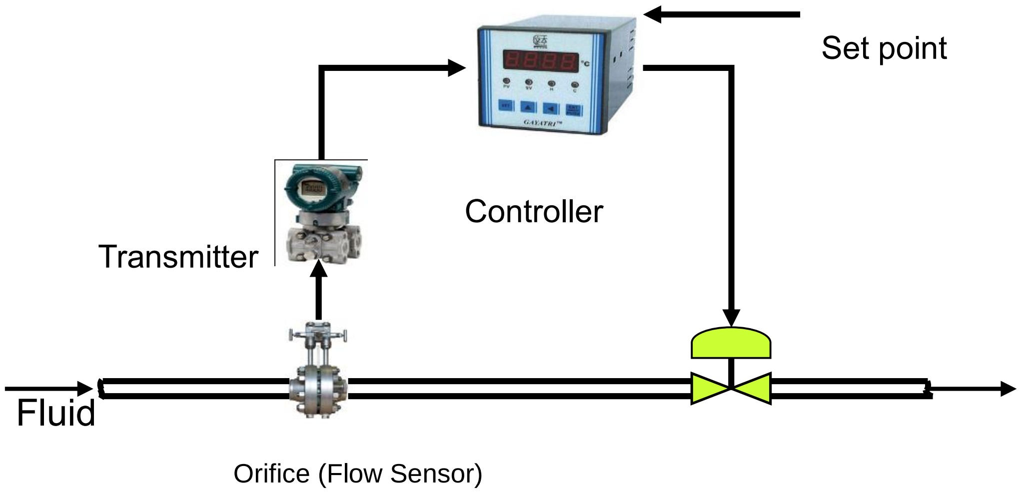
Chapter Seven: Instrumentation and Control Diagrams



Instrumentation

The example level-control problem had three critical pieces of instrumentation: a sensor (measurement device), an actuator (manipulated input device), and a controller. The sensor measured the tank level, the actuator changed the flow rate, and the controller determined how much to vary the actuator, based on the sensor signal. Each device in a control loop must supply or receive a signal from another device.

Sensors (Sensing Element)

A device, usually electronic, detects a variable quantity and measures and converts the measurement into a signal to be recorded elsewhere. A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. There are many common sensors used for chemical processes. These include temperature, level, pressure, flow, composition, and pH. For example, a mercury thermometer converts the measured temperature into expansion and contraction of a liquid which can be read on a calibrated glass tube. A thermocouple converts temperature to an output voltage which can be read by a voltmeter.

Control of Unit Operations

1) Level Control

- A level control is needed whenever there is a V/L or L/L interface.
- Many smaller vessels are sized based on level control response time.

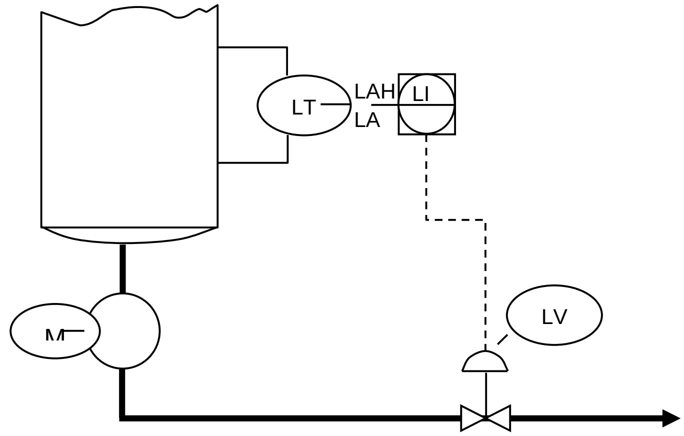


Figure 1: Liquid level control system.

Example 1: A boiler drum with a conventional feedback control system is shown in Figure 2. The level of the boiling liquid is measured and used to adjust the feed water flow rate. This control system tends to be quite sensitive to rapid changes in the disturbance variable, steam flow rate, as a result of the small liquid capacity of the boiler drum. Rapid disturbance changes can occur as a result of steam demands made by downstream processing units.

