Chemical Process Utilities

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Lecture – 30
Insulation of Steam Generators

Welcome to the new concept of insulation of steam generators. As you know, we discussed various aspects of stream distribution network with different accessories and mountings attributed to the boiler house, etcetera. Now when we talk about steam generators, the insulator is a very prominent phenomenon. Before we go into the detail, let us look at what different kinds of topics we covered previously.

We discussed the concept of water for a boiler then we discussed the water carryover. We had a discussion about the external water treatment protocols under the aegis of accessories and mountings. We discussed the safety valves and their selection. How different types of safety valves can be used, what their construction materials are, and how you can select the appropriate one. We discussed the seating reseating concept for the safety of the boiler.

Condensate is an extremely important part of any steam distribution network and steam generation aspect. We discussed the condensate recovery concept.

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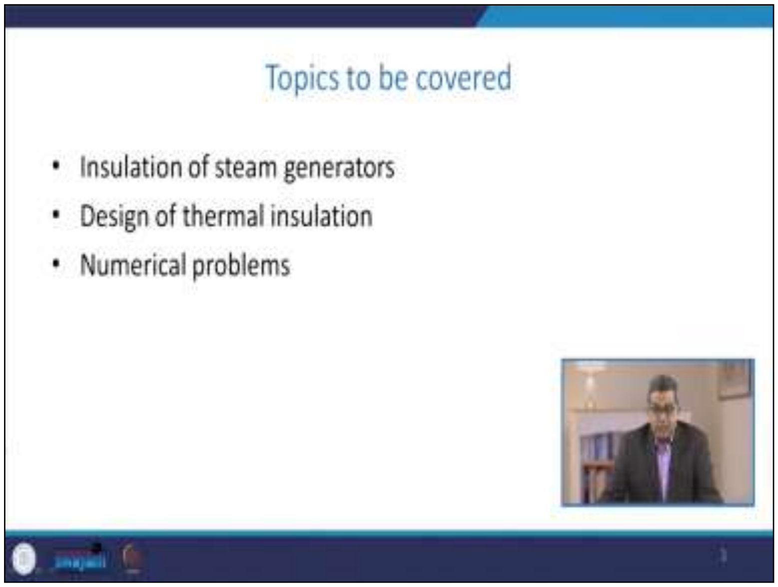

In this particular lecture, we will discuss the insulation aspect of steam generators. We will discuss the various design equations attributed to thermal insulation, and to support all these things, we will discuss a couple of numerical problems.

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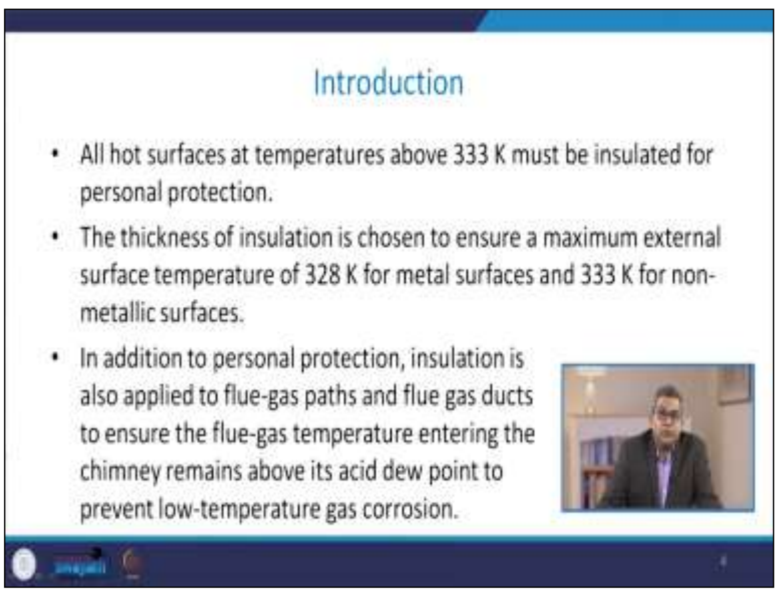

When we talk about insulation, all hot surfaces at a temperature above 333 Kelvin must be insulated for personal protection. It not only ensures the personal safety or the person those who are working around that particular surface must be safe but also ensures that the system's thermal efficiency must be secured properly. The thickness of insulation is usually chosen to ensure a maximum external surface temperature of 328 Kelvin for metal surfaces and 333 Kelvin for the non-metallic surface.

In addition to personal protection, insulation is also applied to the flue gas path and flue gas ducts to ensure the flue gas temperature entering the chimney remains above its acidic dew point to prevent low-temperature gas corrosion. This particular concept is again very important because it is below the acidic dew point. Then the condensation may take place, and whatever the condensate product may have a corrosion aspect, it can create a problem for the system.

Apart from this, you need to maintain the appropriate temperature due to environmental issues. So, all the flue gases must acquire the exit path properly. Additionally, thermal insulation is applied to a steam generator to ensure the steam is supplied to its point of application at the correct temperature without any drop.

