

# 4 Column-Base and Reboiler Arrangements

## 4.1 INTRODUCTION

**t**he design of a column base with its associated reboiler can be a complex matter. It requires simultaneous consideration of fluid mechanics, heat transfer, mass transfer, and process control. For example, the following must be considered when a vertical-thermosyphon, forced-circulation, or kettle-type reboiler is used:

1. Spacing between the vapor-return nozzle and the lowest tray should be large enough to minimize entrainment of liquid drops in the rising vapor. This is typically one vapor nozzle diameter and normally will be specified by the column designer.

2. The maximum liquid level should not be too close to the vapor nozzle as this will promote turbulence in the liquid surface and liquid entrainment into the rising vapor.

3. Minimum liquid level should not be too far below the vapor nozzle, or the falling liquid drops will entrain too much vapor into the liquid pool. In severe cases this may cause foaming in the column base and “gassing” of the reboiler. This difficulty, however, can be largely offset by item 4.

4. There should be a minimum liquid level depth above the nozzle to the drawoff line from the column base or vaporizer separator. This is required for two reasons: first, to permit entrained vapor bubbles to rise and separate from the liquid pool, and second, to minimize the likelihood of vortex formation at the drawoff nozzle. Vortexing (like the swirl at a bathtub or sink drain) is undesirable since it promotes entrainment of vapor into the drawoff line, which may cause “gassing” of the reboiler or bottom product pump or circulating pump. Vortex breakers should be installed routinely.<sup>1</sup>

5. If level-measurement nozzles are not protected by an internal damping chamber, they should have an orientation no more than 90° from the vapor-return nozzle and should not be located under the last downcomer.

In this chapter we consider primarily five types of reboilers: vertical thermosyphon, flooded thermosyphon (steam side), forced circulation, flooded-bundle kettle, and internal reboilers.

## 4.2 VERTICAL THERMOSYPHON REBOILERS\*

### Typical Operation and Design

Vertical-thermosyphon reboilers or calandrias are commonly designed for a mass circulation ratio of about 5–20 parts of liquid to one part of vapor. This means that only about 5–25 percent by weight of reboiler effluent is vapor; on a volumetric basis, however, the numbers are almost reversed.† The tubes are filled with froth, and pure liquid exists in the tubes only for a few inches above the bottom tube sheet.

For most applications, if shell-side steam pressure, tube-side pressure, and composition are fixed, heat-transfer flux will be a maximum when column-base liquid level relative to the bottom tube sheet is about one third of the distance between the two tube sheets<sup>2</sup>—see Figure 4.1A.

If liquid level goes below this point, heat transfer falls off rapidly. As liquid level goes above this point, heat transfer declines only slightly; at a liquid elevation corresponding to the top tube sheet, flux is perhaps 10–15 percent less than maximum. In view of this, it is a conservative practice to maintain column-base liquid level below the top tube sheet and above an elevation corresponding to the midpoint between the two tube sheets. As pointed out by Smith,<sup>3</sup> the above may be influenced by column pressure.

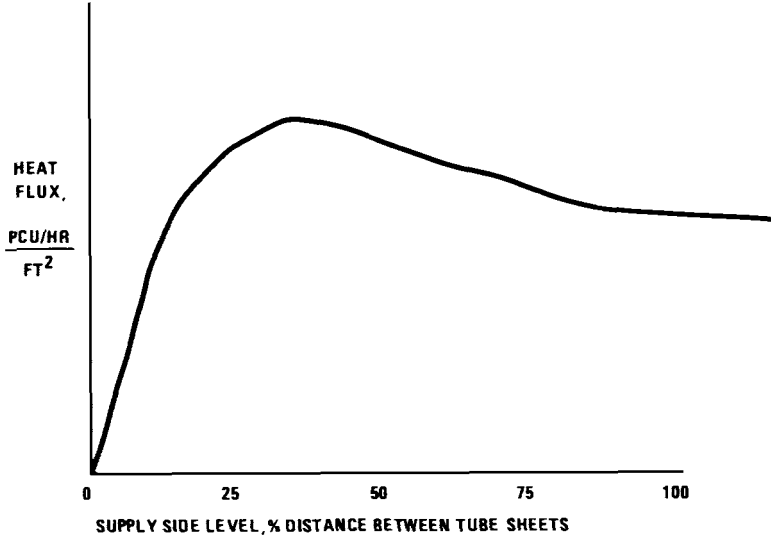
For many applications the practical implementation of the preceding is as illustrated by Figure 4.1B. A level nozzle spacing of 44 inches is suggested for  $\Delta P$  transmitters and 48 inches for displacer transmitters. The top nozzle center should be at least 1 inch below the lip of the vapor-return nozzle, or 1 inch below the elevation of the bottom lip of the internal vapor downspout (if used). The bottom nozzle should be centered 6 inches above the KRL (knuckle radius line) if a  $\Delta P$  transmitter is used, and 2 inches above the KRL if a displacer instrument is used. For either type of transmitter, the following calibration procedure is recommended.

—Zero level should be 6 inches above the KRL.

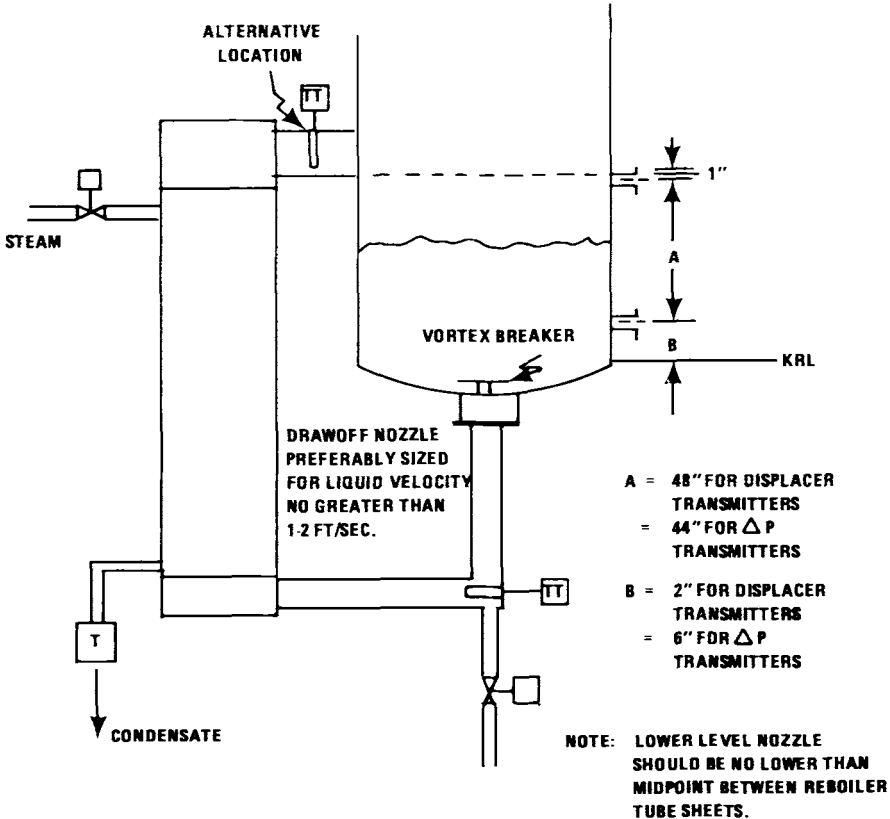
—The transmitter output span should be 3–15 psig for pneumatics, or 4–20 mA for electronics, for  $44 - 6 = 38$  inches of process fluid. This allows 6 inches below the top level nozzle to accommodate changes in liquid-specific gravity.

\* Particularly in the petroleum industry, horizontal-thermosyphon reboilers are sometimes encountered.

† A literature review of thermosyphon reboilers is given by McKee.<sup>4</sup>



**FIGURE 4.1A**  
Vertical thermosyphon—heat flux vs. supply side liquid level



**FIGURE 4.1B**  
Distillation column base with thermosyphon reboiler

Since we normally design the controls to work in the middle of the level transmitter span, the average level will be  $6 + 19 = 25$  inches above the KRL.

Level-measurement techniques, including baffle design, are discussed in Chapter 11.

## Control and Operation Difficulties

A typical thermosyphon reboiler has several additional features that sometimes cause or contribute to control difficulties:

### A. Choked-Flow Instability

When the reboiler heat flux

$$\frac{\text{pcu/hr}}{\text{ft}^2}$$

or

$$\frac{\text{Btu/hr}}{\text{ft}^2}$$

becomes too high, there ensues a violent oscillation of process flow through the reboiler tubes and of reboiler  $\Delta P$ . In one set of experiments,<sup>5</sup> a period of 3–4 seconds was observed; it is not known how general this is. Corrective measures include reducing the vapor exit restrictions and increasing the liquid supply restriction.

### B. Reboiler–Column-Base “Manometer”

From a hydraulics standpoint, a reboiler and column base function crudely as a U-tube manometer whose natural period in seconds is approximately  $\sqrt{l}/1.3$  where  $l$  is the length in feet of the liquid column. Manometer theory says that damping is increased as the liquid flow restriction is increased. There may be a connection between this and choked-flow instability; for a period of 3 seconds,  $l = 15$  feet, which is fairly typical for industrial installations.

### C. Change in Tube Vapor Volume with Change in Steam Rate

For a fixed liquid level in the column base, the volumetric percent vapor in the tubes increases as steam (or other heating medium) flow rate is increased. As shown by Figure 4.2, this effect is very pronounced at low heat loads but tapers off at higher loads. The end result is similar to boiler swell (Chapter 10, reference 6); an abrupt increase in steam flow causes liquid to be displaced back into the column base, with a resulting temporary increase in column base level.

