Fluid Flow Operations
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Module – 11
Lecture – 29
Measurement of Flow-Part 3

Welcome to the massive open online course on Fluid Flow operations. In this lecture we will continue the module 11 as a Measurement of Flow as Part 3. Here we will discuss something some different type of flow measuring devices and their principles.

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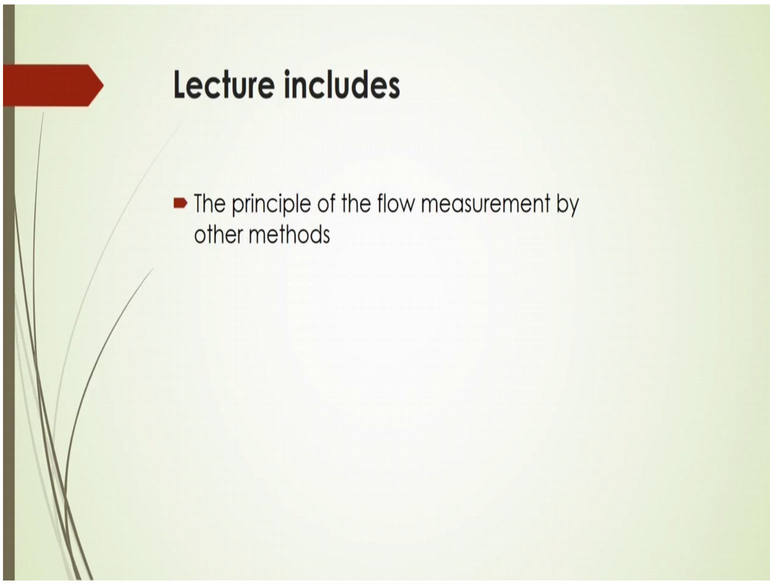

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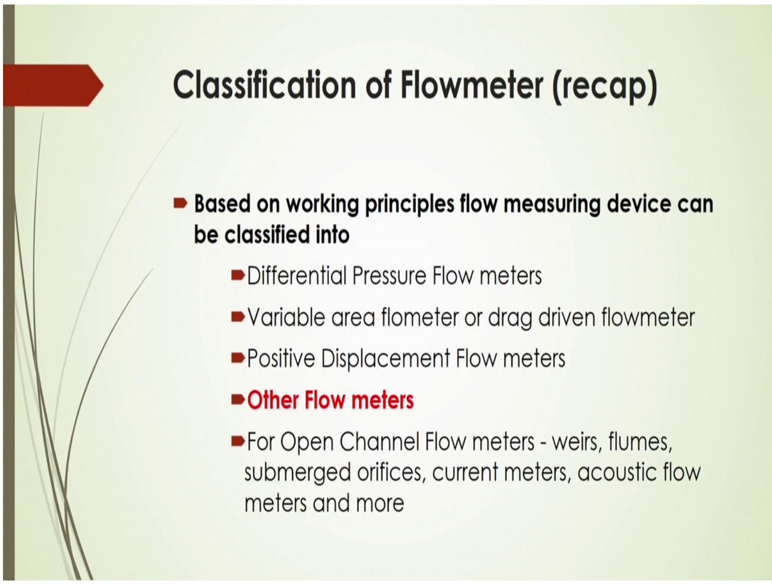

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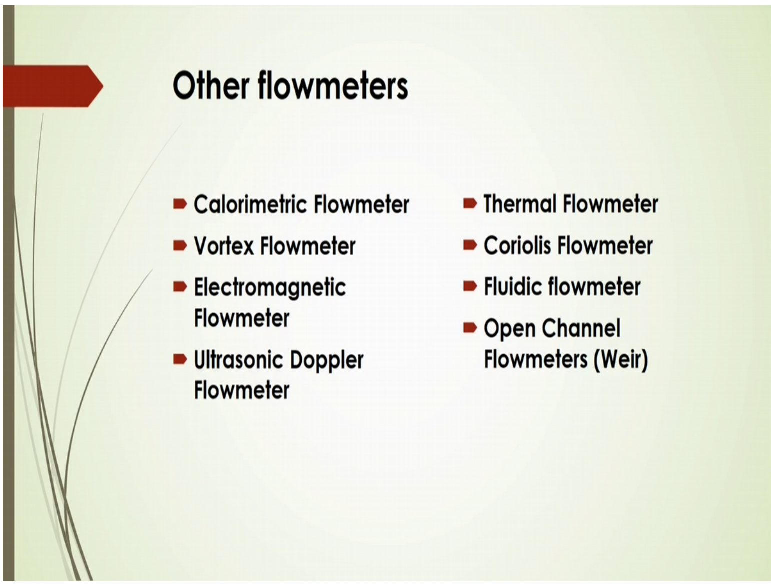

So, this lecture will be actually includes the flow measuring devices like calorimetric flow meter, vortex flow meter, electromagnetic flow meter, ultrasonic Doppler flow meter, even thermal flow meter, Coriolis flow meter, fluidic flow meter how they are working and on what principle basic principles they are working that will be discussed here.

So, before going to that we have the idea that what are the different types of flow meter and we have already discussed in the previous lectures that there are differential pressure flow meters, variable area flow meters like drag driven flow meters, positive displacement flow meters, even open channel flow meters are there.

So, all those different types of flow meters we have discussed, but this type of flow meters will be working on other methods, it would be discussed here in this lecture. So, these are the list the different types of flow meter that you can use, that can be used for measuring the flow rate whenever fluid would to be flowing through the pipe.

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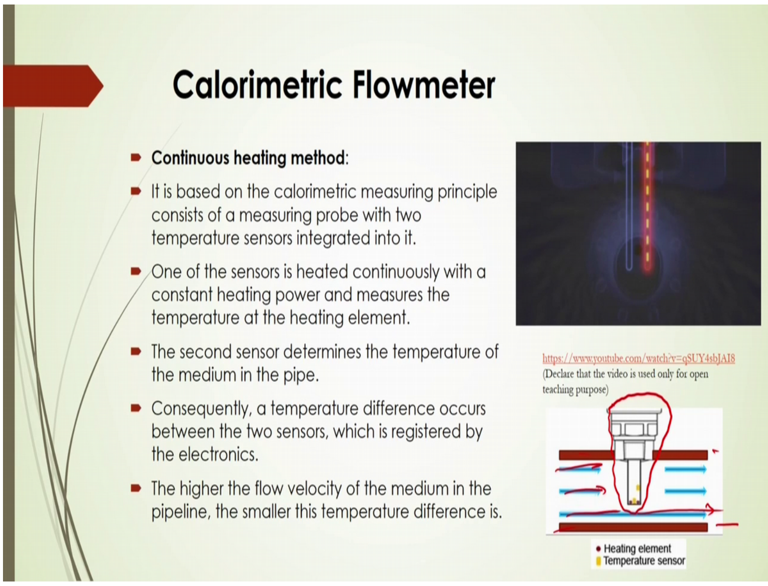

So, let us consider here the basic principles of the calorimetric flow meter, this is one of the important a flow measuring device it is generally being used in what is that based on the calorimetric measuring principles. And, in this case it consist of a measuring probe with two temperature sensors and we shall be integrated into this device.

