Energy Resources and Technology
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Lecture - 2
Quality of Energy

In the last class, we had introduced the essential features of the second law and introduced three equivalent statements of the second law. The first statement was that if left to itself, any closed system tends to raise its disorderliness. Second statement is that if left to itself, any closed system tends to lose its information. Third was, if left to itself, any closed system tends to increase the entropy. So, entropy though in some of the earlier classes or whatever amount of thermodynamics we have been introduced in school or in other classes, that related to heat and heat transfer, while here we are treating it in a different perspective as the quantification of disorder in a system. The reason for doing that will be clear to you soon. So, using that concept that the entropy of any closed system always increases, we had derived the expression for the heat conversion to mechanical and the maximum possible attainable efficiency and what was it? 1 minus T 2 by T 1; that tells you that there is always a maximum efficiency limit, whenever you want to go from heat energy to mechanical energy.

So, what is so special about heat or in other words, let us put it this way. When you are converting from mechanical energy to electrical energy, notice mechanical to electrical, is there any such ultimately attainable limit of the efficiency? Mechanical to electrical conversion, electrical to mechanical conversion, is there any such theoretical limit of the efficiency? Electrical energy to heat energy conversion, say a normal room heater, where you pass current through a coil and then heat is coming out; what is the efficiency of that? Its efficiency is actually 100%, because all the energy that you lose in terms of I square r that is converted to heat energy, so the efficiency is 100%. So, there is no such efficiency limit, while in some conversions, at least one example we have come across, heat to mechanical energy that there is an inherent theoretical limit.

Why so? The moment you ponder this question, you would notice that there is a fundamental distinction between the kind of energy that heat is and the kind of energy that mechanical or electrical energy is. What is the essential distinction? Electrical or mechanical energy is of high orderliness in the sense that suppose there is shaft rotating; there is a shaft rotating, then the shaft, all the molecules in the shaft, they share the common motion, right, that has a very high degree of energy, information contained in it. In contrast, if all the molecules were to move with the same amount of kinetic energy, but in all possible directions, it will be a very disorderly mass, disorderly; but the same amount of energy would be there, but in a disorderly form. Same amount of iron suppose is carrying that amount of energy, but all the molecules are moving in all possible direction, what is the, what is it? Essentially heat; so, it is not difficult to visualize that heat is actually disordered energy; heat is actually disordered energy.

What is heat? The molecules are moving. If it is air, molecules are moving at high velocity. If it is liquid, yes, then also it is moving at high velocity, but not being able to leave the container. If it is solid, then each molecule is hinged to a place and then vibrating. Nevertheless, these are all disorderly motion and that disorderly motion is manifested as what you know as heat. Energy is there, but disorderly energy. So, what is happening actually when you are converting heat energy to mechanical energy? You are converting a disorderly form of energy, high entropy form of energy to a low entropy form of energy, more ordered form of energy, right and then, the second law as we said, as we saw yesterday, says that there is a maximum possible limit. So, you might say in common language, I mean these things are, though I am saying in common language, things you will not find in text books, but these are conceptually more useful.

When you are converting energy in a disordered form to energy in an ordered form, you have to pay for it. You cannot obtain 100% efficiency. While if you are converting an energy from a high quality, high degree of orderliness to another energy of high degree of orderliness for example, mechanical energy to electrical energy, theoretically at least you can do so at 100% efficiency. So, let us consider, these are, these go with names, the quality of energy. The more ordered form of energies are high quality energy, the less ordered forms of energy are low quality energy. So, you have, what can you categorize as high quality energy, out of the various energy forms? Say, mechanical energy; mechanical energy of the motion of a shaft that kind of mechanical energy, very orderly form of energy, something that is very useful to mankind. You would notice that wherever we need to use mechanical energy, we need in that form. So, mechanical energy we need in the form of a high quality energy. Electrical energy, yes, it is a unidirectional motion of the electrons that produces electrical energy and therefore, it is also a high quality energy, it has very high degree of orderliness. So, electrical energy is also high quality energy, but then heat energy as I showed you that it is a low quality energy, but then in this course, we will come across various other forms of energy say solar energy, say wind energy. Are these high quality or low quality?

Let us say wind energy. What do you say about that? Is wind energy a high quality energy or a low quality energy? Low quality, because actually not all the molecules are moving in the same direction, they are moving in all sorts of disorderly direction; only there is an aggregate statistical direction that is all. While there is a cyclone, then also there are molecules moving in the opposite direction. There is the overall aggregate motion in that direction, clear? So, wind energy is a low quality energy and then, the second law would say that in order to convert wind energy to a mechanical energy, then there must be a theoretical maximum, clear? That is not intuitively clear, the moment you study the text books of thermodynamics, but you need to understand it this way that we are actually talking about conversion of an energy form that has a low degree of orderliness, a high entropy to an energy form that has a low entropy and therefore, there must be a theoretical maximum. What the theoretical maximum is, we will come to that when we talk about wind energy.

Solar energy, is that an orderly form of energy or a disorderly form of energy? Obviously, the solar energy is a mixture of various frequencies, right and the direction, the polarization is also not there. So, the axis are different for various components of the waves. So, obviously it is a mixture and a mixture obviously has a low degree of orderliness. So, you have a low degree of orderliness in solar energy and therefore, in order to convert from solar energy to either mechanical energy or electrical energy, there must be a theoretical maximum limit. There are many other forms that you learn about in school, many or various other forms of energy, for example, sound energy. You, obviously in a course that deals with energy engineering, will not talk about sound energy conversion into electrical energy, because we are talking about the energy, bulk energy conversion.

