Heat Exchangers: Fundamentals and Design Analysis

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Lecture - 01
Introduction

Hello everyone, welcome to the course Heat Exchangers Fundamental and Design Analysis. I am professor PK Das. I am from the Department of Mechanical Engineering IIT, Kharagpur, I am one of the instructor of this particular course. Today in the first lecture, I will try to give some background of heat exchangers and some aims and goals of this particular course.

The course will be taken jointly by 2 instructor, I am one of them and professor Indranil Ghosh from the Cryogenic Engineering Centre of IIT, Kharagpur will join me after 1 or 2 lectures and in between we will show up some lectures will be taken by me and some lectures will be taken by professor Indranil Ghosh. There will be 3 teaching assistants who will be assisting us, the participants they will form a forum, the in the forum you can raise your queries, you can raise some questions related to the course and those forum will be conducted by our TS. These will help you in understanding certain things which you could cannot be cover which you are unable to pick up from the lecture. They will be some sort of a liaison between the participants and the instructors.

We are also trying that if we can have some sort of interactive classes between the participants, when the participants will be present on the on one side and on the other side the instructors will be taken. The course has been divided more or less 50-50 between 2 instructors, I will start with it and as I have told professor Indranil Ghosh will take over after 1 or 2 lectures.

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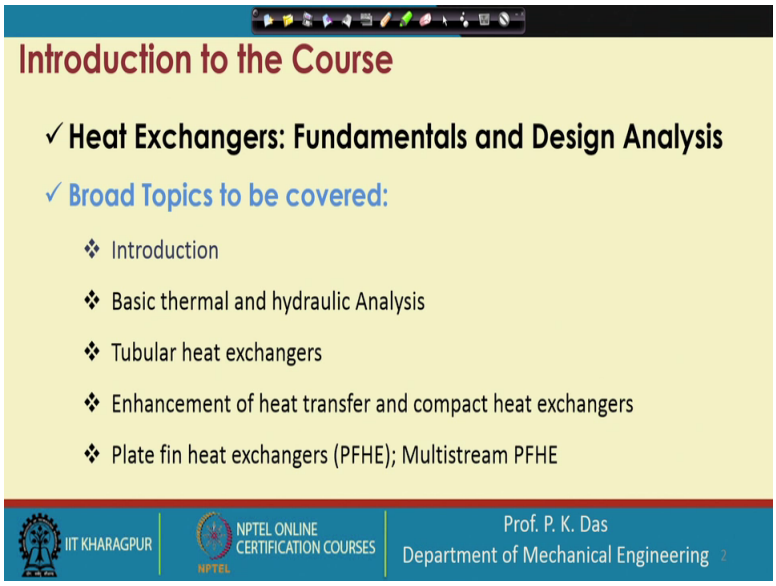

So, we are going to the introduction to the course, the course name as has been already told it is heat exchangers fundamentals and design analysis. So, what we are trying to do that we will first make you familiar with different kind of heat exchangers. We assume that students or participants will be from different background and they might have some basic knowledge of heat exchanger, some might not have a good perception regarding heat exchanger.

So, we will first try to provide that kind of perception or appreciation for heat exchangers. So, after that we would like to so the topics to be covered if we see. So, first is introduction which I have just explained that I we will try to give you some sort of appreciation generate in you some sort of interest regarding heat exchangers, then basic thermal and hydraulic design or analysis rather it is basic thermal and hydraulic analysis.

Heat transfer is the key phenomena which occur in a heat exchanger and it may occur in any mode of heat transfer that is conduction convection and radiation. But we will see that convection dominates, that means in most of the cases convection plays a very key role. So, when convection is there so obviously there is fluid flow involved and we have got many hydraulic issues. So, along with heat transfer we have to have some consideration for the hydraulics of the heat exchanger and in general how the heat transfer and hydraulics is to be considered in a heat exchanger that we will try to make you understand once we give basic introduction to heat exchanger.

Then heat exchangers we will repeat this point time and again that heat exchangers have got vast variety. Probably it is very difficult to name a industry name an industry where we will not find heat exchangers and if heat exchangers are omnipresent in industry and in other field of human activity then we will find that there are large number of varieties and one of the main variety of heat exchanger is tubular heat exchanger, where the main construction geometry is tubular geometry. So, we would like to spend some time on tabular heat exchangers.

