

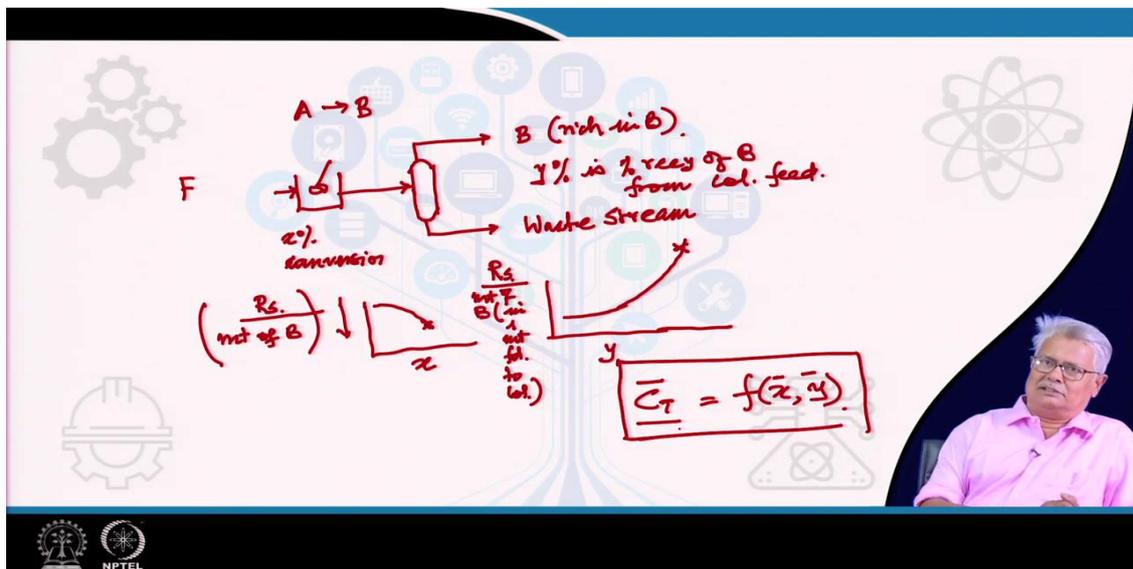
**Principles and Practices of Process Equipment and Plant Design**  
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**Department of Chemical Engineering**  
**Indian Institute of Technology, Kharagpur**

**Lecture - 03**  
**Optimum design and design documentation**

Good morning. In the first two lectures, we had the introduction to the design, how the design processes, what exactly is a process and such details. And at the end of the second lecture, we had come to a point where we were talking about optimal design. And there we had one specific statement which is rather strong that whenever we are going to design a large system which has got several sub components. It is not essential that we would like to perform maximization of each of these units individually.

This was shown on the last slide of the last class. Today, what I want to do is basically start from that particular point. I had committed earlier that optimal design will start with an example of a reactor with a separation system. In most reactor systems, you have a separation section which follows it; it separates the products, makes it recoverable and then stores it.

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A typical example of reaction where reactant 'A' converts to 'B' inside a CSTR. Inlet feed rate is 'F'. The outlet goes to a column, possibly a distillation column. It could be other type of

separation arrangement also. The separation unit produces a product of B, basically it is rich in B, which is of desired product and a waste stream.

Let's say 'x' percent is the conversion, and here 'y' percent is the percentage recovery of B from the column feed. Now, look at these two individual processes carefully. If we want to see the cost parameter which is based on the x and the y values, we can put it like this with a conversion increasing the rupees per metric ton of B will keep on reducing, that means, you will have a curve like this.