So, you have the concept of the quality of energy. Not only the quality of energy, in an energy form like heat, in one sweeping statement we said that it is a low quality energy, but how low? Within low, can there be difference in the lowness or highness?

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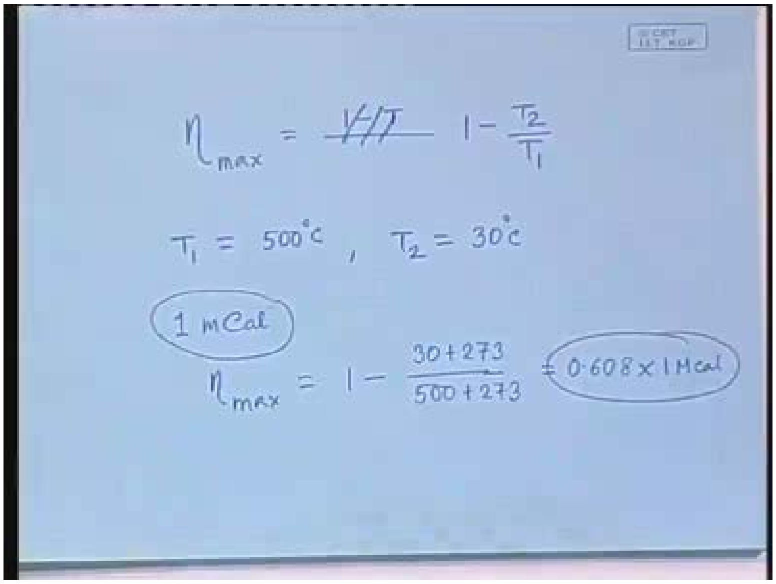

$$\eta_{max} = \cancel{1/T} \quad 1 - \frac{T_2}{T_1}$$

$$T_1 = 500^{\circ}C \quad , \quad T_2 = 30^{\circ}C$$

$$\boxed{1 \text{ mCal}}$$

$$\eta_{max} = 1 - \frac{30+273}{500+273} = \boxed{0.608 \times 1 \text{ Mcal}}$$

Obviously there is, because we said that the efficiency, the theoretical maximum efficiency is 1 minus, sorry, 1 minus T 2 by T 1. Therefore, how much of the energy is convertible depends on these two temperatures. So, if the temperature that we have in the source is very high, obviously you have more amount of energy available. Is that statement correct? No, because you cannot say that till I have defined the sink. There has to be two temperatures. Even a temperature like that in sun, it has no value in terms of energy engineering until you can find a sink. There has to be heat transfer from the source to the sink and a part of that energy is extracted in the form of the mechanical energy, so there has to be two temperatures.

If the two temperatures are stated, then you can easily identify that within some quantity of heat available, how much is actually convertible. For example, if, take this as a problem, solve that; if say T 1 is in case of a thermal power plant, the temperature inside, the temperature to which the steam is heated up is close to 500 degree centigrade, T 2 is a sink temperature that is the cooling tower where the water from the river is brought in and that is used to cool it. So, what is the temperature? Approximately you can say 30 degrees. Then, if a mass of coal, which when burnt produces 1 mega calorie of, 1 mega calorie of heat, how much of that heat can even ideally be converted to mechanical energy and electrical energy, can you calculate that? Do that as a problem.

So, the maximum possible efficiency is in this case eta max 1 minus T 2 by T 1, what is T 2? Wrong; yes, it has to be converted to the absolute scale. So, this is 30 plus 273; this is 500 plus 273 is equal to … How do I do it? 30 plus 273 divided by will do …… there is a bracket know …, 500 plus 273, it will not work. Yeah, this is a calculator which has different kind of functions. You just calculate and tell me how much it is; 0.608. So, you see, it is approximately 60%; it is approximately 60%. So, out of that mass of coal, the amount of heat that it can produce obviously goes up. If you can heat it up you can produce a larger amount of heat, a larger temperature.

Heat amount that will be produced by the coal is fixed, but if you can produce a larger temperature, obviously the ideal conversion efficiency will go up. Now the point is that out of this whole mass of heat, only this much was available for conversion. It is not that the rest of the heat is there; it is there, but you cannot convert it. It is not available for, even theoretically it is not available for conversion. So, we will say that this amount of energy, this into 1, this amount of energy is available energy. Even though the total amount of energy is this, the available energy is this, clear? So, now we have come to the concept of available energy; available energy and unavailable energy, the rest of energy is unavailable.

In the process of conversion that amount of an energy must be dissipated into the environment; we cannot help, right. That amount of energy must be dissipated into the environment. By the way this 608 is the ideal possible efficiency and an average power plant has an efficiency something like 35%, which means that 0.608 that means approximately 60%. 60% is the ideal efficiency set by thermodynamic limit and we are some place below that at the level of 35%. Now, if I ask you is it right for the people to ask the engineers to increase the efficiency higher and higher or how good are we in terms of our engineering? That is not really measured by saying that our efficiency is 35% or 36%. That is really measured by how much are we lagging behind the theoretical maximum? So, that 35% is for the lay public, for the energy engineers what matters is how much are we lagging behind from the theoretical maximum? So, that tells you two different definitions of efficiency.

