Thermal Engineering: Basic and Applied
Dr. Pranab K Mondal
Department of Mechanical Engineering
Indian Institute of Technology-Guwahati

Lecture - 27
Problems on Boiler/Steam Generator

I welcome you all to this session of thermal engineering, basic and applied. And today we shall solve two numerical problems from boiler. I have written here boiler/ steam generator, because boilers are also known as steam generator. As the essential function of boiler is to produce steam and that is why it is also known as steam generator.

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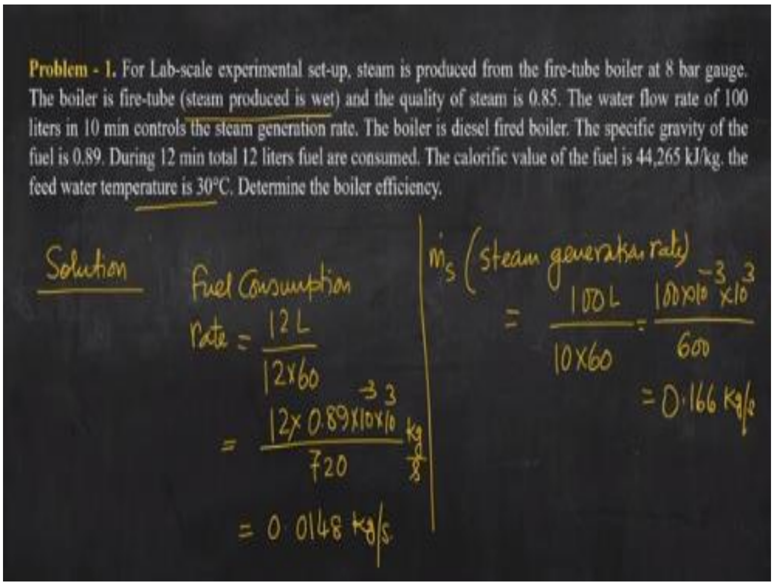

So let us look at the problem 1. So let me read out the problem statement first.

For lab-scale experimental set-up, steam is produced from the fire tube boiler at 8 bar gauge. The boiler is fire-tube (steam produced is wet) and the quality of steam is 0.85. The water flow rate of 100 liters in 10 min controls the steam generation rate. The boiler is diesel fired boiler. The specific gravity of the fuel is 0.89. During 12 min total 12 liters fuel are consumed. The calorific value of the fuel is 44,265 kJ/kg. The feed water temperature is 30°C. Determine the boiler efficiency.

So it is given that for lab-scale experimental setup, steam is produced from the fire tube boiler at 8 bar gauge. So the pressure is given 8 bar gauge at which steam is produced. And it is the lab-scale experimental setup. And the boiler is fire-tube. Steam produced is wet. So in exam sometimes it may not be given that steam produced is wet. So I am underlining the sentence steam produced is wet. So this is basically as we have discussed in the context of fire-tube boiler. Because fire-tube boiler indicates that flue gas is passing through the tube, while water is taken through the cell and steam is also produced. While steam is getting produced, steam is in equilibrium with the water and hence we are going to get wet steam. And the quality of steam is given 0.85. The water flow rate of 100 liters in 10 minute controls the steam generation rate. So that is the water flow rate through the boiler.

The boiler is diesel fired boiler. If you try to recall we have discussed many times that in boiler, water is circulated and upon receiving heat from external source it converted into steam. Now the external source may be due to combustion of coal or diesel fuel. So basically fuel that is being used for the combustion can be coal or diesel. Here it is a diesel fired boiler. Reason is this is lab-scale experimental setup. So here it is very difficult to have coal combustion and that is why it is a diesel fired boiler.

The specific gravity of the fuel is 0.89. During 12 minute total 12 liters fuel are consumed. So it is also given, how much fuel is consumed in 12 minute. The calorific value of the fuel is 44,265 kJ/ kg. The feed water temperature is 30°C. This is very important, so the inlet temperature of feed water is 30°C. We need to calculate the boiler efficiency.

Solution

See we have discussed in one of the previous classes about the boiler efficiency. So what is boiler efficiency? Steam is produced at the cost of some input energy. So when steam is getting produced, we are getting some enthalpy within the steam. It is given that feed water which is entering into the boiler is having temperature 30°C. So you know there will be a change in enthalpy and the change in enthalpy is obtained at the cost of the energy that we are supplying by burning diesel. So from there we can calculate the boiler efficiency. That we have discussed.

