Chemical Process Utilities
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Module No # 12
Lecture No # 59
Brief History of Insulations and it's Fundamental Priniciples

Now let us talk about the brief history on insulation and it is fundamental in this particular lecture the edges of chemical process utility. Now before we go into the detail of this history of insulation let us brief outlook that what we discussed in the previous lecture. In the previous lecture we discussed about the various model about the slag attack on the refractories as were discussing about the refractories.

In this we discussed about the Konig's model then model for Endell, Fehling and Kley apart from this we discussed about the various kinds of refractories like silica, alumina silicate, chrome magnesite all these reflectories we discussed in detail. Now in this particular lecture we are going to cover about the brief history of thermal insulation. We will discuss about the prupose of thermal insulation I will have a look about the temperature ranges for the insulation application.

And we will discuss about the various insulating materials apart from this we will discuss all 3 modesof heat transfer like conduction convection and radiation.

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Brief History of Insulation

- ✓ The true origins of the science is **thermal insulation**, however, are difficult to identify.
- ✓ Organic materials had served as the natural prototype for **thermal insulators**. **e.g.,** fur covering the polar bear or feathers on a bird, cotton, wool, straw, and even hair.

Let us start with the brief history of insulation the true origin of the science is the thermal insulation. However which are difficult to identiy now see the thermal insultation is an integral part of chemical process utilities and without the thermal insulation you cannot achieve the objective of energy conservation or economics. So in this aspect the insulation is very important and previously the organic material they had served as the natural prototype of thermal insulators like for covering the polar bear or feathers on a bird, cotton wool, straw.

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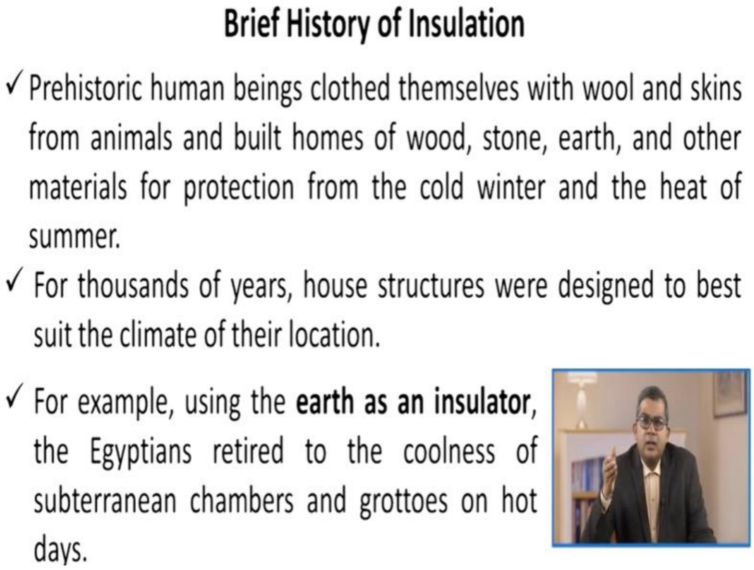

And even here they serve as the material for the insulation now prehistoric human beings cloth themselves with wool and skin from animal and built homes of woodstone earth and other material for the protection from the cold, winter and heat of summer. For thousands of years house is structured they were designed to the best suited the climate of their respected location. For example using the earth as an insulator the Egyptian retired to the coolness of subterrnean chambers and grottoes on hot days.

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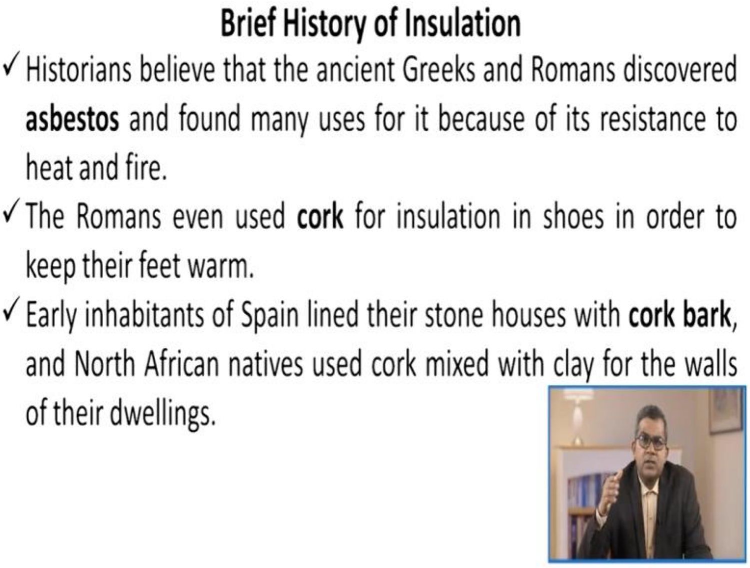

Now historian believed that the ancient greeks asnd romans discovered asbestos and found many uses for it because of its resistance to heat and fire. The womens even used cork for insulation in shoes in order to keep their feet worm early inhabitants of spain lines their stone houses with cork bark and north african natives used cork mixed with the clay for the walls of their dwellings.

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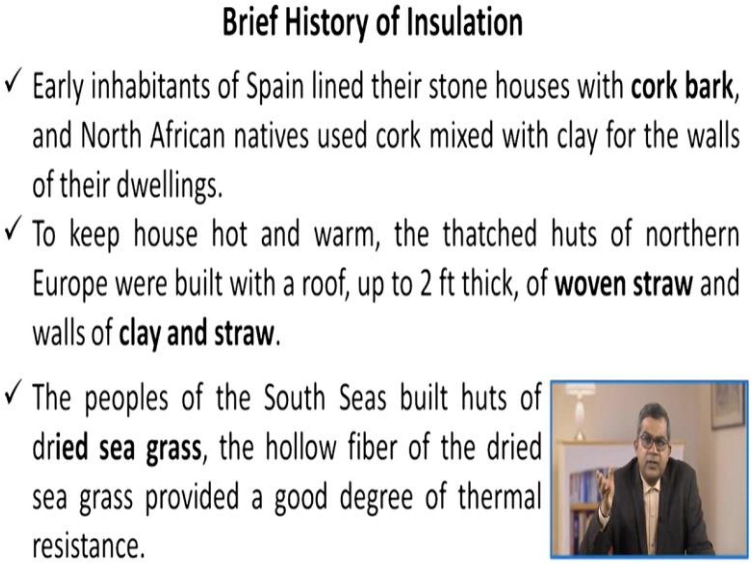

Now early inhabitants of the spain lined their stone houses with cork bark and North African natives used cork mixes with clay for the walls of their dwellings. Now to keep house hot and warm the hatched huts of Northern Europe they were built with a roof up to 2 feet thick of woven straw and walls of clay and straw. The peoples of the south seas built huts for dried sea grass the hollow fiber of the dried sea grass provided a good degree of thermal resistance.

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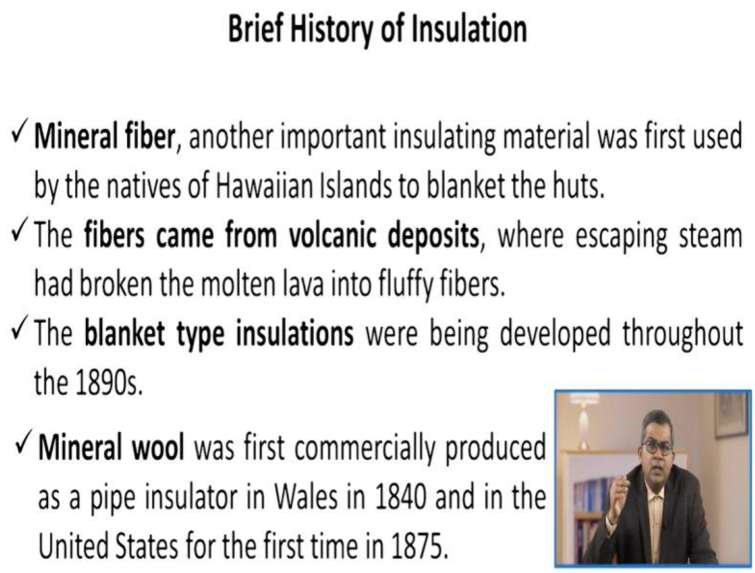

Mineral fibers another important insulating material this was first used by the Hawaiian island to blanket and huts. The fibre came into the valconic deposits where escaping steam had broken the molten lava into fluffy fibre. The blanket type insulation they were being developed throughout in eighteen nineties. Mineral wool was first commerical produced as a pipe insulator in Wales in 1840 and in the united states for first time in 1875.

It was almost 60 years later in 1897 the C.C.Hall a chemcial engineer produced a rock wool. By 1901 he produced this particular product commercially at a plant in Alexandira Indiana. Fiberglass had its first beginning in ancient egypt’s when the people discovered that they could draw hot glass into threads which were placed around the vessel for decoration. Wood shaving also known as Balsa wool were a very popular insulation product due to the wide avaibility of raw materials and their low cost at the turn of the century and it was very popular in homes of north eastern united states.

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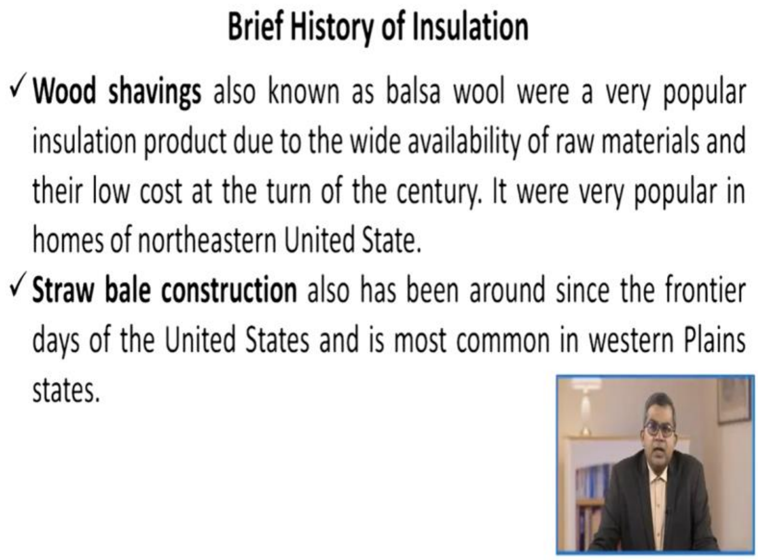

Straw bale construction also has been around since the frontier days of the united states and is most common in western plains states.