Figure 4.2 is derived by running the reboiler computer design program for at least three values of base level and five values of heat load. The program calculates the weight fraction vapor at the end of each of a number of sections of tube length. The cubic feet of vapor in each section of tube are then calculated from the following equation:

$$[\bar{V}_v]_i = \frac{1}{1 + \frac{\rho_v}{\rho_L} \left( \frac{1 - \bar{F}_{wt}}{\bar{F}_{wt}} \right)} \times L \times V'_i$$

where

$\rho_v$  = vapor density, lbm/ft<sup>3</sup>

$\rho_L$  = liquid density, lbm/ft<sup>3</sup>

$$\bar{F}_{wt} = \frac{[F_{wt}]_{i-1} + [F_{wt}]_i}{2}$$

$[F_{wt}]_i$  = weight fraction vapor at exit of tube section  $i$

$L$  = length, in feet, of tube section

$V'_i$  = inside volume of one tube section, ft<sup>3</sup>/ft

The total vapor volume in the tubes is then  $\Sigma[V_v]_i \times n$  where  $n$  is the number of tubes and  $\Sigma[V_v]_i$  = total vapor volume, ft<sup>3</sup>, in one tube.

#### D. Change in Tube Vapor Volume With Change in Column-Base Liquid Level

If heat load is held constant but column-base liquid level is varied, tube vapor volume decreases with increase in liquid level. In cases examined so far, this effect is small compared with that due to changing steam rate.

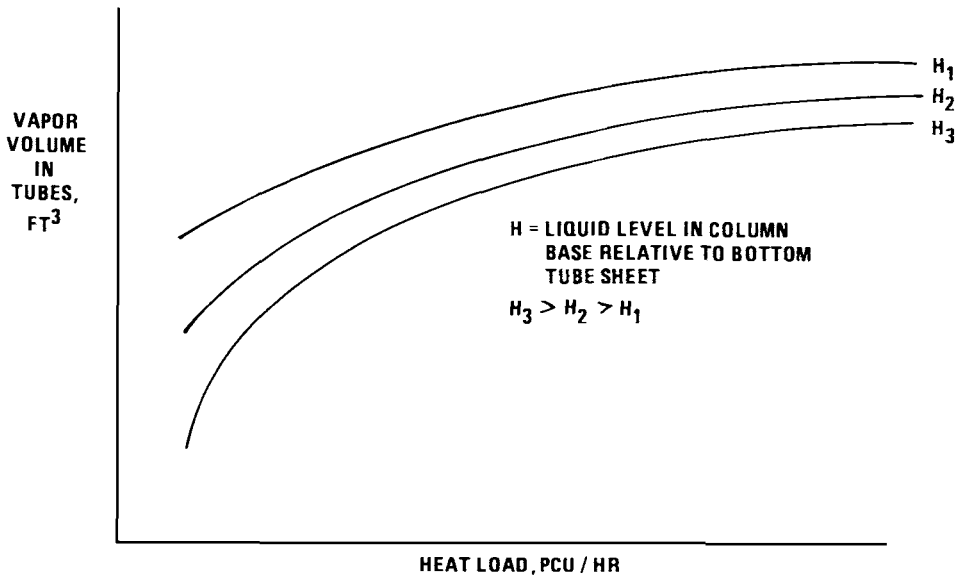


FIGURE 4.2

Relationship between vapor volume in tubes of thermosyphon reboiler, heat load, and base liquid level

### E. Critical Versus Noncritical Steam Flow

When the steam valve pressure drop is high enough that flow is critical, reboiler shell pressure has no effect on steam flow rate. The reboiler has process dynamics different from those obtained with noncritical steam flow. For noncritical flow the steam flow or flow-ratio controller can have much higher gain (often by a factor of 5–10) than when steam flow is critical. If, as sometimes happens, the switching point from critical to noncritical flow occurs at a heat load close to normal operating heat load, controller tuning can present perplexing problems. If the controller is properly tuned for a higher load, the control loop may be unstable at a slightly lower load. Conversely, if the controller is tuned at a lower load, control may be very sluggish at higher loads. Preferably, therefore, the reboiler should be designed to operate over its normal range in one flow regime or the other.

### F. High Concentration of Nonvolatile Components

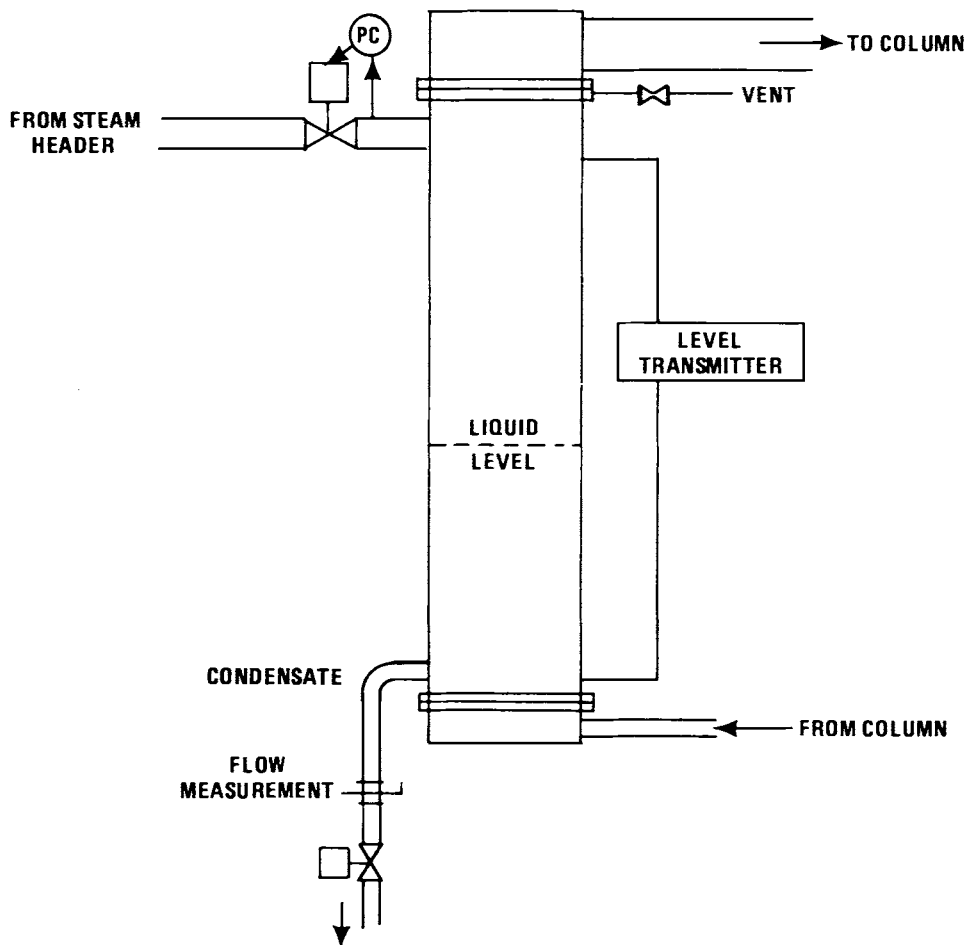
Here the reboiler is fed with a wide boiling range mixture. For the case where the column-base liquid contains only a small amount of low boilers and a large amount of material with a much higher boiling point, perhaps approaching or exceeding maximum steam temperature, thermosyphon action and heat transfer may fall off as liquid level in the column base falls much below the elevation of the top tube sheet. What often happens is that either base level or low boiler concentration gets too low, thermosyphon action ceases, low boilers are completely stripped out in the tubes, and boiling stops. The column contents then drop into the column base. The increase in level and low boilers then permits boilup to resume. The alternate cessation and resumption are violent enough to merit the term *burping*. In view of what is often a rather narrow range of acceptable operating conditions, it is questionable whether a thermosyphon reboiler should be used for such applications. A forced-circulation reboiler would be better. If, however, a thermosyphon is used, one may maintain constant head on it by the overflow and external tank design of Figure 4.17.

## 4.3 FLOODED THERMOSYPHON (STEAM-SIDE) REBOILERS

As shown by Figure 4.3, a flooded thermosyphon reboiler operates by throttling condensate rather than steam flow. The basic principle is that of varying the heat-transfer surface. The chief advantage is that for a given steam flow in pounds per hour, a condensate valve is much smaller than a vapor supply valve. At a high heat load such that shell-side liquid level is low, condensate subcooling is small and there is some cavitation in or flashing across the condensate valve. Fortunately new methods developed by the ISA (see Chapter 11) permit much more accurate prediction of flashing and cavitation, and many valve manufacturers now can provide anticavitation trim. Care must be taken to avoid excessive reboiler  $\Delta T$ , which may cause either film boiling or choked flow. A steam-supply pressure regulator is often used to protect against this.

Control of the condensate valve is sometimes achieved by a steam-flow measurement, sometimes by a condensate-flow measurement (more accurate and cheaper), and sometimes by another process variable. Response is more sluggish than when steam flow is throttled. No trap is required. The theory and design equations are presented in Chapter 15. For troubleshooting, performance tests, startup, and, in some cases, overrides, a liquid-level transmitter should be installed on the reboiler shell side.

