Solutions for Tutorial 18
Level and Inventory Control

18.1 Most plants receive feed material periodically from pipelines, ships, trucks, and railroad cars. Discuss the issues related to the amount of feed material that you would store for a plant that operates continuously.

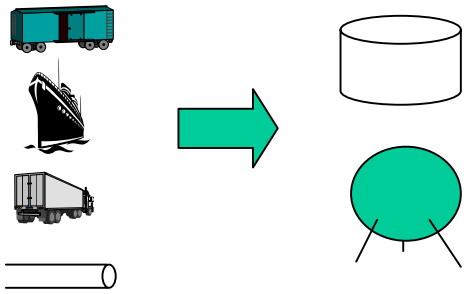


Figure 18.1 Plant delivery with feed inventory.

Advantages: Inventory increases the flexibility in operating the plant. When the plant has large feed inventories, we can change the selection of feed materials at any time and feed the plant at any rate. Thus, large feed inventory (along with large feed storage capacities) improves operability.

Disadvantages: A large inventory of material can have the following disadvantages.

a. Requires expensive land
b. Requires expensive storage facilities
c. Increases "working capital", i.e., money that is invested in material that does not contribute to profit. When the plant is shut down, this capital is recovered, but the potential profit from investing this money is lost during the operation of the plant.
c. Can result in degradation of quality during storage
d. Can increase fire and other hazards

Thus, the engineer must select the appropriate amount of inventory by considering

- the factors above
- the operating conditions, i.e., the feed rates and frequency of switches from one feed type to another,
- the time to ship, transport, and unload feed material from the source to the plant, and
- the frequency and types of feed delivery disruptions.

18.2 A process with two distillation towers is shown in Figure 18.2.

a. Identify all liquid inventory in the process.
b. Discuss advantages and disadvantages for each of the inventories.
c. Critique the type of level control, i.e., which variable is adjusted to control the level, for each inventory. If not acceptable, sketch changes and explain.
d. For every liquid inventory, provide a recommended liquid inventory and explain your recommendation.

The following analysis is provided for the feed drum.

Inventory:	**L-1, Liquid in the feed drum, V-29**
Advantages:	Provides mixing to attenuate feed composition variation and hold-up to attenuate feed flow rate variation
Disadvantages:	Requires a drum, pump, and controls. Also, increases inventory of hydrocarbons in the plant.
Level Control:	No remote sensor or control provided; this is not acceptable. • L-1 should be transmitted to the central control room. • LC-1 should be automated feedback control of the level by adjusting the FC-1 set point in a cascade. • The level controller should be tuned for averaging control.
Inventory:	The inventory should be sized to attenuate the expected disturbances in feed flow and properties. Lacking this information, the level should have 10 minutes hold.

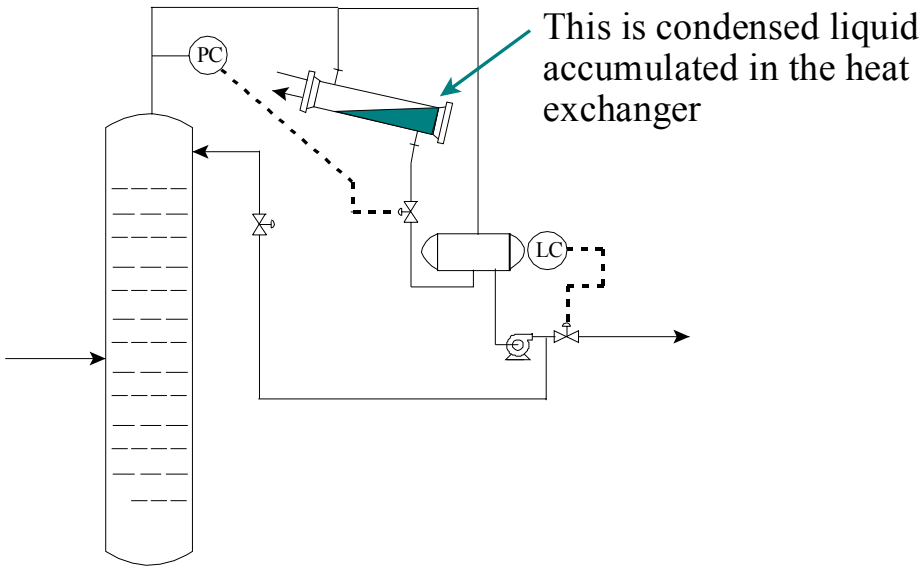
The following analysis is provided for the Depropanizer distillation tower.