$$x \uparrow \rightarrow \left( \frac{Rs}{mt \text{ of } B} \right) \downarrow$$

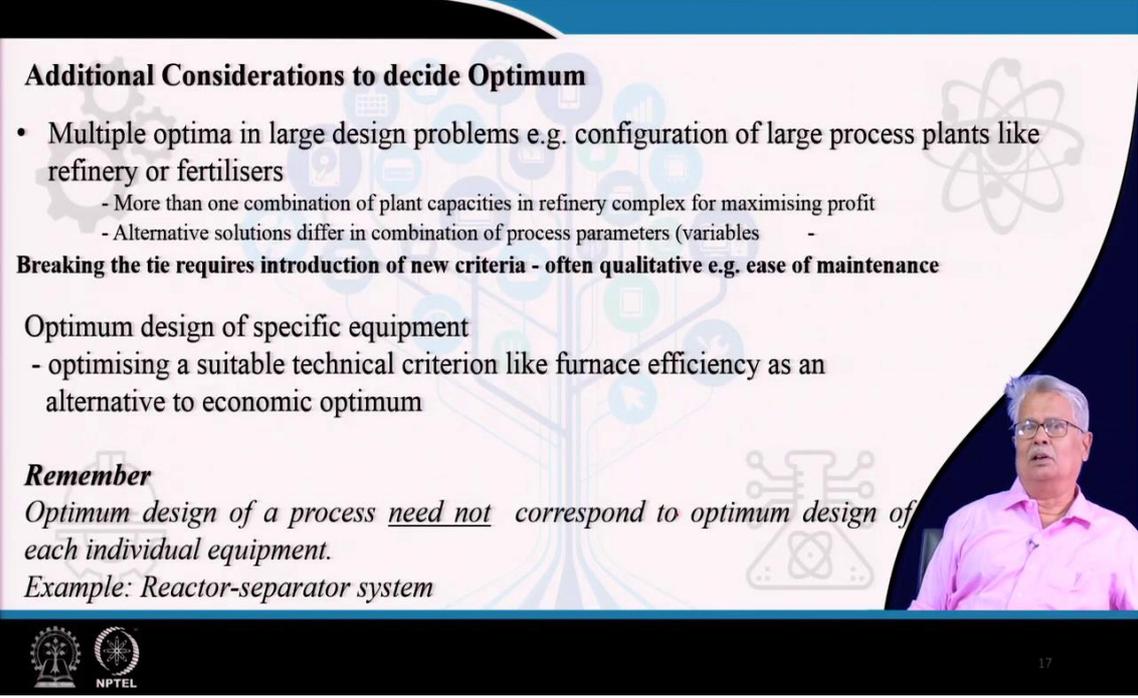
That means, if I have a higher conversion, in that case my production cost per ton of B just from the reactor comes down. And similarly if we plot against y recovery vs the cost of recovery, that means, the recovery cost is basically in rupees per metric ton of B (which is coming from 1 metric ton of feed to column). That means, recovery of B basically is related to the feed and the feed concentration. You will find that initially if you produce it will keep on going up. That means, if you recover more and more, there will be a sharp increase in cost.

So, final total cost is basically a function of x and y. You would like to operate the system so that total cost will be as low as possible. Ideally, you would like to recover as high as possible actually. But since if you look at this and if you solve such a problem, you will find there is a combination of  $\underline{x}$  and  $\underline{y}$  which are the corresponding values of x and y which optimize the total cost and that is the optimized design for such a system. This is what I wanted to say in my last class.

This is very important particularly while you are designing large systems. We also have talked about bringing in new conditions particularly when your number of design variables are large. That means, your objective function like the cost here is a function of a large number of variables and a large number of constraints. Specifically, if they are non-linear, you will always find there is a possibility of having multiple solutions to your optimization problem.

That means, there is a case of tie between the solutions which have the same objective function. So, in order to break the tie, you will be required to bring in new considerations.

