Energy Conservation and Waste Heat Recovery
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Lecture – 03
Introduction to waste heat recovery (Contd.)

In last 2 classes I have tried to give some background of the subject, the necessity of this subject which we are going to learn during the coming few days, and the difference between energy conservation and waste heat recovery. Our impasses will be particularly on waste heat recovery, but it is closely related to energy conservation. So, what is the interrelationship between these 2 aspects and then some useful definitions, its relevance for the industry and for environment all these things I try to explain.

Now, today we will start from that point, we will see in industry what are the options or where the potential lies for waste heat recovery and then we will see how we can gain from waste heat recovery. We will also see how waste heat can be recovered and what are the different usage of waste heat plus we will see in total perspective of energy or energy activity, where does waste heat recovery lie. Now this will constitute more or less 2 lecture classes and with that we will come to an end to the introduction of energy conservation and waste heat recovery.

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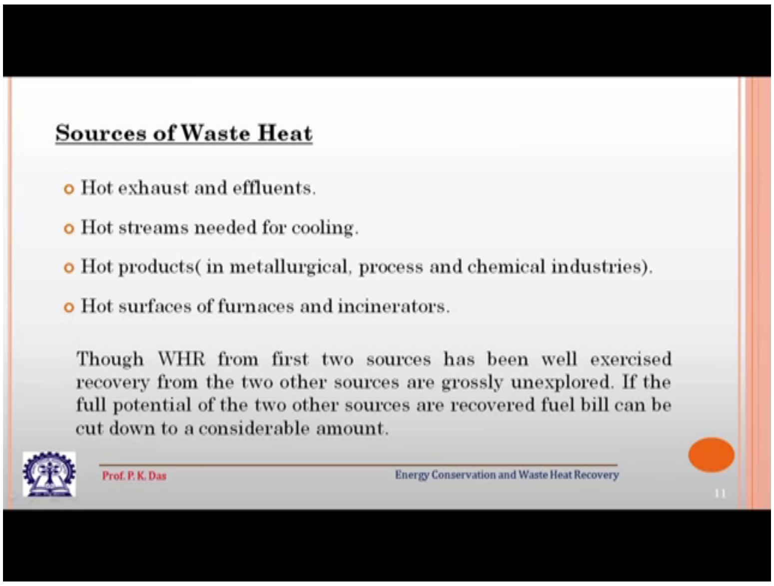

I like to start with the last slide I have shown in the previous class; there we have shown the sources of waste heat. So, in an industry I have told that hot exhaust and effluents they contain waste; heat hot streams that is not exhaust, but it is in between some process of the industry. So, that needs cooling and there also we have got potential for recovering certain amount of energy. Then hot products which is common in metallurgical processes chemical industries and then hot surfaces of furnace and incinerator.

So, this is some sort of a generalized view from where we can tap certain amount of energy because these are basically processes of dumping thermal energy to the environment. Now let us go into little bit details, let us see in specific industry where and how much energy can be tapped. So, this is some sort of a generalized overview and the figures which I will give that is again notional.

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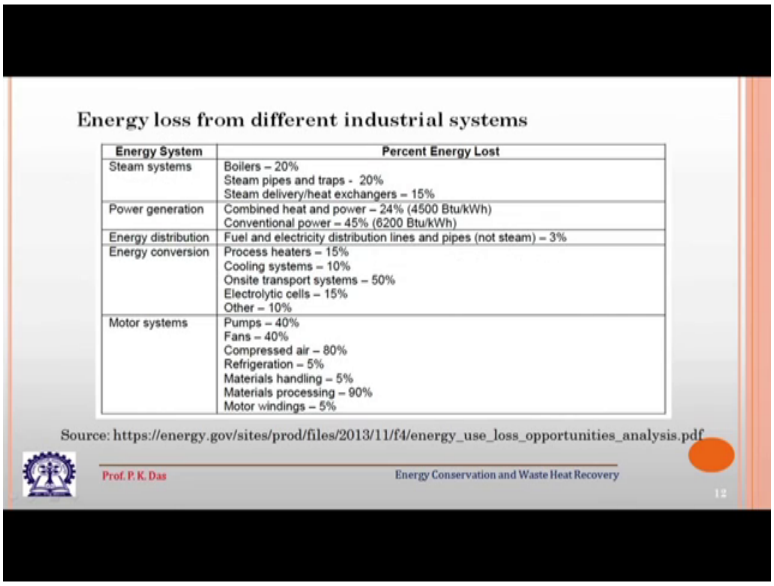

So, for a typical industry there may be some variation of these figures. So, energy loss from different industrial systems, if we consider them to be the energy loss; obviously, there is a potential of recovering them.