Inventory:	**Liquid on trays**
Advantages:	Required for separation by liquid-vapor equilibrium
Disadvantages:	• Slows dynamic responses for control • Increases inventory of hydrocarbons in the plant.
Level Control:	The level is determined by the weir height between the tray and the downcomer.
Inventory:	The liquid is in the form of froth; a typical liquid inventory is 2 inches of clear liquid.

Inventory:	**LC-3 in overhead accumulator, V-30**
Advantages:	• Provides inventory so that small fluctuation does not stop liquid supply to the pumps • Enables smooth flow rate of liquid product and reflux
Disadvantages:	• Increases inventory of hydrocarbons in the plant. • Requires a pressure vessel
Level Control:	Feedback control by adjusting the product flow (FC-5) set point in a cascade.
Inventory:	The inventory should not be too large. Five minutes is recommended, unless the product flow must be very smooth

Inventory:	**LC-2, liquid inventory in the bottoms of tower**
Advantages:	Enables smooth flow to downstream processing unit
Disadvantages:	• Increases inventory of hydrocarbons in the plant. • Increases height and cost of distillation tower
Level Control:	Feedback level control adjusting the valve in the pipe to the downstream distillation tower.
Inventory:	The inventory should not be too large. Five minutes is recommended.

The analysis for the Debutanizer is similar to the Depropanizer; therefore, most of the analysis is not repeated. Only the analysis of the condenser is given.



Before discussing the liquid inventory, we must understand the principles of operation. The exchanger E-28 condenses the overhead vapor, as shown in the figure above. To control pressure, the condenser duty must be adjusted. In this design the liquid in the exchanger influences the condenser duty. As more liquid is accumulated, less area is available for condensation; less liquid is accumulated, more area is available for condensation. The pressure controller manipulates the valve in the exit from the condenser; this affects the liquid flow rate from the condenser.

Inventory:	**Liquid accumulated in the condenser heat exchanger, E-28**
Advantages:	Required for pressure control!
Disadvantages:	Slightly increases the liquid inventory of hydrocarbons.
Level Control:	This system is self-regulatory, so that no level control is required.
Inventory:	The size of the heat exchanger is determined by the maximum heat duty required when no liquid is retained in the exchanger.

18.3 Many levels occur in the process in Figure 18.2.

a. For each level, explain the physical principle that could be used to measure the level using an industrial sensor.
b. What would you recommend for each level?

Two commonly used methods for measuring liquid levels are

1. **The pressure difference between to locations in the vessel.**
2. **The change level in a side chamber, which is measured by a float position or the weight of a metal object that is immersed in the liquid.**

18.4 Two approaches to plant level control are shown in textbook Figure 18.8. In Figure 18.8a, feed is set by flow control; we'll call this feed "push". In Figure 18.8b, the production is set on flow control; we'll call this demand "pull".

Which of these two approaches is used in Figure 11.2? Is the approach used appropriate for this process?

First, the feed drum level is not controlled in the figure. It should be controlled as explained in the answer to question 2. The controller would measure the level and adjust the liquid flow leaving the drum.

With the change above, the inventory control approach involves a "feed push" approach. This seems acceptable because we have no way to adjust the feed to the unit. Therefore, we must process all feed that is sent to the unit, and the levels must send the liquid to downstream equipment.

18.5 Some engineers believe that "Pressure in a closed vessel is similar to liquid inventory in a tank". Discuss this opinion and its impact of control design.

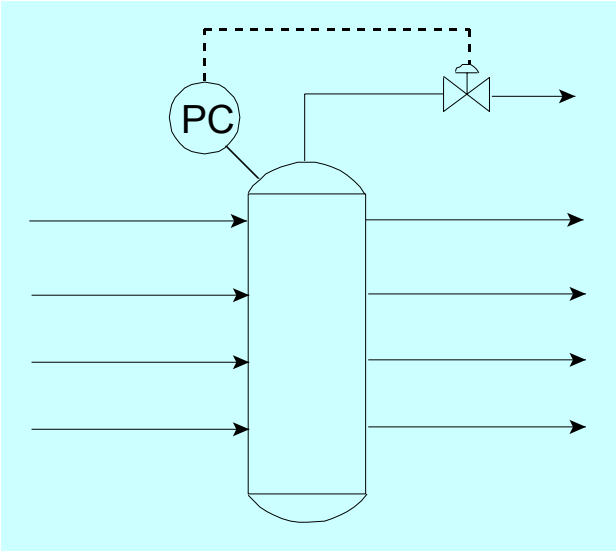
The basis for the similarity is the fundamental balance for both the liquid inventory and the pressure in a closed vessel – total material balance. In particular, a vessel with one phase has a material balance given in the following.