If you watch from the first law, first law means the law of conservation of energy, so this was the total amount of energy out of which this much has been extracted and therefore, the efficiency is the amount that has been extracted divided by the amount that has been taken. As we did in the last class, W by Q 1 that is actually the definition of the first law efficiency, efficiency that comes from the first law definition; but, when we are talking about the real amount of failure that we have, we need to talk about efficiency in terms of how much are we lagging behind from the theoretical maximum. So, there are two definitions of efficiency …...

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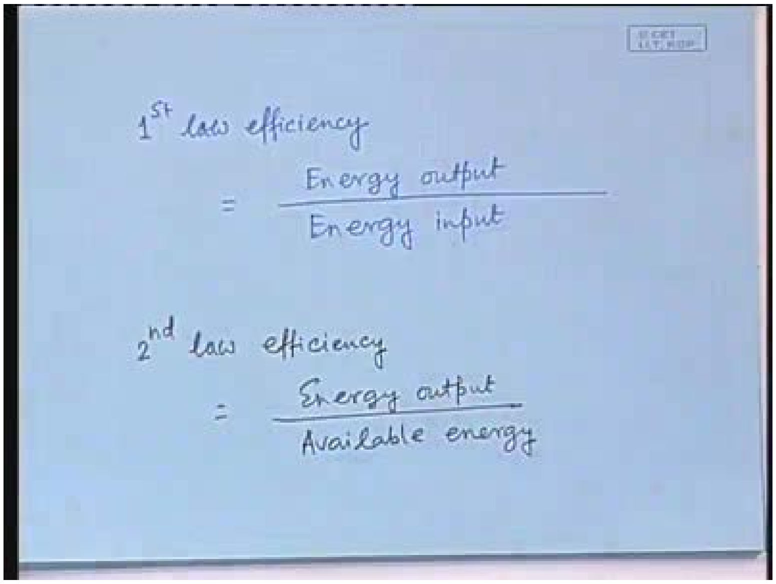

1^{st} law efficiency

$$= \frac{\text{Energy output}}{\text{Energy input}}$$

2^{nd} law efficiency

$$= \frac{\text{Energy output}}{\text{Available energy}}$$

One is first law efficiency, which is nothing but the energy output by energy input, simple stuff and also there is a second law efficiency. How do you define that? How do you define that? Wait; note, the whole amount of input is really available the amount that is there is not really available. So, out of that, how much is available? It is the amount of energy that has been taken times 1 T 2 by T 2, so that goes in the denominator. So, then only you can define the second law efficiency and this second law efficiency is the one that really measures something meaningful in terms of energy engineering, because that tells us how much are we lagging behind from the theoretical maximum. So, there are actually two concepts of energy.

Similarly, we will see that when it goes to wind energy, when it goes to solar energy, there also, there would be this kind of second law efficiency. There will be a thermodynamic limit in the wind energy also and there will be the question of how good are we, our wind turbines, when it comes to the comparison with the theoretical maximum. So, the second law efficiency is more important. So, I have today introduced two concepts. The quality of energy, the quality of heat, quality of heat energy, a mass of coal, a mass of petroleum, the whole amount of petrol that is there in the petrol pump, it has a calorific value. If burnt, it produces a definite amount of heat, but that is not our concern there. What is our concern is how much of that is really available? The more that is the higher the quality of the heat energy; so, within heat energy also there would be differences.

In one single shot we said that heat energy is the low quality energy. In general that is true, but within that low quality energy there is the gradation. Let us try to understand this.

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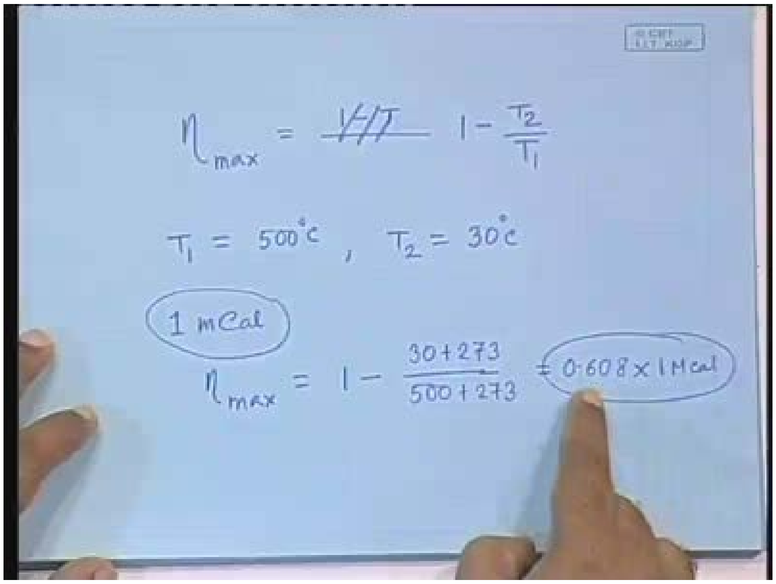