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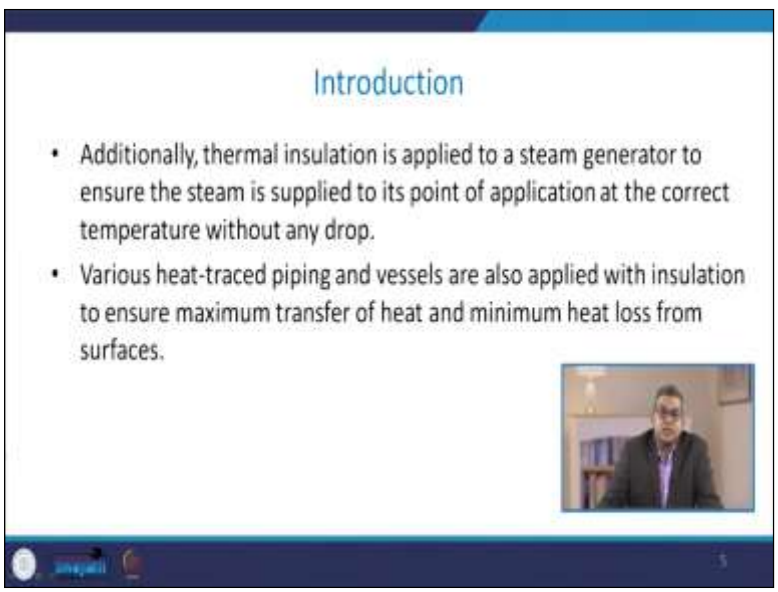

Now, various heat traced piping and vessels are also applied with insulation to ensure maximum heat transfer and minimum heat loss from the surface.

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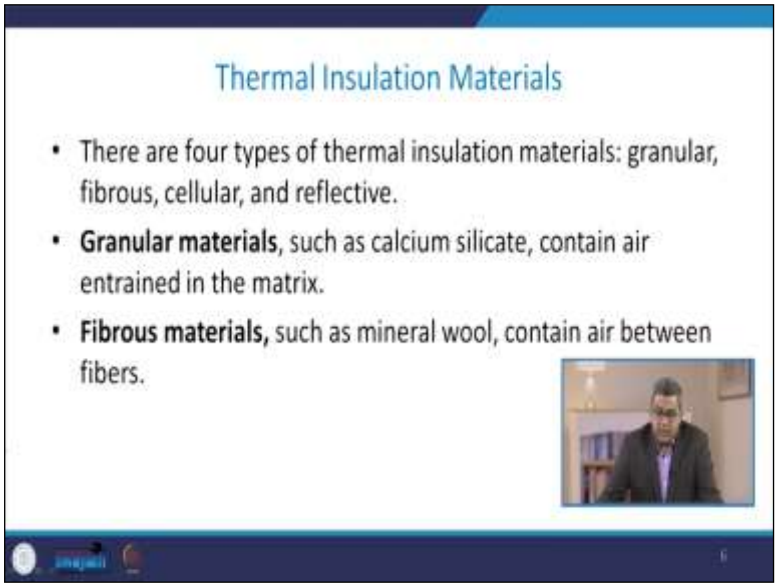

When we talk about thermal insulation, we obviously cannot overlook the importance of thermal insulation materials. There are four types of thermal insulation materials granular, fibrous, cellular, and reflective. Now the granular materials such as calcium silicate contain air entrained in the matrix. So, this acts as the insulating material. Fibrous materials such as mineral wool contain air between the fibers.

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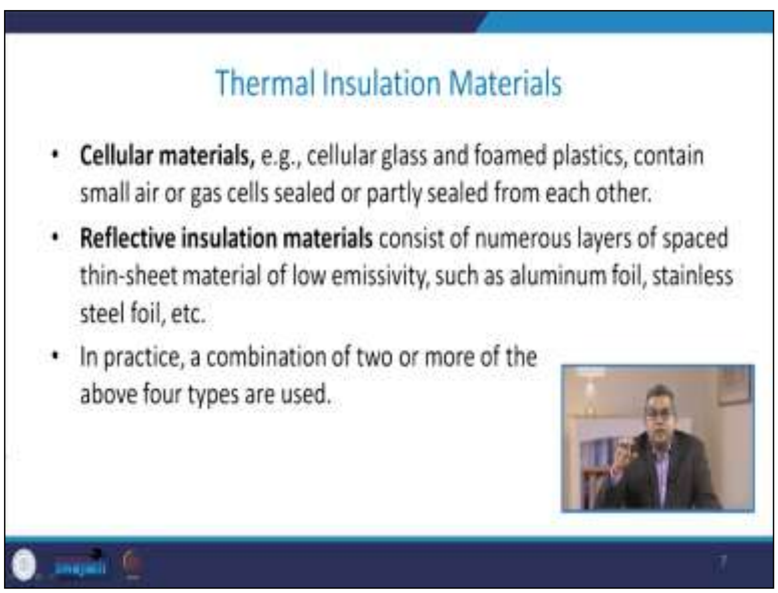

Now the third category is the cellular materials which are cellular glass and foam plastics. This contains small air or gas cells sealed or partly sealed from each other. These are reflective insulation materials. This consists of numerous layers of spaced thin sheet metal materials with low emissivity such as aluminum foil, stainless steel, etc. In practice, a combination of two or more of the above four types is being used.

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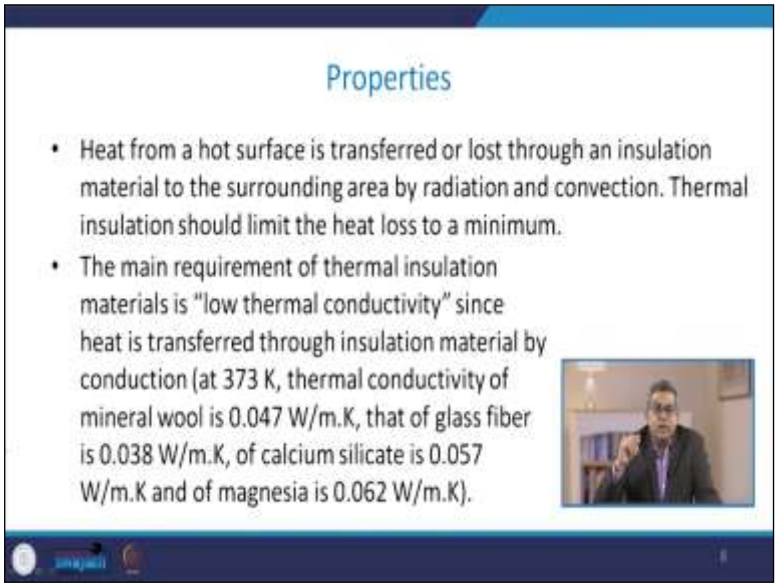

Let us talk about the properties. Now heat from a hot surface is transferred or lost through an insulating material to the surrounding area either by radiation or by convection. Thermal insulation should limit heat loss to a minimum. One main requirement of thermal insulation material is low thermal conductivity since heat is transferred through insulating material by conduction at 373 Kelvin thermal conductivity of said mineral.