Now, steam systems which are very extensively used for industry, there we will have scope for recovering energy. Boilers generally 20 percent of energy can be recovered, steam pipelines and traps lot of energy losses are there because hot steam will be supplied through steam pipeline and there are steam traps for arresting steam flow only for drainage of condensate. So, this also constitute 20 percent of energy loss and then steam delay delivery exchangers, wherever there is any heat exchange process involving steam that also constitute 15 percent.

Then we come to power generation. So, power generation probably this will be elaborated in the following lectures, that it could be combined heat and power if we have got the option for generating both heat and power, then the losses are around 24 percent 25 percent like that and conventional power. So, that is around 45 percent there will be energy loss which can be recovered. These are estimate based on the survey of different industries and as I have mentioned for a specific industry, these values may differ slightly energy distribution there could be fuel and electric electricity distribution not steam pipeline so, there around 3 percent losses there. Then process heater, cooling system, on site transport system, electrolytic cell and other. So, there were some sort of energy conversion is there we can see how much energy loss could be there in these systems.

Then we are having motor systems like palm span compressed air, refrigeration, materials handling, material processing motor winding. So, losses are there you see compressed air that is a very high figure very large figure 80 percent, the reason is that when we compress a gas its temperature increases. So, part of the work that goes for raising its pressure that is paint for raising is raising the pressure of air.

So, part of heat is converted into thermal energy and; obviously, that is a potential loss and that gives a scope of recovery. But we will see though the percentage has been shown this is not the total picture, we will as we proceed with this lecture we will see that not only the amount of energy is important, there are other factors which are to become considered and then only we can have the actual potential of recovering this waste energy, strategy for waste heat recovery.

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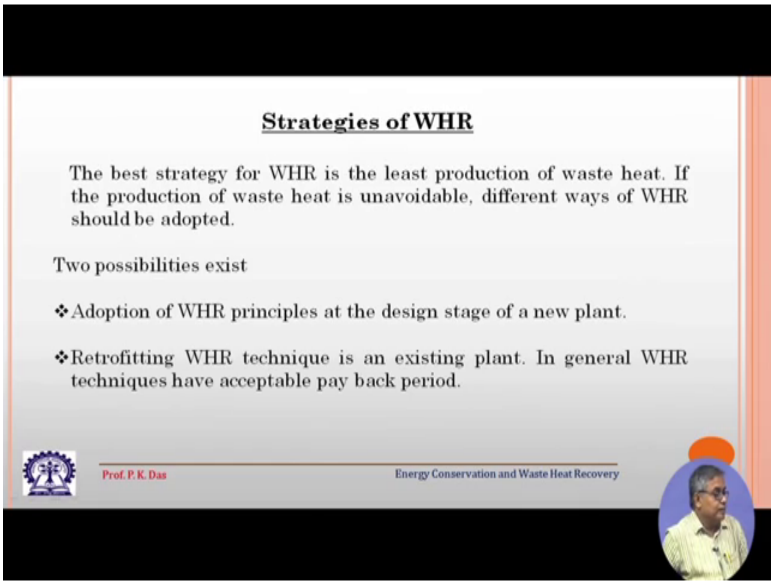

So, if we have to design or select a waste heat recovery system, a in the plant we are we are having or we like to have a facility for waste heat recovery then some sort of a strategy has to be planned. The best strategy could be that we design the plan we design the energy interactions in the plant in such a way that there is no or minimum generation of waste heat. So, that is the best policy or best strategy, but it is not possible always. So, there will be generation of waste energy particularly in the form of thermal energy and then we have to have methods for recovering this that is what is waste heat recovery and that is what we are going to study.

Then again there are 2 possibilities; adoption of waste heat recovery principle at the design stage of a new plant; obviously, this is a better option, then later on we have not to bother that what could be our plan and we can have definitely a better design of the plant and then what happens, in some cases while we are having some sort of existing plant we can estimate that there is lot of waste heat generation and then we have to adopt technique for retrofitting the waste heat recovery principles, waste heat recovery equipment in the existing plant itself.

