Energy Conservation and Waste Heat Recovery

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Lecture - 13
Entropy (Contd.), Exergy

Welcome back to the lecture class of energy conservation and waste heat recovery. We were discussing a regarding entropy generation and we were trying to understand it with the help of an example. The example was like this if we recall; that we are considering a typical process in an industry.

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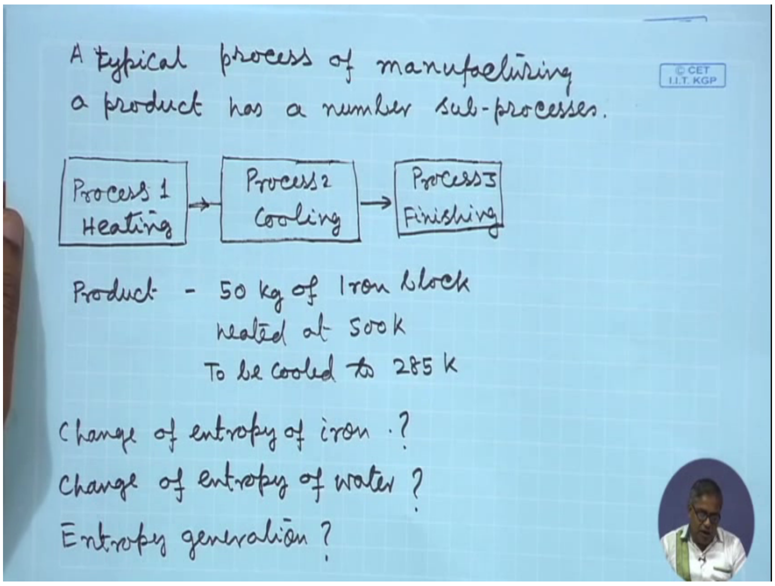

A typical process of manufacturing a product has a number sub-processes.

Process 1 Heating → Process 2 Cooling → Process 3 Finishing

Product - 50 kg of Iron block heated at 500 K
To be cooled to 285 K

Change of entropy of iron ?
Change of entropy of water ?
Entropy generation ?

The process is again made of different sub processes. In sub process 1, iron block will be heated, in sub process 2 it will be cooled and in the sub process 3 it will be sent for finishing. And we are interested in this cooling process. So, 50 kg of iron block according to the arrangement of the industry it is being cooled by plunging it in a tank of water. The water in the tank we assume that it is of enough quantity. So, that by this process the temperature of the water does not change.

But; obviously, the temperature of the iron block changes certain information has been given. 50 kg is the mass of the iron block, initially it is temperature is 500 K and it is to be cooled to 285 K. And we have to calculate the change of entropy of the block change of entropy of water and entropy generation.

We have done the calculations and what we have got is like this let me put it again.

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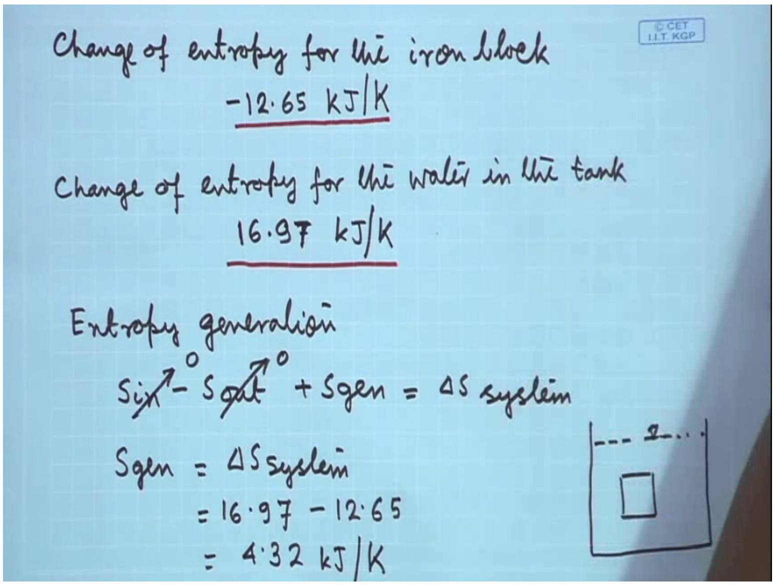

