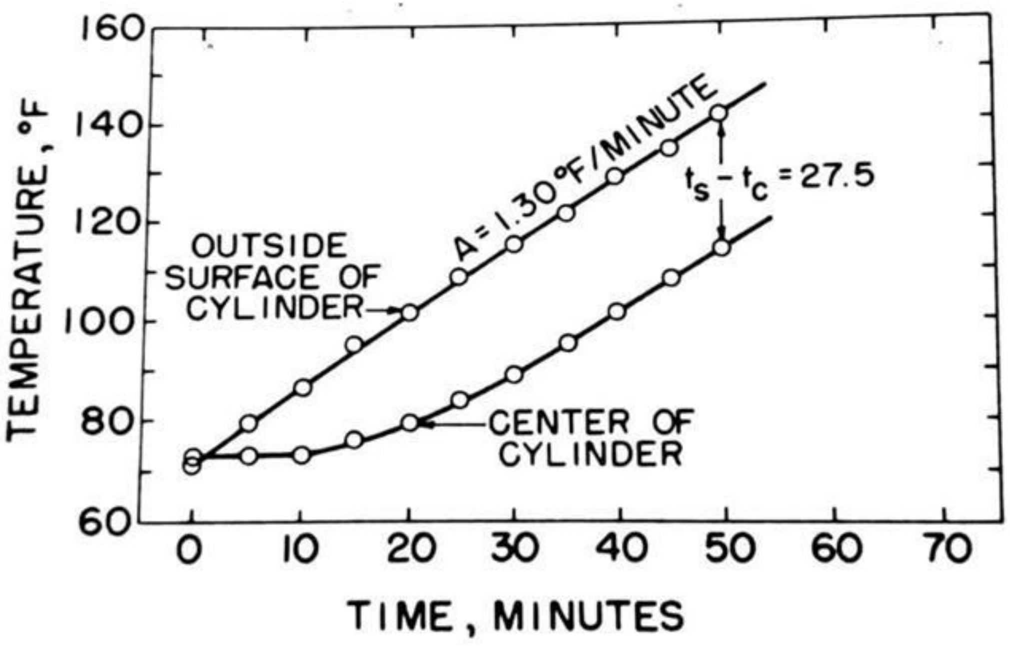
Fill the cylinder with the cleaned food grains and place the entire assembly with end caps and thermocouples in water bath.

• Heat the water bath at constant rate with the help of 1000 W immersion heater. The output of the heater may be noted by connecting the wattmeter in the circuit.

• Stir the water in the tank with the help of a stirrer at suitable speed, driven by a motor of 40 W (1/20hp), 4000 rpm and coupled to a speed regulator.

• Note down the temperatures at the center (Tc) and surface of cylinder (TS1 and TS2) at every 10 minutes time interval. Take
average of surface temperature: TS = (TS1 + TS2)/2.

• Continue the experiment till the temperature difference between Tc and TS, i.e. TS- Tc, becomes constant. • Plot the temperatures (Tc and Ts) vs. time curve.



$$= \frac{R^2 A}{4(Ts - Tc)}$$

Where,
α = Thermal diffusivity of grain sample, cm^2/min
R = Radius of cylinder, cm
A = Constant slope of temperature verses time curve in °C/min

THANK YOU…