Process Design Decisions and Project Economics
Prof. Dr. V. S. Moholkar
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Module - 6
Economic Decision Making
Lecture - 29
Case Study of a Gas Absorber
Selection of Process, Design of Flow sheet and Materials Balance

Welcome, we have seen the principles of generation of a flow sheet, the hierarchal approach to generation off low sheet, various decisions involved in different steps of design. We have also seen the basic principles of project economics and major of process profitability. In this module, we will try to apply these principles for design of a simple system that is a gas absorber.

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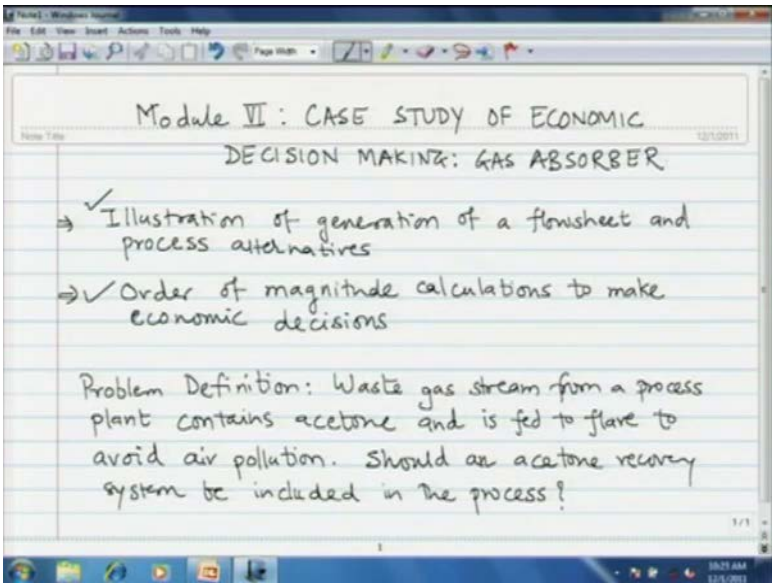

Then we can see how we can generate a flow sheet illustration of generation off low sheet and how we can generate process alternatives for this particular system? Then we shall also see the order of magnitude of calculations for making decisions for the flow sheet based on the economic evaluation of the decision. Let us first define the problem for design of gas absorber. Let us say that we have a gas stream from a process plant, which contains acetone as organic vapour and it is fed to flare.

So, as to convert all the acetone into carbon dioxide, and water to avoid air pollution acetone being a valuable chemical. We have to see whether we should design an acetone recovery system and include it in the process. We have to first answer a question, whether it is worth recovering acetone from that stream? So, let us now see how much of acetone we can recover? Now, in this case study we are going to use different numbers of cost of molar fluorides etcetera. So, these are basically only representative numbers you can apply. The concepts that which we learn in this module to design of any other system, so let us say that the waste cast stream composition is 687 mole per hour of air and 10.3 mole per hour of acetone.

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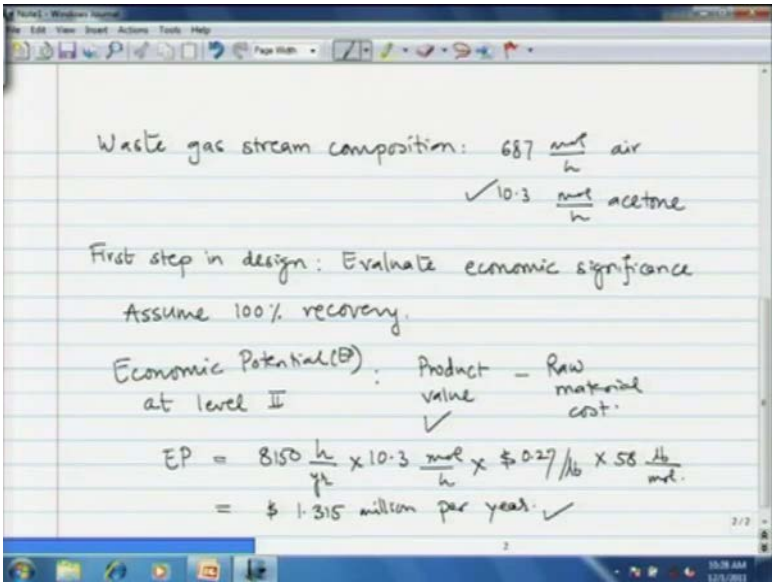

Now, the first step in the design is to evaluate economic significance of the project, we do not know at this moment as what fraction of this 10.3 mole per hour of acetone we are going to recover? However, to evaluate the maximum economic significance that this project will have? We will assume that we are going to recover 100 percent of that acetone. Now, let us apply the hierarchal approach to the process design; the first step is batch versus continuous.

So, let us say that this process is a continuous process, therefore we have to operate absorber in continuous mode to having said that we have to draw the input output structure of the flow sheet. Now, in this case the input stream is the waste gas stream and the output stream will be only air after recovery of all acetone. Therefore, the economic

potential of this particular process at level two will be the product value minus the raw material cost, the raw material.

In this case is the waste gas stream, which is for free means there is no cost involved in that, for that waste gas stream. Therefore, the product value is the economic potential. Now, we have said that we will recover hundred percent of acetone. So, let us say that in a continuous process the number of hours of operation are 8150 hours per year in then 10.3 mole per hour is the acetone recovery. Let us say that the cost of acetone is 27 Cents per pound and the molecular weight of acetone is 58 pound per mole.

