**Thermodynamics**
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**Exergy – Part 1**

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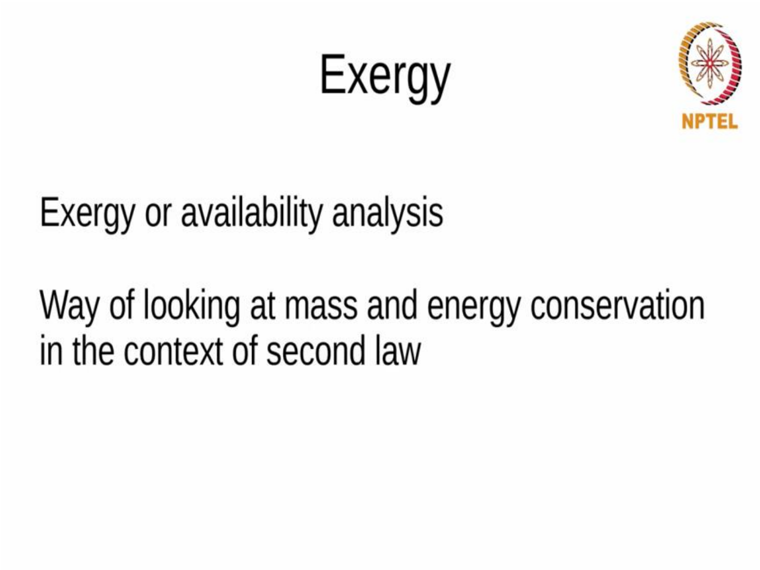


Let's look at the concept of exergy or availability. It is essentially a way of looking at both the first and second laws together.

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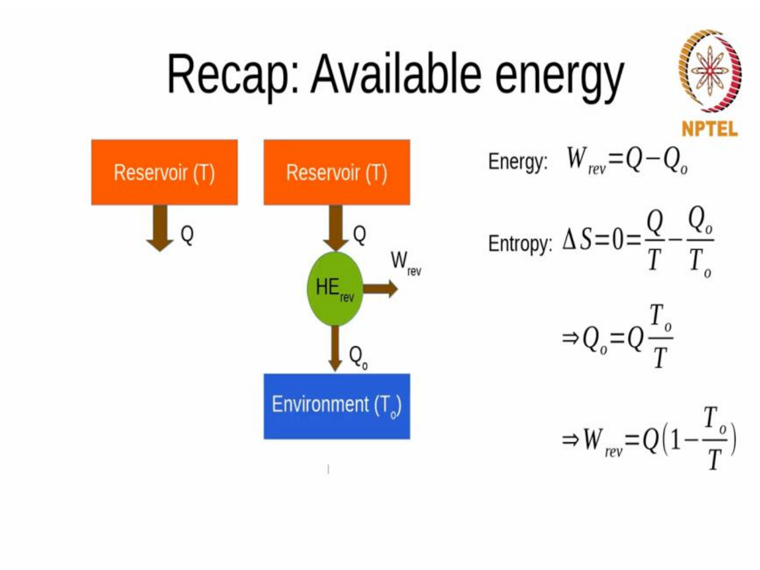


Figure 1.

We looked at the concept of available energy before. Let's recap it.

Figure 1 shows a reservoir at temperature T which gives out Q amount of heat. How much of this heat Q can be converted to work? We know that maximum possible conversion of Q into work happens if we use a reversible heat engine. Figure 1 shows a reversible heat engine running between the reservoir at temperature T and environment at temperature $T_0$ giving out work $W_{rev}$. The engine takes in Q amount of heat and rejects $Q_0$ amount of heat. According to the first law, $W_{rev} = Q - Q_0$ (taking absolute values). We know that $\frac{Q}{T} = \frac{Q_0}{T_0}$ for a reversible heat engine in Fig. 1. Also, $\oint \frac{\delta Q}{T} = \oint dS = \Delta S = \frac{Q}{T} - \frac{Q_0}{T_0} = 0$. Hence, $Q_0 = Q\frac{T_0}{T}$. Hence, $W_{rev} = Q - Q_0 = Q\left(1 - \frac{T_0}{T}\right)$.

