Process Design Decisions and Project Economics
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Module - 2
Flowsheet Synthesis
(Conceptual Design of a Chemical Process)
Lecture - 5
Input / Output Structure of Flowsheet – (Part I)

Welcome. Today, we shall see the input, output structure of flowsheet that is the second lecture of this module the flowsheet synthesis. In the previous lecture, we saw as what input information is available, when we start the designing, the processor we have the reaction basic chemistry of reaction, the Stoichiometry, the reaction conditions, the catalyst and so on and so forth. And then we saw how this information needs too improved, when we start designing a large scale of process from the laboratory experiments.

For example, we need to know the purity of raw materials. The raw material that is used in the laboratory experiments is very pure, but that purity may not be achievable in un-commercial scale. Therefore, we have to see as what side reaction? Or what impact the impurity in raw materials will have on the process. And then we saw as what factors governor the selection of batch verses the continuous nature of the process. Whether, we should go for a small scale batch process, or large scale continuous process.

Now, we found; there are several factors that effect this particular decision. First is the market force. The type of product that you have, the life time of the product and then other factors such as process constrains, suppose your reactor is reaction contains a materials that is thermally decomposing, which we can fund cook and the deposit on the reactor wall or, you have reaction conditions in which falling will occur, where you will have set down the device the reaction vessel and clean it very often. So, in those condition continues process is not possible, and then we saw the level of or the kind of decisions that we have to make while designing a continuous and batch process.

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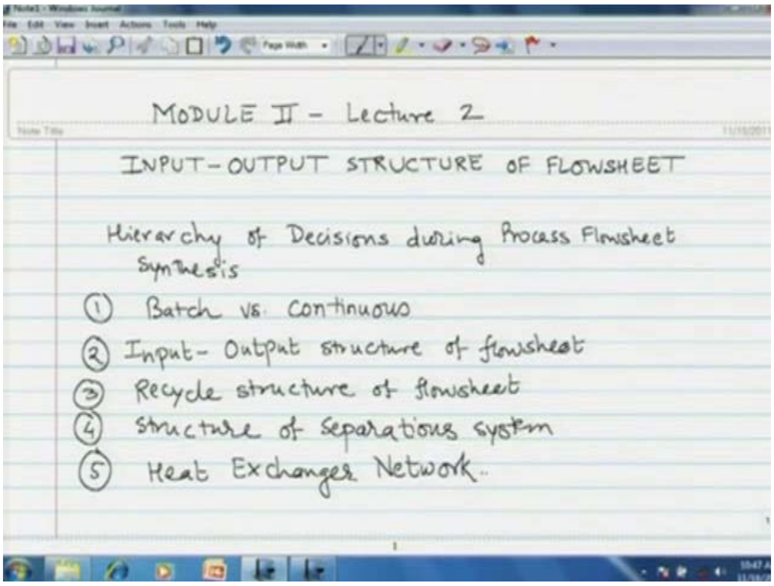

Now, in today's lecture; we go one step ahead and then see the input output structure of the flowsheet. Input output structure of the flowsheet essential means, drawing the box around the process and see what are the raw materials are coming that are going into the process. And what are the products that are coming out. This is essentially the level 2 of the hierarchy of decision during process flowsheet synthesis. The first decision we have already seen that batch verse continuous, second will the input output of the flowsheet, third will be the recycle structure of flowsheet and then come separation system and then heat exchanger network.

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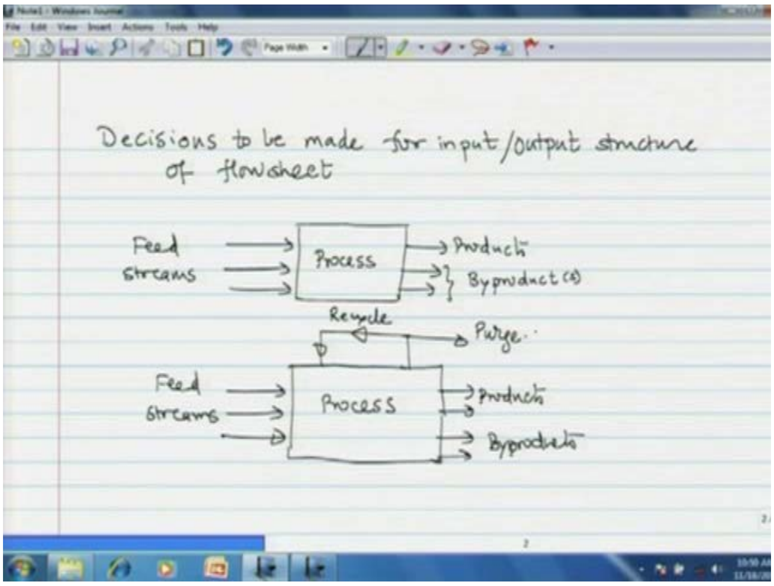

So, we are at the level 2. Let us see, what decisions we need to make for input output structure of flowsheet. In the most general form the input put structure will look like this, a box is representing the process and then reactants going in or the feed stream and then product as well as byproduct coming out of the process. Another structure of flowsheet could be that including a recycle and purge stream. Now, under what circumstances we need to use a recycling purge that we will see in the later part of this lecture ok

So, this particular flowsheet would look like this feeds stream going to the process products and byproducts coming out. And then there will be a recycle stream and purge stream. Why do we need to assess the process with such kind of flowsheet? In many petro chemical processes and also other processing industries, the processing cost is about30 to80 or, even 100 percentage of raw the materials cost.

