Chemical Process Utilities

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Lecture – 1
Introduction to Chemical Process Utilities

Welcome to the chemical process utilities. Now at the outset, we will study utility. So, we will go for a brief introduction about the process utilities and how they can be beneficial for the chemical process industries. In this particular lecture, we are going to cover the introductory aspect of chemical process utilities, and then we will discuss the various verticals of utilities like air, water, electricity, heating units etc.

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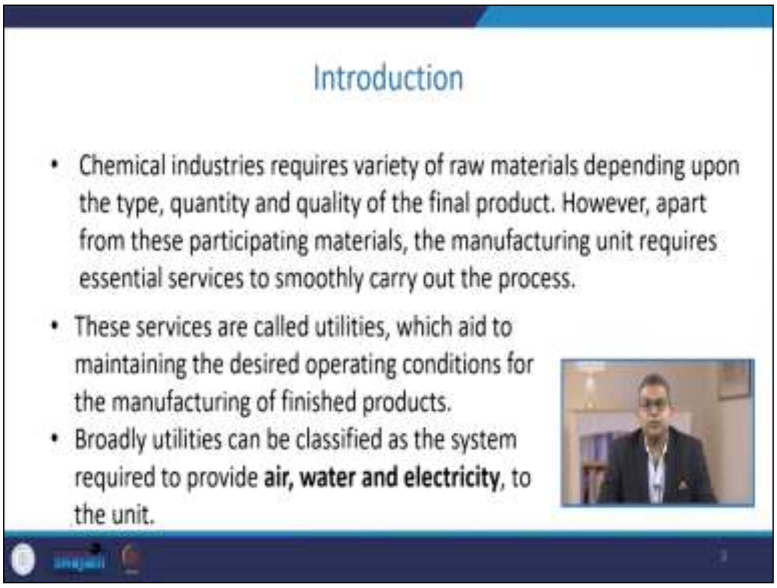

Before we go into the introductory aspect of utilities, let us look at how these utilities are extremely important for any kind of chemical process. Especially when we go for any chemical process, the crux of the chemical process is the conversion of raw material into a useful product, but it is not an easy job. Now suppose if I have one particular raw material, and I am intended to have one product called A. We require a process that may comprise a reactor and other allied things, along with some energy input. Sometimes you may require some catalytic inputs, and all these things are usually governed by chemical kinetics and thermodynamics.

When we look to convert raw material into any useful product, it depends upon various parameters like the types, quantity, and quality of the final product. These parameters are concerned with the consumer's perspective, but from an engineer's perspective one should always look for energy conservation, sustainability, viability, and economic feasibility.

So, all these things are an integral part of this utility aspect. How can we achieve this particular conversion from various raw materials to a useful product? Apart from energy, you may require certain other allied things. These allied things may cover air and water. For example, water may be required to dilute the ingredients. Sometimes you need to have the power to heat things, and sometimes you may require the steam etc.

So, all these things are the contributory or subheads of the utility aspects. Now when we talk about the participating material, sometimes the manufacturing units require essential services with respect to all these basic utilities like air, water, electricity, and heating media. In totality, these services are called utilities, usually intended to maintain the desired operating condition for the smooth functioning of any kind of chemical process. So that you can get the finished product as per your requirement, quality, quantity, and consumer desirables. So, broadly we can classify all these utilities into the different segments like air, water, electricity, etc. So, all these things are the contributory part of the process.

Let us take an example for any kind of typical chemical production industry. The major utilities required to carry out the process requires the boiler where you are generating the steam. When we are talking about steam, it may be either prepared, superheated, or saturated. It requires certain pressure to carry out the boiler operations. It requires a source of water supply, heating etc. We cannot overlook the importance of the source of fuel for heating (or cooling), which may be thermal, electrical, renewable, or fossil fuel. We will discuss all these things in due course of time.

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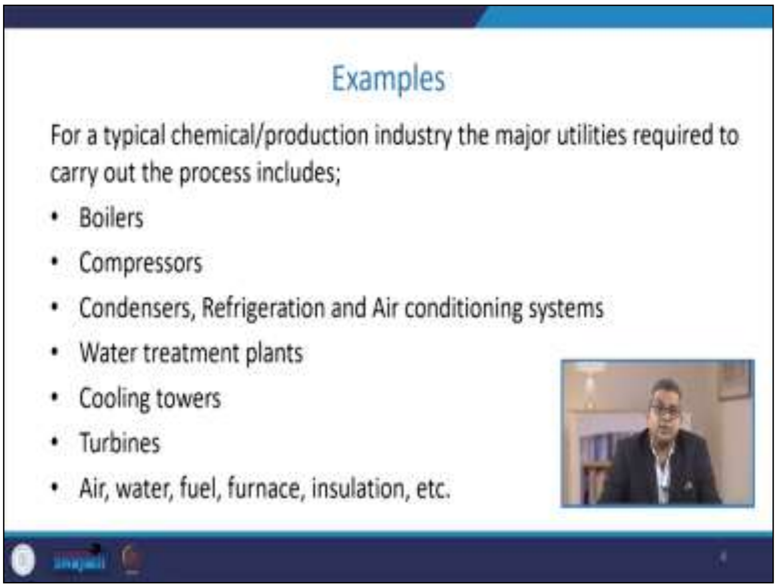

Similarly, when we talk about compressors, the air is an essential utility in chemical industries. It may be used for the pneumatic operation, separation process, among other purposes. Then condensing units, refrigeration, air conditioning systems are all integral parts.

