Plant Design and Economics
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Lecture No-07
Process Utilities

Welcome to lecture 7 of plant design and economics, to run a chemical process industry you need several services or utilities such as water, steam, electricity, compressed air so on and so forth. So in today's class we will be familiar with various process utilities.

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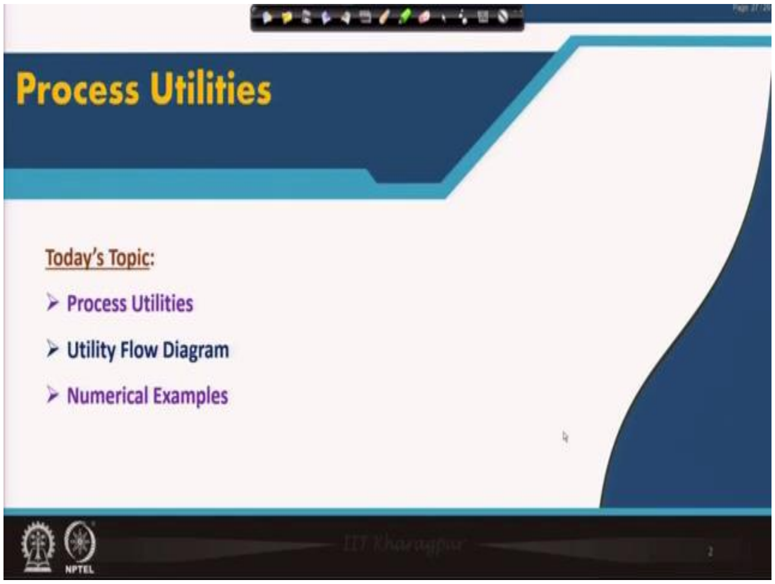

So this will be today's topic, we will talk about various process utilities first, then we will briefly talk about utility flow diagram and we will take one or two numerical examples.

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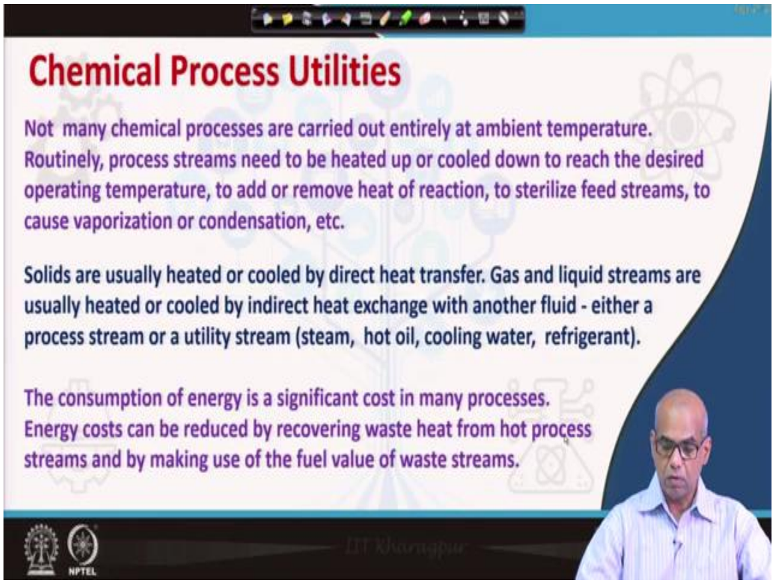

Not many chemical processes are carried out entirely at ambient temperature. They are carried out at various temperatures depending on what temperature will be the optimum temperature for the particular process. So routinely process streams need to be heated up or pulled down to reach the desired operating temperature to add or remove heat of reaction, to sterilize feed streams or to cause vaporization or condensation etcetera.

Solids are usually heated or cooled by direct heat transfer. Gas and liquid streams are usually heated or cooled by indirect heat exchanger with another fluid-either a process steam or utility stream such as steam, hot oil, cooling water, refrigerant etc. The consumption of energy is a significant cost in many processes. Energy cost can be reduced by recovering waste heat from hot process streams and by making use of the fuel value of waste streams.

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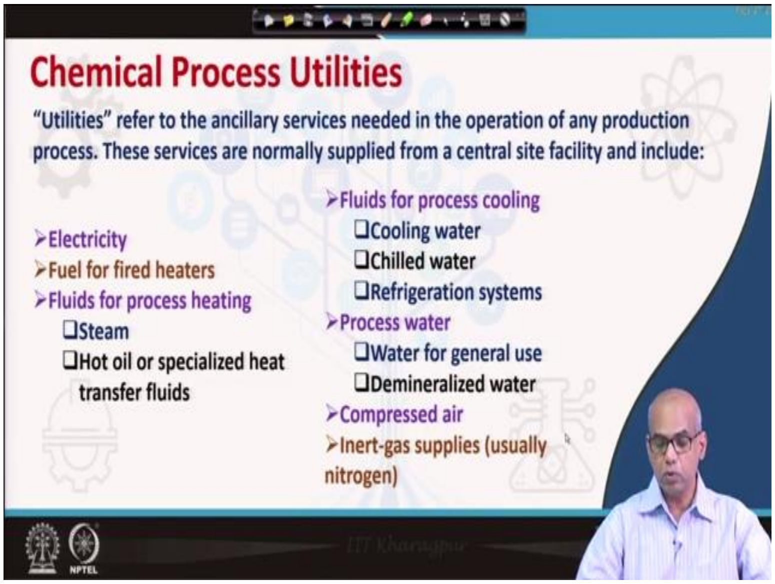

What do you mean by utilities? Utilities refer to the ancillary services needed in the operation of any production process. These services are normally supplied from a central site facility and include electricity, fuel for fired heaters, fluids for process heating such as steam, hot oil or specialized heat transfer fluids, fluids for process cooling such as cooling water, chilled water, refrigeration systems process water: such as water for general use, demineralized water, compressed air, inert-gas supplies which is usually nitrogen in chemical process industry.

