Thermal Engineering: Basic and Applied

Dr. Pranab K Mondal
Department of Mechanical Engineering
Indian Institute of Technology - Guwahati

Lecture - 33
Factors that Affect the Efficiency, Problem on Flow Nozzle

I welcome you all to the session of thermal engineering basic and applied and today we shall discuss rather identify the several factors, those affect the nozzle efficiency and then we shall solve one numerical problem on the flow nozzle. So first of all we need to identify those factors which are very important considering their influential role on the efficiency of the nozzle and then we shall discuss about their actual role. So it is better to write the nozzle efficiency that we could derive in the last class. So what is the mathematical expression of the nozzle efficiency?

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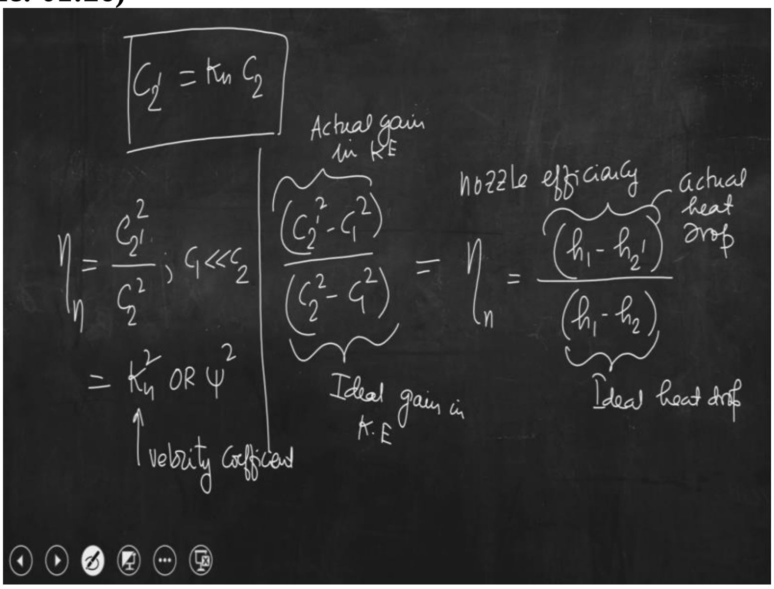

Nozzle efficiency

We could express mathematically as the ratio of actual heat drop to that due to isentropic process. In other word it is the ratio of actual gain in kinetic energy to that due to isentropic process.

$$\eta_n = \frac{h_1 - h_2'}{h_1 - h_2}$$

where $h_1 - h_2 =$ Ideal heat drop and $h_1 - h_2' =$ actual heat drop

We also could relate this quantity to the velocity.

$$\eta_n = \frac{c_2'^2 - c_1^2}{c_2^2 - c_1^2}$$

where $c_2'^2 - c_1^2 =$ Actual gain in K. E and $c_2^2 - c_1^2 =$ Ideal gain in K. E

So basically this is the actual gain in kinetic energy of the steam that is as it is passing through the nozzle to that due to isentropic process. So you know that we also have discussed that this nozzle efficiency can be written as below considering the fact that $c_1 \ll c_2$

$$\eta_n = \frac{c_2'^2}{c_2^2} = \psi^2 \text{ or } K_n^2$$

$$\text{Where } \psi \text{ or } K_n = \text{Velocity coefficient}$$

Now the value of this coefficient has been discussed in the last class that it varies from 0.93 to 0.97 depending on the surface properties of the internal surface of the nozzle. So if the surface is very rough then $K_n$would be little away from 1 and the surface is relatively smoother than it should be closer to 1.

So basically that you have studied in fluid mechanics

$$c_2{}' = K_n c_2$$

So from this relation you can see that if $K_n = 1$ that means if the surface is atomistically smooth, then there is no frictional effect and the actual velocity is equal to the velocity that is obtained by modeling the flow as an isentropic process. Now having established the expression of nozzle efficiency, let us now look at the several factors, those affect the nozzle efficiency.

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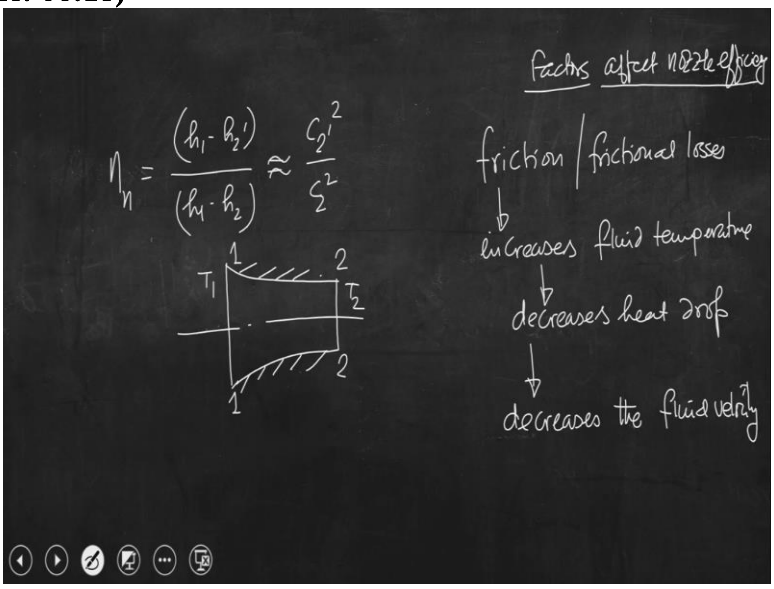

$$\text{Nozzle efficiency}, \eta_n = \frac{(h_1 - h_2')}{(h_1 - h_2)} \approx \frac{c_2'^2}{c_2}$$

So basically when there is a flow of steam through a nozzle or any channel, we have studied in fluid mechanics that frictional effect or frictional losses cannot trivially neglected to be precise.