Sometimes you need to carry out any process at a specified temperature because, ultimately, the reaction kinetics dictates. Reaction kinetics or thermodynamics usually offer a very small spectrum of temperature zone. If you change the temperature of any process, the results may be catastrophic. Sometimes you need to store things at a specified temperature. So, you may require a refrigeration system.

Similarly, utilities also include water treatment plants. Other examples include cooling towers, turbines, air, water, fuel, furnace insulation etc. We can list all these utilities in a number of ways because they are usually an integral part of every chemical process.

So, let us start the introduction. If you go to see any industrial operation, you will find that utilities are generally located outside the production line. For example, the industril boilers can be centralized or some discrete type boilers system. But they are not within the periphery of the area in question.

Utilities work similar to the internal organs of the body, without which no work or no production or system can be carried out. It not only helps to maintain the operational conditions like temperature, pressure, flow rate, concentration etc., but also helps to generate the profit for the specific process plant.

Now, as I told you these utilities contribute significantly with respect to the cost of the product because if you go for the superheated steam or if you go for steam or high-pressure steam or if you go for, say, heating or cooling media, then also every heating operation every cooling operation they require a substantial quantity of resources with respect to the monetary aspect.

So, when you pump money, you definitely have to see that they are also contributing to the plant's profit, which is why the viability of energy efficiency all these things you need to look into.

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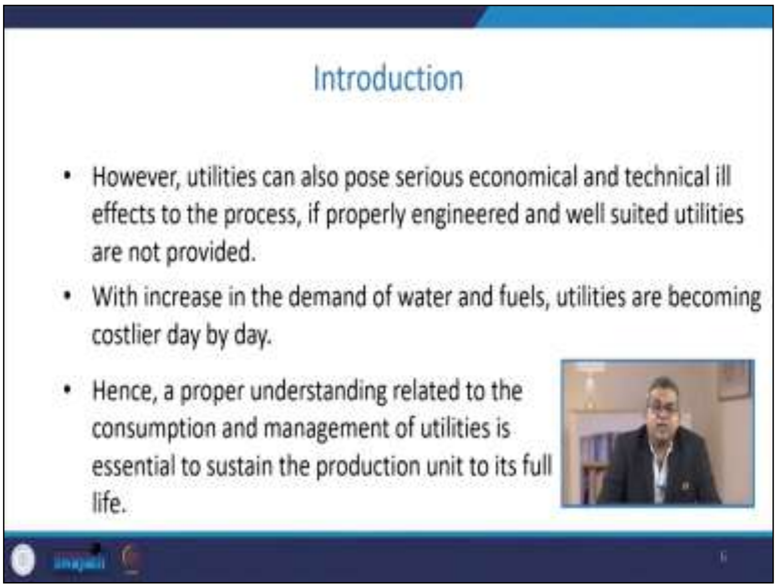

Now, these utilities can also pose a serious economic and technical constraint to the process. If the boiler fails, it not only puts an economic burden on the industry but also you may not achieve the desired result, and obviously, there are some attributed hazards within it. So, you need to have these things properly engineered you have to be acquainted with the well-suited utilities, and you have to be very careful while designing all those utility items.

Let us take an example that you may require a high temperature in various catalytic operations. There are only two ways to obtain high temperature; either you go for the electrical approach or the boiler approach, and usually, the chemical kinetics suggests a very narrow range of temperature. In that case, you have to be very specific you have to be very properly designed.

And if you go beyond that particular temperature range may be on the lower or higher side; in both cases, the product or efficiency of the reaction may not be up to the mark.

You may end up with a lower profitability aspect. With the increase in the demand of water and fuel, it is obviously quite easy to see because we are in the era of the industrial revolution modified industries revolution.

The choice, demands, and needs of people are changing. With an increase in demand for the product, the demand for utilities is also increasing. With limited suplly of utilities like water and fuel, the challenge to meet out all those requirements is very difficult. This increases the cost towards the utilities. So, it gives again a more and more impetus towards them the properly engineered properly designed system.

Therefore, a proper understanding related to the consumption related to the management of utility is essential to sustain the production unit to its complete life. Now recall sustainability viability feasibility all these are the budge words related to the utility.

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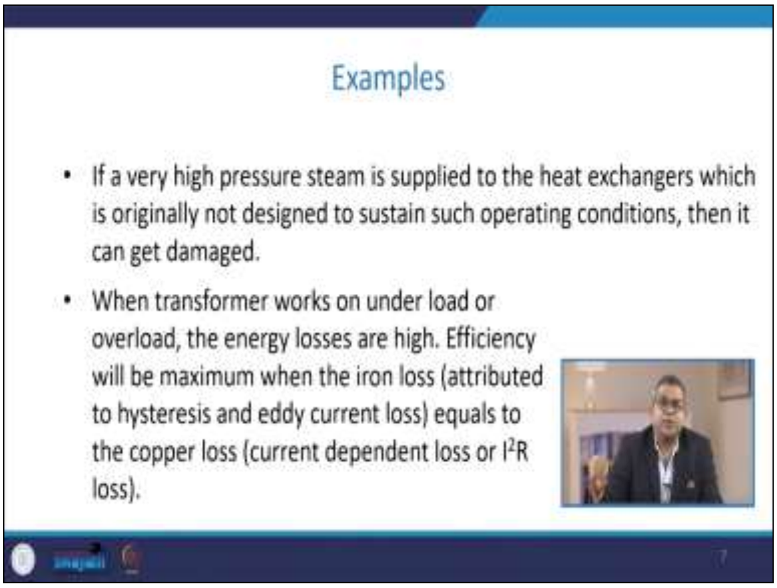

Let us take one example if we produce very high-pressure steam to supply on a heat exchanger that was originally not designed to sustain such operating conditions, and it can get damaged. So, the engineering perspective definitely comes into the picture. Similarly, if all these things are properly engineered, what will happen if you achieve a high temperature with respect to your high-pressure steam?