So, both are followed in the industrial practice.

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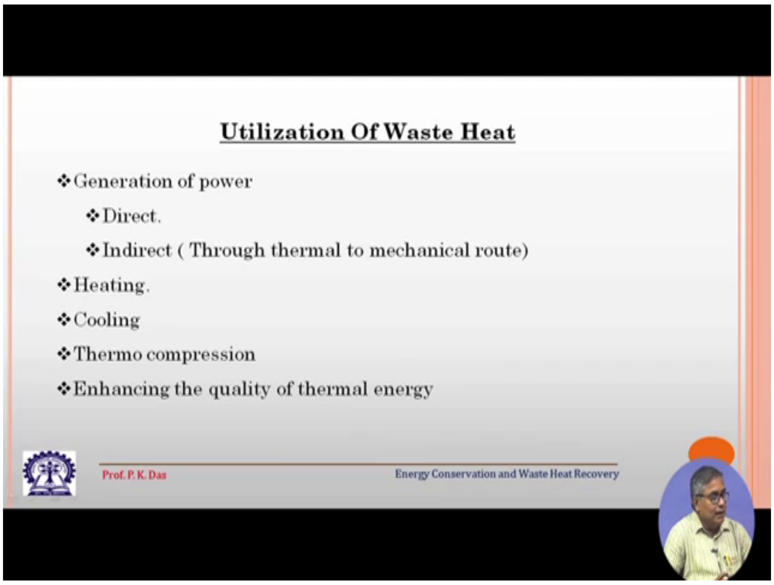

Then how we can utilize waste heat? First we can generate power as it is thermal energy we know from fossil fuel or from nuclear power we get thermal energy and from that thermal energy we ultimately generate electrical energy. What is the path? The path is from thermal energy, we generate mechanical energy and then mechanical energy which is generally the motive power of some sort of a turbine or it could be the reciprocating motion of a piston that can be ultimately converted into electrical energy, which is easy or which is very convenient for exploitation of energy for different purposes different n usage.

So, generation of power definitely it is a very good option desirable option from waste heat recovery, from recovered waste heat we can generate power and then there are 2 ways one is direct; that means, from the thermal energy we are directly getting the electrical energy. The methods will be developed the methods will be discussed by the other instructor of this course professed Andrew Bhattacharya, there is thermoelectric method, Therma unique method, thermal photovoltaic methods. So, by this method directly we can get electrical energy without going through the thermal mechanical path and; obviously, we can generate power and then there is indirect method which it which is more conventional; that means, thermal energy we are getting from there we will get mechanical energy and ultimately it will get converted into electrical energy.

Then we have got heating so; obviously, thermal energy we are getting as waste heat and that can be utilized for heating some other stream, for generating steam for heating some sort of a product and so on and so forth. So, this heating can be done with the help of thermal energy then cooling is also possible. One example is absorption cooler or absorption chiller. So, there we are using thermal energy for producing low temperature. So, this is also a very lucrative option of using waste heat, then thermal compression.

So, thermal compression it needs little bit of explain explanation is like this, that some sort of a mechanical power we can get from waste heat let us say this kind of arrangement.

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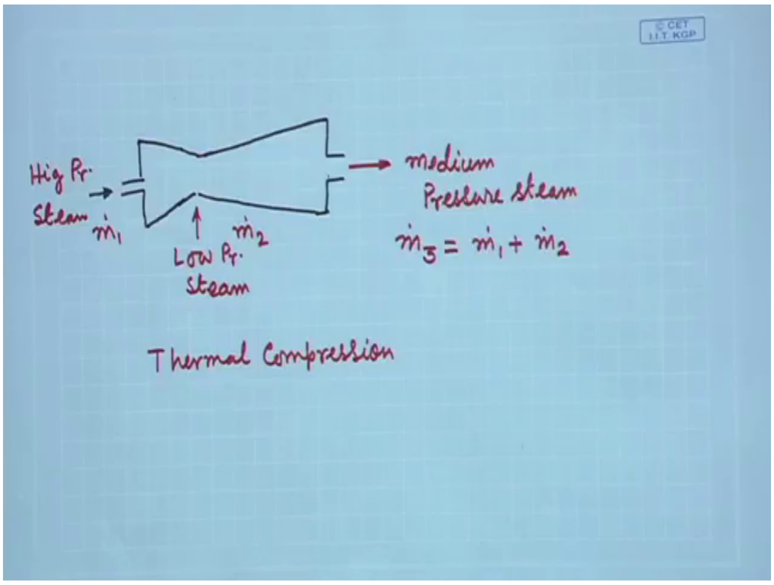

We have got low pressure steam and we have got high pressure steam; obviously, high pressure steam is valuable and we have to we have its other usage, but part of the high pressure steam we can use as a driving steam. So, this is your high pressure steam and then here we are getting low pressure steam and at the end we are getting medium pressure steam.

