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Control Schemes and Control strategies for Distillation Column Control

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Abstract: Industrial processes need to be controlled for the purpose of maintaining quality, consistency, enhancing productivity, ensuring safe operation, maximising profits and complying with regulatory authorities. Distillation is one of the important unit operations in many Industries and hence various controls and control schemes associated with distillation operation are discussed here.
Also the schemes discussed in this paper are for separation of binary mixture.

Keywords: Feedback, Feedforward, Cascade, Reflux, Distillate, composition

INTRODUCTION

According to Luyben;'There are many different types of distillation columns and many different types of control structures. The selection of the "best" control structure is easy. Factors that influence the selection include volatilities, product purities, reflux ratio, column pressure, cost of energy, column size and composition of the feed.'[1] The basic objective of the control system of this type of separation is to keep the composition of the distillate constant. Other goals include keeping the distillate flow constant or maximizing the total distillate production. The main goal of a batch distillation is to produce a product of specified composition at minimum cost. This often means that operating time must be reduced to some minimum while product purity or recovery is maintained within acceptable limits. If product removal is too fast, separation and the quantity of the product are reduced. Conversely, if the product is withdrawn to maintain separation, its withdrawal rate is reduced and operating time is increased. [2]

CONTROL STRATEGIES

Minimum number of controlled and manipulated variables associated with the distillation column operation are given below in Table 1[3]

Controlled Variable	Manipulated variable
Overhead composition	Reflux flow
Bottoms composition	Reboiler heating media flow
Accumulator level	Distillate flow
Bottoms level	Bottoms flow

Table 1: Variables of Distillation column

This may result in multiple configurations, however, the pairing of variables generally follow one of the 3 principles- energy balance control, material balance control, and ratio control.
Energy balance control uses reflux and reboiler heating media flow to control compositions, thus fixing the energy inputs.
Material balance control uses the distillate and bottoms product flows to control compositions, thus fixing the overall material balance.
Ratio control utilizes a ratio of any two flow rates at each end of the column. The two common examples of ratio control are the control of reflux-to-distillate ratio and the boil-up-to-bottoms ratio.
There are many valve and sensor issues to be considered in the design of a control strategy. The sensor location, analyzer type of sensor, sensitivity, consistency and reliability are few factors affecting the distillation column control based on sensor choice. Similarly, the control engineer must decide which valves will be used to control the column inventories. Factors affecting the selection are Linearity, range, resolution, size etc.[5]

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For a given feed rate only one degree of freedom is available for material balance control. If overhead product (distillate) is a manipulated variable (controlled directly to maintain composition), then the bottom product cannot be independent but must be manipulated to close the overall material balance according to the following equations[6]

F = D + B

Accumulation = Inflow − Outflow

Accumulation = F − (D + B)

Because accumulation is zero at steady state, B is dependent upon F and D, as expressed by

B = F – D

or if the bottoms product is the manipulated variable: D = F − B

where: F = feed rate (the inflow)

D = overhead rate (an outflow)

B = bottoms rate (an outflow)

I. Composition Control

Choices for controlling product compositions include

(1) Controlling top or bottom composition only (where effective feedforward/ feedback systems can be designed to compensate for load changes) and

(2) Controlling of both product compositions (minimizes energy use and columns in which the problems of interaction are small).

1. Feedback Control

The most direct scheme for control of distillate purity is achieved by measuring composition of the distillate and manipulating the reflux ratio as shown in Fig 1 below