Therefore, the net economic potential of the process that is the net value of the acetone that is recovered in the absorber is over 1 million Dollars. This is an attractive figure, so the economic potential at level one is quite promising and encouraging to go to the next step. Now, that we have decided to recover acetone, we have to see which process we will use for the recovery for vapor recovery from a gas stream.

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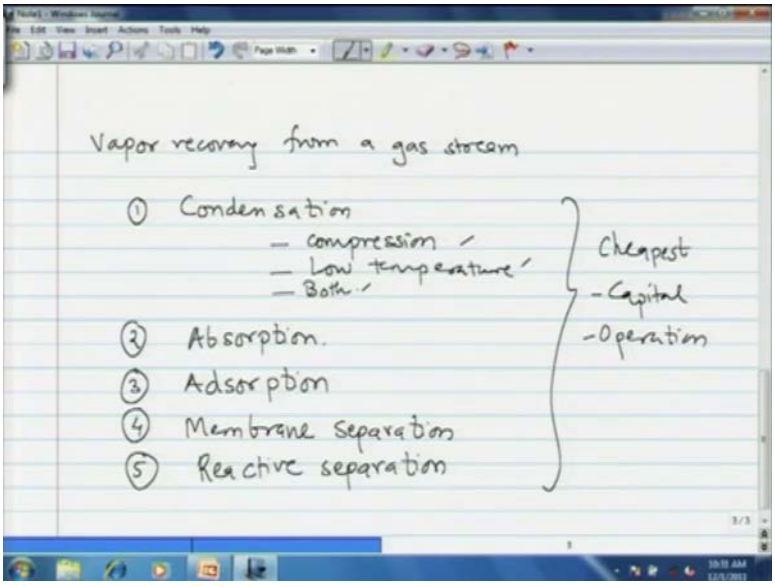

We have several options the first option is that of condensation. Now, condensation either by compression or by cooling or low temperature or both, now which of these technique we have to apply depends on the pvt characteristics of thermodynamic properties of the vapor. The second choice of process would be absorption in a suitable solvent obviously what will come out of the process will not be pure acetone, but acetone dissolved in the solvent.

We will need another unit to recover acetone from that stream. The third option will be that of adsorption where we will use a certain adsorbent for removal of acetone, but again to recover acetone from the adsorption process, we will have to regenerate the adsorbent to have desorption that would be either thermal desorption or pressuring desorption solid. So, the fourth option will be that of membrane separation, membrane in which acetone will dissolve on one side and will diffuse on the other side.

It can be recovered on the permit side that is solution diffusion mechanism, which is popularly known as… So, that membrane separation is an option and finally, we could use simple reaction in which acetone will react and can be set rated. However, whether we recover acetone from the product depends on the kind of reaction that is involved, okay? So, we have different options for the recovery of gas stream. Now, obviously we have to choose the cheapest alternative cheapest in terms of the capital cost and also the operating cost.

But when we try to design a process on industry scale or commercial scale another factor that comes into picture is the experience with the particular process. Suppose, the industry has already some adsorption units, so the industry has experience of designing and operating and unit adsorption unit. So, when a new system is to be chosen the company may would like to go for adsorption. Now, same thing happens for condensation many petroleum companies use condensation systems because the company has experience in designing and operating of such units.

Therefore, condensation may be the preferred process, so cost may not be the always, cost may not be always the governing criterion for choice of particular process the experience technology is also an important factor. Now, before choosing the process, we have to see previous studies in which this processes might have compared flare has given an analysis.

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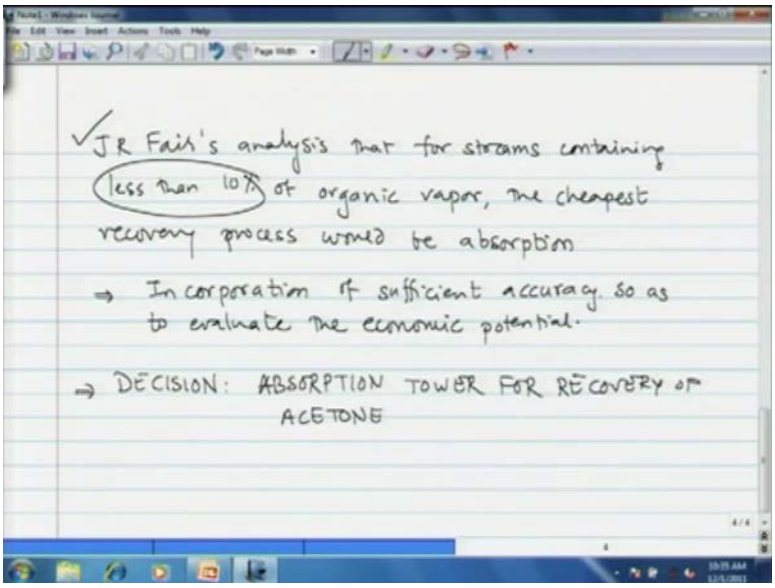

That for streams containing less than 10 percent of vapors organic vapor or solvent vapor. The cheapest recovery process would be absorption, then we try to design a process we have to incorporate only sufficient accuracy, because we have to design a process to evaluate six its economic potential. So, we need not incorporate all the details into it so we have to design a system only to sufficient accuracy.