$$\eta_{max} = 1 - \frac{T_2}{T_1}$$

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1 mCal

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We have seen that the ideal theoretical efficiency or the amount of available energy from this amount of coal is like .6%, .6 times the total amount. You often hear about the, let us put the question this way. The gas that goes out of the stack in the power plant, that is also heated; that is also hot. Supposing an energy engineer thinks that I want to utilize that amount of heat and convert it into mechanical and electrical energy or if you go through, go by train to Calcutta, you will find that in the right hand side, there is a big thermal power plant and that is the Kolaghat thermal power plant. If you look at it, you will find there are big, what should I say, chimney like things; not the big ones, shorter ones, you see the steam coming out. Have you seen that? Those are the cooling towers where the steam from the power plant comes and the water from the river is spread, as and when the steam is cooled down and the water absorb the heat and becomes steam and that is what you see. That is the cooling tower. The steam tells you that there is an enormous amount of heat there which is being wasted into the atmosphere, right. So, if you want to utilize that amount of heat, obviously you could think that I would like to utilize that amount of heat.

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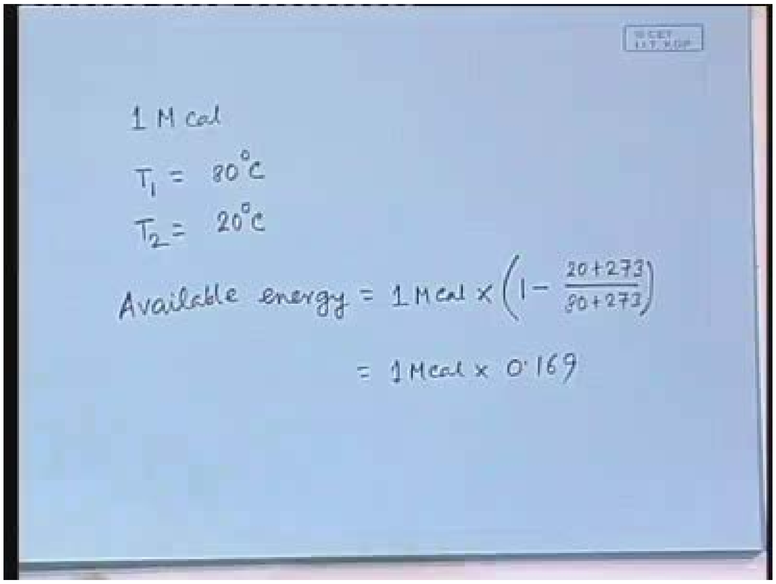

1 M cal

$T_1 = 80^\circ C$

$T_2 = 20^\circ C$

$$\text{Available energy} = 1\,\text{Mcal} \times \left(1 - \frac{20+273}{80+273}\right)$$

$$= 1\,\text{Mcal} \times 0{\cdot}169$$

So, let us do the problem, then. Suppose, again 1 mega calorie of heat is available that way, so one - the temperature T 1 would then be, which temperature? The temperature as, the temperature that the steam has when it enters that coolant chamber say, that is something like that is at lower pressure. So, the temperature will not be, will be lower than 100 degrees say, that is 80 degrees and T 2 is the outside water temperature say, 20 degrees. How much of that is then available energy? Calculate that. So, available energy is equal to 1 mega calorie times 1 minus T 2 by T 1. How much it is? So, this is …. into how much? 0.169. So, you see, the ideal efficiency is how much? 17%, approximately 17%.

So, you see, if you imagine a converter that would convert that amount of energy into mechanical energy, its ideal efficiency is something like 17%. It cannot reach anything beyond. So, out of that only a tiny amount of energy is really available as the available energy and in order to make a converter, obviously this will have its own inefficiencies and so, you will be able to reach at most like 9%, 10%. It will not be worth it. In terms of economics, they do not work out and that is why we do not have that ….. So, that tells you that even though the amount of energy is 1 mega calorie, there is a distinction between how much was available in that one and in this one. So, that is the important concept of how much is the available energy. Now, this available energy goes with a name. It is also called exergy.

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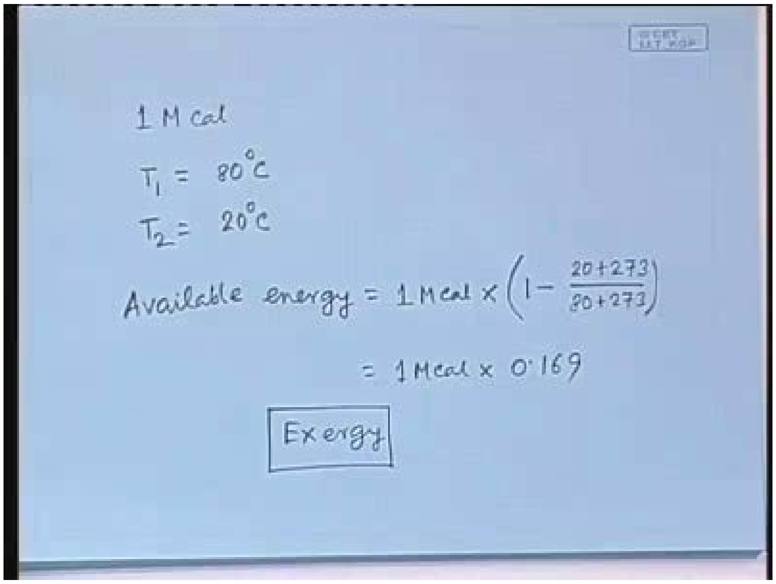

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$\boxed{\text{Exergy}}$

It is also called exergy. So, in any amount of heat, how much is the available amount of energy? So, today we introduced the concept of the quality of energy; high quality, low quality energy and then the concept of exergy. In making any energy analysis, for us, it is more meaningful to talk in terms of the exergy analyses than the energy itself, because whenever there is a, there is a question of conversion from one form to another, it is the exergy that really matters, not the energy. So, wherever we talk about the, in any industrial process for example, wherever there is a conversion, there is a conversion and we are trying to assess how good is the industry functioning, it is exergy that really matters, clear?