And one of the sensor in this case, the two sensors one of the sensors is heated continuously with a constant heating power and it measures with the temperature at the heating element. And, the second sensor which is being used in this device generally determines the temperature of the medium in which this that is sensors is emerged and also what is the which fluid actually the being flowing. So, in that medium the second sensor would be emerged.

And the consequently, temperature difference will occurs between these two sensors and which we will actually be registered by the electronic sorry electrical mechanicals mechanics and the higher the flow velocity of the medium, it will be giving the temperature difference even smaller. So, based on that principles this velocity of the fluid will be measured.

So, here basically the device will have two sensors: one sensor will measure the temperature, the of the atmosphere and other sensor will measure the temperature of the fluid and based on this differences of these fluid you will be able to calculate, what would be the heat energy supplied there and that heat energy supplied will be required, more heat energy will be required based on that what is that a velocity of that.

So, accordingly we can say that what will be the energy supplied that will be proportional to this fluid flow. Here you will see that schematic of these devices here, so here this is one pipe and this through this pipe that the fluid will be flowing at a certain flow rate. And, this case this sensor this devices that is here it is called calorimetric flow meter and this calorimetric flow meter will be consisting these two sensors of this and then based on the temperature between of these two sensors the flow rate can be calculated.

Now, here one video is giving or which shows the basic actually fundamentals of this calorimetric flow meter and you see now here two sensors are there. So, two sensors are there, in this devices and then from one sensors there will be heat will be supplied and an another sensor there will be atmospheric temperature will be there that sensors will measure the temperature in here, when there will be no fluid now flow then you will see there will be a what is that the sensors will have certain temperature and it will be the same temperature.

When fluid would be flowing you will see there and this heat will be of course, reducing from that sensor and it would be decreasing and at the same time you will see that to keep this temperature difference of these two sensors constant, then we have to supply or that electrical energy would be supplied from the sources, so that the temperature will be remain constant.

So, that case if the flow rate will be more higher, then you will have to supply the more electric energy to keep that temperature difference of these two sensors constant. So, based on these principles you can say that what should be the flow rate because, that flow rate will give you that what would be the change of the temperature difference.

Now, to keep this temperature difference you have to supply more energy, that more energy supplying it will be proportional to that flow rate. So, this mechanism is being used to calculate the, what is that flow rate of this ah flow. So, this so calorimetric flow meter it works based on these principles. So, here how see if suppose there is a air or fluid is flowing through that pipe, then how this water molecule or fluid molecule is actually taking out that heat energy which is supplied from the electric source and the how this energy is absorbing by this flow.

Now, more flow will be there then more energy will be absorbing from the sources of from the sensor and then you have to supply more energy there accordingly, that more supply of energy will give you the how much actually flow rate will be the because before you have to actually measure the certain flow rate you have to actually calibrate these things that, by knowing that flow rate what would be the heat energy is being observed by this, what is that fluid there you have to know. So, based on that you can actually obtain what should be the flow rate based on this electrical energy.

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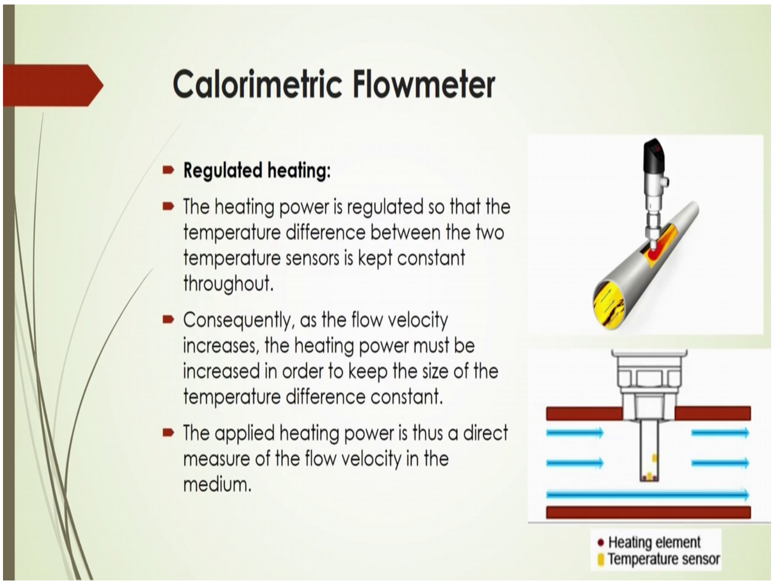

Now, so this is the basic principle for that, so the heating power is regulated so that the temperature difference between the two temperature sensors should be kept constant throughout the operation and in that case as the flow velocity increases, the heating power must be increased in order to keep the size of the temperature difference are constant.

So, the applied heating power is thus a direct measure of the flow velocity in the medium, if you know the flow velocity, then you will be able to calculate what should be the volumetric flow rate there just by multiplying the cross sectional area with this velocity.

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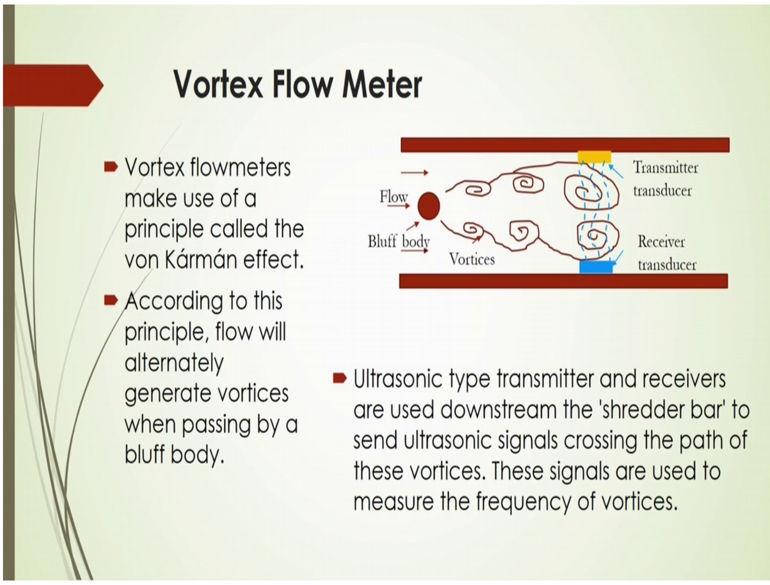

Now, another important flow meter it is called vortex flow meter, it is a basically you will see whenever we have already discussed that if there is a obstruction of the flow, then in the downstream of this flow obstruction it is sometimes it is called bluff body. The downstream position of this bluff body you will see there will be a formation of vortex and that vortex you will see the how many vortex will be form that based on the flow rate it will be there.

So, Karman I think he has you have already discussed that, the Karman we has developed or proposed one equation that how many vortexes will be formed there and it depends on the flow rate and also the cross sectional area of the bluff body there. So, based on that principals, this vortex flow meter is actually being developed and according to this principles flow will alternatively generate the vortexes when passing by a bluff body.