So, the principle is called thermal compression let me explain it once again. So, we are taking less amount of high pressure steam in some sort of a venturi like arrangement and we are taking a high volume of our high volume flow rate of low pressure steam and we are producing medium pressure steam. So, let us say this is m dot 1, this is m dot 2 where m dot denotes the mass flow rate. So, medium pressure stream we are getting m dot 3 which is equal to m dot 1 plus m dot 2. So, by this method this low pressure steam which we could have waste heat. So, now, we are raising its pressure it is now medium pressure steam and it can produce some other or it can perform some other it can give some other services.

So, basically what we have done the low pressure steam we have compressed to medium pressure steam. So, that is why it is called thermal compression. This is a very unique and typical example of utilizing waste heat, then there is another example enhancing the quality of thermal energy how it can be done? We are familiar and we will again elaborate later on the principle of heat pump. Now in a heat pump we take energy which is at low temperature thermal energy we spend certain amount of mechanical work and then we get thermal energy at high temperature. So, we will discuss that the quality of thermal energy that depends on the temperature. So, here it is possible to enhance the quality of thermal energy with the help of waste heat; obviously, some amount of mechanical work is needed.

So, thermal compression and enhancing the quality of thermal energy they have something in common, that here certain ex external energy has to be supplied in the first case external energy has to be supplied in the form of high pressure steam in the second case external energy has to be supplied in the form of electrical work.

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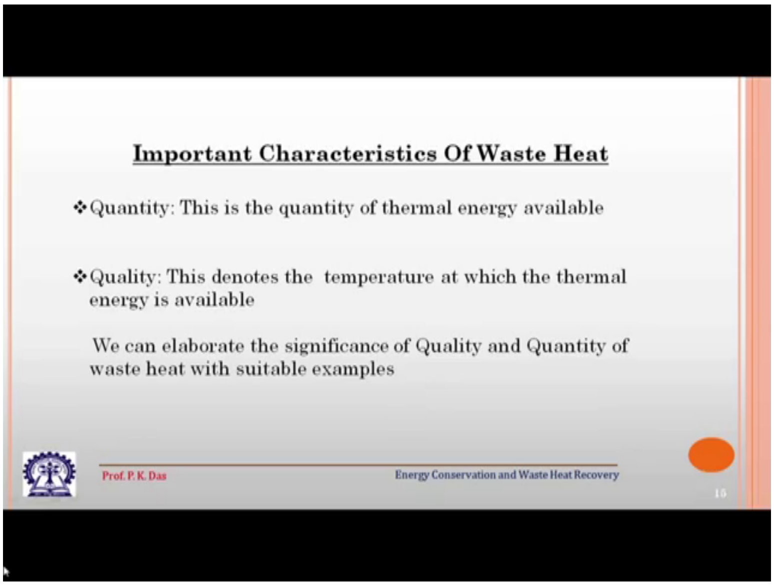

Important characteristics of waste heat. So, quantity is very important, the more waste heat we get there will be possibilities of having a better system, having a workable system, having a profitable system which can give us payback within a small period of time for the investment of waste heat recovery devices.

So, quantity is important, but at the same time quality is important what is quality? See quality let us put it like this, that basically as waste heat we are getting thermal energy and quality of thermal energy depends on its temperature. So, higher the temperature of waste heat we will have better option of converting it into some useful purpose getting some output profitable output out of this waste heat. So, temperature is very important, but again we have to keep it in mind that though we are getting let us say we waste heat we are getting certain at a certain elevated temperature, but if it is not of suitable quantity again designing or planning or selecting a waste heat recovery device becomes impossible or difficult.