In such cases, we need to assess the value addition of the process. We need to do material balance from outside process as what is the total cost of material that is going in and what is the total cost of material that is coming out. And then if that economic potential is promising then we needs to go to the next stage.

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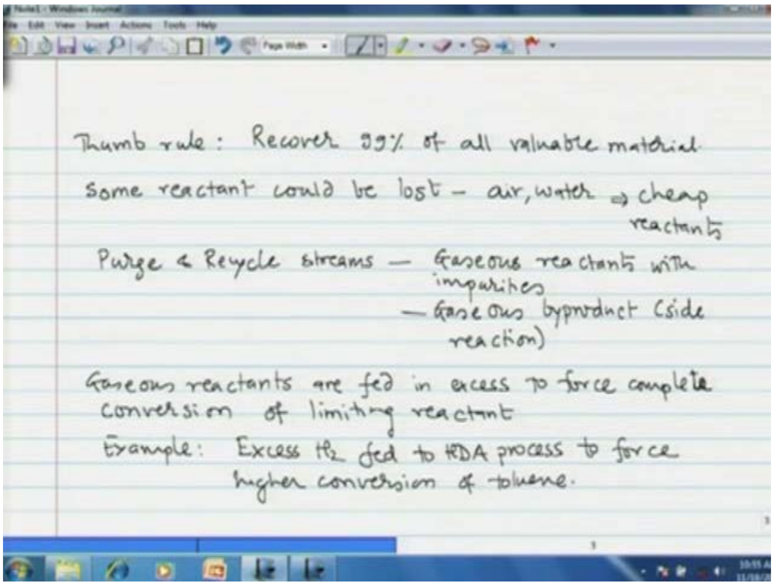

Another thumb rule is that, we have to recover 99 percentage of all valuable material. Now, as you will see in both of the general type of flowsheet no reactant leaves the process. That means, we recover all valuable reactants to all most 100 percentages and recycle them into the process. Because in many processes the value addition is limited so the lost of reactant could inverse adversely affect the economy of the process. Now, some reactants could be lost and what are those reactants? The one those are cheapest. For example, air or water now, we would not like to recover air because air is free you can use as much as you can. Water in some cases is recycled into the process, if the process plant is not located in locality where water is abundantly available. Now, those factors we are going to see in detail in process economics part so we do not discuss them here,

Now, as per as the purge and recycle streams are concerned; these are used, when you have gases reactants with impurities or, you have a gases byproduct which could may be side reaction. If we recycle all the gas that comes out of the process which includes the UN reacted reactant. Then these impurities or byproducts make at accumulated into the process. And which would make the recycle look larger and larger and then ultimately that would hamper in the process ok

In some cases, the byproduct can trigger further side reactions so it is very essential to remove these byproducts from their reaction. In many cases the gases reactants are feeding exists to force complete conversion of the limiting reactant. Examples, of this would be excess hydrogen feed to H D A process hydro deal alcoholism process to force higher conversion of tolere. Now, we saw in previous lecture; that methane is comes as an impurity with hydrogen, methane is also generated in the reaction. Therefore, it is essential to keep the level of methane below certain limit in the process. And hence a purge stream is ((Refer Time: 10:21)) but obviously, hydrogen also lost from the purge streams.

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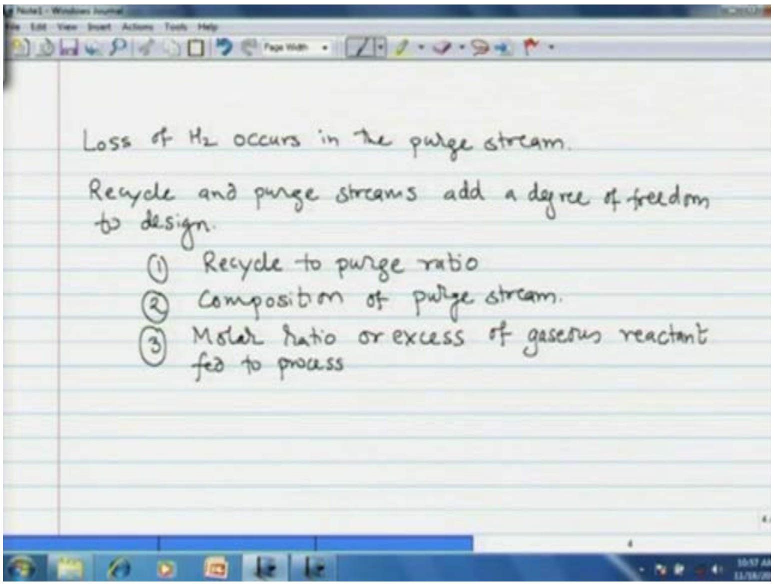

So, that is the loss lost of hydrogen occurs in the purge stream. Now, recycling pure streams had a degree of freedom to the process design. And the variables that represent the degree of freedom are the recycle to purge ratio, how much gas we should throw out as purge. And second the composition of the purge stream. Another variable that comes indirectly with recycle and purge stream is the molar ratio or excess of gases reactant that is feed to the process.