A special version of a flooded reboiler designed for low-boiling materials (requiring low-temperature steam) is shown in Figure 4.4. Steam to the reboiler is throttled in a conventional fashion—usually flow controlled or flow-ratio controlled—but there is neither a trap nor a condensate pot. Instead condensate is removed through a loop seal whose top is vented to atmosphere. The height



**FIGURE 4.3**  
Flooded reboiler

of the loop is typically 5–10 feet. This arrangement has the equation:

$$H_L \rho \frac{g_L}{g_C} = H_S \rho \frac{g_L}{g_C} + P_S + \Delta P_{\text{line}} \quad (4.1)$$

where

$H_L$  = loop-seal or standpipe height, feet

$H_S$  = condensate level in the shell, feet

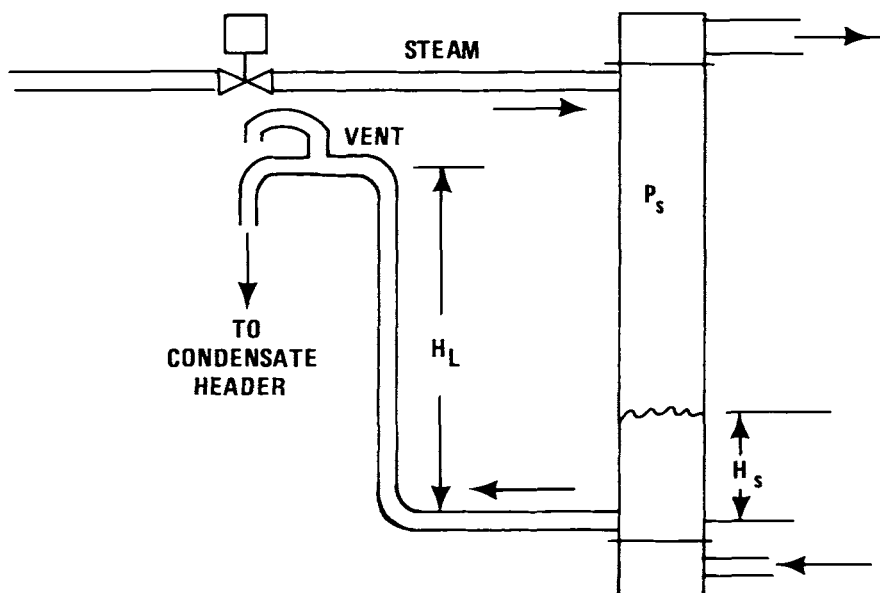
$P_S$  = shell pressure, lbf/ft<sup>2</sup> absolute

$\rho$  = condensate density, lbm/ft<sup>3</sup>

Now the absolute value of  $P_S$  does not change very much so boilup rate is mostly controlled by variation in exposed tube area.

#### 4.4 FORCED-CIRCULATION REBOILERS

Forced-circulation reboilers are commonly horizontal as shown in Figure 4.5, but also occasionally are vertical. To minimize pressure drop, a restriction downstream of the reboiler is sized to prevent vaporization in the reboiler tubes. This restriction may be in the vapor line to the column or right at the vapor nozzle outlet.



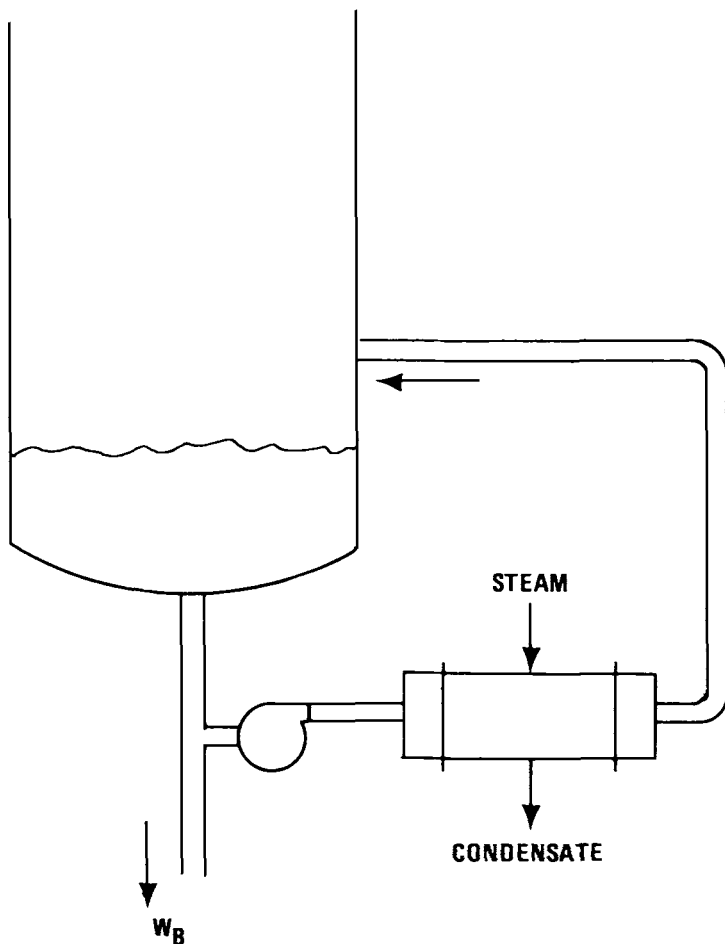
**FIGURE 4.4**  
Flooded reboiler for low boiling point materials



Forced-circulation reboilers are widely used for vacuum columns because of their lower pressure drop, for applications where a thermosyphon would be expected to foul, and for applications where thermally sensitive materials are being distilled.

#### 4.5 FLOODED-BUNDLE KETTLE REBOILERS

Kettle-type reboilers are sometimes used with vacuum columns. They eliminate the need for the circulating pump required with a forced-circulation reboiler, and avoid the temperature elevation encountered in the lower end of a thermosyphon reboiler. The usual arrangement is that of the flooded-bundle type



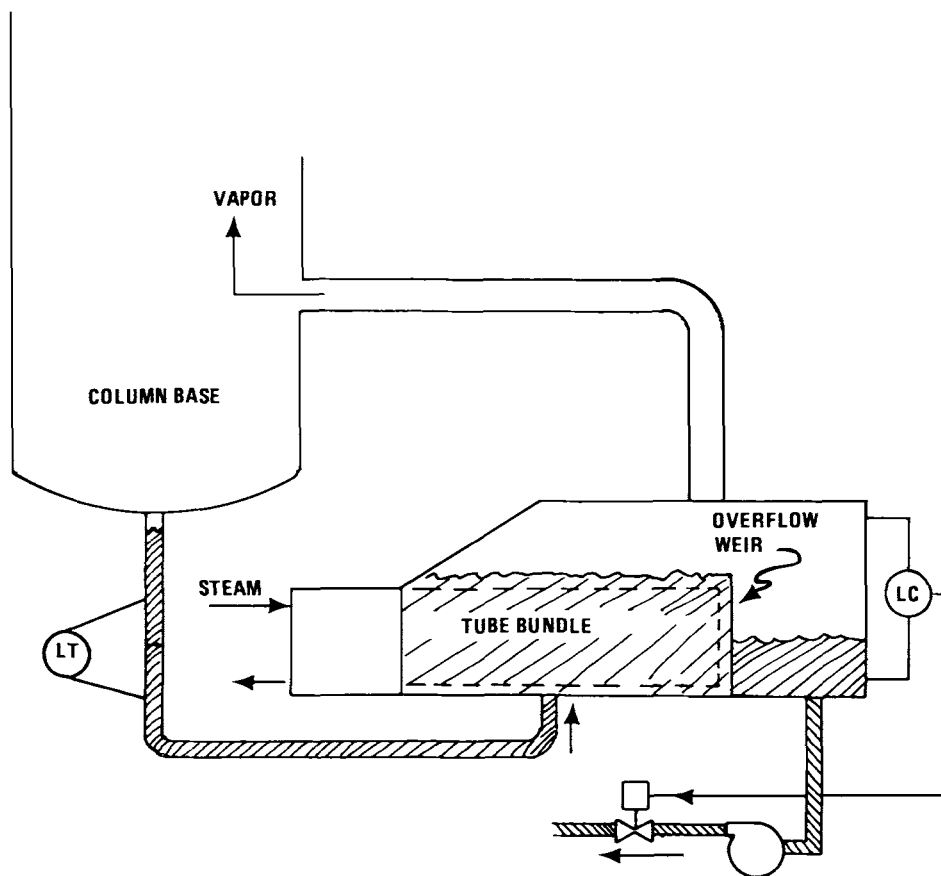
**FIGURE 4.5**  
Column base with forced-circulation reboiler

shown on Figure 4.6. This is very similar to an internal reboiler with an isolating baffle or chamber, as will be discussed in the next section.

The column base runs empty and there is just enough liquid head in the line connecting the column base to the reboiler to overcome the pressure difference between the kettle reboiler and the column base. To protect the tube bundle in the event that boilup temporarily exceeds downflow, a head measurement must be made on the tube bundle chamber. This can be connected to an interlock, or, as shown on Figure 4.7, to suitable overrides.

Shown here are two overrides (pneumatic devices illustrated). One has a latch-up circuit with a gain 25 relay, which provides a high signal the first time the reboiler is filled with liquid; the steam valve is held closed until the level covers the tubes. Once latched up this circuit does not function again until it is unlatched by switching to "shutdown."

The other circuit is intended to shut the steam valve if the total head drops below a certain amount after normal operation has been in effect. This requires