Your heat exchanger is well equipped with all these kinds of sustainable effects. Then what will happen to the condensed steam? See, whenever you are producing the steam, you require some water conditioning like demineralization, deionization etc. Again it costs more. Then you require certain another purification aspect. So, the condensed steam or condensed water you cannot afford to let go. So, all these things with the engineering perspective you need to keep in your mind.

In another example, the energy losses are very high when a transformer works on either underload or overload. The efficiency will be maximum when iron losses (attributed to hysteresis and eddy current) equal the copper loss (a current dependent or I^2R loss).

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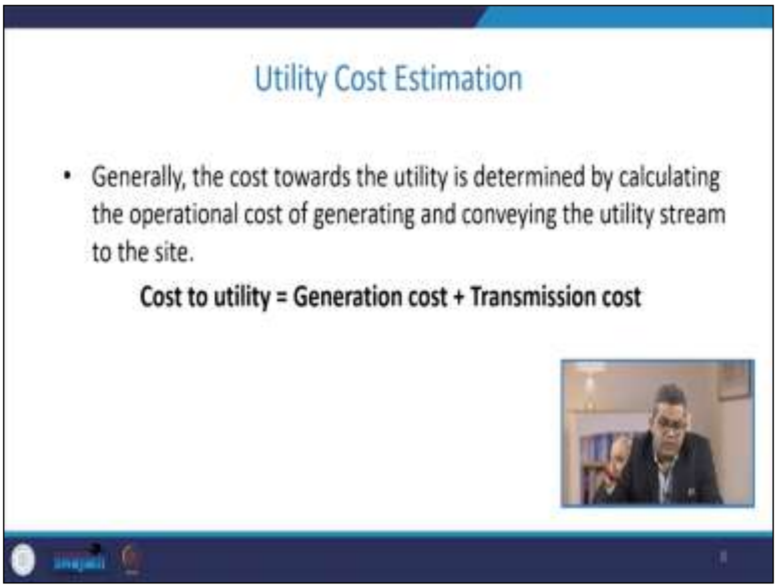

Sometimes people are interested that how to estimate the cost of utility? It is a very primitive formula that the cost towards the utility is usually determined by calculating the operational cost of generation and conveying the utility stream to the other side. So, simple mathematical formula is that cost to utility is equal to the generation cost plus transmission cost.

Cost to utility = Generation cost + Transmission cost

Now here there are so many verticals which we will discuss in due course of time or you can say various parameters which we will discuss in due course of time like what is the generation cost there see we all know that we cannot make a system hundred percent perfect. So, in that case the generation cost is again on the higher side.

There are certain transmission losses. Maybe if you talk about electricity, then there are certain losses and we are very much aware of the plant load factor PLF. Say suppose if it is 50% then 50% of electricity is losing to the transmission. So, during the engine ring of all these utility items we need to look into small things.

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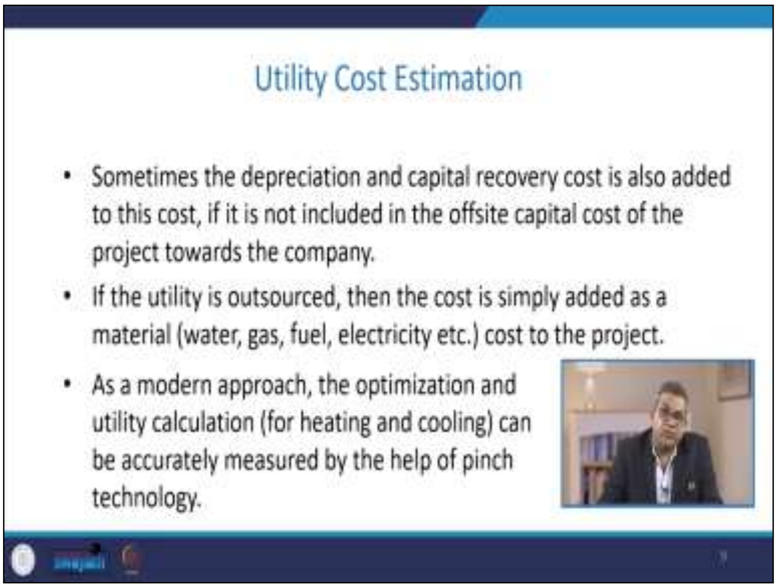

Sometimes we need to look into the depreciation cost and the capital recovery cost. So, all these depreciated costs and the capital recovery cost also added to the major cost factor. If it is not included in the offsite the capital cost of the project towards the company, then your company will definitely run into laws. Now, if the utilities outsource because sometimes some small units may not afford to have the boiler or high-end utility equipment within their campus or within their facilities.