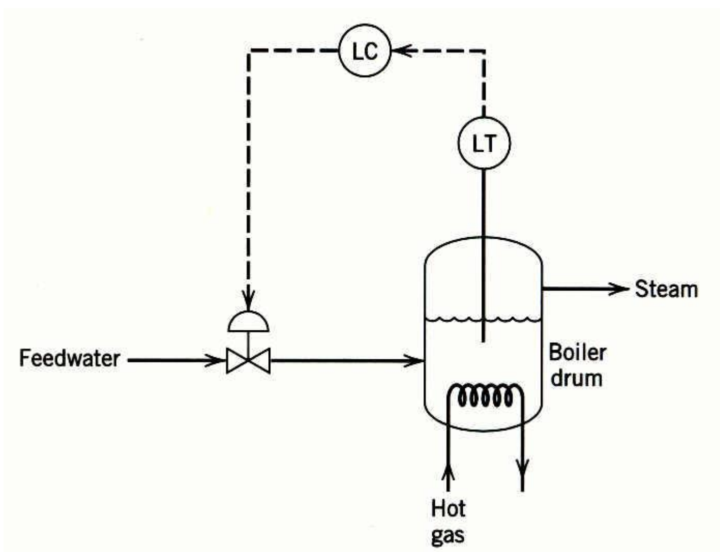


Figure 2: Feedback control of the liquid level in a boiler drum.

The feedforward control scheme in Figure 3 can provide better control of the liquid level. Here the steam flow rate is measured, and the feedforward controller adjusts the feed water flow rate.

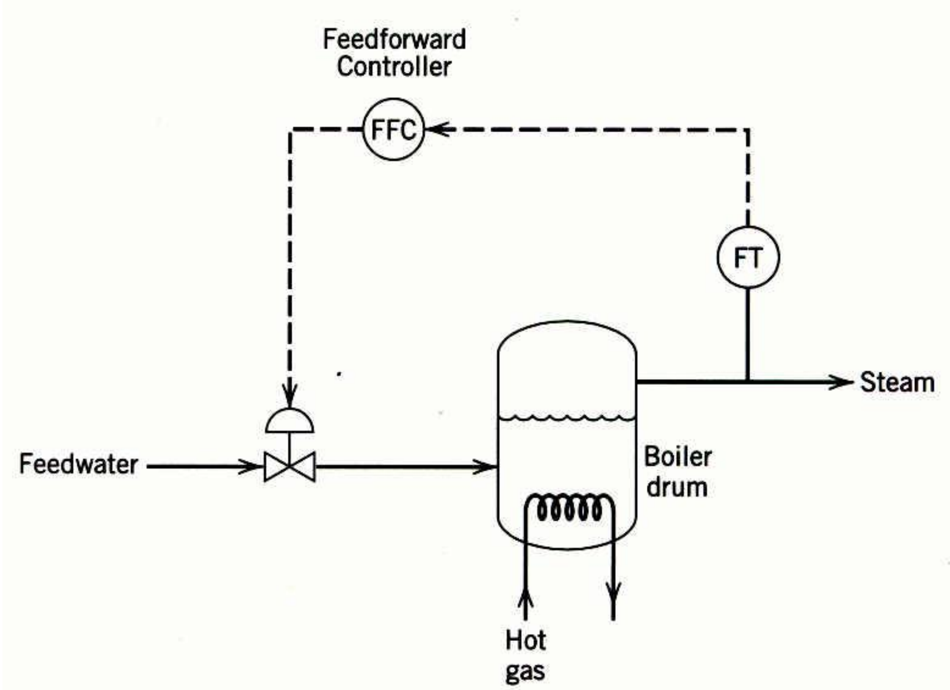


Figure 3: Feedforward control of the liquid level in a boiler drum.

2) Pressure Control

- Pressure control is usually by venting gas or vapor.
- In hydrocarbon processes, off-gas is often vented to fuel.
- In other processes, nitrogen may be brought in to maintain pressure and vented via scrubbers.
- Most common arrangement is direct venting.
- Several vessels that are connected may have a single pressure controller.