So, as to evaluate the economic potential, now based on flares analysis let us say we make a decision of using absorption tower for recovery of acetone. The flow rates of acetone and air are sufficiently the flow rate or let us say that content of acetone in the waste gas stream is sufficiently low to meet the criteria of less than 10 percent. Therefore, we decide to for the absorption process so that is the first decision that we make. Now, based on this decision we have to generate a very simple design problem.

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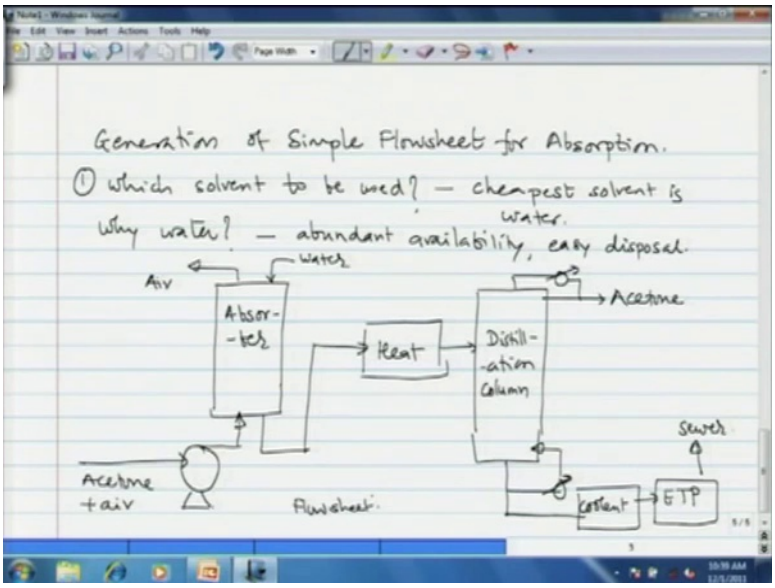

The first question that will come to our mind is which solvent to be used for absorption of acetone. Now, here we have several options we may use an organic solvent or we may use an alcohol or some other process, but the cheapest will be water. Why water? Apart from the cost, it is abundant availability and we can easily dispose it of after treatment. That may not be the case with organic solvents, now based on this let us try to design a very simple system for absorption, okay?

Let us say we have acetone and air stream coming from the process that we need to compress slightly to moderate pressure. Then we have the absorber air exists the absorber water is used as the solvent. Then the stream containing water and acetone is heated and then fed to a distillation column in which pure acetone is recovered. The water after having the reboil vapor, reboil is sent to a coolant and then to a effluent treatment unit or effluent treatment plant ETP and the stream from ETP is disposed in a sewer.

So, this is a simple flow sheet that we can draw for a gas absorption system coupled with recovery of acetone; that is another thing distillation column is a recovery of pure acetone, okay? Now, what process alternatives that we can see from this the first process alternative is that of recycling of water, whether we should continuously through away water effluent treatment plant and later to a sewer.

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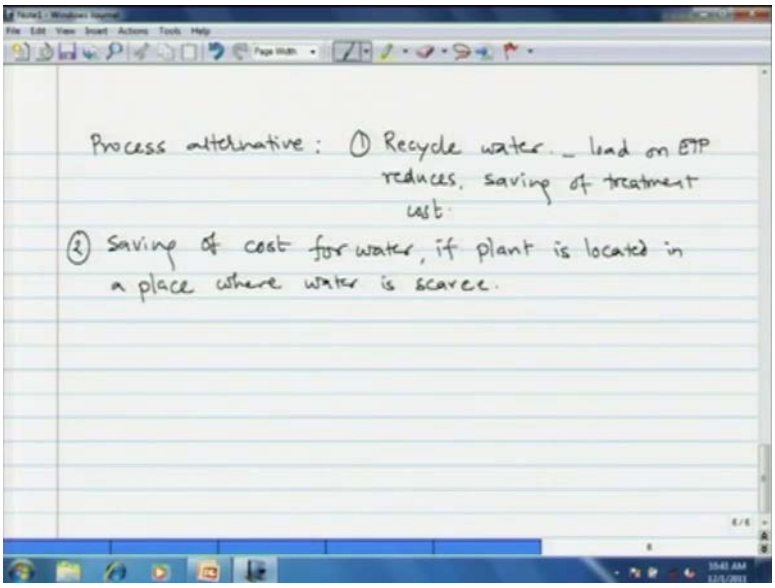

We can recycle water, if we recycle water then we have we do not need any effluent treatment system or let us say the load on effluent treatment system reduces. So, we save some cost, let us say if the plant is located at location where water is not abundantly available. Then the recycling water is absolutely essential saving of cost for water, if plant is located in a place where water is scarce. So, these are the advantages for recycling water. Now, let us see a flow sheet of recycling water will look like the first unit will remain the same; that is the absorber. Let us draw that flow sheet flow sheet with recycling of water the first unit, which is the absorption column remains the same.