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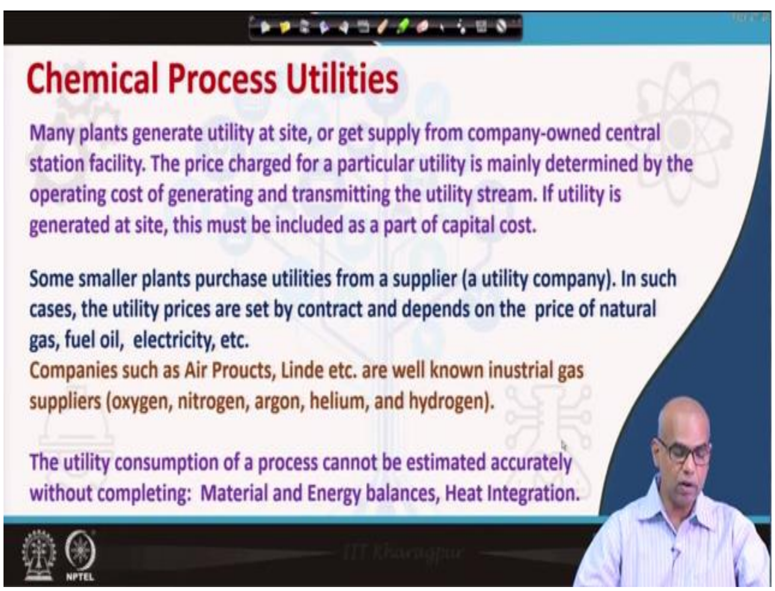

Many plants generate utility at site or get supply from company-owned central station facility. The price charged for a particular utility is mainly determined by the operating cost of generating and transmitting the utility stream. The utility is generated at site, this must be included as part of capital cost. So any utility is generated at site, you must include this as part of capital cost. Some smaller plants purchase utilities from a utility company.

In such cases the utility prices are set by contract between these two companies and generally depend on the price of natural gas, fuel oil, electricity etc. Companies such as Air Products, Linde, are well known companies for supplying industrial gases such as oxygen, nitrogen, argon, helium and hydrogen. The utility consumption of a process cannot be estimated accurately without you complete material balance, energy balance as well as heat integration.

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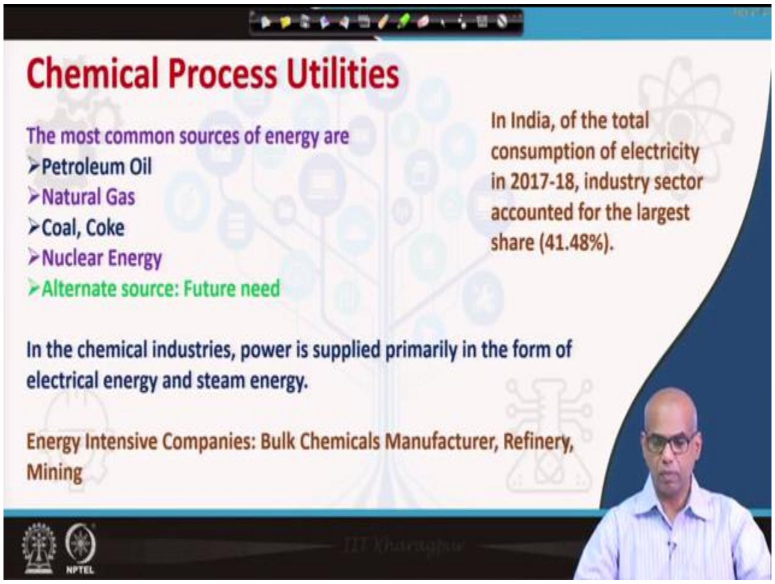

The most common sources of energy are petroleum oil, natural gas, coal, coke, nuclear energy and also alternate sources which we must think to use more and more in future. In the chemical industries, power is supplied primarily in the form of electrical energy and steam energy. Some of the intensive energy intensive companies are Bulk Chemicals Manufacturer, Refineries, Mining etcetera.

In India, of the total consumption of electricity in 2017 and 18, industry sector accounted for the largest share about 42%.

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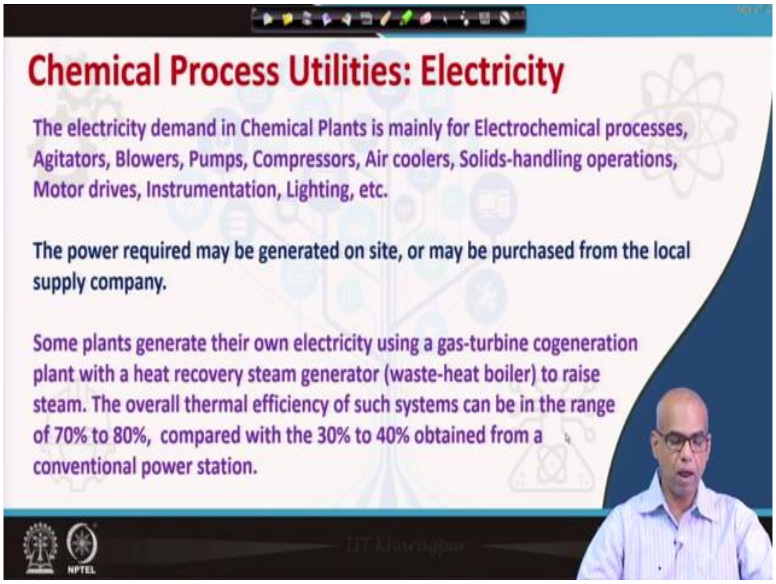

Now, let us talk about individual utilities in some more details. Let us start with electricity. The electricity demand in chemical plants is mainly for electrochemical processes, Agitators, Blowers, Pumps, Compressors, Air coolers, Solids-handling operations, Motor drives, Instrumentation, Lighting etc. The power required may be generated on site or may be purchased from the local supply company.

It depends on which will be more convenient and cost effective. Some plants generate their own electricity using a gas-turbine cogeneration plant with a heat recovery system generator; waste-heat boiler to raise steam. The overall thermal efficiency of such systems can be in the range of 70 to 80% compared with the 30 to 40% obtained from a conventional power station.