Then heat exchanger is an industrial device we want to get best out of it; that means, spending small amount of time, spending small amount of power, spending small amount of space we want to have more capacity from the heat exchanger and as I have told that heat transfer is the key mechanism or key phenomena occurring in a heat exchanger. So, heat transfer should be very effective and we should have heat transfer at a very high rate or enhanced rate in heat exchangers. So, that is why enhancement of heat transfer that becomes very important in the discussion and design of heat exchanger.

So, when we are talking about enhanced heat transfer we have a whole class of heat exchangers which have been made over the years very compact. So, that within a small volume or giving a very small temperature difference we are capable of transferring heat at a very high rate. So, those heat exchangers are called compact heat exchangers they are very important and they are replacing the conventional heat exchanger very rapidly newer applications are coming and newer compact exchangers are being designed. So, we will spend some time on compact heat exchanger.

Then among the compact heat exchanger there is plate fin heat exchanger which is very important because of it is flexibility. I do not want to tell what are the what are the merits of plate fin heat exchanger over, other heat exchanger in general and other compact heat exchanger in particular when we will discuss plate fin heat exchanger we will discuss that. But plate fin heat exchanger is so important that we like to spend some time on plate fin heat exchanger and this is one of the one of the important topics of the course which we are going to offer and then in plate fin heat exchanger there is a capability of taking number of streams. This is one thing I like to spend some time or my colleague will spend some time.

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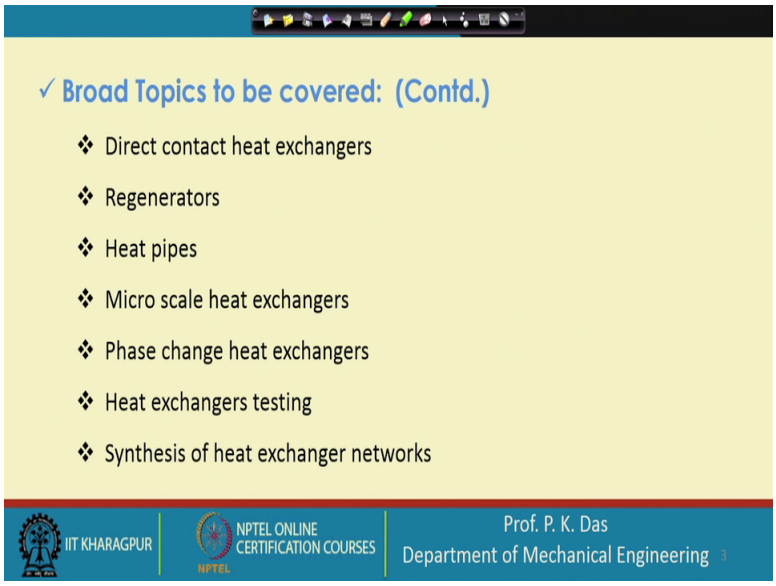

Then direct contact heat exchanger. What is a direct contact heat exchanger? We will discuss what is a heat exchanger and I will give some idea, but it is like this sometimes the fluid streams they can mix together in a heat exchanger; so this is called direct contact heat exchanger. Though direct contact heat exchanger are not many in number, but they again occupy a very key position in the family of heat exchanger and again we would like to discuss direct contact heat exchanger specially because, they are slightly different from indirect contact heat exchangers.

Then regenerators, regenerators are heat exchanger for recovering waste heat or energy conservation. So, I think I have not to tell this tell second word regarding the importance of regenerators. So, regenerators are very important particularly with the concern for energy and concern for environment and we thought that we should spend some time on regenerators. Then heat pipe heat pipe is again kind of it can be considered to be a device for energy conservation, they are special type of heat exchanger and they are very efficient they have got unique use and we will find that in many demand they play a very key role. So, we will try to explain the principle of heat pipes separately.

