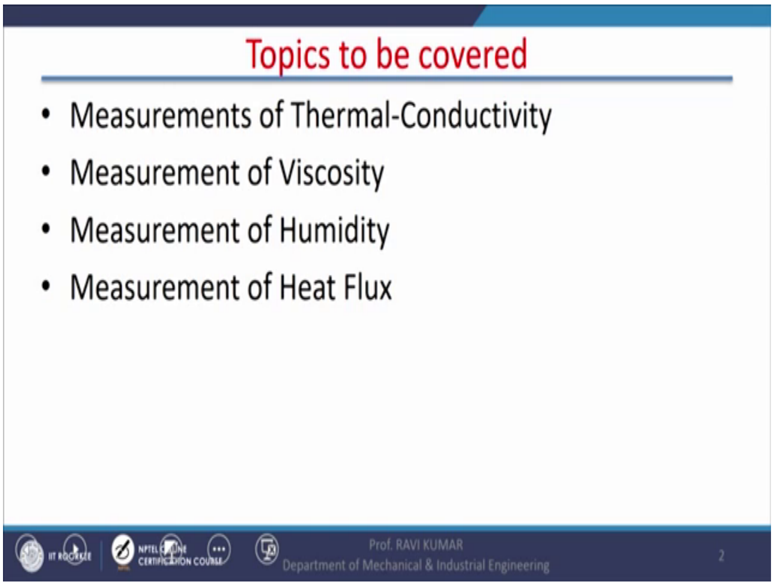
Mechanical Measurement Systems
Prof. Ravi Kumar
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture - 37
Thermophysical Properties Measurement

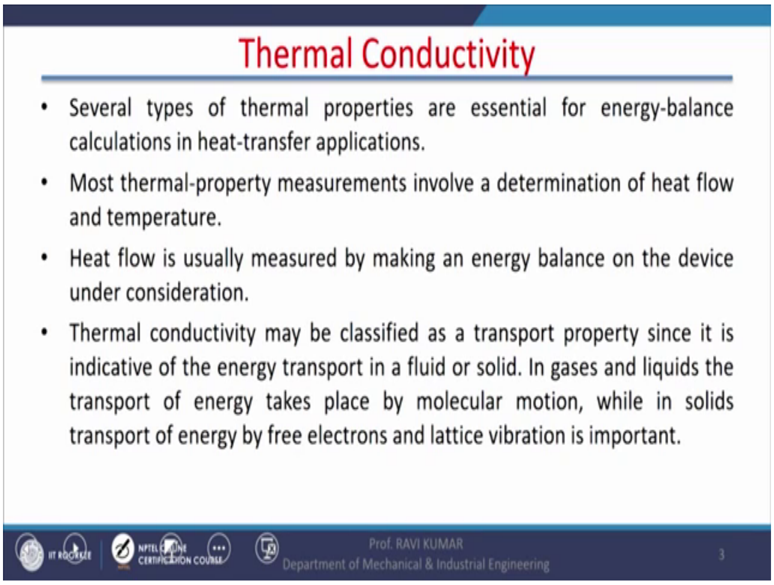
Hello, I welcome you all in this course on Mechanical Measurement Systems and today we will discuss about Thermo Physical Property Measurement.

(Refer Slide Time: 00:31)



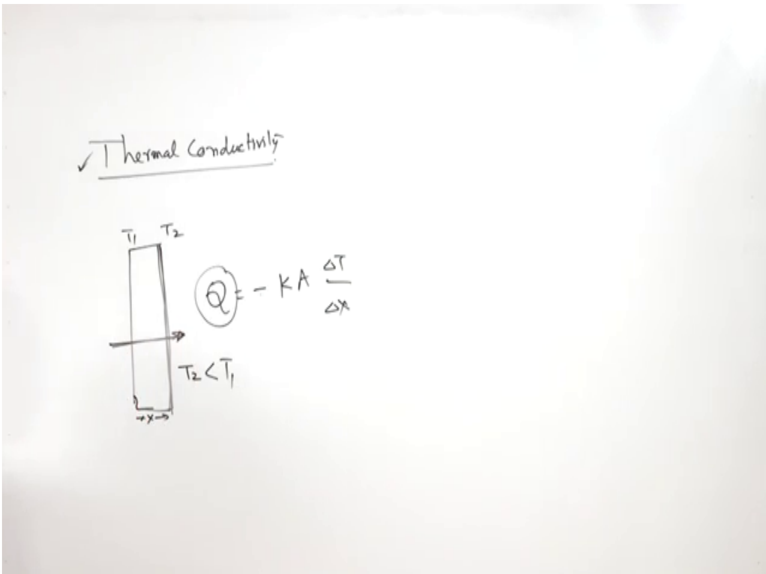
And the topics to be covered in today's lecture are Measurement of Thermal Conductivity, Measurement of Viscosity, Measurement of Humidity and Measurement of Heat Flux.

(Refer Slide Time: 00:39)



So, we shall start with the Measurement of Thermal Conductivity.