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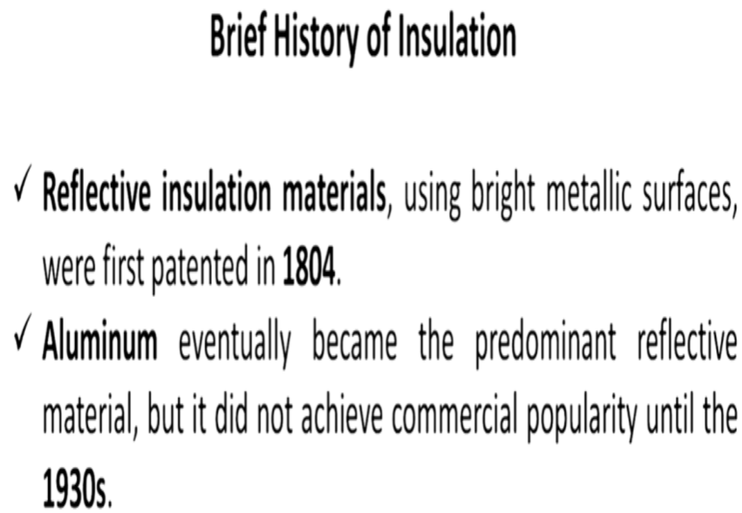

Reflective insulation materials they are being used for almost 200 years ago and they are using the bright metallic surfaces they were first patended in 1804. Aluminum is again very good insulation material aluminum eventually became the predominant reflective material but it did not achieve commerical popularity until 1930.

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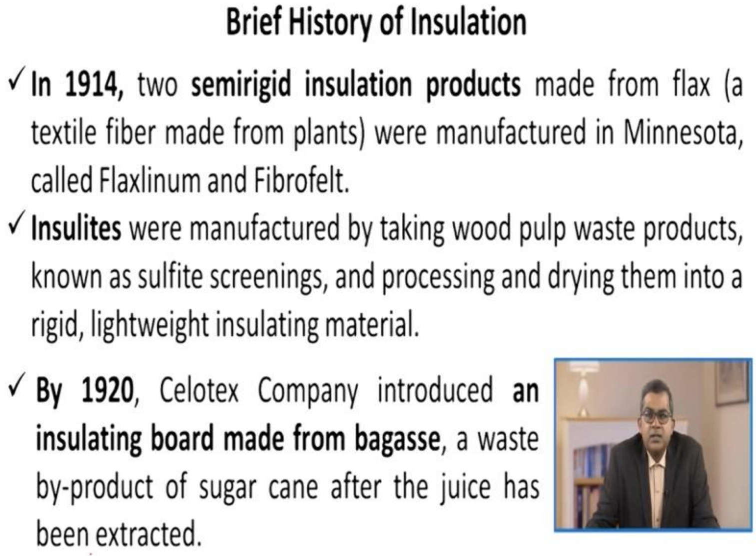

In 1914 the 2 semirigid insulation product made from flex textile fiber made from plants. They were manufactured in Minnesota called Flaxlinum and Fibrofelt. Insulities was manufactured by taking wood pulp waste product known as a sulphite screenings and processing asnd drying them into a rigid lightweight insulating material. In 1920 Celotex company introduced an insulating board made from Bagesse a waste by-product of sugarcane after the juice has been extracted.

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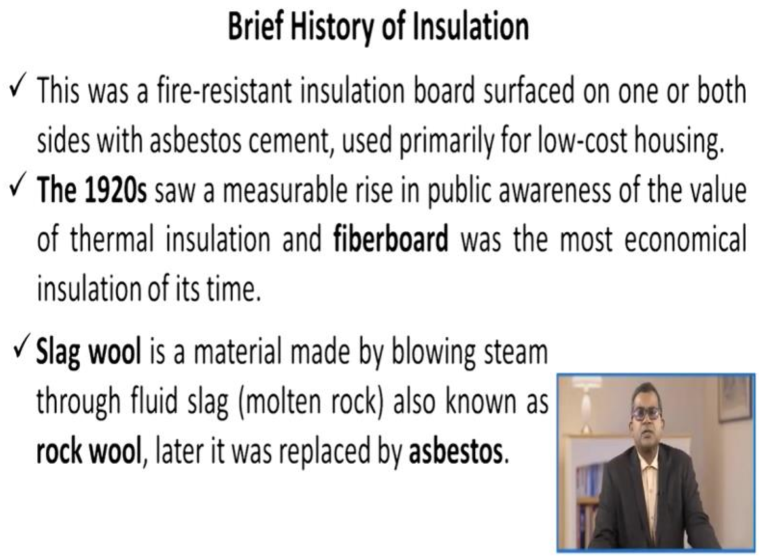

And this was the first fire resistant insulation board surfaced on one or oth sides with asbestos cement used primarily for low cost housing. In 1920 this particular saw the measurable rise in the public awareness of the value of thermal insulation and fiber board was the most ecnomical insulation of its time. Slag wool is a material made by blowing steam through fluid slag molten rock also known as rock wool later it was replaved by asbestos.

The glass fiber production started in mid 1930 in 1928 the gradual introduction of air conditioning system into home design also contribute to a greater need of thermal insulation in house hold appliances.

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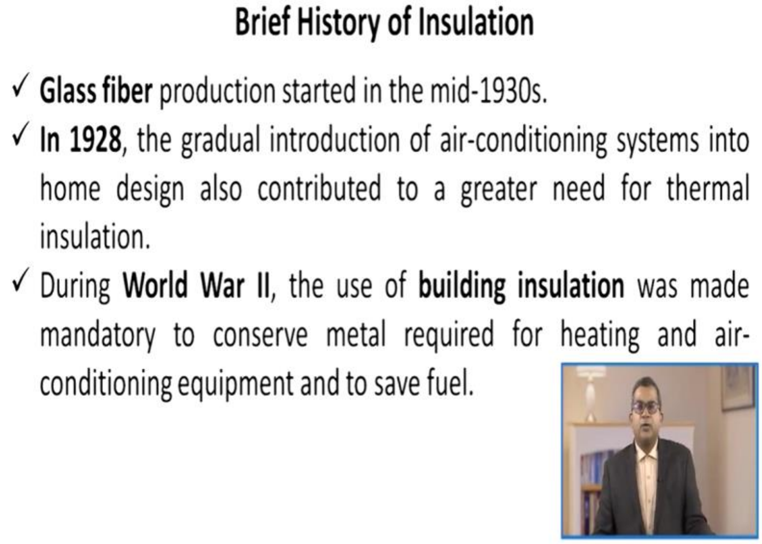

During world war 2 the use of building insulation was made mandatory to conserve metal required for heating and air conditioning equipment and to save fuel.

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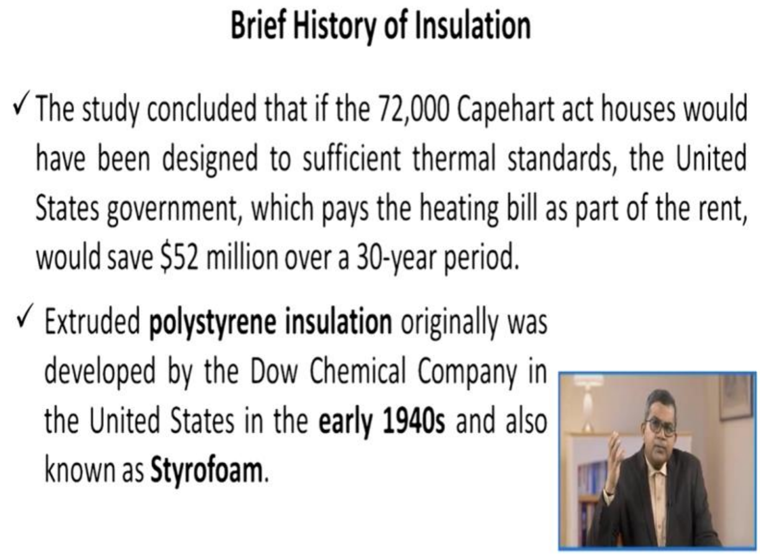

The study concluded that if 72,000 Capehart act houses would hav ebeen designed to sufficient thermal standards. The united states government which pays the heating bill as part of the rent would save 52 milliion dollar over a 30 years period. Extruded polystyrene insulation orginally was developed by the Dow chemical company in the unites states in the early 1940 and also known as Styrofoam. It is a very popular very common insulating material as on date.

It was first used as a floation material in life raft and life boats because it is fully closed cell structure renders it highly resistance to water absorption. The insulating properties of Styrofoam combined with the advantage of the closed cell structure led to its development as a thermal insulation material. Initial application were in the low temperature situation for cold stores floors wall and ceiling panel and pipe insulations.

In 1950 Dow’s extruded polystyrene foam extended its impact to other areas of construction industries as thermal insulation in commerical and residential building.

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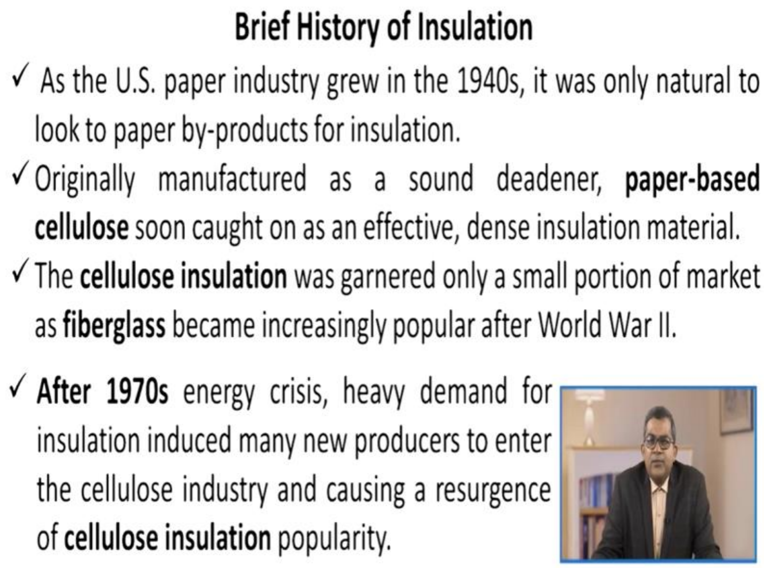

As the US paper industry grew in 1940 it was only natural to look to paper by-product for insulation. Originally manufactured as a sound deadener paper based cellulose soon caught on as an effective dense insulation material. The cellulose insulation was garnered only a small portion of market as fiberglass became increasingly popular after world war 2. After 1970 energy crisis heavy demand for insualtion posed and it indused many new producers to enter the cellulose industry in causing the resurgence of cellulose insulation popularity.