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**Additional Considerations to decide Optimum**

- Multiple optima in large design problems e.g. configuration of large process plants like refinery or fertilisers
  - More than one combination of plant capacities in refinery complex for maximising profit
  - Alternative solutions differ in combination of process parameters (variables)

**Breaking the tie requires introduction of new criteria - often qualitative e.g. ease of maintenance**

Optimum design of specific equipment

- optimising a suitable technical criterion like furnace efficiency as an alternative to economic optimum

**Remember**

*Optimum design of a process need not correspond to optimum design of each individual equipment.*

*Example: Reactor-separator system*

The slide features a speaker overlay on the right side, showing a man in a pink shirt. The background of the slide is light blue with faint technical icons like a gear, a circuit board, and a molecular structure.

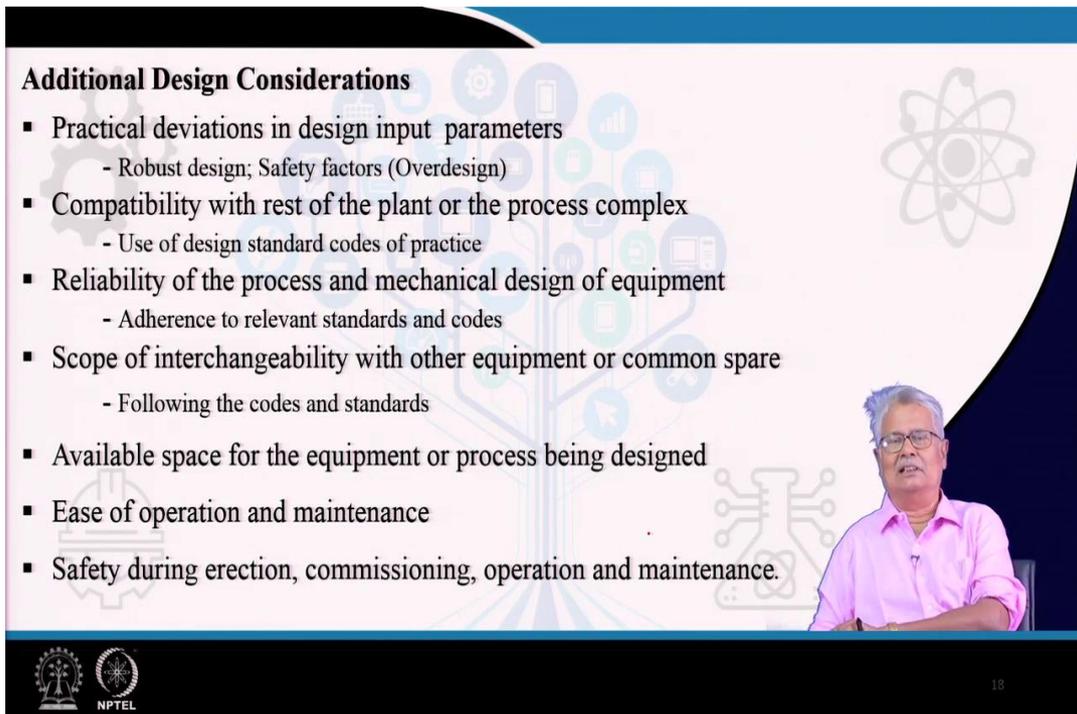
These considerations could be what I am listing here. The first thing it could be the multiple optima definitely we recognize. For example, in large process plants like refinery or fertilizer, they do exist. An example of this is more than one combination of the plant capacities for generating maximized profit of your plant; that means, there are alternative operating or alternative design options for the refinery or the fertilizer complex.

So, we have to break this. That means, out of these options, we normally bring in a new criteria; a typical such a criteria could be ease of maintenance as I have listed here. You could also bring in criteria like a lower amount of pollution among these two competing options, and decide based on which criteria you are going to set your actual plan which has the same optimum objective function with that means the economic objective is the same.

But you are bringing in the new criteria which could be either a quantitative criteria or a qualitative criteria as examples of maintenance and pollution that I have given here. You definitely can design other criteria. In case of specific equipment optimizing, the design usually will involve instead of economic parameters, suitable technical criteria like the furnace efficiency which could be an optimum alternative. That means, instead of economic optimum what you do is you try to maximize the efficiency of a problem.