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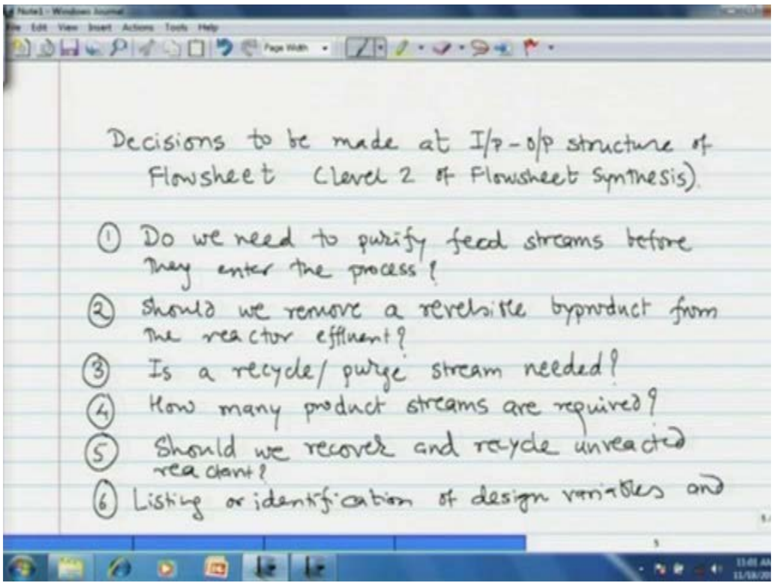

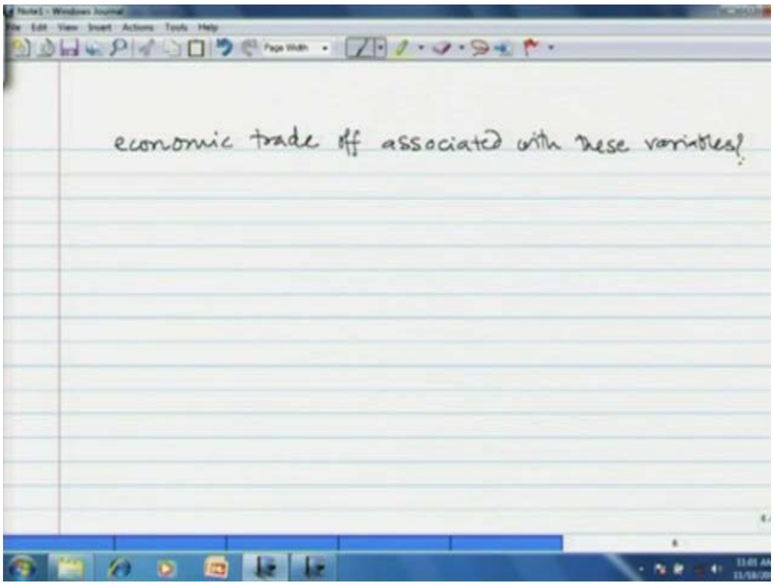

With this introduction now, we shall see what are the decisions, that we need to make while deciding the input output structure of flowsheets. Now, as we saw input output structure of the flowsheet is level 2 of flowsheet synthesis. Now, the decisions are in the first place. Do we need to purify the recycle stream I am sorry, that do we need to purify the feed stream before they enter the process? Then should we remove a reversible byproduct from the process or, from the reactor effluent the stream coming out of the reactor? And third decision is that is a recycle purge stream needed?

Then, forth is that; how many products streams are required? And then should we recover and recycle un-reacted reactant? And finally, listing of design variables and then the economy trade off associated with this variables? As we will see; in the following discussion, every variable will have 2 sides. It is like a 2 sides of coin, if you increase that variable some benefits will occurs, some demerits. And if you decrease that variables some benefits and some demerits so that is what we mean by economy trade off.

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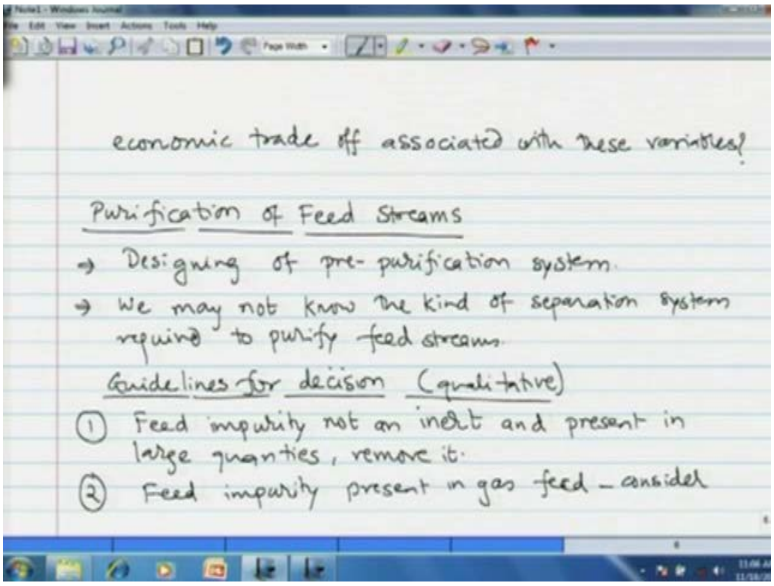