So, it is required that at a certain flow rate that you have to pass that liquid through a bluff body and in the downstream of that flow there will be a formation of vortex. If you once know that the frequency of that vortexes, then you will be able to calculate what should be the flow rate because this frequency of this vortices are directly proportional to this flow rate of the fluid.

Now, in this case how to actually measure that vortex frequency so, in that case you have to use some ultrasonic source of operation and in that case ultrasonic type of transmitter and receiver to be used there in the downstream of the shredded bar and which will send the ultrasonic signals, whenever crossing the path of this vortices and this signals will be used to measure that frequency of the vortices.

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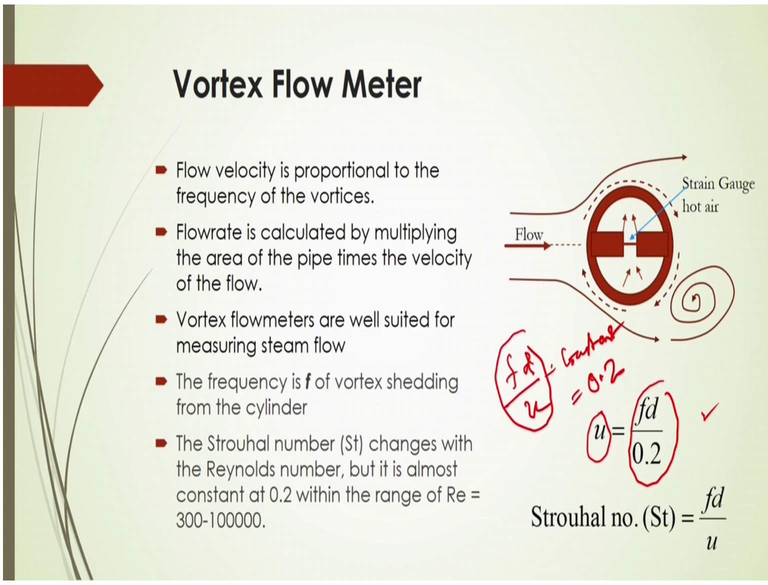

Now, in this case how that this flow velocity will be related to that frequency of the vortices that is given as per Karman equation. Now, this flow velocity since it is proportional to the frequency of the vortices we can say that, this f will be is equal to sum that is what is that f as a function of what is that velocity will be there? So, in that case not only that velocity it may sometime should be happen that what should be the area of the pipe.

So, in that case size of the pipe also one important factor there. So, based on that size of the tube as or pipe and also the velocity of the fluid, then you can say this ratio of the vortex frequencies multiplied by the diameter of the pipe and to its velocity of the fluid it will be constant as per Karman's principles. So, in that case you can say that fd by u that is f is if it is a frequency of the vortices and d is the diameter of the pipe and if you say that use the velocity of the fluid, then you can say that fd f into d by u that should be is equal to constant.

So, it is this constant value is coming is equal to 0.2. So, this ratio that is fd by u that will be is equal to or it is denoted by that it is called sometimes Strouhal number, this Strouhal number changes with the Reynolds number; that means, here velocity of the fluid and also the properties of the fluid and also geometric variables of the pipe there. So, in that case within the range of Reynolds number it is seen that 300 to 10,000 Reynolds number from 300 to 10,000, then this Strouhal number is coming to constant it is almost equals to 0.2.

So, based on this we can calculate what should be the velocity if you once know this, what is that frequency of the vortices, that frequency can be calculated by this ultrasonic type of transmitter and receivers. So, in that case that whenever fluid will be flowing through that pipe and it would be crossing that two that is receivers and the transmitter, then the signals that would cross the path of this vortices and based on that the signals will give you the frequency of the vortices.

So, once you know that frequency of the vortices then you will be able to calculate what should be the velocity of the flow and that will be as per this equation here. So, once you know this velocity of this flow of the fluid, then you will be able to calculate what would be volumetric flow rate there because this if you know the cross sectional area, then you have to multiply this velocity this cross sectional area, then you will be able to calculate what should be the volumetric flow rate.

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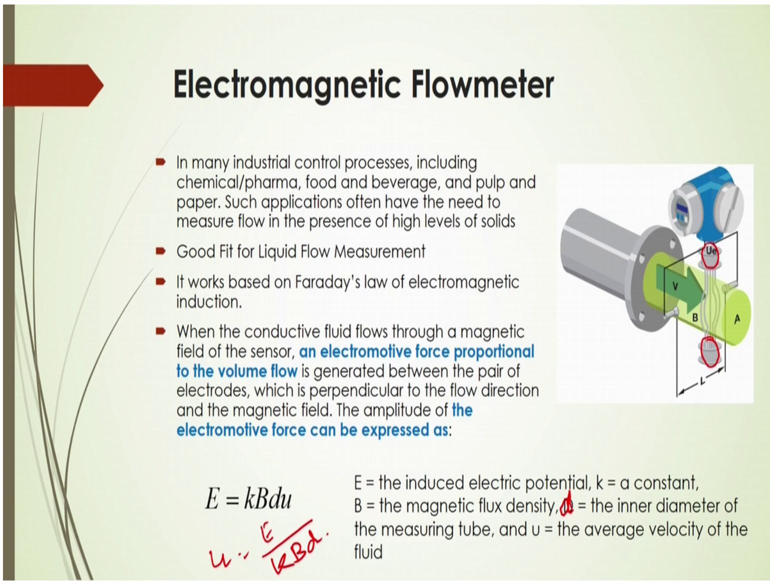

Now, another important electromagnetic flow meter these very important in industry generally this type of devices are being used in industry like chemical industry, pharmaceutical industry, even food industry, beverage industry, pulp paper where you will see some you know that particulates systems are there maybe some solid particles are there that a certain label.

So, in that case through calculate the flow rate this type of electromagnetic flow meter are generally being used because that is actually slurry it is not a few liquid here solid contaminants should be some extent that is called hype it is there, then of course, you cannot measure this flow meter by certain what is that rotameter or venturi meter or some other orifice meter it is very difficult.

So, in that case special equipment of flow meter or device can be used. So, to major this type of flow rate, then you have to use this electromagnetic flow meter it works very well to calculate the flow rate for this slurry type of flow. Now, in this case, it works generally based on the Faraday’s law of electromagnetic induction.

So, whenever fluid would be flowing generally this fluid are being conductive fluid when it will be flows through a magnetic field of sensor, then in that case you will see one a electromagnetic force that will be generated and that electromagnetic force would be proportional to the volumetric flow rate of the fluid and that by you will see this electromagnetic force will be generated between the pair of the electrodes it is shown in the figure this two electrodes will be there.

So between these two electrodes pair that means, here there will be a generation of electromagnetic force and you can get the more electromagnetic force if you supply more or if the fluid will be flowing with a more velocity or volumetric flow rate. And also this magnetic field of course, will be working to the normal direction of the fluid.

And it's amplitude of the electromagnetic force can be expressed as here E that will be is equal to k into B into D into u, where E is called the induced electric potential or you can say electromotive force and also k is one constant that depends on the device and also that can be calculated by calibration of this devices. And B is the magnetic flux density and D here D if the inner diameter you can say this is small d D is inner diameter of the measuring tube and u is the average velocity of the fluid.