Wool is 0.047 watts per meter Kelvin of glass fiber, it is 0.038 watts per meter Kelvin, calcium silicate is 0.057 watts per meter Kelvin, and magnesia, it is 0.062 watt per meter Kelvin. Thermal insulation material should have the following properties to ensure the satisfactory performance of the material for the life of a plant. Now, this is again very you can say the important thing because it should possess because any material cannot possess thermal insulation property.

So, there must be some requirement compatibility with the process. Now the material must be suitable for continuous use at maximum operating temperature without degradation to its physical properties. It must be noncorrosive to plant and pipework if wet by rain or leakage of water or steam. It should not be permanently damaged if contaminated with water. It should have adequate compressive strength to resist local loads such as food traffic, ladders, etcetera.

It must have adequate flexural strength and impact resistance to permit transportation and application without breakage. The material must be noncombustible it should not cause any discomfort or health hazard to the operating person. It should be tight free of whites, and well anchored. Now removal and replacement should be required only during the maintenance or modification of the plant.

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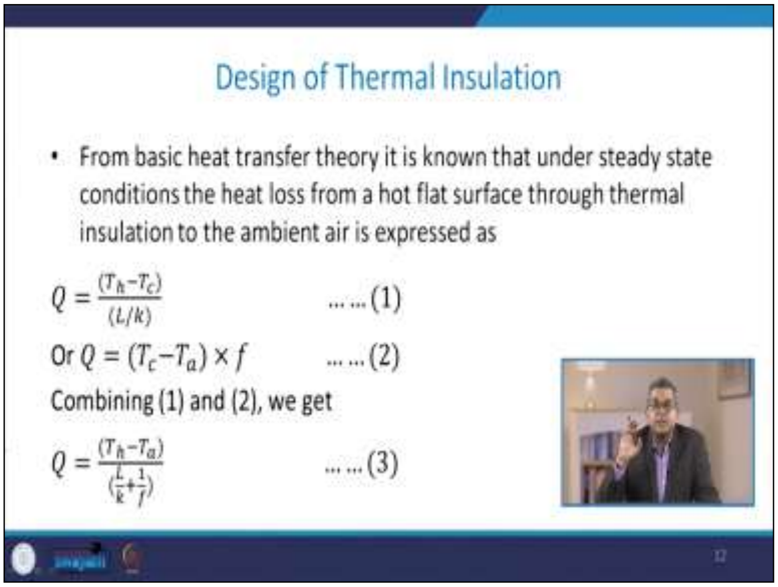

Now let us talk about the design of thermal insulation. From basic heat transfer theory, it is known that under steady-state conditions, the heat loss from a hot splat surface through thermal insulation to the ambient air is usually expressed as

$$Q = \frac{(T_h - T_c)}{(L/k)} \qquad \text{... ... (1)}$$

Or $Q = (T_c - T_a) \times f$ ... ... (2)

Combining (1) and (2), we get

$$Q = \frac{(T_h - T_a)}{(\frac{L}{k} + \frac{1}{f})} \qquad \text{... ... (3)}$$

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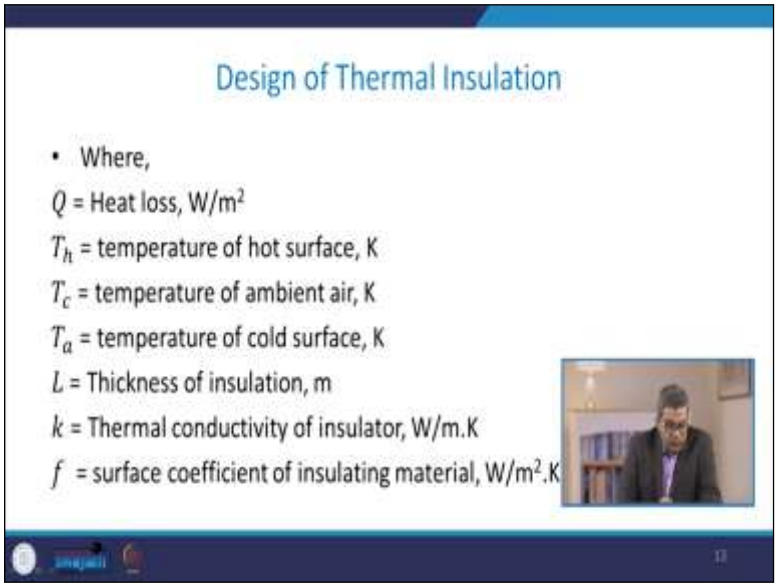