Urea formaldehyde form insulation sometimes referred as UFFI this was introduced in the building industry in way back 1960. Now health complaint is started from the occupants of Urea fomaldehyde form insulation insulated homes in 1978 and by 1980 UFFI was banned across Canada reportedly due to the long term health risk to occupants of houses insulated with

UFFI. It is the one of the main reason mixture of formaldehyde and all the formaldehyde compunds it contributes the most indoor air problem because of its water solubility.

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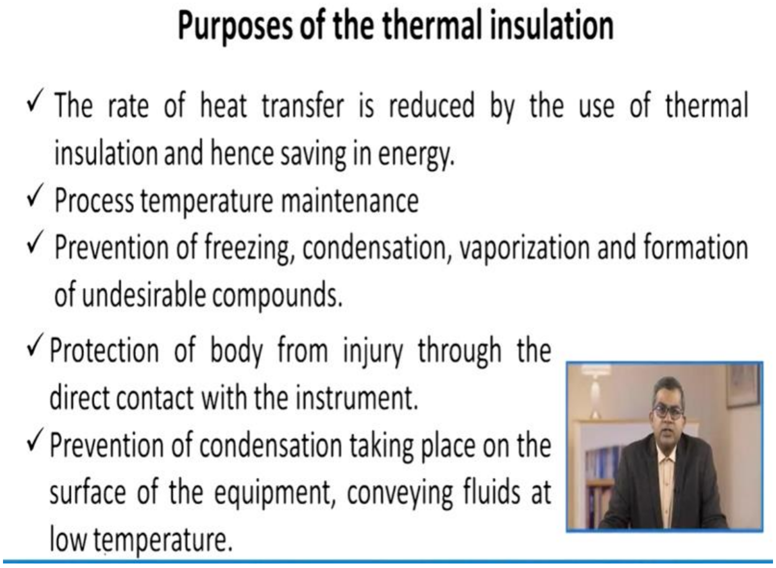

Now let us talk about the purpose of thermal insulation the rate of heat transfer is reduced by the use of thermal insulation and saving its energy. It is foremost requirement process temperature maintenance can be easily maintained. It can help in the prevention freezing condensation vaporization formation of undesirable compounds. It can help in the protection of a body from injury through the direct contact with the instrument.

It can help in the prevention of condensation taking place on the surface of equipment converying fluids at a very low temperature.

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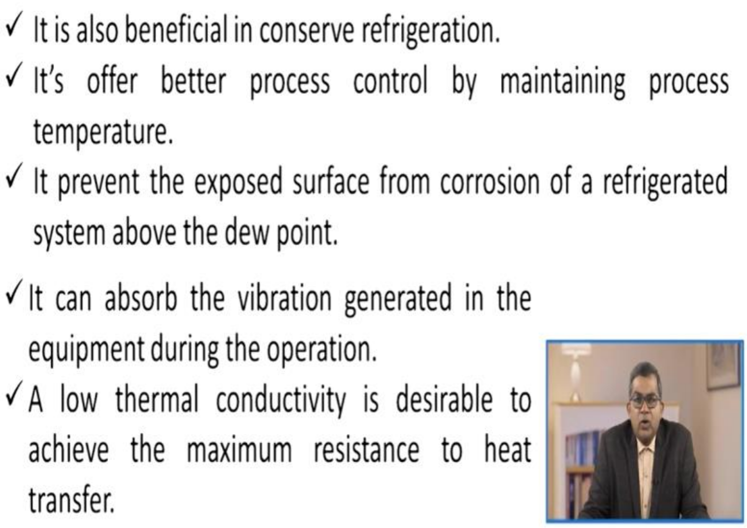

It is also beneficial to conserve refrigration its offer better process control by maintaining process temperature. It prevent the expose surface from corrosion of a refrigerator system above the due point. It can absorb the vibration generated in the equipment during the operation. A low thermal conductivity is desirable to achieve the maximum resistance to heat transfer.

Now basis of thickness of insulation says that temperature usually specified on the outer surface of the insulation one must consider heat loss per unit dimension. Now if economic thickness is considered then necessary formation requried or cost of heat required working period and cost to the finish. The temperature condition for the surface of insulation should be specified the reason required for the insulation to provide the specified condition at the boundary surface of the containment system.

They are to avoid the differential thermal expansion between the insulated surface and adjacent to structure to prevent the condensation of moisture at internal surface to prevent the condensation of the moisture at the external surface. And to ensure the wall of the containment system are not subjected to excess temperature. Specified fluid conditoin at the delivery point special thickness required for the given duty.

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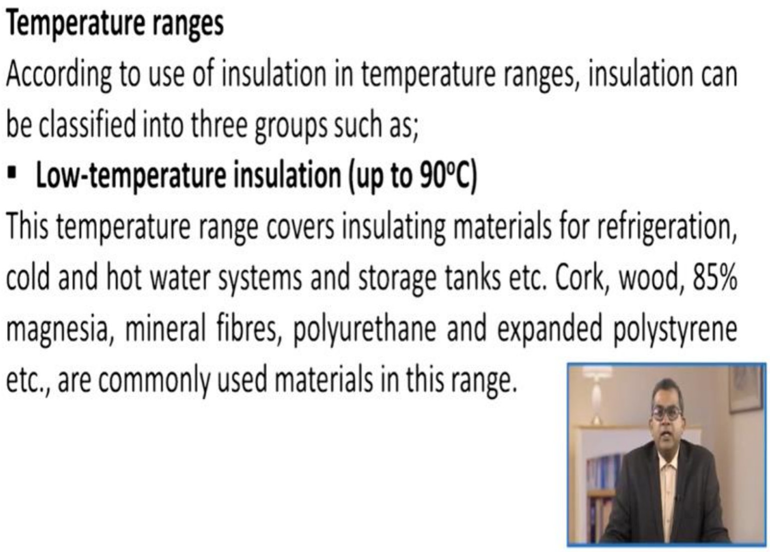

Let us talk about the temperature ranges according to the use of insulation in the tempature ranges insulation can be classified in 3 different groups. One is the low temperature insulation that is up to 90 degree now this temperature range cover insulating material for refrigeration cold and hot water systems and storage tanks. Cor wood 85% magnesia, mineral fibers polyurethane and expanded polystyrene etc., they are the commonly used material in this range.

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- **Medium-temperature insulation (90-325ºC)**
  - ✓ Insulators in this range used in low temperature heating, steam raising equipment's, flue ducts and steam lines etc.
  - ✓ The materials including 85% magnesia, calcium silicate, mineral fibers and asbestos are used in this temperature range.

The medium temperature insulation ranges from 90 to 325 Celsius the insulator in this range used in low temperature heating system raising equipments flow ducts and steam lines. The material including 85% megnesia, calcium silicate, mineral fibers and asbestos they are used in this temperature range.

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- **High-temperature insulation (above 325ºC)**
  - ✓ Used in superheated steam system, oven dryers and furnaces etc.
  - ✓ Mostly asbestos, mineral fibers, mica and vermiculite based insulation, ceramic fibers, fireclay or silica-based insulation and calcium silicate.

Last category in this regard is the high temperature insulation and that is above 325 degree Celsius using the super heated steam system, oven dryers and furnaces. Mostly asbestos, mineral fibers, mica, vermiculite based insulation, ceramic fibers, firelcay or silica-based insulation and calcium silicate. Let us talk about the insulating material. Now insulating materials can also be classified into organic and inorganic type. The organic insulating materials this includes the hydrocarbon polymers expand to obtain the high void structure such as polyurethane foam and thermocol that is expanded polystyrene.

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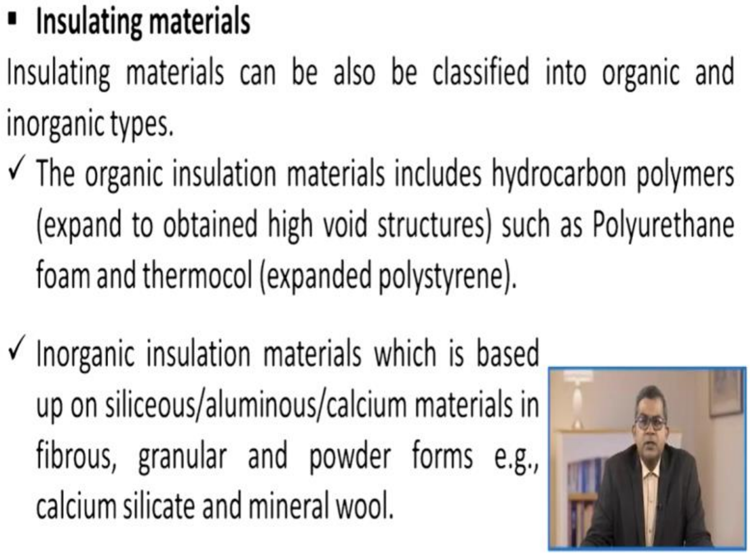

Inorganic insulation material which is based up on siliceous aluminatious calcium material in fiberous granular and powder forms like calcium silicate and mineral wools.