So basically it depends on the fluid viscosity and it also depends on the surface roughness or surface properties. So basically it depends on properties of the bounding surface. So when there is a flow through a confinement and that confinement is bounded by several surfaces, so the properties of those surfaces also play an important role to dictate the frictional loss.

So we know friction tends to decrease the velocity. Why? Because that is the resistance. So we have studied in fluid mechanics that if the surface is having roughness, then it is because of this roughness, velocity of fluid very close to the surface is equal to 0 as it provides a resistance to the flow. So not only the velocity will decrease, it is because of this reason the temperature of fluid which is passing through a confinement will also increase. So basically it heats off the fluid which is being transported through the nozzle.

Why I am talking about friction? Because to model the flow through a nozzle, we have assumed that it can be modeled by an isentropic process. So if we assume that the process is an isentropic process, we have considered that the frictional loss is absent. There is no heat loss from the flowing steam to the surroundings through a wall. So basically we have considered first factor that affects the nozzle efficiency is the friction or frictional losses.

Now if friction increases then fluid temperature will increase, if fluid temperature increases then heat drop that we have written in the nozzle efficiency expression that is the ideal heat drop that we are not supposed to get. So I mean suppose in one case surface roughness is there and in other case surface roughness is even more severe. So if we consider these 2 cases, then we will be getting relatively higher heat drop in the former case, while in the latter case heat drop will be less, because more is the surface roughness more will be the temperature of the fluid which is passing through the confinement and heat drop will be less. So basically friction increases fluid temperature and it decreases heat drop. This is quite trivial.

So basically if the temperature of fluid increases then definitely the heat drop decreases. If we consider the confinement as shown in the slide through which steam is flowing and suppose this is section 2 2 and this is section 1 1 and the surface is very rough and the nozzle surfaces are insulated. So basically it is because of this insulation that is provided at the outer periphery of the nozzle, there is no heat leakage. So, our objective is to minimize heat transfer from the flowing steam to the surroundings but it is because of the friction, fluid temperature at the exit of the nozzle increases. Suppose if section 1 1 temperature is T_1 and section 2 2 temperature is T_2 and now T_2 increases because of this frictional effect then $T_1 - T_2$ will decrease. And not only that the frictional effect will also try to reduce the velocity. So basically let us quickly review the effect of friction.

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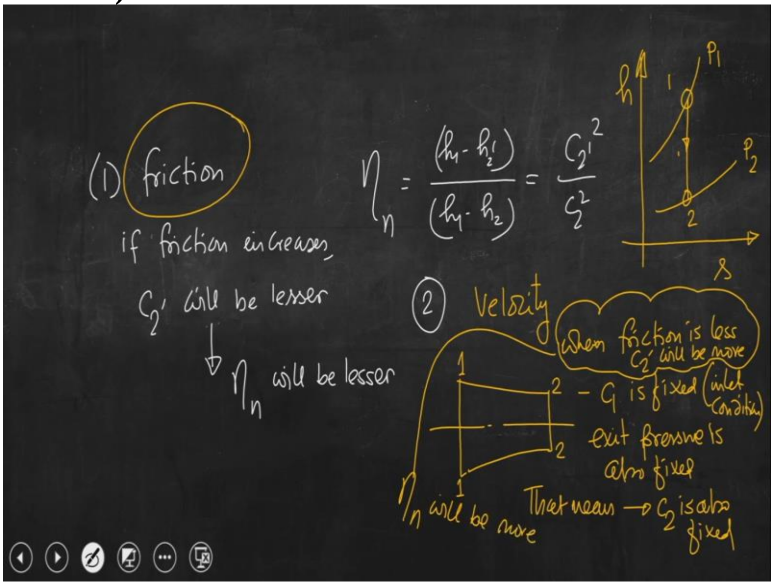

1) Friction

If friction increases, then heat drop will reduce, velocity of steam at the exit will also reduce.

$$\eta_n = \frac{(h_1 - h_2')}{(h_1 - h_2)} = \frac{c_2'^2}{c_2}$$

So if friction increases, then $c_2{}'$ will be lesser so the effect is η_n will be less. So efficiency of the nozzle will reduce. So that means our objective should be to have internal surfaces of the nozzle closer to a very smooth surface. So it is very unlikely to have a surface which would be atomistically smooth. Our objective should be to have a surface closer to that one, so that we can minimize the frictional effect to increase the fluid velocity at the exit. And hence the efficiency of the nozzle will increase. Our ultimate aim is to get higher fluid velocity at the exit of the nozzle because we want to have a jet of steam.