So, if these utilities are outsourced means you are purchasing from somewhere else, then the cost is simply added as a material, water, gas, fuel, electricity etc., in the cost of the project. Now, as a modern approach, the optimization and utility calculation maybe for heating and cooling can be accurately measured with the help of pinch technology. So, as an engineer, you must always be aware of the new technologies new avenues through which you can adopt all those things, and you carry out the analysis to reduce the cost of either transmission or a generation of utility.

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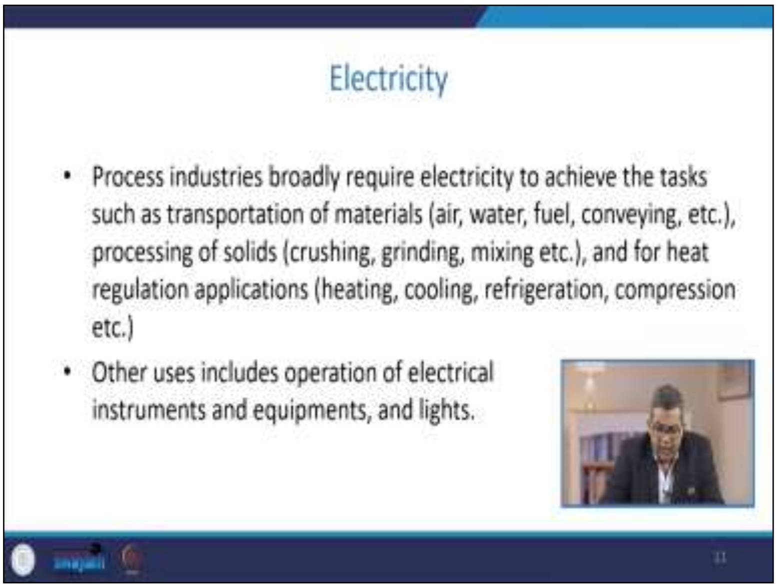

Now again I am taking one example of electricity though we will take this thing later on in detail that the process industry broadly require electricity to achieve the task like sometimes transport transportation of material may be air water fuel conveying system etc pumping etc is one of the best example to run the pump you require the electricity. Processing of solids crushing grinding mixing etc you may require the motors etc and a heat regulation applications like heating cooling refrigeration compression etc.

So other uses may include the operation of electrical instruments, equipment, lights, housekeeping equipment, some cleaning equipments etc. So, electricity poses a very vast role in the utility requirement.

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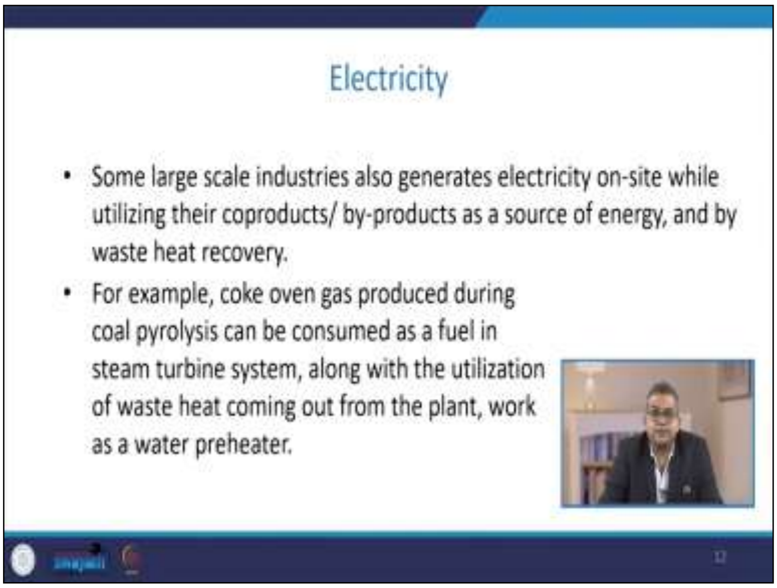

Sometimes large-scale industry also generates electricity on-site while utilizing their co-products as a source of energy and waste heat recovery. One example is that suppose you are performing or your industry the chemical formula suggests that your reaction is exothermic in nature. So, you cannot let go of all the energy or the heat being liberated in due course of time to the atmosphere because it damages economic damage to your industry and poses environmental issues.

So, it is better to check the viability and try to produce the electricity within the cam within the facilities. I am giving you an example like Cochon gas produced during coal pyrolysis. This can be consumed as a fuel in the steam turbine system along with the utilization of waste heat that may come out from the plant and water this works as a water preheater.

If your boiler is working, say at around 150 degrees Celsius under that specified pressure and if your inlet water supply is atmospheric temperature, there definitely may be a chance of thermal shock, and it can damage your boiler. So, it is always advisable to pre-heat the water. So, that the thermal shock or thermal your thermodynamics law can be prevailed.