(Refer Slide Time: 00:44)

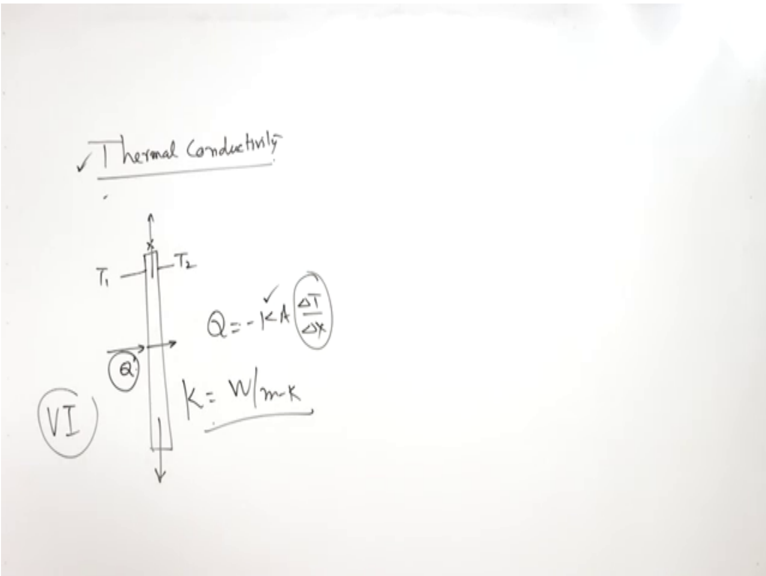


In most of the heat transfer calculations, we often do the energy balance, right and thermal conductivity is a property of any substance which is indicative of the heat transmission through conduction because there are three modes of heat transfer, that is conduction, convection and radiation and it is a transport property also because it is indicative of the transportation of energy in a solid, liquid or gas, right. So, it is a transport property and specially in the case of conduction, conduction heat transfer, this property becomes very important because it shows how fast heat can be transmitted through a solid object, right.

It is as we know the heat transfer through conduction in unidirectional. Heat transfer through conduction in any slab is denoted by Q is equal to minus K A delta T by delta X. X is the thickness of the slab and delta T is the temperature difference that is T 2 minus T 1 and because the heat transmission is taking place in this direction, that is why T 2 is always less than T 1 because heat itself is defined as the energy in transition by virtue of temperature difference.

So, T 1 is always higher than T 2. So, delta T is T 2 minus T 1. So, it will be a negative value and this negative negative will be cancelled out and A is the cross section area through which the heat transmission is taking place. Now, here we have to find the heat transfer. Sorry here we have to find thermal conductivity of this material.

(Refer Slide Time: 03:01)

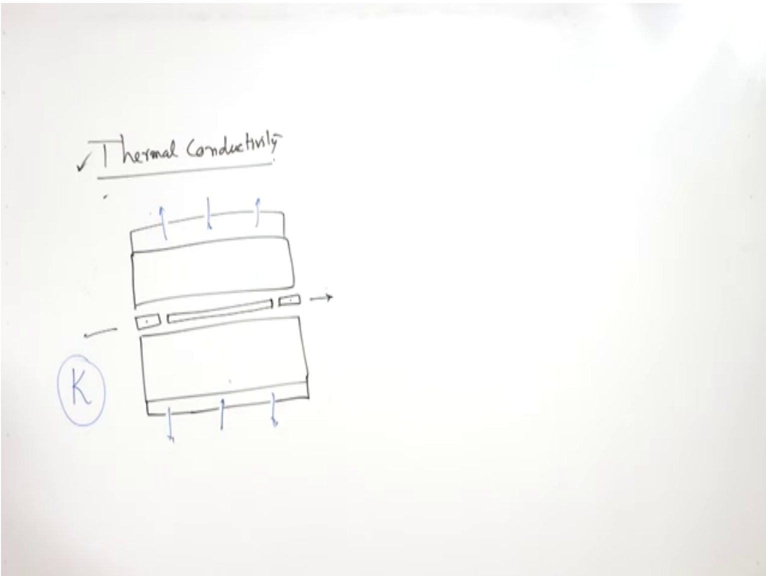


So, what we can do? We can take one slab I mean we can take one slab and in this slab, we will, I will just give you we can take one slab, right and heat this side is heated and heat transmission takes place. Q thickness of the slab is known, X temperature on the both sides we can measure by T 1 and T 2 and this is the constant heat flux, right.

So, Q is measured if it is electrically heated or the joule heating, then it is going to be VI. I is the current in the wire and V is the potential difference and this heat transmission is taking place in this direction and we can measure that or we can determine, not measure Q is equal to minus KA delta T by delta X. Here delta T by delta X is known to us. Cross section area is known to us and we can simply determine the value of K.

The unit of K is in S I unit is watt per meter Kelvin. Now, here there is a problem. The problem is heat transmission because the surrounding, it is surrounded by the air. So, heat transmission will also take place in this direction. There may not be uniform heating of the plate, right. So, apparatus has been designed, it is known as guard heater type of thermal conductivity measurement system.