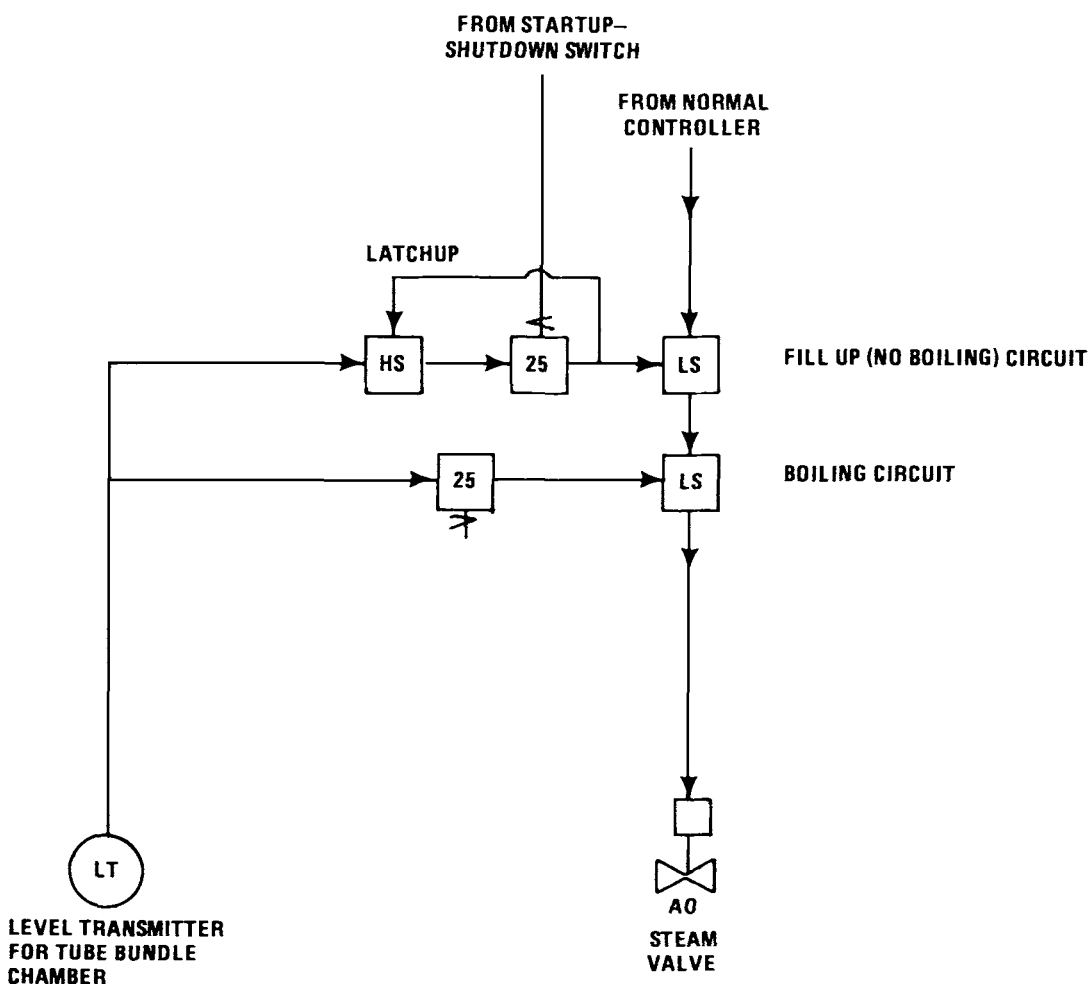


**FIGURE 4.6**  
Kettle-type reboiler with internal weir

field calibration since the presence of froth between the tubes produces an average density well below that of clear liquid.

## 4.6 INTERNAL REBOILERS

Internal reboilers, usually in the form of horizontal, cylindrical bundles of U-tubes with the heating medium in the tubes, have been used to a modest extent. In comparison with external reboilers, pumping and pressure-drop considerations are eliminated, as are piping and reboiler shell. Offsetting these in part, however, is the fact that the column base must be longer (taller) to provide



**FIGURE 4.7**  
Protective circuits for tube bundle chamber in kettle-type reboiler

adequate space for controlling the froth level. There is also the added difficulty of controlling the level of a variable-density froth. In addition, the column must be shut down to clean the tubes.

Two basic arrangements for installing and operating internal reboilers are employed:

1. Tube bundle without isolating baffle or chamber.
2. Tube bundle with isolating chamber.

### Tube Bundle Without Isolating Baffle or Chamber

This case is illustrated in Figure 4.8. Here the tube bundle\* is submerged in a pool of liquid. Above the bundle we normally find froth, not clear liquid. Some bubbles, of course, exist in the spaces between the tubes. Since most level instruments really measure head, not level, there is the practical problem of measuring or predicting true level accurately enough to prevent the froth from rising high enough to flood the lower tray or trays. As indicated by the literature, this is no trivial problem.<sup>7</sup>

From the column or reboiler designer it is necessary to get an estimate of relative froth density:

$$\phi = \frac{\text{Froth density, lbm/ft}^3}{\text{Clear liquid density, lbm/ft}^3} \quad (4.2)$$

The Hepp<sup>7</sup> correlation may be used to estimate  $\phi$ :

$$\phi = 1 - 0.62 \, v \sqrt{\rho_v} \quad (4.3)$$

where

$v$  = vapor velocity, ft/sec

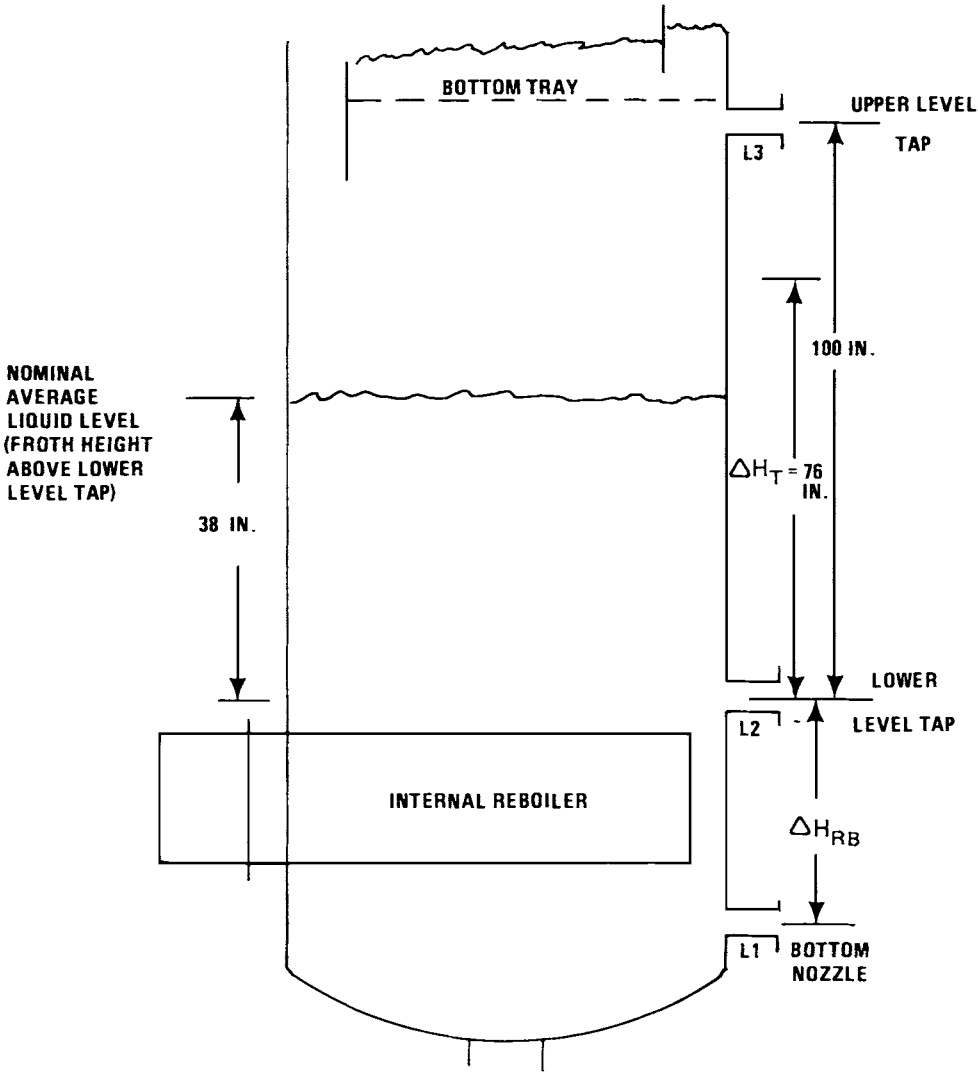
$\rho_v$  = vapor density, lbm/ft<sup>3</sup>

To get adequate holdup for level control, we must take  $\phi$  into account. If, for example,  $\phi = 0.5$ , we need twice the volume that would be required for clear liquid. Thus this type of internal reboiler probably should not be used in vacuum towers since the required base froth volume would be too great.

For the particular case where  $\phi = 0.5$ , the nozzle spacing of Figure 4.8 is suggested. Note that  $L_1$  and  $L_3$  are the nozzles used for level control (see discussion in Chapter 11).  $L_3$  and  $L_2$  are used to determine that the bundle is covered by liquid. To allow for variations in froth density, the top 24 inches between  $L_2$  and  $L_3$  are clearance; the level transmitter is calibrated such that "100 percent" level is 76 inches above  $L_2$ .

Although liquid level can come a little way below the top of the tube bundle without causing either fouling or a reduction in heat transfer, it is more conservative to keep the bundle submerged.

\* Sometimes the bundle consists of U-tubes; sometimes it is a two-pass bundle extending through the column with the intermediate head on the far side. The latter design is better than the former for flooded-tube operation.



**FIGURE 4.8**  
Column base with internal reboiler—no baffles or weirs

### **Tube Bundle with Isolating Chamber**

As shown by Figure 4.9, internal reboilers are sometimes isolated from the column base by an isolating baffle, chamber, or "bathtub." The downcomer from the last tray dumps into the chamber and the excess overflows into the column base. The outlet weir from the chamber is generally set high enough to flood the tube bundle. There are now two problems: (1) controlling level in the column, and (2) protecting the tube bundle if boil-off exceeds downflow.

In theory it is possible to run base level at elevations above the bottom of the isolating chamber (in the space between  $L_2$  and  $L_4$  in Figure 4.9). Some columns have been built this way. In practice it is undesirable because cross-sectional area, and therefore holdup at this elevation, are limited. Thus it is recommended that the level be measured and controlled below the isolating chamber.