So basically for the boiler, let us quickly write what is mass flow rate of steam. Now how much is the steam generation rate? It is given that the water flow rate of 100 liters in 10 minute control the steam generation rate.

$$\text{Steam generation rate}, \dot{m}_s = \frac{100\text{L}}{10 \times 60} = \frac{100 \times 10^{-3} \times 10^{3}}{600} = 0.166 \frac{\text{kg}}{\text{s}}$$

Because we are familiar with the unit of mass flow rate as kg/s, so I have converted the unit liter into kg. That is very intuitive. So this is the steam generation rate.

And you can also write the fuel consumption rate. For fuel consumption rate, it is given that total 12 liters fuel are consumed in 12 minute and specific gravity is given as 0.89.

$$\text{Fuel consumption rate} = \frac{12\text{ L}}{12 \times 60} = \frac{12 \times 0.89 \times 10^{-3} \times 10^{3}}{720} = 0.0148 \frac{\text{kg}}{\text{s}}$$

So we have calculated these two quantities. We have discussed that in a boiler, there are two different streams; one is the stream of flue gas and other is the stream of water and steam. So at least we could calculate the flow rate of steam and flow rate of fuel. So knowing these two quantities, next we can proceed with the calculation of the efficiency. For that we also need to know the enthalpy of steam that is obtained at the outlet of the boiler. So let us now move to calculate the enthalpy of steam that is being produced.

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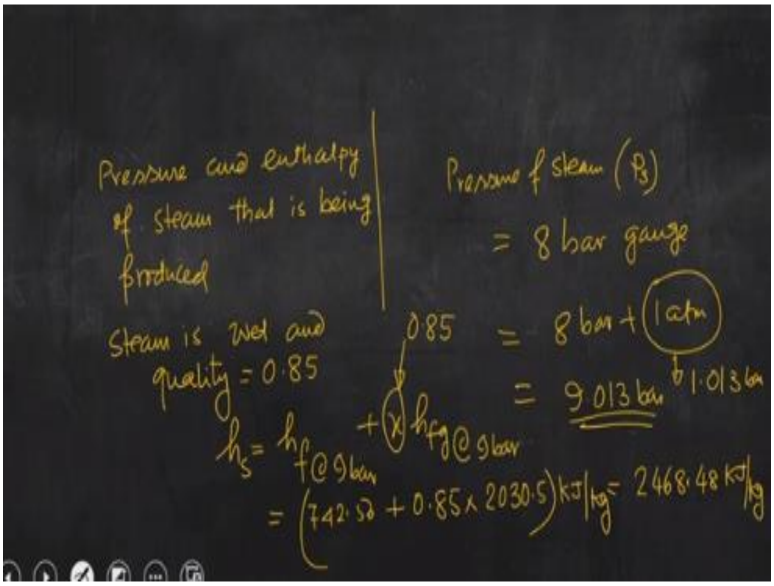

So now we need to calculate pressure and enthalpy of steam that is being produced. So pressure of steam is given in the problem statement. It is already given in the first line of the problem statement that steam is produced from the fire-tube boiler at 8 bar gauge. So that is the pressure.

$$\text{Pressure of steam } (P_s) = 8 \text{ bar gauge}$$

$$\Rightarrow P_s = 8 \text{ bar} + 1\text{atm} = 9.013 \text{ bar}; \text{ as } 1\text{atm} = 0.013 \text{ bar}$$

What about enthalpy? See already it is mentioned that steam produced is wet. Even if it is not mentioned in the problem statement, then also you should consider that the steam produced is wet, as the boiler is fire-tube. Because the produced steam will be in equilibrium with the water. So now steam is wet and quality is given as 0.85.

Now we can calculate the enthalpy of that steam wet steam. So h_s is the enthalpy of the wet steam at pressure 9.013 bar, because this is the pressure at which steam will be available in the boiler.

$$h_s = h_{f@9bar} + x\, h_{fg@9bar}$$

So here, I am only taking 9 bar because we will be taking properties from the steam table. You can take 9.013 bar. So you should not be confused, because ideally we are supposed to take 9.013 bar, but for that we need to go for linear interpolation by taking data from steam table. But we can also consider 9 bar and it will not be a gross mistake.

$$h_s = h_{f@9bar} + x\, h_{fg@9bar}$$

$$\Rightarrow h_s = (742.56 + 0.85 \times 2030.5)\frac{\text{kJ}}{\text{kg}} = 2468.48\frac{\text{kJ}}{\text{kg}}$$

Let me tell you once again h_f is the enthalpy of saturated liquid and that we will be getting from pressure 9 bar from steam table and we also know that $x = 0.85$. So only thing is ideally this pressure should be 9.013 bar and in that case, we need to go for linear interpolation. Instead I have taken 9 bar because, grossly it will not give that much erroneous result. So we have calculating h_s that is enthalpy of steam produced in the boiler. Now let me write the expression for efficiency of the boiler.