{Accumulation of material} = {material in} - {material out)

The accumulation of material for a gas can be related to pressure using a gas law; for example, for an ideal gas, (with ρ = density)

$$d(\text{mass})/dt = V(MW)/(RT) * dP/dt = \rho_{in}F_{in} - \rho_{out}F_{out}$$

Thus, controlling pressure is equivalent to controlling mass in an isothermal, constant composition, fixed volume vessel. The system below shows how the control could be implemented. Note that measuring all flows and manipulating one flow as the difference among the others is not recommended. Measurement errors would be significant with this approach, while the pressure represents the effect of the true flows and is not affected by measurement errors.



Follow-up Question: One might wonder whether pressure can be self-regulatory and non-self-regulatory, as liquid level can. End-of-Chapter question 18.7 addresses this issue.

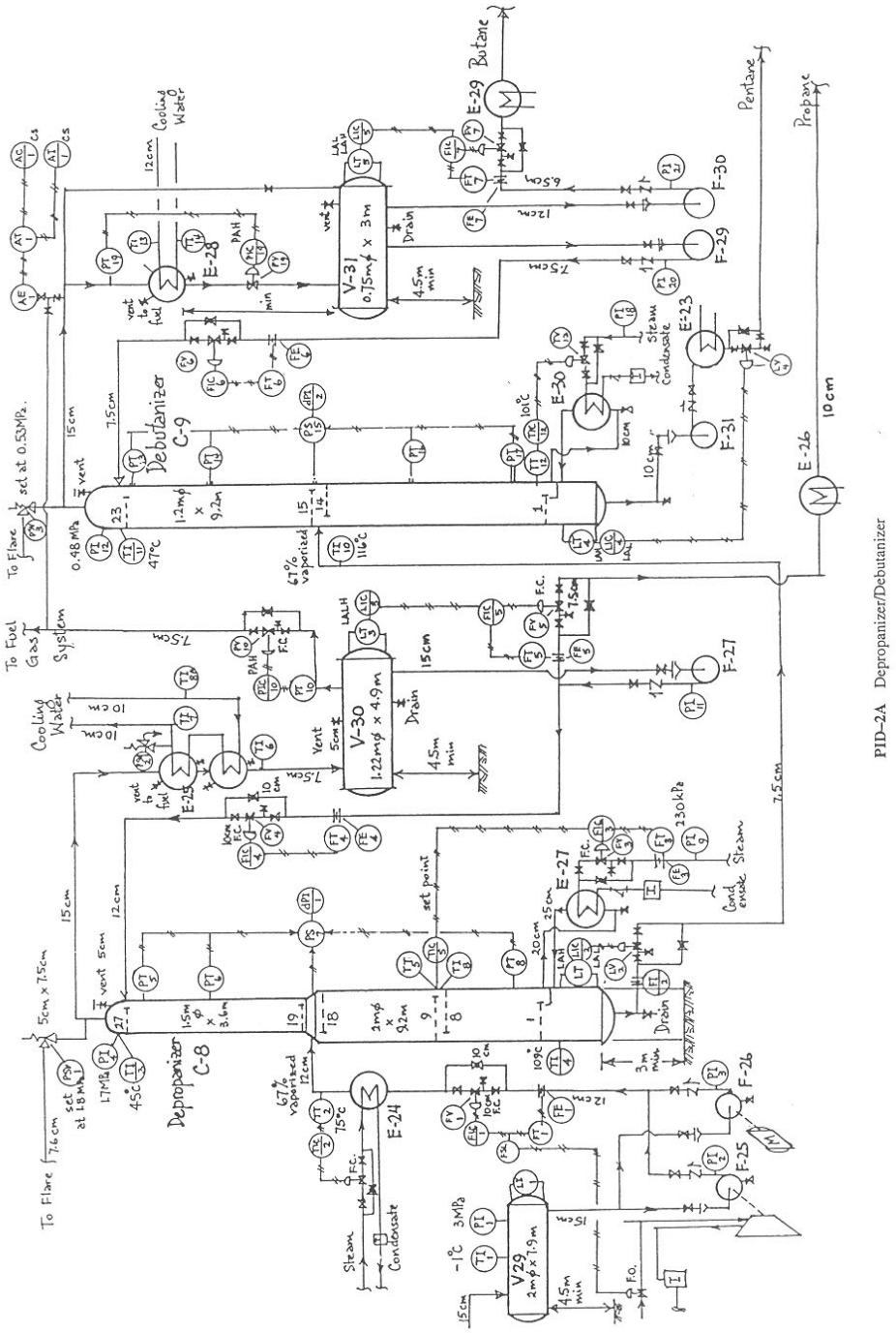


Figure 18.2. Distillation process (from Woods, *Process Design and Engineering Practice*, Prentice Hall, 1995)