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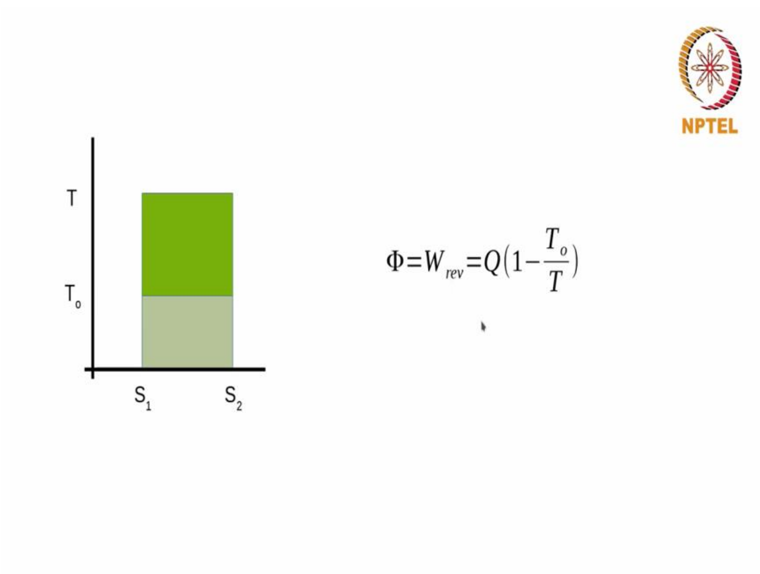


Figure 2.

Figure 2 shows a T-S diagram for the reversible heat engine of Fig. 1. We know that the magnitude of the amount of heat rejected to the environment is $|T_0(S_1 - S_2)|$. This heat is not converted to work. The temperature reservoir at T supplies heat for conversion to work. The maximum possible work output is $W_{rev} = Q\left(1 - \frac{T_0}{T}\right)$. The exergy ($\varphi$) of the constant temperature reservoir at T, in this case, is the maximum possible work output we can get from it which is $W_{rev} = Q\left(1 - \frac{T_0}{T}\right)$.

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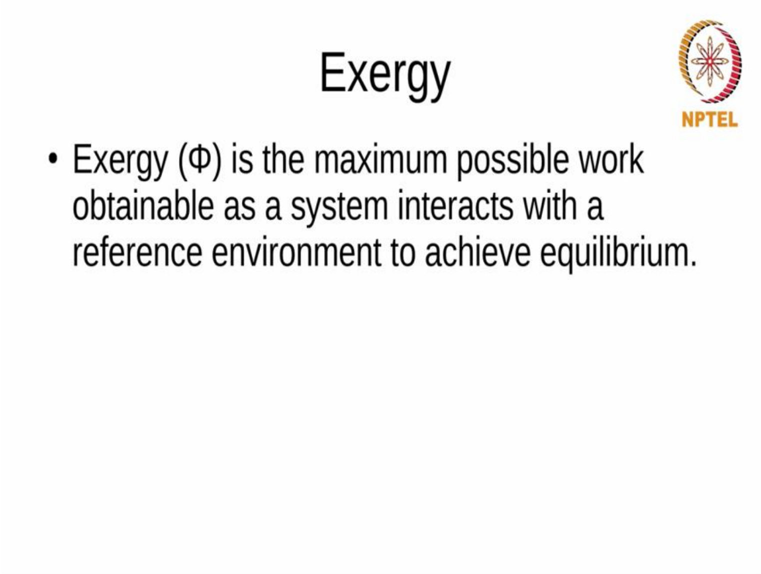


Exergy ($\varphi$) is the maximum possible work obtainable as a system interacts with a reference environment to achieve equilibrium. Alternatively, we can also define it as the minimum possible work you need to give in order to take the system which is in equilibrium with the reference environment to whatever the state it was in.