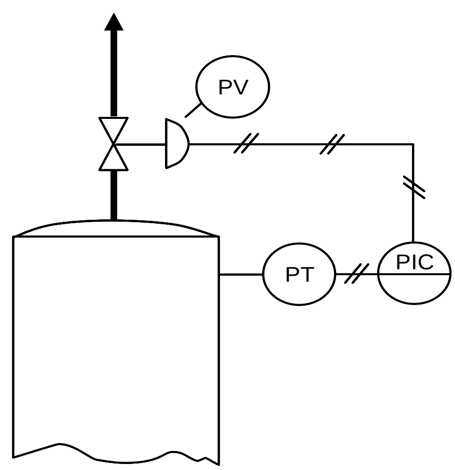


Figure 4: Pressure control system.

3) Flow Control

- Most common arrangement is a control valve downstream of a pump or compressor.

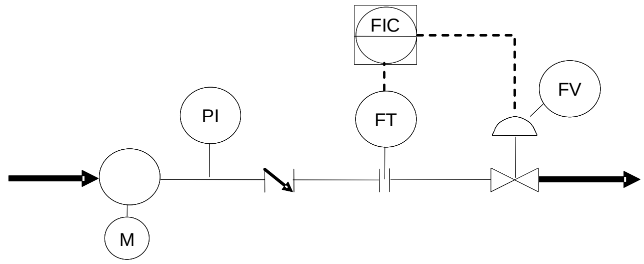


Figure 5: Flowrate control system.

Example 2: Vaporizer Flow Control

- Vaporizer flow control needs to prevent liquid accumulation.
- Hence use the level controller to actuate heat input to the vaporizer and maintain a constant inventory.
- Control of liquid flow in is easier than control of vapor flows out.

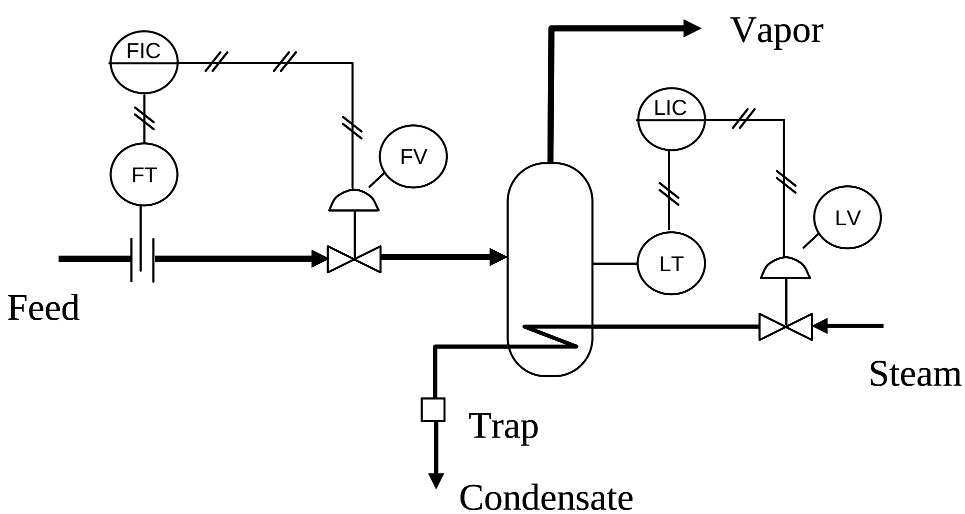


Figure 6: Vaporizer control system.

4) Temperature Control: Single Stream

- Heaters and coolers are usually controlled by manipulating the flow rate of the hot or cold utility stream.
- Final control element can be on the inlet or outlet of the utility side.

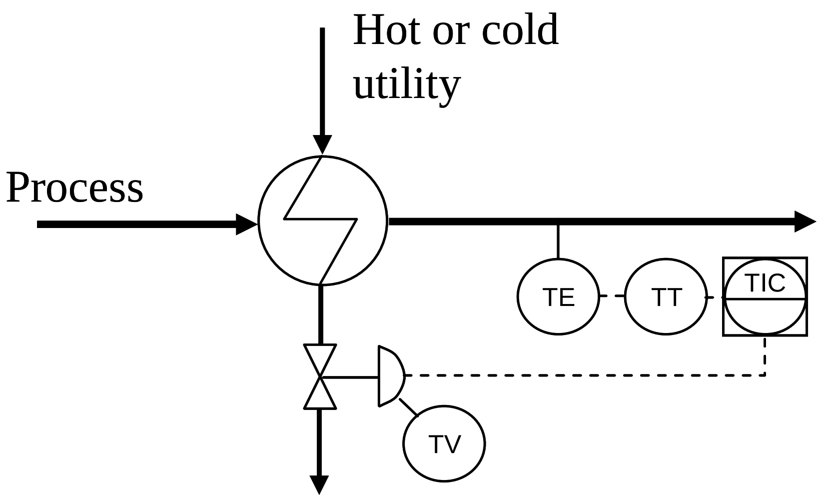


Figure 7: Temperature control system.