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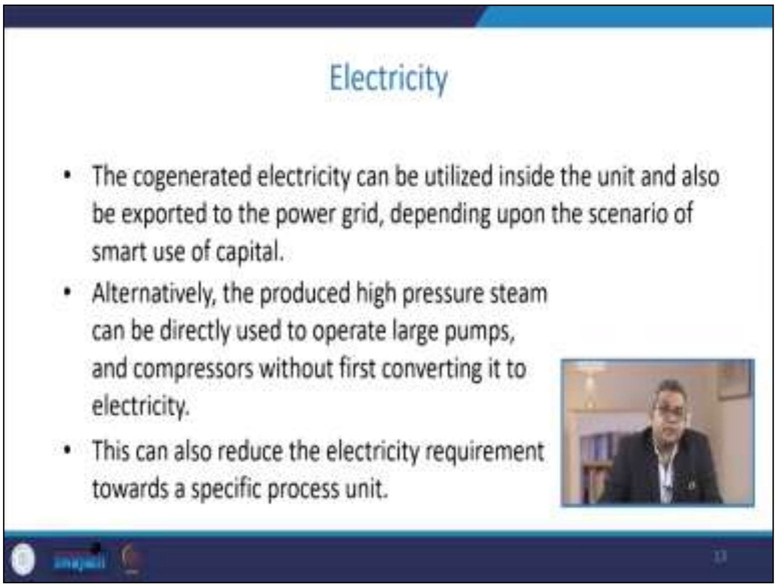

The co-generated electricity in the previous examples can be utilized inside the unit, and also it can be exported to the power distribution units that depend upon the scenario of smart use of capital. Otherwise, the produced high-pressure steam can directly be used to operate a very large pump if your industry is equipped with this or a compressor without first converting it into electricity.

Because once you are converting it into electricity again, you need to put forward some of the capital expenditure. So, this can reduce the electricity required for a specific process unit. Now, this particular aspect gives you an idea that as an engineering perspective, you can think in a broadway.

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Similarly, another example is that for heating application utilization of electricity is in an expensive operation at it is only carried out for specific operations like handling of biological processes drugs maybe sometimes other temperatures sensitive processes applications etc.

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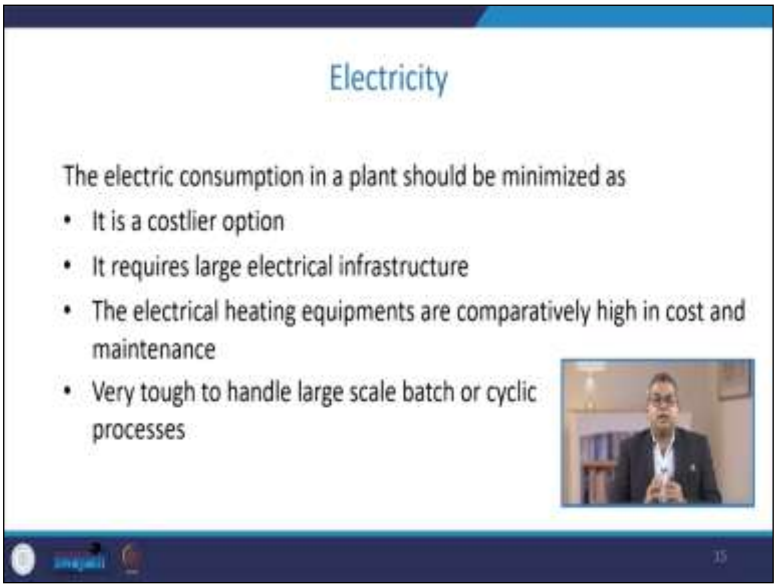

So, the electric consumption in a particular plant can be minimized, keeping the fact that it is a costlier operation. Sometimes it requires a large electrical infrastructure. The electrical heating equipment is comparatively high in cost and maintenance, and sometimes they are very tough to handle the large size scale batch or cyclic processes.

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Another example I would like to put forward is the furnaces and fired heat. Now some industrial units and processes require very high heating, say 250 degrees Celsius or above, which cannot be achieved using the conventional heat source like steam or sometimes some say water etc. Sometimes, if we use direct electrical heating again, it will be a costlier affair.

So, fired heaters are the primary source of high thermal energy. They may be used in industrial heating operations like refining in chemical plants etc. The process stream is usually heated by furnaces either directly or indirectly using a tubular furnace or heat transfer utilities. For this purpose, you require a suitable heat transfer media that may sometimes be diatherm or other synthetic or organic heat transfer media.

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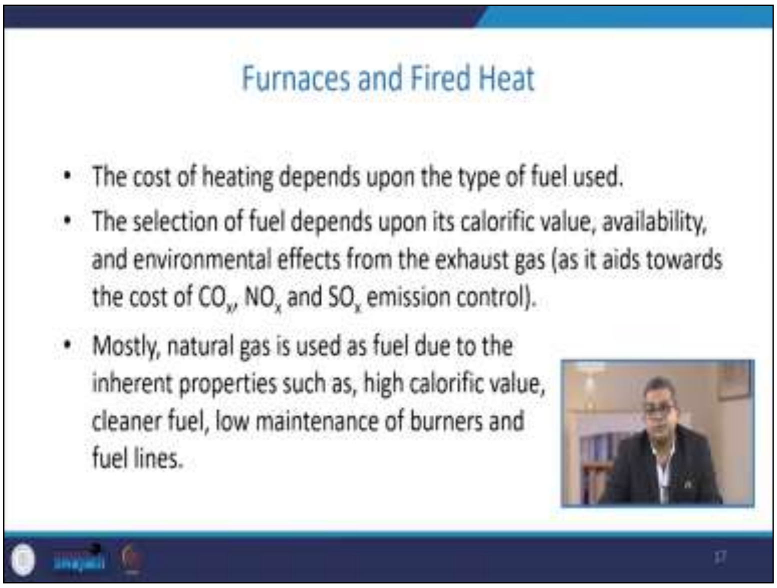

Now the cost of heating again on depends on what type of fuel you are using if you are again the availability choice and the cost of the fuel is again a very debatable issue we will discuss in due course of time but if you are using the costlier fuel then obviously the cost of heating would be on the higher side and ultimately it will be reflected at the cost of your product.