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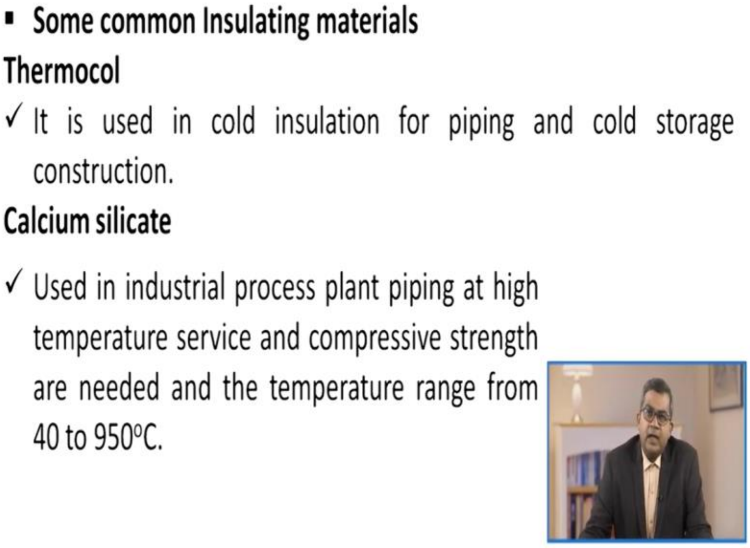

There are some common insulating materials like thermocl it is used in the fold insulation for piping and cold storage construction and its very popular. The calcium silicate used in industrial process plant piping at high temperature service and compressive strength are needed and the temperature ranges from 40 to 950 degree Celsius.

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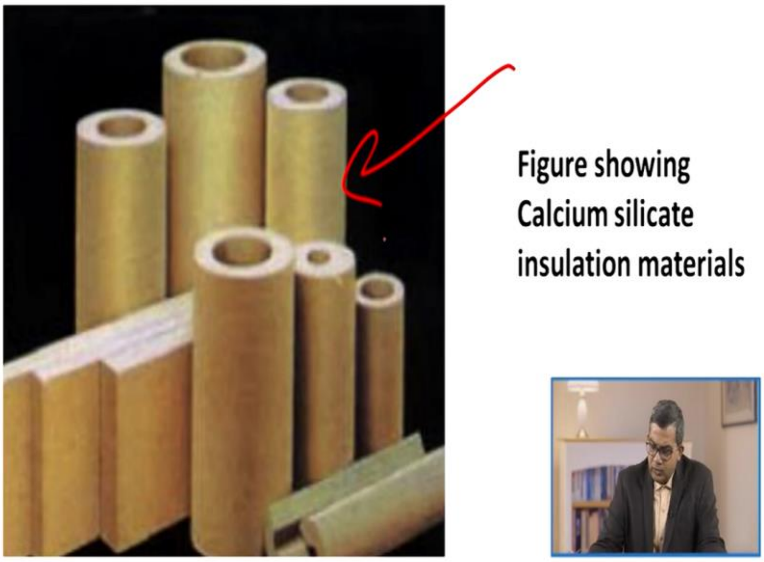

Now this is the figure which shows the calcium silicate insulation material.

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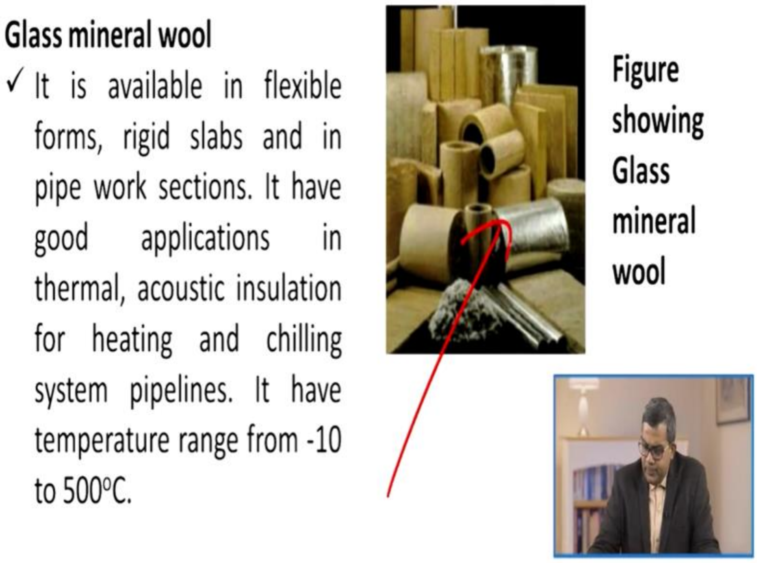

Now glass mineral wools now it is available in flexible form rigid slabs and in pipe works sections it has a good application in thermal, acoustic insulation for heating and chilling system pipelines . It have the temperature ranges from -10 to 500 degree Celsius and here you see that this is the glass mineral wool.

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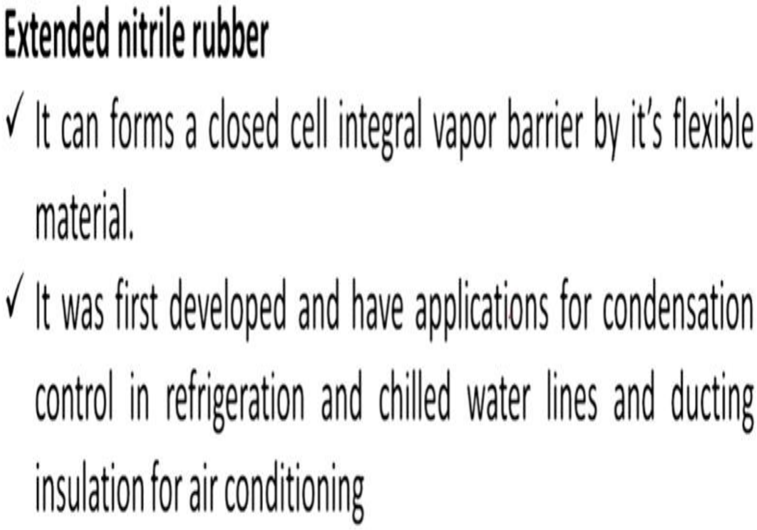

Extended nitrile rubber now it can form a closed cell integral vapour barrier by its flexible material. It was first developed and have application for condensation control in refrigeration and chilled water lines and ducting insulation for air conditioning.

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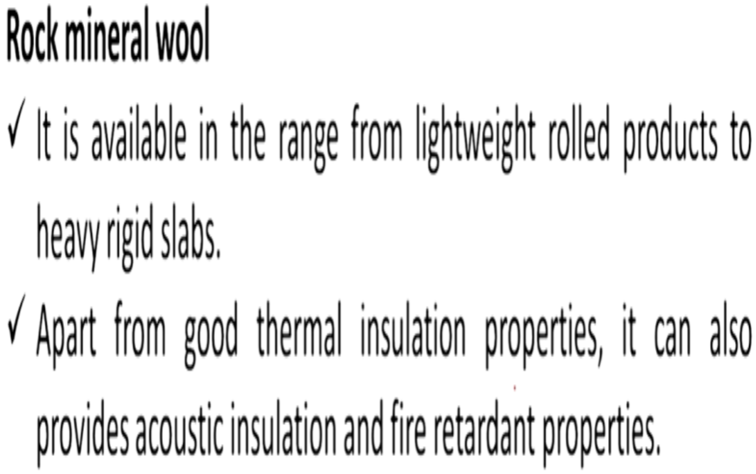

Rock mineral wool it is available in the range from lightweight rolled products to heavy rigid slabs. Apart from good thermal insulation properties it can also provide acoustic insulation and fire retardant properties.

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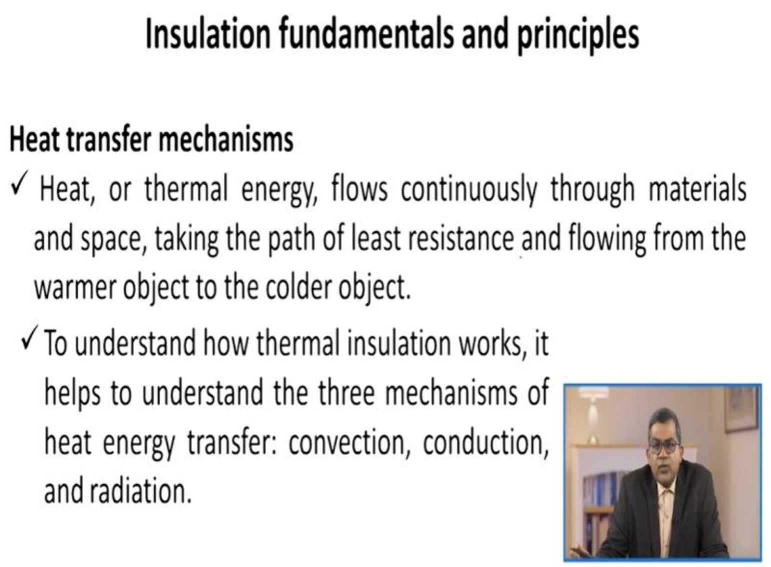

Now let us talk about the insulation fundamental and principles now in this category the heat transfer mechanism played a very vital role. So let us talk about the heat transfer mechanism. Heat or thermal energy flows continously through material and space taking the path of least resistance and flowing from the warmer object to the colder object. To understand how thermal insulation works it helps to understand the 3 mechanism of heat energy transfer one is convection, conduction and radiation.

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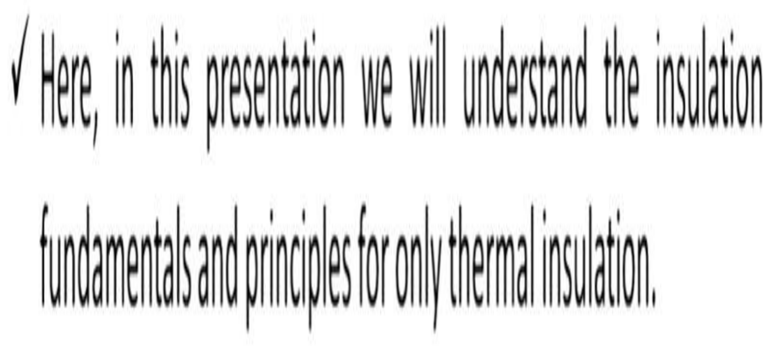

Now in this paritcular aspect we will understand that the insulation fundamental and principle for the only thermal insulation. Let us talk about the convection.

