**Experimental Methods in Fluid Mechanics**
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Lecture 28
Transient response of thermal system, Thermocouple compensation, high speed flow
Contd

Good afternoon, we will continue our discussion on experimental methods in fluid mechanics and in continuation of my last discussion on the transient response characteristics, today we will discuss about the measurement of temperature in high speed flow. So, we will see what are the different techniques available to measure the temperature of high speed flow.

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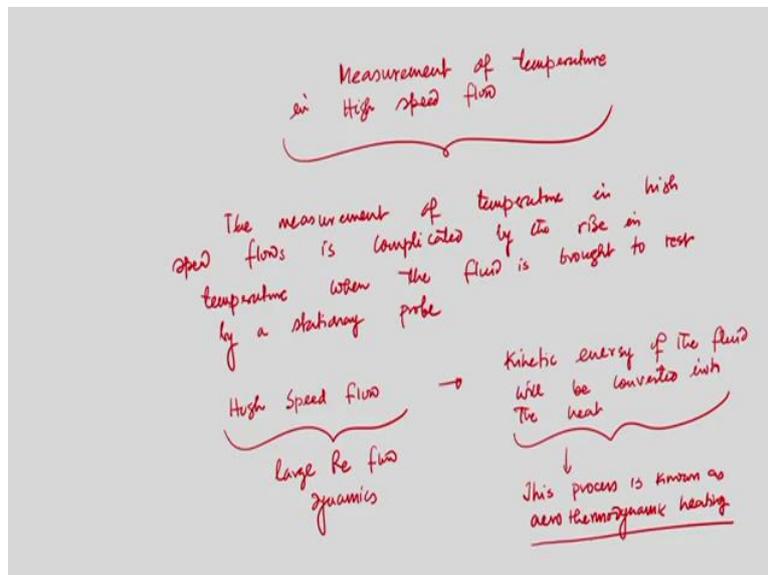
So, you know measurement of temperatures in high speed flow. So, if we know that when there is a flow field and the velocity of the flow field is very high and if we insert a probe, then physically you are trying to disturb the flow field and that is what we have discussed in the context of thermocouple that this is not a measurement where we can measure temperature using a non invasive way.

So, that means if you would like to measure temperature in high speed flow, we need to insert a probe. The moment when you insert the probe, the probe will try to disturb the flow field. Not only the you know disturbance, but also there will be the you know another important phenomenon that we have studied in our undergraduate fluid mechanics.

That means, if we try to disturb the flow field by inserting a probe that is that means any object we are putting inside the flow field and that object will try to bring the fluid particles

rest in the close vicinity of the object. So, what will happen if we place an object which is our temperature measurement or temperature measuring probe? The you know placing of that probe in the flow field will bring the fluid particle or the flow suddenly in a rest condition and because of the sudden deceleration, there will be rise in temperature.

So, we are trying to measure the temperature of the flow field, but the sudden deceleration of the fluid, will try to increase the fluid temperature if the process is not isentropic. That is what we have studied in our fluid mechanics course. So, the measurement of temperature in high speed flows is complicated task by the rise in temperature rest by a stationary probe.

That means, it is not a case that the probe is moving with the fluid, instead we are putting the probe and the probe, the placing of the probe will bring the fluid or the fluid flow to be decelerated and because of this deceleration there will be a rise in temperature and that will you makes the measurement very complex.

So, the process you know that if we put a stationary probe in a high-speed flow, then the rise in temperature because of this process, that means the kinetic energy of the fluid will be converted into the heat. So, this process is known as aero thermodynamic heating in the context of you know high speed flow of high speed flow dynamics.

So, I mean in the area of high speed, so that is I can write that, large Reynolds number flow dynamics. That means the kinetic energy of the fluid will increase, but will be converted, will be converted into the heat energy and this process known as aero thermodynamic heating. So, I am underlining these two words that is aero thermodynamic heating.