Example 3: Heat Exchangers Temperature Control

- Temperature control for a heat exchanger is usually by manipulating the flow through a bypass.
- Only one side of an exchanger can be temperature controlled.
- It is also common to see heat exchangers with temperature control on the downstream heater and cooler.

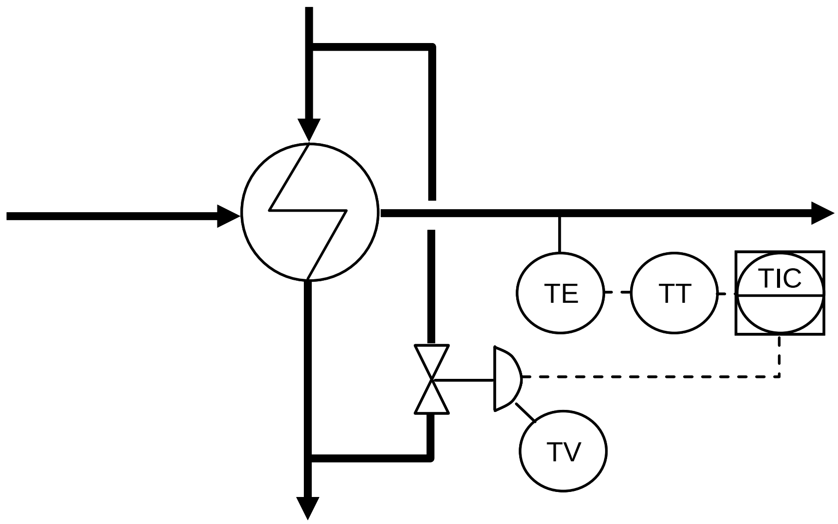


Figure 8: Temperature control of heat exchanger.

Example 4: Air Coolers Temperature Control

- Ambient air temperature varies, so air coolers are oversized and controlled by manipulating a bypass.
- Alternatively, the air cooler can use a variable speed motor, louvers, or variable pitch fans.

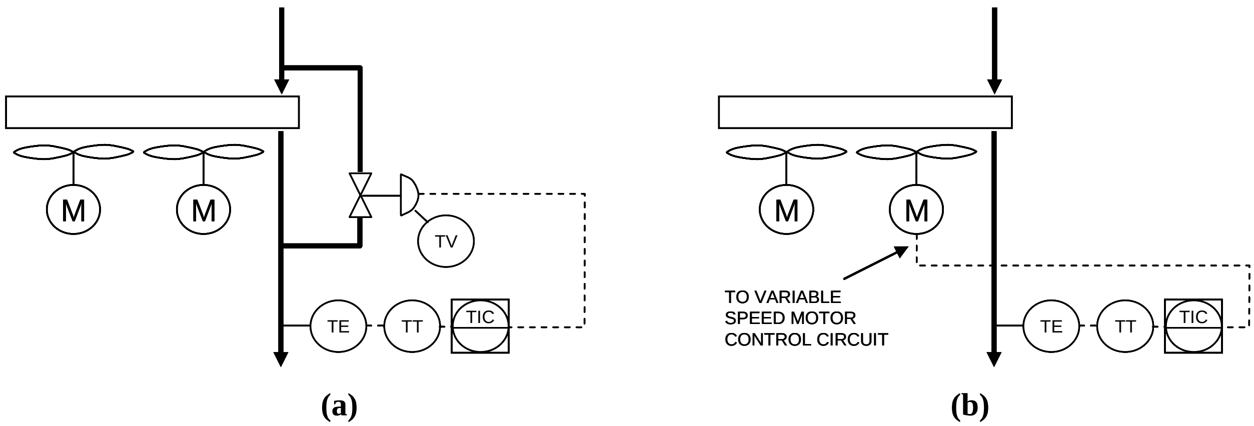


Figure 9: Temperature control of air coolers.