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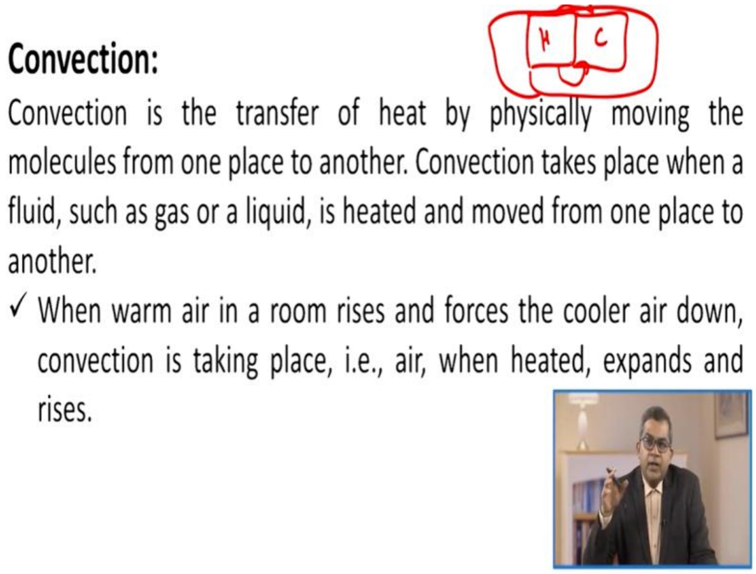

Now convection is the transfer of heat physically by moving the moelcules from one place to another. Now convection takes place when a fluid such as a gas or liquid is heated and move from one place to another. Now when warm in the room raises and a forces a cooler air down the convection is taking place and air when heated expands and rises.

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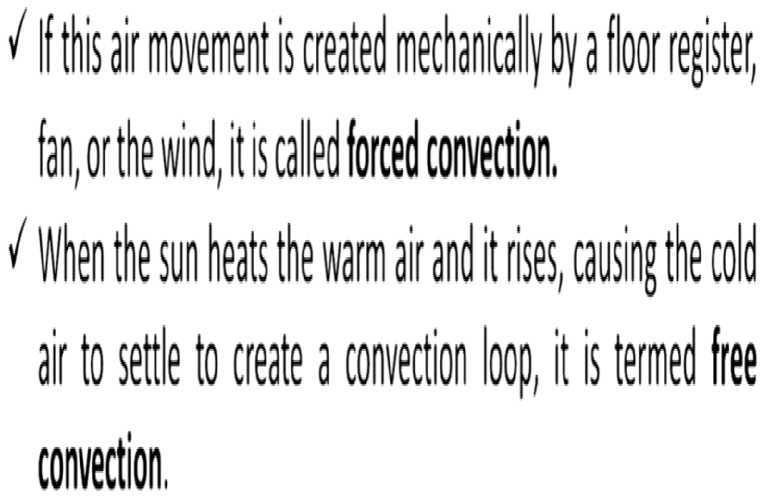

Now if this air movement is created mechanically by a flow register fan or wind it is called a force convection. When the sun heats the valve air and it raises causing the cold air to settle to create a convection to loop it is termed as a free convection.

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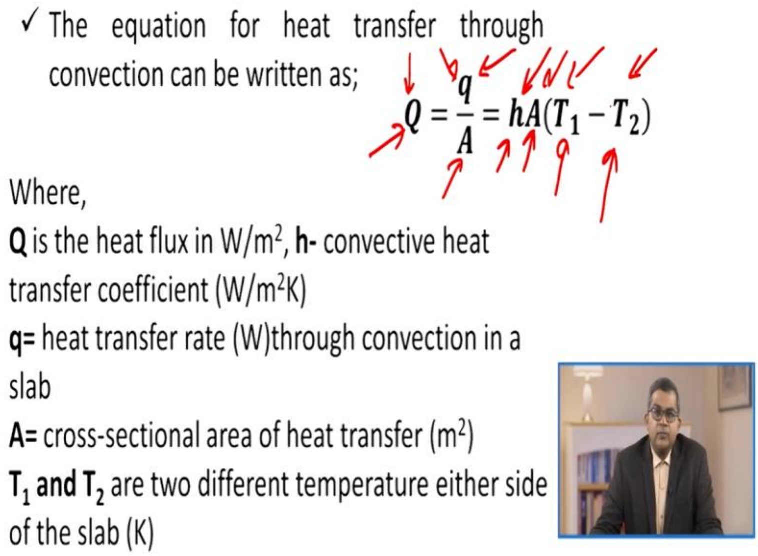

Now the equation for the heat transfer through convection it can be written as Q that is the Q = q over A = h_A into $T_1 – T_2$. Now here this Q is the heat flux having the unit in watt per meter square. Now h is the convective heat transfer coefficient having the unit of watt per meter square Kelvin. This q is the heat transfer rate in watts through the convection in a slab. A is the cross sectional area of heat transfer and represented in terms of square meter. The T_1 and T_2 they are the 2 temperature different temperature in either side of the slab.

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The equation for heat transfer through convection can be written as;

$$Q = \frac{q}{A} = hA(T_1 - T_2)$$

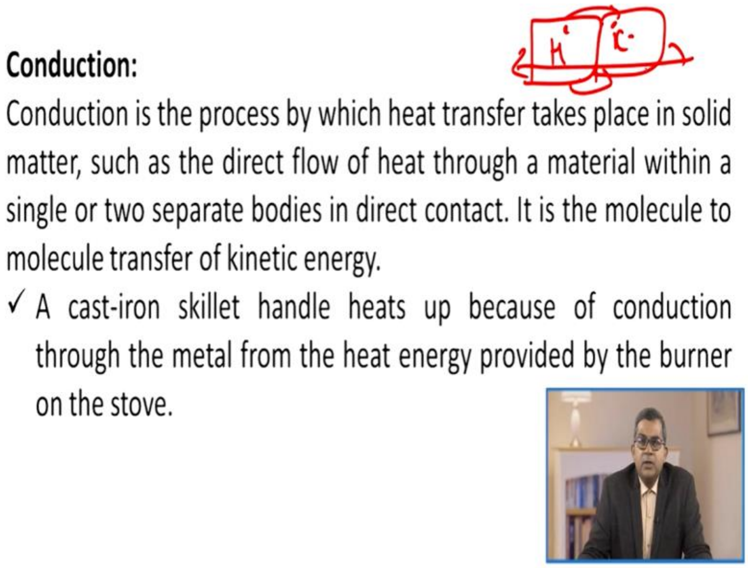
Where,

Q is the heat flux in W/m^2, h- convective heat transfer coefficient (W/m^{2}K)

q= heat transfer rate (W)through convection in a slab

A= cross-sectional area of heat transfer (m^2)

T_1 and T_2 are two different temperature either side of the slab (K)



Let us talk about the conduction. Conduction is a process by which heat transfer takes place in solid metal such as direct flow of heat through a material within single or 2 separate bodies in direct contact. Now it is the molecule to mocule transfer of kinetic energy so suppose this is the hotter body and this is the colder body. This molecule to molecule transfer takes place with respect to the kinetic energies until the temperature in both the slabs become uniform.

A cast iron skillet handle heats up because of the conduction through the metal from the heat energy provided by the burner on the stove.

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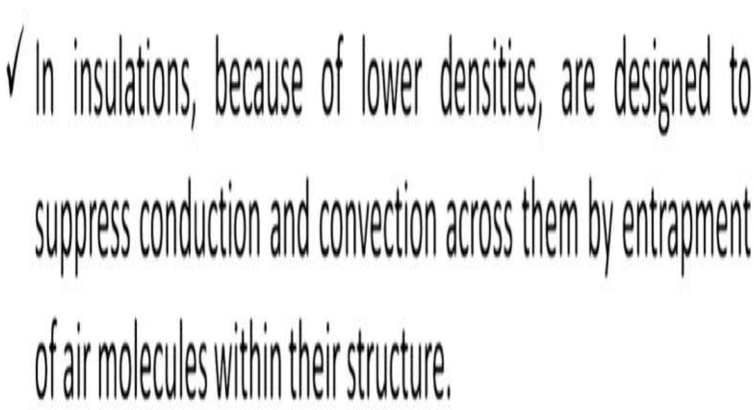

In insulation because of lower densities they are designed to suppress the conduction and convecttion across them by interactment of air molecules within their structure.

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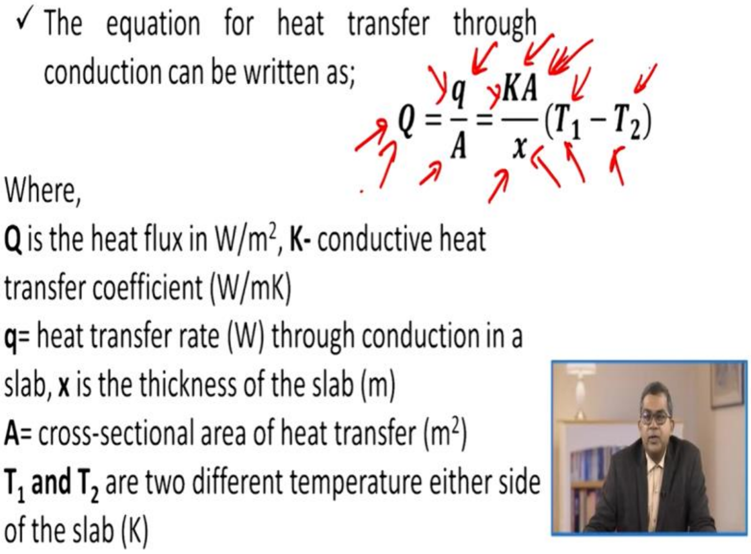

Now again let us talk about the mathematical representation or equation for heat transfer through conduction this can be written as Q, q over A this KA upon x into $T_1 - T_2$. Now this Q is the heat flux in watt per meter square K is the conductive heat transfer coefficient having the unit of watt Kelvin this q is heat transfer rate in watt through the conduction slab x is the thickness of the slab in meter.

A is the area of cross section of heat transfer in meter square and T_1 and T_2 they are the 2 different temperature on either side of the slab and they are represented in Kelvin.