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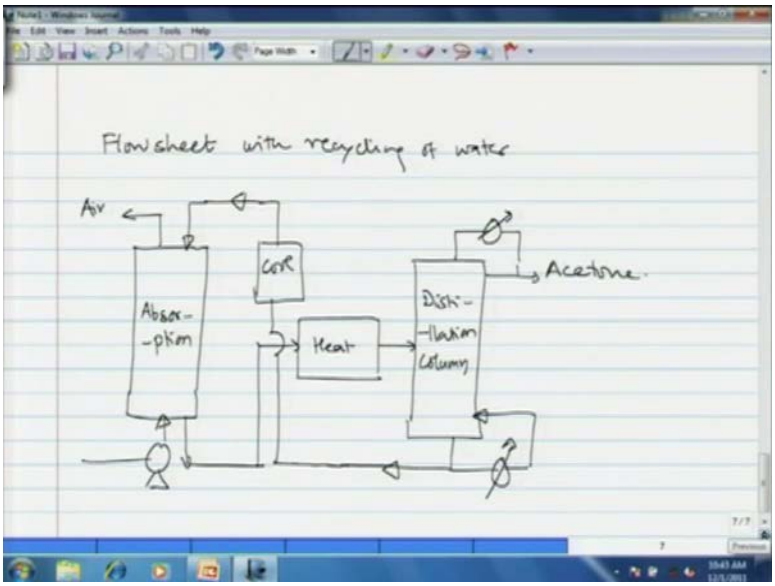

The stream emerging from absorber contains some water with dissolved acetone, which is heated. Then the distillation column now here at outlet of distillation column, we have the recycling of water. Of course, here before putting the water back into the absorber we have to cool it. Then pure acetone is recovered from the top of distillation column. So, this is how the flow sheet with recycling of water look like. You can see here that there is no effluent treatment here. Now, what are the other side of the coin like, suppose we use recycled water.

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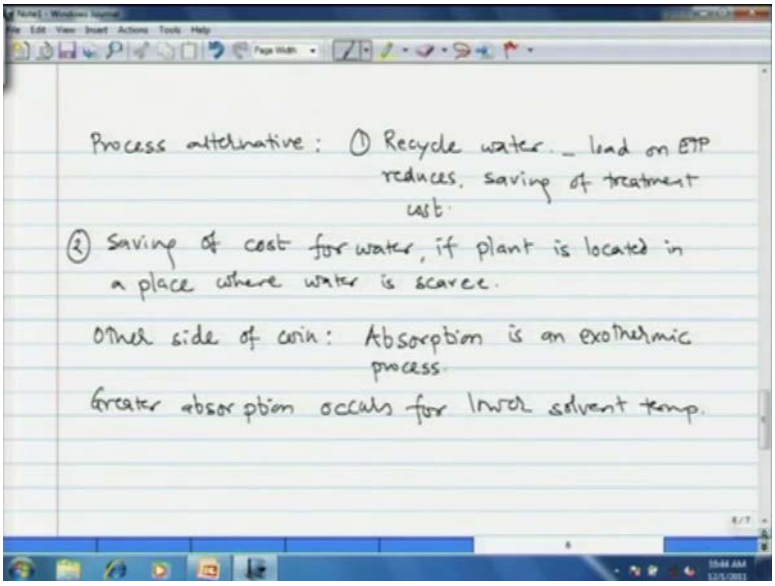

What are the demerits that we are likely to face now? You know that absorption is an exothermic process, any solute that dissolves in solvent liberates the heat of the solution. Therefore, greater absorption occurs for low solvent temperatures. Now, we are recycling water from the distillation column and intermediately it is being cooled. Now, the temperature of water that will out of the distillation column, which is which is basically as you see is a side stream from the reboiler would be about 100 degree centigrade or 200 and 12 degrees Fahrenheit

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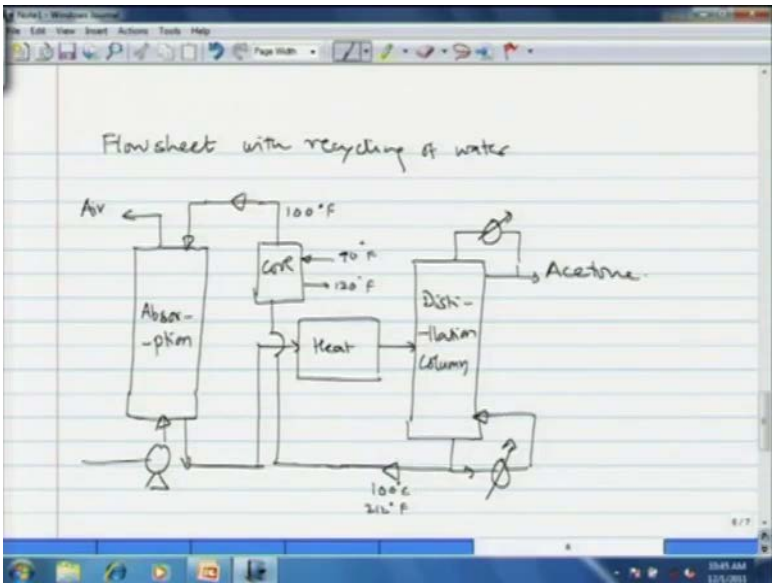

Now, with recycling we have to cool it intermediate. Now, for cooling the stream we will use let us say cooling water, which enters the cooler at ninety degrees Fahrenheit and leaves at 120 degrees Fahrenheit. If this particular cooler is operated in counter current mode, then with the delta t mean constraint the minimum temperature that the water coming out of cooler will have is 100 degrees Fahrenheit, which enters the adsorption column. In case where water is being fed fresh continuously as you see in this flow sheet, the flow sheet without recycling of water, the water that may come in will be at much low temperature.