So, once you know the electro motive forces or you can say that induced electric potential, then you will be able to calculate what should be the velocity of the fluid that velocity of the fluid will be here u will be is equal to, then E that is E by K B into d. So, from this equation you will be able to calculate what should be the velocity of the fluid and then what should be the volumetric flow rate of the fluid.

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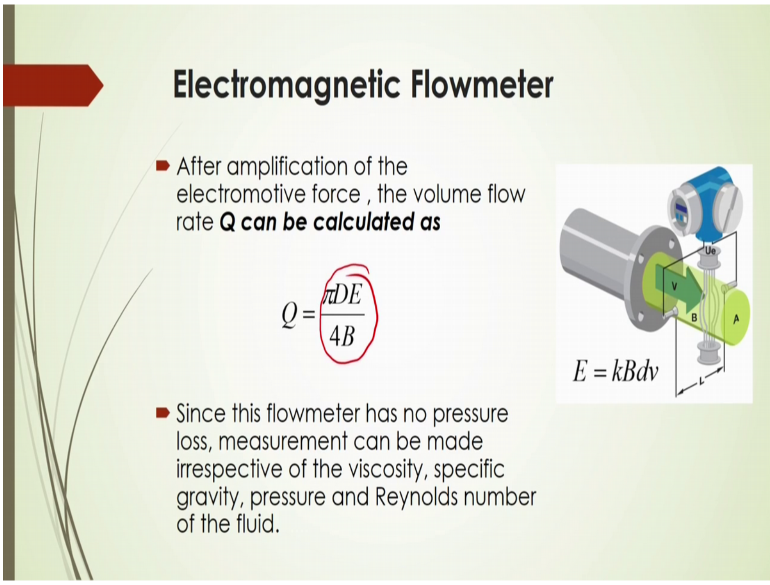

And here after you will see that amplification of the electromotive force, then volume flow rate Q can be calculated as this, here pi D E by 4B here. Since this flow meter has no pressure loss and measurement can be made irrespective of the viscosity, specific gravity, pressure and Reynolds number of the fluid.

So, this is the advantage of this flow meter that it does not depends on the pressure, it does not actually the any fluid properties will not affect on this measurement, so I think it is very useful and also for particulate system where the conventional measuring system cannot be used, you can use this type of electromagnetic flow meter for this slurry flow system.

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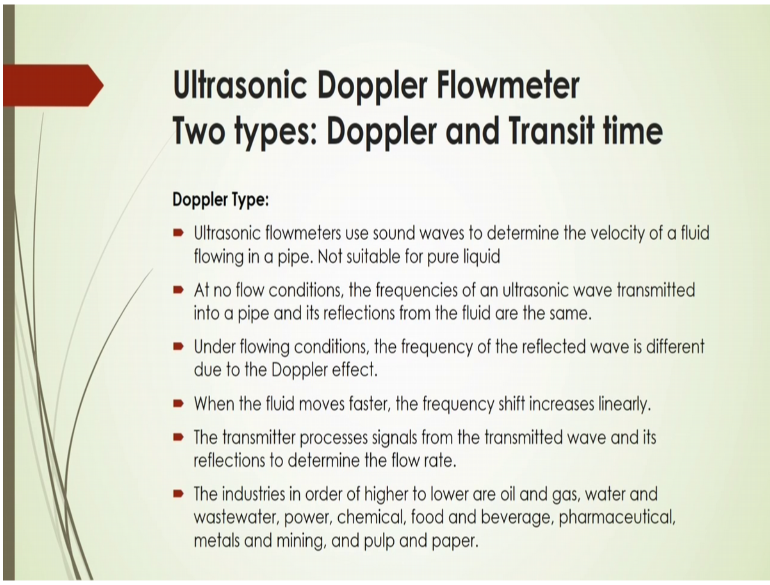

Another important flow meters are here like, ultrasonic Doppler flow meter the two types they are it will be Doppler and transit time flow meter and Doppler type here in this case again that it will be based on the ultrasonic principle. Ultrasonic flow meters used in this case sound waves to determine the velocity of a fluid that is flowing in a pipe and it is generally not suitable for the pure liquid. And at no flow conditions, the frequencies of an ultrasonic wave transmitted into a pipe and in that gets its relations or it reflections from the fluid are the same here.

And under flowing conditions, the frequency of the reflected wave will be different due to the Doppler effect in that case and this when the fluid will be moving faster, then frequency shift increases linearly and the transmitter processes signals from the transmitted web and it's relations to determine the flow rate. So, this is basically as per that what is that here we have discussed that vortex flow meter.

So, exactly the same principles it will be coming that you have to find out the frequency here and of an ultrasonic wave and then you have to relate with that flow rate of that ultrasonic wave, that is transmitted into a pipe. And also this type of equipments whenever you are going to use there that industries in order to higher or lower oil and gas, water and wastewater, power, chemical, food and beverage, pharmaceuticals, industries you have to be very careful they are whether you are using this pure liquid form or not.

So, pure liquid would not be actually giving that correct frequency of ultrasonic wave whenever it will be used. So, that should be that is why the in industries for a lower or higher that case condition of this flow generally for oil or gas you will see it will give you the good frequencies of the ultrasonic wave, they are in water even waste water systems also.

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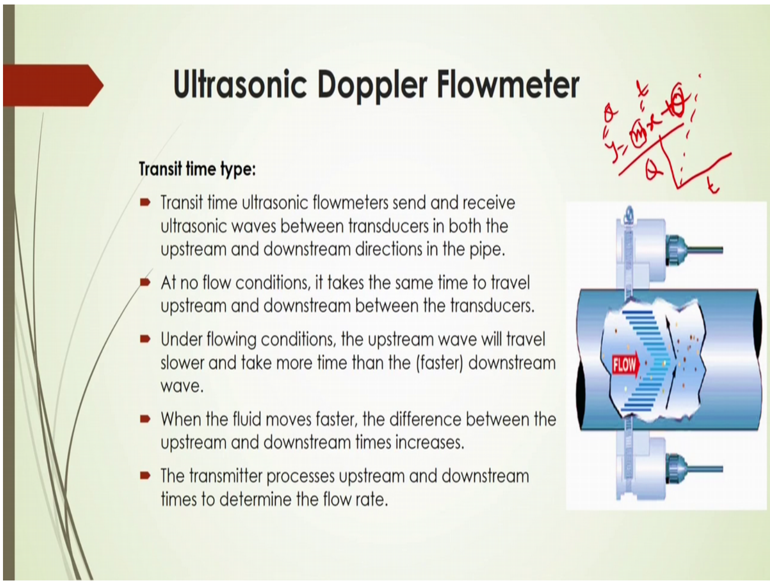

So, for those operations this type of flow meter will be used generally for Doppler type and also another important type is for this transit time type, here in this case this device will send and receive the ultrasonic waves between the transducer in both the upstream and downstream directions in the pipe. And, also you will see there will be no flow conditions there and it will takes the same time to travel upstream and downstream between the transducer there yet to transducer will be placed.