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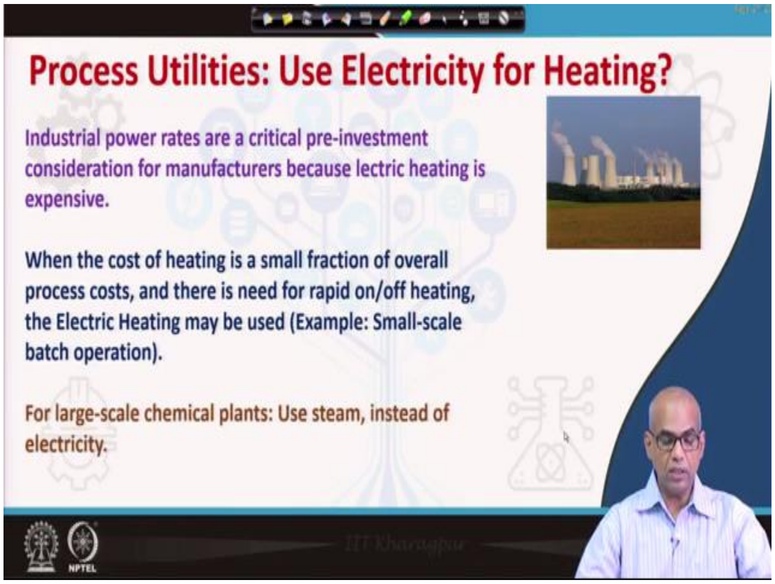

Should we use electricity for heating in industry? Industrial power rates are a critical pre-investment consideration for manufacturers because electric heating is expensive. When the cost of heating is small fraction of overall process costs and there is need for rapid on/off heating, the electric heating may be used. For example, small scale batch operations for large scale chemical plants, better we should use steam instead of electricity for heating.

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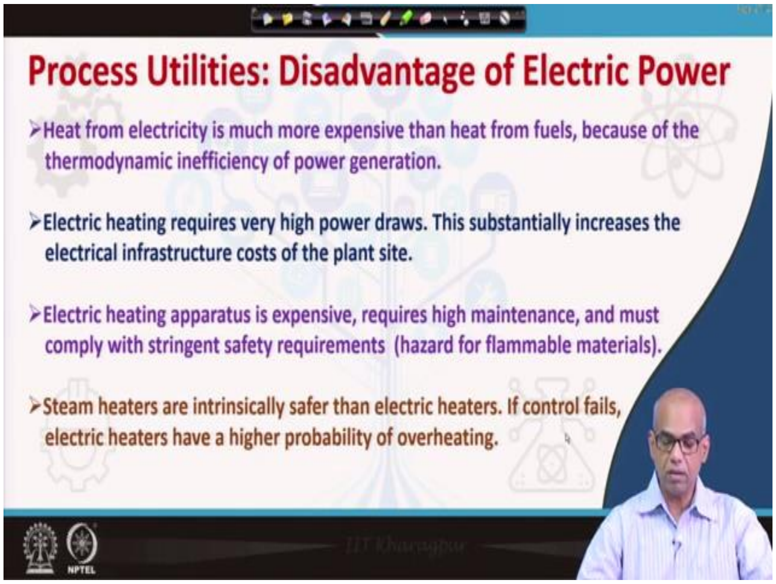

There are certain disadvantages of using electric power heat from electricity is much more expensive than heat from fuels because of the thermodynamic inefficiency of power generation. Electric heating requires very high power draws. This substantially increases the electrical infrastructure cost of the plant site. Electric heating apparatus are expensive, requires high maintenance and must comply with very stringent safety requirements.

This may also be hazard for flammable materials. Steam heaters are intrinsically safer than electric heaters. If control fails, electric heaters have a higher probability of overheating. The highest temperature that can be obtained with steam is fixed by its pressure. So when control fails, electric heaters have a much higher probability of overheating. So steam heaters are intrinsically safer when you compare it with electric heaters.

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Now let us move on to next utilities - fired heat. Fired heaters are used for process heating duties above the highest temperature that can be reached using high pressure steam typically above 250 degree Celsius using steam at 40 bar. Process streams may be heated directly in the furnace tubes or indirectly using a hot oil circuit or heat transfer fluid. The cost of fired heat can be calculated from the price of the fuel fired.

Most fired process heaters use natural gas as fuel because natural gas as fuel is cleaner; it has low maintenance of burners and fuel lines.

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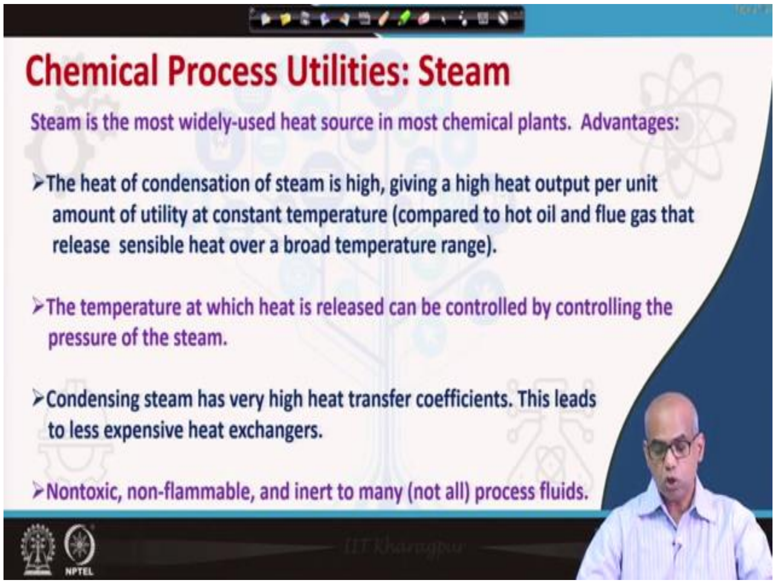

Steam is the most widely used heat sources in most chemical plants. So steam is the very very important process utility. It has several advantages such as the heat of condensation of steam is high giving a high heat output per unit amount of utility at constant temperature compared to hot oil and flue gas that release sensible heat over a broad range of temperature. The temperature at which heat is released can be controlled by controlling the pressure of the steam.

Condensing steam has very high heat transfer coefficients, so this will lead to low cost heat exchanger. Steam is nontoxic, non-flammable and also inert to many process fluids but, remember steam is not inert to all process fluids but it is inert to most of the process fluids. Another advantage is that when steam pipe leaks it is easily detectable, it is visible.