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The equation for heat transfer through conduction can be written as;

$$Q = \frac{q}{A} = \frac{KA}{x}(T_1 - T_2)$$

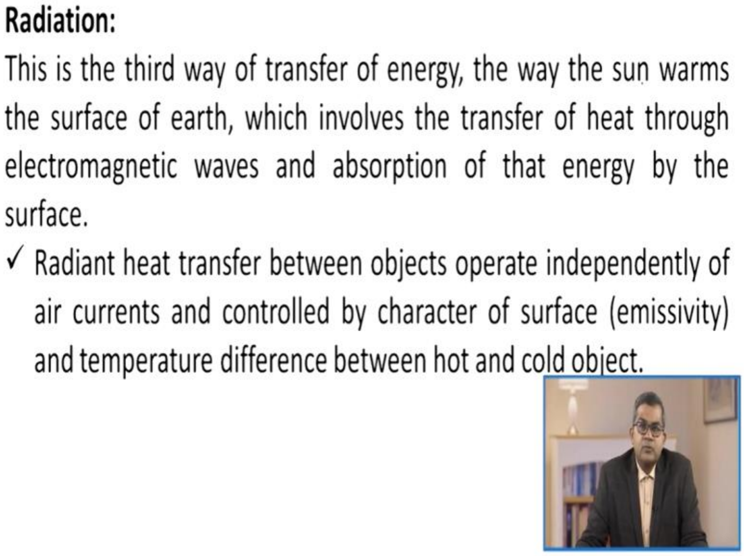
Where,

Q is the heat flux in W/m^2, K- conductive heat transfer coefficient (W/mK)

q= heat transfer rate (W) through conduction in a slab, x is the thickness of the slab (m)

A= cross-sectional area of heat transfer (m^2)

T_1 and T_2 are two different temperature either side of the slab (K)



Let us talk about the radiation now this is the third way of transfer of energy the way the sun wants the surface of earth which involves the transfer of the heat through electromagnetic waves and absorption of that energy by the surface. The radiant heat transfer between object operates independently of air current and controlled by character of surface emissivity and the temperature difference between hot and cold object.

Now emissivity refers to the ability of materials surface to emit radiant energy all of the material have emissivity between ranging from 0 to 1. Now the equation again we need to represent this with the help of a mathematical correlation or equation.

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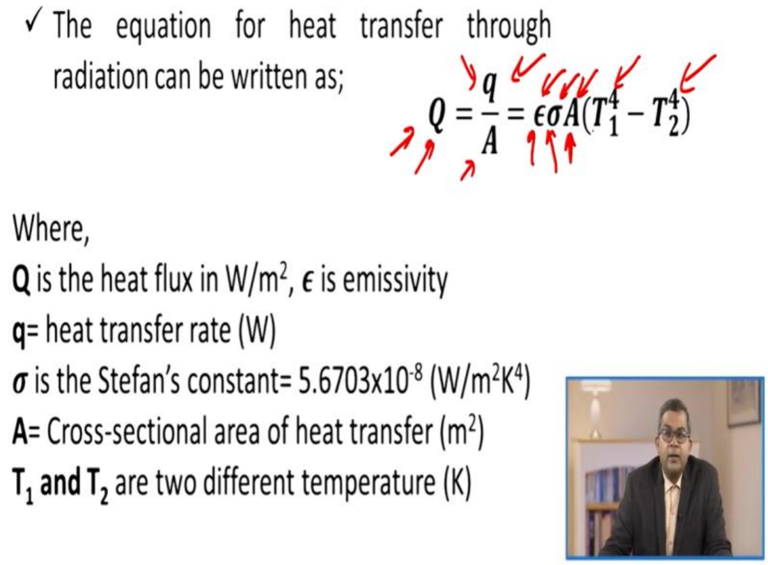

So the equation for the heat transfer through radiation can be written as Q = q over A epsilon small sigma A T_1 to the power 4 – T_2 to the power 4. Now Q is the heat flux in watt per meter square epsilon is the emmisivity this one. This is q is the heat transfer rate w theta is the difference constant and A is the area of cross section of heat transfer and represented as meter square and T_1 asnd T_2 again they are the 2 different temperature and unit is Kelvin.

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The equation for heat transfer through radiation can be written as;

$$Q = \frac{q}{A} = \epsilon \sigma A (T_1^4 - T_2^4)$$

Where,

Q is the heat flux in W/m^2, ϵ is emissivity

q= heat transfer rate (W)

σ is the Stefan's constant= 5.6703x10^{-8} (W/m^{2}K^4)

A= Cross-sectional area of heat transfer (m^2)

T_1 and T_2 are two different temperature (K)

Resistance of these modes of heat transfer may be retarded by the elements of a building wall section, the elements includes;

1. **Outside surface film:** outside surface traps a thin film of air, which resists heat flow, this film section varies with wind velocity and surface roughness.
2. **Material layer:** each layer of material contributes to the resistance of heat flow, usually according to its density.

Now resistance of these modes of heat transfer this maybe retarded by the elements of a building wall section and the elements includes outside surface film. The outside surface traps a thin film of air which is resist the heat flow this film section varies with wind velocity and surface roughness. Material layer each layer of material contributes to the resistance of heat flow usually according to its density.

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3. **Airspace**: each measurable airspace, as well as its thickness, also adds to the overall resistance.

4. **Inside surface film:** the inside surface of a building section also traps a thin film of air.

Air space such mesurable airspace as well as its thickness also add to the overall resistence inside surface film. The inside surface of building section also traps a think film of air.

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Heat flow

The heat always flows from a warmer object to a colder object, in terms of buildings, we refer to heat flow in a number of different ways.

- ✓ It is the measurement of this heat flow that allows for the mathematical analysis of wall, floor, and ceiling assemblies.
- ✓ Here, U-Value and R-value are most common method used.

Let us talk about the heat flow, the heat always flows from a warmer object to colder object in terms of buildings and we refer to heat flow in a number of different ways. It is the measurement of this heat flow that allows for the mathematical analysis of wall, floor and ceiling assemblies.. Here U value and R value are most common method used.

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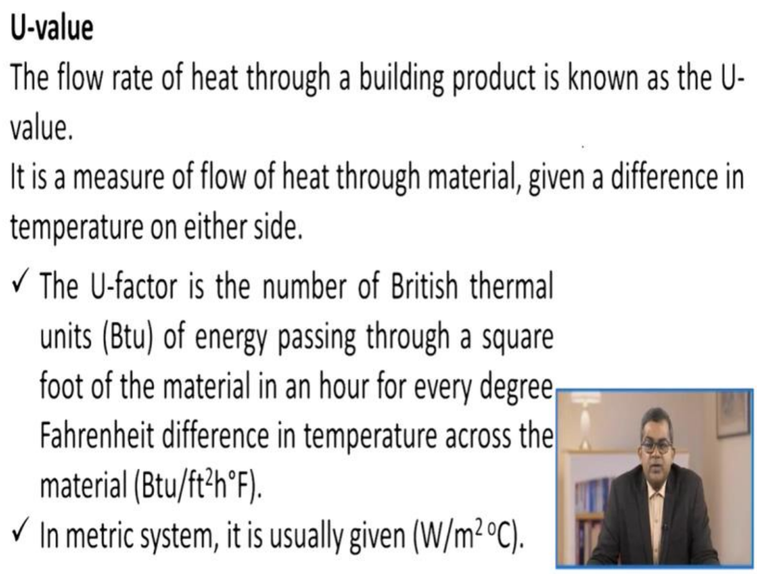

Let us talk about U value the flow rate of heat through a building product is known as U value. It is a major of flow of heat though material given a different temperature on either side. The u factor is the number of British thermal unit that is representation of BTU that is energy passing through a square foot of the material in hour for every degree Farenheit difference in termperature at across the material.

And that is the BTU per feet square hour degree Farhenheit in metric system it is usually given as watt per meter square degree.

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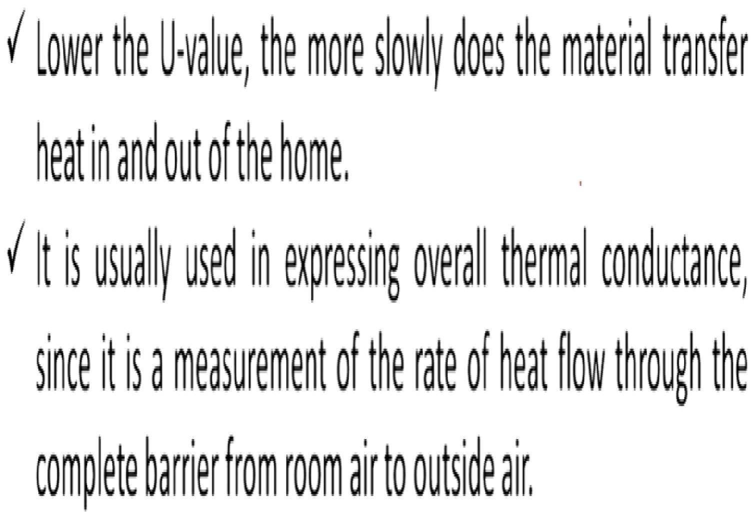

Lower the U value the more slowly does the material transfer heating and out of the home. It is usually used in expressing overall thermal conductance since it is a measurement of the rate of heat flow through the complete barrier from room air to outside air.