So, between these two transducer you will see that it takes the same time to travel this path of this upstream and downstream. And under the following conditions this upstream wave, that will travel slower and take more time than the downstream wave we should be very faster in that case and when the fluid moves faster the difference between this upstream and downstream times will increase. So, that actually the time of that upstream and downstream will give you that flow rate of the fluid. So, the transmitter process processes that, upstream downstream times here and which will be used to calculate that flow rate.

So, very important that only transit time type here also you can that only two that here transducer to be will be used in the upstream and downstream, then what is the time to take or travel the this ultrasound wave from this upstream to the downstream that you have to actually noted down. And when you have the time of this travelling of this wave from this upstream to the downstream and you can then relate this flow rate with this time.

So, you have to calibrate this fast with known a velocity of the flow rate and the calculate the time and then they are you have to then make a what is that one relationship between this flow rate and with this time and then you will get the relationship time versus that flow rate. Once you know this then you will be able to calculate one what is that one relationship y is equal to m x plus c.

So, in that case c is the what is that intercept and m will be slope here in this case in x axis you can fix time and in the q or flow rate and the y axis, then that is y will be is equal to Q here x will be is equal to time. Then once you know this time then what will be the flow rate and after that you have to calculate what will be the m and c by known values of what is that parameter of the flow rate and with respect to time then once you form this equations, then for any other flow rate for any other time then you will be able to calculate the flow rate once you know the time by this devices.

So, this type of devises are being used in generally for that paper industry wastewater treatment systems and also that oil industry, gas industries there. So, in that case the time to be, accurately measured for that you can use that what is the online measurement there by data logging system. So, that will be useful and after analyzing that time lag you will be able to calculate what will be the flow rate.

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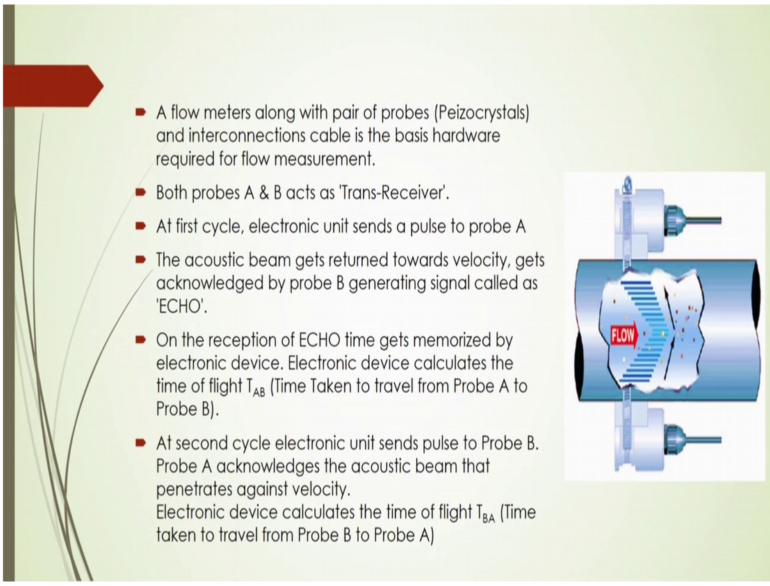

Now, a flow meters along the pair of this probes generally and interconnections cable is the basis hardware required for this flow measurement. Both probes A and B you can say acts as trans receiver and also at the first cycle you will see there will be some electrical condition and where the electronic unit sends a pulse to probe. And the acoustic beam that case gets returned towards the velocity gets acknowledged by the probe B and it will generate the signals we should be called as echo.

And on the receptions of the echo times gets memorized by the electronic devices. Now, electronic device that calculates the time applied that is T AB of this what is that ultrasonic wave from this upstream to the downstream and or time taken to travel from probe A to probe B here because in upstream and downstream you are putting this probe A and B. And second cycle what will happen the electronic unit sends pulse to probe B and probe A acknowledges that acoustic beam that penetrates against velocity. And electronic device this will calculate the time of the flight T BA time taken to travel from B to probe B.

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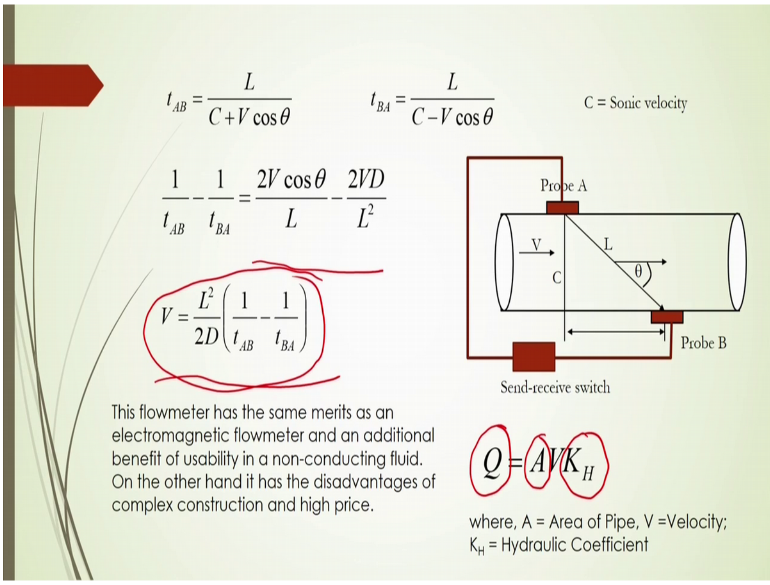

Once you know that time like that T AB which will be L by C plus V cos theta one equations by this formula you can calculate where C is called sonic velocity and V is the fluid velocity. And theta is the angle of this, what is that probe A and B where you are substituting or you are attaching and what would be the angle with that flow that is given theta as it is shown in the figure. And similarity T BA that will be L divided by V minus V cos theta.

So, 1 by T AB minus one by T BA you have to calculate and then you will get the simplified form of this and then finally, you will be able to calculate what would be the V is equal to L square by two d into one by T AB minus T BA. So, once you know this signals time that from T AB to T BA, then you will be able to calculate what would be the velocity here.

And L is the length here between these two probe and D is the diameter of the pipe and T AB and T BA is the time for this here it is described that that echo or time that gets memorized by the electronic devices and electronic device calculates the time of flight T AB, from what is that probe A to probe B and vice versa.

So, once you know this velocity, then you will be able to calculate what would be the flow rate that will be proportional to this velocity and to be coming as A into V into K H this a is the area of the pipe that is cross sectional area of the pipe and V is the velocity and K H is it is called hydraulic coefficient and this will give you the what is that exact measurement of the flow rate, and it would be calculated based on the device with some known experimental condition.