Micro scale heat exchangers with the advancement of industry particularly with the advancement of electronic industry, the miniaturization that has taken a that has taken the center stage. So, as we go for very high scale of integration of the electronic component, then on a small surface we have to dissipate more amount of heat. But at the same time

the component should be small enough so we should have heat exchangers which are very efficient. But at the same time which are of miniature size this demand is not only there for electronic industry there are other places where miniaturization has shown it is benefit. So, micro scale heat exchangers it needs a special mention and some attention from us we are going to give it.

Then phase change heat exchanger, phase change heat exchanger generally talk about phase change between liquid and vapour and vice versa. So, basically these are evaporators, boilers, condensers etcetera. Their design principle are again slightly different compared to conventional heat exchangers, so we are going to give due importance to this kind of heat exchangers. Then heat exchanger testing we can manufacture a new heat exchanger. So probably following the best design practice we can manufacture a new heat exchanger, but we are not sure whether what we have manufactured according to some specification that will serve the purpose or not.

So, what is needed we need to test the heat exchanger for it is performance that could be one requirement or in the industry we have got already manufactured and installed heat exchanger we are not very sure regarding it is performance, so we need to test it. So, these are the requirements of heat exchanger testing, heat exchanger testing itself is a very elaborate and complex topic.

But within the purview of this course we are trying to touch upon this topic and give some sort of basic idea how heat exchangers are tested. Then in an industry not a single heat exchanger is used heat exchangers are used in numbers very large in numbers, if we consider the petroleum refinery there will be very large number of heat exchangers and these heat exchangers do not operate as an individual unit. The whole plant is to be designed by integrating quote unquote integrating different streams of fluid through heat exchangers and this integration is heat integration or integration from the point of thermal energy.

So, then what we get in a plant a network a network of heat exchanger, how we can synthesize this synthesize this kind of heat exchanger network. So, that that is again a different topic the fundamentals of heat exchanger is needed, but heat exchanger network synthesis needs certain other kind of considerations and that we are going to do spend some time on it. Certain thing we have not mentioned categorically because we have got

limitation of the time and how much one can give in a course. But obviously there are certain thing which were which we are going to cover though it is not appearing in this list, like fouling of heat exchanger is a very important aspect of heat exchanger design analysis maintenance etcetera so that will be covered.

Then some aspects of the mechanical design that will be covered when we are telling regarding the other aspects of heat exchanger design or heat exchanger analysis those separately mechanical design we will not be taken into consideration.

Then equally important are the manufacturing techniques of heat exchanger that itself can create another course, but obviously when unique features are there something we have to tell regarding the uniqueness of the manufacturing of heat exchanger we are going to mention it. So, this is more or less is the course structure and we will go in the sequence it has been mentioned there will be numerical examples etcetera equations and obviously there will be description for different heat exchanger.

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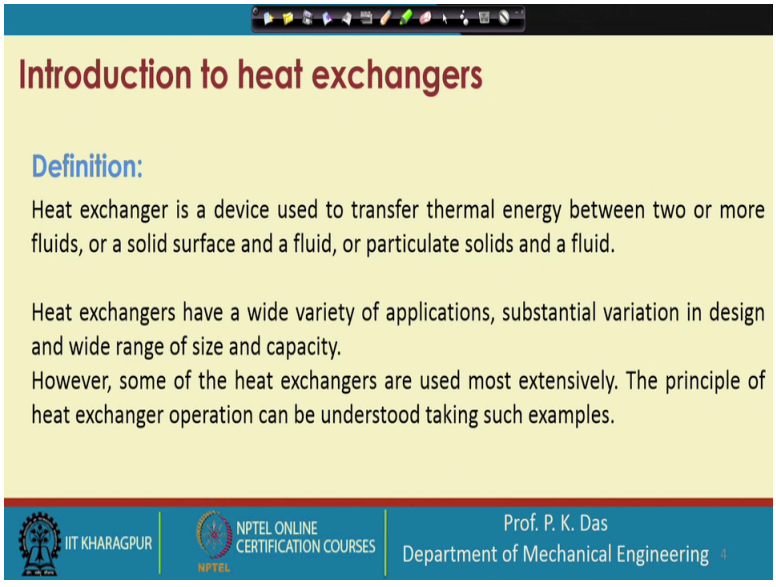

Now, once we have got some idea what we are going to do in this particular course, let us have some definition of heat exchanger. This definition I have picked up from the book of RK Shah and Sekulic whose reference has been given for this particular course. So, the definition goes like this; heat exchanger is a device used to transfer thermal energy between 2 or more fluids or is solid surface and a fluid or particulate solids and the fluid.