So, let us come to now another issue. Yesterday, we said that when we convert, when we actually go about the societal process which essentially means that we take the things that are available in nature, convert them into form that are more useful, like taking the oak or ore? and putting it through a long industrial process finally to make a pen, a sword or whatever or railway walance, things that are useful in the sense they have large amount of information, they have very high amount of orderliness and naturally very low entropy and we do that conversion and in that process, always if you take the whole into consideration, then the entropy increases.

What do we mean by whole? The definitions of the second law that I have given so far, all state that let they be closed system; so, let they be closed system. Now, the moment we say that the tree is open system, the man is open system and the animal is open system, the society is open system, then obviously how do we imagine the application of the second law? Then, we have to take into account the environment together, together with it. In other words, if you have to take the whole, then the entropy increases. That means the system and its environment taken together, the entropy definitely has to increase. That is the statement of the second law.

But then, we want to arrest that increase of entropy; we want to arrest that increase of entropy and we are trying to use the amount of negentropy that is there in our environment. Again, what is the concept of negentropy? The relative amount of orderliness that is there in our immediate environment; the ores are negentropy stocks and one prime source of negentropy for the Earth is the solar energy, the sunlight that comes, because that is how it comes, in a very orderly, relatively orderly fashion and after all, the Earth also radiates the same amount of energy, otherwise it will heat up; also radiates the same amount of energy, but that does it, that is done in a more disorderly form and that is what is absorbed, that orderliness is absorbed by the plants and that orderliness is finally taken by the animals, that orderliness is finally used by the society. So, ultimately the source is there - the relative orderliness in solar energy. So, there are two sources really - one solar energy and two - the amount of negentropy stocks that have been built.

There are two types of negentropy stocks that have been built really. One is like the manganese ore, for example. In the geological process, it is unlikely that every place will be homogeneous. So, there are some relative concentrations of manganese, iron, tungsten, like that in some places and these are the ores, alright. But, the other energy sources that we talk of like the coal, like the petroleum and other things, these have been built up over the years. Through what process? Through what process? These are fossil fuels; fossil fuels in the sense that these are remains of living organisms. Coal - remains of trees, while remains of other marine organisms, whatever it is, but these were at one time living organisms. That means these are concentrated forms of solar energy, taken, accumulated over a huge length of time, but finally concentrated and available to us as a negentropy stock, clear? So, these are also ultimately the creation of solar energy that has been received for some millions of years.

So, these are the negentropy stocks and what we do is we take out the iron ore, we take out the manganese ore, we take out the nickel, we take out the cobalt, we take out the copper and we put that through industrial processes, which uses energy, to make copper, to make cobalt, to make nickel, to make rubber. So, after all this, what we do with it? We use them. Now, imagine what is happening while we will use them? Suppose a carpenter is using a chisel and a hammer and hammering away. The chisel obviously, was produced in similar process, ultimately from iron ore to the chisel. The hammer was made in this way, same way. The car uses a tyre and the tyre was obviously made in the same way, from the things that you have in nature as a relatively more concentrated form negentropy stocks; use them to make the tyre and the fellow rides the car. What happens to the tyre? Slowly, the chisel and the hammer that wears off, right; the car tyres wear off. While it wears off, what happens to the molecules that formed it?

The car tyre consists of molecules. What happens to the molecules? Did they vanish? While the fellow is chiseling off, what happens to the molecules of iron that were there? While it was sort of something that was flat, slowly with hammering, it becomes rounded off. What happens to those molecules that were there in the edges? They are still there, they did not vanish, but they got dissipated in the environment. If they are still there, you might argue that it is still possible to take that environment and then extract it and to get that iron back, to get that rubber back. But, is it really possible to get the rubber out of the road? No; because, it is now in a distributed, dispersed, unorganized form.

So, what is the societal process doing? We are converting then the things that we earlier converted into an organized, orderly, low entropy form through the process of use they again become unorganized, disorderly, high entropy forms. They are no longer useful; they are no longer usable. Notice that what all I mean. We have some negentropy stocks. They are finite; they are not infinite. The iron ores are finite, the manganese ores are finite, the coal mines are finite, the amount of petroleum that we have is finite and through the use of the coal, the petroleum, we are making iron, we are making cobalt, we are making copper and using them, we are making rubber; we are using them making plastic, using them and through the process, they become dispersed in high entropy state, when they are no longer available, right.

