Thermodynamics

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Lecture 43

Beyond Ideal Gases - Part 2

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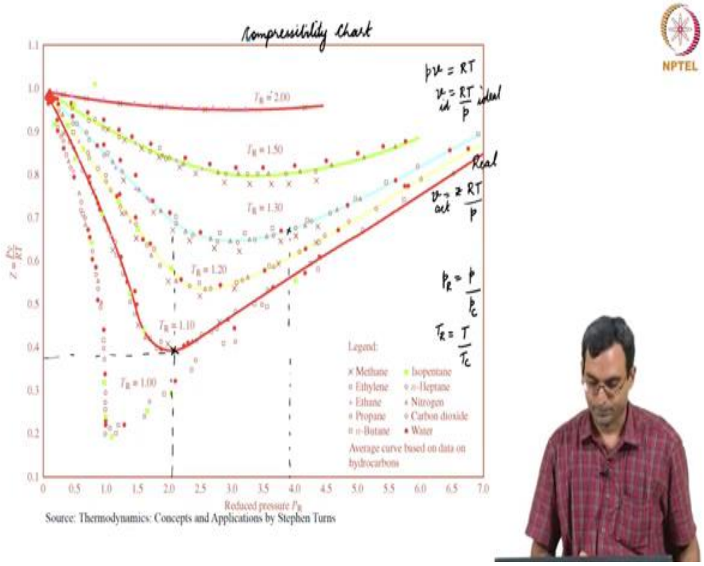

Figure 1.

Figure 1 shows a plot of compressibility factor Z versus reduced pressure at different reduced temperatures. Reduced pressure (p_R) equals the pressure divided by the critical pressure ($p_R = \frac{p}{p_c}$). Similarly, reduced temperature (T_R) equals the temperature divided by the critical temperature ($T_R = \frac{T}{T_c}$).

We know that when the molecules are far apart from each other (the pressure is low), there is not much attractive force between the molecules. At such condition, the behaviour of the gas is close to ideal gas behaviour. In the graph shown in Fig. 1, towards left ($p_R < 0.5$), where the pressure is low, we see that the value of Z is close to 1 irrespective of temperature. At high temperatures (for example, $T_R = 2$), the value of Z is close to 1 irrespective what the pressure is. Hence, at very low pressures ($p_R < 0.5$) and very high temperatures ($T_R = 2$), the gas behaves like an ideal gas. The graph shown in Fig. 1 has data points for different gases like methane, ethane, propane, nitrogen, etc. For any particular value of p_R and T_R, the value of Z for all these gases is the same.

We know that $\frac{pv}{RT} = Z$. Hence, $v = Z\frac{RT}{p}$. If Z=1 (if the gas is ideal), $v = \frac{RT}{p}$. Hence, Z gives the ratio of the specific volume occupied by the real gas to the specific volume occupied by the ideal gas (it applies to volumes also if we consider a system where mass is fixed). The value of Z corresponding to p_R=2 and T_R=1.1 is around 0.4. It means that the actual volume equals 0.4 times the volume occupied by the ideal gas at the same pressure and temperature conditions. Hence, the Z is essentially the correction for the volume occupied by the real gas. If we know the volume of the real gas in advance, then by taking the ratio of the actual volume and the volume calculated by ideal gas relation, we can calculate Z, which can be used to calculate pressure and temperature of the gas. This is one way to deal with real gases.

We also have tables for different gases (air, nitrogen, methane, etc.) which present gas properties at different conditions. We can use these properties to calculate other properties.

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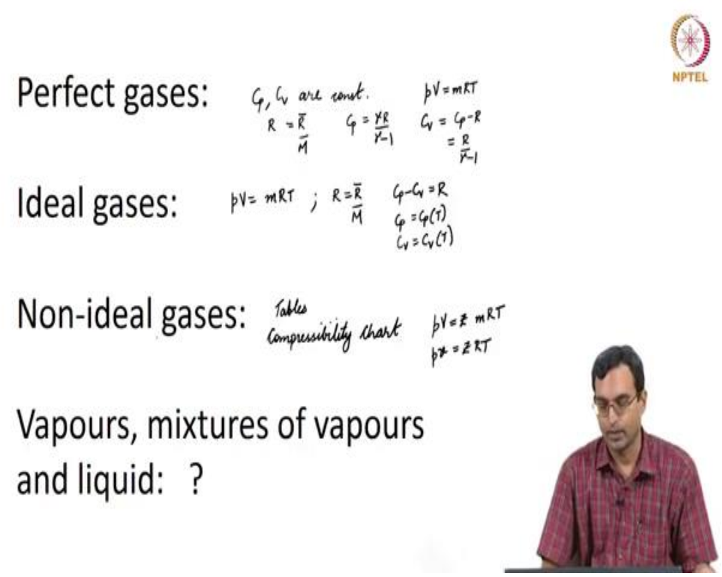