So, basically I repeat again that when you design a complex or a large system, you definitely need not always maximize the individual units. It is the whole optimum combination of the different units and the sub modules which need not be maximized, or minimized, or optimized individually is to be seen at.

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**Additional Design Considerations**

- Practical deviations in design input parameters
  - Robust design; Safety factors (Overdesign)
- Compatibility with rest of the plant or the process complex
  - Use of design standard codes of practice
- Reliability of the process and mechanical design of equipment
  - Adherence to relevant standards and codes
- Scope of interchangeability with other equipment or common spare
  - Following the codes and standards
- Available space for the equipment or process being designed
- Ease of operation and maintenance
- Safety during erection, commissioning, operation and maintenance.

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When we are talking about the designs and the design consideration, we should also remember a few things. Our design is basically based on certain inputs, but these inputs are decided by us. It is not exactly the exact value of the input design that has been used, but will be available when the design comes to practice. Robust design is one in which the design which I am producing can tolerate input variations, the design input variations within a limited level.

We normally resort to safety factors, that means, we slightly over design when we have to take care of certain uncertainties, but there are mathematical techniques to evaluate such uncertainties and robustness of a design mathematically as well which we are not going to really hear in details, but there are techniques for this we will know this much. Normally, it is based on a sort of statistical random simulation of your design and looking at the result of that.

When we are talking about additional design considerations, one of the major things is the compatibility with the rest of the plant. That means, if part of the plant has been designed as

per the ASME code, it is desirable that whatever new design that I make, should also conform to that in order to make it compatible.

The reliability of the process and mechanical designing of equipment definitely is greatly improved if we refer to the relevant standards and codes. There are codes which relate to the material quality, there are codes which relate to the design of pressure vessels, there are codes which relate to the design of heat exchangers and columns and other things.

Definitely, making a design as per the code gives us certain advantages like interchangeability of equipment, reliability of equipment. Also, following a uniform code will definitely attract less insurance price which is normally particularly for hazardous plants, a large fraction of the operating cost – a reasonably large.

There are practical considerations which have to be there like the available space for the equipment; the ease of operation and maintenance; and certainly the safety during the erection, commissioning, maintenance and operation, it cannot be ignored.

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**Role of design codes and standards in design**

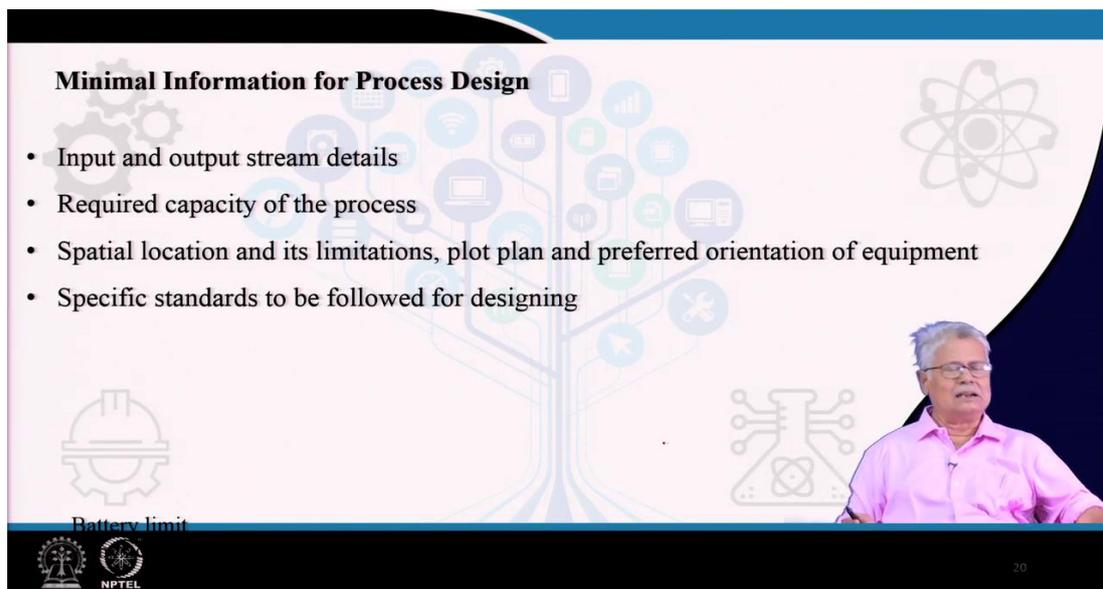
- ✓ Generate design compatible with the rest of the facility
- ✓ Ensure reliability of equipment.
- ✓ Interchangeability with other equipment or common spare
- ✓ Standard material of construction – readily available
- ✓ Standards greatly reduce time to deliver *reliable* design and get it fabricated.