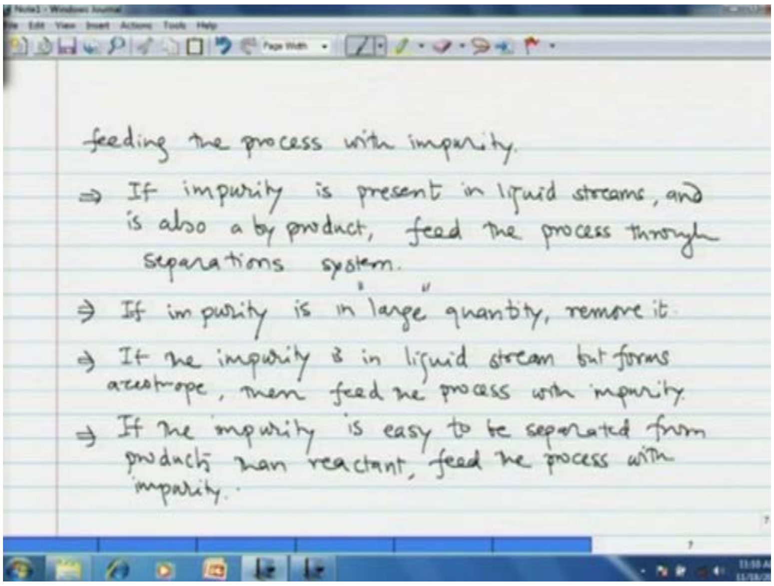

Now, let us see each of these decisions 1 by 1. The first decision was; the purification of the feeds stream. Now, purification will necessitate designing offer pre purification system. Now, in some cases; you may like to feed the process from tail rather then head which means, if the impurities present in the feeds streams are also byproducts of the reaction then it is a good idea to feed the process from back. So, that sorry, to feed the process from front so that these impurities get removed along with byproducts of the process. And then relatively pure streams can be obtained at ((Refer Time: 17:20)).

However, we may not know what kind of separations system that is required to purify the feeds streams. But still let us see under what circumstances we should purifier or, we should not purifier the feeds streams. So, some guidelines for decision are as flow of course, these guideline are qualitative not quantitative. First, if the feed impurity is not inert and is present in significant quantities, it is better to remove it at the inlet of process. That point we note feed impurity not and inert component, which means it is going to trigger side reactions, give further byproducts which would complicate the separation system design.

Then the next guideline is that if the feed impurity is present in the gas feed stream first consider feeding the process with impurity. Now, why is that because separating impurities or gases impurities is difficult? We require a membrane process which is an expensive component in terms of both capital and operating cost for the process. So, when you have an impurity in the gas stream first consider feeding the process with impurity. That point also be note, feed impurity present in gas feed then consider feeding the process with impurity.

Now, of course, if the impurity is a catalyst poison then we have to remove it at any cost. So, that point we will deal late. Then if the feed impurity is present in liquid stream and is also byproduct of the process as I said. Then it is better to feed the process from head rather than tail. Then if the impurity is in large quantity whether it is inert or not inert that does not matter, if impurity is in large quantity then it is better to remove it, because it will unnecessarily oversize the reaction equipment. However, the word large is qualitative there is no quantitative guideline as how large is large. So, that point you note, if impurity is in large quantity remove it ok.

Then, if the impurity is in liquid stream but forms and Azeotrope with the reactant then feed the process with impurity. Azeotropic distillation is one of the expensive operations of chemical industry. So, if you have to remove an impurity that is forming Azeotrope, you have to go for either extractive distillation or either entertainer which will add to the cost of processing. So, it will be good idea to feed the process with the impurity.

Now, depending on the process it could be that the impurity is easy to separate from products then reacted. And then you can afford a feed with impurity that point also be note. That if the impurity is easy to be separated from products than reactant then feed the process with impurity. And finally, if the impurity is a catalyst poison then we have to remove it no matter the cost is involved because catalyst is one of the most expensive components of the process.