Change of entropy for the iron block

-12.65 kJ/K

Change of entropy for the water in the tank

16.97 kJ/K

Entropy generation

$$\cancel{S_{in}}^{0} - \cancel{S_{out}}^{0} + S_{gen} = \Delta S_{system}$$

$$S_{gen} = \Delta S_{system} = 16.97 - 12.65 = 4.32 \text{ kJ/K}$$

Change of entropy for the iron block, that is, we have got minus 12.65 minus 12.65 kilo Joule per Kelvin this k is a small letter this K is a capital letter

So, change of entropy for the iron block and please note that it is negative. Why it is negative? Because, heat has transferred from the iron block to the water in the tank and I have told the direction of heat flow is also I mean is also indicative of the direction of entropy flow or entropy transferred. So, if there is heat loss from the iron block there is also decrease of entropy for the iron block.

Then we can determine change of entropy for the water in the tank and then that we have calculated as 6; sorry, 16.97 kilo Joule per Kelvin. So, this is positive heat has been transferred to the block from the block to the water in the tank. So, water has gained heat it has also gained entropy.

Then next thing which we should calculate is what. What is the entropy generation? We can think of our entropy balance equation. Our entropy balance equation is, what is our entropy balance equation? We can do it in different way; we can use an entropy balance equation, we can use our considering iron and the water as 2 separate system we can do it.

So, let us do by any of this method. So, entropy balance equation if we write S in minus S out is equal plus S gen that is equal to delta S to system. Now, if we think of let us say if we think that this is the tank and this is the iron block water in the tank and iron block that constitute the system and there is no heat transfer out of the tank. So, then what we can think what we can see that is S in is equal to 0, S out is equal to 0 these 2 terms can be written as 0 and then S gen or delta S gen is equal to delta S system. So, what is the change of entropy of the system? Change of entropy of the system is 16 plus 0.97 minus 12.65. So, we can get something around 4.32 kilo Joule per Kelvin. So, this is our entropy generative.

Now, we have got some figures, we also got some sort of understanding of the process, but let us look into this little bit in a little bit close manner. Now, what we can get is this that during the process there is certain finite amount of entropy generation. And entropy generation is associated with irreversibility of the process.

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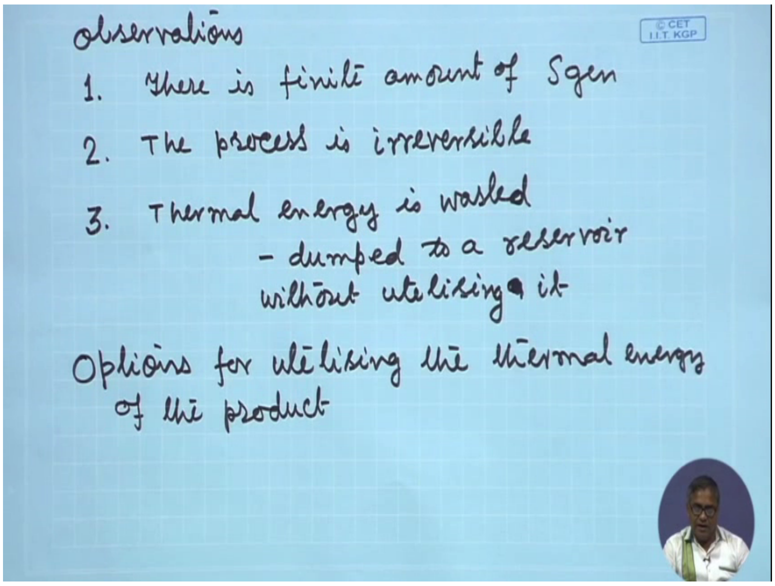

observations

1. There is finite amount of Sgen
2. The process is irreversible
3. Thermal energy is wasted
   - dumped to a reservoir
   without utilising it

Options for utilising the thermal energy of the product

So, let us write down our observations. First observation is there is finite amount of S gen; second as S gen is related to the reversibility of the process, the process is irreversible. Now, with this let us go to the domain of waste heat recovery. So, what we can see here we have got a process in which there was heating hot product came out that hot product has to be cooled.