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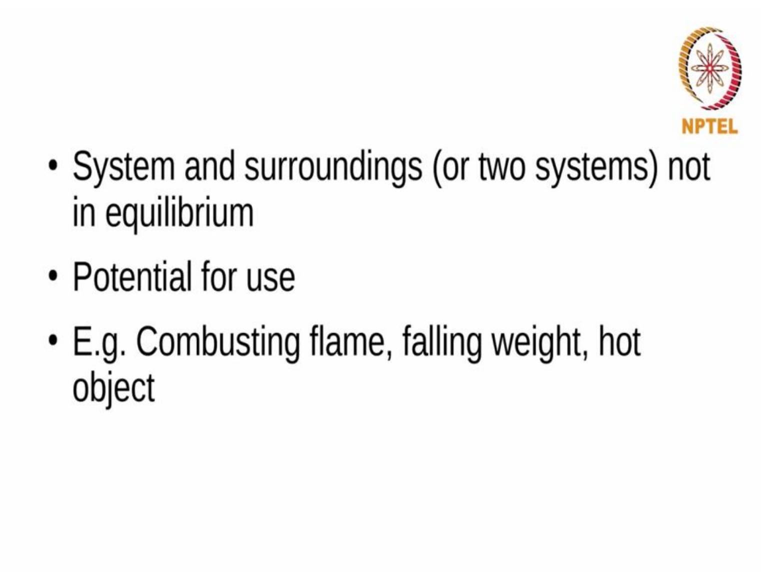


If the system and surroundings are in equilibrium, then there is no potential for use (i.e. no potential to get work as output). For example, a weight lying on the ground has no potential for use. However, a falling weight can be used to get some work output. Similarly, a combusting flame which generates hot gases can be used to get work. Hence, if the system and surroundings are in equilibrium, we won't get any work output.

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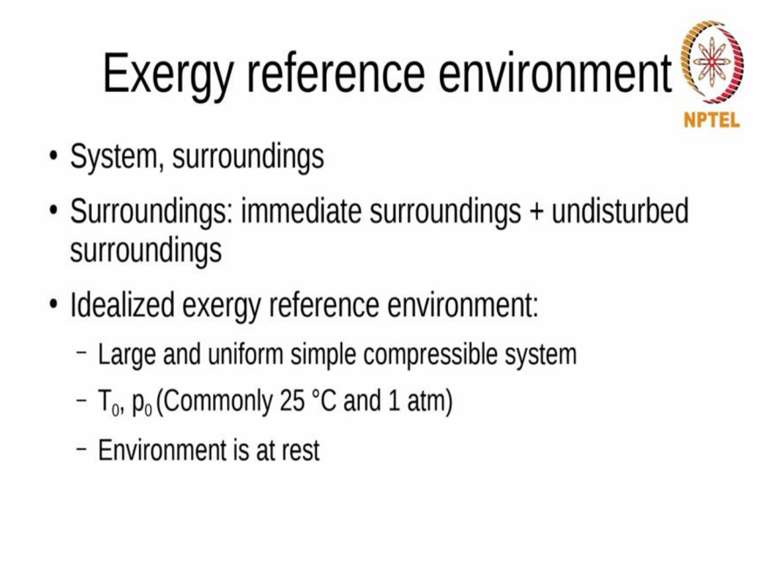


We have been talking about the system and the surroundings. The surroundings is essentially called as exergy reference environment. The surroundings (exergy reference environment) can be divided into immediate surroundings and the undisturbed surroundings. The immediate surroundings gets affected by the system, whereas the undisturbed surroundings which is far from the system stays undisturbed. In general, when we talk of the reference environment, we mean undisturbed surroundings.

For doing exergy analysis, the idealized exergy reference environment is assumed to be large and uniform. We consider only simple compressible systems. The temperature and pressure of the reference environment are fixed. The common values are 25 ℃ and 1 atm. However, these can be the temperature and pressure at the place where the system is. The reference environment is assumed to be at rest.

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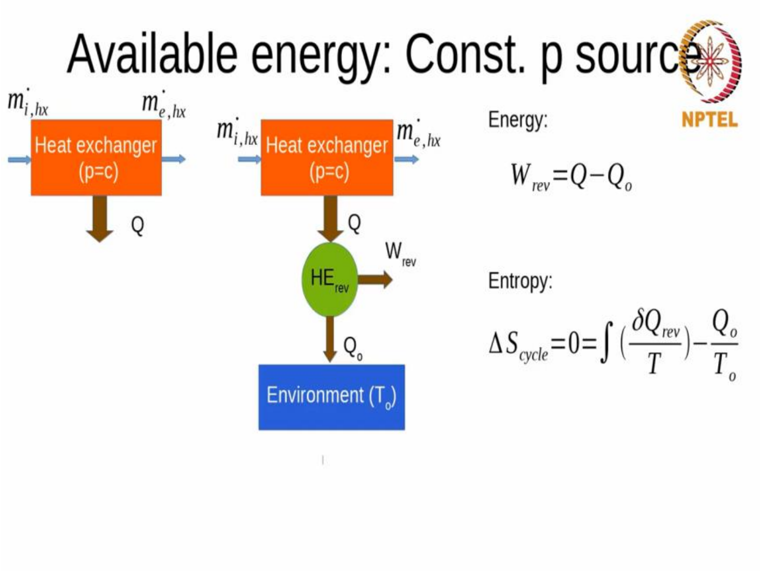


Figure 3.