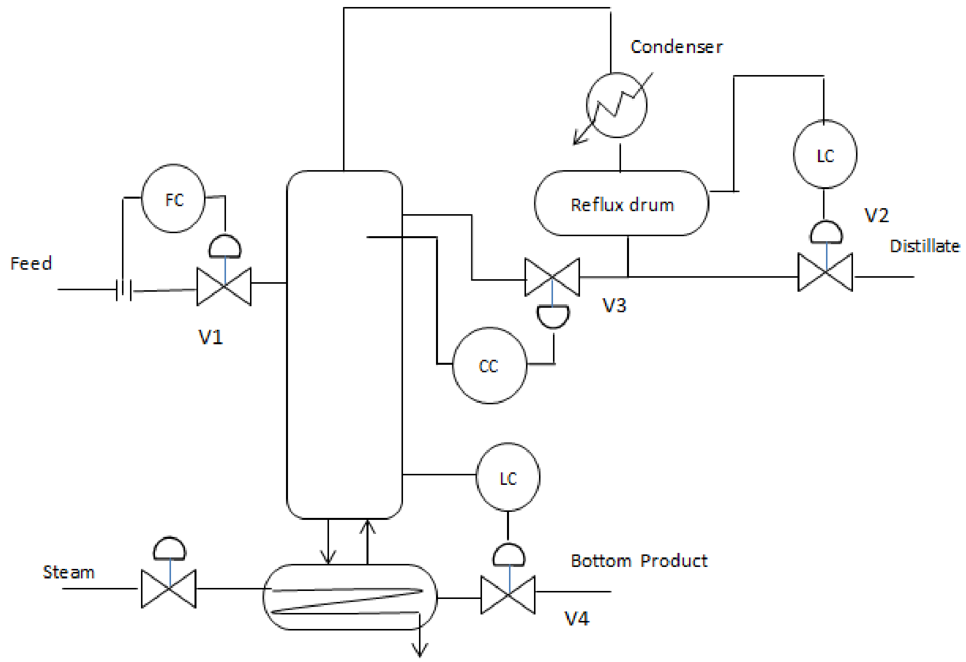

Figure 1: Feedback Control of distillate composition

Feed is maintained at a constant rate by Valve V1. Level in the reflux drum and column bottom is maintained by an averaging type of level controller by manipulating valve V2 and V4 respectively. Reflux is controlled by manipulating valve V3 based on signal from the composition controller, CC.

An alternative strategy could be by interchanging the signals to valves V2 and V3. Signal from composition controller, CC can be used to manipulate valve V2 whereas level in the reflux drum can be manipulated by valve V3.
However, in both these schemes, composition is used as the measured variable which is expensive, especially if it is an online one and at times it is impractical. There will be a delay in getting results of composition analysis from the laboratory and thus the control scheme will not be effective.

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Distillation process is based on separation of components based of their volatilities which is a temperature dependent function; therefore; an indirect measurement of composition is inferred from temperature measurement of the top plate, to control distillate purity as shown in Fig 2.
Any change in composition will be reflected as a temperature change, assuming constant column pressure[5].

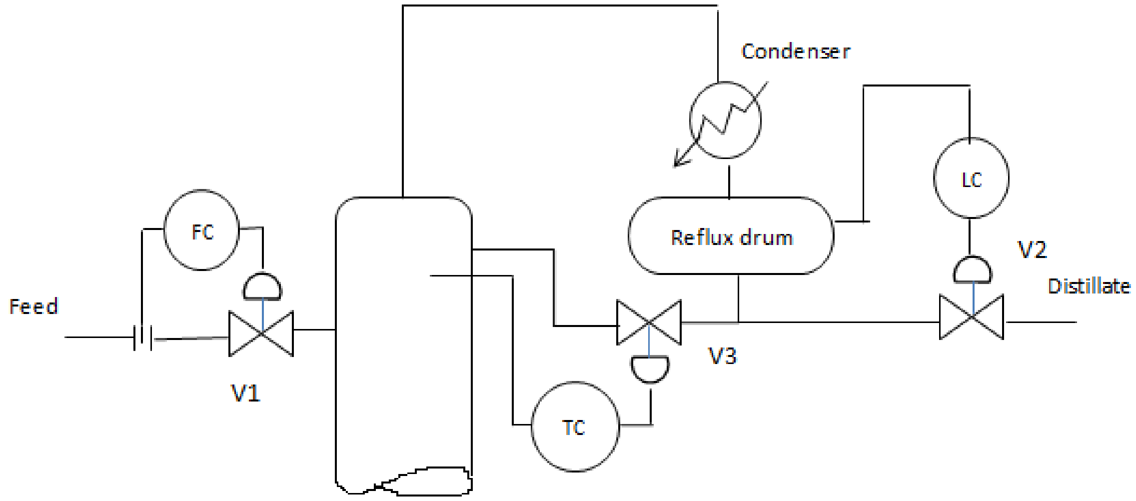

Figure 2: Indirect scheme for distillate composition control

Usually the temperature controller will be located on the top tray for controlling distillate purity; however; if the purity of bottom product is important, the temperature measurement can be carried out in the lower section. In this case, the temperature controller can be used to manipulate the steam input to the reboiler.

