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Revision Memo

- 12/02
- General revision with the following principal changes:
1.

Rewording, typos, and editing for clarity.
2.

An abbreviated "Compression section" added. Situation typically requires consulting with Machinery Section of EETD.
3.

Edited Figures for accuracy

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SCOPE

This sub section describes the methods used to control fractionators and gives the basis for choosing the control method to use for a specific design.

REFERENCES

DESIGN PRACTICES

[Section XII C, D, E](#)

[Section IX](#), Heat Exchange Equipment

OTHER REFERENCES

Other valuable guidance can be found in reports previously issued on the subject. E.g:

1. R&D Report EE.19ER70, Advanced Pipestill Control, June, 1970.
2. Control of Towers - Ingolstadt Refinery, Outgoing Letter #79024, November 1, 1963.
3. R&D report EE.IRW61, Improving Superfractionator Control Through Systems Engineering, October, 1961.
4. EE.62E.72 - Temperature Profile Advanced Control of Distillation Towers.
5. EE.95E.76 - Pressure Minimization Control in light Ends Distillation Tower.
6. EE.26E.80 - Fuels Vacuum Pipestill Control Optimization.
7. EE.123E.81 - Product Quality Control of light Ends Distillation Towers Material Balance vs. Energy Balance Control.

BACKGROUND

The purpose of a fractionator is to separate the feed stream into selected fractions that make up the desired products. The purpose of fractionator control is to maintain the desired degree of separation as conditions change (either rapidly or slowly), and to give the operator a means of adjusting the separation as feed conditions (e.g. rate, composition) and/or product requirements (e.g. specifications, demands) change.

The ability of a fractionator to separate adjacent fractions is a function of heat input. Increasing the heat input increases the internal reflux and results in sharper separation, as limited by allowable liquid and vapor tray loadings and condenser capacity.

There are three common control methods: material balance control, control by inference (using temperature to infer a composition), and control by analysis (using a process analyzer to measure the composition).

CONTROL OF TOWER PRESSURE

PURPOSE

Constant pressure is required for good regulatory control of fractionators. For example, because of the relationship between pressure and boiling point for a hydrocarbon mixture, a varying pressure would require corresponding variations in tray temperature, for the composition to remain constant. A constant tray temperature (with varying pressure) would produce a varying composition. This phenomenon is especially troublesome in light ends towers, where a small change in temperature (or pressure) can cause a large change in composition.

Fortunately, fractionator pressure response to control valve action is relatively fast and, with the methods outlined herein, stable tower pressure control is usually not difficult to obtain.

TOWERS WITH NET OVERHEAD GAS PRODUCT

A. No Compression Required

1. **No Condensation** - The overhead gas may go to:

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a. A downstream process with the pressure controlled in the downstream process (the tower “rides” on the downstream control). A variable friction ΔP from the tower to the downstream pressure control point would give a varying tower pressure and thus would probably make this system unsatisfactory. This system is highly restricted in practical use. It is predominantly used where slight variation is tolerable, the downstream pressure is stable, and the fractionator conditions (feed rate, composition, and temperature) are relatively constant.

b. A lower-pressure process, fuel system, or flare, in which case the control valve is placed in the overhead line. See [Figure 1](#) control of tower pressure.

2. **Overhead Partially Condensed** - As in the case with no condensation, the overhead gas may go to a downstream process with the pressure controlled in the downstream process and the tower riding on the downstream control. When the gas goes to a lower-pressure process or other system, the control valve is placed in the gas line from the distillate drum. See [Figures 2 A/B](#). If the condenser is located below the distillate drum, as shown in [Figure 2B](#), it is necessary to check the full range of operating conditions and insure that slug flow will not occur in the riser. Such slug flow would cause unstable tower pressure control.

B. Compression Required

When the desired destination of the overhead gas is at a higher pressure than the fractionator, a compression stage will be required. Operating gas rate, turndown, and required pressure boost will dictate the compressor type. The choice of overhead pressure control scheme will require an analysis of the overhead system including the compression stage. E.g:

- Suction throttling
- Spillback
- Variable speed driver
- Combination of the above

TOWERS WITH OVERHEAD TOTALLY CONDENSED

With total condensation, the basic objective is to match the heat removal in the condenser to the tower heat input. The ability to match is based on measurement of pressure, which will change if heat balance is upset. Alternatively adjusting the reboiler heat input can compensate subcooled condensing, but this would generally result in less than desirable energy usage.

Adjusting Coolant Flow Rate - When water is used as the cooling medium, it is throttled at the condenser outlet. This is done to prevent corrosion problems caused by oxygen coming out of solution if the water is throttled at the inlet. See [Figure 3](#).

Experience with this method shows that (especially at less than design capacity) the outlet water temperature approach to the inlet gas temperature (counter-current condenser construction) is so close that the temperature difference must be called zero. This is a very important consideration since the temperature of the overhead thus determines whether the outlet water temperature will exceed the allowable limit. This limit is based on fouling and corrosion for the type of water and the specific refinery (see [Section IX-B](#)). If the allowable water temperature would be exceeded, one of the alternative control methods covered below would have to be used.