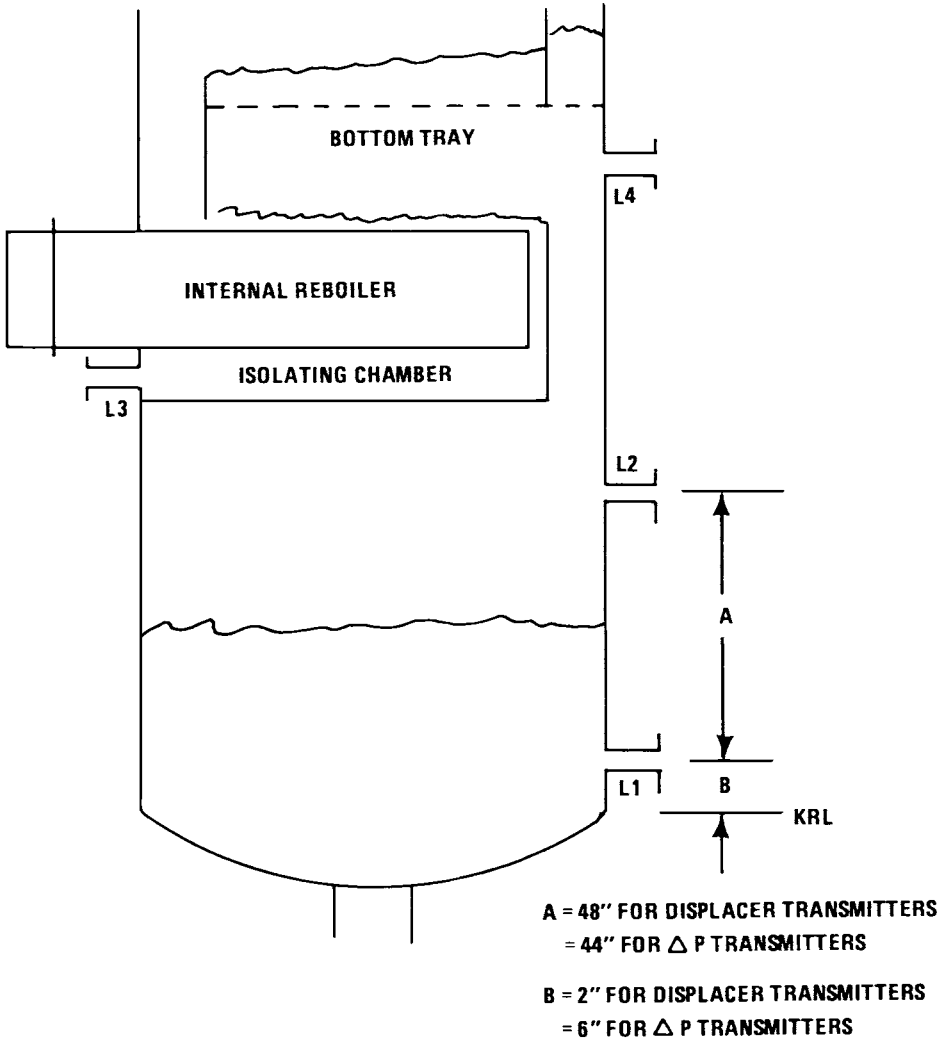
In the event that boilup exceeds downflow, the level in the isolating chamber drops and exposes tubes. With many organics, this causes a type of fouling called "varnish." To prevent this from happening, one should provide a second level transmitter, connected to nozzles  $L_3$  and  $L_4$ . The output of this transmitter should be connected to an override in the heating medium control valve circuit; a low level should pinch this valve.

## **4.7 STEAM SUPPLY AND CONDENSATE REMOVAL**

Steam supplies for distillation columns are commonly arranged as shown in Figure 4.10. From a high-pressure header, steam is let down to a lower pressure through a "reducing station." This may feature a transmitter, controller, and valve, but is often a self-contained, self-actuated pressure regulator. In some cases there is also a desuperheater. This last item is sometimes installed because of a common misunderstanding about the effect of superheat on reboilers; it simply reduces slightly the amount of condensate<sup>8</sup> and usually does not, as sometimes believed, reduce reboiler heat-transfer capacity.

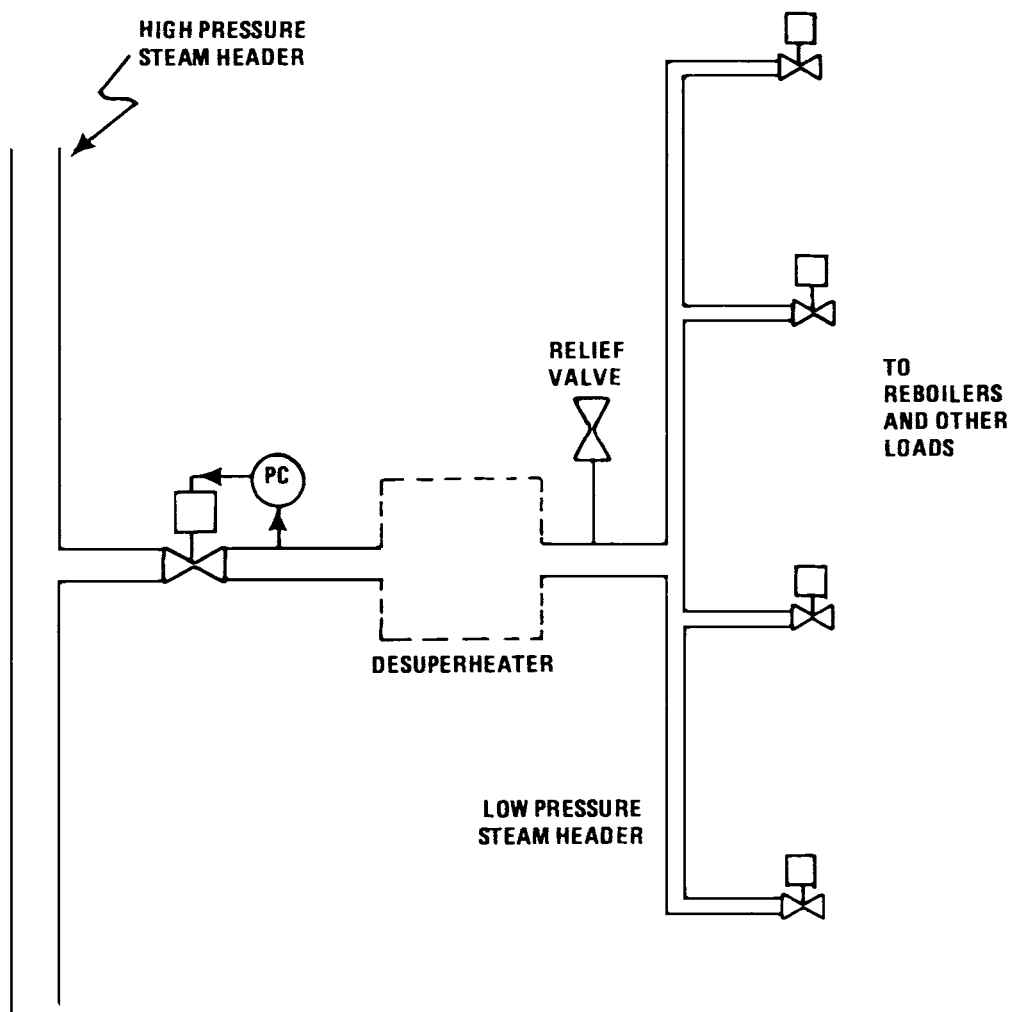
The reduced-pressure header may serve one load or many. For a design with only two or three loads, there is often a severe interaction between the loads and the pressure reducer. Suppose, for example, that steam flow to one reboiler is increased. This drops pressure in the reduced-pressure header. The pressure controller opens the upstream valve to restore pressure, but in the meantime the lower pressure may have caused another reboiler supply valve to open. If all of the controllers are tuned tightly, there may ensue "fighting" among the controls and substantial swings in header pressure and steam flows to the various reboilers.

For a header with many loads, header pressure is really constant at only one point; at the far end of a distillation train, header pressure may be much lower. Particularly for a small number of loads, it may be more logical to eliminate the pressure reduction. A system such as shown in Figure 4.11 may



**FIGURE 4.9**  
**Column base with isolated internal reboiler**

be used instead. Here each reboiler is supplied from a valve connected directly to the high-pressure header. This saves one valve and controller and the higher pressure drop means smaller valves. There is more likelihood of critical pressure drop, and less probability that flow regimes will switch during normal operation (see Section 4.2). This figure also illustrates temperature and pressure compensation of the steam flow meter. Header pressure and temperature variations severely impair the accuracy of many uncompensated plant steam flow meters. A suitable scheme for temperature and pressure compensation is given in Chapter 11. Errors in steam-flow metering without such compensation are also discussed.



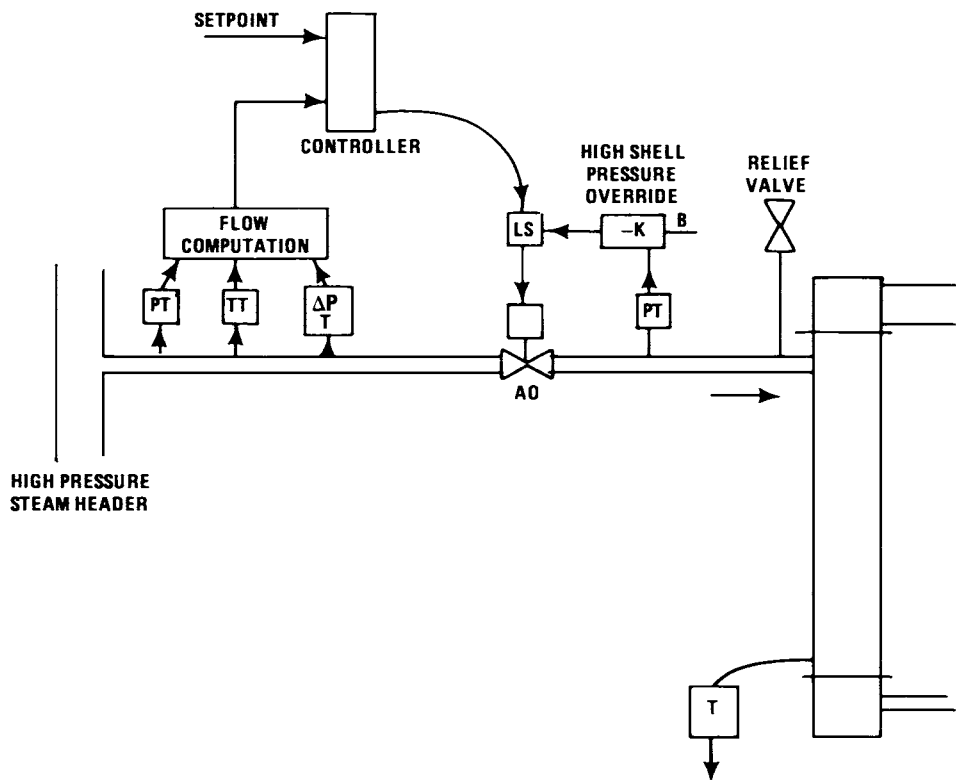
**FIGURE 4.10**  
Steam header configuration



When header pressure variations are small, temperature compensation is sometimes omitted since temperature changes more slowly than pressure.