(Refer Slide Time: 04:46)



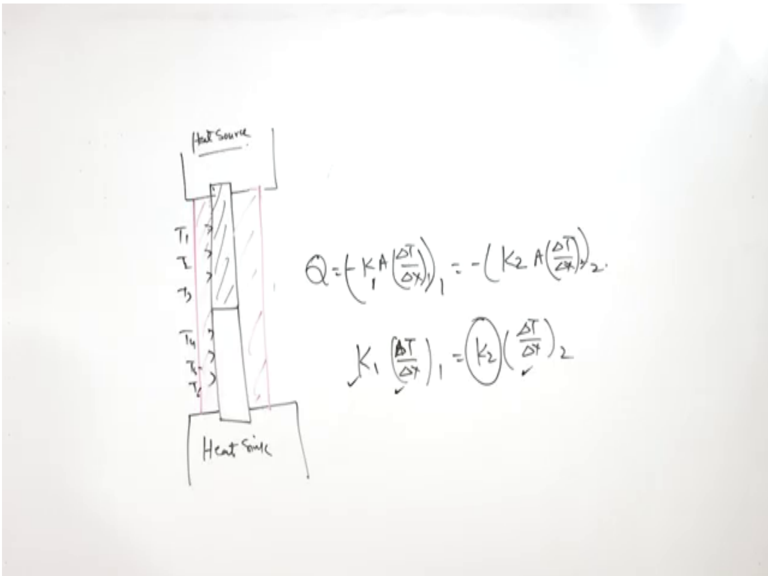
So, in this system there is a thin plate and on the both sides, there are guard heaters because even if we insulate the plate, even if we insulate this bare plate, in that case also suppose both sides are insulated, in that case also the temperature field will be developed especially in the case where this is also an insulating material, a temperature field will be developed. So, in order to avoid this, guard heaters are used. Temperature of guard heaters is the temperature of this plate.

So, there is no heat transmission in this direction, in the lateral directions, right and then, this guard, this heater, the guard plate heater is sandwiched between the sample at the top and at the bottom, right and this sample is jacketed and cooling water is circulated in the jacket. Cooling water is coming in and then, cooling water is going out here or this side also it is jacketed.

So, cooling water is coming in and the cooling water is going out and heat taken away by the cooling water is the heat transmission geometry of the section is known to us, right and this is how we can calculate the value of thermal conductivity. That is for the solids and this is the Brittas is known as guard plate heaters type of separators and it is very popular and it is a very I mean cost effective instrument for determining the thermal conductivity of the solids.

For connecting material there is another method of cylinders. In this case, suppose I wanted to have the thermal conductivity of copper or in any conductive material. So, for that purpose cylinders are used.

(Refer Slide Time: 07:09)



There are two cylinders in contact with each other, right. This cylinder is connected to the heat source. It is connected to heat source at temperature the or let us say heat source, right and the bottom one is connected to heat sink.

Now, when this side is connected to heat, so as they are identical in dimensions. So, when they are connected in series with the heat sources, the scenes heat sink, the flute, the heat will flow in this direction and this arrangement is insulated, so that there is no radial heat transfer. The entire arrangement is insulated, so that there is no radial heat transfer.

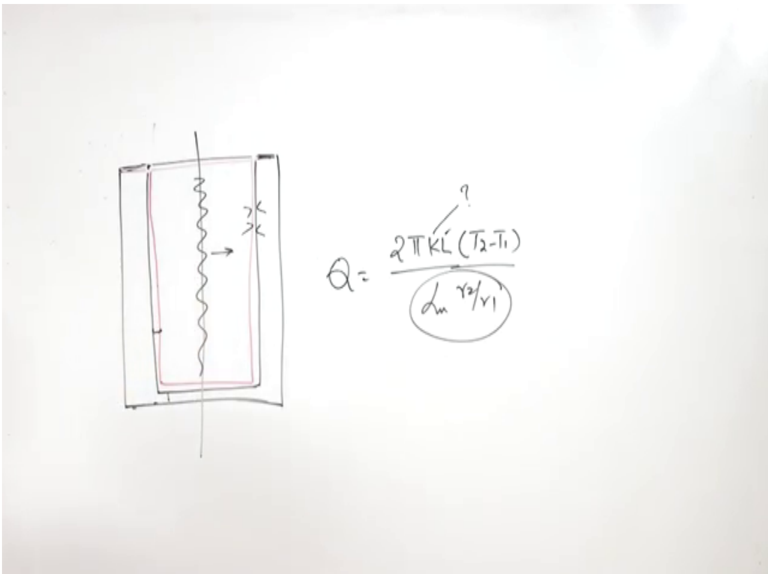
Thermocouples are fixed on the surface, right and now heat transmission takes place in this direction and thermocouple reading is taken I mean this is let us say T1 T2 T3 T4 T5 T6 or we can have more number of thermocouples, right.

Now, heat transmission is equal to minus KA delta T by delta X. The distance between these thermocouples is also noted. So, Q is equal to K delta T minus delta X and these two cylinders, they are connected in the series, right. So, that is going to be 1 is equal to minus. So, this is let us say K1 and this is K2 A delta T by delta X area is same only, delta T divided by delta X1 and delta T by delta X2, right. So, we will get K1 delta T by delta X1 is equal to K2 delta T by delta X2.

Now, here K1 is known, this cylinder is known as thermal conductivity or reference cylinder, right. So, this is known to us. This we have measured delta T by delta X because we have temperature at different locations. So, we can always calculate delta T by delta X delta T by delta X for second cylinder is also known. So, we can easily find the value of unknown thermal conductivity, right.

So, this is normally used for finding out the thermal conductivity of conductive material, now thermal conductivity of liquid and gases in order to find the thermal conductivity of the liquids.

(Refer Slide Time: 10:35)



Two, cylinder method is used, there are two cylinders. Cylinder 1, this is one cylinder right and inside that there is another cylinder, right. From the top they are insulated. They are insulated at the top. So, insulation is here. Both the cylinders are insulated, right and there is a gap between the inner wall of the outer cylinder and outer wall of inner cylinder. Now, this gap is very small.