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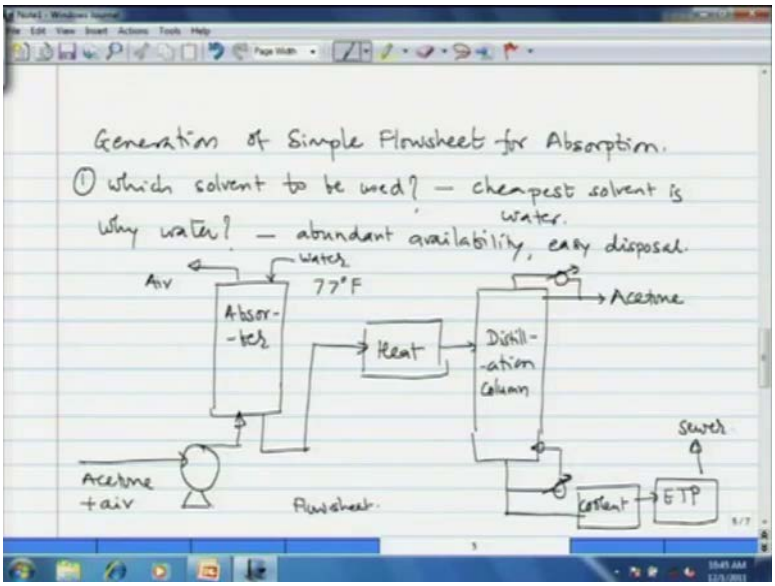

Suppose, it is let us say drawn from a bore, borewell in the process plant area. Then that water could be at 77 degrees Fahrenheit. Then the extension of absorption that will occur in this water will be higher that point we note is that the water emerging from intermediate cooler, differ every cycle to absorption column can have minimum possible temperature of 100 degrees Fahrenheit.

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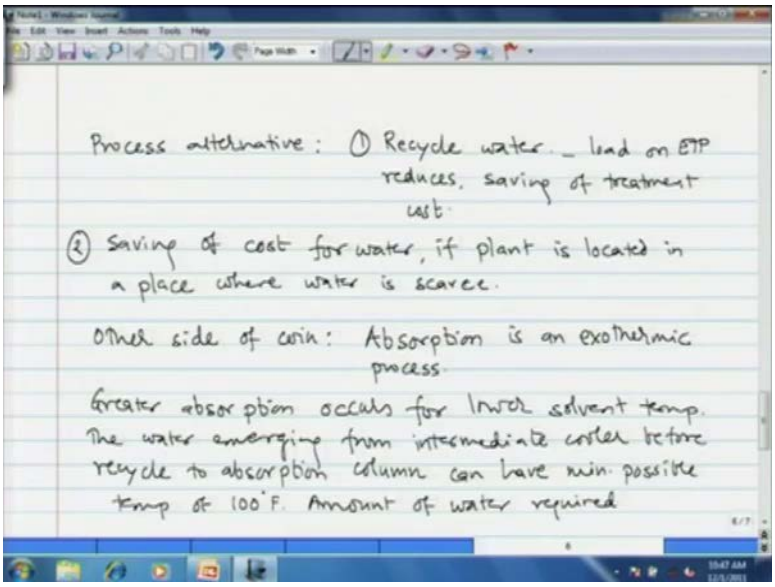

Therefore, the amount of water that will be required will be higher as compared to the continuous water fed flow sheet the first flow sheet.

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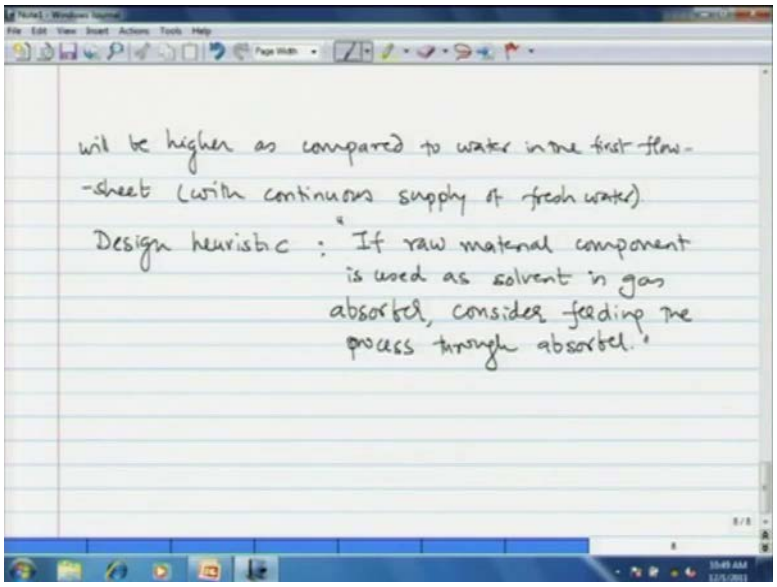

We can have design heuristic to reach a decision. In such cases is that if the raw material component used is solvent for the absorber, consider feeding the process through absorber, so the option of recycling of water has given us two flow sheets. Now, we do not know at this stage, which one is cheaper. So, we have to design both of them, so that completes the level two of the design the input output structure. The next stage is the material energy balance.