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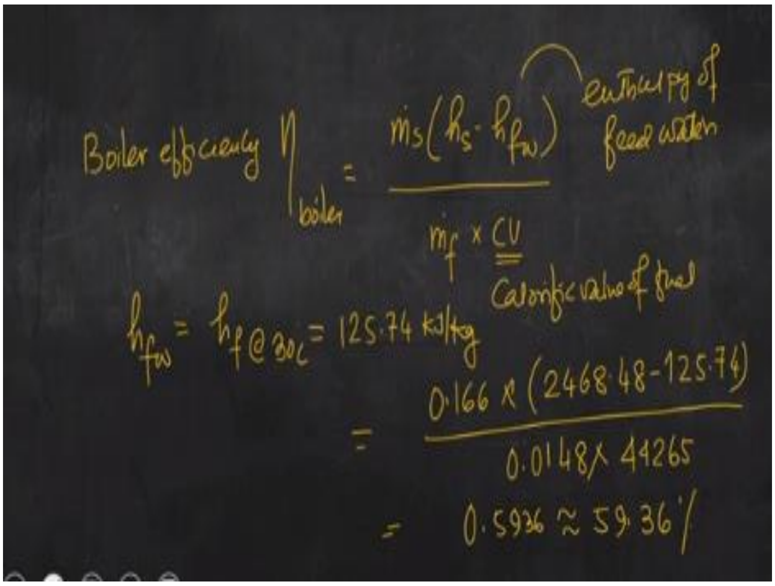

$$\text{Boiler efficiency}, \eta_{boiler} = \frac{\dot{m}_s(h_s - h_{fw})}{\dot{m}_f \times CV}$$

$$\dot{m}_s = \text{Mass flow rate of steam}, \ \dot{m}_f = \text{Mass flow rate of fuel}$$

$$h_s = \text{enthaply of steam}, \qquad h_f = \text{enthalpy of feed water}$$

$$CV = \text{Calorific vale of the fuel}$$

So now, how can we calculate enthalpy of feedwater? If we go to the problem statement, it is given feedwater temperature is 30°C. And if we try to recall the ideal or actual Rankine cycle, liquid which is pumped to the boiler is the saturated liquid. And then it is pumped to another pressure which is the pressure of the boiler. In the problem statement, nothing is mentioned about the pump work. So, we really do not know what the pump work is. As feedwater temperature is given 30°C that is at the inlet to the boiler. So we shall consider that

$$h_{fw} = h_{f@30°C} = 125.74 \frac{\text{kJ}}{\text{kg}}$$

This we have calculated from steam table. Had it been the temperature of feedwater when it is entering into the pump, then this enthalpy plus the pump work would have been the enthalpy of feedwater at the inlet to the boiler. But no information is given about the pump work, so we are straightaway considering that this is the feedwater enthalpy at the inlet to the boiler.

So now we have calculated everything, and calorific value of fuel is given. So we can directly plug in the values of all these quantities in the boiler efficiency expression.

$$\text{Boiler efficiency}, \eta_{boiler} = \frac{\dot{m}_s(h_s - h_{fw})}{\dot{m}_f \times CV}$$

$$\Rightarrow \eta_{boiler} = \frac{0.166 \times (2468.48 - 125.74)}{0.0148 \times 44265} = 0.5936 = 59.36\%$$

So this is the efficiency of the boiler. So try to understand efficiency of the boiler is not even more than 60% from this particular example, and the data that we have taken to calculate the efficiency are obtained from lab-scale experiment. So we can see the efficiency is close to 60%.

Now you may argue with me that if we would have considered 9.013 bar and if we consider the pump work which is added to the feedwater before it enters into the boiler, then considering all those aspects, efficiency would have been either less than this or little higher than this. That we need to consider. Now even if we consider efficiency is roughly 60% then why the remaining 40% is not available?

