Lecture 1.6
Engineering Solutions through Process Design
How do Engineers Design Processes to Solve Problems?

Design is the most creative of engineering activities. Engineers are often engaged in the invention of new products and processes through the application of scientific principles and concepts.

Product design and process design both complement and inform one another. Engineers design products based on market needs and taking into account functionality, aesthetic, safety and other considerations. At the same time, engineers also design processes to help mass manufacture these products.

When it comes to process design, engineers are typically concerned with problems like, "How do I take something produced in a lab and mass produce it for consumers?" Or, "How do I develop a safe and profitable manufacturing system that will produce products on a large scale to meet the market demand?"

To understand how process design works, it's important to highlight three components that make up any manufacturing system. They are: the inputs, or raw materials; the outputs, or the products demanded by the market; and a process that transforms the raw materials to the products represented. The process can comprise different equipment arranged in a specific sequence, operating at the right settings or conditions. Each equipment helps in some aspect of the transformation of raw materials into products.

In process design, we know what the available inputs are, i.e. the quality of raw materials available to make the product, and the outputs that we want, which are determined by market requirements. Our task is to design a process to transform the inputs into the desired outputs. This involves figuring out the sequence of the equipment and their sizes, and the required operating conditions.

For any manufactured product, there are many ways where we can combine and process raw materials to get what we want. We need engineers from various disciplines to work together to assess and evaluate the different options. These are then taken to the stage of detailed engineering design before a final selection is made.

Let's imagine that we are design engineers working in a petrochemical complex that produces 500 million kg of vinyl chloride monomer per year. Vinyl chloride monomer, or VCM, is a molecule that comprises carbon, hydrogen and chlorine. For various reasons, there is now a new demand for another 400 million kg per year. VCM is a toxic substance and any new facility that manufactures it must satisfy stringent governmental and safety regulations.

This is the problem that we need to solve. To do this, the design team will need to brainstorm to generate ideas and potential solutions to the problem. Let's imagine that from the analysis of the problem, we have brainstormed and come up with three possible solutions:

Solution 1. A competitor's VCM plant located about 100 km away from the petrochemical complex is known to have some spare capacity. They could produce the extra 400 million kg and ship it to our petrochemical complex by truck or rail in tank car quantities. In this case, the design team projects the purchase price and designs appropriate storage facilities. This is perhaps the simplest solution to meet the increased market demand. If we can strike a deal with the competitor, we only need to expand our current storage facilities.

Solution 2. Purchase chlorine gas and ship it by pipeline from a nearby plant. After that, we'll react the chlorine with in-house ethylene to produce VCM and Hydrogen Chloride as a by-product. If we do this, we'll need to design a pipeline that can withstand the corrosive nature of chlorine gas, design a reactor system to help chlorine react with ethylene, and design the purification system to ensure the separation of the VCM product. We also need to be concerned about the by-product, hydrogen chloride. We can either make use of it within the complex or dispose it off. Storage facilities need to be designed for the extra VCM produced.

Solution 3. We can acquire Hydrogen Chloride either from the market or from other processes of our petrochemical complex and put it through a series of reactions. Hydrogen chloride prices are quite low in the market, and it's very easy to acquire acetylene and ethylene from petrochemical complexes. If we choose this option, we'll need to design pipelines, reactors and purification equipment together with VCM storage facilities.

In order to come up with the possible solutions above, we'll need: (a) a deep knowledge of the relevant fundamental domain (in this case, Chemistry); (b) an understanding of the components (chemical molecules here) that are locally available for manufacture; (c) familiarity with process equipment, such as storage tanks, heat exchangers, reactors, purification systems, etc.; and (d) a mastery of scientific and engineering principles governing each of the equipment chosen in the design.

How do we decide which process to implement? This is where we have to more questions to consider.

We certainly must consider issues like profitability, safety, and the type of equipment needed. But apart from that, engineers have to ask:

What is the correct sequence of arranging the process equipment? How can we connect them so that we consume the least amount of energy and resources? In some cases, the answer is straightforward. In other cases, we'll need to rely on the collective design experience of the team, research literature and computer simulations to determine this.

How much overdesign is needed to handle uncertainties in our understanding of the process?

What are the things that could go wrong in the operation once the design is fixed? Anything that could go wrong may actually go wrong during the operational lifetime of the process. So, we need a systematic hazard and safety analysis to accompany our design. A HAZOP (Hazard and Operability) analysis is carried out to systematically check all of the anticipated eventualities. If the process risk is high, or if the profitability is poor, that particular design is eliminated from further consideration.

What are the key parameters that should be measured to ensure safety and quality? ***How should information flow from the control room to the process and back?*** Design of Instrumentation and Control Systems are an important constituent of process design.

For each of the design alternatives that make the final cut, a rigorous cost estimation and profitability analysis is made. We'll choose the most promising design and use it to build and operate a pilot-scale unit, or a ***pilot plant***.

A pilot plant is a small-scale production unit. It's like an overgrown laboratory setup, and its chief purpose is to provide us with quantitative data. Having a pilot plant will allow engineers to monitor the operations and use the collected data to determine and correct any operational bottlenecks before the design is scaled-up to commercial size. Pilot plants are also necessary for minimising risk encountered when developing new and unproven technologies. It also helps engineers to gain the much-needed operating experience.

This approach allows us to ensure that we are building a commercially successful manufacturing plant.

If the designed process meets our objectives, we can commence commercial scale production. In commercial production, the main goal is to manufacture goods in the quantity and quality that the market expects.

Again, we will continuously monitor the process to take note of any significant deviations from the expected behaviour. These will be handled by a vigilant maintenance team.

From time to time, these processes are also retrofitted to bring in new technologies into existing designs. Thus, it should be clear that process design is not a once-through operation but an iterative process of refinement.