So, the selection of fuel always depends on various factors like calorific value availability. Availability is again an important issue. There are so many parameters like continuous availability, which can be affected by certain political issues. Sometimes the availability depends on the supply chain etc. So, availability is again a very key factor when deciding the selection of fuel. Environmental factors from the exhaust gas because every state they have its own norms apart from the central norms.

So, all these things are contributory factors. Sometimes you may get, say, coal at a very cheaper cost because maybe your plant is situated nearby the mining area, but the environmental constraints put forward, and definitely you need to put certain more effort or certain more capital expenditure towards the to meet out various kind of environmental regulations and again it is a contributory factor to your product.

Natural gas is used as a fuel due to its inherent properties like it has a high calorific value, cleaner fuel, low maintenance of burners etc. So, it is again a very good candidate for the heat transfer aspect.

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Now natural gas burners can also allow the co-firing of a waste gas stream like hydrogen gas low molecular weight organic compounds. Sometimes you may get all these low molecular weight organic compounds as a by-product of a waste product from any industrial facilities air saturated with them. Now the cost of heating in a fired heat heater can be estimated as the cost of heating is equal to the cost of fuel-fired heater duty divided by the furnace efficiency.

In the furnace, the efficiency of the radiative heat transfer is usually 0.6, and there are radiative as well as the convective heat transfer it is typically considered as 0.85.

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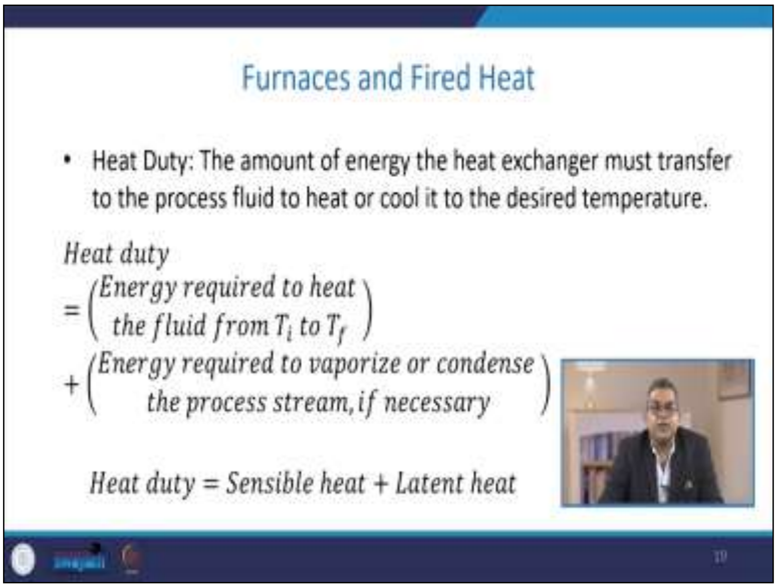

Another buzzword is that heat duty is the amount of energy the heat exchanger must transfer to the process fluid to heat or cool it at the desired temperature. See, every time, we are more concerned about the desired temperature of the process. So, in that case, the heat duty the concept of heat duty again plays a vital role. Now, this heat duty is equal to the energy required to heat the fluid from, say, initial temperature T_i to the final temperature T_f.

$$Heat\ duty = \begin{pmatrix} Energy\ required\ to\ heat \\ the\ fluid\ from\ T_i\ to\ T_f \end{pmatrix} + \begin{pmatrix} Energy\ required\ to\ vaporize\ or\ condense \\ the\ process\ stream,\ if\ necessary \end{pmatrix}$$

$$Heat\ duty = Sensible\ heat + Latent\ heat$$

So, how much energy is required plus the energy required to vaporize or condense the process steam if required or if necessary. In other words, you may say that heat duty is equal to sensible heat plus latent heat.

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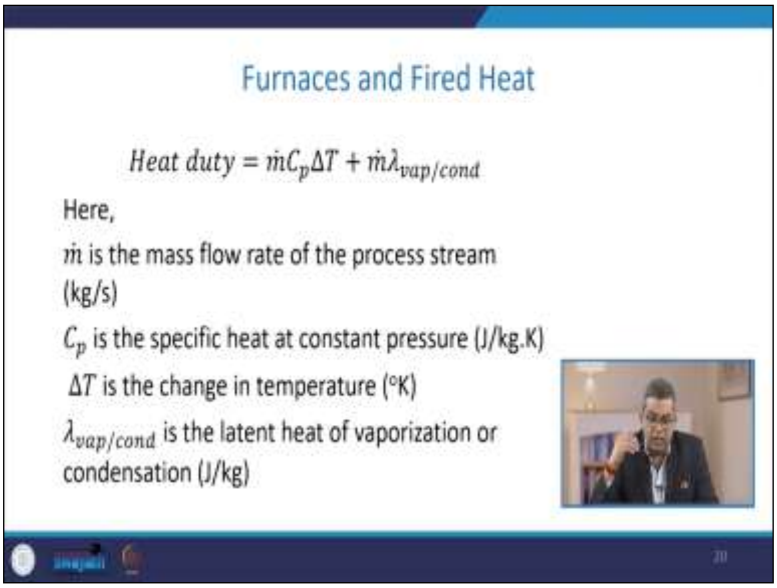