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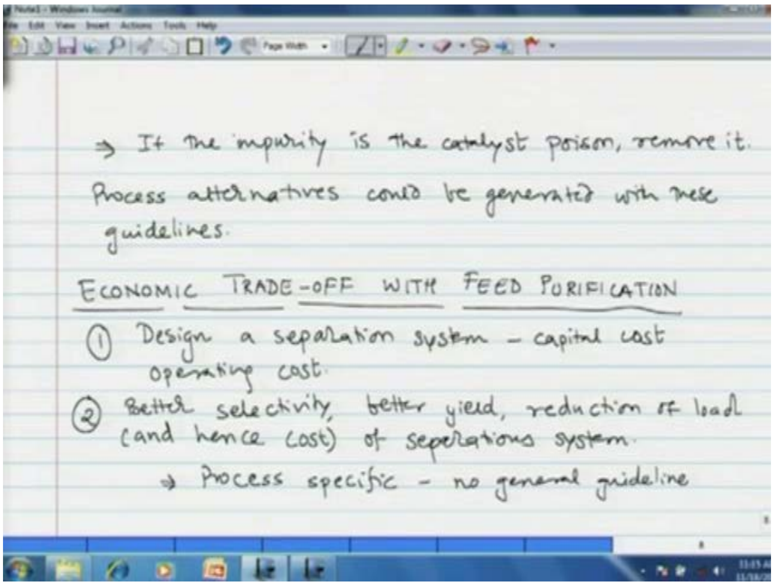

So, that point we know, if the feed impurity is catalyst poison as many sulfur containing gases or sulfur containing liquid reactants, we have to remove the impurity. Now, if you are not sure, that any of the guideline that we choose for designing the process is correct, then we list the other option as process alternative. So, process alternatives could be generated with these guidelines.

Now, what are the economic trades off with feed purification? One side of the coin is that you have to design a separation system to remove the impurity. So, you have capital cost, additional capital cost and then the operating cost for the system. However, the benefit from feed purification is that, better selectivity, better yield and since selectivity is large, you cut down the cost of separation system, so the reduction of load and hence the cost of separations systems. Now, both of these factors are reaction specific or process specific, you cannot use any of these as a general guideline. So, the decision whether you have to purify the feeds streams or not depends on the process.

For example, in the process of caustic soda manufacture using membranes, the brine has to be purified to P P B level to reduce the contain of hardness like, irons like, calcium magnesium. Now, this would require use of expensive ion exchange diarizing columns. However, if you do not purify brine to that level, the ions that represent like, calcium magnesium they can damage the membrane which is far more expensive component of the process. Therefore, you have to go for feed purification system although it adds to additional cost of the process.

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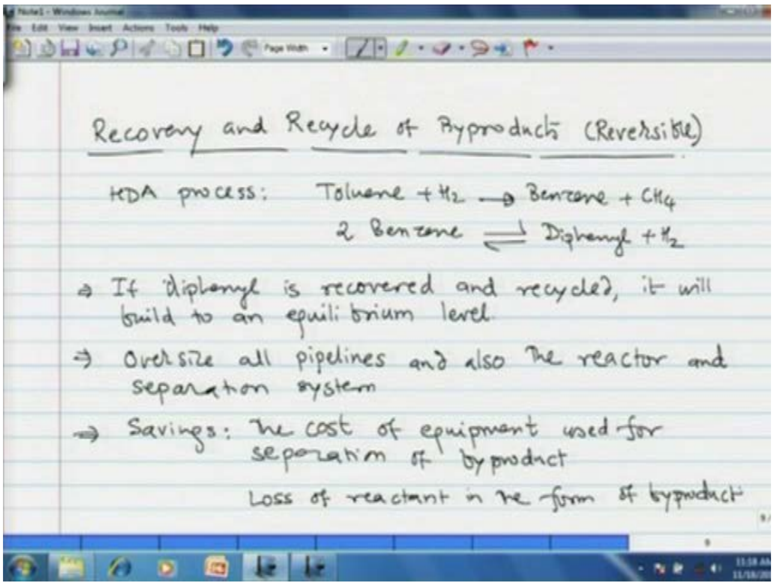

Now, let us see recovery and recycle of byproduct especially, the reversibly byproducts. Now, this we shall see with the example of H D A process. I would write again the basic reaction involved in H D A process toluene plus hydrogen gives benzene plus methane and 2 moles of benzene combine reversibly to give a byproduct Diphenyl with the liberation of hydrogen

If we recycle the Diphenyl rather than removing it then it will beat to an equilibrium level in the process and it will stay constant. If Diphenyl is recovered and recycled, it will beat to an equilibrium level in the process. Now, to accommodate this additional component, you will have to oversize all pipelines and also the reactor separation system. However, we save the cost of equipment used for separation of the byproduct. And we also save the lost of reactant in the form of byproduct. Let us see this trade off with the example of H D A process.