Where,

Q = Heat loss, W/m^2

T_h = temperature of hot surface, K

T_c = temperature of ambient air, K

T_a = temperature of cold surface, K

L = Thickness of insulation, m

k = Thermal conductivity of insulator, W/m.K

f = surface coefficient of insulating material, W/m^2.K

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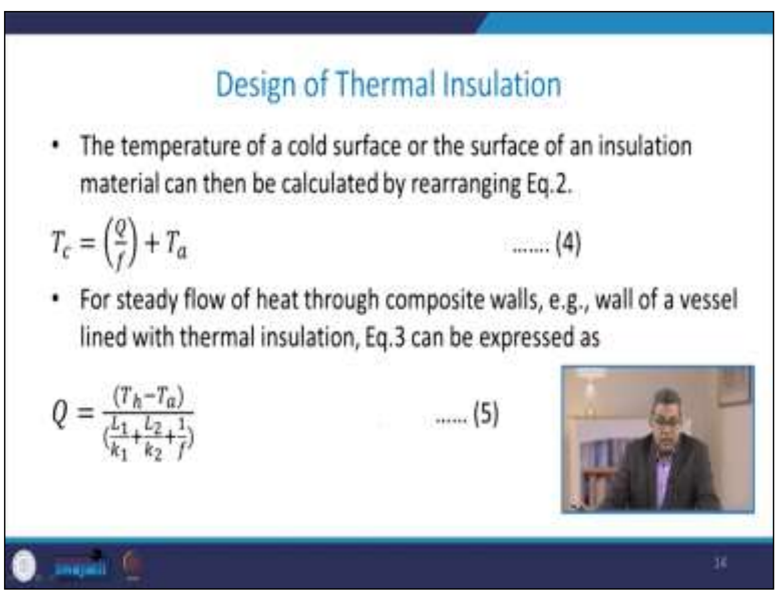

The temperature of a cold surface or the surface of an insulation material can then be calculated by rearranging Eq.2.

$$T_c = \left(\frac{Q}{f}\right) + T_a \qquad \ldots\ldots. (4)$$

For steady flow of heat through composite walls, e.g., wall of a vessel lined with thermal insulation, Eq.3 can be expressed as

$$\boldsymbol{Q} = \frac{(T_h - T_a)}{\left(\frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{1}{f}\right)} \qquad \textbf{...... (5)}$$

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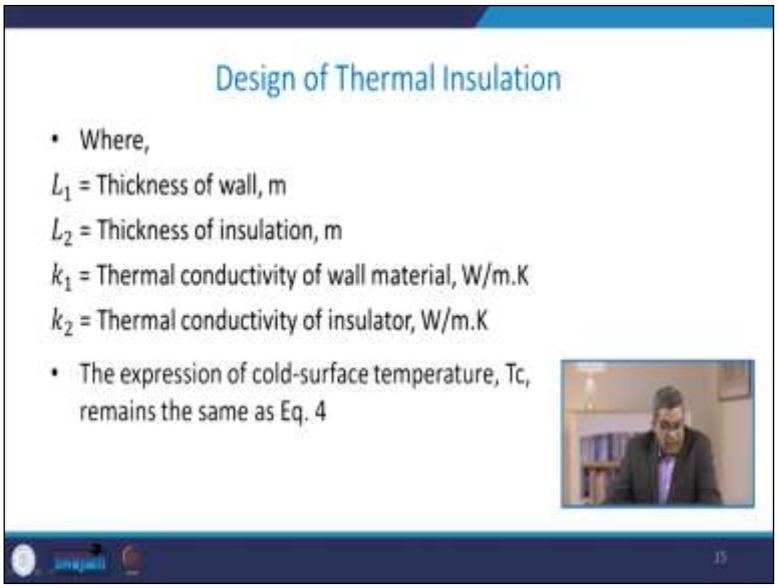

Where,

L_1 = Thickness of wall, m

L_2 = Thickness of insulation, m

k_1 = Thermal conductivity of wall material, W/m.K

k_2 = Thermal conductivity of insulator, W/m.K

The expression of cold-surface temperature, Tc, remains the same as Eq. 4

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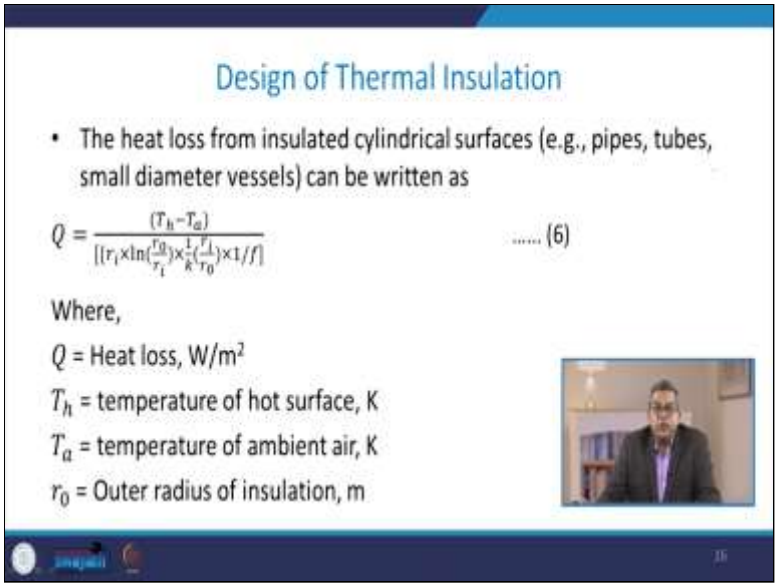

The heat loss from insulated cylindrical surfaces (e.g., pipes, tubes, small diameter vessels) can be written as

$$Q = \frac{(T_h - T_a)}{[\{r_i \times \ln(\frac{r_0}{r_i}) \times \frac{1}{k}(\frac{r_i}{r_0}) \times 1/f]} \qquad \ldots\ldots (6)$$

