Open-Ended Problems: A Future Chemical Engineering Education Approach. J. Patrick Abulencia and Louis Theodore.

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Term Projects (4): Plant Design

30.1 Chemical Plant Shipping Facilities
30.2 Plant Tank Farms
30.3 Chemical Plant Storage Requirements
30.4 Inside Battery Limits (ISBL) and Process Flow Approach

Term Project 30.1

Chemical Plant Shipping Facilities

A large chemical plant complex is likely to have facilities for shipping by pipeline, sea, inland waterway, rail, and road. Smaller plants may have facilities for only one or two of these modes. In any case, they must be designed for safe loading and unloading. In addition, there is often a major economic incentive to load and unload ships, barges, rail cars and trucks as quickly as possible.

The cost of shipping materials, both raw materials and products, is often a very significant factor in the chemical industry. The energy cost associated with shipping can range from 0.001 gallons of fuel per ton·mile of cargo moved for supertankers to 0.2 for cargo jet aircraft.

A new process plant on the Ohio River expects to receive 500,000 gallons per day of a single raw material and ship out 100,000 gallons per day of each of two liquid products and 500,000 lbs each of four solid products. Estimate the total shipping cost per day for this plant's operations if all shipments are by barge and if all shipments are by rail. Data is provided

Table 30.1 Shipping Cost Data

Material		**Distance shipped**
Feed		800 miles
Liquid product A		250 miles
Liquid product B		200 miles
Solid product C		40 miles
Solid product D		300 miles
Solid product E		45 miles
Solid product F		120 miles
Shipping costs:		
Barge:	20 to 80 miles	\$0.03 / ton·mile
	80 to 300 miles	\$0.02 / ton·mile
	300 to 1000 miles	\$0.015 / ton·mile
Rail:	10 to 100 miles	\$0.08 / ton·mile
	100 to 1000 miles	\$0.04 / ton·mile

in Table 30.1. Assume the liquids all have a specific gravity of 1.0. Also, attempt to devise an optimum shipping schedule [1].

Comment: Transport by ship and/or barge is usually much cheaper than transport by rail or truck. It often requires longer travel times, however, and thus more inventory is tied up in shipping.

Term Project 30.2

Plant Tank Farms

Liquid feeds, products, intermediates, and fuels at chemical and petrochemical plants are stored in tanks, which are usually located in a *tank farm* adjacent to the process plant area. The tank capacities are most often expressed in gallons or barrels (one barrel = 42 gallons). The individual tanks may range in size from a thousand gallons or less to several million gallons.

Whenever possible, liquids are stored at ambient temperature and pressure. Volatile liquids may have to be stored under pressure. In addition, they often require vapor recovery systems or other devices to prevent releases to the atmosphere as the tanks are filled and emptied. Liquids which are very viscous at ambient temperature or which would solidify at ambient temperature are kept in heated tanks.

Standard practice calls for each tank to be surrounded by a dike or berm sufficiently high to contain all the liquids stored in a tank in case it should rupture. Fire fighting equipment is permanently located near tanks containing flammable liquids.

Consider the same process plant described in the previous term project (30.1). The new process plant expects to receive 500,000 gallons per day of a single raw material and ship out 100,000 gallons per day of each of two liquid products and 500,000 lbs each of four solid products. If shipments are all made by barge, the plant will require tankage for a 15 day supply of feed and a 10 day supply of each product. If shipments are by rail, which can be schedules more reliably, the plant will require a 7 day supply of feed and a 5 day supply of each product. For ease of maintenance, there should be at least three tanks for each liquid, with one tank being "off-line" at any given time [2].

1. Determine at least one set of storage tank requirements for the liquid feed and products. Available standard tank sizes and capacities are provided in Table 30.2.

TABLE 30.2 Available Standard Tanks

Capacity Gallons	Height Feet	Diameter Feet
216,000	30	35
429,000	36	45
1,040,000	36	70
2,110,000	36	100
4,060,000	48	120

2. Resolve the problem for various inventory tie-up costs. In effect, assign a time factor to each mode of travel and a cost associated with the lost time.
3. Also consider the following: Storage tanks can present major risks both in terms of fire and environmental pollution. In both cases this is primarily due to the large inventories of materials that could be involved in any accident. There has been a major effort in industry in the last several decades to reduce the amount of storage at process plants, especially for flammable and/or toxic materials. Suggest how the inventory of both feed and products could be reduced.