Example 5: Temperature Control of CSTR

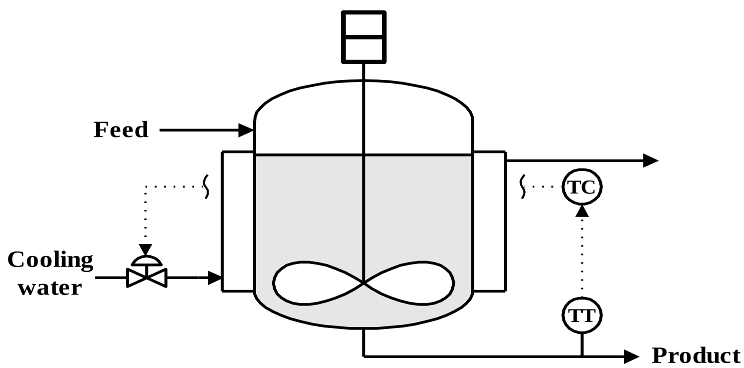


Figure 10: Temperature control of CSTR.

Distillation Control

- Distillation control is a specialized subject in its own right.
- In addition to controlling condenser pressure and level in the sump, a simple distillation column has two degrees of freedom.

  - Material balance (split) and energy balance (heat input or removed).
  - So, it needs two controllers.
  - So, it has the possibility that the controllers will interact and “fight” each other.
- Side streams, intermediate condensers & reboilers, pump-arounds, etc. all add extra complexity and degrees of freedom.

Energy Balance (LQ) Distillation Column Control Structure

The LQ control structure is the most natural control structure for a simple distillation column. This is because the separation in a distillation column occurs due to successive condensation and vaporization of the counter-current vapour and liquid streams flowing through the column. Adjusting the cold reflux, the source of condensation, and the reboiler duty, the source of vaporization, is then a natural choice for regulating the separation achieved in the column. The LQ control structure shown in Figure (11 a) is thus the most commonly applied distillation control structure. It is also sometimes referred to as an energy balance structure as changing L (cold reflux) or Q alters the energy balance across the column to affect the distillate to bottoms product split.

Material Balance Distillation Column Control Structures

The other control structures are referred to as material balance structures as the product split is directly adjusted by changing the distillate or bottoms stream flow rate. The material balance structures are applied when a level loop for the LQ structure would be ineffective due to a very small product stream (D or B) flow rate. Figures 11 b, c, and D show schematics of DQ, LB, and DB distillation column control structures. The DQ structure is thus appropriate for columns with a very large reflux ratio ($L/D > 4$). The distillate stream flow is then a fraction of the reflux stream so that the reflux drum level cannot be maintained using the distillate. The level must then be controlled using reflux. The LB structure is appropriate for columns with a small bottom flow rate compared to the boil-up. The bottom stream is then not appropriate for level control and the reboiler duty must be used instead. The DB control structure is used very rarely as both D and B cannot be set independently due to the steady state overall material balance constraint. In dynamics, however, the control structure may be used when the reflux and reboil are much larger than the distillate and bottoms respectively.