The slide features a background with various technical icons like gears, a circuit board, and a molecular structure. In the bottom right corner, a man with glasses and a pink shirt is visible, likely the presenter. The NPTEL logo is in the bottom left corner, and the number 19 is in the bottom right corner.

We talked about a reliable design that means the design has to be functional in practice that is the first and the foremost requirement. The second thing is the design has to be reliable; that means if I am designing for a client, the client should be confident that I have designed it correctly, and he gets much more confidence in me when I tell that I have designed this as per the standards or certain design codes which are applicable for his specific design case.

We definitely will be generating some sort of compatibility with other equipment which are designed with the same code. It will make the design reliable. It will ensure interchangeability. There are material standards which ensure that the material which is available and which is being used or to be used for my design is of standard quality. Basically the use of standards helps in another way by reducing the delivery time of generating a reliable design and to get it fabricated.

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**Minimal Information for Process Design**

- Input and output stream details
- Required capacity of the process
- Spatial location and its limitations, plot plan and preferred orientation of equipment
- Specific standards to be followed for designing

Battery limit

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Perhaps now we should focus on the process design problem. Normally, whenever we design a process, we need to know the boundary limit, that means, whatever streams are input to this particular boundary and what are the output streams leaving this boundary. We definitely have to have an idea about the required capacity; it is 6 tons per hour or 0.6 ton per hour.

The spatial location and its limitations for example, the space available, the contour of the ground on which we are going to build this. If we need the wind direction in order to have a proper safe orientation of equipment. We definitely need to decide on the specific standards to be followed for designing. So, these are the basic minimum requirements before you start your design.

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**Design Problem and its Documentation**

- *Expression of functional interest*  
*Concept design phase –*
  - Designer considers potential alternatives and compares those heuristically.
  - Based on heuristics and experience, a finite number of alternatives are selected
- *Preliminary design specifications' (PDS document)*  
Attempts to identify & quantify the design deliverables - capacity, material & process fluid, properties, process stream conditions at inlet & outlet of process...  
  