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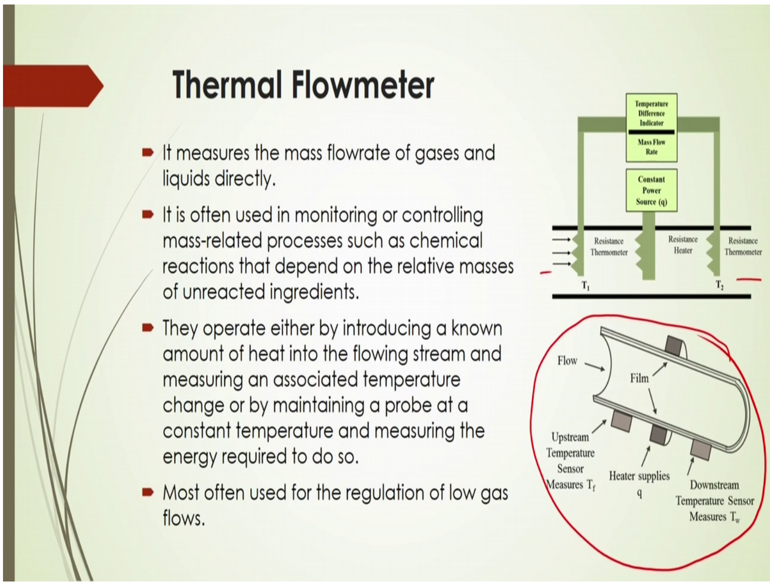

Now, another important flow meter it is called thermal flow meter this is one of the widely used flow meter and it measures the mass flow rate of the gases and liquids directly here. And in this case you will see the as per figure shown here, there is a pipe how this there are different part of this devices are given here and it is often used in monitoring or controlling mass related process such as chemical reactions that depend on the relative masses of unreacted ingredients.

And also this type of equipments generally used based on the amount of heat is supplied and into the flowing stream and measuring and associated temperature change by maintaining a probe at a constant temperature and measuring the energy required to do so. So, based on that temperature differences and energy requirement that will depends on the flow rate and based on that, what would be the flow rate you can calculate. And in this case generally this type of equipments are being used for regulation of the low gas flows here in this case, so when fluid will be flowing there in this figure it is shown that.

How the upstream temperature sensor and downstream temperature sensors, how it’s temperature will be changing after supplying the heat as amount of q from the surface of the pipe and then based on that temperature differences you will be able to calculate what would be the flow rate there.

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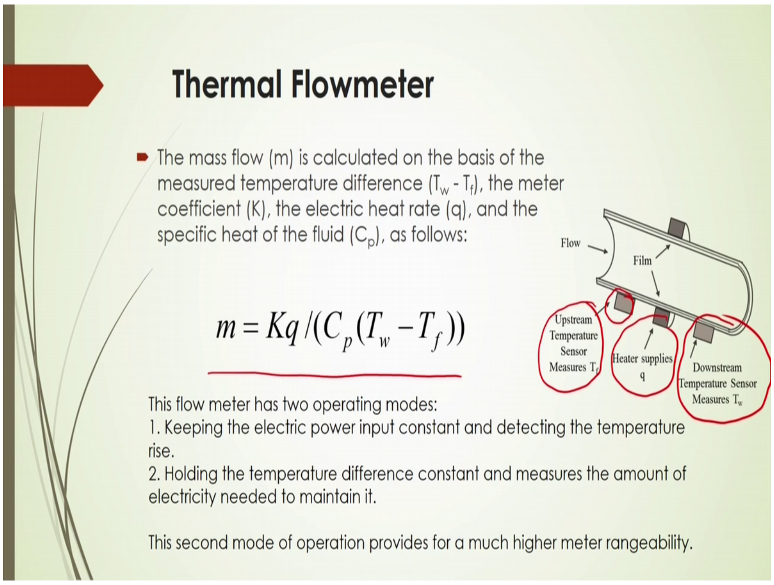

Now, the mass flow can be calculated on the basis of this measured temperature differences of these T w and T f here it is shown here this; this probe will give you the up stream temperature sensor as T f and this would be downstream temperature sensor which will give you the temperature of the downstream fluid.

And if heat is supplied as a q amount here, then from the certain what is that meter coefficient; that means, by considering that loss coefficient of the heat, then from the electric heat rate and the specific heat of the fluid. Then you will be able to calculate this mass flow rate of the fluid as K into q divided by C p into T w minus T f this is simply cooling law of the Newton, then you will be able to calculate.

Now, in this case K is what is called meter constant because you will see if you are not using this what will happen you will not be able to exactly calculated what would be the flow rate because there will be some heat energy loss. So, upon considering that heat energy loss here you have to correct this equality just by considering that meter constant there.

So, we have to use these principles to calculate the mass flow rate once you know, the temperature difference. So, has two operating modes of this thermal flow meter in this case first one is keeping the electric power input constant and detecting the temperature rise one method. And other method is that, the holding the temperature differences constant and measures the amount of electricity needed to maintain this constant temperature.

So, by this two modes you will able to calculate what would be the flow rate and in this case very interesting once you keep the electric power input constant only you will see that, there will be change in temperature difference. Another way that if you are going to keep this temperature difference constant, then you have to control the electricity there electricity supply that is called heat energy supply by that electrical energy.

And the second mode that is the keeping temperature difference constant by continuously supplying of electricity this provides a mask higher meter rangeability, in this case because you are just regulating the heat energy supplied there, not the temperature difference regulation. But temperature difference regulation is very tough in this case because you are using that temperature, (Refer Time: 32:55), then you have to input the temperature controller there and it is sometimes should be erroneous.

So, it is better to keep this what is that temperature difference are constant there and by just maintaining that constant or you can say that amount of electricity supplying.

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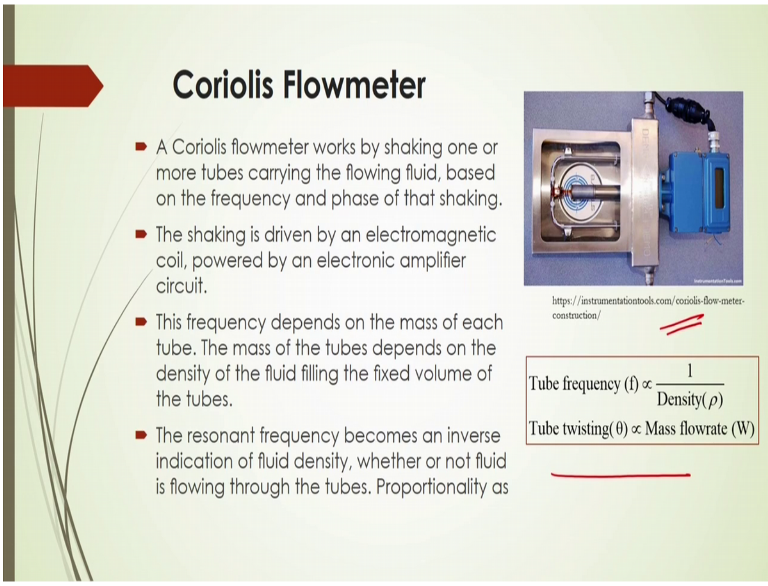

Another one important that Coriolis flow meter, it generally works of based on the shaking of one or more tubes and in this case whenever tubes will be a shaking based on the fluid energy that is supplied at a particular velocity of the fluid it will be give you certain frequency. And of course, there will be some phase change of that shaking and based on that shaking you will be see you will be able to calculate that flow rate.