So, when we are giving definition we like to be bit generalized I have given a general definition, but after that we try to create the impression; so that we can have a proper perspective regarding heat exchanger. So, now I like to tell what are the common features and which are so common in heat exchanger according to this particular definition. Heat exchangers have wide variety of application there will be substantial variation in their design, heat exchanger could be very small heat exchanger could be gigantic in size. Some of the heat exchangers are used most commonly most comprehensively it is used why some of the heat exchanger are not that common.

So, principle of heat exchanger operation we like to explain at the very beginning of the course taking some common heat exchangers. So, let us see what is the principle of operation of heat exchanger many of you may be aware of the principle of operation. But for the benefit of others and for the sake of completeness please bear with me let us take the most basic construction of heat exchanger and try to understand how does a heat exchanger operates.

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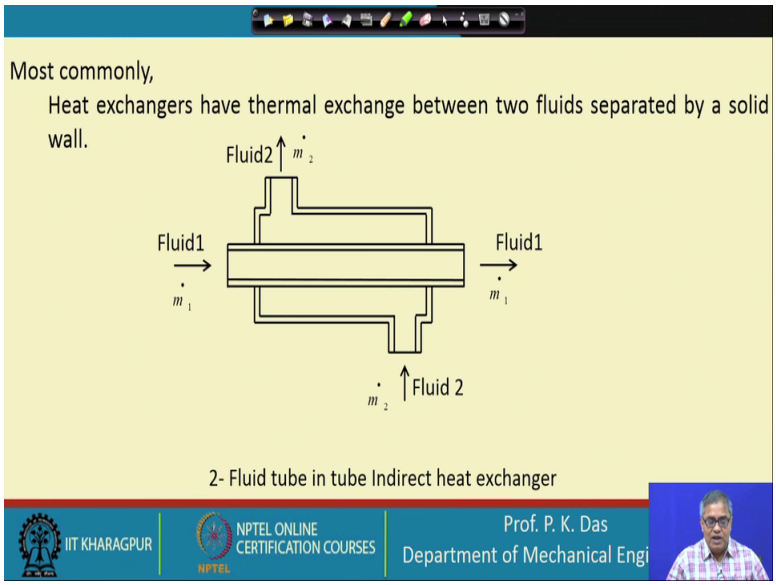

Most commonly heat exchanger have thermal exchange between 2 fluids, though we have given a general description of heat exchanger definition of heat exchanger that it can be heat exchanged between number of fluids or there could be heat exchange between a fluid and the solid. But most of the heat exchanger will have only 2 fluids and probably we are having probably we are having the most basic most basic construction

of heat exchanger shown in this particular slide which is called 2 fluid tube in tube indirect heat exchanger some terminologies are to be explained, so let us give some time.

So, let us say there are let us let us appreciate that there are 2 fluid, the one fluid that is fluid 1 and it is mass flow rate is M dot 1 that is entering the central tube and then it is going out there is no change in mass flow rate the same fluid is coming out. Then fluid 2 which has got a mass flow rate 2, so this is entering here and it is occupying in some sort of occupying some sort of annular cell surrounding the first tube and then it goes out. Now, if there is a temperature difference between these 2 fluids then there will be exchange of thermal energy, the temperature difference will act as the potential for transport of thermal energy and there will be exchange of thermal energy or in common word there will be heat transfer.

So, let us say the fluid 1 is hot fluid the inlet temperature here the temperature at which the fluid 1 is entering that is higher compared to the temperature of fluid 2 at the entry point. Then what we will find that fluid 1 it is coming with a higher temperature it is temperature will fall down when it goes out, fluid 2 it is coming at a lower comparatively lower temperature it is temperature will go up as it passes through this annular cell and goes out. So, this is the basic principle of heat transfer or rather basic principle of operation in a heat exchanger 2 fluids they are exchanging heat due to temperature difference.