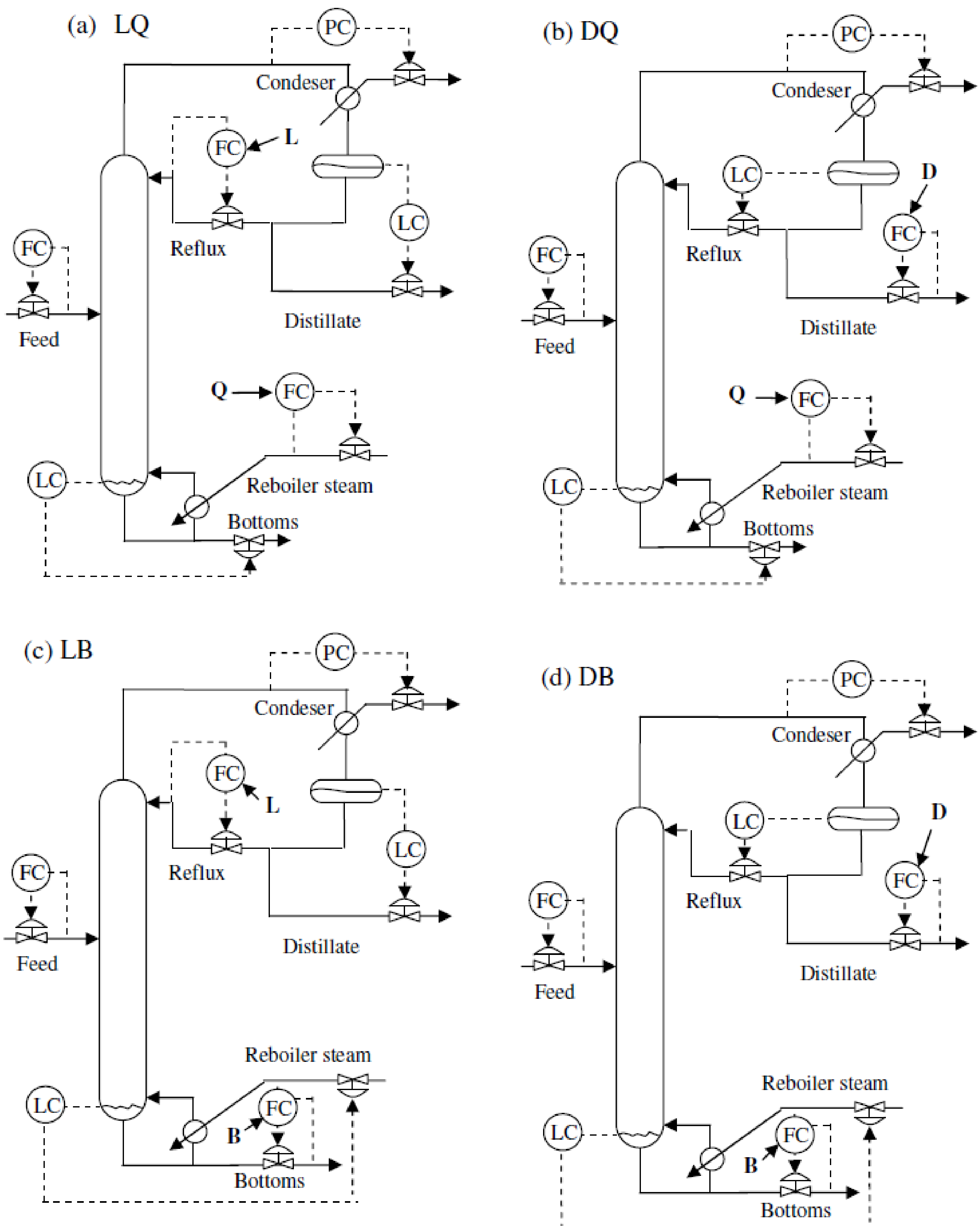


Figure 11: Schematics of LQ, DQ, LB and DB distillation column control structures.

Batch Distillation

- Reflux flow control adjusted based on temperature (used to infer composition).