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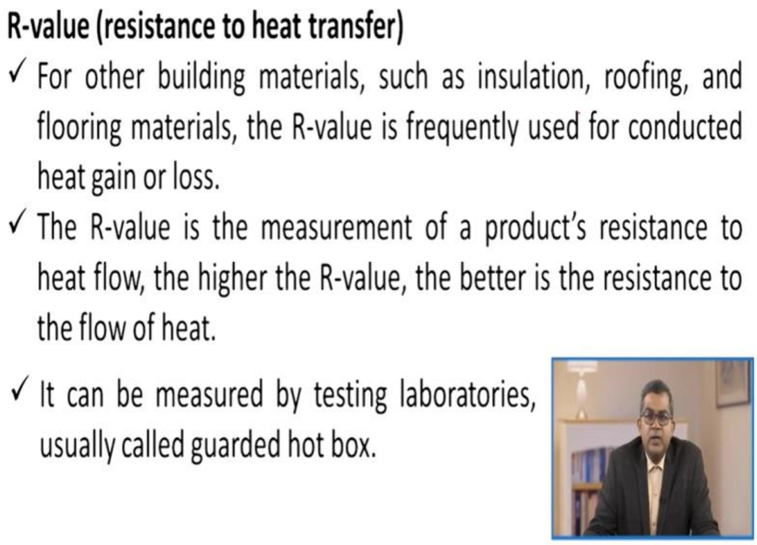

R value that is resistance to heat transfer for other building materials such as insulation roofing and flooring material the R value is frequently used for conducted heat gain or loss. The R value is the measurement of a product resistence to heat flow and higher R value the better is the resistance to the flow of heat. It can be measured by testing laboratories usually called guarded hot box.

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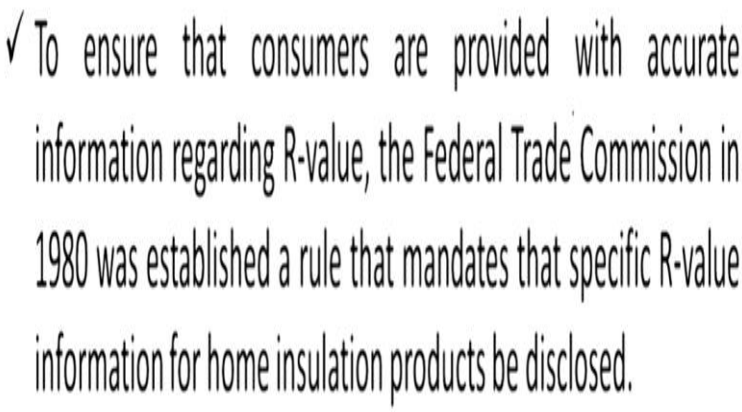

To ensure that consumer are provided with accurate information regarding R value the federal trade commission in 1980 established a rule that mandates the specific R value information for home insulation product to be disclosed.

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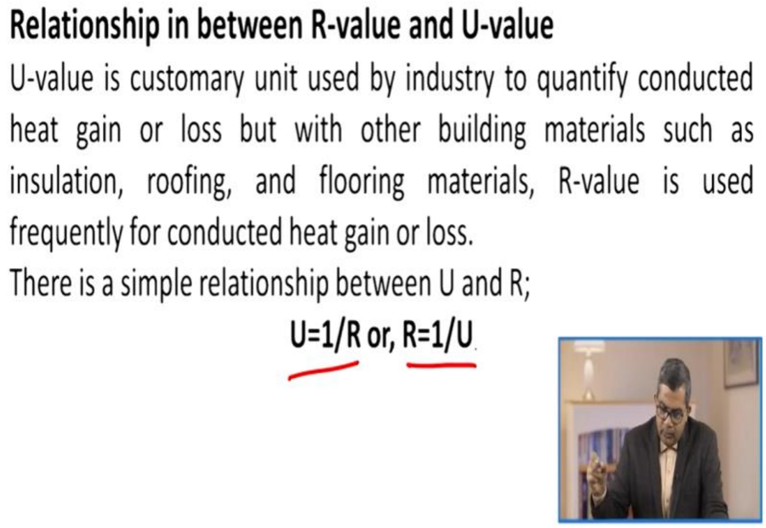

Relationship between R value and U value is customary unit used by the industry to quantify conducted heat gain or loss. But with other building material such as insulation roofing and flooring materials R value is used frequently for conducted gian or loss. There is simple relationship between U and R U = 1 by R or R = 1 by U.

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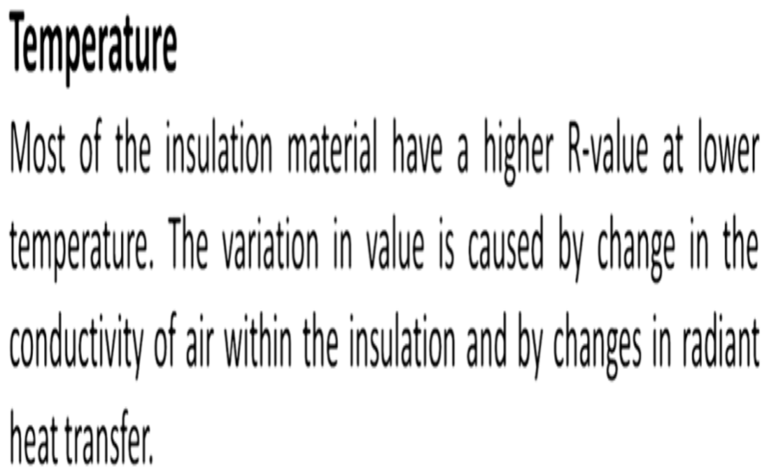
There is a simple relationship between U and R;
U=1/R or, R=1/U



Let us talk about the temperature this is the one of the most common phenomena to be addressed in the insulation. Most of the insulation material have a higher R value at lower temperature. The variation in values is caused by the change in conductivity of air within the insulation and by changes in radiant heat transfer.

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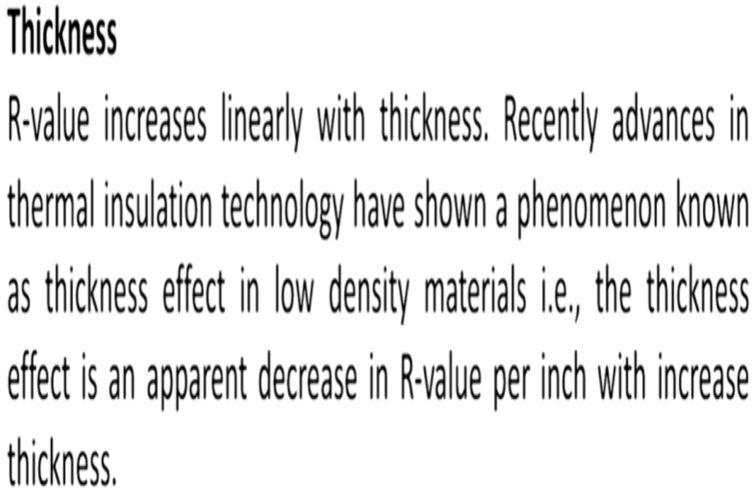

Thickness value increases linearly with thickness recently advances in thermal insulation technology have been shown a phenomenon known as thickness effect in low density material and that is the thickness effect and is an apparent decrease in R value per inch with increases thickness.

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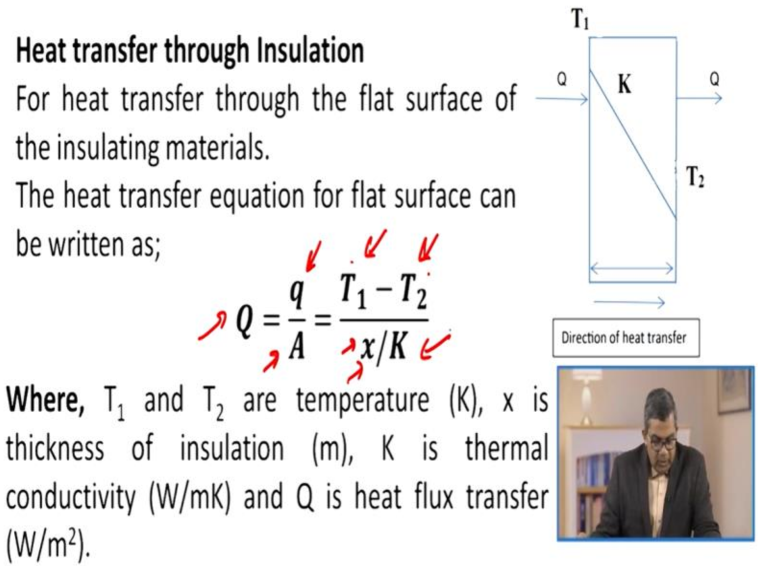

Heat transfer through insulation for heat transfer through the flat surface of the insulating material. The heat transfer equation for flat surface these can be written as Q = q over A that is equal to $T_1 – T_2$ upon x over K where T_1 and T_2 they are temperature in Kelvin x is the thickness of insulating material or insulation. K is the thermal conductivity and having the unit of watt pet meter Kelvin. And Q is the heat flux transfer watt per meter square.

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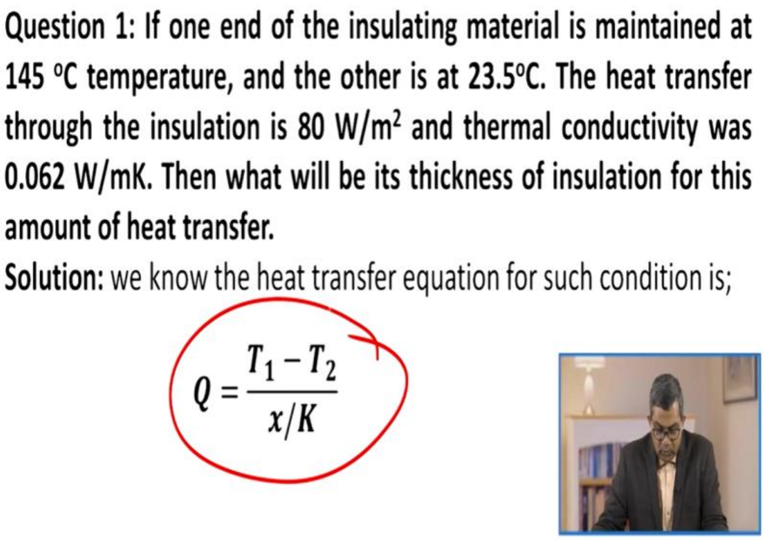
The heat transfer equation for flat surface can be written as;

$$Q = \frac{q}{A} = \frac{T_1 - T_2}{x/K}$$

Where, T_1 and T_2 are temperature (K), x is thickness of insulation (m), K is thermal conductivity (W/mK) and Q is heat flux transfer (W/m^2).