But they are not coming into contact with each other, so that is why it is called indirect heat exchanger. So, there is a solid wall this central tube wall of the central tube is the solid wall which separates these 2 fluids. So, that is why it is and it is an indirect type heat exchanger and most of the heat exchangers we will find that they are indirect type. Most of the heat exchanger there may be different geometry different construction they are 2 fluid heat exchanger, but indirect type heat exchanger is not the not the sole kind of heat exchanger they are could be other type so let us see.

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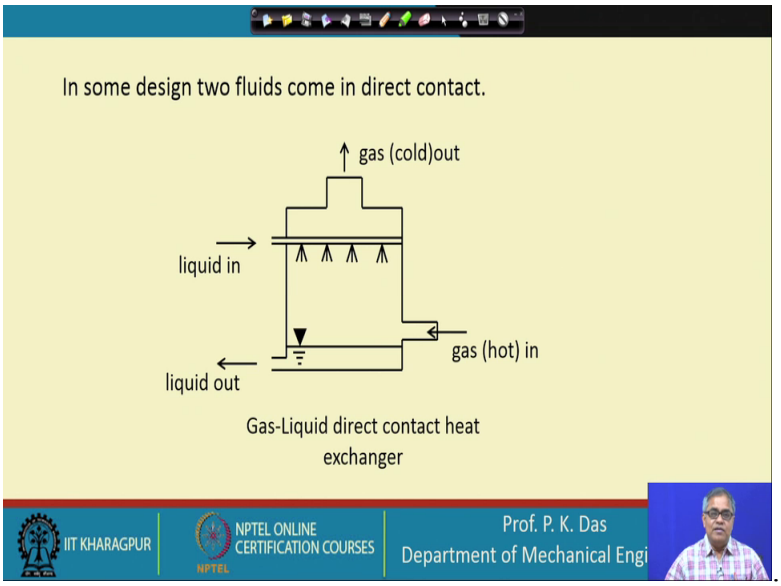

In this heat exchanger we have got 2 fluid 1 is gas let us say we want to cool a hot gas. So, the hot gas that is in and then a liquid that is at a lower temperature let us say water, so we are sprinkling water in the hot gas so the hot gas can be cooled here. Of course, there could be 2 mechanism of cooling first thing due to the temperature difference between the hot gas and the cold liquid droplet there could be sensible heat transfer and the liquid may evaporate all show while evaporating they may take this liquid may take certain amount of latent heat from the hot gas. So, that ultimately the gas temperature will come down.

But please mind that 2 fluid streams that is liquid and gas they are intermingling with each other, they are not separated by another solid surface. So, that is why this kind of heat exchangers are called direct contact heat exchanger. So, this is one main variety of heat exchanger though this type of heat exchangers are not as many as we can find the as we can find very large number of indirect contact heat exchanger.

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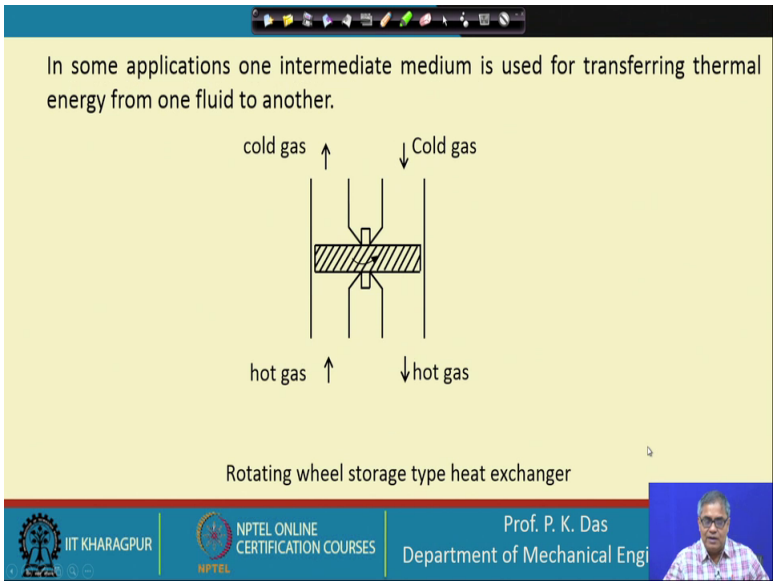