2. Feed Forward Control of Distillate Purity
   If the disturbances are known, then feedforward control scheme can be used to control the distillate composition as shown in figure 3.

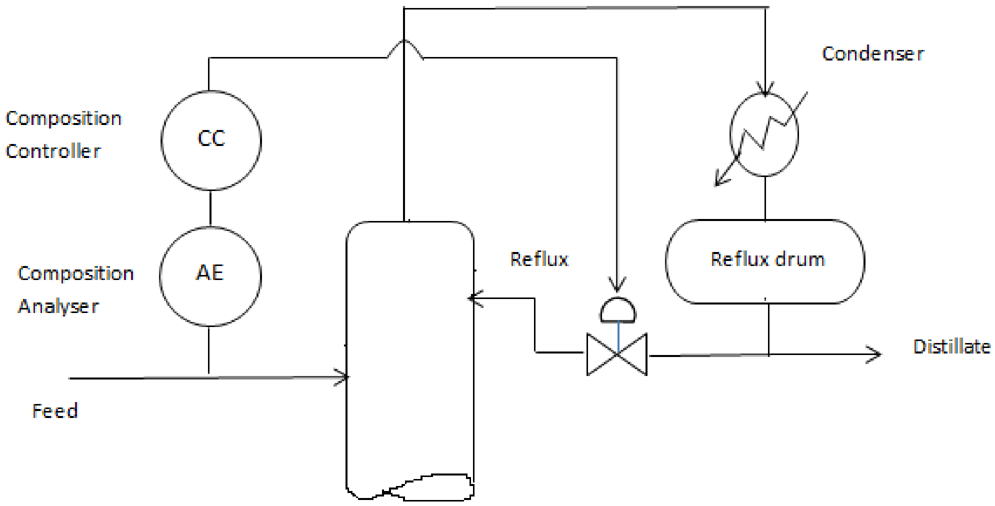

Figure 3: Feedforward control of distillation column

One of the major disturbances to the distillation operation is the change in composition of the feed. Hence, in Feed forward control scheme any change in the composition will be detected by an Analyser element (AE) whose output is then compared with the set point and error signal generated by the composition controller will then be used to manipulate reflux flow rate.
Another method of implementing feed forward control is by combining feed flow rate with top plate temperature which can then act as set point to the flow control valve of Reflux.

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3. Cascade control of Distillate Purity

When the purity of top product is of importance, cascade control scheme is used to compensate for flow changes in the reflux and/or temperature changes of the top plate. If any of these two parameters change, reflux flow rate is manipulated.
Simple proportional controllers are normally used as secondary controllers, the reason being that the primary loop will have integral action and remove stationary error anyway. In some applications PI secondary loop controllers may be beneficial, most notably when the primary loop is very slow compared to the secondary loop [7]
Here, the temperature control loop is the primary loop and Flow control loop is the secondary Loop. Output of the Temperature controller, TC acts as the set pint for the Flow controller, FC