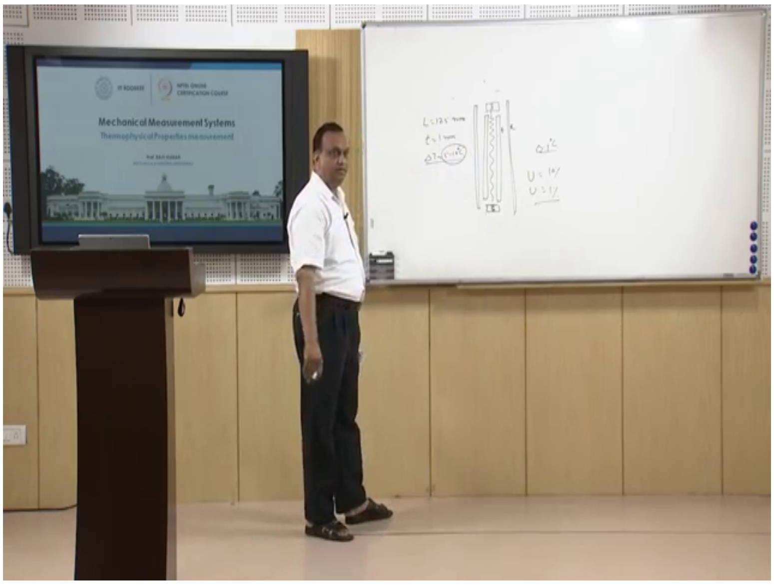
The length we can take these cylinders is approximately 5 inches of the height and the diameter of inner cylinder is approximately 1 and half inch. If one and a half inch comes around to be 38 mm right and this gap between the inner wall of the outer cylinder, an outer wall of inner cylinder is 0.025 inch or it comes to 625 mm, right. So, these are the approximate dimensions. They may vary also. I mean as a designer you can vary these dimensions as well they are not to be followed very strictly.

So, when the liquid is filled in this column, right and in the center, there is heater, radial heat transfer takes place. Now, for the cylinders if the radial heat transfer is taking place, then we have the equation for the radial heat transfer in the cylinder, that is Q is the heat transmission. This is equal to 2 pi KL T2 minus T1 divided by natural log off R2 by R.

So, these are 2 pi K. K has to be found out, Q is constant heat flux or constant heating that we know from V, VA heating through this wire length is we know the length. Temperature difference can be measured with the help of thermocouples fixing at these places, that is a temperature difference between the thin layer of fluid and then, these dimensions are also known to us. So, this is another method of finding out, I think this is the first one. So, this is the method for finding out the thermal conductivity of liquids and in the gases also this can be used, right.

There is another method for finding out the thermal conductivity of the gases with the guarded heater.

(Refer Slide Time: 14:07)



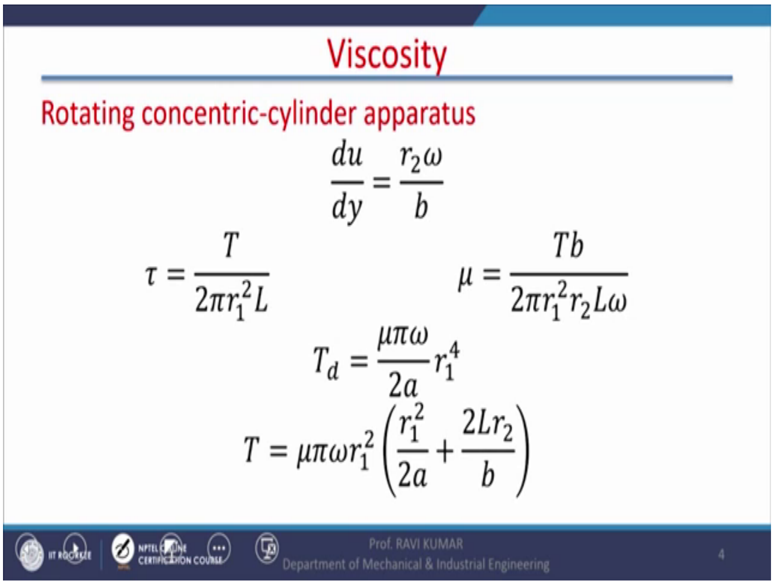
So, in the guarded heater there is an emitter and concentric to the emitter, there is a heater and it is enveloped with a receiver. This is receiver. An emitter has both sides the guarded heater. The purpose of the guarded heater is that there is no transmission of heat in axial direction. So, there is always transmission of heat in the radial direction. This is emitter and this is a receiver.

Now, we have the geometry of this. The length of this, height of this I mean heater is approximately 125 millimeters 5 inches. So, 5 inches comes around 125 millimeters thickness, T is 1 millimeter. Temperature difference of the order of 5 to 10 degree centigrade is maintained because if you maintain lower temperature, the uncertainty in the measurement will be high because for example, a thermocouple has an accuracy of 0.1 degree centigrade. So, what I am measuring the temperature of the order of 1 degree. So, if I have measuring the temperature of the order of 1 degree, the uncertainty in the measurement is going to be 10 percent.

If I am measuring temperature 10 degree uncertainty, the measurement is going to be 1 percent, right. So, that is why in order to reduce the error in the measurement, this temperature difference is maintained and an emitter emits the heat and through conduction is go to the receiver, right and using the same formula, we use for the cylinders here, the thermal conductivity is determined.