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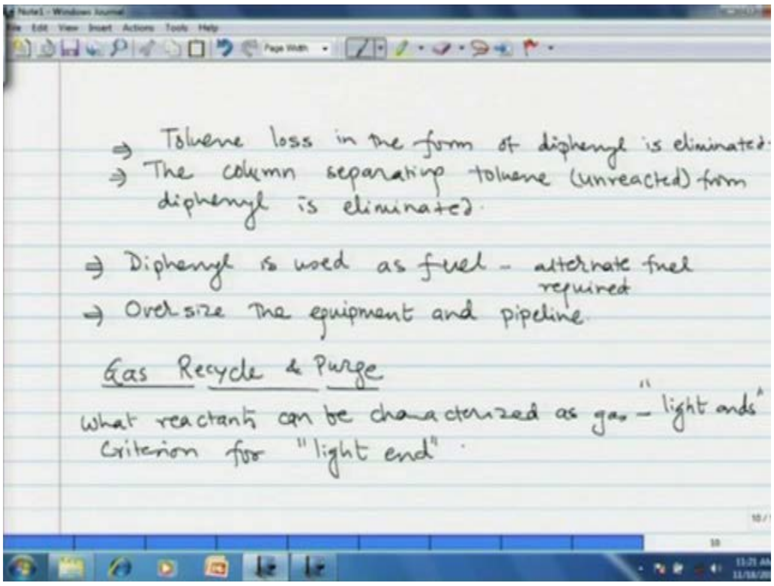

If you recover Diphenyl, then toluene loss in the form of Diphenyl is eliminated. Second, the distillation column separating toluene, the UN reacted part of the toluene from Diphenyl is eliminated. However, Diphenyl is used as a fuel in the process so; you will have to buy now, alternative fuel. And then as I guess said you will have to oversize the equipment and pipeline. Now, let us see what factors govern decision on gas recycle and purge stream. As I mention earlier, gas recycle and purge stream adds a degree of freedom to the process in terms of the ratio of recycle to purge and the composition of purge stream. However, when gas stream should be purged, in the first place we will see; what reactants can be characterized as gas now, in process industry this component are also called as light ends. So, we have to first see the criteria of light end.

Since, the transport of liquid stream is much easier than, gas streams for liquid transfer to only need a pump. You would like to have as much of reactants in gas space in liquid phases as possible and affect gas too. But in some cases; light ends cannot be avoided so for light ends here we use a criteria of liquefaction.

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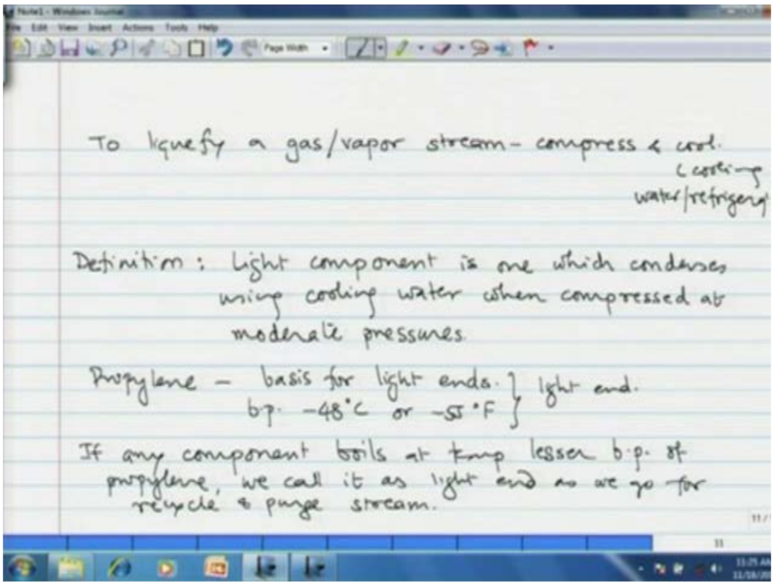

To liquefy, a gas or vapor stream, you need to compress and cool or condense. Now, cooling could be with simple cooling water or with refrigeration. Now, if we define a light component as the one which condenses using cooling water when, compressed at moderate pressures then we can use propylene has a basis. Propylene will condense with cooling water when compressed 2 pressures about 8 to 10 bar ok.

Therefore, if the boiling point of the particular component is below the boiling point of propylene which is minus 48 degree centigrade or minus 55 degree Fahrenheit. We would characterize that component as light end. Therefore, if any component boils at temperature lesser than boiling point of propylene, we would call it as light end and then we have to go for a gas recycle and purge stream. Now, new technologies are available for separation of gases components like, membranes process. But not much cost as available where we can, I means while designing the membranes process so that factor we keep aside.

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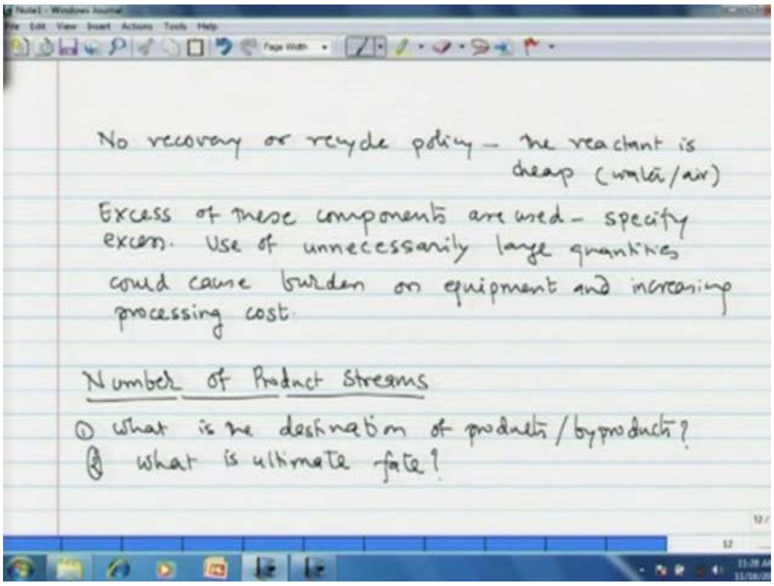

When, we go for No recovery or recycle of a particular reactant. Obviously, when the reactant is cheap like water and air now, excess of these compounds components used are used in the process. For example, in combustion reaction we used excess of air. However, air contains only 20 percentage oxygen, 20 more percentage oxygen then 80 percentage nitrogen which a relatively inert component.