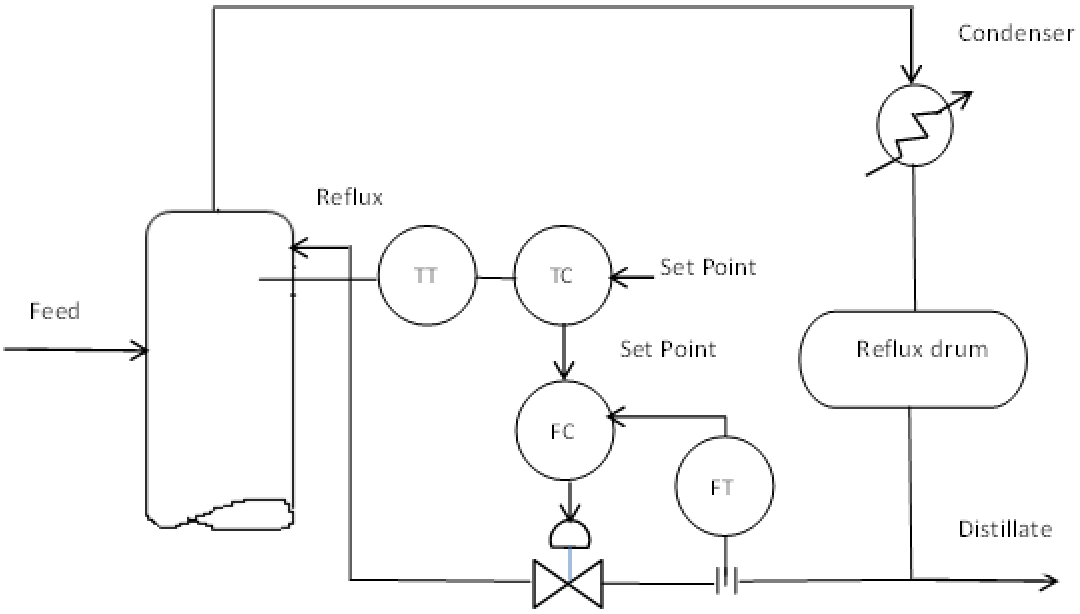

Figure 4: Cascade control of distillate Purity

If the purity of bottom product is of importance, temperature of the bottom plate is cascaded to the flow controller for bottom product. Here again, TT and TC form the primary loop whereas FT and FC form the secondary Loop

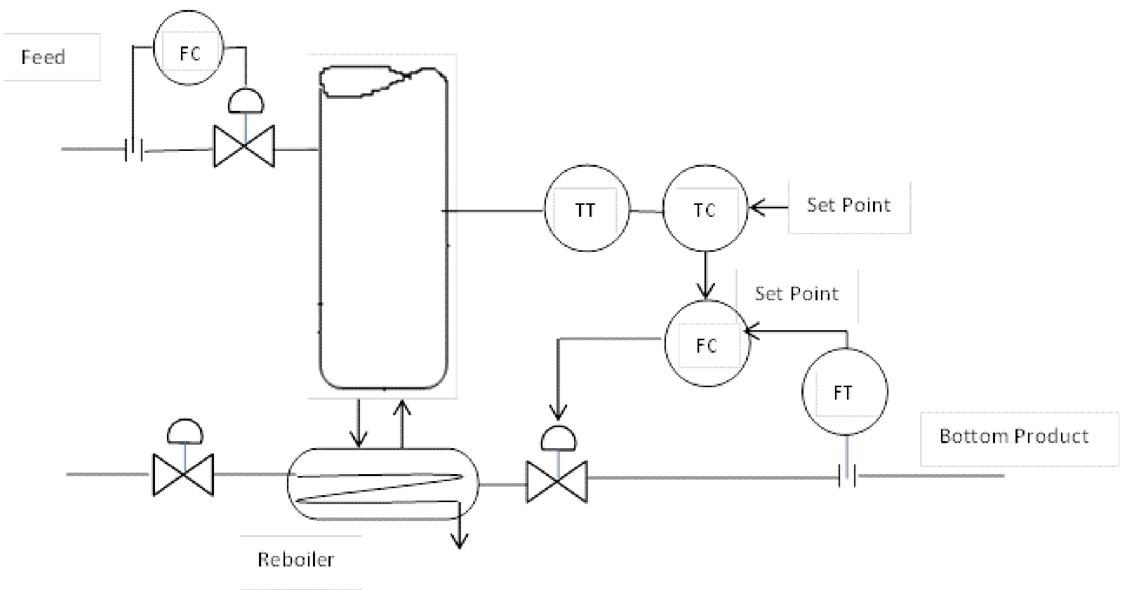

Fig 5: Cascade control of Bottom product Purity

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II Pressure Control System

Changes in pressure affects temperature, composition, condensation , vapourisation and hence is one of the major control variable.

Pressure control is integrated with condenser operation. Following two methods are commonly used for column pressure control[4]

Method I- Controlling the vapour inventory

This is the simplest and direct method of pressure control for column producing a vapor product. The pressure controller regulates the vapor inventory and therefore the column pressure. An important consideration here is the proper piping of the vapor line to avoid liquid pockets.