   Comment: Transport by ship and/or barge is usually much cheaper than transport by rail or truck. It often requires longer travel times, however, and thus more inventory is tied up in shipping.

Term Project 30.3

Chemical Plant Storage Requirements

A chemical plant uses two liquid feeds of different densities;

Table 30.3 Feed Data, Project 30.3

Feed 1:	110,000 lb/day	ρ = 49 lb/ft^3
Feed 2:	50,000 lb/day	ρ = 68 lb/ft^3

produces four different liquid chemical products of varying density. Refer to Table 30.3. and 30.4

Table 30.4 Product Data, Term project 30.3

Product A:	40,000 lb/day	$\rho = 52$ lb/ft^3
Product B:	25,000 lb/day	$\rho = 62$ lb/ft^3
Product C:	10,000 lb/day	$\rho = 52$ lb/ft^3
Product D:	95,000 lb/day	$\rho = 47$ lb/ft^3

The plants storage requirements call for maintaining 4 to 5 weeks supply of each feed, 4 to 6 weeks supply of products A, B, and C; and 1 to 2 weeks supply of product D. The plant operates year round, but each tank must be emptied once a year for a week of maintenance. Tanks are normally "dedicated" to one feed or product, but one or two could be used as "swing" tanks, with one day of cleaning required between use with different liquids.

Specify several efficient set of tanks from the "standard" sizes given below in Table 30.5 to meet this plant's needs. Storage requirements are provided in Table 30.6. Select which set you consider to be most efficient and explain why. The number of tanks required will be quite large. If market forces, such as fluctuating demand, require this much storage, they may all be necessary. More modern commercial operations, such as "just-in-time" manufacturing, call for reducing in-plant inventory to the absolute minimum possible [3].
Comment: There is no single, simple method for determining the optimum mix of storage tanks for a chemical plant. Most often, estimates are made of the minimum and maximum amounts of feeds, intermediates, and products that must be kept on hand. Then some additional allowance is made to permit periodic cleaning and maintenance of the tanks. The minimum number of tanks may not always be optimum if the tanks are extremely large. Several smaller tanks may cost somewhat more initially but they offer more flexibility in use [4].

Table 30.5 Tank Sizes; Term Project 30.3

Standard Tank Sizes, Gallons		
2,800	16,800	281,000
5,600	28,100	561,000
8,400	56,100	1,123,000
11,200	140,000	

Table 30.6 Storage Requirements; Term Project 30.3

Material	lb/day	Gal/day	Days	Gals storage required
Feed 1	110,000	16,800	28 – 35	470,200 – 587,800
Feed 2	50,000	5500	28 – 35	154,000 – 192,500
Product A	40,000	5750	28 – 42	161,100 – 241,700
Product B	25,000	3020	28 – 42	84,500 – 126,700
Product C	10,000	1440	28 – 42	40,300 – 60,400
Product D	95,000	15,120	7 – 14	105,800 – 211,700

Term Project 30.4

Inside Battery Limits (ISBL) and Process Flow Approach

The physical layout of chemical and petrochemical plants may appear to be complex at first glance, but it generally follows a very logical pattern. Process units within a major chemical plant complex each deal with one or two major products. The individual pieces of equipment involved in their manufacture—reactors, columns, heat exchangers, compressors, etc.—are grouped together and operated from a control room located either within the unit or nearby. These individual process units are often referred to as *inside battery limits*, or ISBL, plants. Separate support units are referred to as *outside battery units*, or OSBL. Steam plants, cooling towers, electrical substations, storage facilities, shipping facilities, and waste treatment plants are considered OSBL. They are usually operated from different control rooms than the ISBL plants.

Within the ISBL units themselves, there are two basic approaches to plant layout: the *process flow* approach and the *common equipment* approach. In the process flow approach, equipment is arranged in the same order as it would be on a well-planned flowsheet, i.e., in the order of the main material flows in the plant. This is similar to the common "assembly line" approach in many factory installations. In the common equipment method, all pieces of similar equipment are grouped together. Pumps are all adjacent to one another, heat exchangers are grouped together, etc.

The process flow approach has two main advantages. First, piping lengths from one piece of equipment to the next are minimized. This saves both in capital cost for piping and in energy cost to move materials from one piece of equipment to the next. Second, it is an easier plant to "learn". Engineers, operators and maintenance staff can learn the function of each piece of equipment faster.