So, we know how to deal with a perfect gas ($pV = mRT, C_p$ and C_v are constant, $C_p - C_v = R$, etc.), an ideal gas ($pV = mRT, C_p = C_p(T), C_v = C_v(T), C_p(T) - C_v(T) = R$, etc.) and a non-ideal gas ($pv = ZRT$, tables, compressibility chart). For the purpose of this course, we will employ perfect gas model because we do not alwasy know the values of C_p and C_v as functions of temperature. We can use these models for liquid vapors also.

How to deal with a mixture of vapour and liquid? Why do we need to deal with mixtures of vapour and liquid?

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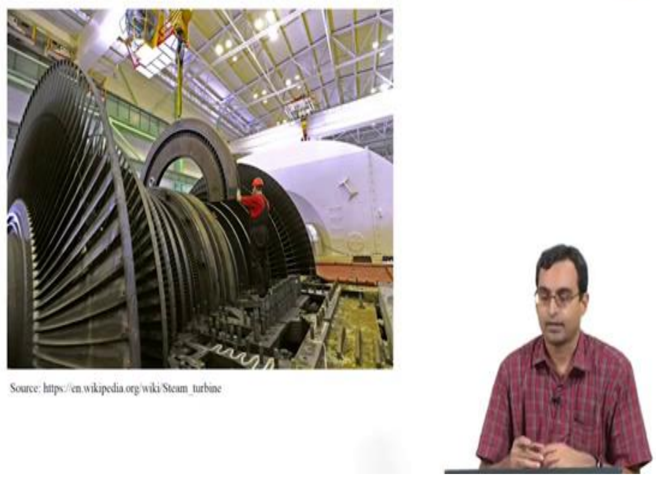

Figure 2.

We see that mixtures of vapour and liquid are fairly common in real life applications. One of those applications is shown in Fig. 2. It is a steam turbine and it is used for producing electricity.

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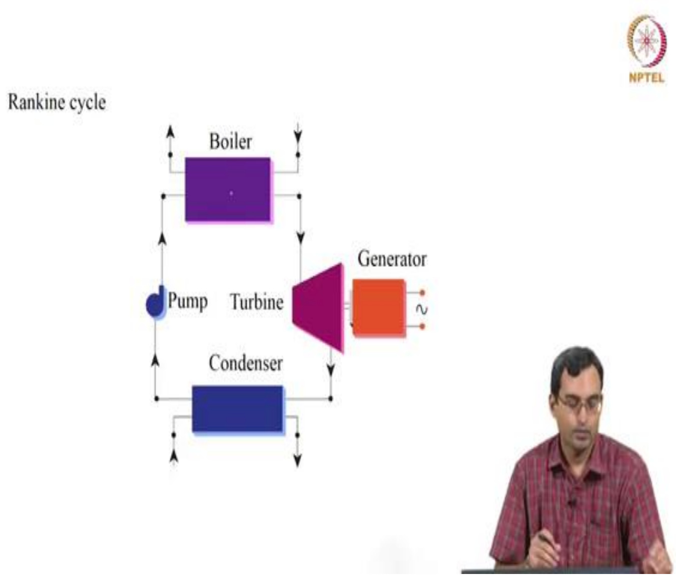

Figure 3.

In a coal power plant, Rankine cycle is employed for power production. We will look at this cycle in a lot of detail towards the end of this course.

The Rankine cycle consists of 4 components: a pump, a boiler, a turbine and a condenser (see Fig. 3). A pump takes in low pressure water and gives out high pressure water. This high pressure water enters boiler where it boils and we get high pressure steam at the exit of the boiler. This high pressure steam is expanded in the turbine which drives generator to generate electricity. At the exit of the turbine, we get low pressure low temperature steam which is sent to the condenser where the steam condenses into water. This water is sent back to the pump and the cycle continues. In the boiler and the condenser (also in the turbine and the pump in small traces), at some point in time, we have a mixture of water and vapour. Hence, we need to know how to deal with the mixture of liquid and its vapour.