Now, if I need to represent this particular formula mathematically, that is

$$Heat\ duty = \dot{m}C_p\Delta T + \dot{m}\lambda_{vap/cond}$$

Here,

$\dot{m}$ is the mass flow rate of the process stream (kg/s)

C_p is the specific heat at constant pressure (J/kg.K)

ΔT is the change in temperature (^oK)

$\lambda_{vap/cond}$ is the latent heat of vaporization or condensation (J/kg)

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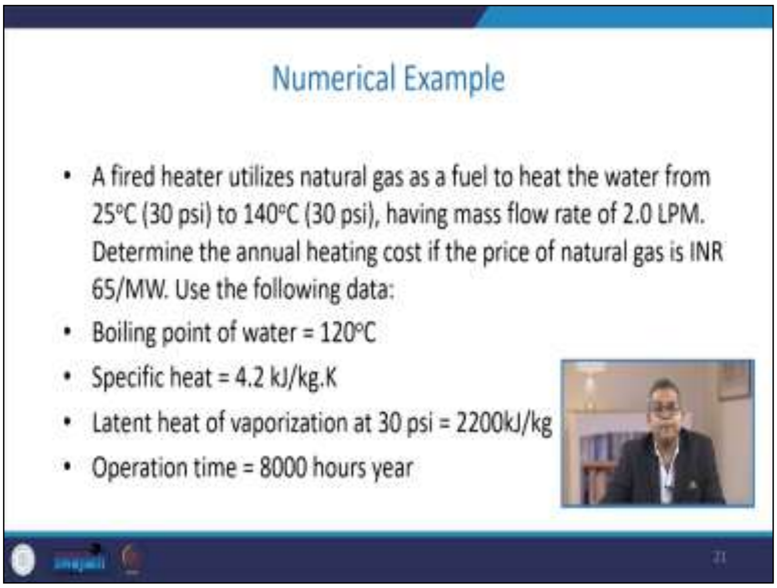

Now let us take one example that is a numerical example. A fired heater usually utilize natural gas as a fuel to heat the water from say 25 degree Celsius which is maintained at 30 psi to 140 degree Celsius at 30 psi. So, pressure is constant it is having the mass flow rate of 2 liters per minute and determining the annual heating cost if the price of natural gas is 65 rupees per megawatt.

So, you may use the following data like the boiling point of water under the given condition is 120 degrees Celsius specific heat is 1.4 kilojoules per kilogram Kelvin and the latent heat of vaporization at the specified pressure is 2200 kilojoule per kilogram and operating time operation time is 8000 hours in a year.

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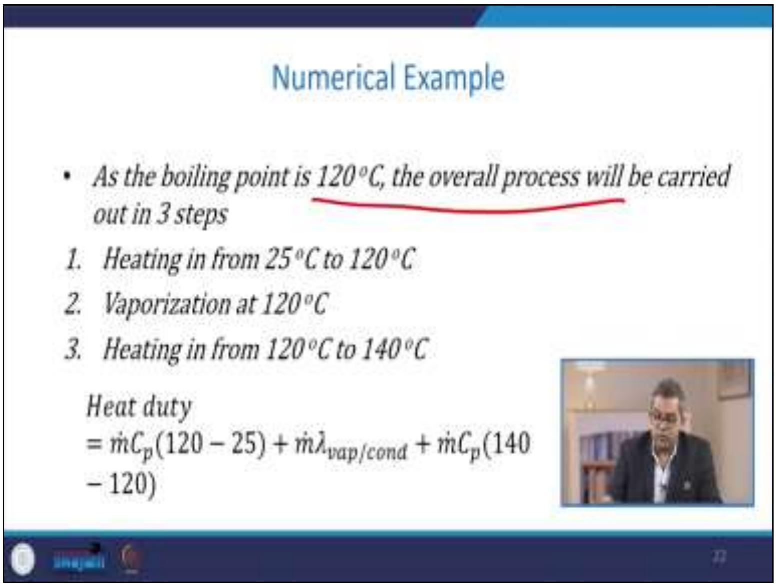

As you notice that the boiling point is 120 degrees Celsius. The overall process can be carried out in three different steps. First is heating from 25 degrees Celsius to 120 degree Celsius then you need to carry out because the temperature is 120 degrees Celsius. So, you need to carry out vaporization at the 120 degrees Celsius at specified pressure that is 30 psi, heating from 120 to 140 degree Celsius. So, you can calculate the heat duty with this particular formula

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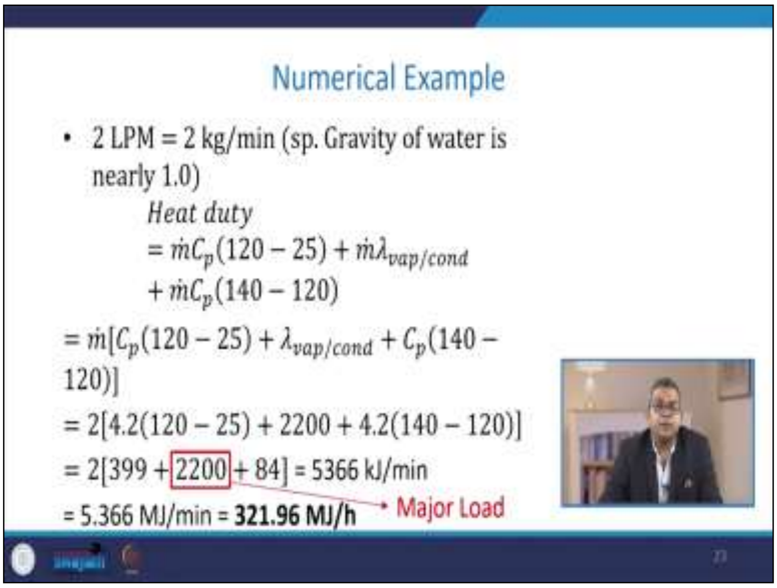

Now 2 liter per minute that is 2 kilogram per minute because the specific gravity of water is nearly one. So, you can calculate the heat duty by calculating this formula. Now see the major load is attributed to 2200. So, it carries out to be 321.96 mega joules per hour.