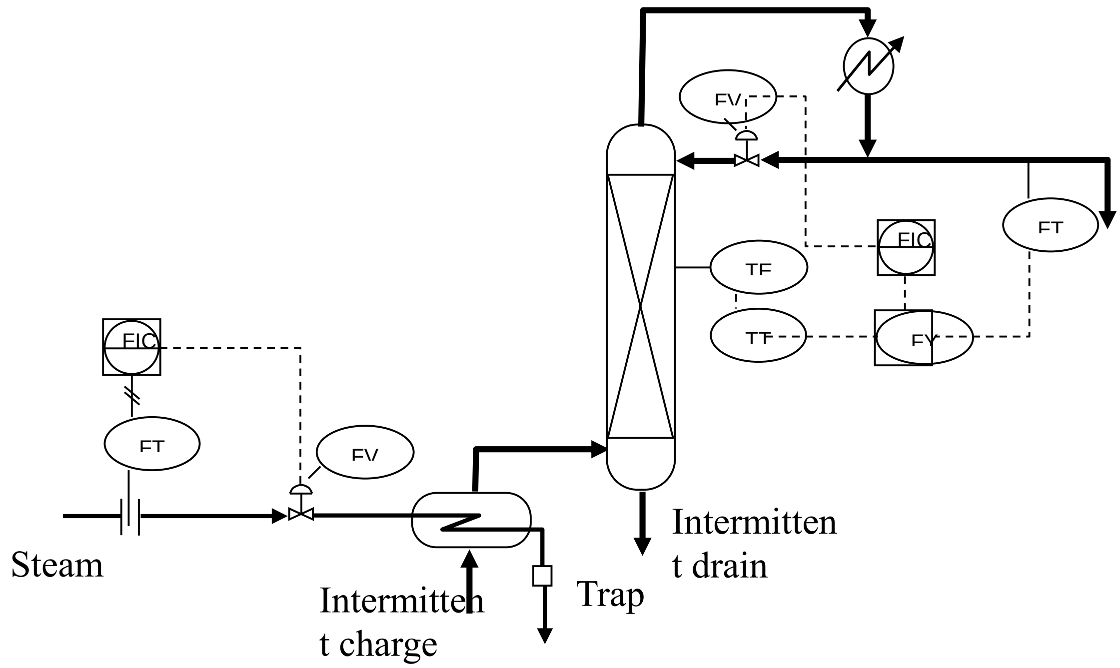


Figure 12: Batch distillation column control system.

Control of Miscellaneous Systems

Vapor Absorption Cycle

In addition to compression systems, refrigerant absorption systems are also applied industrially. The absorption-based refrigeration cycle and its control scheme are shown in Figure 13. Ammonia (refrigerant) rich strong liquor is distilled at high pressure to recover liquid ammonia as the distillate and ammonia lean weak liquor as the bottoms. The liquid ammonia is fed to the evaporator where it absorbs heat from the process stream to be chilled and evaporates. Vapor ammonia is absorbed by the 'weak liquor' water stream. The 'strong liquor' so formed is fed to the distillation column to complete the closed-circuit refrigerant loop. The temperature of the chilled process stream is controlled by adjusting the level set point of the evaporator. The heat transfer rate is thus varied by changing the area across which heat transfer occurs. The evaporator level controller adjusts the distillate liquid ammonia flow. An increase in the level of the evaporator implies an increase in the ammonia evaporation rate so that the weak liquor rate is increased in ratio to absorb the ammonia vapors. The strong liquor is cooled and collected in a surge drum. The level of the surge drum is not controlled. Liquid from the surge drum is pumped back to the distillation column through a process-to-process heater that recovers heat from the hot 'weak liquor' bottoms from the distillation column. The flow rate of the strong liquor to the column is adjusted to maintain the column's bottom level. Also, the steam to the reboiler is manipulated to maintain a tray temperature.