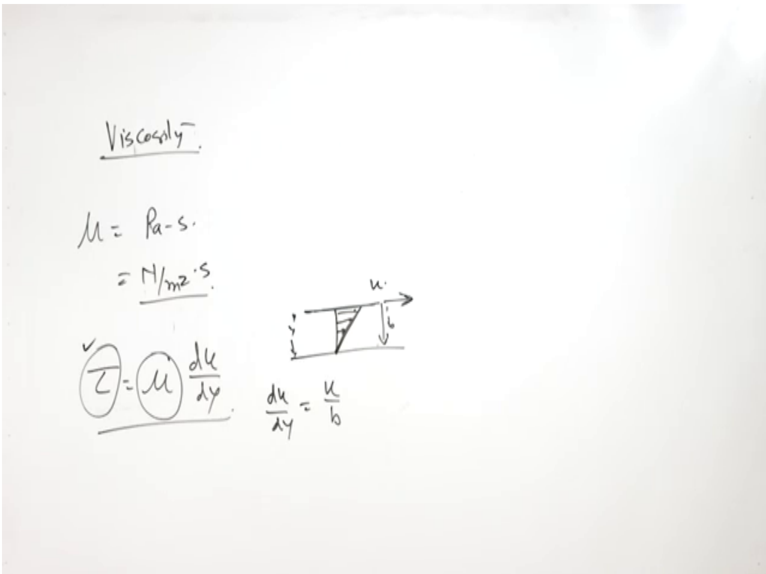
Now, after thermal conductivity we will take up the Viscosity.

(Refer Slide Time: 16:08)



How to measure the viscosity of the fluid because in heat transfer and fluid flow, the determination of the viscosity is equally important. So, we will take up another thermo physical property of the fluid which is widely used in fluid mechanics and heat transfer, that is viscosity.

(Refer Slide Time: 16:24)

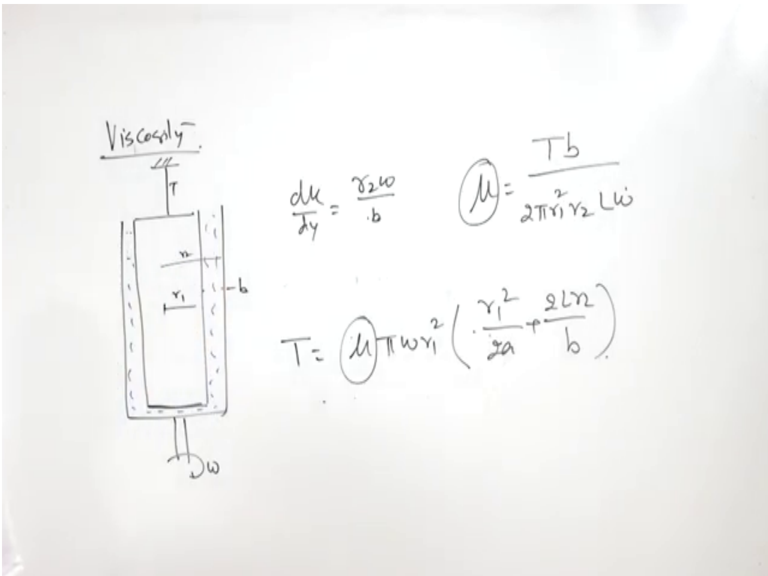


Viscosity is the S I unit. It is denoted by pascal second or it is newton per meter square second, ok. Now, for finding out the viscosity, we know the relation shearing stress is equal to mu du by dy, right.

Now, if we take this du by dy, suppose there are two plates separated by a very small distance and there the gap is filled with some fluid, right. If this plate is stationary and this is moving with a certain velocity u in this direction, so velocity vector is going to be like this, right and if the distance between these two plates is y, then du by dy is going to be u by v.

V is the distance between these two plates, right and regarding the shearing stress, shearing stress how much force is exerted in this direction divided by the area of this plate that will give the shearing stress. So, through this also we can find the value of viscosity of the fluid, but there is a little more sophisticated method for finding out the viscosity of the fluid in this case.

(Refer Slide Time: 18:10)



Two cylinders are taken. One is fixed, the inner cylinder is fixed and outer rotates with certain rpm and this gap is filled with fluid for which the viscosity has to be found out, and this cylinder is there is a mechanism to find the torque develop in this cylinder by the movement of or torque transmission to the cylinder by virtue of rotation of the cylinder, ok.

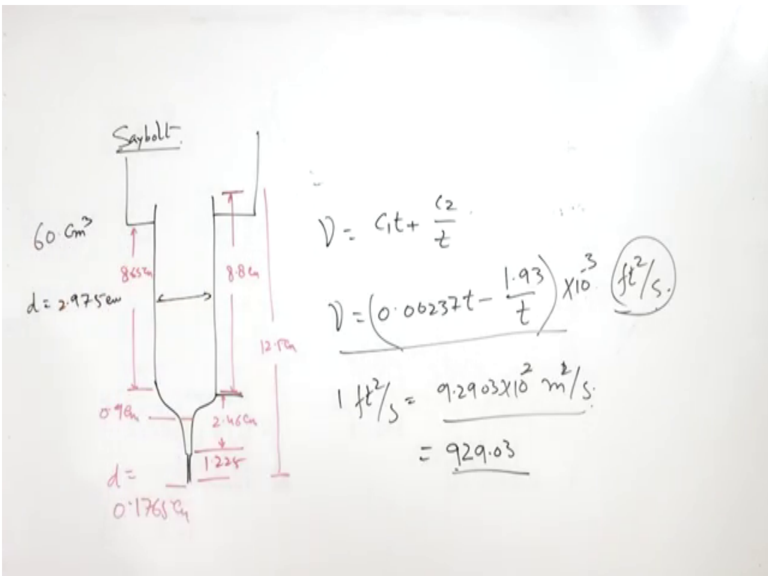
Now, the inside radius suppose it is r 1 and the outer radius is r 2 and the thickness of this or the gap between these two is b, fine. In this case, du by dy the velocity gradient is going to be r 2 omega by b because this cylinder is stationary and that is moving with certain rotational speed. So, when it is moving with certain rotational speed, the linear velocity is going to be r 2 omega and b divided by b will give us du by dy,.