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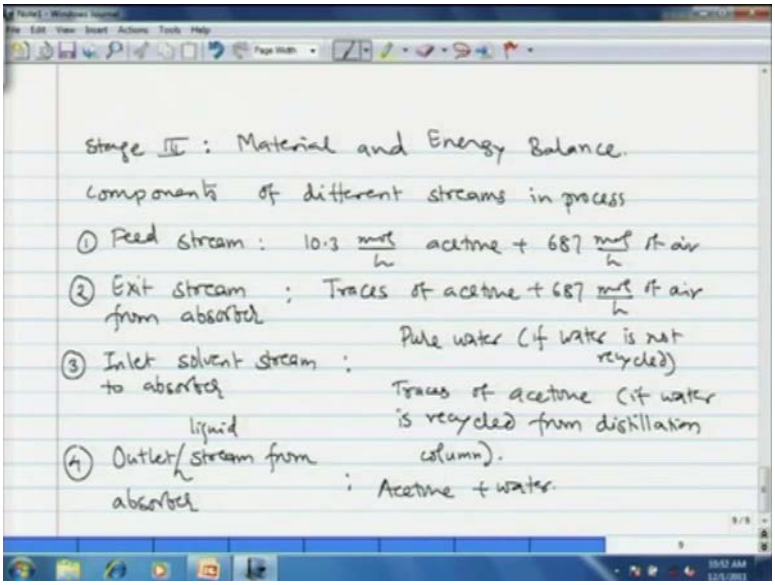

Now, before we do that let us try to identify the components of different streams in the process The heat stream to absorber has 10.3 mole per hour of acetone and 687 mole per hour of air. If the extent of absorption is 99 percent or higher, then the exit stream from absorber will contain only traces of acetone. All air may be some air will dissolve in water that will be negligibly small, so we ignore it.

Now, the inlet solvent stream to absorber it will be pure water, if water is not recycled or it may contain some traces of acetone. If water is recycled from distillation column, now the outlet stream, outlet liquid stream that we put from absorber will contain most of the acetone 10.3 mole per hour. So, acetone plus water this, we see that acetone exit in the process is at three location; first the air that is leaving from the absorber.

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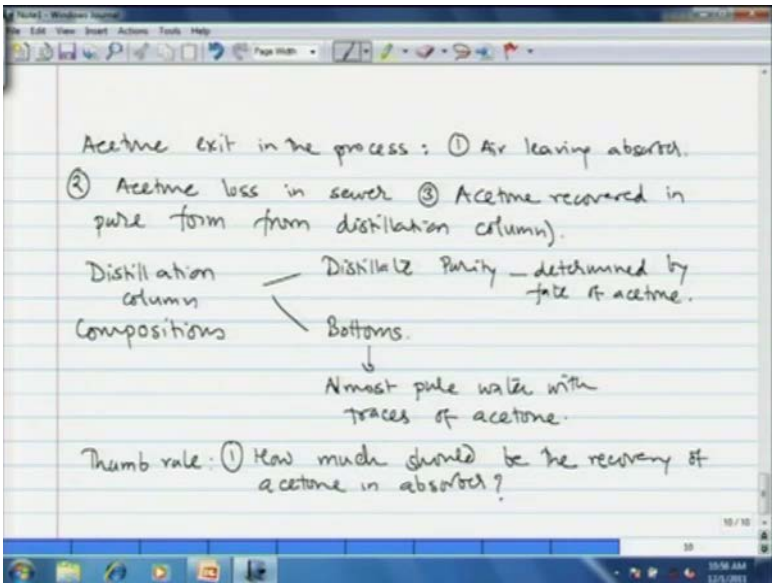

Now, if water is not recycled, then some acetone may also leave in the sewer and finally, acetone that is recovered in the pure form from the distillation column. Now, for distillation column what would be the composition of top product and the bottom product? Acetone will be recovered as distillate and the water will be recovered as the bottoms. However, the purity of the distillate will be determined from the fate of acetone that is being recovered. If it is recycled to the reactor, then the purity that is required could be a bit less.

Let us say 90 percent, 95 percent pure could be sufficient. However, if acetone is being sold as a byproduct of the process, then purity has to be relatively higher may be 99 percent or 99.9 percent. So, the purity factor will be determined from the fate of acetone the bottoms will be almost pure water with traces of acetone. Now, to decide the mass balance, we have to start with some thumb rule like our first question. How much it should be the recovery of acetone in absorber, first question.

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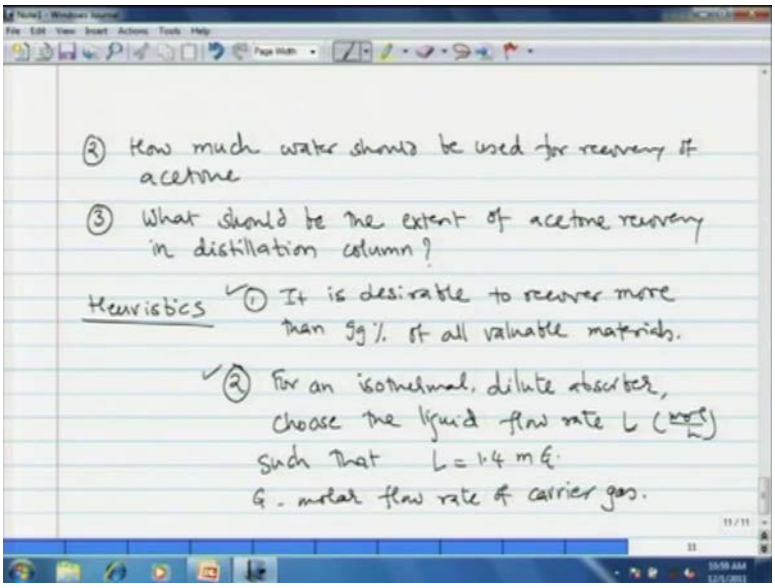

Second question, how much water we should use for recovery of the acetone? Second sorry, the third is what should be the extent of acetone recovery in distillation column? These are open ended questions, I told you in the first lecture that design problems are always under defined. We do not have all the information that is needed for designing of the system. Now, what we should do in that case?