2) Velocity

See this is basically something which is again related to friction. So this is the main factor, now I will be discussing about velocity, but you can see the velocity is directly linked to the frictional effect. Say there is a flow nozzle as shown in the slide with section 2 2 and 1 1. I would like to write one important thing that c_1 is fixed because that steam is coming out from steam generator boiler. So c_1 c 1 is fixed. So this is inlet condition. Exit pressure is also fixed. Then let us try to map the process in h-s plane. So the pressure lines p_1, p_2 are drawn with points 1 and 2. So, the inlet condition 1 is fixed, and the process is isentropic, hence the outlet velocity c_2 is also fixed. Now c_1 and c_2 are fixed and $c_1$is not even there in this expression of nozzle efficiency because the magnitude of c_1 is very, very less as compared to c_2. So basically from this particular analysis we can understand c_2 is also fixed. So if this is the case then we can play with $c_2{}'$ and perhaps we can modulate the efficiency of the flow nozzle. So when friction is less then fluid that means frictional resistance is less, so velocity at the exit of the flow nozzle will be high. So when friction is less $c_2{}'$ c 2 will be more. So basically even in actual scenario when frictional resistance reduces, actual velocity will be more. So efficiency η_n will be more. So if we try to understand the effect of velocity on the flow nozzle carefully, then it is again directly related to the frictional effect. So this is about 2.

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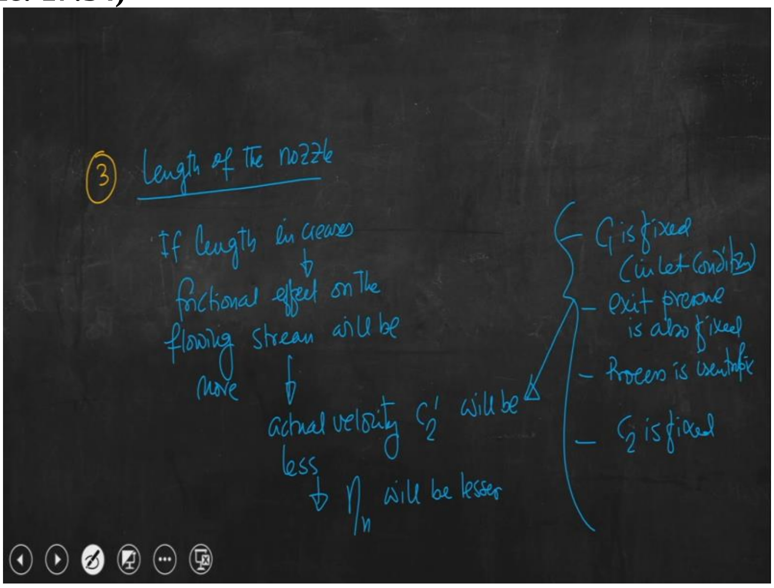

So we have identified that if friction increases c_2 will reduce, efficiency will reduce. Velocity increases that is again because of less friction. Here I am talking about actual velocity, because c_1 is fixed and c_2 is also fixed and that is why I have written these 3 lines. So if frictional resistance is less actual velocity will be more and efficiency will be more.

1) Length of the nozzle

Finally the last factor that is length of the nozzle. So now let us see how we can relate this particular factor to the efficiency, to the frictional effect of the flowing steam. We have studied from fluid mechanics that frictional resistance loss due to frictional effect depends on length. So basically if length increases, frictional effect on the flowing steam will be more. So now that we could relate the effect of length to the frictional effect, the remaining part is straight forward.

So if length increases, frictional resistance will be more and if frictional resistance is more, velocity at the exit of the nozzle will be less and efficiency will be less. Hence actual velocity $c_2{}'$ will be less and nozzle efficiency will be lesser. Why I am talking about actual velocity because to arrive at this particular point c_1c 1 is fixed that is inlet condition, exit pressure is also fixed. Process is isentropic, hence c_2 is fixed. So that means inlet conditions are constant and that we have discussed in the last class. When someone is designing the nozzle he or she also needs to know the exit pressure. And also you know p_2 is fixed, inlet condition 1 is fixed and process is isentropic that means velocity c_2 will be fixed. So for a given value of c_2 if length of the nozzle increases, frictional resistance will be more which in turn will reduce the actual velocity of steam leaving the nozzle and ultimate consequence is the reduction in nozzle efficiency that we have discussed.

So with this we have identified several factors those directly or indirectly affect the nozzle efficiency. What we have understood? Most importantly we have understood that it is the frictional effect which is very, very important to be looked at while designing the flow nozzle because it directly affect the heat drop and nozzle efficiency is directly related to the heat drop. We could relate the gain in kinetic energy to the heat drop using steady flow energy equation. So the frictional heating will increase the fluid temperature, so the actual heat drop in real applications will be less. So higher the frictional resistance, lesser will be the heat drop and if lesser is the heat drop, nozzle efficiency will be less. So this is all that we have discussed. So we have to stop today and we shall continue our discussion with this problem in the next class. Thank you.