Now, the shaking a generally is driven by an electromagnetic coil that will be powered by electronic amplifier circuit and this frequency depends on the mass of its tube and that mass of the tube depends on the density of the fluid that is filling in the fixed volume of the tube as per figure shown here. And the resonant frequency becomes an inverse indication of the fluid density and whether or not that fluid is flowing through the tubes that proportionality will be there.

So, tube frequency depends on that density of the fluid and density that depends on the what is that how much volume of that fixed amount of volume that is filling in the tubes, so that will give you the tube frequency there. So, once you know that tube frequency how, then you will be able to calculate that mass flow rate and in that case if you know that frequency that is tube frequency that frequency will come at what is that based on that electromagnetic coil that power by electronic amplifier circuit.

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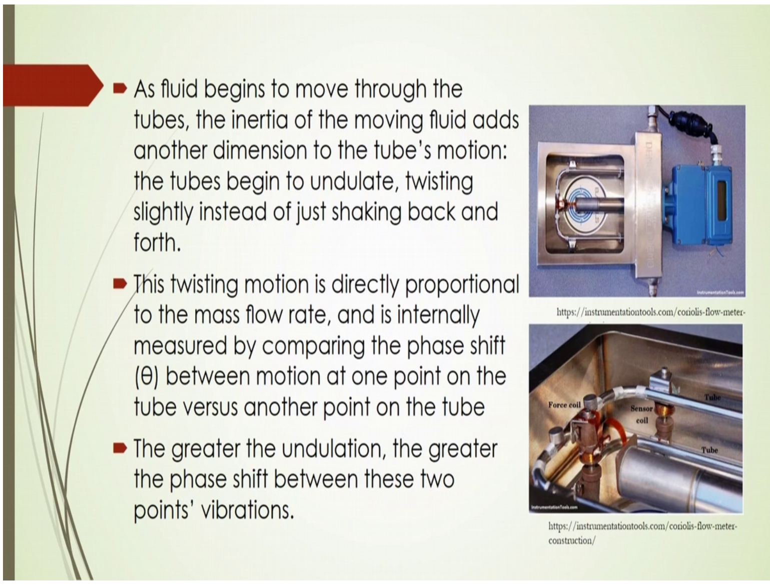

And, in that case the inertia of the moving fluids that adds the dimension that is to vibrate or shake to the tubes motion in the other direction and that case the tubes begin to undulate, twisting slightly instead of just shaking back and forth. And this twisting motion is directly proportional to the mass flow rate and is internally measured by the comparing the phase shift that is theta between the motion at one point on the tube versus another point on the tube.

Now the greater that undulation you will get the greater phase shift between the phase between these two points vibrations and based on that vibrations and twisting motions you will be able to calculate the mass flow rate as given by this equation here. So, mass flow rate will be actually proportional to that tube twisting or tube twisting is actually that mass flow rate there because, here inertia force is important whenever moving of the fluid and which will add the dimension to the tubes motion there.

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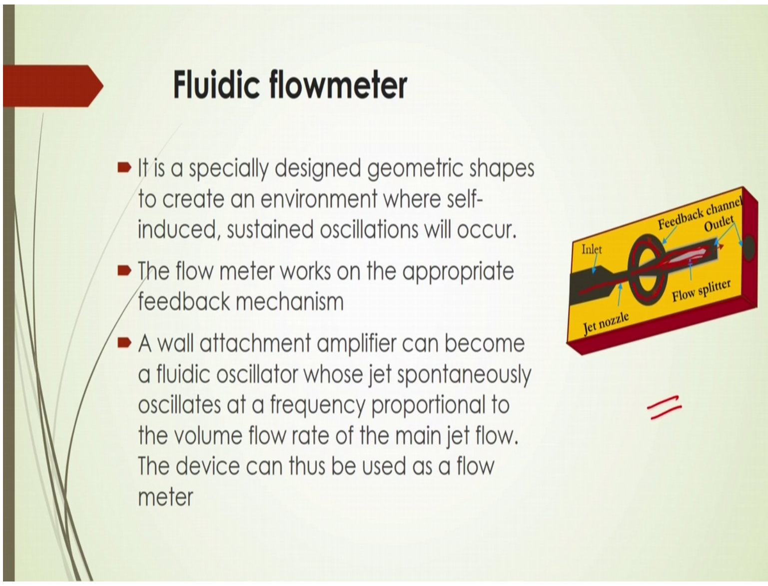

And, nowadays that one flow meter it is called fluidic flow meter is actually being coming in picture in literature that are being developed it is called fluidic flow meter and it is specially designed based on the geometric shapes to create an environment where self induced sustained oscillations is generated. And this type of flow meter as shown in figure here works on the appropriate feedback mechanism whenever you will see the fluid would be flowing though the nozzle and it would be passing through the diverging sections here dividing.

And then it will see here somewhat is that feedbacker will be used and that case through this feedbacker there will be a flowing of flow fluid and there will be a you know that oscillations will be made and based on that oscillations, after amplifying this oscillations where it is called fluidic oscillations and made by some fluidic oscillator.

And, in that case that oscillator will have some jet and it will spontaneously oscillate certain frequency and that frequencies proportional to the volumetric flow rate of the main jet flow. Generally this type of flow meter is being used for measuring the flow rate which is coming out from the jet. So, this flow meter is designed based on that again that oscillation of the fluid.

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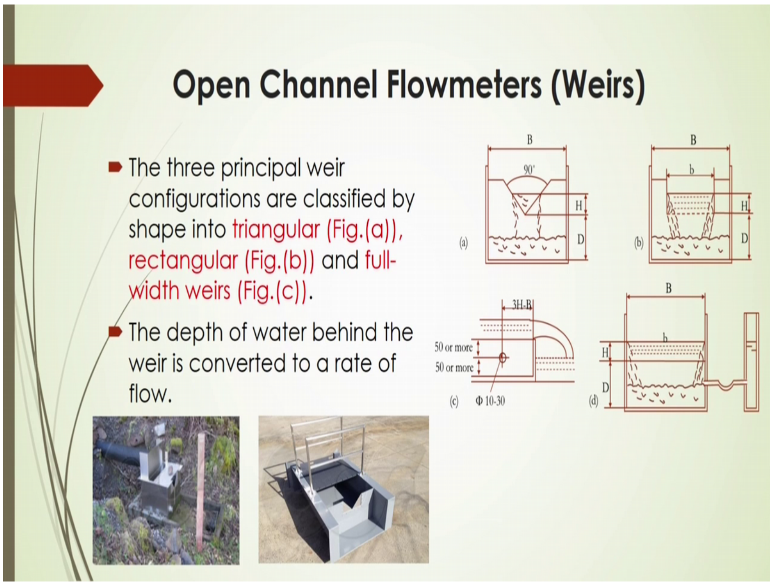

Another already we have discussed that channel flow meters that is weirs and there are three principles weir are generally at configured to measure the flow rate in open channel, those are actually triangular, rectangular and also full width weirs as shown in figure a b c respectively and the depth of the water behind the weir is converted to a rate of the flow.