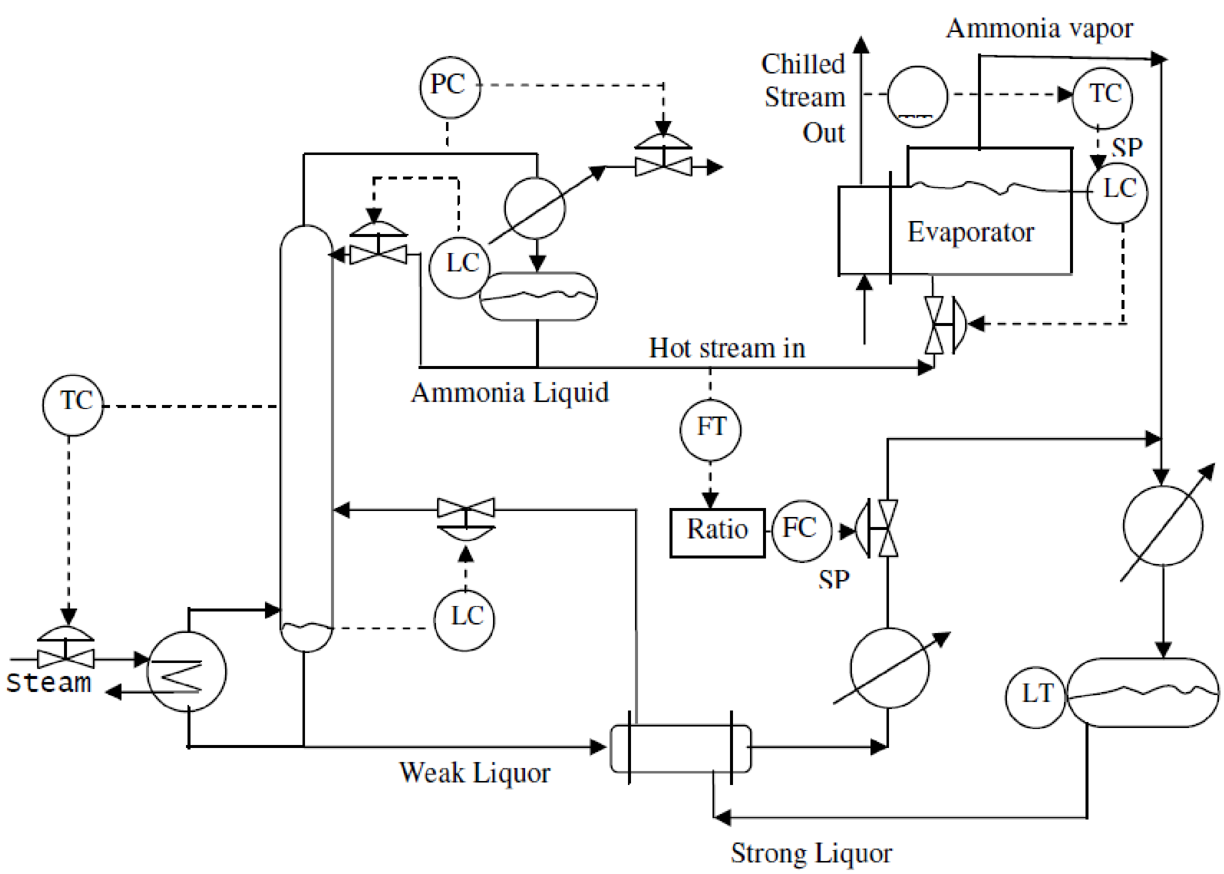
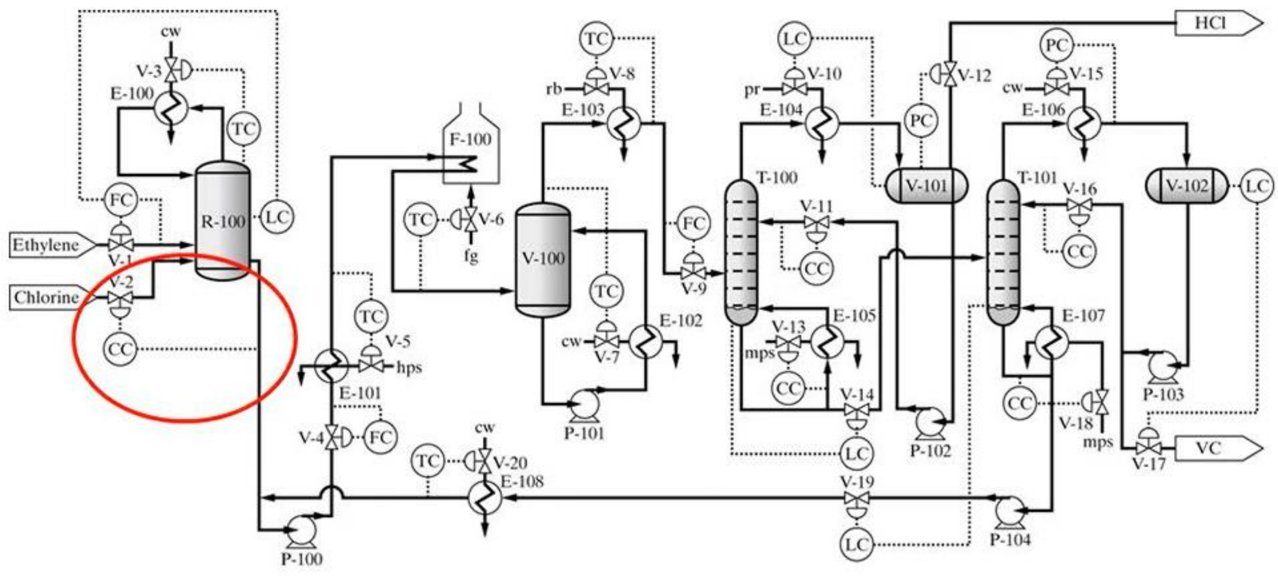


Figure 13: Absorption refrigeration control system.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