- Marks start of process design

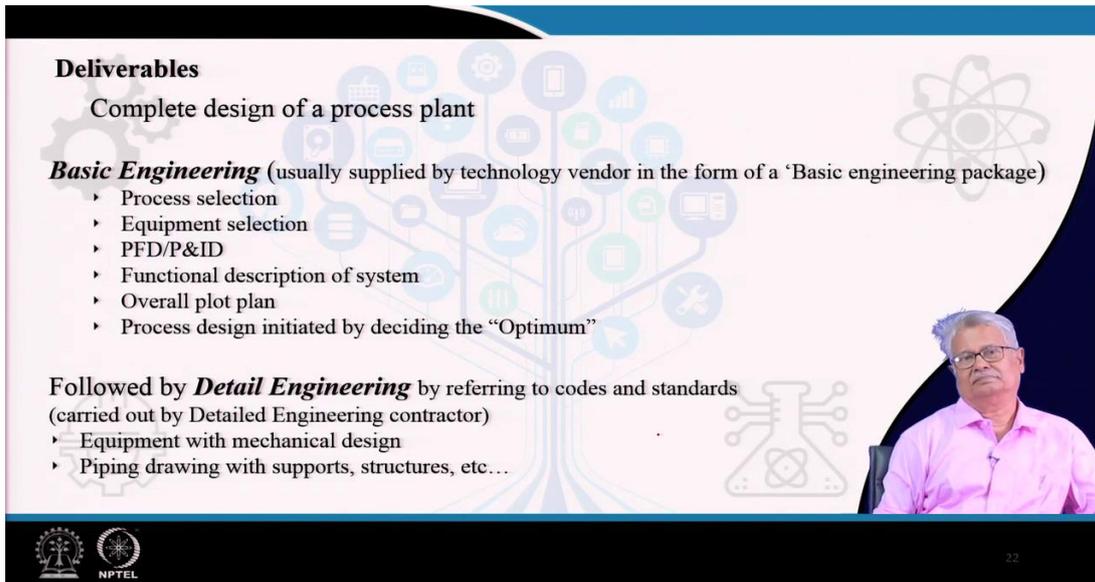
The slide features a background with various icons related to engineering and design, including gears, a tree, and a circuit board. In the bottom right corner, there is a video inset of a man with glasses and a pink shirt speaking. The NPTEL logo is visible in the bottom left corner, and the number '21' is in the bottom right corner.

Now, the problem of design is rather initially pretty vague. Your client will have an expression that he would like to have a plant which manufactures ammonia. So, he expresses his functional interest. Then listening to that, the designer will conceptualize the product design that means, the product is basically the design which he has to deliver.

What he does in his mind, he definitely will be considering different technologies for this ammonia plant. But all these will initially be done mostly in his mind without doing any quantitative calculation, that means, he heuristically come things, and he heuristically decides these are the companies and these are the technologies perhaps which can meet the requirement of my client.

Based on the heuristics and experience, he decides finally a finite number of alternatives. Now, based on these, at this particular point, a preliminary design specification which is much more detailed than the functional interest which is typically called the PDS document is produced. It attempts to identify and quantify the design deliverables, that means, this outlines clearly the deliverables from the design – the capacity, the material, the process fluid, properties and such things. This marks the start of process design.

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**Deliverables**

Complete design of a process plant

**Basic Engineering** (usually supplied by technology vendor in the form of a 'Basic engineering package')

- Process selection
- Equipment selection
- PFD/P&ID
- Functional description of system
- Overall plot plan
- Process design initiated by deciding the "Optimum"

Followed by **Detail Engineering** by referring to codes and standards (carried out by Detailed Engineering contractor)

- Equipment with mechanical design
- Piping drawing with supports, structures, etc...

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If you look at the deliverables, when we are talking about a complete design of a process plant that is the deliverable. Now, the question is what exactly is a complete design? Your delivery of the design document should be such a document which will contain the complete design of a process plant. That means, based on this possibly, only the detailed engineering can be done. Then, the fabrication of the equipment can be done, erection can be done; the plant can then be started.

I have used the term basic engineering. The basic engineering document is basically supplied by the technology vendor in the form of a basic engineering package. A typical example of this is the Merox plant, which is meant for removing mercaptans from light hydrocarbons, is a technology which is sold by Universal Oil Products which is UOP.

What they do is to the client, they provide a basic engineering package. It talks about the process, the equipment selection and the selected vendors from which the equipment can be purchased, it includes a "PFD", it includes a "P & ID" details. It has a functional description of the system. It has an overall suggested plot plan. The process design is after this and is expected to be optimized.

This definitely is a document on which the detailed engineering is started. The detailed engineering will definitely involve codes and standards.