So, in that process both the things are depleting. One - the energy sources, two - the negentropy sources, like the manganese ores are no longer in the form that were there 100 years back, right. You do not have that considerable manganese ores any further. Now, the ores that are remaining requires much more energy, in order to extract. So, these are all finite resources, finite negentropy stocks that are slowly depleting. On top of it, the way we utilize all that were by using fossil fuel that itself is depleting. So, that is essentially the crux of the crisis that mankind is facing. Many people do not understand that; many people only talk about the oil price, but it is not as, you know, simple as that.

It is basically that the Earth has finite resources in terms of the negentropy stock and the negentropy stock in terms of the energy sources as well as the material sources, both are depleting and as the negentropy stock in terms of material resources are depleting, they require more and more energy in order to use and the energy resources are also depleting. That is the crux of the crisis. So, in that sense, before we end the class today, we need to understand that we have various ways of arresting that crisis and that will be the essential content of this course. How can we, in terms of engineering, arrest that crisis? We need to understand various things. But, when we have understood this amount of thermodynamics, notice the thermodynamics developed in terms of thermo that means heat, but I have been dealing with in terms of a general concept of orderliness, disorderliness.

What is …..? It tells many things. For example, there are things that come in your daily life. In the winter, you need hot water, right. You need hot water to take bath and the hot water should be like 30 degrees, while the water that comes at that time is like 10 degrees or so. So, you need to heat that. What is normally done is that water is heated up to something like 60 degree - 65 degrees and then it is mixed with cold water, finally you take bath, right. So, you have a mixing process. Now, if you have a hot water and a cold water and you have a mixture, which one has a higher entropy? Hot water and cold water, there is information in it. You can dip two thermometers and say that it has this temperature, that that temperature. The moment you mix that that information is lost. So, in that sense, the hot water and cold water, they, the two buckets of different temperature water, they have higher degree of orderliness; mixture has lower degree, you can easily calculate.

Suppose there is 1 kilogram of water, 1 litre of water at 65 degree. It is mixed with another kilogram of water at say, 10 degrees. Can you calculate how much will be entropy generated?

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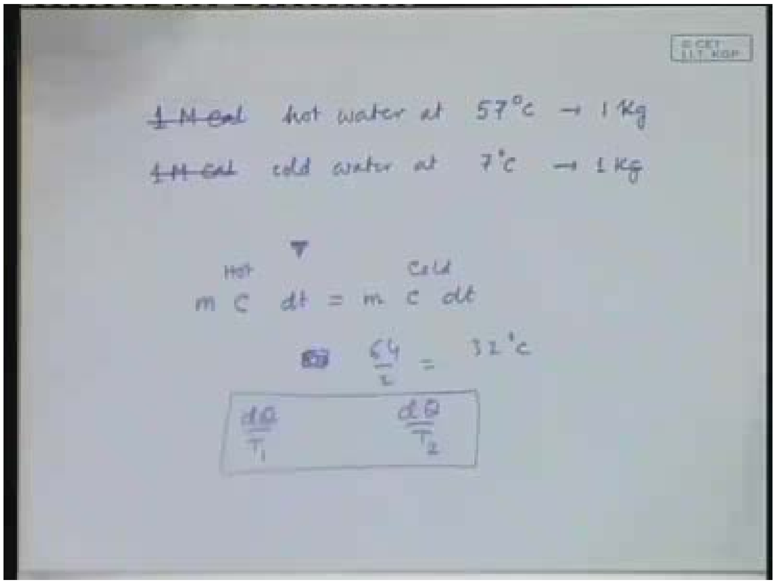

~~1 M cal~~ hot water at 57°c → 1 Kg

~~1 M cal~~ cold water at 7°c → 1 Kg

$$\overset{\text{Hot}}{m\,c\,dt} = \overset{\text{Cold}}{m\,c\,dt}$$

$$\frac{64}{2} = 32^{\circ}c$$

$$\boxed{\frac{dQ}{T_1} \qquad \frac{dQ}{T_2}}$$

So, you have suppose 1 mega calorie, 1 mega calorie of hot water at say, at say 57 degree centigrade and 1 mega calorie of cold water at say, 7 degree. Now, suppose this is also 1 kg and this is also 1 kg, so how much will be the, if you mix these two, then how much will be the temperature of the resulting water and how much will be entropy generated? That is what we are trying to find out. So, we are actually having 1 kg 1 kg equal amount and this is at 57 degrees, this is at 7 degree. So, suppose after you mix up, these fellows stabilize at a temperature say, T. So, you have m c dt for the hot water. This is the amount that the water loses and that would be equal to the m c dt of the cold water. So, this is for the hot water and this is for the cold water.

It is easy to see that since the two masses are the same, its capacities are the same; so, they will change temperature by the same amount. As a result, the final temperature will be somewhere in between, actually this plus this by 2. So, you have, the temperature, it will be how much? 57 plus 7 is 64; 64 by 2 is 32 degrees. So, in order to get the temperature from 57 to 32 what has happened? The hot water has lost an entropy of the amount dQ by T and the cold water has gained an entropy of the amount, again dQ by T. Now, you see, the amount of the heat is the same. The amount of heat lost by the hot water is the amount of heat gained by the cold water. But then, this temperature say T 1 and this temperature say T 2, these are different and T 1 is a higher temperature and T 2 is a lower temperature, as a result of which the amount of entropy that is lost by the hot water is smaller than the amount of entropy that is gained by the cold water.