Now, the industry has adopted a process of cooling this hot product by plunging it in a large mass of water. The mass of water is so large that it will not change the temperature of the water, hot product when it is plunged into water it will not change the temperature of the water.

So, what we are doing? We are dumping certain amount of thermal energy into some sort of a reservoir. So obviously, we can term this as waste heat. So, you see this is a good example the example which we have taken this is a good example of waste heat because the thermal energy that could have been utilized somewhere we have wasted out.

Now, how we know that we have wasted out? We have wasted out from the common sense this hot water sorry the water in the tank it is temperature has not increased, we cannot do anything else with that water. So, from common sense we have wasted the thermal energy. And from thermodynamic point of view we can see that the process which I have taken which we have taken it has got irreversibility and due to that irreversibility the amount of energy which could have been extracted from the process that opportunity we have lost.

So, now we can relate irreversibility, we can relate entropy generation with the potential or rather with the way we are converting the useful energy the available energy into some sort of purposes and if that purpose is not fulfilled; if we cannot convert it then we will see irreversibility is increasing and; obviously, entropy generation is increasing. So, things are interrelated and as we proceed it will be clear to us.

So, the third point what I write is that; thermal energy is wasted dumped to a reservoir without utilizing it. And see that we have dumped thermal energy into a reservoir without utilizing it that is also clear from the irreversibility associated with the process.

Now, the second question then it will come that how we could have utilized this thermal energy. One way is that let me write. The logical questions now come that options for utilizing the thermal energy of the product.

So, let us first discuss that theoretically what is possible. Now, what we have got? The product we have got at 500 degree K sorry at 500 K and the ambient temperature let us assume that the tank water is also at the ambient temperature. So, that is available at 285 K. So, it would have been possible to transfer this heat from 500 K to 285 K, but while doing so part of this thermal energy we could have extracted in the form of work or in other words one could have thought of having some sort of heat engine cycle between these 2 temperatures. See, I have told that theoretically I am looking for possibilities practically whether it will be possible, it will be feasible, viable, that is a different question, but at least one could have thought and one can calculate with now your knowledge you can calculate what could be the entropy generation if we do that.

The second option could have been that, we could have taken a finite amount of liquid may be a flowing liquid stream and with the help of that we could have cooled the hot product by that the liquid stream could have been heated it is temperature could have been higher compared to the ambient temperature which we have assumed 285 K and then we could have utilized that hot stream of liquid for some purpose.

So, you see in that entropy generation again can be calculated for the third option. So, the first option; when we have cooled the hot block in plunging cooled the hot block by plunging it in a large mass of water we can calculate, what is the entropy generation? We could have think of an ideal heat engine which can run between the temperature of the hot object and the temperature of the ambient we can calculate the entropy generation. And, third option is that let us say the thermal energy of the hot object is utilized for heating some liquid to some intermediate temperature and we can calculate the entropy generation and you will find in the first case as I have shown we will have the maximum amount of entropy generation.

So, entropy generation then this becomes a tool, suppose I have got different options of waste heat recovery. We can use entropy generation as a tool as a tool to judge which option is better. So, this we will keep it in mind and probably we will try to use in our future exercise. With this I like to go to a new topic which is very essential for the discussion of thermodynamics.