Let us move to the third kind which is again a prime variety of heat exchanger, in some application one intermediate museum is used for transferring energy from one fluid to another fluid. What does it mean it means that there will be an intermediate medium one fluid will transfer heat to the intermediate medium for temporarily thermal energy will get stored in that intermediate medium, so this is basically a storage type heat exchanger. So, from one fluid thermal energy or heat will get stored in some intermediate medium, this intermediate medium could be a solid could be a circulating fluid and again the solid could be stationary or moving solid depending upon design and a way again we can have some sort of a phase change medium for the inter medium as the intermediate medium or for some substance which is changing it is phase as the intermediate medium.

So, as I have told that the one fluid stream let us say hot fluid stream will transfer heat to be intermediate medium, intermediate medium temporarily we will store it and it will then transfer heat to the cold fluid stream. So, here I have shown schematically one arrangement which is very important very common and we will elaborate, we will discuss more elaborately this particular type of heat exchanger in later stage of this particular course.

So, here you see there is a rotating wheel let us say we are thinking of a power plant where hot product of combustion is to be sent to the atmosphere. So, what we are doing that hot product of combustion we are sending through this passage, but in between there

is a wheel which is rotating at a slow speed. So, as the wheel is rotating and the gas is passing through it the portion of the wheel which is in contact with the hot gas that will get heated up and then this wheel is coming to the other side through which we are making the ambient air to pass.

So, the ambient air will get heated up when it is passing through the through the hot wheel and then that hot air will be used for combustion. Obviously, this will save fuel this will help us recovering certain amount of heat which we could have dumped or wasted which we could have dumped to the atmosphere or wasted. So, that is the advantage and obviously it gives us protection of the environment, so this is called a rotating wheel type storage heat exchanger so this is another variation. Well the classification of heat exchanger and some may be some minor kind of variation we will discuss later but let us proceed.

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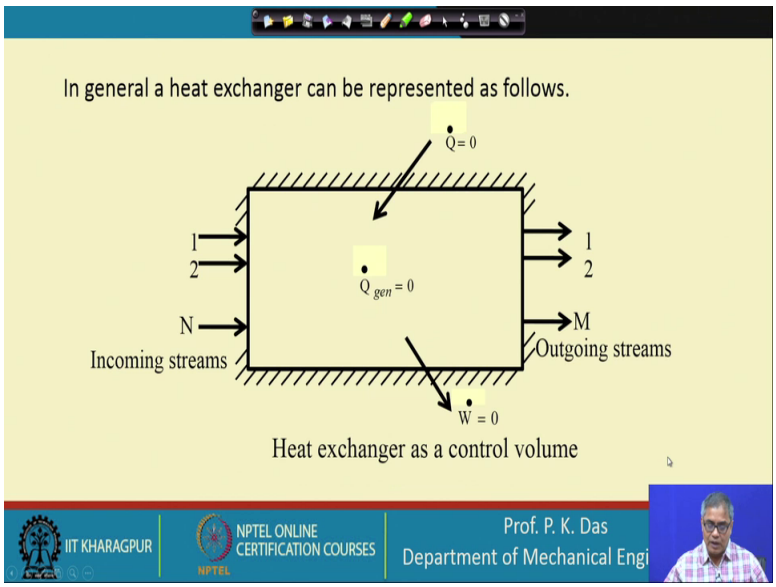

In general heat exchanger can be represented as a control volume. So, in the control volume number of streams are entering let us say N number of streams are entering and M number of streams are going out and we can 3 we can see 3 quantities which we have put 0 Q dot is equal to 0. That means, the envelope of the heat exchanger that is insulated w dot is equal to 0; that means, within the heat exchanger there is no work done or no work is being transferred from the outside and Q dot z is equal to 0, so heat generation

within the heat exchanger is 0. So, this is a very common type of representation of the heat exchanger.