Where,

Q = Heat loss, W/m^2

T_h = temperature of hot surface, K

T_a = temperature of ambient air, K

r_0 = Outer radius of insulation, m

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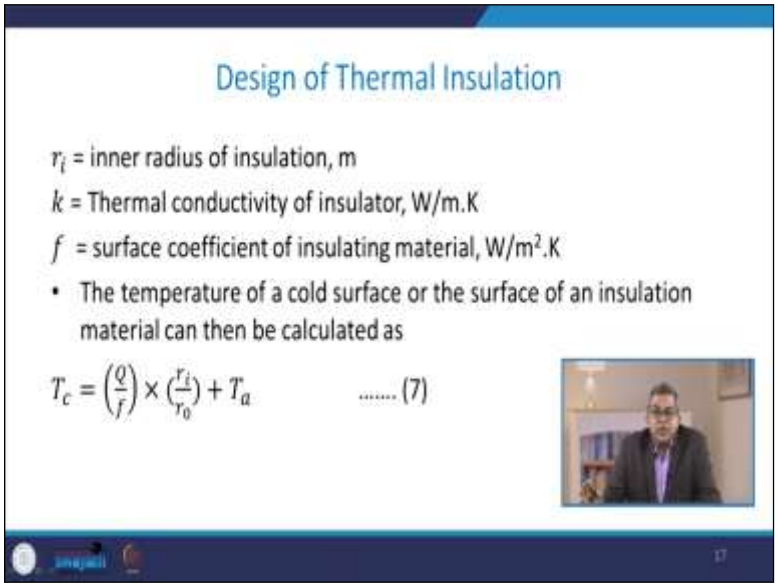

r_i = inner radius of insulation, m

k = Thermal conductivity of insulator, W/m.K

f = surface coefficient of insulating material, W/m^2.K

The temperature of a cold surface or the surface of an insulation material can then be calculated as

$$T_c = \left(\frac{Q}{f}\right) \times \left(\frac{r_i}{r_0}\right) + T_a \quad \ldots\ldots (7)$$

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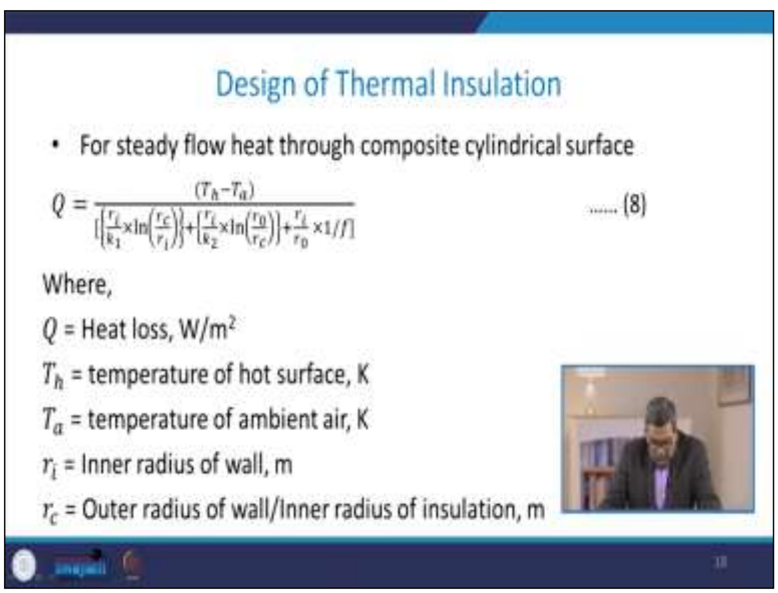

For steady flow heat through composite cylindrical surface

$$Q = \frac{(T_h - T_a)}{[\{\frac{r_i}{k_1} \times \ln\left(\frac{r_c}{r_i}\right)\} + \{\frac{r_i}{k_2} \times \ln\left(\frac{r_0}{r_c}\right)\} + \frac{r_i}{r_0} \times 1/f]} \quad \ldots\ldots (8)$$

Where,

Q = Heat loss, W/m^2

T_h = temperature of hot surface, K

T_a = temperature of ambient air, K

r_i = Inner radius of wall, m

r_c = Outer radius of wall/Inner radius of insulation, m

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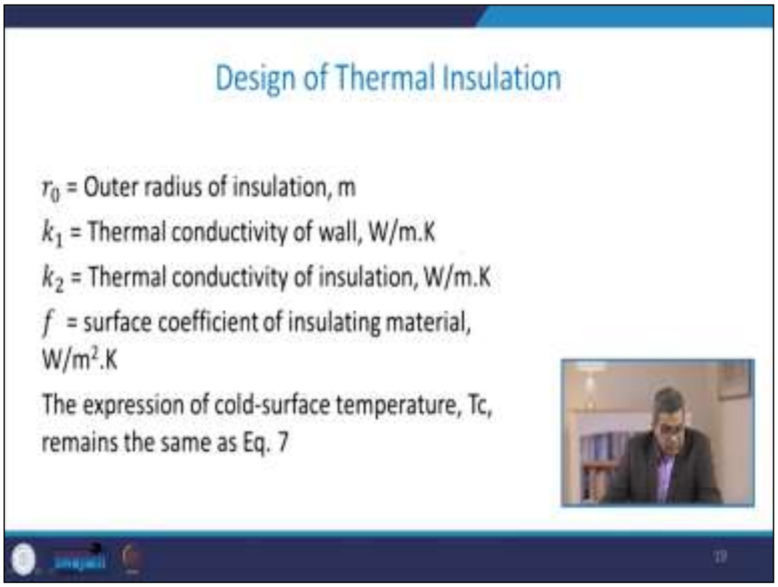