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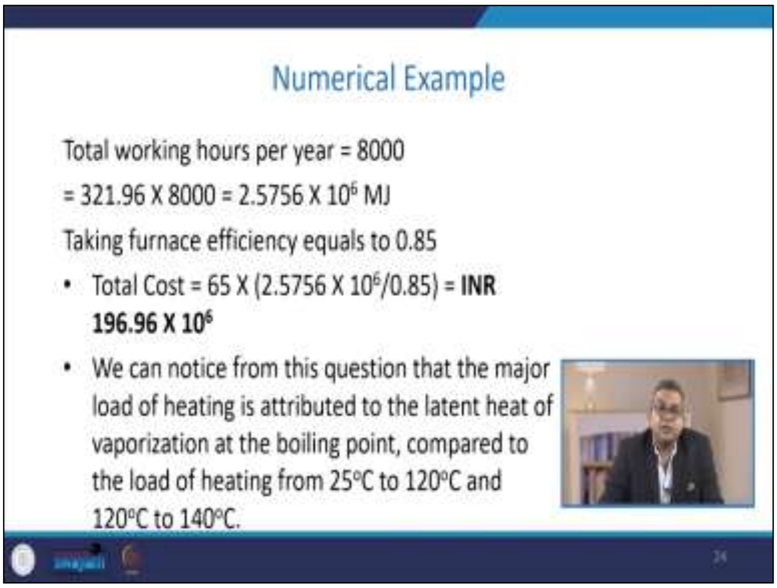

So, we have the total working hour per year of 8000. So, if you multiply by this, we can get this value 2.5756 into 10 to the power 6 megajoule. If we see that the efficiency usually furnace efficiency equal to 0.85, then the total cost would be around 196.96 into 10 to the power 6 rupees. So we can notice from this equation or question that the major load of heating is attributed to the latent heat of vaporization at the boiling point compared to a load of heating from 25 degrees Celsius to 120 degrees Celsius and 120 to 140 degrees Celsius.

$$Heat\ duty = \dot{m}C_p(120 - 25) + \dot{m}\lambda_{vap/cond} + \dot{m}C_p(140 - 120)$$

- 2 LPM = 2 kg/min (sp. Gravity of water is nearly 1.0)

$$Heat\ duty = \dot{m}C_p(120 - 25) + \dot{m}\lambda_{vap/cond} + \dot{m}C_p(140 - 120)$$

$= \dot{m}[C_p(120 - 25) + \lambda_{vap/cond} + C_p(140 - 120)]$

$= 2[4.2(120 - 25) + 2200 + 4.2(140 - 120)]$

$= 2[399 + 2200 + 84]$ = 5366 kJ/min

= 5.366 MJ/min = **321.96 MJ/h**

Total working hours per year = 8000

= 321.96 X 8000 = 2.5756 X 10^6 MJ

Taking furnace efficiency equals to 0.85

- Total Cost = 65 X (2.5756 X 10^6/0.85) = **INR 196.96 X 10^6**

So, as an engineer, you need to find out which step is the main contributor to the load. So, by this way we are coming up to the end of this lecture.

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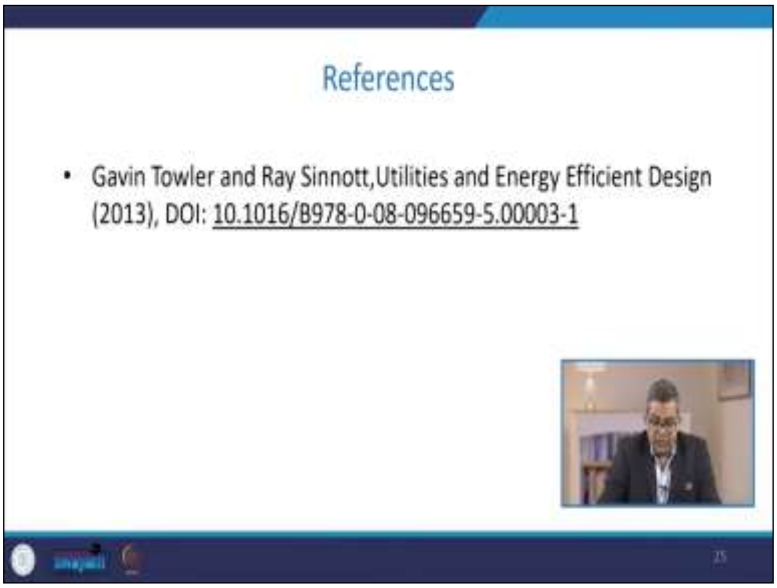

If you need any kind of assistance as a reference material you can you can go through this particular difference and thank you very much.