Then, torque is force into distance x now torque here. So, torque is force and force is shearing stress multiplied by the surface area. So, shearing stress is torque surface area is 2 pi r 1 l, right and x is r 1 right. So, it comes to be tau into 2 pi r 1 square l. L is the length of the cylinder and here from here we can get the value of tau is equal to t by 2 pi r 1 square l, fine.

Now, we have the value of tau, we have the value of du by dy, right. So, we can get the value of mu. It is going to be Tb divided by 2 pi r 1 square r 2 l omega. So, this is going to be the value of viscosity of the fluid. Now, here we have not taken into account the viscous force or viscosity of the fluid which is at the bottom of the cylinder. We have taken only the shearing effect of the fluid which is surrounding the cylinder, not at the bottom of the cylinder.

So, for this purpose if we take this also into account, then final expression for torque can be written as mu by omega r 1 square r 1 square by 2 a plus 2 l r 2 by b and from here we can find the value of mu. Now, for finding out the viscosity of the fluid, there is a very popular device which is known as saybolt.

(Refer Slide Time: 22:17)



Viscosity meter saybolt. Saybolt viscosity meter is a device and it is nothing, but a vessel of a fixed geometry. The volume of this vessel is 60 ml. The entire volume of this vessel is 60 ml, this diameter is 2.975 centimeters. Height this is I will take some other, height this is 8.8 centimeter, diameter height, ok. The entire height is 12.5 centimeter. They are all fixed dimensions. Saybolt viscometer has all fixed dimensions. Volume is 60 centimeter cube. This is centimeter cube 60 cc and this height this height this is muzzle. This height is 1.225 centimeters, diameter of this is 0.1765 centimeters. So, all dimensions are fixed here. What is left? Yes, this is 0.9 centimeters and this height is 2.46 centimeters.

Drawing this figure may not be having the same proportion in the dimensions, but these are salient and dimensions of this tube used for viscosity measurement and this is house like this and this height is 8.65 centimeter. This is 8.75 centimeters. So, everything is fixed here. So, there is no flexibility.

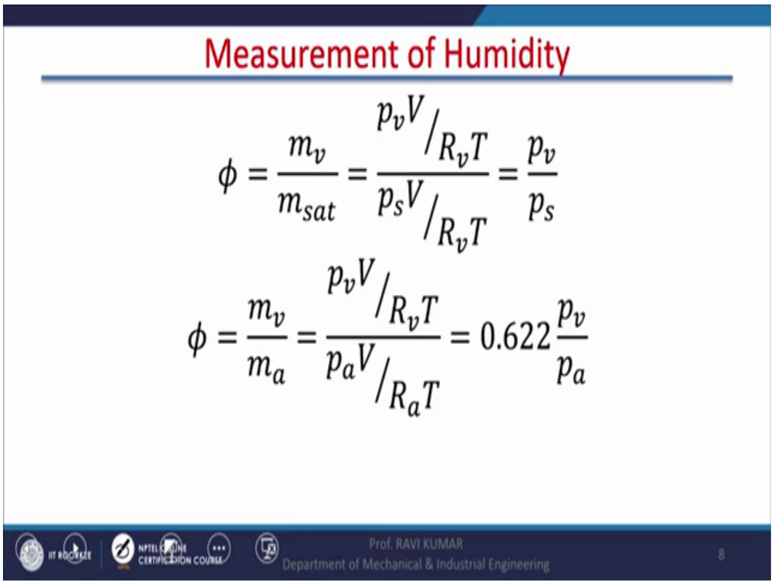
Now, any fluid for which the viscosity is required to be measured will be filled here. This opening will be, this wall will be opened and time will be noted. How much time it is taking to drain off the vessel and there is a relation that kinematic viscosity is equal to c 1 t plus c 2 divided by t, where c 1 is equal to 0.00 or we can write is equal to 0.00237 t. So, this is c 2 is minus 1.93 divided by t multiplied by 10 to power minus 3 feet to square per second because it was I mean this is very old device in that time inch pond system used for the measurement.

So, these are constants for finding out the kinematic viscosity of the fluid and 1 feet per square second, 1 feet square per second is equal to 9.2903 into 10 to power minus 2 meter square per second or 9.2903 929.03 strokes because viscosity is also expressed in terms of strokes. So, q centi stroke. So, 1 centi stroke consist of 100 strokes.

So, these are 929.03 strokes and 1 centi stroke consists of 100 strokes. So, 1 feet per square a second is 929.03 into 10 to power minus 2 meter square per second and it is going to be equal to 929.03 stokes, right.