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### Deliverables

*Block Flow Diagram*

- Sub-processes as individual blocks
- Provides overall idea of large and complex plants consisting of several processes
- Only important features shown

The deliverables, the first thing whenever we are talking about a process design will be a flow diagram. It is going to be a block flow diagram that means the sub processes being conceived as blocks as shown in the attached figure here presented. These are the individual blocks. If you look at it, it provides the overall idea of the large and complex plants. What all sub blocks or sub plants it consists of, but it contains and displays only the important features.

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### Process Flow Diagram

Starting basis for generating the detailed design of a plant

- Process scheme with streams
- Major equipment symbols, names and identification numbers
- Interconnection with other systems
- Major bypass and recirculation lines
- System ratings and operational values
- Composition of streams

**Stream table**

(i) stream flow rate, (ii) flow rates and composition of stream components,

(iii) temperature, pressure

(iv) phases (V/L/S/mixture) flowing

(v) enthalpy

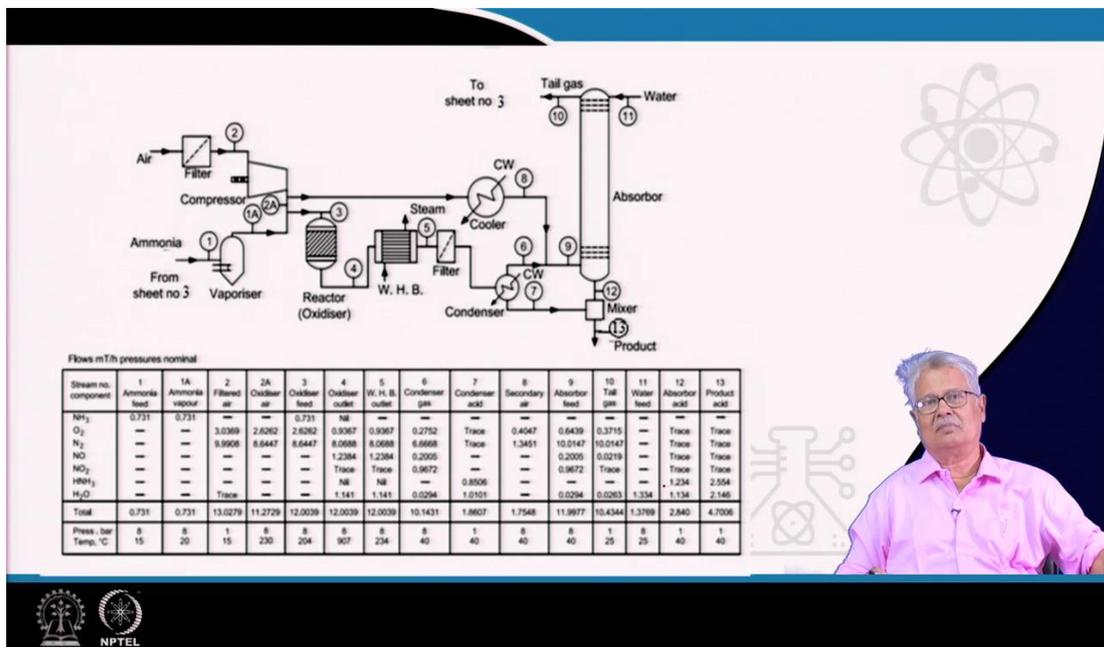
Flows mT/h pressures nominal

Stream no. component	1 Ammonia feed	1A Ammonia vapour	2 Filtered air	2A Oxidiser air	3 Oxidiser feed	4 Oxidiser outlet	5 W. H. B.	6 Condenser gas	7 Condenser acid	8 Secondary air	9 Absorber feed	10 Tail gas	11 Water feed	12 Absorber acid	13 Product acid
NH <sub>3</sub>	0.731	0.731	---	---	0.731	0.8	---	---	---	---	---	---	---	---	---
O <sub>2</sub>	---	---	3.0369	2.6262	2.6262	0.9367	0.9367	0.2752	Trace	0.4047	0.6439	0.3715	---	Trace	Trace
N <sub>2</sub>	---	---	8.9908	8.6447	8.6447	8.0588	8.0588	6.8666	Trace	1.3451	10.0147	10.0147	---	Trace	Trace
NO	---	---	---	---	---	1.2384	1.2384	0.2005	---	---	0.2005	0.0219	---	Trace	Trace
NO <sub>2</sub>	---	---	---	---	---	Trace	Trace	0.9672	---	---	0.9672	Trace	---	Trace	Trace
HNH <sub>3</sub>	---	---	---	---	---	Nil	Nil	---	0.8806	---	---	---	---	1.234	2.554
H <sub>2</sub> O	---	---	Trace	---	---	1.141	1.141	0.0294	0.0293	---	0.0294	0.0293	1.334	1.334	2.146
Total	0.731	0.731	13.0279	11.2729	12.0039	12.0039	10.1431	1.8607	1.7548	11.9977	10.4344	1.3769	2.840	4.7006	---
Press. bar	8	8	1	8	8	8	8	1	8	8	8	1	8	1	1
Temp. °C	15	20	15	220	204	267	234	40	40	40	40	25	25	40	40

Next is perhaps the starting basis of the detailed design. Now, for this, what you require is a process flow diagram which must contain and show all streams major equipment, interconnection with other systems, the bypass and the circular circulation lines, system ratings particularly the pressure temperature if there is any such thing which has to be specifically mentioned, the operating values and the composition of stream.

Now, you definitely will be having a stream table which basically is a table that you can see here below the diagram which contains stream number wise. The stream details which includes phases, temperature, pressure, enthalpy and flow rate.