So, if we put a probe in high speed flow field, the placing of the probe will try to, rather will decelerate the flow velocity and there will be a rise in heat, rise in temperature in the, I mean there will be you know conversion of energy from kinetic energy to the heat energy and as a result of which there will be a rise in temperature. So, now this rise in temperature makes the measurement of temperature in high speed flow a very complicated task.
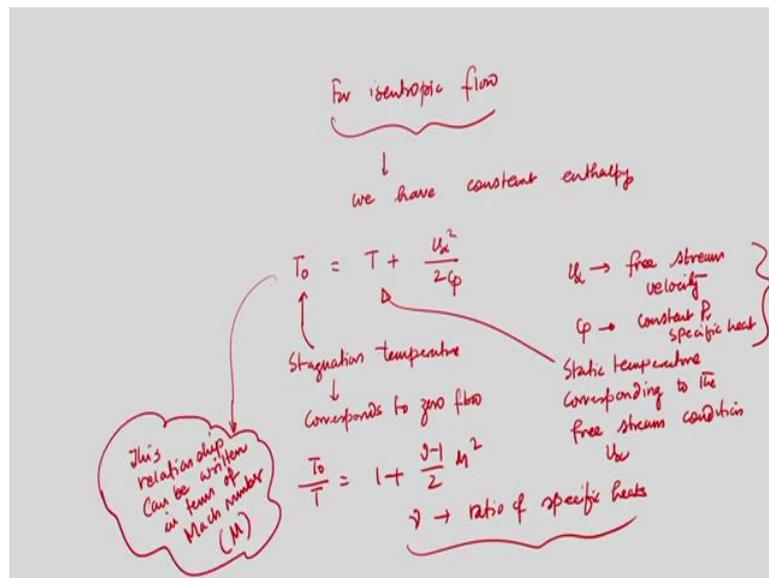
So, if we consider that for an isentropic flow, for isentropic flow, that is what we have studied in our undergraduate fluid mechanics as well as you know fluids mechanics course that if we consider the flow to be an isentropic flow, then we have constant enthalpy and we can write that T naught will be equal to T plus u infinity square y 2 into Cp.

So, this T naught is known as stagnation point temperature. Stagnation temperature which corresponds to 0 flow and this T is the static temperature corresponding to the free stream condition, U infinity and U infinity is the free stream velocity, and Cp is the constant pressure specific heat. So, this is what we have studied in our undergraduate text.

Now, this relationship can be retained in terms of mark number that is 1 plus gamma minus 1 upon 2 into m square, where gamma is the ratio of specific heat. Now, when gamma, I mean when mark, and m is the mark numbers. That means, this relationship can be written in terms of mark number.

That means, if we go to the next slide, that means we have written this relationship in terms of mark number and we can write this is m square. So, this is the relationship we have studied, we have derived in our undergraduate compressible fluid flow, in compressible fluid mechanics course.

Now, when mark number is less than equal to 0.3, we have studied that low speed flow, then static pressure and stagnation pressure sorry static and stagnation temperature are equal. That means, if the flow, you know mark number is less than or equal to 0.3, that is the low speed flow, the static and stagnation temperature are approximately equal.

We are trying to and our objective would be to measure the temperature, free stream temperature T infinity that is not the stagnation temperature but if we would place a probe to measure the temperature, we will get the stagnant temperatures. But, if mark number less than equal to 0.3 then static and stagnation temperature will be equal and will be approximately equal and there is no problem.

So, the probe, the ideal probe will measure the stagnation temperature. But our objective is to measure the static temperature, real temperature. So, our objective will be to measure the temperature which is not the stagnation temperature. That means, I can write that real temperature or a real probe will indicate a temperature.

So, if the probe is ideal probe, we will measure the stagnant temperature, but the process or I mean the process is not an isentropic process. So, the real probe will indicate a temperature say that is known as recovery temperature, TR. Recovery temperature and as the process is

not isentropic. That means, if we place a probe in the flow field, the probe will give, will measure temperature that is stagnation temperature that is the ideal condition. But mark number less than or equal to 0.3 may not be the case always and the probe will measure a temperature which is known as the recovery temperature as the processes are not isentropic.