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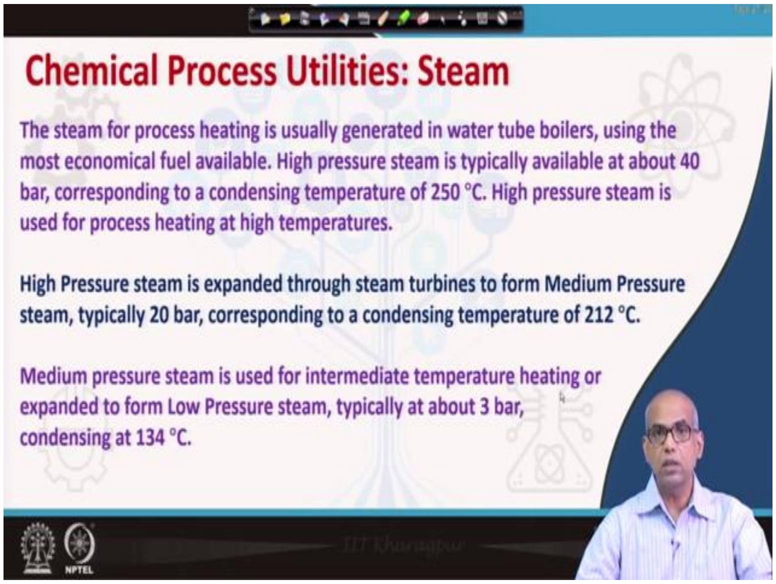

The steam for process heating is usually generated in water tube boilers using the most economical fuel that is available. High pressure steam is typically available at above 40 bar corresponding to a condensing temperature up to 250 degree Celsius. High pressure steam is used for process heating at high temperatures. High pressure steam is expanded through steam turbines to form medium pressure steam, typically at 20 bar, corresponding to a condensing temperature of 212 degree Celsius.

Medium pressure steam is used for intermediate temperature heating or expanded to form low pressure steam, typically at about 3 bar, condensing at 134 degree Celsius.

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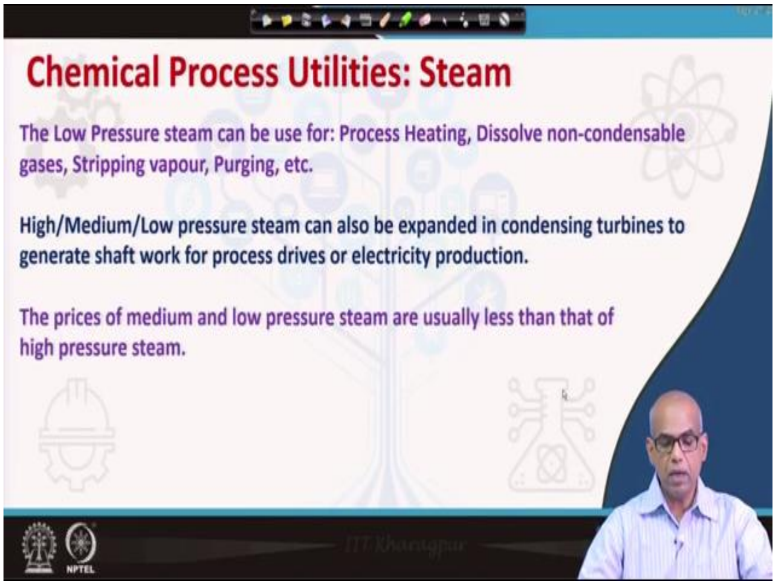

The low pressure steam can be used for process heating, dissolve non-condensable gases, stripping vapour, purging etcetera. High pressure steam, medium pressure steam or low pressure steam can also be expanded in condensing turbines to generate shaft work for process drives or electricity production. The prices of medium and low pressure steam are usually less than the price of high pressure steam.

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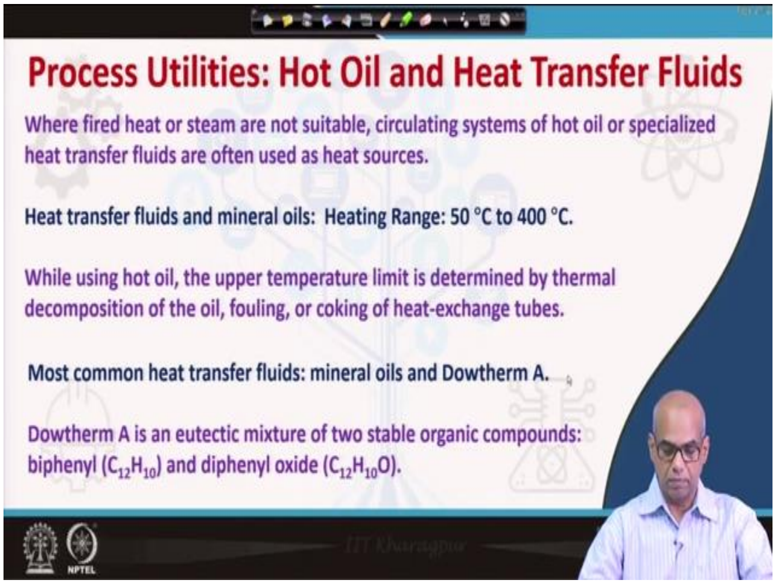

Now let us move on to hot oil and heat transfer fluids. Where fired heat or steam are not suitable, circulating systems of hot oil or specialized heat transfer fluids are often used as heat sources. So there will be circulating system of hot oil or specialized heat transfer fluids. Heat transfer fluids and mineral oils are typically used for heating in the range of 50 degree Celsius to 400 degree Celsius.

While using hot oil, the upper temperature limit is determined by thermal decomposition of the oil, fouling or coking of heat-exchanger tubes. You cannot use hot oil above the temperature at which it will decompose. Most common heat transfer fluids are mineral oils and Dowtherm A. Dowtherm A is an eutectic mixture of two stable organic compounds: biphenyl and diphenyl oxide. It is a trademark of Dow company.