Therefore, when we choose excess; we have to define how much excess, because giving unnecessarily large quantities of air could put burden on your bluer, which uses electricity for operation. So, that point is also being note. Excess of components used specify excess. Use of unnecessarily large quantities would cause burden on equipment. And increasing the operating cost then we see the decision of the number of products streams. The products and byproducts emerging from the process; what is their destination? And what is their fate, what we would ultimately do with these products and by products?

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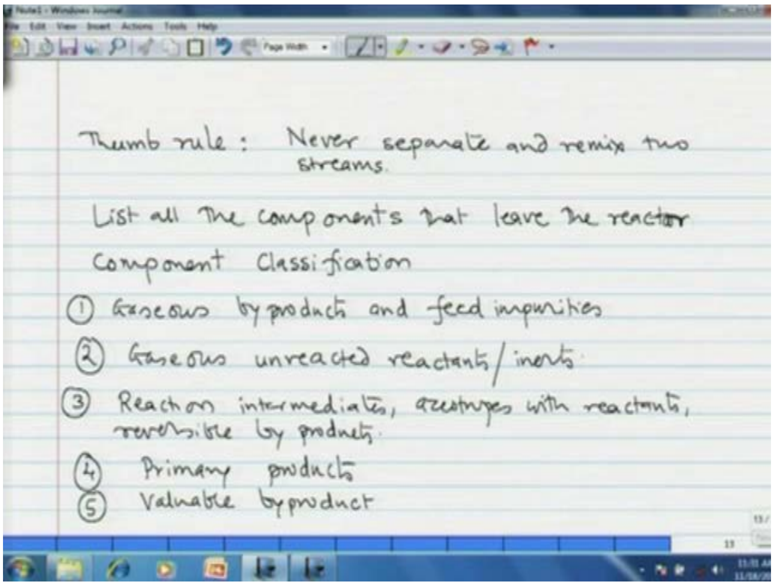

Now, a thumb rule that governs the number of the products stream is that; never separate and remix 2 streams. Now, to decide upon the number of the products streams, we will have to list all the components that leave the process or leave the reactor leave the reactor. Now, what are the component classification many components, newer components will leave the reactor. But how do you classify them? Component classification, we need to classify these components before we decide the destination of them.

First category of components is gaseous byproduct and the feed impurities. That would come out of the reactor UN reacted. Then second are gaseous reactants UN reacted. Now, this UN reacted reactant may also contain some inerts. Then third category is reaction intermediates then Azeotrope with reactants. Then reversible byproduct we put them in the same category then the liquid reactant sorry, and the primary product then valuable byproducts.

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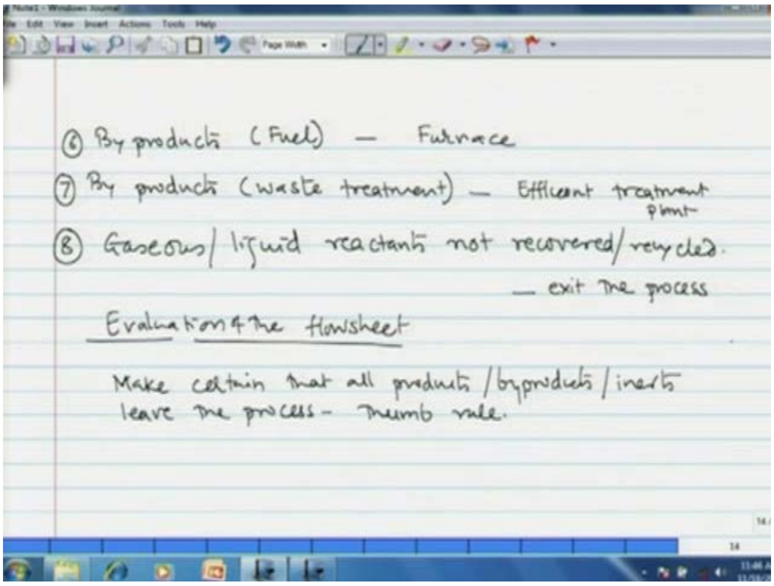

Then, the byproducts that could be used as fuel and byproducts that could that need treatment before disposal. Now, some reactants may not be recovered and recycled so we list them separately. Gaseous or liquid reactants not recovered and recycled. Now, let us see, what is the destination of each of this category of components; the gaseous products sorry, gaseous byproducts and feed impurity, if they are small in quantity they could be vented. However, we need to scarab this gas to remove the polluting components. Then the gaseous UN reacted reactant plus inert.