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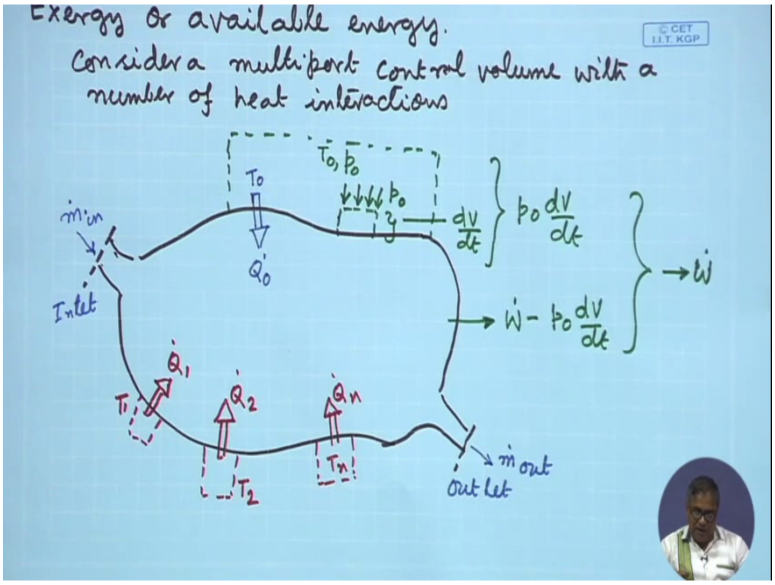

Exergy or available energy.

Consider a multiport control volume with a number of heat interactions

So, we like to introduce to Exergy or available energy. Again, exergy available energy are exergy or available energy, that is, closely related to the entropy transfer, but there is something more than that we also try to see a combination of first and second law. So, let us proceed logically. Again let us consider a multiport control volume with a number of heat interactions.

So, let us have some sort of a arbitrary. Let us have some sort of arbitrary control volume. Let us say in this direction from this direction mass is entering I am putting m dot in this is inlet from this side mass is going out. So, I am putting m dot out and this is outlet, though; I have told that it is multiport notionally I am showing only one port for entry and one port for exit, but it is having more than that.

Let us say we have got different point where thermal interaction takes place. So, this is Q dot amount of heat Q dot 1 amount of heat is entering the control volume at a temperature T 1. Q dot 2 amount of heat is entering at a temperature T 2 and let us say it is an arbitrary port or arbitrary point where Q dot n amount of heat is entering at a temperature T n.

So, basically we are having different kind of heat interactions, then we are also having some sort of work interaction let us say here we show some sort of work interaction. The quantity I will write just in a few moment. So, this control volume is interacting with number of heat transfer sources or thermal reservoir thermal bodies it is also interacting with the ambient.

So, the ambient or the surrounding 2 different attributes of this ambient or surrounding is very relevant for our case, that is; one is temperature of the ambient and another is the pressure of the ambient. Let us say this portion of the control volume is interacting with the ambient and ambient is given by as I have told that we have denoted it by T 0 and p 0. So, T 0 is the temperature of the ambient and p 0 is the pressure of the ambient. Then what kind of interaction it can have? First thing, that it will have some heat; it may have some heat interaction. So, this is Q dot 0 and this is taking place at T 0.

Second thing if the wall of the control volume is not rigid, then it will have some sort of change of volume, because there is a pressure p 0 acting over here. This change of volume, let us say with time this change of volume takes place. So, this change of volume we can write as dv dt. And then this work done that will be p 0 into dv dt. And then here the work done is p 0 minus sorry w dot minus p 0 dv dt. So, total work which I will get from the control volume is equal to w dot capital W dot.

So, this is; what is my control volume for analysis. So, some mass is entering though I have shown one port of inlet and one port of outlet, but really there are multiple ports of inlet and outlet and then there are number of places where heat interaction is happening and then part of the control volume is interacting with the ambient. So, there could be heat transfer and if the control surface is a movable surface, then there will be also interaction between the surrounding and the control volume there will be change of volume and some work will be done by the atmospheric pressure or by the pressure of the environment.