Steam condensate removal is most commonly achieved by traps—devices that, in effect, are very simple level controllers. Many plants have experienced the need for high maintenance with these. Sometimes enough steam leaks through to impair the accuracy of steam-consumption estimates based on steam flow metering. In addition, as pointed out by Mathur,<sup>9</sup> a rapid closure of the steam valve may cause a vacuum in the shell and pull back condensate through the trap with possible hammering and vibration in the shell. As a result, some reboilers, particularly large ones, are now equipped with condensate seal pots. These pots then have conventional level controllers.

Two practical problems are associated with the selection of condensate removal valves: (1) in sizing calculations allowance usually must be made for some flashing, and (2) the pressure drop increases with flow rate since reboiler shell pressure increases with load. This means that the installed valve flow



**FIGURE 4.11**  
Improved steam supply and flow control system

characteristic should be between linear and square root. Anticavitation trim may be required.

## 4.8 REQUIRED HOLDUP FOR LEVEL CONTROL

Base level is most commonly controlled by manipulating one of three variables: (1) bottom-product withdrawal, (2) steam or other heating medium flow, or (3) feed flow. Avoid scheme 2, if at all possible, because of reboiler and column-base "swell," mentioned earlier. It is sometimes required, however, if the bottom-product flow is very small.

In the discussion that follows, the basic criterion for choosing column-base holdup will be good, or at least adequate, control of the column. As mentioned earlier, good composition control is favored by small holdups. But if the column base serves as a feed vessel for another step, its required volume may be influenced by downstream requirements. This is discussed in Chapter 5. If possible, we will avoid the use of separate, intermediate buffer tanks to feed another process step.

For maximum flow smoothing, we recommend a PI level controller cascaded to flow control. The PI level controller should have, as indicated by Figure 4.12, auto overrides to keep the liquid level between the level transmitter taps. Quantitative design is discussed in Chapter 16.

### Base-Level Control via Bottom-Product Withdrawal

In addition to the auto overrides of Figure 4.12, we commonly have three more overrides. One pinches the bottom product flow if a downstream level gets too high. A second pinches the feed flow if column base level becomes too high, while a third pinches bottom product flow if column base composition has too high a concentration of low boilers.

The characteristic time constant for this system is:

$$\tau_H = \frac{A_B \Delta H_T}{K_{cb} Q_{mFB}} \quad (4.4)$$

where

$A_B$  = column-base cross-sectional area, ft<sup>2</sup>

$\Delta H_T$  = level transmitter span, feet

$K_{cb}$  = level controller gain

$Q_{mFB}$  = bottom-product flow-transmitter span, ft<sup>3</sup>/min

For this system it is usually satisfactory to make  $\tau_H \geq 10$  minutes.

If flow smoothing is noncritical (as, for example, if bottom-product flow goes to a large storage tank), it will be satisfactory to use a proportional-only level controller as shown in Figure 4.13.

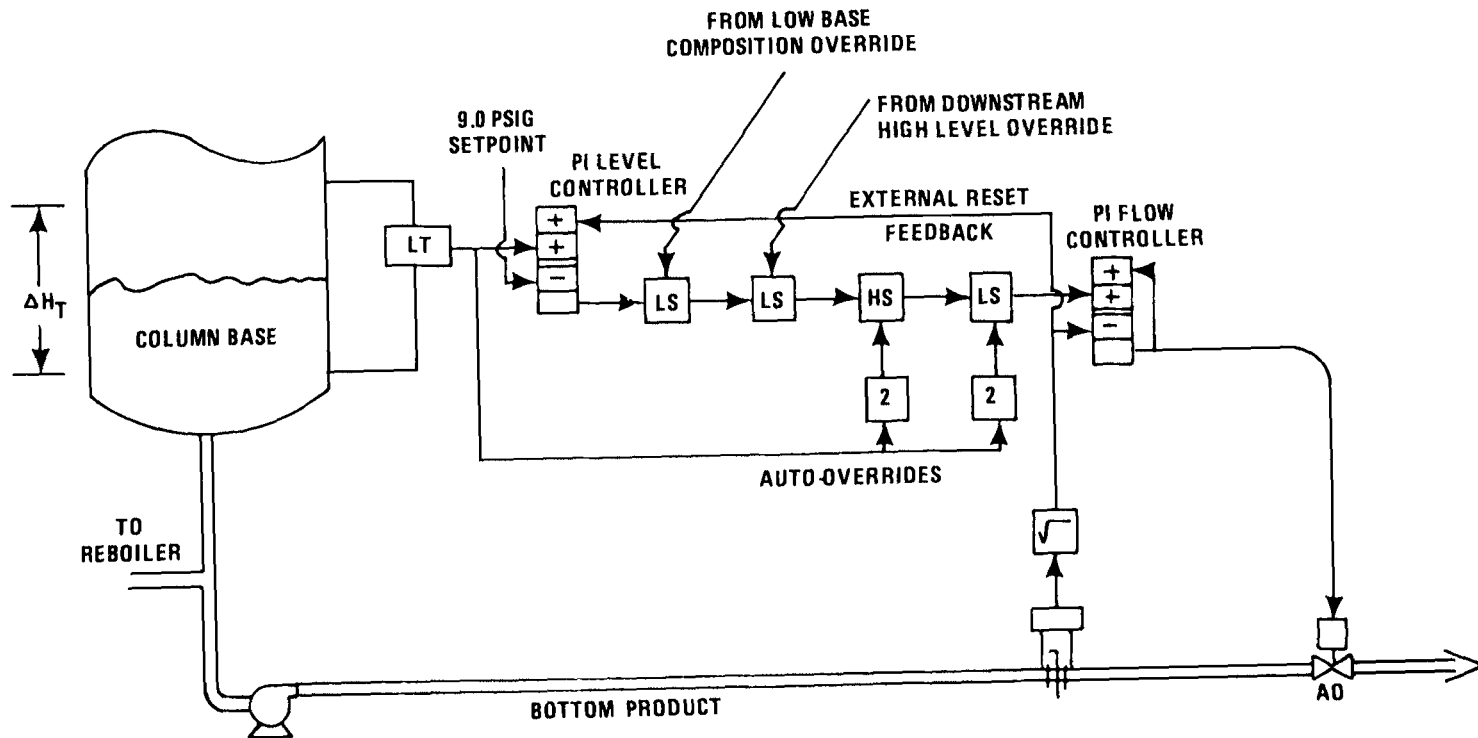


FIGURE 4.12  
Level control of column base via bottom product throttling, cascade arrangement

The dynamic response of the proportional-only, averaging level control system may be defined by a first-order time constant:

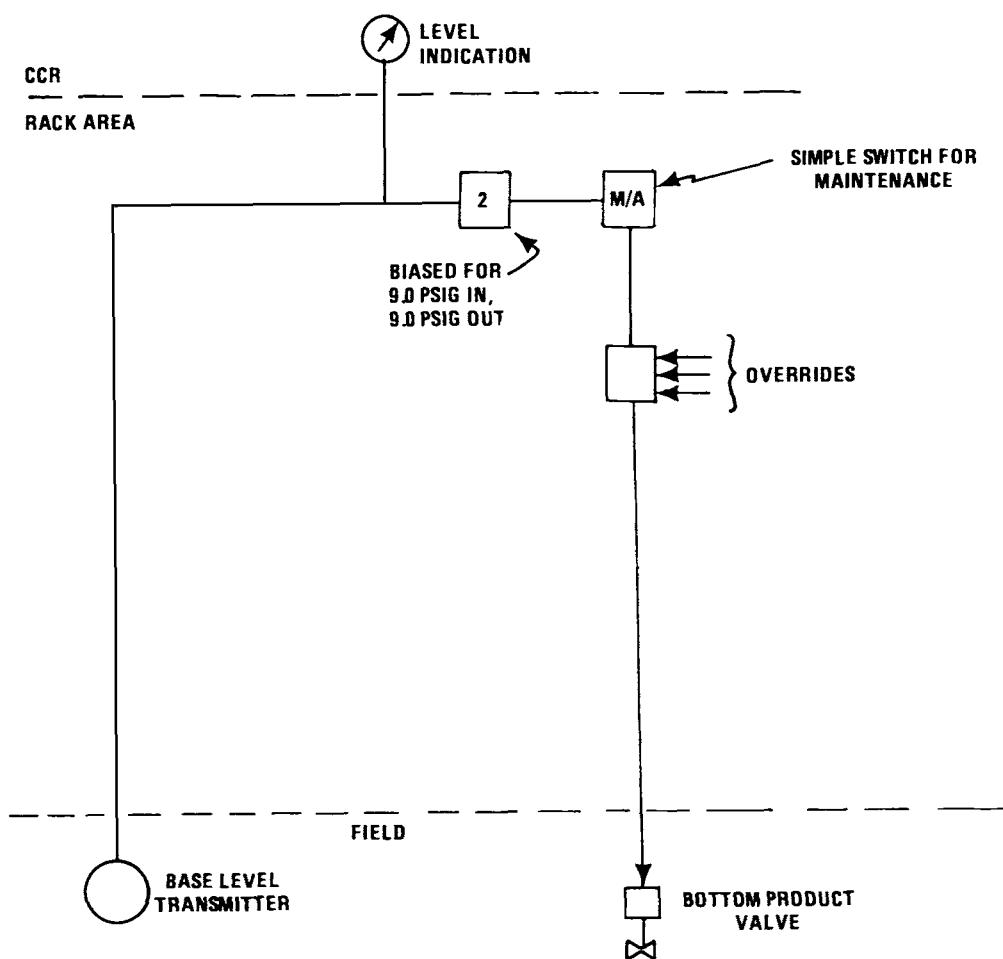
$$\tau_H = \frac{A_B \Delta H_T}{K_c \times 12 \times \frac{dQ_o}{d\theta_c}} \quad (4.4a)$$

where

$\tau_H$  is in minutes

$A_B$  = cross-sectional area,  $\text{ft}^2$ , of the column base or vaporizer separator

$\Delta H_T$  = level transmitter span, in feet, of process fluid



**FIGURE 4.13**

**Proportional-only level control system for column base**

$K_c$  = controller gain

$Q_o$  = manipulated flow, ft<sup>3</sup>/min

$\theta_c$  = signal to valve positioner, psig

For a linear installed flow characteristic,

$$\frac{dQ_o}{d\theta_c} = \text{valve gain} = (Q_o)_{\max}/12$$

$$(Q_o)_{\max} \cong 4 Q_{FS}$$

$$Q_{FS} = \text{flow sheet or average flow, ft}^3/\text{min}$$

There is some uncertainty in valve gain because of differences in the valve-sizing philosophy followed by various instrument engineers. As a result of some adverse experiences due to undersizing holdups by using a factor of 2 to multiply  $Q_{FS}$  to get  $(Q_o)_{\max}$ , we now lean to using a factor of 4 for design calculations early in a project. See, however, the discussion in Chapter 11.