r_0 = Outer radius of insulation, m

k_1 = Thermal conductivity of wall, W/m.K

k_2 = Thermal conductivity of insulation, W/m.K

f = surface coefficient of insulating material, W/m^2.K

The expression of cold-surface temperature, Tc, remains the same as Eq. 7

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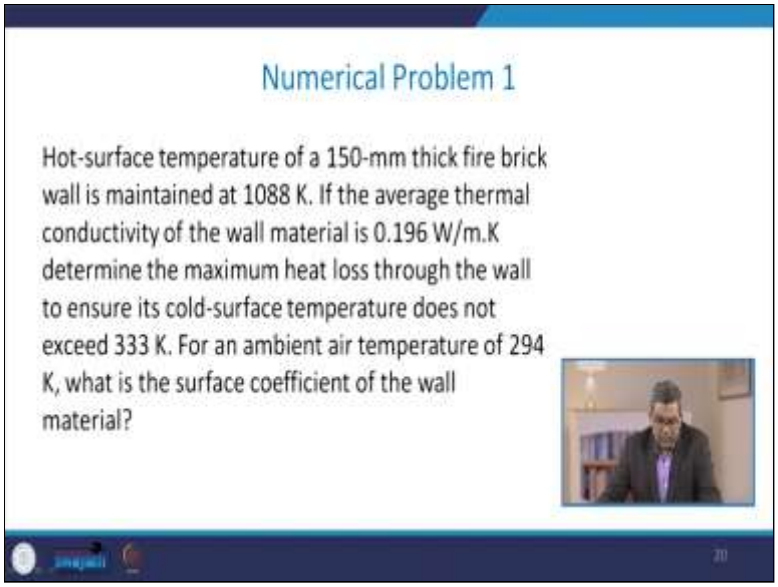

Now let us talk about couple of numericals problem. Now for problem number one the hot surface temperature of 150 millimeter thick fire brick valve is maintained at 1088 Kelvin. Now if the average thermal conductivity of the valve material is 0.196 watt per meter Kelvin you need to determine the maximum heat loss through the valve to ensure its cold surface temperature does not exceed 333 Kelvin.

For an ambient air temperature of 294 Kelvin what is the surface coefficient of the valve material let us have the solution.

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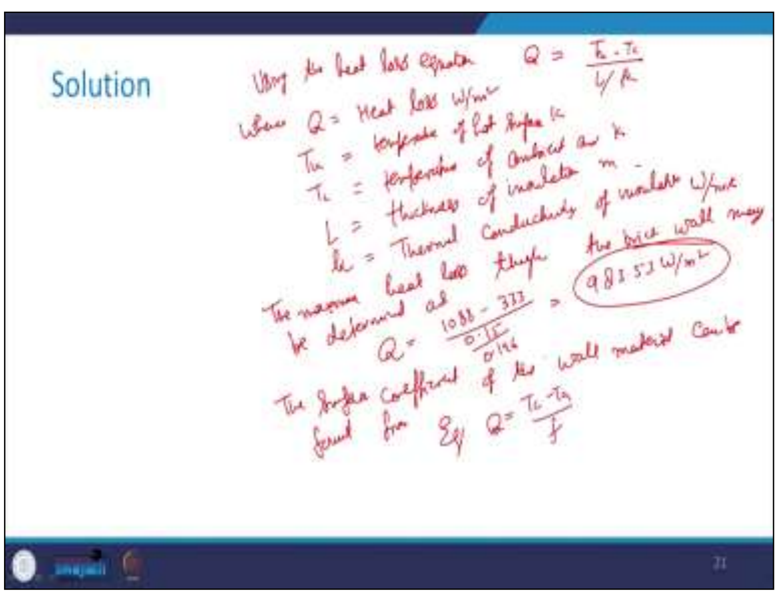

Now we have we can use the heat loss equation Q is equal to T h - T c upon L by k where Q is equal to heat loss in watt per meter square T h is equal to temperature of hot surface Kelvin T c is the temperature of ambient air in Kelvin L is the thickness of insulation in meter k is the thermal conductivity of insulator in watt per meter Kelvin.

Applying Eq. 1, the maximum heat loss through the brick wall may be determined as

$$Q = \frac{1088 - 333}{\frac{0.15}{0.196}} = \mathbf{986.53\ W/m^2}$$

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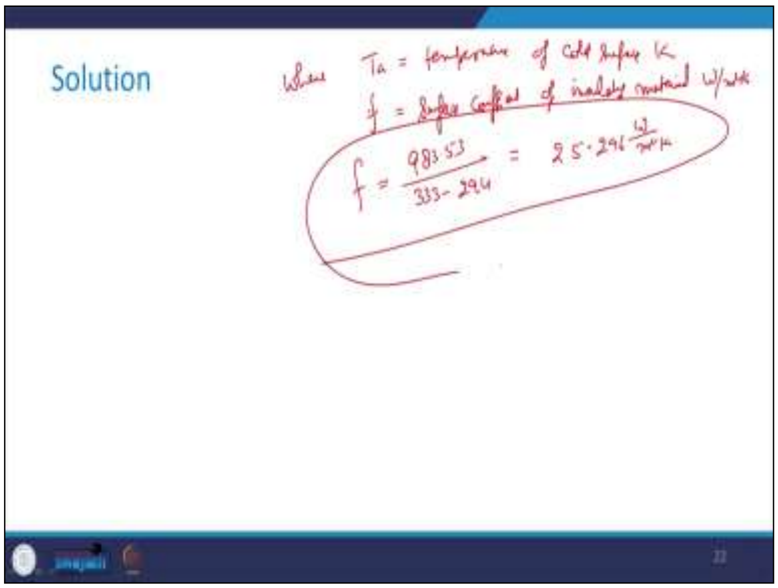

The surface coefficient of the wall material can be found from Eq. 2 as

$$f = \frac{986.53}{333 - 294} = \mathbf{25.296}\,\frac{\boldsymbol{W}}{\boldsymbol{m^2.K}}$$

So, now let us discuss about the second problem and second problem that is attributed to the similar type of thermal insulation.