Now let us take up couple of question as a numerical if first question that is if one end of the insulating material is maintained at 145 degree Celsius temperature and the other end is maintained at 23.5 degree Celusius. The heat transfer through the insulation is 80 wattt per meter squared and thermal conductivity is 0.062 watt per meter Kelvin then what will be thickness of the insulation for this amount of heat transfer?

Now see in this particualr to solve this particular question we are having this heat transfer equation and that is Q = T_1 – T_2 over x over K.

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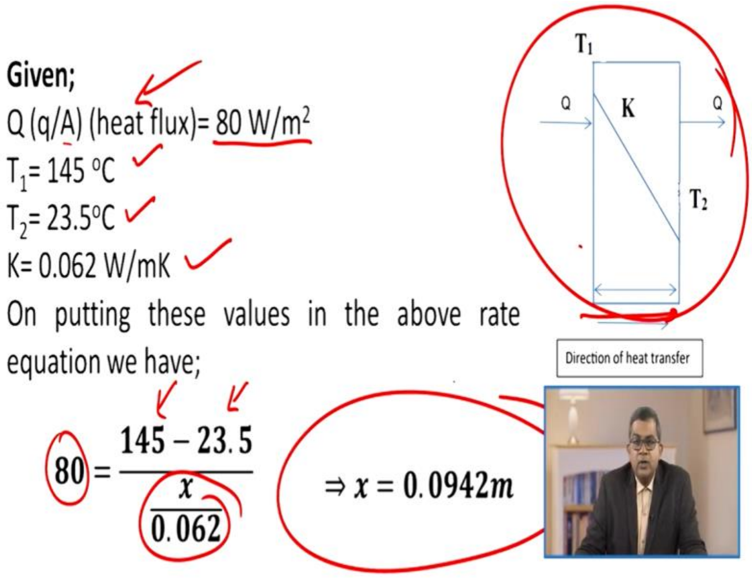
we know the heat transfer equation for such condition is;

$$Q = \frac{T_1 - T_2}{x/K}$$



Now it is given that Q into q/A that is heat flux is 80 watt per meter square now this is the direction of heat transfer and this is the typical figure of a slab. Here, T_1 is given as 145 degree Celsius and T_2 is given as 23.5 degree Celsius and K is also supplied in the question and that is 0.062 watt per meter Kelvin. Now if we substitute these values in the this rate equation then we have 80 = 145 – 23.5 over x over 0.062. So you will get the x = 0.0942 meter.

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Given;

Q (q/A) (heat flux)= 80 W/m^2

T_1= 145 ^{o}C

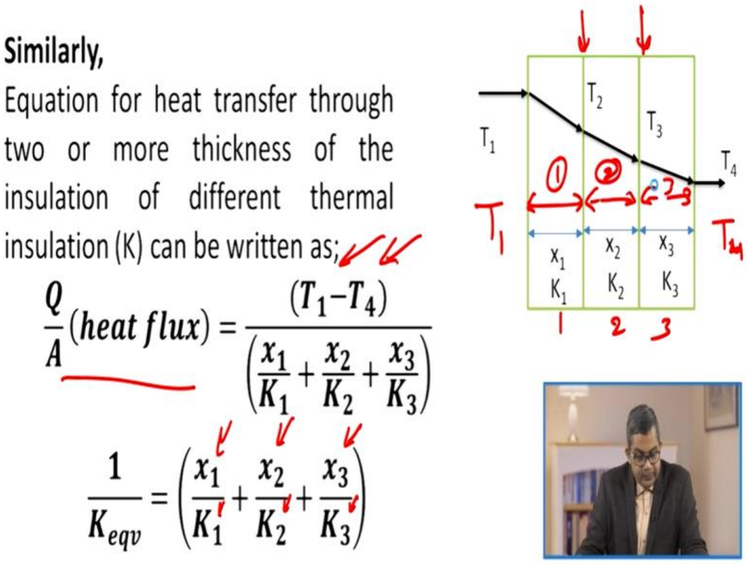
T_2= 23.5^{o}C

K= 0.062 W/mK

On putting these values in the above rate equation we have;

$$80 = \frac{145 - 23.5}{\frac{x}{0.062}}$$

$$\Rightarrow x = 0.0942m$$



Similarly equation for heat transfer through 2 or more thickness for the insulation of different thermal insulation K can be written as Q over A that is the heat flux that is equal to $T_1 – T_4$ upon x_1 over K_1 + x_2 over K_2 + x_3 over K_3. Actually here you are having 3 different slabs 1, 2 and 3. So this is represented and here the initial temperature is T 1 and finally the temperature is T_4 and these 3 slabs are aligned together.

So the interface temperature is T_1 between T first slab and second slab and interface temperature is T_3 between slab 2 and slab 3. So it is one upon K equivalent is equal to x_1 over K_1 + x_2 over K_2 + x_3 over K_3. Now here x_1 is the length of this slab number 1 x 2 is the length of this slab number 2 and x_3 is for third step.

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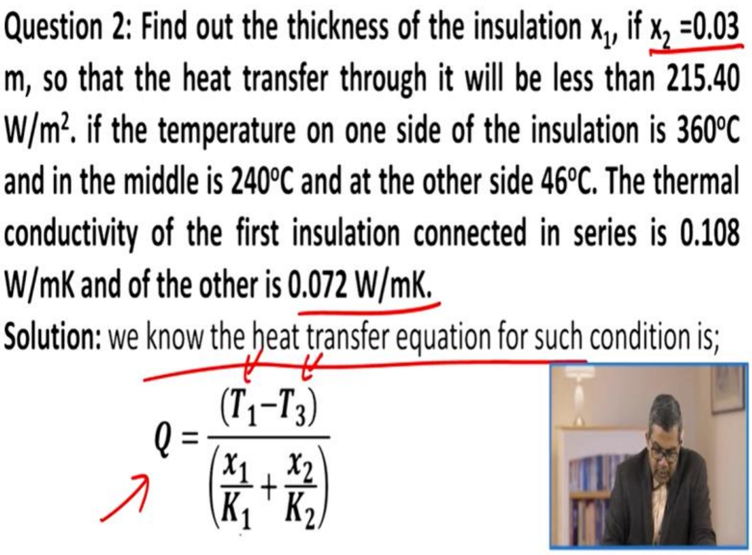
Similarly,

Equation for heat transfer through two or more thickness of the insulation of different thermal insulation (K) can be written as;

$$\frac{Q}{A}(heat\ flux) = \frac{(T_1 - T_4)}{\left(\frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3}\right)}$$

$$\frac{1}{K_{eqv}} = \left(\frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3}\right)$$



Let us talk about the sceond question in this particular question find out the thickness of the insulation x1 if x 2 = 0.03 meter. So that the heat transfer through it will be less than 215.40 watt per meter square. If the temperature on one side of the insulation is the 360 degrees Celsius and in the middle is 240 degree Celsius and the other side is 46 degree Celsius. The thermal conductivity of the first insulation connected to the series is 0.108 watt per meter Kelvin and the other side is 0.072 watt per meter Kelvin.

So we know that the heat transfer equation for such condition which is already discussed that is Q = $T_1 - T_3$ upon x_1 over K_1 + x_2 over K_2.

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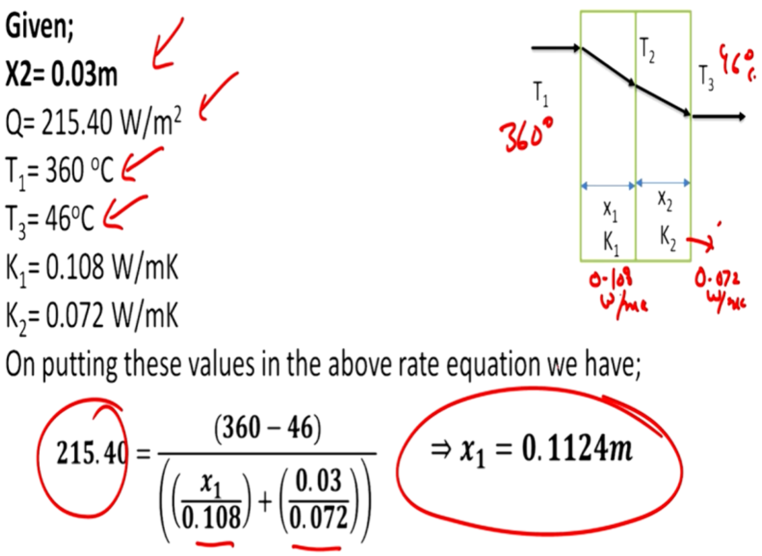
we know the heat transfer equation for such condition is;

$$\boldsymbol{Q = \frac{(T_1 - T_3)}{\left(\frac{x_1}{K_1} + \frac{x_2}{K_2}\right)}}$$



It is given that $X_2 = 0.03$ meter Q = 215.40 watt per meter square T_1 is given as 360 degree Celsius T_3 is given as 46 degree Celsius K 1 is given as 0.108 watt per meter Kelvin and K_2 is given as 0.072 watt per meter Kelvin. Now if we substitute this values in this particular equation then we get 215.40 = 360 – 46 upon x_1 over 0.108 + 0.03 over 0.072. So by this way we get x 1 = 0.1124 meter.

So in this particular chapter we discussed the various aspects of insulation we categorized the different parameters and discussed couple of numericals.

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Given;

X2= 0.03m

Q= 215.40 W/m^2

T_1= 360 °C

T_3= 46°C

K_1= 0.108 W/mK

K_2= 0.072 W/mK

On putting these values in the above rate equation we have;

$$\mathbf{215.40 = \frac{(360 - 46)}{\left(\left(\frac{x_1}{0.108}\right) + \left(\frac{0.03}{0.072}\right)\right)}}$$

$$\Rightarrow \boldsymbol{x_1 = 0.1124m}$$

References

- Richard T. Bynum, Insulation Handbook, McGraw-Hill Companies, Inc., (2014), ISBN: 0-07-134872-7, DOI: 10.1036/0071414614.
- Alireza Bahadori, Thermal Insulation Handbook for oil, gas and petrochemical industries, Elsevier (2013), ISBN: 978-0-12-800010-6.

For your convenience we have enlisted couple of references if you wish you can have further study with the help of these references thank you very much.