We should either use the heuristics or thumb rule that are developed using past experience or we should try to look into the data of previous designs, that is data, that is available in the literature or the data that is maintained by the company. So, let us see some heuristics for answering these questions. The first heuristic is it is desirable to recover more than 99 percent of all valuable material. This is a heuristic that we have already seen when we did the material balance for the HDA process.

The second heuristic that we are going to use is that for an isothermal and dilute absorber use the liquid flow rate l in mole per hour. This is very important the unit of liquid flow rate is not kg per mole such that l is equal to 1.4 m into G where G is the molar flow rate of gas and is the carrier gas that we should note. G does not include the acetone moles, but only air moles. So, these two heuristics we are going to use for designing the absorber. Now, with these heuristics let us try to do the metal balance.

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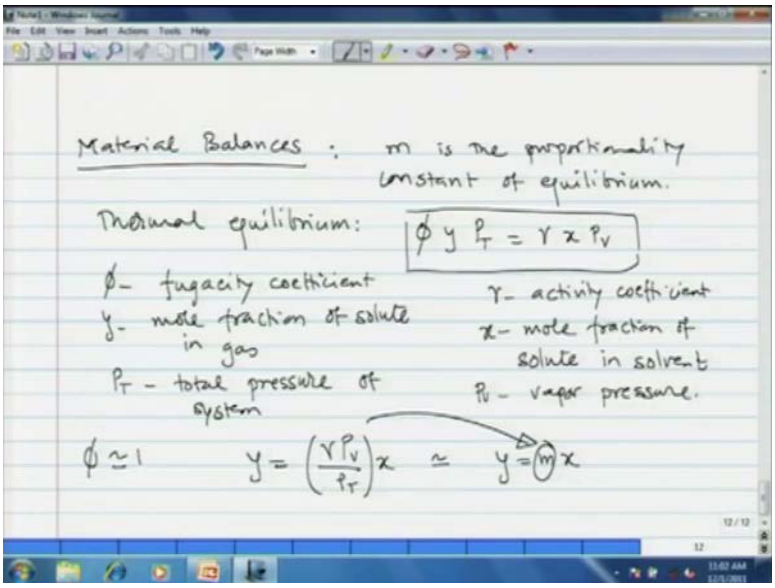

Now, m that we have seen just now n is equal to 1.4 m G m is the proportionality constant of equilibrium thermal equilibrium of a process would always necessitate. This particular relation phi y into P T is equal to gamma into x into P V where phi is the fugacity coefficient y is the mole fraction of solute in gas. P T is a total pressure of the system gamma is activity coefficient x is the mole fraction of solute in solvent and P V is a vapor pressure.

So, the equilibrium will always be defined by this relation. Now, in the present situation the total pressure of the absorber is close to atmospheric. We have acetone in very dilute concentration, only 10.3 mole per hour in 687 moles per hour of air. Therefore, we can migulate phi, so phi can be assumed to be 1. Now, with this the equilibrium relation becomes y is equal to gamma P V by P T into x, which is often given in the form y is equal to m x and m is essentially this gamma P V by P T. Now, let us try to determine the value of m in this case for simplicity, we assume recycling of water at present. We will assume that water is being fed continuously to the process fresh water.

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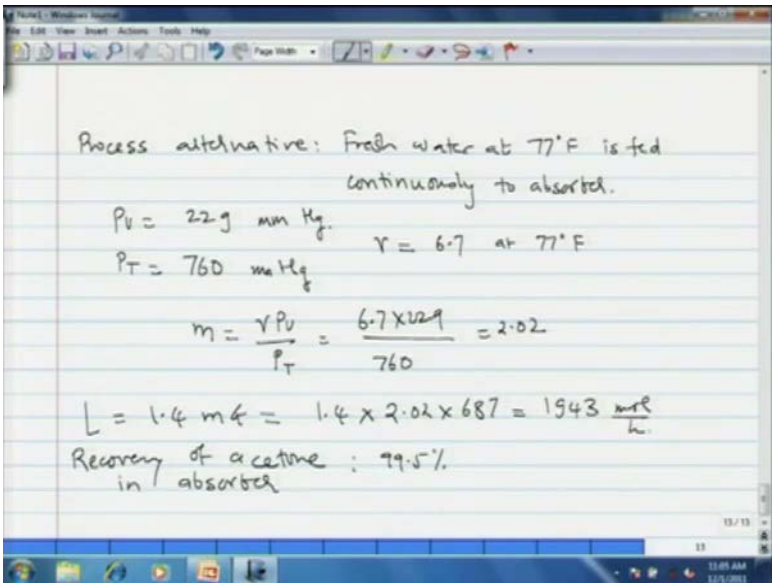

Fresh water at 77 degrees Fahrenheit or something like 20 degree centigrade is FED fresh continuously to absorber. Now, vapor pressure of acetone in for such temperature is about 229 mm mercury. The total pressure is 77 mm mercury the activity coefficient gamma for acetone. Water resistant is 6.7 at 77 degrees Fahrenheit. Now, with this numbers, we can immediately calculate value of mm will be gamma P V by P T, which is 6.7 into 229 divided by 67, which is equal to 2.02.