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This is the same thing separately shown.

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*Piping and Instrumentation Diagram (P&ID)*

- Functional relationship of piping, instrumentation, equipment
- All of piping, including physical sequence of branches, reducers, valves and the equipment
- Instrumentation and control components
- Control and interlock schemes

*Plot Plan*

- Plant layout; Relative location of equipment on a scaled plan

*Isometric drawings*

- Spatial location and routing details of every physical item in the plant

*Fabrication Drawings*

- Complete details of the mechanical fabrication, support and fixing of the equipment

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After all, you have conceded the plant. You have decided on the alternative designs. You have come to a state where the process is finalized. The process streams are identified, the majority of the equipment are identified, the details of the plants and instrumentations are also known.

Now, how to document these? This is done in a document which is called the piping and instrumentation diagram or P and ID. The P and ID definitely shows the functional relationship of the piping instruments and the equipment. All piping including safety and any emergency handling facility is also shown.

The control and instrumentation components are definitely shown here. This gives us an idea of what exactly are the parameters controlled, what are the parameters measured, what are the relationship between the different individual equipment, how this material flows from one equipment to the other through the pipes.

Naturally, if you have to build a plant, you require a plot. So, the plot plan shows the plant layout which definitely will be included and very clearly showing the relative location of the equipment in a scaled plan. For example, if you have a particular wind direction, a furnace usually is located downwind, so that any heat from the furnace does not affect your plant or it is conducted away without affecting your plant in a safe location.

In order to show the equipment and the individual piping, you must have the details of their special location, that means, the isometric drawings are usually essential in order to have a 3D view or a 3D idea of your plant. So, you have the isometric drawings of the equipment and the piping, and the structural as well. For example, if you have a pipe rack, naturally you require an isometric drawing of the same as well.

Now, once you have completed these things at least in a preliminary fashion, you have to ask for fabrication of your equipment. So far, what you have completed is going to be the input of the fabrication. So, the fabricator has to be given the fabrication drawings which he reviews first, maybe he will ask for a set of clarifications from you, the designer.

When these are finalized, the fabricator starts fabricating it, and finally, delivers it to the site. I think I will stop here today. With this, the design overview is fairly complete for your work or session.

Thank you.