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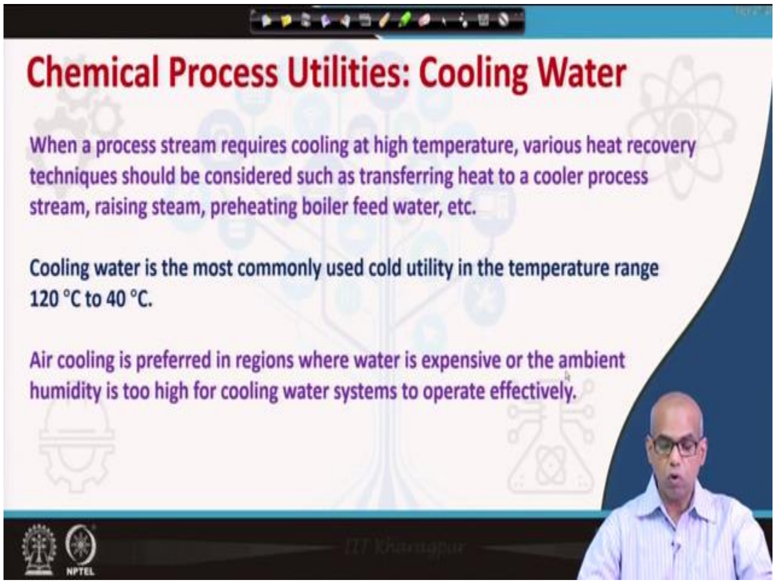

Let us now move on to next utility cooling water. When a process stream requires cooling at high temperature, you must consider various heat recovery techniques such as transferring heat to a cooler process stream, raising steam, preheating boiler feed water etc. So the heat must be reused. Cooling water is the most commonly used cold utility in the temperature range of 120 degree Celsius to 40 degree Celsius.

Air cooling is preferred in regions where water is expensive or the ambient humidity is too high for cooling water systems to operate effectively.

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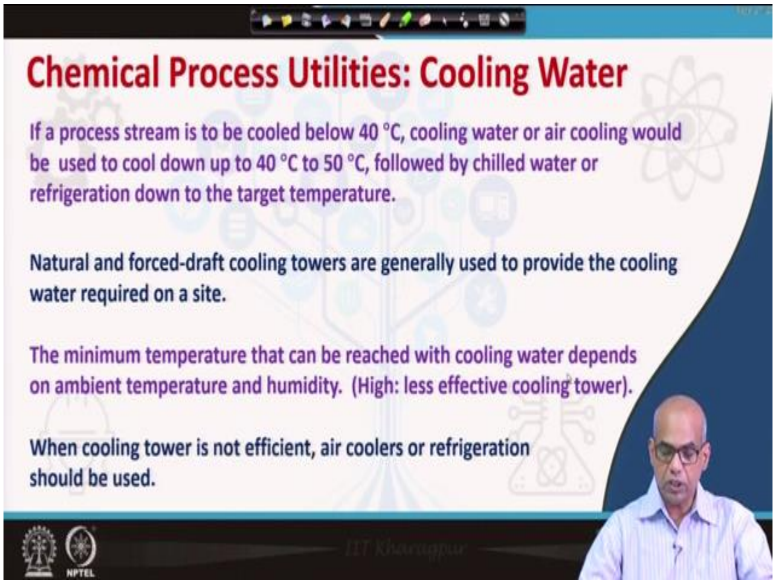

If a process stream is to be cooled below 40 degree Celsius, cooling water or air cooling would be used to cool down up to 40 degree Celsius or 50 degree Celsius and then it will be followed by chilled water or a refrigeration down to the target temperature. So you cool it down up to 40 degree Celsius or 50 degree Celsius by cooling water then use chilled water or refrigeration system to cool down further to the desired target temperature.

Natural and forced-draft cooling towers are generally used to provide the cooling water required on a site. The minimum temperature that can be reached with cooling tower will depend on ambient temperature and humidity. If the ambient temperature and humidity are very high then the cooling tower will be less effective when cooling tower is not efficient, air coolers or refrigeration should be used.

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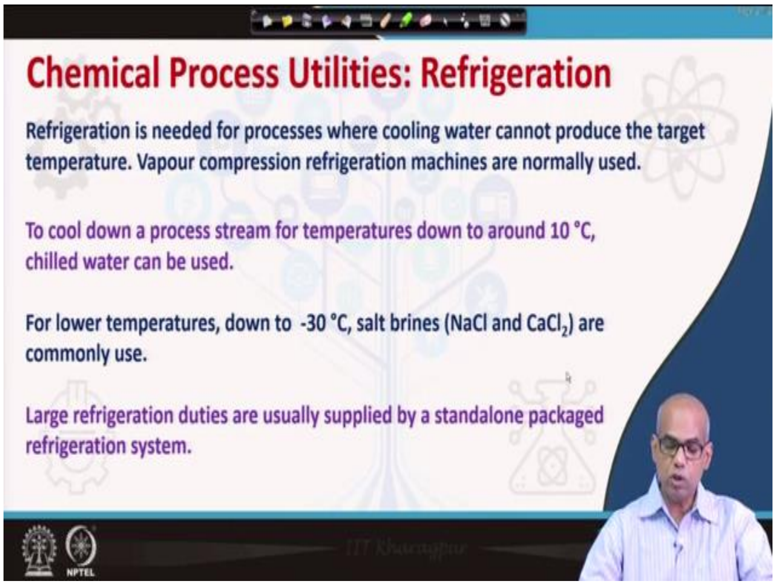

Now let us move on to refrigeration. Refrigeration is needed for processes where cooling water cannot produce the target temperature. Vapour compression refrigeration machines are normally used. To cool down a process stream for temperatures down to around 10 degree Celsius, chilled water can be used. For further lower temperatures, say down to -30 degrees Celsius, salt brines, sodium chloride, calcium chloride are commonly used.

So up to 40 to 50 degree Celsius you use cooling water, up to around 10 degree Celsius you can use chilled water, below that down to -30 degree Celsius salt brines can be used. Large refrigeration duties are usually supplied by a standalone packaged refrigeration system.