Earlier it was suggested (Section 4.1) that a generally useful level transmitter span would be 38 inches of process fluid. Then if the valve positioner input span is 12 psi:

$$A_B = \frac{2 \times 4 \times A_{FS}}{38/12} \times \tau_H \quad (4.5)$$

$$= 2.53 Q_{FS} \tau_H \quad (4.6)$$

This is the required column-base cross-sectional area.

### Base-Level Control via Feed-Flow Manipulation

Here  $\tau_H$  should be 20 minutes or more and base-level control should be cascaded to feed-flow control. A mathematical analysis is given in Chapter 16.

### Base-Level Control via Steam-Flow Manipulation

In this case  $\tau_H$  should be 20 minutes or more. In addition, the level controller should be cascaded to a steam-flow controller with a linear flow transmitter (or orifice  $\Delta P$  transmitter, and square-root extractor). Further, for a thermosyphon reboiler, one should make the volume  $A_B \times \Delta H_T$  at least ten times the volume inside the reboiler tubes.

For this design:

$$\tau_H = \frac{A_B \Delta H_T}{K_{cb} \left[ \frac{(w_{\sigma})_m \lambda_{\sigma}}{\rho_p \lambda_p} \right]} \quad (4.7)$$

where

$(w_{\sigma})_m$  = input span of steam flow transmitter, pounds per minute; that is, maximum steam flow

$\lambda_{st}$  = steam latent heat of condensation, pcu/lb

$\lambda_p$  = process fluid latent heat of condensation, pcu/lb

$\rho_p$  = process fluid density, lbm/ft<sup>3</sup>

Note that the term in brackets

$$\frac{(w_{st})_m \lambda_{st}}{\rho_p \lambda_p}$$

is the process vapor flow corresponding to  $(w_{st})_m$ . A typical control system arrangement for level control via steam-flow control is shown in Figure 4.14.

Much difficulty has been encountered when trying to control base level by adjusting steam flow to a thermosyphon reboiler. It therefore is recommended that all such applications be subjected to a dynamic analysis such as presented in Chapter 16.

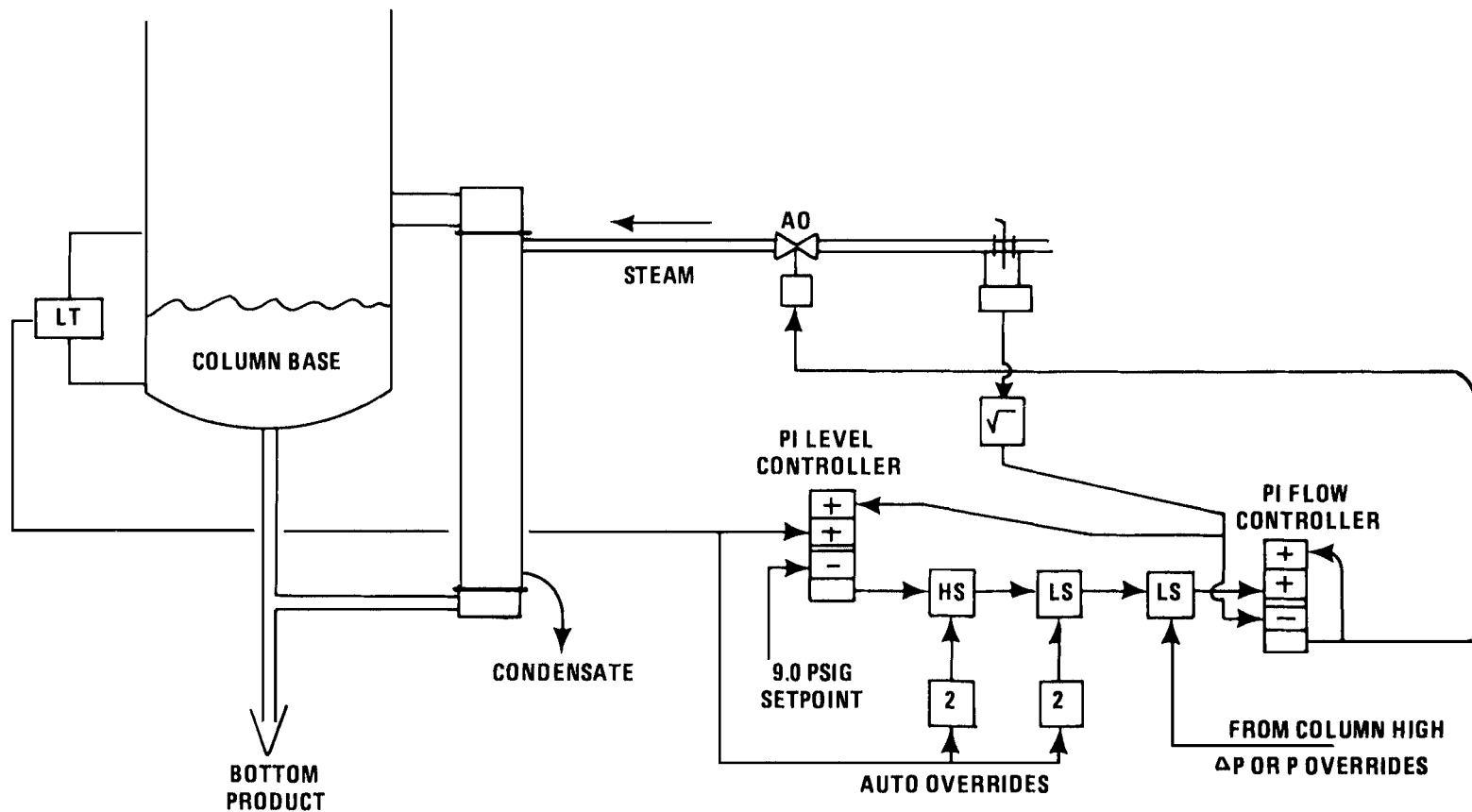
### Minimum Holdup Design

For those distillations involving thermally degradable materials, it is necessary to keep the amount of hot-liquid storage to a minimum. The preferred design of Figure 4.15 involves maintaining liquid level in a small-diameter pot or "peanut." Level nozzle spacing should be chosen as before for the same reasons. If a thermosyphon reboiler is used, care should be taken to ensure that the lower level nozzle is not below the midpoint of the tube length. Note that for overall process control, it may be necessary to send the bottom product to a cooler and surge tank to get adequate flow smoothing for the next process step. (See Figure 4.17.) If this arrangement is used, the bottom product valve may be used with an override to maintain a low level in the column base. When this valve is pinched, the bypass valve opens to send material to the column base.

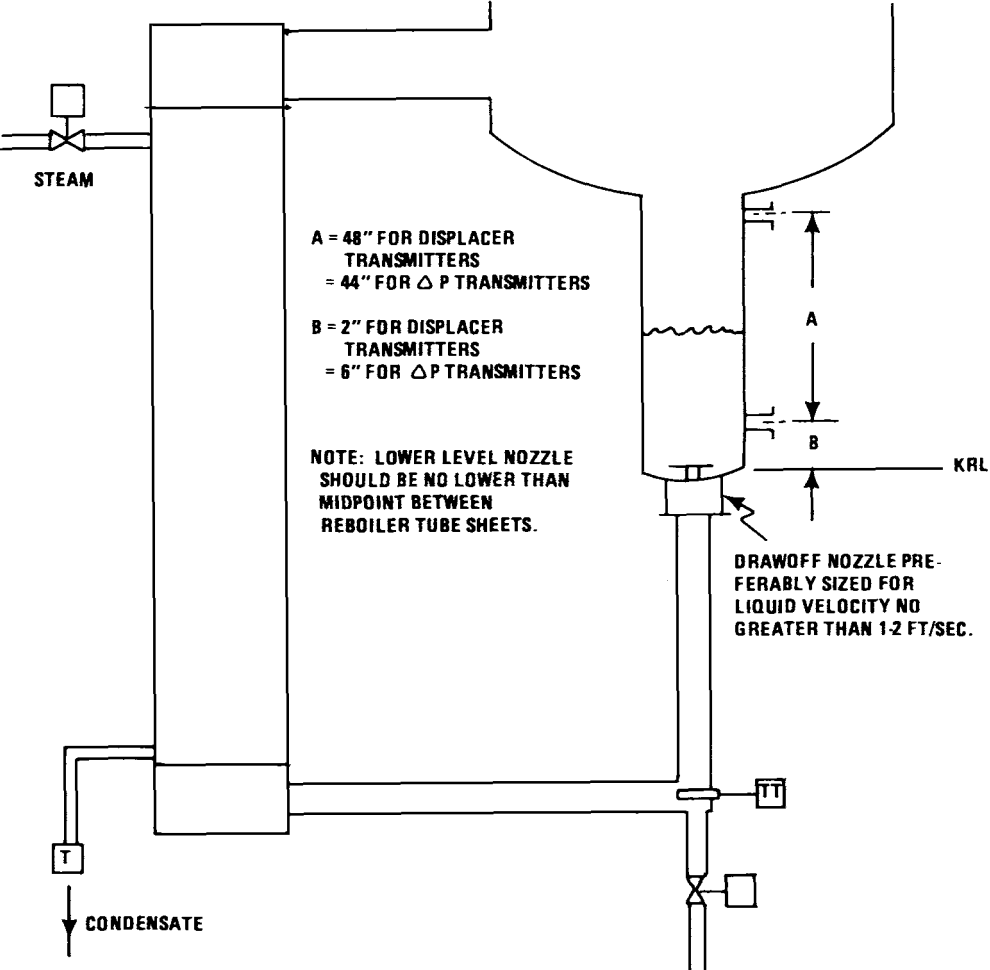
If a cooler is used, it should be noted that the surge tank may act as a condenser via the equalizing line. This may or may not be undesirable.