So, quantity and quality both are important, quality gives us flexibility of selecting method, quality gives us the quality gives us enables us to select baton better methods for exploiting waste heat, but in quality there is something else also. So, if temperature we can take as the physical quality, there is also some chemical quality of the waste heat particularly when we are dealing with exhaust gases. The exhaust gases sometimes it could be very obnoxious. Obnoxious in the sense it may have some time components which are corrosive, which can create fouling, which can which is loaded with particulates. So, if it is taken into a device it will erode the device, it will create some sort of a damage to the surface of the device. So, this chemical quality that is also very important.

We will elaborate the significance of quality and quantity of waste heat with some suitable example.

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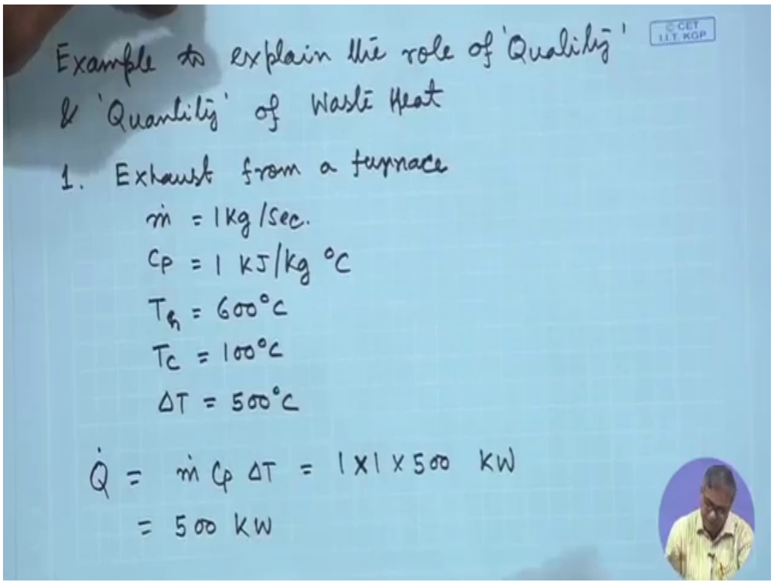

So, let us take one example, let us say we are having example to explain the role of quality and quantity of waste heat. So, first one let us say we have got exhaust from a furnace I am taking figures which are easy to handle. So, let us say the mass flow rate m dot is 1 kg per second that is the mass flow rate, exhaust let us say Cp we are taking that it is 1 kilo joule per kg degree celsius and then the temperature exhaust or let us say high temperature which we are getting at the exhaust of the at the exit of the furnace.

Let us say that is something around 600 degree Celsius. Let us say we have got an option and we are cooling it to 100 degree Celsius, the hot gas that is being cooled 400 degree Celsius and by this process we are extracting thermal energy we are extracting waste heat. So, Tc that is equal to your 100 degree Celsius. So, what we have got delta T we have got that is equal to your 500 degree Celsius. So, how much energy we can extract from it? So, let us say Q which we are extracting that will be m dot Cp into delta T that is equal to 1 into 1 into 500 500 and it is kg per second. So, it is kilo joule per kg per second. So, it will be kilowatt. So, this will be 500 kilowatt, some example we have taken.

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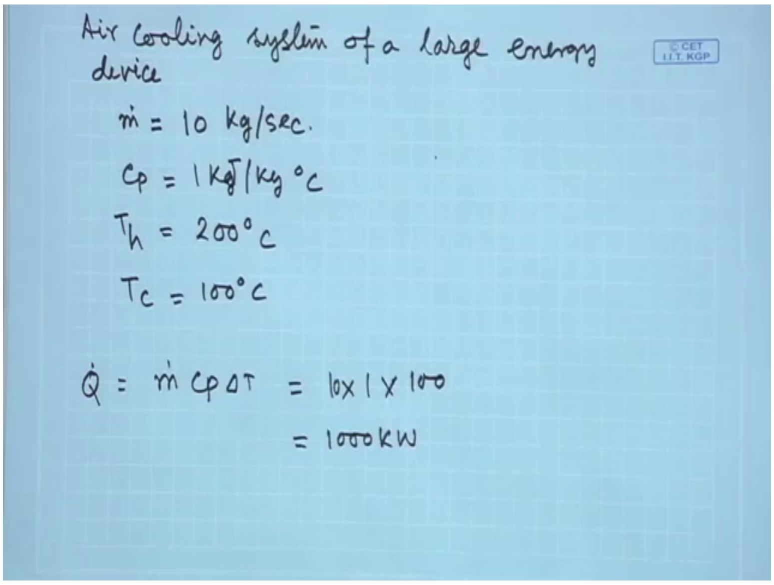