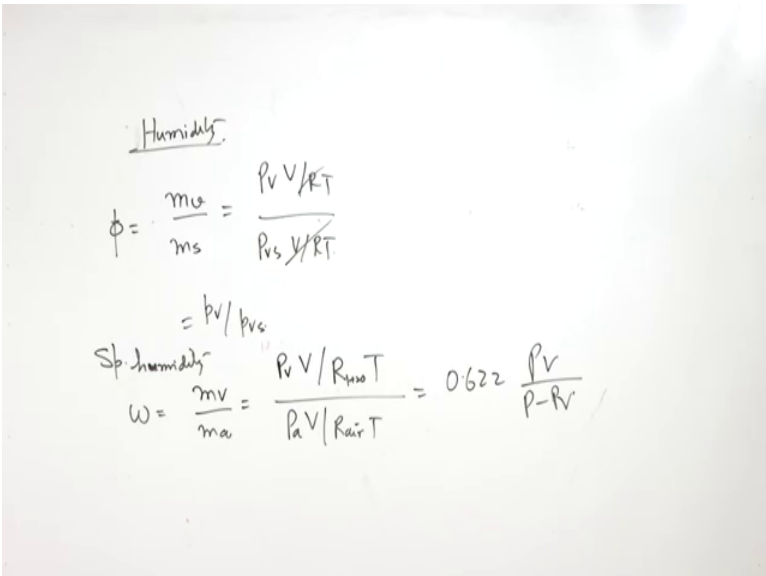
Now, these strokes and 1 stroke consists of hundreds centi strokes, right. So, this is how the viscosity, kinematic viscosity can be measured with the help of saybolt viscometer.

(Refer Slide Time: 27:41)



Now, we will go for a rather very important measurement which is really important for the mechanical engineers, that is humidity measurement.

(Refer Slide Time: 27:43)

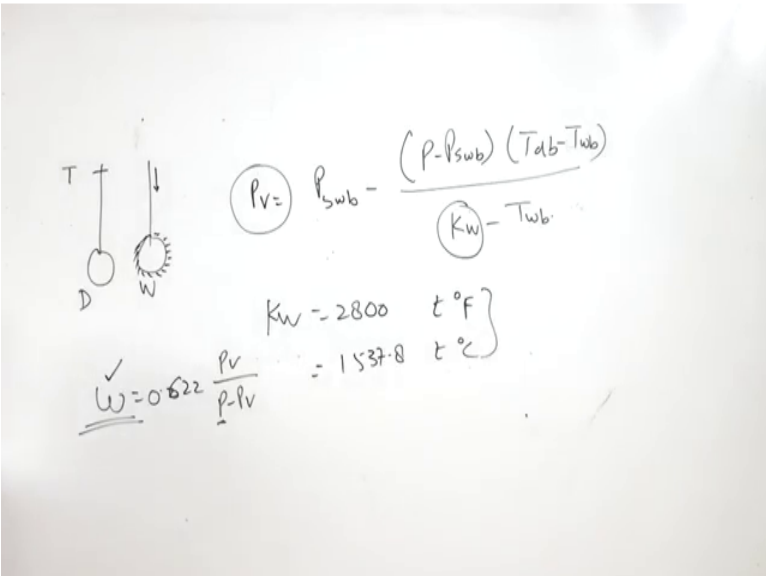


So, humidity measurement, there are two types of humidities. One is relative humidity and it is denoted by phi. Now, relative humidity is mass of the water vapor in here divided by mass of the water vapor in saturated, sorry mass of the water vapor in saturated air, right.

So, it is Pv over R T and this is Pv s V over RT. Temperature is constant and volume is constant. So, they will be cancelled out. So, it is going to be Pv by Pvs. This is relative humidity. Another is specific humidity. Specific humidity is equal to mass of pressure, sorry mass of water vapor and mass. Sorry mass of water vapor and mass of dry air and mass of the vapor and mass of the air can be then measured.

Now, P pressure is same Pv V divided by R water and P divided by Pa Vr air and T and this final results in because there I mean gas constant for water vapor and gas constant for air, right. If we take them into the account, then it comes out to be 0.622 Pv by P minus Pv. If we consider that the sample of air consists of only vapor and air, now how to calculate the humidity. For calculation of the humidity, there is a hygrometer. Hygrometer has a dry bulb by the wet bulb.

(Refer Slide Time: 29:58)



So, bulb is covered with a wick or cold or a wet cloth and when the humidity in the air is low, the evaporation is high. When evaporation is high, suppose it is showing some temperature T degree centigrade that is dryable temperature, normal temperature in the room when on the bulb. When your operation takes place, the cooling of this bulb takes place and there is a dip in temperature. Lower the humidity of air, higher is a dip. So, there is a relation for finding out the Pv that is P wet bulb minus P minus Ps wet bulb P driver minus T wet bulb divided by k w minus T wet bulb, right.

Now, kw is 2800, 20 is in fahrenheit and it is 1537.8 T is in degree centigrade. Once we have the value of Pv with us, then easily we can find the basic humidity bulb 662 Pv by P minus Pv. So, total pressure of the air is known, Pv is known. That is how we can calculate the value of specific heat. Sorry, that is how we calculate the value of specific humidity of the air.

Now, last one is heat flux, the measurement of heat flux.