So, if you take the whole thing into consideration, it is easy to see that the overall entropy goes up. So, if you mix a hot water and the cold water, the overall entropy goes up and that is why it is energetically more prudent, logical to have not a mixture of hot water and cold water, not to first heat the water to 57 degrees and then mix with the cold water; rather mix and heat up the whole water, 2 kgs of water to the temperature that you want, 32 degrees. So, you see, if you understand energy engineering, such mundane things take a different meaning when it comes to the energetic perspective.

Then, let us also consider the situation of the heating of rooms by means of air conditioners. In the winter, you need to heat up. In the summer you need to cool, in the winter you need to heat up. Now, that can be done in two possible ways. One, simply use a room heater kind of thing, where you have a wire which is heated up by I square r means and the heat is put into the room by means of fan or something. In this case, what is the efficiency? 100% really, because the amount of energy that is generated by I square r, the complete amount of energy is put into the room, while the other possibility is use the same air conditioner, but in the opposite way.

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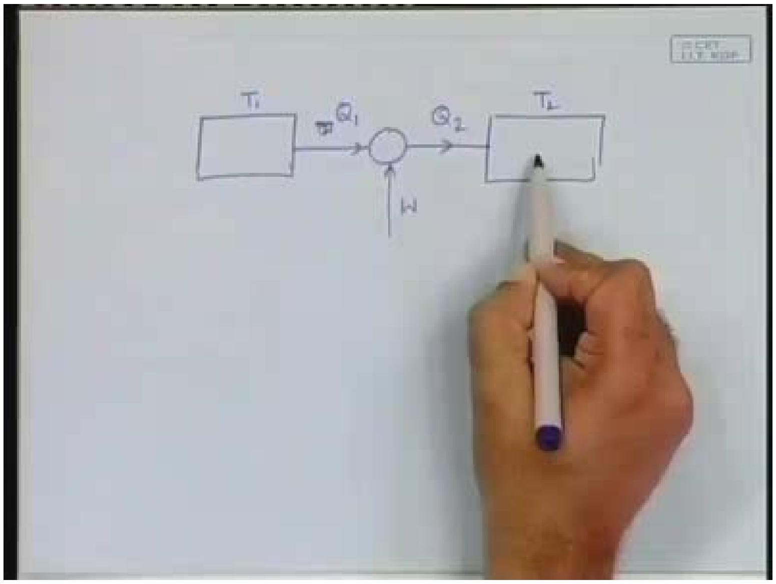

In that case, it will normally be a heat engine something like this, which takes heat. So, it takes some Q 1 quantity of heat, puts Q 2 quantity of heat, use an amount of energy that is W. This Q 1 is at a, at a lower temperature say T 1 and this is T 2 and Q 2 is at a higher temperature. So, it takes heat and puts there. Now, suppose the outside is cooler than the inside, then also you can run the same way. You can use it as heat engine. But, what happens in that case is that you are giving energy. Actually you are taking that energy from outside; even though that is colder, you are taking that energy from outside and putting it into the inside of the room. As a result, it is not the whole energy that is coming from the electricity, only a part is coming from the electricity; the rest of the heat is obtained from outside. As a result, the amount of electricity that is necessary is far less.

So, even though the normal room heater, the I square r heater, its efficiency is 100%, its efficiency is even larger than that. So, these are the simple things that you learn, if you understand the energy aspect of it little more clearly. So, a normal, the proper energetic way of running an air conditioning system in summer in winter is simply to run the air conditioner in reverse, instead for putting I square r heating element in it, the same air conditioner will work in a better way. So, you see, in energy engineering the moment you understand the laws of the thermodynamics, a few things become immediately clear and that is what is most important for the energy engineers.

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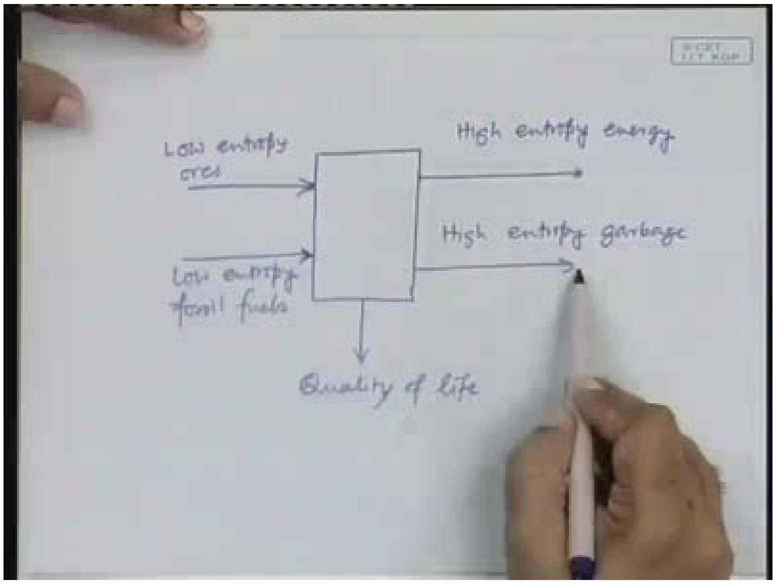

If you take an energetic view of the societal activity, then you can take society as a block and then here will be the low entropy ores that goes in, then what goes out are high entropy energy that is never recoverable. It also takes in low entropy fossil fuels and also puts out the high entropy garbage and the output is the quality of life. So, it takes in low entropy ores, takes in low entropy fossil fuels, gives out high entropy energy, gives out high entropy garbage and as a result, we have this. So, these things are the main concern for us, the energy engineers. So, this day I told that the Earth as a system receives solar energy; part of it goes, part of it is used and finally, we have some kind of an energy balance for the whole planet.