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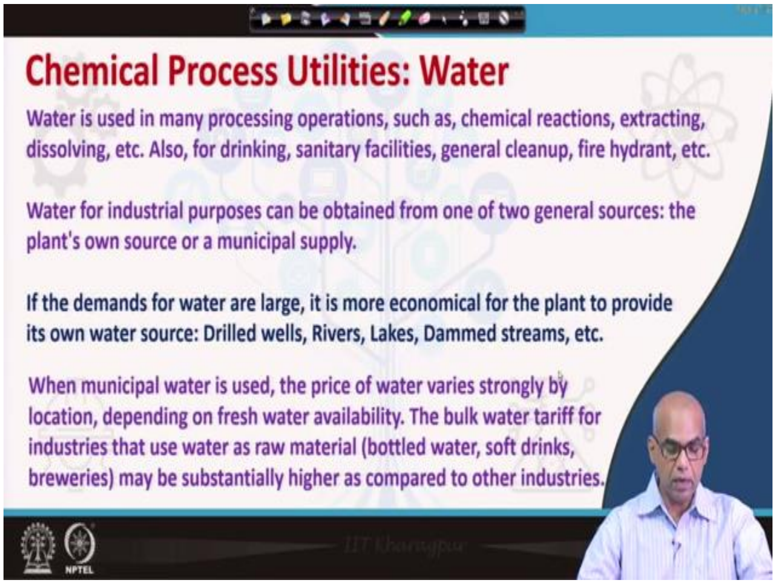

Let us move on to water as utility. Water is used in many process of processing operations such as chemical reactions, extracting, dissolving etcetera. It is also used for drinking, sanitary facilities, general cleanup, washing in fire hydrant etcetera. Water for industrial purposes can be obtained from one of the two general sources: first the plant's own source or second a municipal supply.

If the demands for water are large, it is more economical for the plant to provide its own water source: Drilled wells, Rivers, Lakes, Dammed streams etcetera. can be used. When municipal water is used, the price of water varies strongly by location depending on fresh water availability. The bulk water tariff for industries that use water as raw materials such as bottled water, soft drinks, breweries etcetera.

May be substantially higher as compared to other industries. So industries such as bottled water who produces bottled water, soft drinks, breweries etcetera. there they use water as raw materials. So water tariff charge by say municipality may be substantially higher as compared to cases for other industries.

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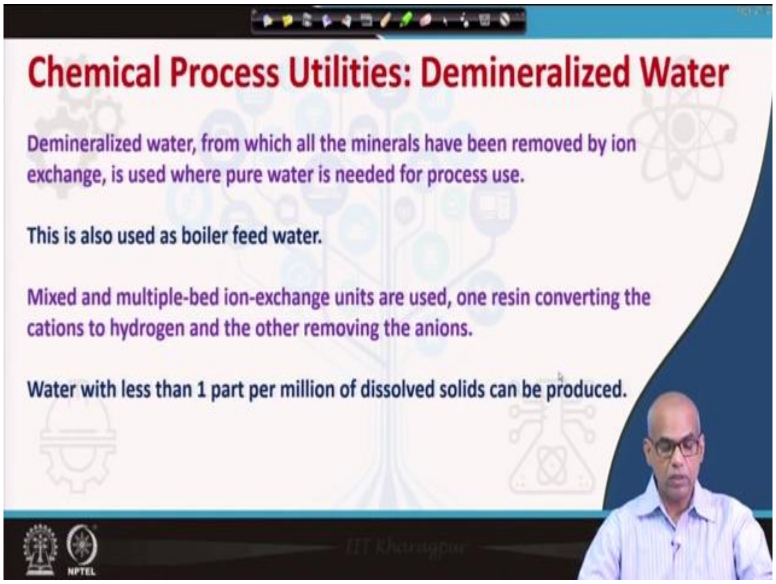

Demineralized water, from which all the minerals have been removed by ion exchange, is used where pure water is needed for process. This is also used for boiler feed water. Mixed and multiple-bed ion-exchange units are used one resin converting the cations to hydrogen and the other removing the anions. Water with less than 1 part per million of dissolving solids can be produced.

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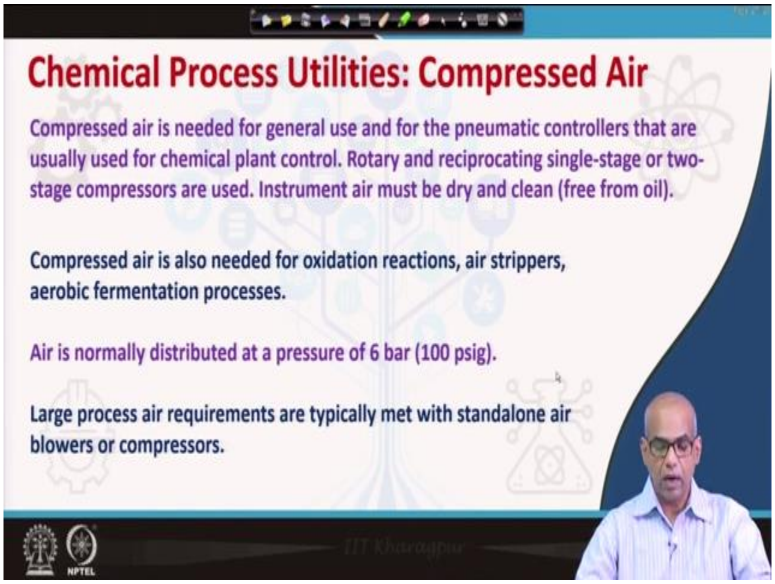

Now, let us move on to compressed air. Compressed air is needed for general use and for the pneumatic controllers that are usually used for chemical plant control. In chemical process industries pneumatic controllers are routinely used. So, pneumatic controllers will receive pneumatic signal. So you will need compressed air for that purpose. Rotary and reciprocating single-stage or two-stage compressors are used to generate compressed airs.

Instrument air must be dry and clean and it should also be free from oil. Compressed air is also needed for oxidation reactions, air strippers, aerobic fermentations etcetera. Air is normally distributed at a pressure of 6 bar. Large process air requirements are typically met with standalone air blowers or compressors.