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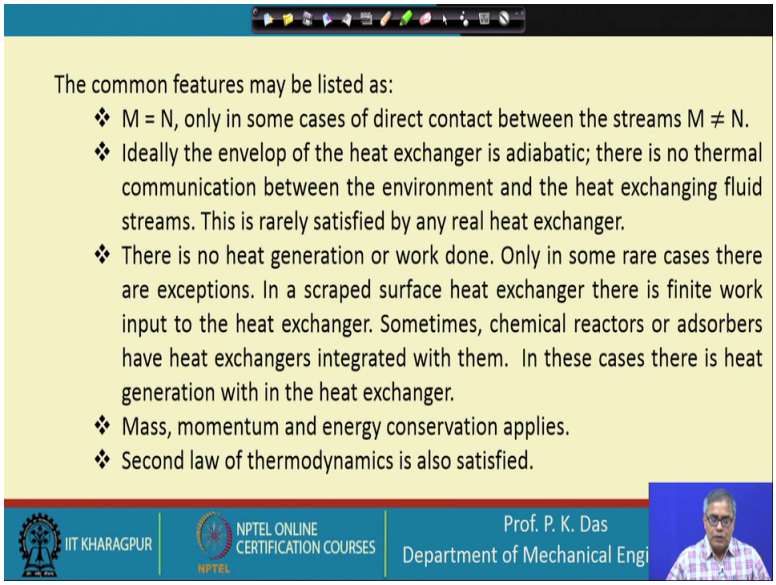

But there can be some exception M is equal to N only in some cases of direct contact M is equal to N in most of the cases only in some cases of direct contact between these streams M is not equal to N, otherwise heat exchangers are indirect contact and M is equal to N. Ideally the envelope of the heat exchanger should be insulated, but in most of the cases it is not in practical heat exchanger real heat exchanger it is not.

There is no heat generation within the heat exchanger, but if there is absorption or if there is some sort of a reaction then there is heat generation and again some heat exchanger very few heat exchanger there are work input because, there is some sort of agitation created in the fluid mass momentum and energy balance applies and obviously heat exchanger analysis or heat exchanger should the principle of heat exchanger obeys second law of thermodynamics.

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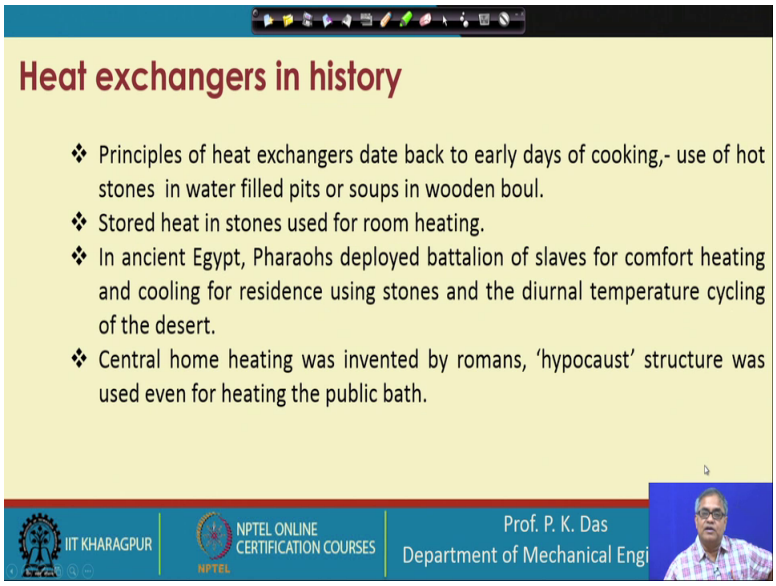

Now, very quickly let me take up the heat exchangers in history, the principle of heat exchangers date back from when people started or learnt the art of cooking. So, you see initially the cooking pots particularly which are made earthen pot and metallic pot those were not there, for cooking what they used to do they used to use the principle of storage heat transfer like stones were heated and then those stones were placed in water. So, that the water will be heated and or boiling and then that could be used for cooking. So, that was the principle used by the cooking for cooking meat.

The similar kind of storage heat in was used for room heating in cold countries, in Egypt pharaohs they deployed large number of people. So, they are dwelling will be covered by stone which will be cooled during night and early in the morning those cold stone will be placed in the room and again during night those stones will be taken back to the desert to get cooled.

Then in ancient room we can see central home heating and that was by heating the floor panel of the door sorry of the room, where hot gas used to be sent through a chamber below the home. So, we can see in the next slide how it is.