So, this is what we can represent this is how we can represent a general control volume with different kind of interaction. Now, if I write first law of thermodynamics for this control volume.

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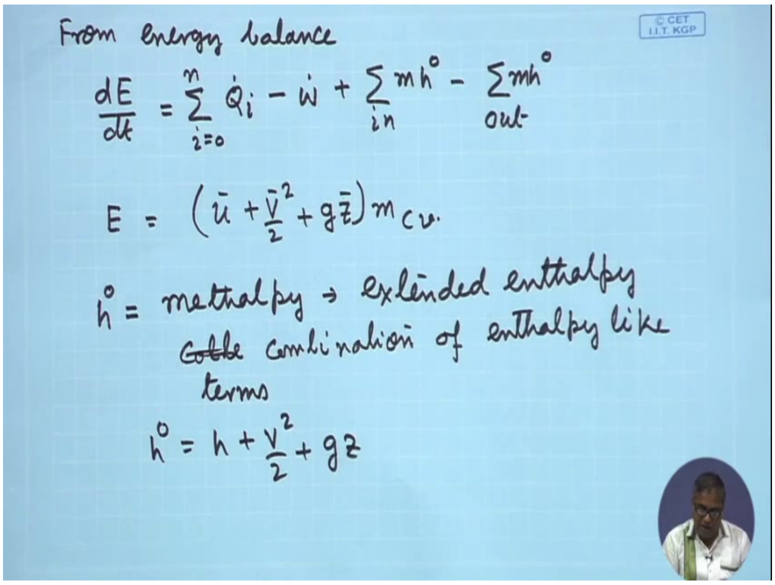

From energy balance

$$\frac{dE}{dt} = \sum_{i=0}^{n} \dot{Q}_i - \dot{W} + \sum_{in} m h^0 - \sum_{out} m h^0$$

$$E = \left(\bar{u} + \frac{\bar{V}^2}{2} + g\bar{z}\right) m_{c.v.}$$

h^0 = methalpy → extended enthalpy
~~Coble~~ combination of enthalpy like terms

$$h^0 = h + \frac{V^2}{2} + gz$$

So, from energy balance first law is nothing, but energy balance from energy balance what we get? d E d t that is equal to i is equal to 0 to n Q dot i minus W dot plus m h 0 in minus m h 0 out. This expression needs certain explanation, because this is slightly different the way we have written the energy balance equation or first law for an open system.

E denotes the energy within the control volume. So, what could be E? E is the energy within the control volume. So, E is equal to u plus v square by 2 plus g z into mass of the control volume. So, this is our E that is the energy storage done within the control volume. There are number of sources for or rather there are number of points where interaction with the environment is taking place with the surrounding is taking place as for as heat transfer is concerned. So, Q i.

W we have written what is the word transfer and then this is the amount of energy which is entering the control volume. And I have introduced a new term which is given by h dot this called methyl py, this is extended enthalpy it is basically a combination of or rather collection of combination of enthalpy like terms what are that h plus v square by 2 plus g z. So, this has got no other significance only we like to keep our equation little bit simple, that is, why we have introduced it? Otherwise, it has got no other implication or significance.

So, this is how we can write our first law of thermodynamics for this control volume or energy balance for the control volume. Here I like to I here to attract your attention to one point you see we are having different forms of energy here, some of them are stored energy and some of them are energy in transit. you know that energy in transit has got 2 different may have 2 different forms either it could be heat or it could be work either it could be heat or it could be work.

So, work done that is denoted by a single term and heat transfer that is a summation term depending on temperature at which heat transfer is taking place. So, we can differentiate them, particularly when we like to when we introduce second law of thermodynamics we can differentiate them.

So, sometimes I have talked about quality of energy. So, this is what is coming. So, all the work they are having the same quality and highest grade of energy, but heat we will differentiate it depending on it is temperature in to different grades that we will see later on. So, this is your energy balance equation. We like to make a combination of first law and second law. So, entropy balance equation we are going to write soon, but that will be in our next class.

Thank you.