Let us say we are taking another example and here this is air cooling system of a large energy device, I am not going into the details of the device and then here also let us say m dot is equal to what let us say it is 10 kg per second, and Cp let us take the same value 1 kg per sorry 1 kilo joule per kg degree Celsius and then Th that is let us say 200 degree Celsius and Tc it is 100 degree Celsius. Delta T we have kept same the here the exhaust gas we have taken the property to be equivalent to that of air, which may not be true in a practical case, but this is an example. So, in this case Q dot will be again m dot Cp delta T. So, this will be 1 into 1 into 100 it is not 1 it is 10 into 1 into 100 because mass flow rate is your 10 kg per second. So, how much I will get here I will get 1000 kilowatt.

So, in the second case we are getting more energy, but what we are what is the difference between these 2 cases? In the first case we are having the highest temperature at 600 degree Celsius that gives us a lot of option. See one option there is that we can generate power from the waste heat source which I have taken in the first example, in the second example power generation is almost impossible. So, what we can have, we can have only some heating in the first case both heating and power generation is possible and when we are having power generation; obviously, we are creating high quality energy the energy which is having lot of flexibility for use which is desirable form of energy in any kind of usage.

So; obviously, the quality of the waste heat that is important. So, this by this example I think one can understand what is the role of quality and quantity. Apart from that; obviously, the chemical quality is important and that depends or that varies from application to application.

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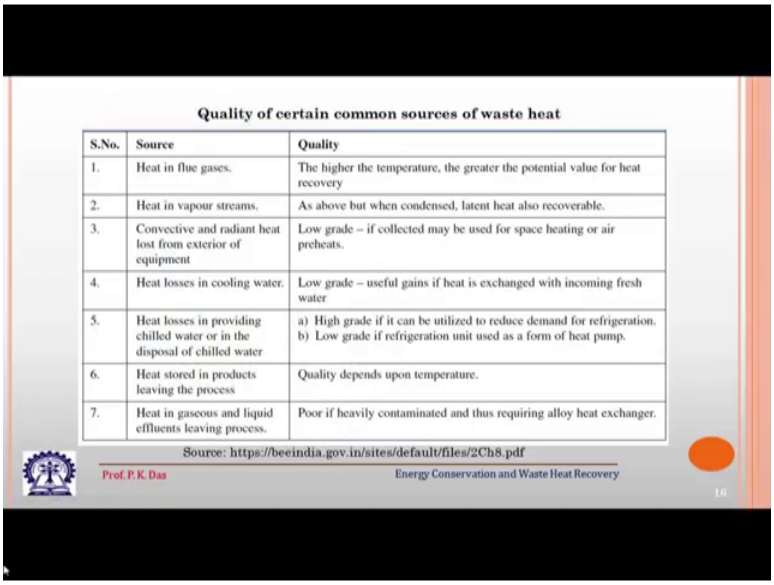

S.No.	Source	Quality
1.	Heat in flue gases.	The higher the temperature, the greater the potential value for heat recovery
2.	Heat in vapour streams.	As above but when condensed, latent heat also recoverable.
3.	Convective and radiant heat lost from exterior of equipment	Low grade – if collected may be used for space heating or air preheats.
4.	Heat losses in cooling water.	Low grade – useful gains if heat is exchanged with incoming fresh water
5.	Heat losses in providing chilled water or in the disposal of chilled water	a) High grade if it can be utilized to reduce demand for refrigeration. b) Low grade if refrigeration unit used as a form of heat pump.
6.	Heat stored in products leaving the process	Quality depends upon temperature.
7.	Heat in gaseous and liquid effluents leaving process.	Poor if heavily contaminated and thus requiring alloy heat exchanger.

Now, based on this temperature, we see temperature basically that is the indicator of the physical quantity of waste heat. So, based on that the waste heat sources can be divided grossly broadly little bit loosely into three categories.