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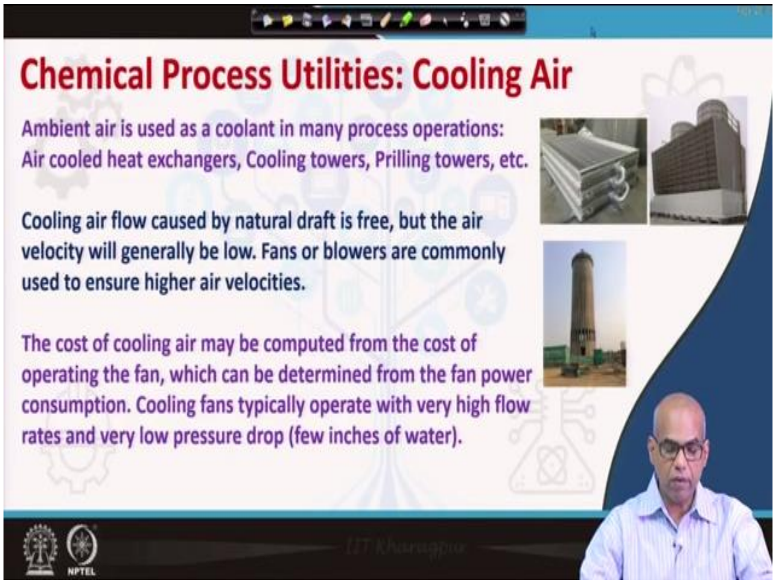

Now let us move on to cooling air. Ambient air is caused;, ambient air is used as a coolant in many process operations. For example, air cooled heat exchanger, cooling towers, prilling towers is used in urea manufacture. So ambient air is used as a coolant in several important process operations such as heat exchangers, cooling towers, priling towers etcetera. Cooling air flow caused by natural draft is free, but the air velocity will generally be quite low.

Fans or blowers are commonly used to ensure higher air velocities. The cost of cooling air may be computed from the cost of operating the fan, which can be determined from the fan power consumption. Cooling fans typically operate with very high flow rates and very low pressure drops about few inches of water.

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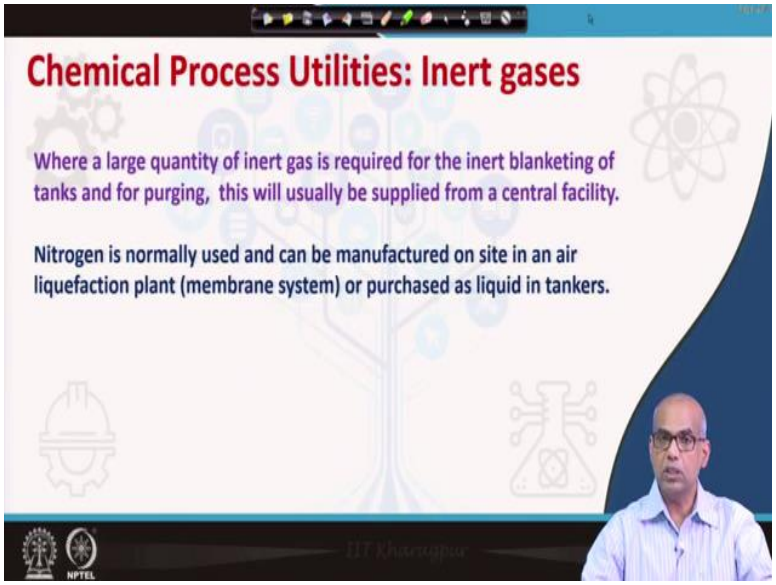

Next, we move on to inert gases where a large quantity of inert gas is required for the inert blanketing of tanks and for purging, this will usually be supplied from central facility. So inert gas is used to have an inert environment. It will be required for the inert blanketing of tanks and for purging. Nitrogen is normally used and can be manufactured on site in an air liquefaction plant or it may also be purchased as liquid nitrogen in tankers from utility supply companies.

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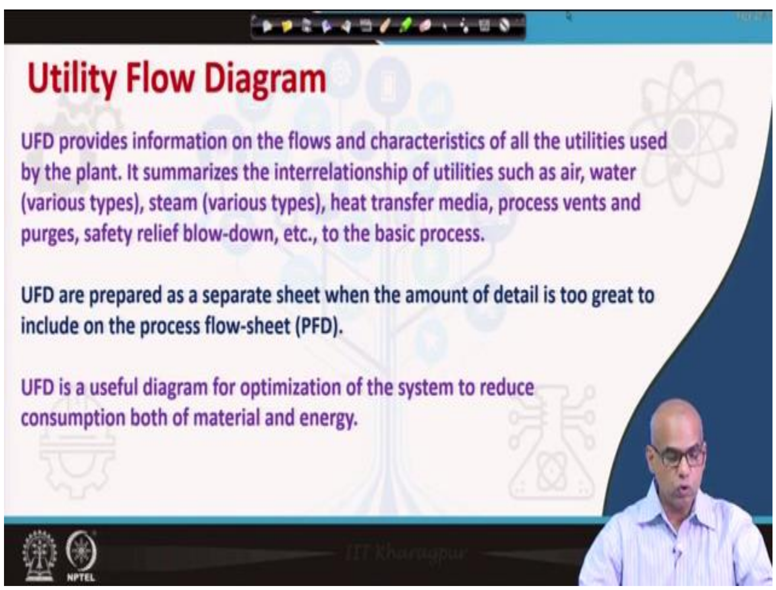

Now, we have talked about various chemical engineering flow diagrams such as block flow diagrams, process flow diagrams, piping an instrumentation diagram. Chemical engineers also use utility flow diagram. Utility flow diagram provides information on the flows and characteristic of all the utilities used by the plant. It summarizes the interrelationship of utilities such as air, water, steam, heat transfer media, process vents and purges, safety relief blow-down etc. to the basic process.

Utility flow diagram are prepared as a separate sheet when the amount of detail is too great to include on the process flow-sheet. So there is large amount of information when the process is quite complex, large then it will not be possible to include the information on the service or utility lines on the process flow-sheet. In that case we will use a separate flow-sheet which will call utility flow diagram.

Utility flow diagram is a useful diagram for optimization of the system to reduce consumption of both material and energy.