So, let us talk about how much is the, what is the energy balance ….. like?

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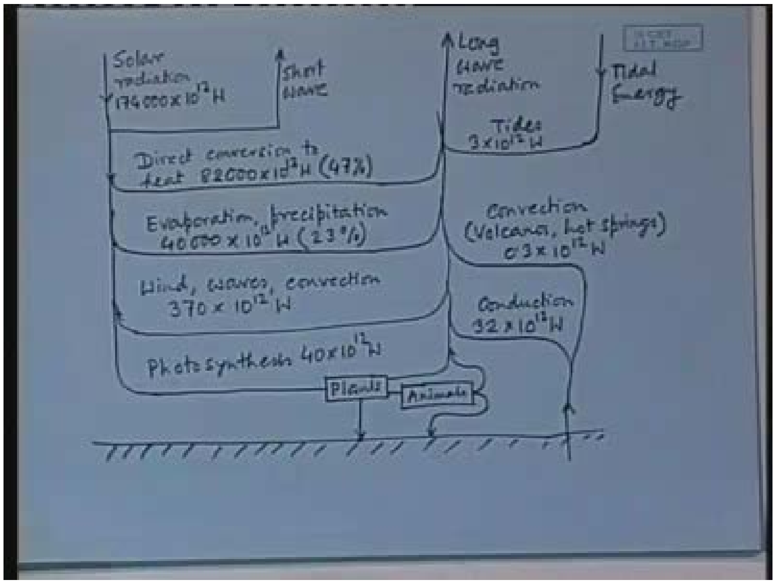

The first thing that comes in from the Earth, suppose this is our Earth, is the solar radiation, which is around 174000 into 10 to the power 12 Watts. Now, as it comes, a part of it goes out as reflected immediately. So, this is short wave; the one that is absorbed and radiated back that is long wave that is in the infrared range, but this is the direct radiation I am talking about. A part then goes into and a part goes as a direct conversion to heat; absorbed, converted into heat and radiated back. So, that amount is 82000 into 10 to the power 12 Watts. So, that is approximately 47% of what is coming. So, this amount will go out as, as long wave.

A part again will be absorbed in the water bodies and it will evaporate, right; so, evaporation and precipitation, this cycle of water that will also take a part of that incoming solar radiation. So, incoming solar radiation is that energy, also supplies the energy necessary for this water cycle and how much is that energy? That is evaporation precipitation this is 40,000 into 10 to the power 12 Watts, which is approximately 23% and then at the end of the day, that is also turned into heat energy and radiated back. Then comes, the energy that goes into producing the wind. So, wind, waves, convection, etc. That is approximately 370 into 10 to the power 12 Watts. At the end of the day what happens to it? It also goes out, because the amount that has come in must ultimately go out in various ways and it is the various ways that distributes the energy that comes in and then lastly what comes in is absorbed like the photosynthesis. This is 40 into 10 to the power 12 watts; very tiny percentage of that is absorbed in the plants, which then becomes useful for man. So, what grows is plants. Then, plants decay generating heat and that again is going out. Only a part of that then goes to animals and then a part of that goes up and finally, another part of that goes to the ground. Some parts of the plants also go to the ground. These plants in the history going into the ground that is what has created the coal. These animal bodies that have gone into the ground that has produced the petroleum reserves. So, this is our Earth.

Now, what additionally happens? Is there any other additional input of energy into the Earth? Yes, tides; so, tide is another something that is coming, the tides; tidal energy. Tidal energy produce tides and what happens to the energy that was there in the tides? Ultimately it gets converted into heat and it goes out. So, it must go out the same way like this, same channel. This energy is 3 into 10 to the power 12 Watts. There are also heat coming from within the Earth – volcanoes, hot springs, those things. So, those are terrestrial sources that go out like this and there are two ways in which they go. One is conduction that goes again as heat; 32 into 10 to the power 12 Watts. So, that is conducted into the surface and then it is radiated as heat and there is another part that is convection, which is volcanoes, hot springs, etc. That is 0.3 into 10 to the power 12 Watts. So, that again in that form goes out.

So, notice that in this whole energy flow sheet you have the two inputs solar energy radiation and tidal energy input and from here it is the geothermal energy ….. the system. Plant bodies and animal bodies are going in and geothermal energy is coming out from the body of the Earth, but this is the total flow chart of energy. Out of that, the direct solar radiation is usable, which is not used right now. Only this part is used directly or indirectly, the rest of it goes. Tidal energy can be used and the amount that is here, this can be used as a resource. Now, these ones, the ones that are always coming, these ones are finite, non-renewable, but the ones that are coming all the time, they are the renewable sources of energy. So, we will divide the talk in terms of, the future classes into dealing with the non-renewable fossil fuels, how to use them and the renewable things and here are the quantities, relative magnitude that you should keep track of. Thank you, that is all for today.