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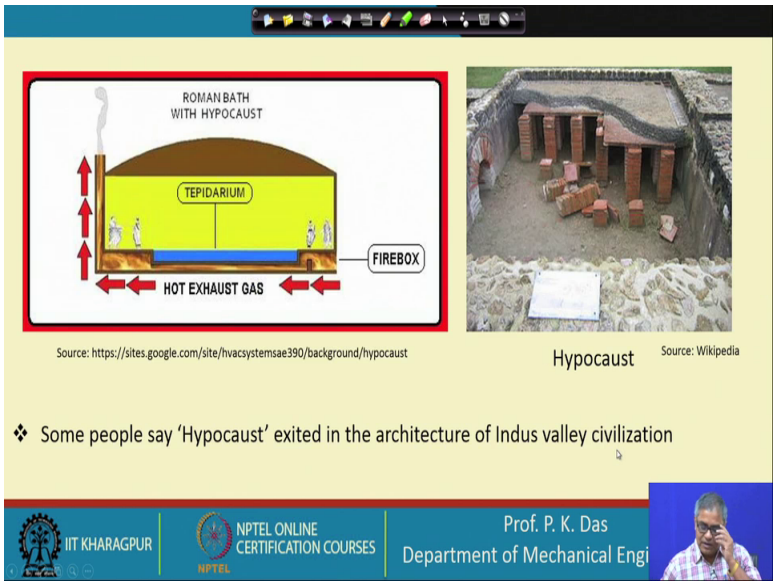

So, this is a bath, roman bath public bath which was very common in Rome yeah and you see below these there is this is firebox here heat is generated. So, the hot gas that passes through this and at the top there is liquid. So, you see this is heat transfer between 2 liquids and this is the early concept of heat exchanger.

The physical construction was something like this here you can see below this there are this stone structure through which the hot product of combustion will pass and at the top of this there could be a room or there could be a bath which will be kept heated and this structure is called hypocaust and this acts architecture some people say it is also common in your Indus valley say civilisation, but it has not been authenticated.

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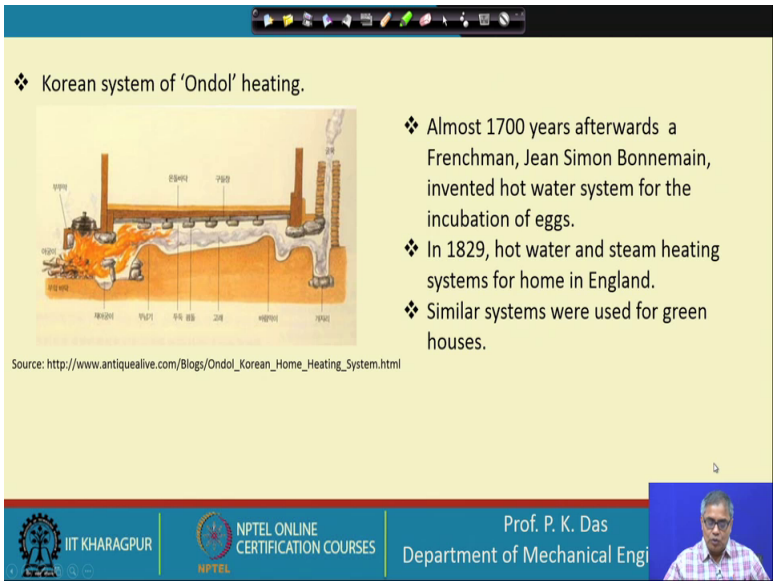

While the roman structure roman ancient architecture this is invented in sorry this is discovered in many number of places. So, you can see the repetition of this concept even in Korea and in Korea this particular concept is still used in a different form by electrical heating for your room air conditioning.

So, you can see this is the earliest use of heat exchanger what one can say. Next, we will go for the different classification of heat exchangers. But in the this lecture I have tried to give you some idea regarding the heat exchanger and what could be the vastness of heat exchanger and how even ancient people knew the use of heat exchanger the way we know it, though the design construction was slightly different.

Thank you and if you have got any query please interact with the TS in the forum.