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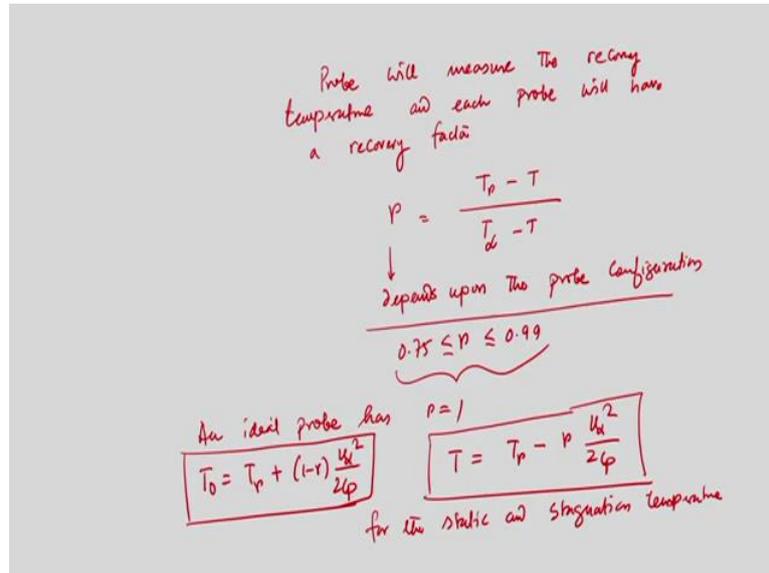
That means, if we design a probe to measure the temperature in high speed flow, the probe will measure recovery temperature and the recovery temperatures should be related with the static temperature using a factor and each probe will have a recovery factor, r which is nothing but Tr minus T divided by T infinity minus T. So, this R depends upon the probe configuration, r value which is typically 0.99, less than 0.99, greater than 0.75.

So, the value of r varies between these two value. So, if we now talk about an ideal probe, definitely value of r will be equal to 1. So, an ideal probe has r equal to 1 and this value of r will depends upon the probe configuration. Now, question is if we use the T is equal to Tr minus r into u infinity square by 2Cp, so if we use the following formulas, I mean this formula, T is equal to Tr minus r into u infinity square by 2Cp for the static and stagnation temperature.

So, Tr is equal to T minus r into u infinity square by 2Cp and T naught will be equal to Tr plus 1 minus r u infinity square by twice Cp. So, these two formulas are used to measure the static and to stagnation temperature. So, that means r is not equal to 1. If r is equal to 1 then it will be the ideal probe, but seems the processes are not isentropic process and that is why the

recovery factor is coming into the picture, the value of, typical value of r is given and we can use these formulas to calculate the static and stagnation pressure respectively.

So, now that means whether you are using any special probe to measure the temperature in high speed flow or you are using any ordinary probe to measure the temperature in high speed flow, we need to keep in mind that placing the probe in the flow field will disturb the flow and as a result, the temperature which you will get, I mean which you will measure is not the static temperature, is not the actual temperature which you are interested in, rather we will get the temperature that is that is not the actual temperature.

So, that means the kinetic energy will be suddenly converted, arrested and the fluid which will stop, I mean the deceleration of the fluid will increase the kinetic energy into the other form of energy that is heat and the temperature will be increased. The rise in temperature that is what is very important and very complex. So, we can use these two formulas to measure the static and stagnation temperature for the high speed flow.