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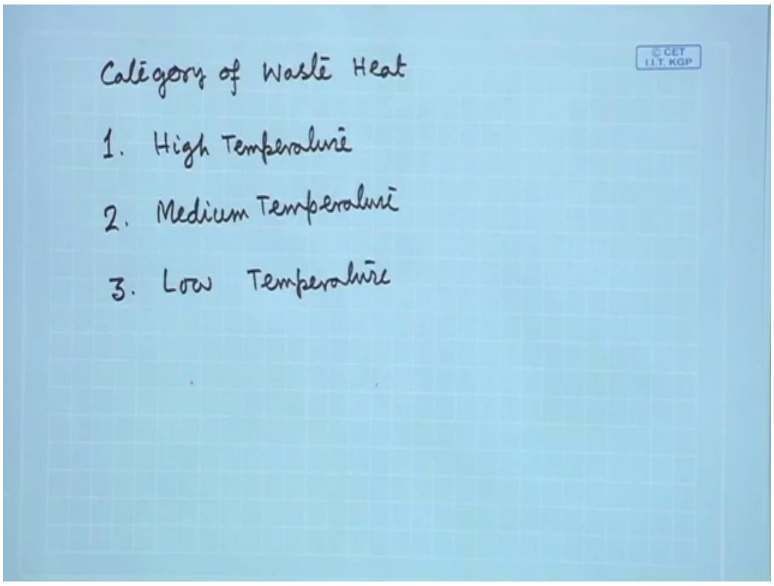

Category of waste heat; one is high temperature, second one is medium temperature and third one is low temperature.

So, now I like you to show some of these high temperature sources, medium temperature sources and low temperature sources and have some discussion on it. So, if you see if you in this particular slide you see quality of certain common sources of waste heat, I have told here we are having heating through gas what is its quality heating vapor stream and like that it has been shown what could be the quality.

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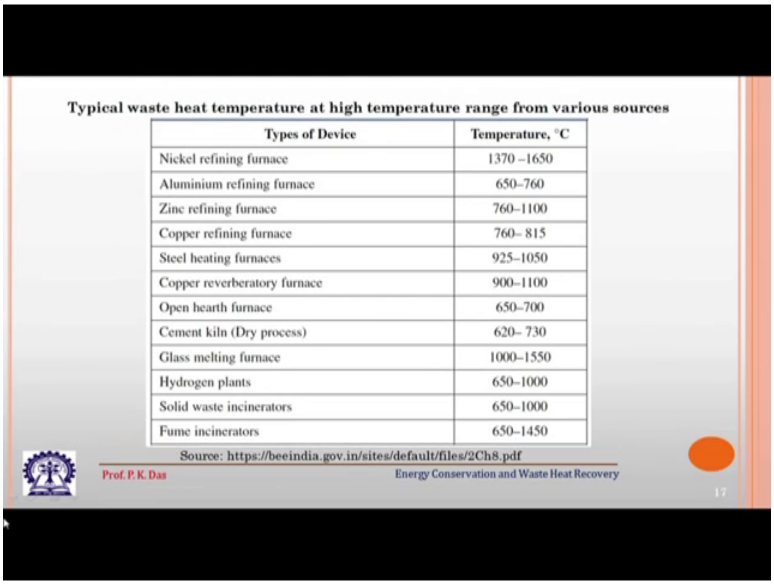

Typical waste heat temperature at high temperature range from various sources

Types of Device	Temperature, °C
Nickel refining furnace	1370 –1650
Aluminium refining furnace	650–760
Zinc refining furnace	760–1100
Copper refining furnace	760– 815
Steel heating furnaces	925–1050
Copper reverberatory furnace	900–1100
Open hearth furnace	650–700
Cement kiln (Dry process)	620– 730
Glass melting furnace	1000–1550
Hydrogen plants	650–1000
Solid waste incinerators	650–1000
Fume incinerators	650–1450

Source: https://beeindia.gov.in/sites/default/files/2Ch8.pdf

And next if we go typical waste heat temperature at high temperature range from various sources and there is something common. If you see generally these are from different metal working or metallurgical processes or furnaces cement kiln. So, which is also kind of furnace glass melting furnace, these are the sources from where we get waste heat at high temperature and temperature could be very high like the first one nickel refining furnace its temperature could be as high as 1650 degree Celsius.