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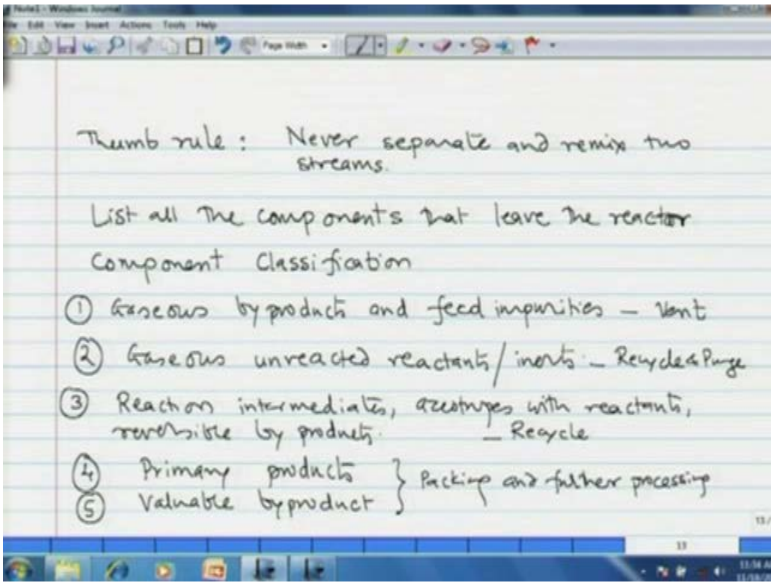

Now, you have here the option of recycle and purge; reaction intermediates Azeotropic reactants, reversible byproduct you have the option of recycling that. You may also remove them; but it is better to recycle them back to the reactor. Primary product and valuable byproduct will go to packing and further processing. Or, let us say packing and further processing. Byproducts that are used as fuel may go to furnish or other heat equipment that is in the process.

The waste byproducts or liquid byproducts that need waste treatment to remove or to lower. The B O D or C O D may go to efficient treatment plant and the gaseous and liquid reactants that are neither revered nor recycled can leave the process. Or, let us say they exist the process. Gaseous reactants can be simply vented liquid reactants can be break.

Now, while evaluating a flowsheet; we have to assure that all reactants UN reacted reactant and byproducts and products leave the process. At each stage we have to evaluate the flowsheet. And the thumb rule that we used is that makes a return that all products, byproducts and inters leave the process. This is a thumb rule that is to be used for evaluation of the flowsheet.

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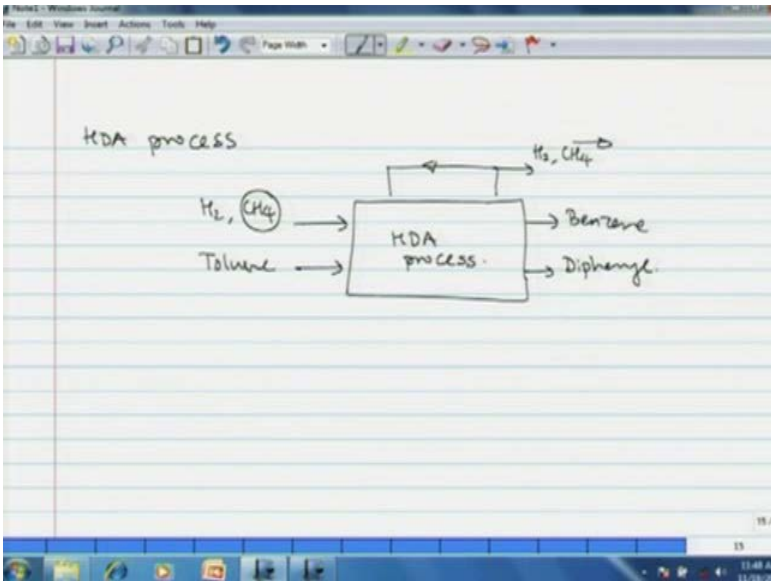

Now, let us take example of H D A process, the input output structure process of the H D A process would look this you have 2 feeds streams, the gaseous feeds stream of hydrogen with inert methane as impurity. And then toluene and the main product is benzene, side product if it is recovered and not recycled is Diphenyl. And then you have the recycle and purge stream containing methane and hydrogen. Now, the impurity main impurity in hydrogen is methane and we have to make sure that while designing the process; all inert that enters with fresh hydrogen should leave with the purge.

We also need to consider, what the impurities that could be present in toluene are. Now, these impurities can give further side reaction like formation of trephine etcetera. However, to make the process operable, we have to make sure that all products, byproducts and inter leave the process; that is the thumb rule. If any inert is not removed then it may buildup in the recycle loop and then will make process inoperable.

So, in this lecture, we have seen certain decisions for deciding the input output structure of the flowsheet. In the next lecture, we shall try to identify the major design variables and then we shall try to do an overall material balance around the process. And then evaluate the cost of various streams; feeds streams, products streams, byproducts stream, purge stream and then finally, decide the economic potential of the process.