## 4.9 MISCELLANEOUS COLUMN-BASE DESIGNS

A large number of column-base designs have appeared in the literature,<sup>10</sup> and it is our understanding that there are various proprietary designs that have never been publicized. Many of these include baffle arrangements intended to make the column base and reboiler function as an efficient stage of separation. An occasionally encountered design for this purpose is illustrated in Figure 4.16. As can be seen, the thermosyphon reboiler suction is taken from behind the outlet weir for the last downcomer, which extends almost to the base. This means that reboiler feed is richer in low boilers than is the column-base contents.



**FIGURE 4.14**  
Column base level control by steam flow manipulation, cascade arrangement



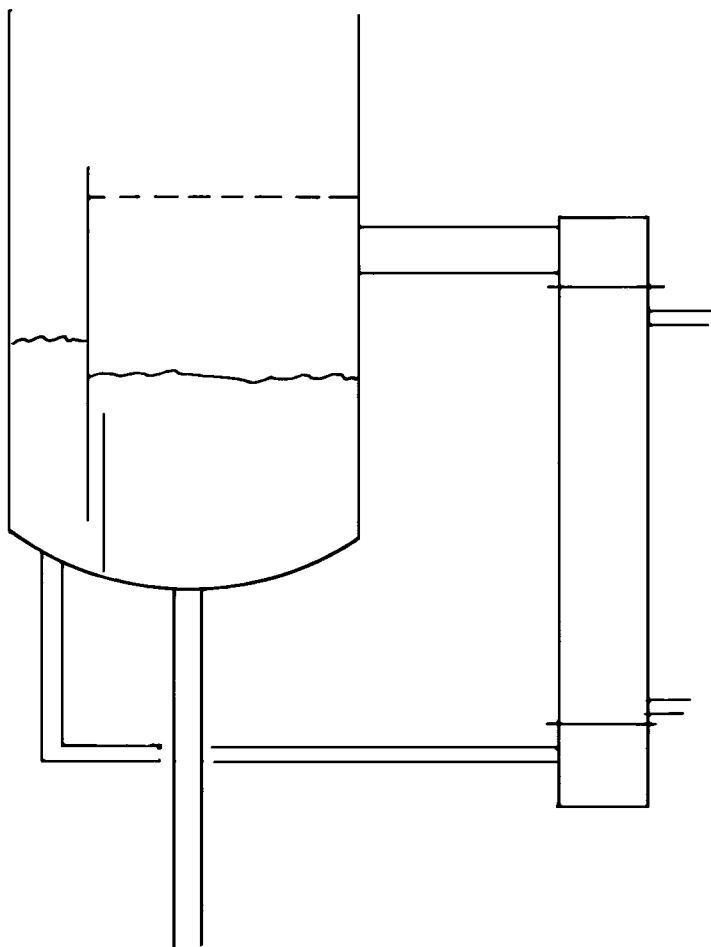
**FIGURE 4.15**  
Column base design and arrangement for minimum holdup



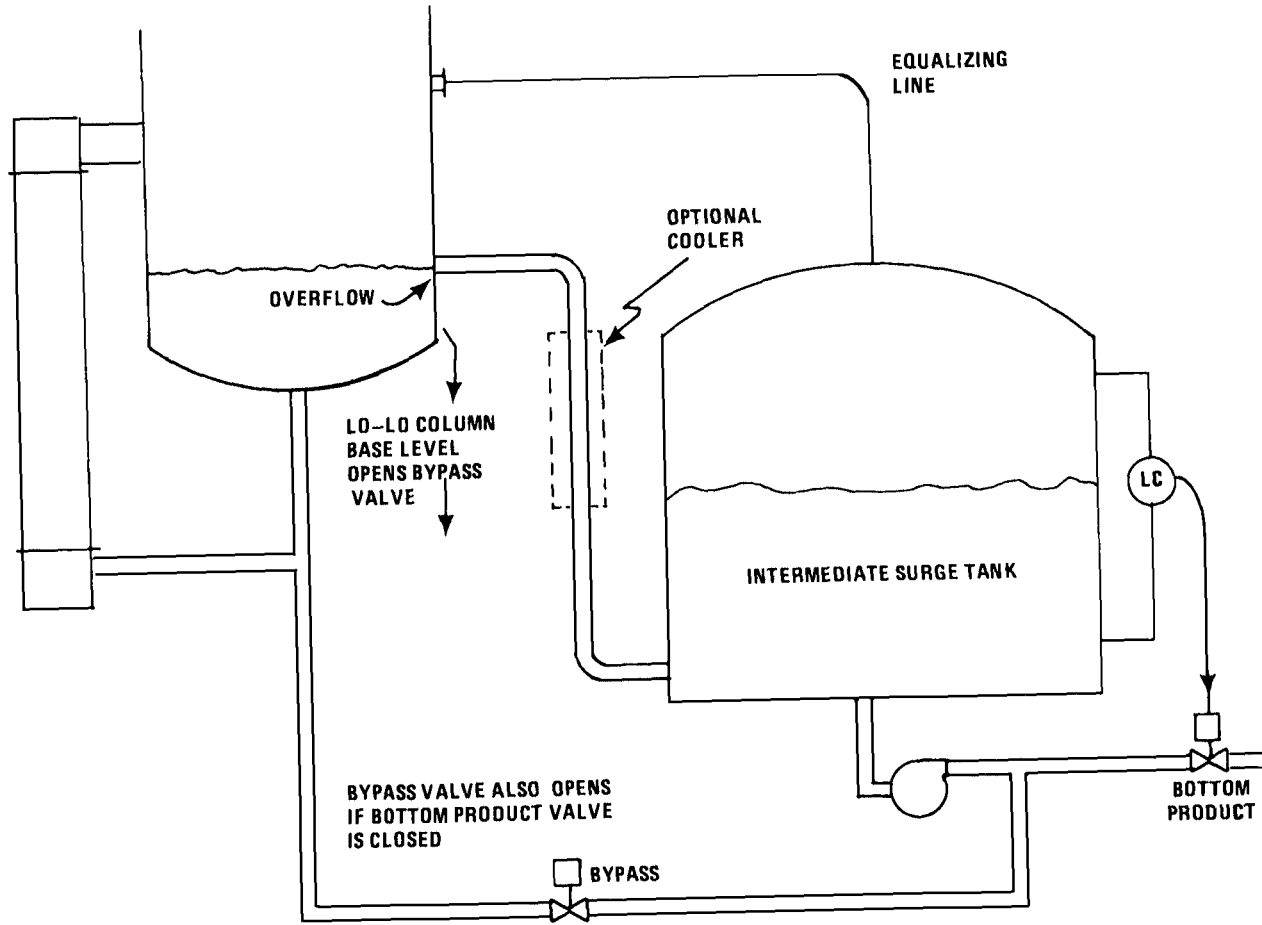
When the column base is too small for smooth level control, an external surge tank must be used. One way of connecting the two is to overflow from the column base into the bottom product receiver as shown in Figure 4.17. A recycle line back to the column base (or to a feed tank) facilitates startup and can be used to protect the column base—and therefore also the reboiler—from excessively low level. The bottom product receiver, as a minimum, should have enough holdup to contain the entire column contents.

#### 4.10 MISCELLANEOUS REBOILER DESIGNS

Two other types of reboilers are sometimes encountered: (1) reboilers with hot oil as a heating medium, and (2) direct-fired reboilers. Both are more common in the petroleum industry than in chemical plants.



**FIGURE 4.16**  
Reboiler piping arrangement for preferential boiling of reflux from lowest downcomer



**FIGURE 4.17**  
Arrangement for column base overflow into intermediate surge vessel

Hot-oil reboilers may be like steam-heated reboilers except that there is no phase change on the oil side. Best practice is to estimate boilup  $w_{BU}$  from the equation:

$$w_{BU} \lambda_{BU} = w_{oil} c_p (T_{in} - T_{out}) \quad (4.8)$$

This requires measuring oil-flow rate and inlet and outlet temperatures.

For higher temperatures than available with steam, use is made of other condensing media such as Dowtherm or p-cymene. For even higher temperatures, direct-fired reboilers may be used.

## REFERENCES

1. Patterson, F. M., *Oil Gas J.*, 118–120 (Aug. 4, 1969).
2. Frank, O., and R. D. Prickett, *Chem. Eng.*, 107–110 (Sept. 3, 1973).
3. Smith, J. V., *Chem. Eng. Prog.*, 68–70 (July 1974).
4. McKee, H. R., *IEC*, 62: 76–82 (Dec. 1970).
5. Shellene, K. R., C. V. Stempling, N. H. Snyder, and D. M. Church, "Experimental Study of a Vertical Thermosyphon Reboiler" presented at Ninth National Heat Transfer Conference AIChE-ASME, Seattle, Wash., Aug. 1967.
6. Grabbe, E. M., *Handbook of Automation, Computation and Control*, Vol. 3, New York, 1961.
7. Hepp, P. S., *Chem. Eng. Prog.*, 59: 66–69 (Feb. 1963).
8. Dobratz, C. J., and C. F. Oldershaw, *Chem. Eng.*, 146 (July 31, 1967).
9. Mathur, J., *Chem. Eng.*, 101–106 (Sept. 3, 1973).
10. Jacobs, J. K., *Hydr. Proc.*, 40: 189–196 (July 1961).