So, you have to know the depth of the flow and if you know the depth of the flow then you will be able to calculate what would be the pressure difference and based on which also we will be able to calculate what would be the flow rate.

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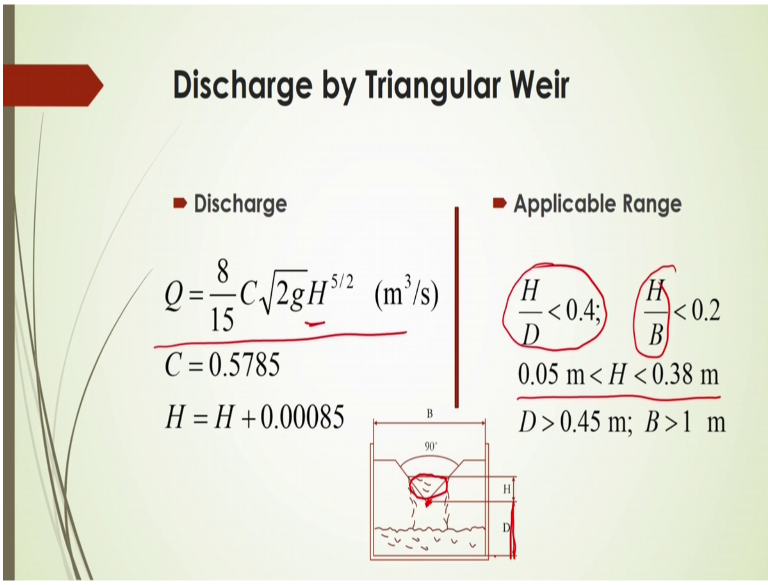

Now, what would be that flow rate or it is called discharge from the open channel for the triangular weir, this discharge will be calculated based on this what is that open height of the channel here it is depth of the water behind the weir. And this weir already we have discussed in the earlier lecture, so what is that weir design of the weir all this things.

So, here see there would be a flow is in the triangular weir this is the liquid height here the H and this is the, what is that distance from this base of this weir end here. So, once you know this height of this water in the weir, then you will be able to calculate what would be the discharge. So, based on this equation given here Q will be is equal to 18 by 15 into C into root over 2 g H to the power 5 by 2 this by equation will give you that what will be the discharge.

And, C is called what is that we are constant and it is generally 0.5785 for triangular weir and this type of equation generally it is empirical equation and it actually valid only within a certain range of flow rate and also or geometrical variables. So, in that case it is H by D that should be is equal to 0.4 and H by B should be less than 0.2 and H height of the weir that is a water height in the weir that will be within the range of 0.5 to 0.38 and D should be is greater than 0.45 and B is will be greater than 1 meter.

And, so based on these about within these range of that is geometry of this weir then you will be able to calculate the flow rate here. So, this has one disadvantage that it will work only within a certain range of geometric variables of this weir.

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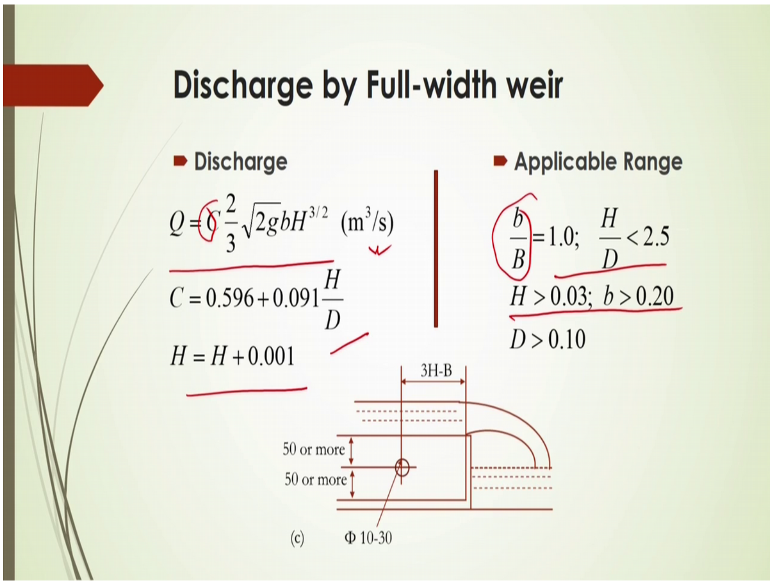

And in the case of full width weir you can calculate that or measure the discharge by this equation and again here the C is on constant that is called weir constant here and this weir constant you can get it based on the geometry that would be depends on that, that it will depends on H and D here that H will be calculated by this equation.

And finally, then what should be the discharge that you can calculate from this equation, this also we will have certain limit and it will work only within a range of this heres it is given. In this case H of course, again that should not be less than o.03 and B should not be less than 0.20 and also the D that is given in that here ah; that means, weir into that a bottom of the liquid that should not be less than 0.10.

So, in this lecture we then got the idea of the principal how the different flow meters works other than that conventional way by just getting the what is the drag force, pressure force all those things and these are these flow meters basically based on that oscillatory mechanism and what is that sonic wave, as well as what is that some what is that vortex frequency.

So, based on these principles there are several other devices of flow meter are being designed and nowadays are commercially available and these are the equipments can be used for the measurement of flow rate in the pipe even in different flow conditions and even different types of flow and whether this slurry flow or pure water flow or some contaminants are present in the water that based on those criteria you can select this is flow meters to measure this, specially that electromagnetic flow meter that is being used for slurry system as an example.

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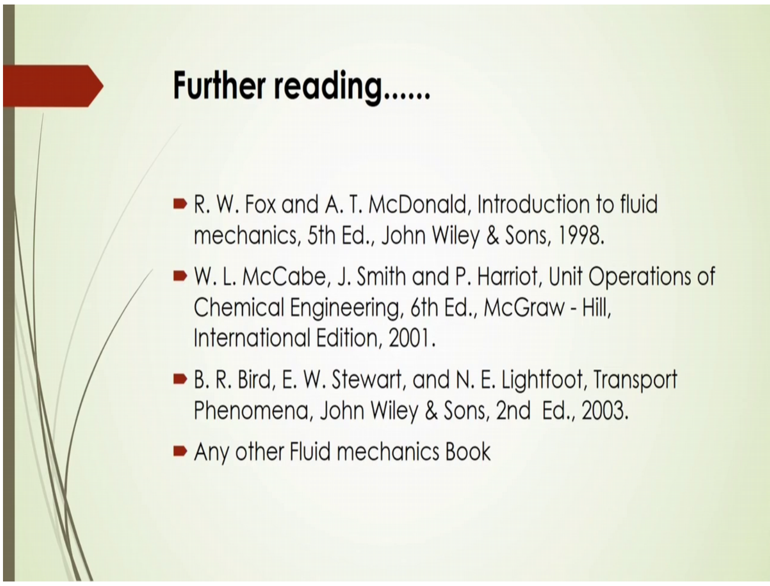

So, I think it will be useful for your further actually design of the flow meter based on this principles and I would now stop this lecture here and you should read further to more about the flow meter from this text books, and also other sources you can follow.

Thank you.