Then for the molar flow rate of 687moles of air, the liquid water that is water flow rate that is required is l is equal to 1.4 into m into G; that is 1.4 into 2.02 into 687. That is 1943 mole per hour. Now, we will say that the recovery of acetone in absorber is 99.5 percent; that is a value that we choose from thumb rule of recovering. 99 percent or more of all valuable material and with these we can very easily calculate the acetone loss from absorber with exiting air.

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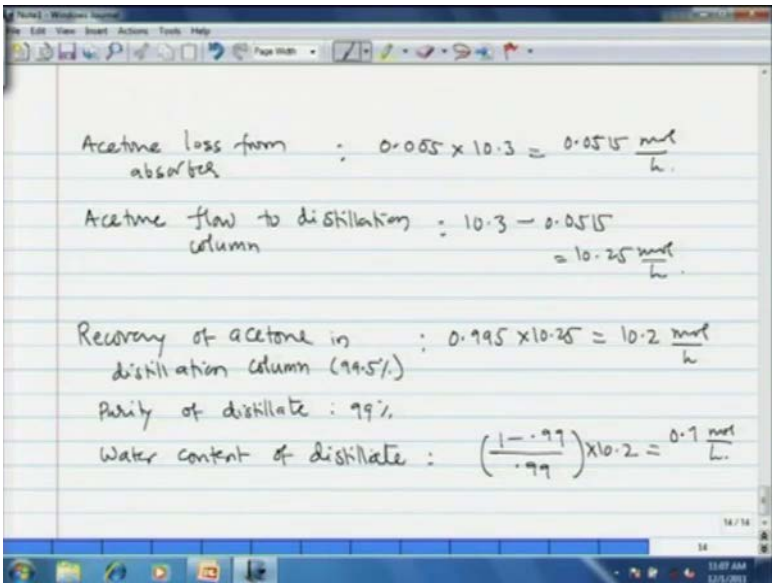

That will be nearly 0.05 into sorry, 0.005 not 0.05. 0.005 into 10.3; that is 0.0515 mole per hour. Now, the acetone flow to distillation column would be 10.3 minus this loss which is equal to approximately 10.25 mole per hour. Out of this acetone the recovery at in distribution column is again 99.5 percent. Thus the acetone that is recovered as distillate is 10.2 mole per hour.

Now, the purity of distillate, if we assume to be 99 percent, then the water content of the distillate can be immediately calculated as 1 minus 0.99 divided by 0.99 into 10.2 mole per hour is equal to 0.1 mole per hour. So, you can see that out of 1943 moles of water that are fed to the distillation column only 0.1 mole ends up in distillate, which is negligibly small.

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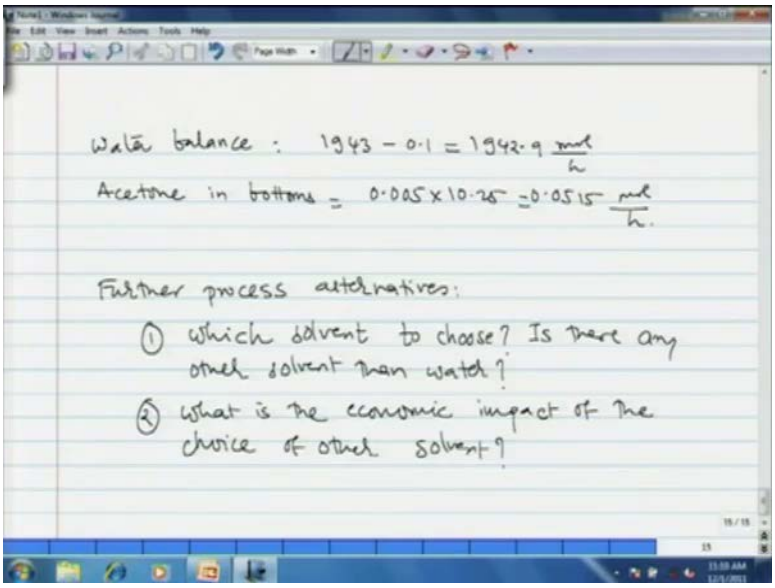

Now, similarly we can do water balance, the water that ends up in bottoms of the distillation column is 1942.9 mole per hour, just 0,1 mole less that the water that is fed to the system. Acetone in bottoms would be 0.005 into 10.25 that is equal to 0.0515 mole per hour. So, you just saw how we can very easily calculate material balance from a completely open ended problem if we use make, if we make use of the thumb rule or heuristics.

Now, in the next lecture, we will see the energy balance for the process and then we shall see further process based on the metal and energy balance. For example, what solvent to choose that point you note here. The next lectures questions that we are going to deal with further process alternatives, we have done calculations using water as a solvent, but is there any other alternative for this particular process? What is the economic impact of the choice of other solvent?

One important thing that we have not included in the material balance is the loss of water through absorber. Since, absorber is essentially a gas liquid contactor the air that will exit from absorber will be saturated with water vapor. Therefore, not all of the water that enters the absorber will come out. Some small loss of water will be there that loss depends on the vapor pressure of water you have already learnt. Those things in humidification of pressure in mass transfer two course. Now, water being a very cheap solvent, we do not account for that loss. If we have to reduce the loss then we have to

decrease the temperature of absorber. However, in some cases that loss may be so high that it can completely kill the economics of the absorber system. Those things we will deal with in the next lecture.