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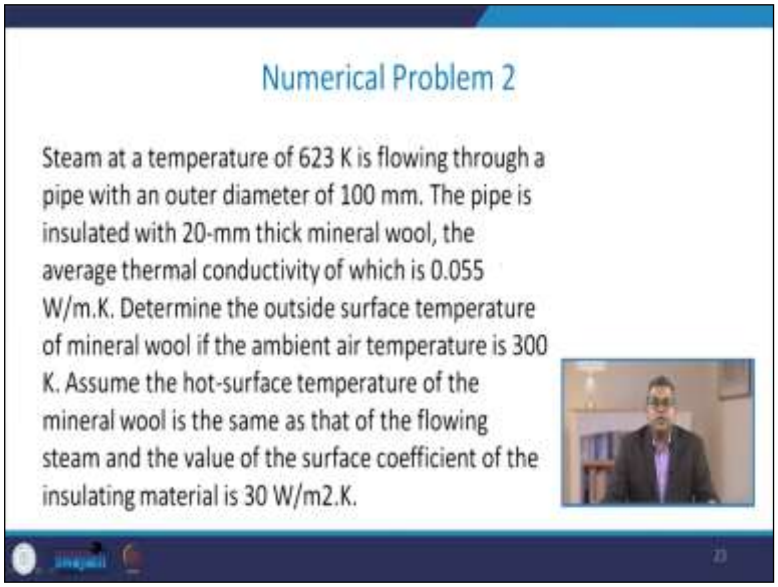

Now steam at a temperature of 623 Kelvin is flowing through a pipe with an outer diameter of 100 millimeter the pipe is insulated with 20 millimeter thick mineral wool the average thermal conductivity of which is 0.055 watt per meter Kelvin. You need to determine the outside surface temperature of mineral wool if ambient temperature is 300 Kelvin. You may assume the hot surface temperature of the mineral wool is the same as that of the flowing steam.

And the value of the surface coefficient of the insulating material is 30 watt per meter square Kelvin let us discuss.

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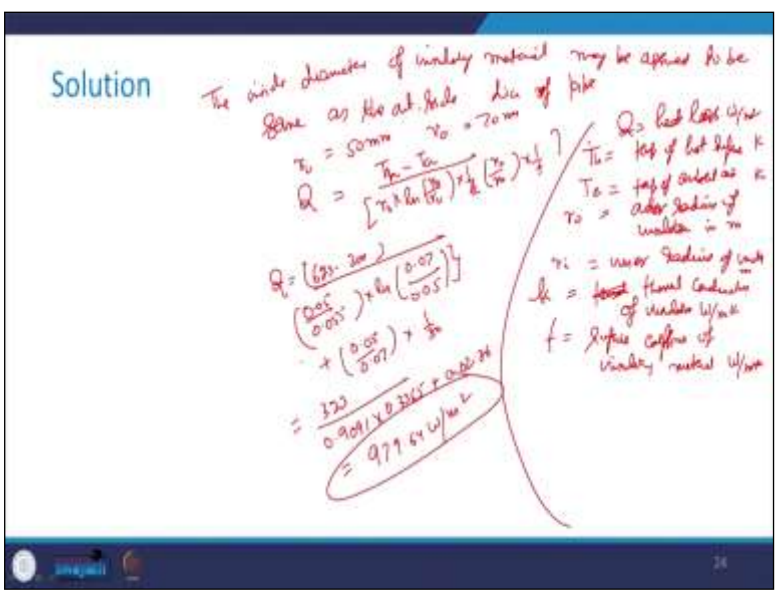

The inside diameter of insulating material may be assumed to be the same as the outside diameter of the pipe.

Hence; $r_i = 50\,mm,\ r_0 = 70\,mm$; Applying Eq.6:

$$Q = (623 - 300)/[\left\{\left(\frac{0.05}{0.055}\right) \times \ln\left(\frac{0.07}{0.05}\right)\right\} + \left(\frac{0.05}{0.07}\right) \times 1/30]$$

$$= 323/(0.9091 \times 0.3365 + 0.0238)$$

$$= \mathbf{979.64\ W/m^2}$$

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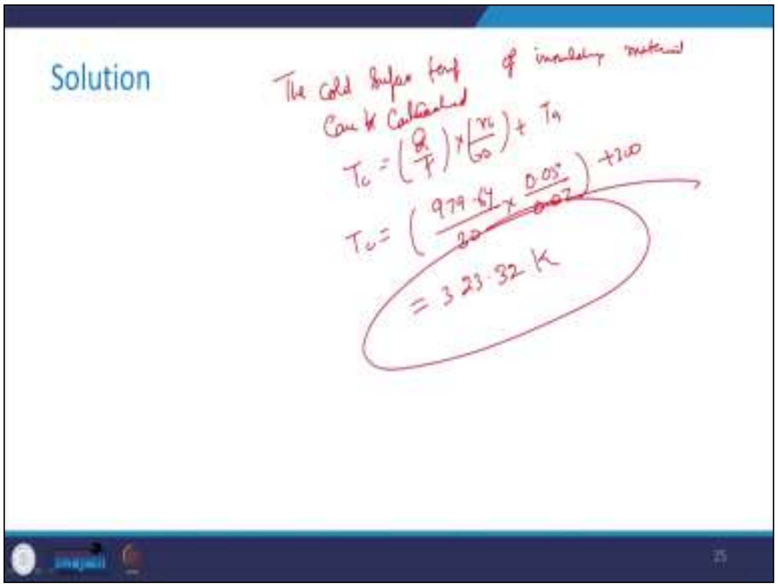