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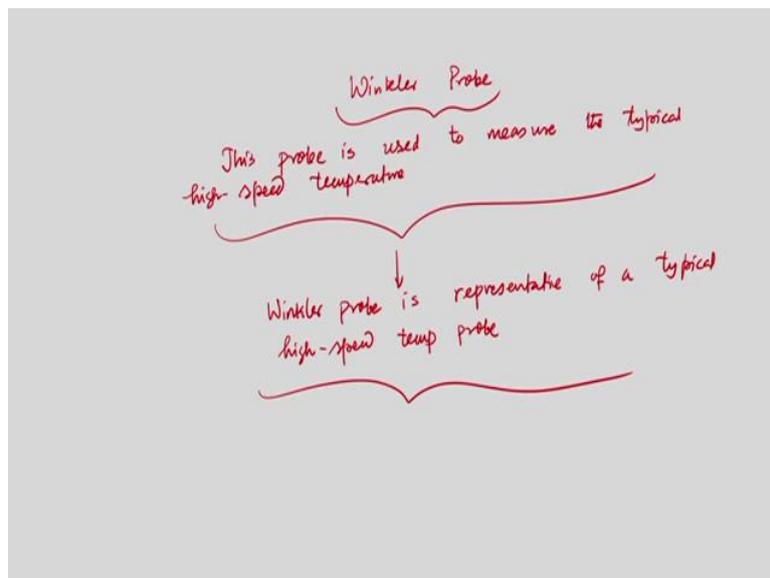
Now, there is a special probe which is known as Winkler probe. So, that is Winkler probe which is used to measure, this probe used to measure the typical high speed temperature. So, this probe is used to measure, this probe used to measure the typical high speed temperature and I can say that the Winkler probe is representative of a typical high speed temperature probe. So, at least we will see schematically the geometrical configuration of this probe and then we will try to know by how this probe can measure the temperature in the context of high speed flows.
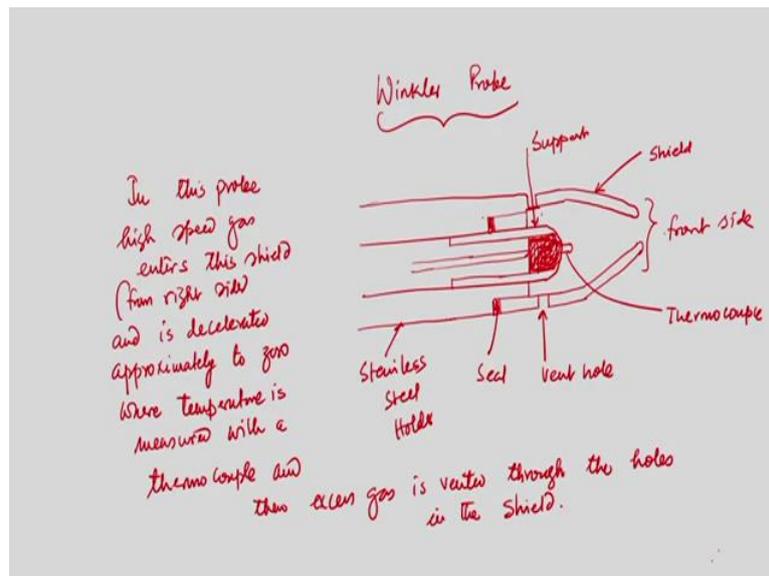
So, if we try to draw the schematic that is Winkler probe, we are getting, we will draw the schematic now. So, this is the schematic of the Winkler probe. So, these are known as seal, this is vent hole, this is thermocouple, this is shield and this is support. This is seal and this is stainless steel holder. So, this is a schematic depiction of a Winkler probe.

We can see that, so thermocouple is there, but this portion is the front side. So, what we can see that in this probe, high-speed gas enters the shield from right side and is decelerated, decelerated approximately to 0, where temperature is measured with a thermocouple and then excess gas is vented through the holes in the shield.

So, this is the process. We have drawn the schematic. From the schematic we have seen that if we place the probe there will be you know, as if we are trying to disturb the flow field. Placing the probe in the flow field will allow enough fluid to be suddenly decelerated and as a result of which, there will be a conversion of, there will be conversion of kinetic energy into the heat.