The common equipment approach also has advantages. Piping and wiring from utility services is minimized. Initial construction may be simpler because similar pieces of equipment can be installed at the same time by the same crews. Maintenance may be simplified, particularly for major plant overhauls. Pump maintenance crews, for instance, can do all their work in one place rather than have to move from pump to pump.

Most real process plants are laid out in a combination of the two basic approaches. The process flow approach seems to predominate, but features of each can be found in almost any large plant.

Regardless of the layout approach used, each plant layout design represents a compromise involving cost, convenience, and safety. The least expensive plant, both to build and to operate, would be one with the absolute minimum of space between pieces of equipment and between various process units. The safest plant would be one in which equipment and process units are very widely separated, so that there is no chance of a fire or explosion at one piece of equipment spreading to another. Convenience, both in terms of construction and operation, usually calls for something in between in terms of equipment spacing, but it does not necessarily lead to a safer or less expensive plant layout [5].

Based on the above descriptions, prepare an ISBL process plant layout for the plant sketches below in Figure 30.1 using the process flow approach [5].

Sizes are as follows (See also Table 30.7):

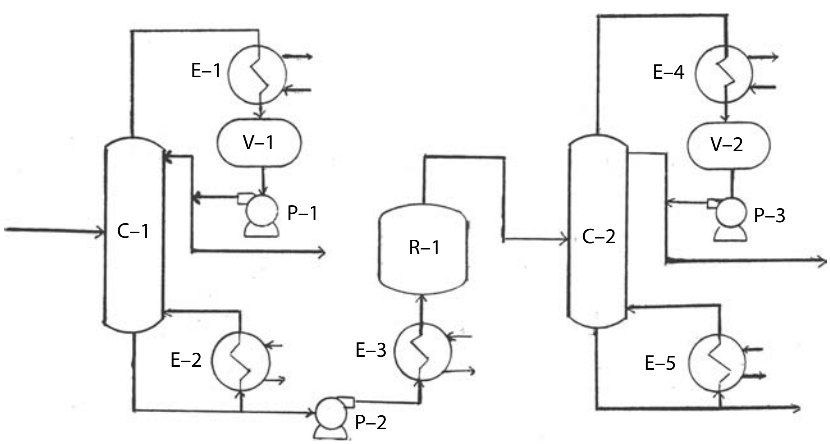

Figure 30.1 ISBL process plant layout

Table 30.7 Equipment Description; Term Project 30.4

Column 1	7 ft diameter x 83 ft tall, vertical cylinder
Exchanger 1	3 ft diameter x 9 ft long, horizontal cylinder
Exchanger 2	4 ft diameter x 8 ft long, horizontal cylinder
Vessel 1	4 ft diameter x 10 ft long, horizontal vessel
Pump 1	Approximately 2 ft x 2 ft x 4 ft
Pump 2	Approximately 2 ft x 2 ft x 4 ft
Exchanger 3	2 ft diameter x 8 ft long, horizontal cylinder
Reactor 1	8 ft diameter x 18 ft tall, vertical cylinder
Column 2	5 ft diameter x 70 ft tall, vertical cylinder
Exchanger 4	3 ft diameter x 7 ft long, horizontal cylinder
Exchanger 5	2 ft diameter x 6 ft long, horizontal cylinder
Vessel 2	3 ft diameter x 8 ft long, horizontal vessel
Pump 3	Approximately 1.5 ft x 1.5 ft x 3 ft

Vessels 1 and 2 are located underneath exchangers 2 and 5, respectively, to permit gravity flow into the vessels. Otherwise all equipment is located at ground level, or just high enough above ground level for maintenance access. Common rules-of-thumb for spacing between equipment, based on both safety and maintenance convenience considerations, call for the following minimum clearances around equipment (see Table 30.8). Note

Table 30.8 Equipment Spacing; Term Project 30.4

Columns	6 ft or one column diameter, whichever is less
Exchangers	5 ft
Pumps	4 ft
Vessels	3 ft
Reactors	12 ft

that these are typical spacing; they are not valid for all types of process plants. Much closer spacing and more vertical stacking of equipment is common in places where available land is limited. Such is the case in many large European chemical manufacturing locations.

References

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4. J. Reynolds, J. Jeris, and L. Theodore, *Handbook of Chemical and Environmental Engineering Calculations,* John Wiley & Sons, Hoboken, NJ, 2004.
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