The cold surface temperature of the insulating material can be calculated using eq. 7**as,**

$$T_c = \left(\frac{979.64}{30} \times \frac{0.05}{0.07}\right) + 300$$

$$= \mathbf{323.32\ K}$$

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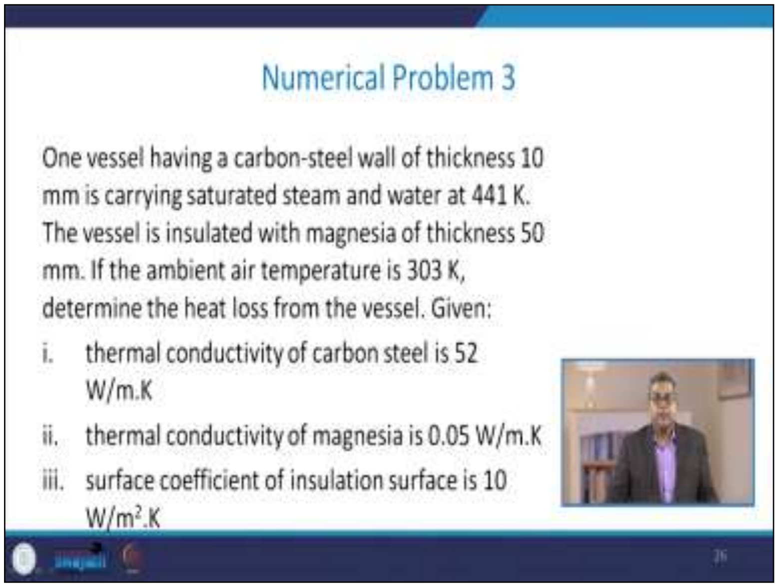

One vessel having a carbon-steel wall of thickness 10 mm is carrying saturated steam and water at 441 K. The vessel is insulated with magnesia of thickness 50 mm. If the ambient air temperature is 303 K, determine the heat loss from the vessel. Given:

i. thermal conductivity of carbon steel is 52 W/m.K

ii. thermal conductivity of magnesia is 0.05 W/m.K

iii. surface coefficient of insulation surface is 10 W/m^2.K

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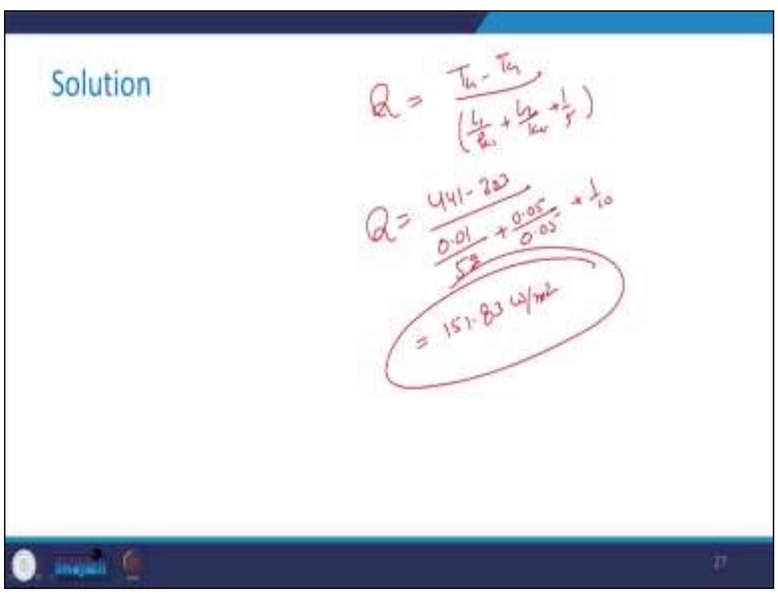

Assuming no temperature drop across the metal and applying eq. 5

$$Q = \frac{441 - 303}{\frac{0.01}{52} + \frac{0.05}{0.05} + \frac{1}{10}}$$

$$= 151.83\ W/m^2$$

So, in this particular lecture we have discussed about the thermal insulation of steam generators. We gave the importance of the insulation we discussed the various type of insulation. We solved couple of numericals as an examples.

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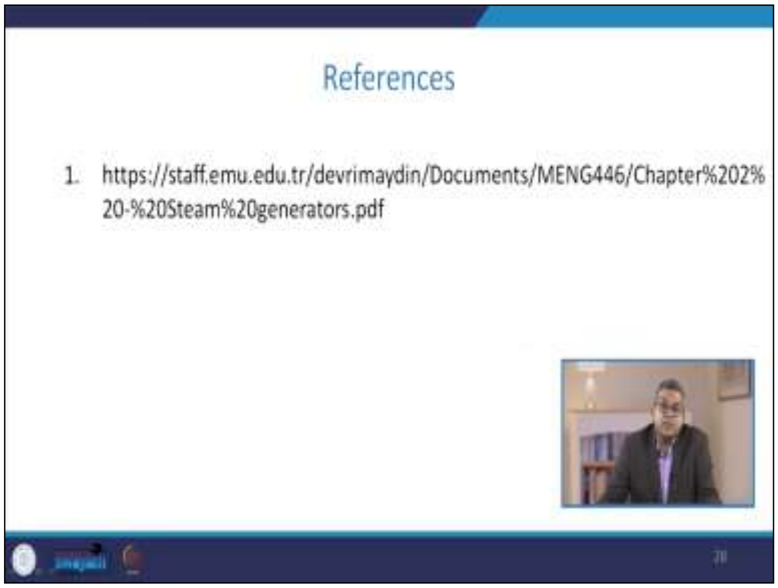

And if you wish to have a further reference you can go for this particular reference for your convenience, thank you very much.