We have come across a heat source at constant temperature quite a lot of times. We briefly looked at a heat source at constant pressure also. Let's look at it in more detail.

Constant pressure heat sources are quite common (e.g. a boiler and a condenser). In these heat sources, pressure remains constant, whereas the temperature changes. Figure 3 shows a heat exchanger (a constant pressure heat source). To get maximum work from such a heat source, we need to run a reversible heat engine between the heat source and the surrounding environment at $T_0$ ($T_0$ is constant) as shown in Fig. 3. This heat engine takes in heat Q from the heat source, gives out work $W_{rev}$ and rejects heat $Q_0$ to the environment. According to the first law, $W_{rev} = Q - Q_0$ (considering the absolute values). The entropy change for the cycle is given as $\Delta S_{cycle} = 0 = \int \frac{\delta Q_{rev}}{T} - \frac{Q_0}{T_0}$. The temperature of the heat source is changing here. Hence, we need to run a sequence of reversible heat engines.

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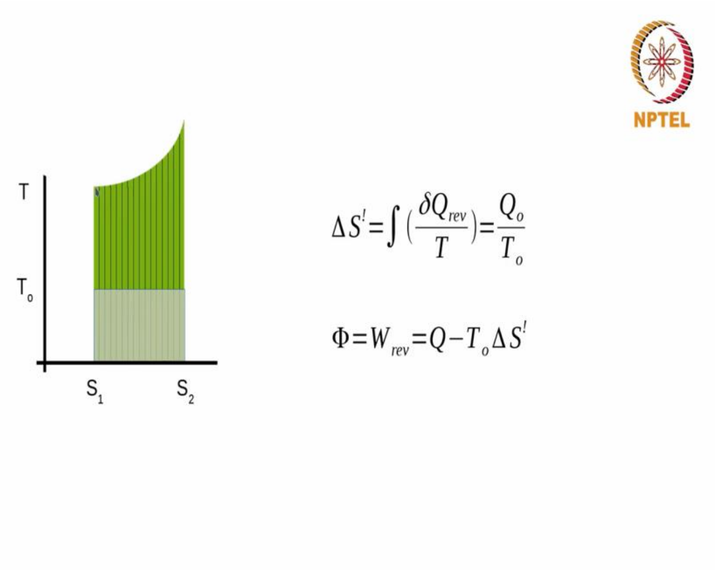


Figure 4.

Figure 4 shows a T-S diagram where the temperature of the heat source is varying (as in the case of the reversible heat engine of Fig. 3), whereas the temperature of the surrounding environment is constant. In this case, we can divide the region on the T-S diagram into rectangles as shown. Each rectangle corresponds to a Carnot's cycle (reversible cycle). The first rectangle (the leftmost rectangle) corresponds to a Carnot's cycle $C_1$ which takes in heat at temperature T and rejects heat at temperature $T_0$. The next rectangle corresponds to a Carnot's cycle $C_2$ which takes in heat at slightly higher temperature than $C_1$ and rejects heat at $T_0$. The next rectangle corresponds to $C_3$ which takes in heat at slightly higher temperature than $C_2$ and rejects heat at $T_0$. In this way, the green part of the T-S diagram in Fig. 4 is composed of many Carnot's cycles taking in heat at higher and higher temperatures and rejecting heat at $T_0$. Hence, in this case, $\int \frac{\delta Q_{rev}}{T} = \frac{Q_0}{T_0} = \Delta S`$ (considering absolute values) as the engines are reversible. We can also write $Q_0 = T_0 \Delta S`$. Hence, exergy of the constant pressure reservoir is $\varphi = W_{rev} = Q - Q_0 = Q - T_0 \Delta S`$.