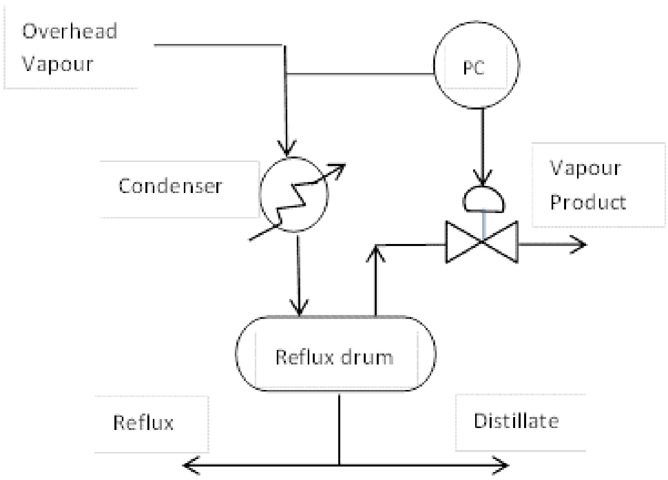

Figure 6: Pressure control using vapour inventory

Method II-Controlling the condensate

This method is used with total condensers generating liquid product. Part of the condenser surface is flooded with liquid at all times. The flow of condensate from the condenser is controlled by varying the flooded area. Increasing the flooded area (by reducing flow) increases the column pressure (less surface area for condensation).

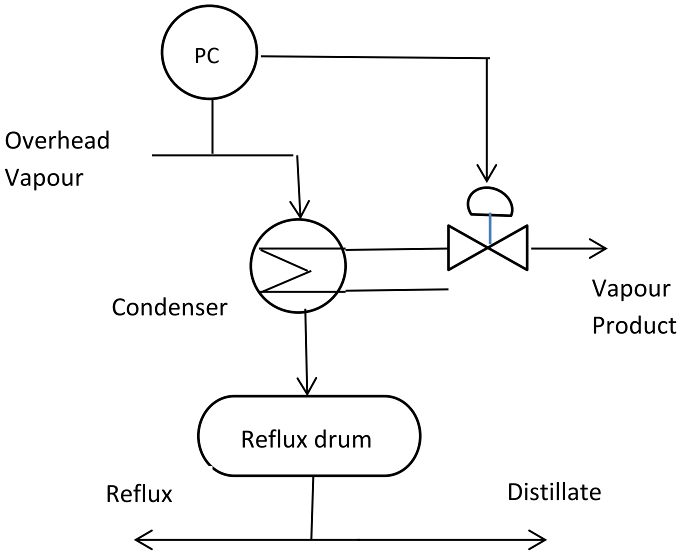

Figure 7: Pressure control using condensate flow

Pressure can also be controlled by adjusting the flow of coolant to the condenser. Operation using cooling water can cause fouling problems at low flow condition, when cooling water velocity is low and outlet temperature is high.

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III Level control or material balance

A simple feedback control system to control level in the reflux drum can be achieved by measuring the level in the reflux drum and manipulating either the distillate flow or Reflux flow. Generally the largest flow is used to control level. The reason is that it is then less likely that the flow will saturate, For example, consider control of top level (reflux drum) where one issue is whether to use L or D as an input. The 'largest flow' rule gives that one should use distillate D (the 'conventional choice') if $L/D < 1$, and reflux L for higher reflux columns with $L/D > 1$.[1]
However, cascade control system is more effective to achieve the material balance.
Figure 8.shows the cascade control scheme for level control in Reflux drum. Here, the output of LC (Primary Controller) acts as a set point for the flow Controller (Secondary Controller). Thus, any changes in the reflux flow and/or level of reflux drum is used to manipulate reflux Flow rate. Distillate flow rate is maintained constant. Similarly, Level in the reboiler can be controlled by manipulating either the bottom flow rate or Steam flow rate.