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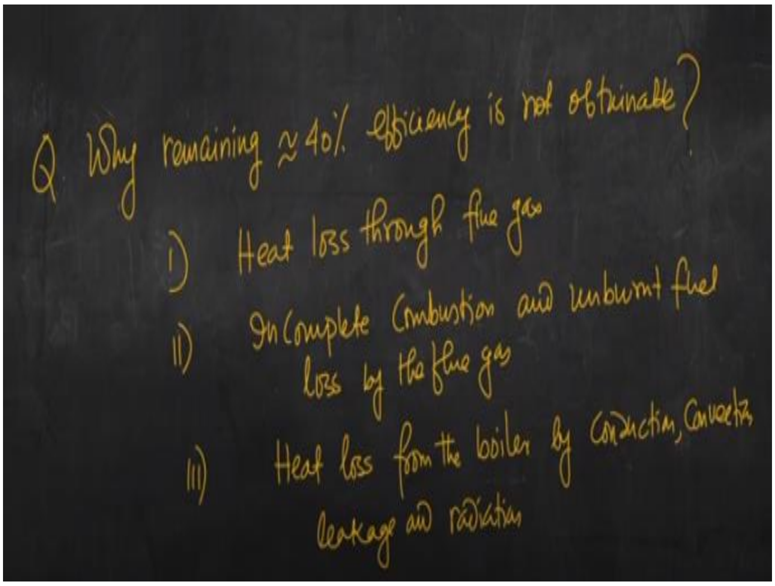

Question- Why remaining almost 40% efficiency is not obtainable? There are several factors for which we are not going to get this 40% of efficiency. What are those?

Number 1- The heat loss through the flue gas.

That means, if we try to recall the schematic of the fire tube or water tube boiler, we can see that in the combustion chamber flue gas is produced, that flue gas is directed towards the top of the boiler, while it is passing through the water tube or the fire tube.

Eventually it is going out from the boiler to the surroundings. And we have seen that significant amount of energy will be lost, if we do not take several attempts like setting up economizer to increase the temperature of the feedwater or to heat up the feedwater. So we have discussed all those aspects. Even then we can see that significant amount of energy is going to be discharged from the boiler without doing the conversion.

Number 2- Incomplete combustion and unburnt fuel loss by the flue gas.
Number 3- Heat loss from the boiler by conduction, convection leakage and radiation.

So these issues are there. If we go to the mathematical formula of the efficiency we can see that we are multiplying mass flow rate of fuel into calorific value of fuel. So if certain amount of fuel is not taking part in the combustion then perhaps that would be loss of energy. So that part is not going to be utilized. So the incomplete combustion and unburnt fuel loss by the flue is one of the reason for which the remaining 40% efficiency is not obtained. So the fuel which is not utilized will be taken by the flue gas and so that is again a loss.

And heat loss from the boiler, because you know that when the combustion is taking place inside the boiler some amount of energy will be lost through several modes of heat transfer that is conduction through the wall and surroundings. Then there is air flow so that flow will again try to enhance the heat transfer, so that is convection. And finally, temperature is very high, hence the radiation effect cannot be trivially ignored. And there must be certain amount of heat leakage from the boiler.

Accounting for all these aspects efficiency achievable is not more than 60% that we have solved through the numerical problem in today's class. So to summarize, we have discussed about the classification of boiler. Then we have seen the different flow cycles inside the boiler. Then in boiler attachments, we discussed about mandatory components those are necessary and without which boiler cannot be certified, but those components are not directly affecting the boiler performance. We have also discussed about the accessories which are not mandatory component, but these components directly affect the boiler performance.

Then we have discussed about the characteristics of superheaters. And finally, we have discussed about one important topic that the sole objective of placing superheaters in the boiler is to get superheated steam or to increase the steam temperature before it enters into the turbine. We have seen that in practical scenarios, sometimes the temperature at exit of the superheater is so high that we need to have temperature control. We have also discussed that part. And finally, today we have solved one numerical problem. By solving this problem, we have understood that efficiency of the boiler cannot be more than 60%, at least from the data that we have taken for the example that we have solved in today's class.

And we have also discussed about the several issues because of which the efficiency cannot be achievable beyond 60%. So with this I stop here today and I also would like to complete this particular module of this class. From next class onwards, we shall discuss the next module of this particular course.