So, you see this is good enough for having some sort of a power cycle; this is good enough for generating electricity by using some sort of usual thermal power cycle, like one can easily have some sort of a gas turbine or steam turbine plant using this kind of sources. But again one has to keep it in mind that this is only the temperature amount of heat we are getting or total amount of the exhaust gases must flow rate of exhaust gases that is also important for designing the waste heat recovery system, in this case if we want to design some sort of a thermal power plant out of this waste heat gas. So, the amount of gas which is coming out that is also important.

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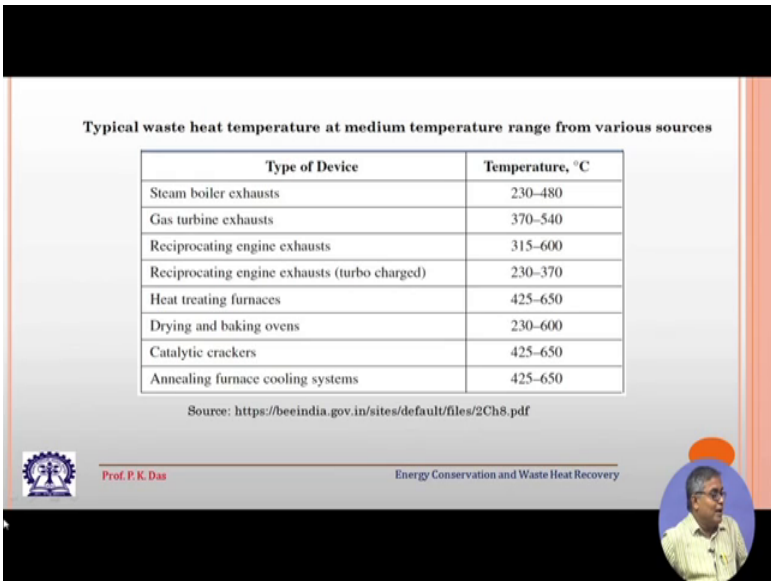

So, probably sometimes these gases are dirty that also you have to keep it in mind, next one that shows typical lowest heat temperature at medium temperature range from various sources. So, here you can see the maximum temperature goes up to 650, if not a conventional Rankin cycle or steam power cycle we can have other kind of Rankin cycle like your organic Rankin cycle or kalina cycle which have vapor power cycles for generating certain amount of power when waste heat is available at this temperature and; obviously, heating that is very much possible utilizing this waste heat.

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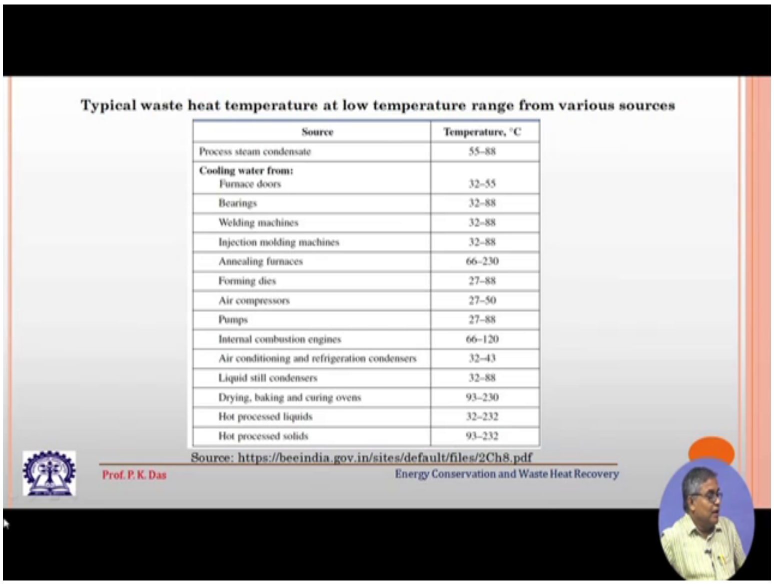

Next if we see there are many examples it could be furnace walls, it could be bearing, it could be palm, it could be air conditioning and refrigeration condensers, process condensate etcetera, but here the highest temperature would be 100, 150, 200 degree Celsius and for many cases it is less than 100 degree Celsius. So, though we will get waste heat, quite if in quite a few cases we will not be able to use the waste heat in and in other cases probably some sort of heating can be done no other profitable usage of waste heat is possible. So, with this I like to end this lecture, again some more aspects and particularly the advantages of using waste heat or using waste heat recovery in your plan that will be explained in the next lecture.

Thank you.