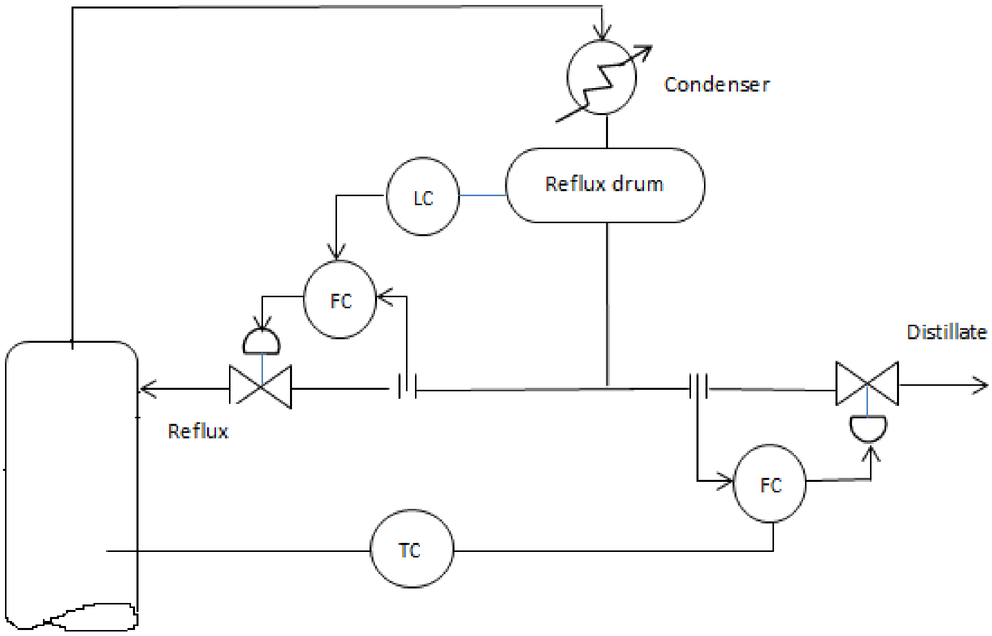

Figure 8: Cascade control of level in Reflux Drum

Figure 9 shows the cascade control scheme for level control of column bottom. LC senses and controls the bottom level and is cascaded to FC of the bottom flow. Steam Flow is maintained at constant flow rate.

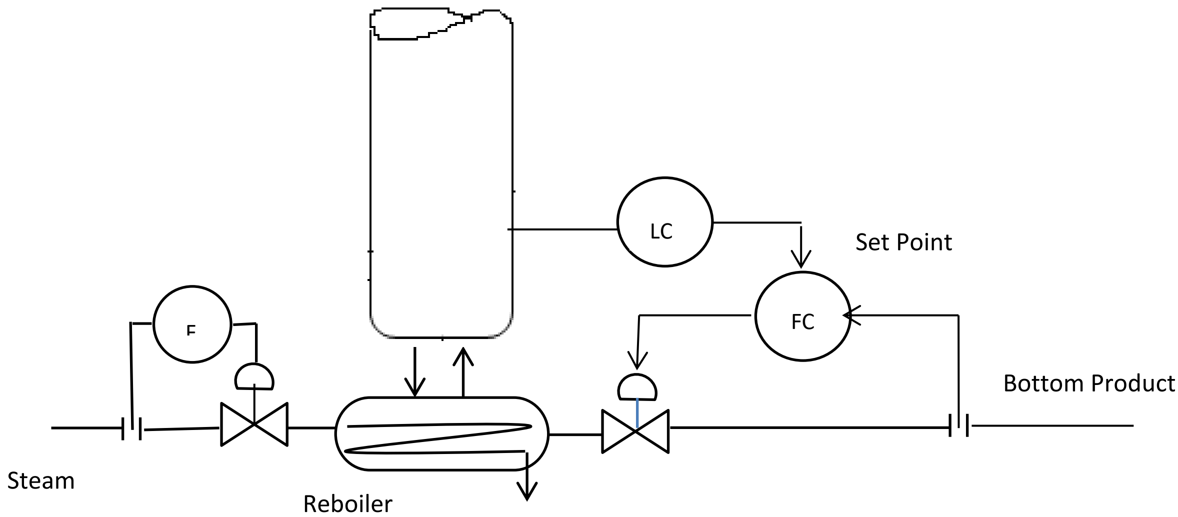

Figure 9: Cascade control of column bottom level

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CONCLUSION

Selection of appropriate control strategy and scheme depends on the reflus ratio, the boil up ratio and also the type of controller. The type of controller is decided based on the dead time or lag in the system. The dead time in turn depends on the load. If the residence time of water in condenser is not significant, simple proportional action is good enough for pressure control; however; large residence time necessitates integral controller.

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