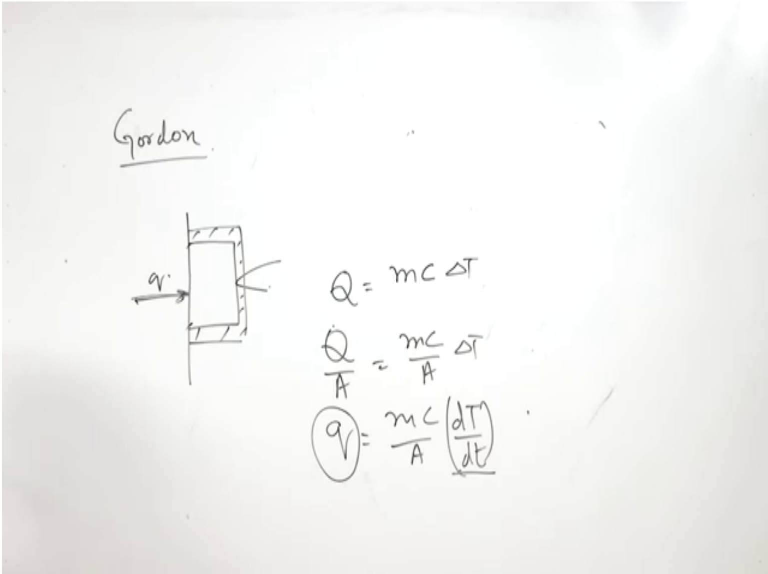
(Refer Slide Time: 32:02)

Now, heat flux is required sometimes say we can always measure the heat flux as Q by A right, but sometimes heat flux is directly is directly required to be measured and for this purpose, heat flux sensors are used. For example, suppose I want to have heat transmission to the walls in case of fire.

So, in case of fire if I want to have heat transfer to the wall because in that case I need heat flux meter. It will be difficult to calculate the heat transfer and then, divide it by the cross section area. So, at different locations in the room if I want to have heat flux in this room in case of fire, I will embed heat flux sensors at different walls on the ceiling of the room and heat flux. That is how the heat flux can be calculated.

Now, for finding out the heat flux, there is a slug sensor type of heat flux slug.

(Refer Slide Time: 33:07)



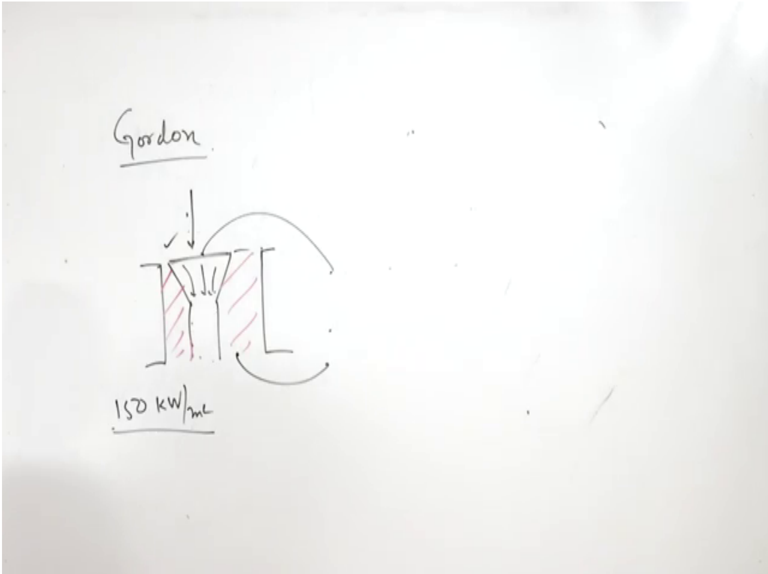
This slug sensor type of heat flux is embedded in the wall. It is embedded in the wall and a thermocouple is provided when the heat is coming in that is Q, right and Q is or let us say heat flux Q is minus k dt by dx. Now, in this flux sensor when heat is transmitted, right energy will be stored in it and temperature will start increasing energy stored Q. It is not the heat transfer rate, it is energy only joules and kilojoules. It is m c delta t, right.

Now, I want to have heat flux. So, it has to be divided by cross section area. So, Q by A is equal to m c by a delta t. Now, I want to have rate of heat transfer that is ensuring heat transfer. So, for in order to find the rate of heat transfer or the Q mc by A dT by dt, now from this thermocouple we will measure this value dT by dt and ultimately which will give us the heat flux falling on this wall, but this type of heat flux if there is a steady state, it is difficult to calculate the heat flux.

It can give the heat flux only in the transient state first of all. Second thing is the heat transfer characteristic of all the entire object is changed because this is an abstraction type of heat flux measuring device. So, it is possible that if the surrounding wall is an insulating material, the entire heat will like to go through this sensor only, right.

So, the heat transfer characteristic or transmission characteristics of the surrounding wall is also changed by using this select type of heat exchange. This heat flux meter and the last one is Gordon heat flux, Gordon type of heat flux.

(Refer Slide Time: 35:51)



The heat flux meter is embedded in the wall. It is a constant end surface, right. A copper wire is fixed here and this is all copper. This is all copper, right and one copper wire, the copper wire is fixed here, right and when the heat comes in this direction, the transmission of the heat in the radial direction is measured, right.

This flux meter is accurate and it can measure heat flux up to 150 kilo watt per meter square of this order only. Heat loss is radiation from this side, radiation heat transmission on the backside of the plate and that has to be taken into account otherwise this type of meter is quite suitable and it is frequently used for heat flux measurement of any of the or heat flux measurement falling on any object.

So, this is all for today. Thank you very much. In the next lecture, we will start with the flow visualization techniques.