And the rise in temperature will create a problem to measure the temperature using this probe in the high speed flows. And that is the very difficult task in measuring temperature for the high speed flows. Now, this is the schematic. What we can see that from the right side, that is the frontal side, so the high speed gas will enter this shield first. What we can see?

That the geometry of the shield is initially very small, I mean I can see that towards the right side if we see, that geometry is such that it is narrowing down the, you know the geometry is narrowing down the flow area and as a result of which velocity will be increased. Now,

suddenly the area is increased, I mean gradually the area is increasing, so fluid will be decelerated.

And as if the thermocouple is placed and the decelerated flow, I mean will be the seal will be designed in such a way that during the movement from within the shield, the flow field will be decelerated approximately to 0 at the thermocouple where temperature will be measured and the excess gas that will be vented through the vent hole in the shield. So, what we can do?

That means, we are decelerating the flow definitely, but you know that is the typical probe which is used in measuring temperature for the high speed flows. So, the flow which is approaching the shield will have definitely high velocity, the geometry of the shield itself increase the velocity of the incoming gas, high speed gas and that we will be now entering into the shield area, where area is gradually increasing and the velocity will be decelerated.

So, now what will happen? When the velocity is decelerated, we can see from the schematic, the velocity will be decelerated approximately to 0, where the temperature is measured using thermocouple and we will measure the temperature and excess gas will be vented through the vent hole. So, this is only the you know probe available to measure temperature in high speed flows.

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So, I mean again if I go back to my previous slide so, we have discussed about that, using the probe, if we place in the flow field, there will be sudden deceleration and there will be a rise

in temperature and this rise in temperature will be problematic in measuring temperature of high speed flows.

And for that, we have discussed that there will be a probe recovery factor and that recovery factor, we have defined, the value of the recovery factor will be equal to 1 for the ideal probe but since all the processes are not isentropic process, ideal process, so the value of r will be always less than 1 and for that, we have same two different equations which will be used to measure the static and stagnation temperature using a special probe, that is the Winkler probe, and we have discussed about the configuration of the Winkler probe.

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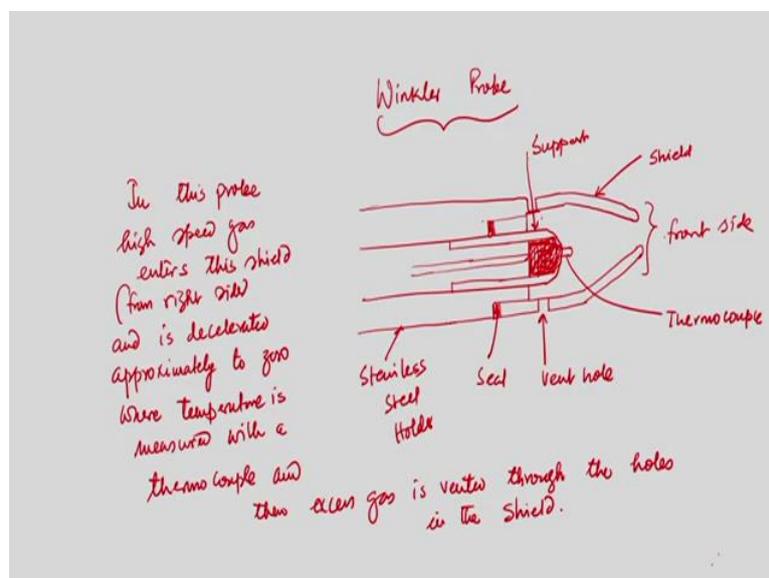
So, Winkler probe is essentially what is done that velocity will be increased and that velocity increase will mimic the velocity of the high speed flows, but it is now decelerated as the flow passes through the shield area and that it will be approximated to 0 where temperature will be measured in the thermocouple. So, I mean, we can measure the temperature using this probe for the high speed flows. So, with this I stop my discussion today and we will continue our discussion in the next class. Thank you.