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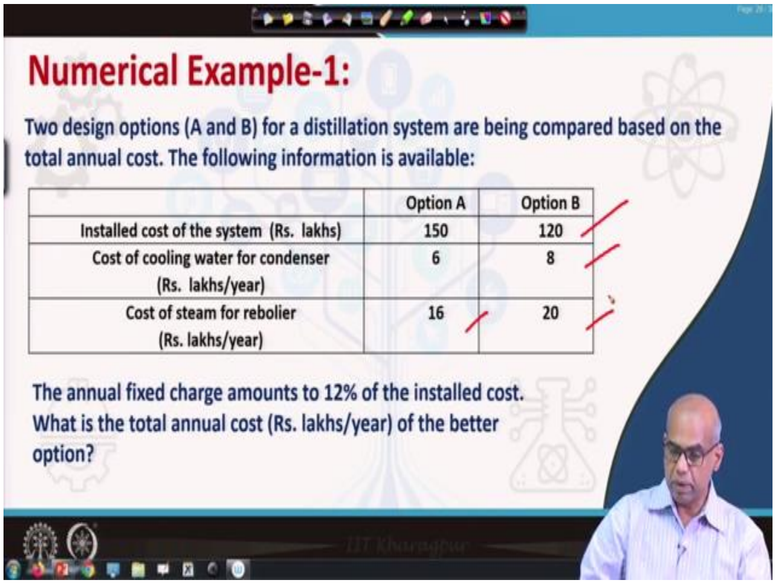

Now, let us take a simple example. We have two design options: option A and option B for a distillation system and these two options are being compared based on the total annual cost. We have the following information's available as shown in the table. Installed cost of the system is 15000000 for option A and 12000000 for option B. Cost of cooling water for condenser in lakhs per year for option A is 6 and for option B is 8.

Cost of steam for reboiler in lakhs per year for option A is 16 and for option B is 20. The annual fixed charge amounts to 12% of the installed cost. What is the total annual cost of the better option in rupees lakhs per year? So you have two design options for a distillation system, installed cost for both are given, cost of cooling water per condenser in lakhs per year given, cost of steam for reboiler in lakhs per year given.

Also given is annual fixed charge which is 12% of the installed cost. So you have to find out which option is better and what is the total annual cost of the better option?So this has to be done on the basis of total annual cost.

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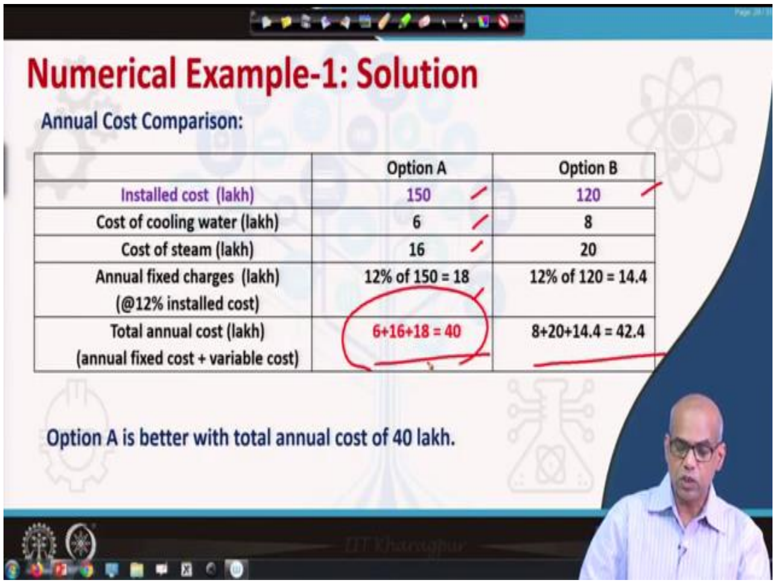

So let us prepare this table for annual cost comparison. Note the installed cost, 150 lakh for option A and 120 lakh for option B, they are not annual cost. But 12% of that is annual fixed cost. So let us add up the annual cost. Cost of cooling water 6 lakh for option A, cost of steam 16 lakh per year for option A and annual fixed cost which is 12% of the installed cost, this will become 18 lakh for option A.

If you add it will be 40 lakh. So annual cost for option A is rupees 40 lakh the same way we calculate annual cost for option B and it will be 42.4 lakhs. So obviously option A is a better option and it has total annual cost of rupees 40 lakhs.

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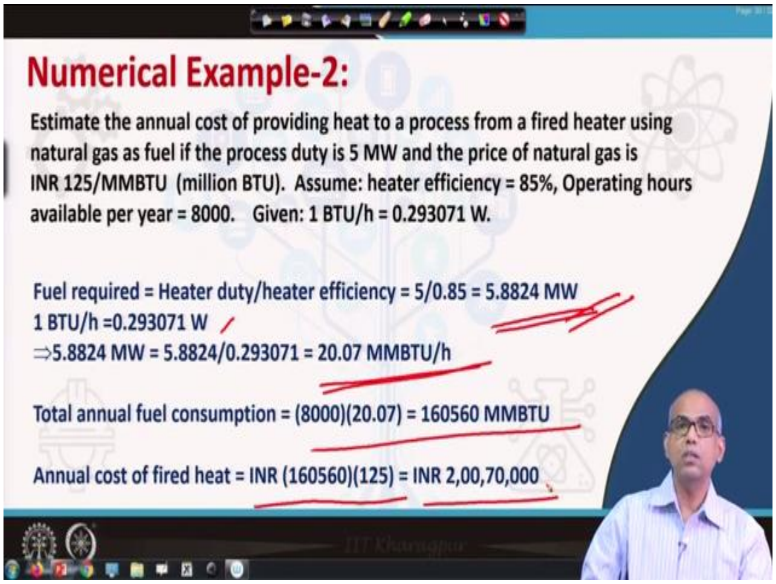

Now, let us take another simple problem. Estimate the annual cost of providing heat to a process from a fired heater using natural gas as fuel if the process duty is 5 megawatt. The process duty is 5 megawatt and the price of natural gas is rupees 125 per million British thermal unit, Million BTU. This is the common unit for expressing energy in the natural gas. We assume heater efficiency to 85%, operating hours available in a year 8000 and also it is given that 1 BTU per hour is equal to 0.293071 watt.

So how do you go about it? So first find fuel required. Fuel required can be computed from heater duty and heater efficiency. Heater duty is 5 megawatt, heater efficiency is 85%. So 5 by 0.85 which is 5.8824 megawatt is the fuel required. It is given 1 BTU per hour is 0.293071 watt. So we convert 5.8824 megawatt to Million BTU per hour. Now there are 8,000 hour in one year. So, total annual fuel consumption can be computed by multiplying 20.07 with 8,000.

So that gives me 160560 Million BTU. Since the price of natural gas is rupees 125 per million BTU, so the annual cost of fired heat will be 160560 multiplied by 125 which is 2,00,70,000 Indian rupees. So with this we stop our discussion on process utility here. Thank you for watching.