When air is used as the cooling medium (with “air fin” condensers), the comparable control method would be to adjust the coolant flow rate by means of: (1) adjustable louvers over the tubes, (2) adjustable blade pitch on the air fans, (3) hot air recirculation or (4) variable speed fans or (5) combination of two or more of these techniques. Problems that have been experienced with the first three methods are:

1. Flimsy and sticky mechanism for moving the louvers.
2. Insufficient force from the device that moves the louver mechanism.
3. Poor design and operation of the device (a position controller) which translates controller output to blade pitch.
4. The effect on the tower operation of sudden changes in air conditions, such as passing clouds and sudden showers. These changes are equivalent to changing the cooling water temperature with a water-cooled condenser. In locations where such changing air temperatures have been a problem, the control method must take this factor into account. Weather upsets can be compensated for by internal reflux control or the drumless, flooded condenser method, described below.

Solving Problems 1, 2 or 3 requires intensive engineering follow-up of contractors and suppliers. Since the extent of this follow-up is uncertain at the time of process design, control by adjustment of louvers or blade pitch is considered a last choice. The method can be avoided where a drum is not required by using the drumless flooded condenser method, described below.

Drumless Flooded Condenser - This method, shown in [Figure 4](#), emphasizes the principle that tower pressure is an excellent detector of heat balance. The pressure controller sets the reflux rate directly, thus maintaining the heat balance. The net result on the condenser is that a condensate level builds up to the extent that the tube surface exposed to condensing duty is just sufficient to condense the product plus the reflux called for by the pressure controller. For example, a call for more reflux lowers the level exposing more surface for condensation of the additional required reflux.

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A result of this control method is that a reflux drum becomes unnecessary, since it would simply fill with liquid, and is therefore not used. This can be an important cost reduction item. Thus, the full control system for the tower is: constant heat input in the reboiler, heat removal by pressure control of reflux, overhead product removal by flow control, and bottoms product removal by level control. This is a material balance method and some means must be available to the operator to give him a basis for setting the product flow controller. An indication of composition must be selected in order to establish the desired balance conditions. It could be a tray temperature measurement, a fixed percentage of feed based on feed tank analysis or an analysis (periodically from the laboratory or continuously on-line) of the overhead product. Tray temperature control can be accomplished without operator action by cascading a tray temperature controller to the distillate flow controller set point. All this shows a good example of the inter-relation of temperature and pressure control of fractionators.

The problem outlined above relating to the effect of fast weather changes on air fin condensers is overcome by the use of the flooded condenser system. The net effect of weather change is a change in reflux temperature, which upsets the tower heat balance. The flooded condenser system reacts quickly to this upset and restores the balance.

A variation of the flooded condenser system is shown in [Figure 5](#). In this arrangement, the overhead product flow control and reflux-pressure control are transposed to allow the use of temperature control on a tray instead of constant heat input and material balance control. This variation allows the flow rate changes in the tower overhead, leveraged by the reflux/product ratio, to pass downstream. Since tower overhead flow rates are notorious for variability, the product flow rate can fluctuate widely and rapidly. Therefore, this energy balance method is a doubtful choice for feeding a downstream unit, unless a surge tank is used.

The lack of a reflux drum, which typically serves to protect the pump from loss of liquid and to furnish a location for venting any non-condensibles that collect, makes it necessary to add these features.

1. A three foot long pot is needed at the condenser outlet, designed for a full length gage glass (useful during startup).
2. The elevation of the bottom tangent of the pot should be 15 ft above grade, minimum.
3. The pump suction line should be sized for a maximum pressure drop of 0.25 psi/100 ft and should be kept as vertically direct and short as practicable.
4. The reflux pump should be specified to have the lowest NPSH requirement of the available standard pumps.
5. A vent must be provided above the condenser liquid outlets for removal of non-condensable.
6. A pump bypass with a restriction orifice sized for 25% of pump design rate should be provided. This is used during startup when the condensate rate is insufficient for safe pump operation.

In the early years of using this method, it was also thought to be necessary to slope air fins to insure that liquid flow and condensate level were consistent with the theory. Such sloping has since been found to be unnecessary.

Another design feature that has sometimes been included with this method is the addition of an arbitrary amount (such as 10%)

of extra surface. For additional treatment of this technique, see DP-IX-F

Response of Drumless, Flooded Condenser Pressure Control Method - In the Advanced Control Section, a detailed method is given for computing the ability of the drumless, flooded condenser control method to control fractionation tower pressure (response time - from upset to regaining stability). The examples given indicate that there should be no need to check normal fractionator application for response. However, this method can be used to check the response time for other condensing applications as well. This method can also be applied to unusual fractionator applications that have a higher surface-to-condensate rate ratio than the examples (caused by high heat removal per pound of condensate, low heat transfer coefficient or low mean temperature difference). Classic example is steam condensing reboilers. This control method was discovered within the heritage-Exxon organization (at Lago about 1959) and is proprietary company know-how.

Flooded Condenser, With Drum (Condenser Above Drum) - When a distillate drum is required, a variation of the flooded condenser method as shown in [Figure 6](#) can be used. The design includes the following points:

1. Control valve ΔP will be the condensate static head from drum level to condenser level (use the limiting case of the level at the bottom of the bundle), less condenser and line friction. Note that to develop this head for the control valve, it is necessary that the condensate line be sealed.
2. The balance line is without valves, which allows the drum to be without a safety valve. The balance line can arbitrarily be made one size smaller than the tower vapor line or it can be computed. The size computation is based on the vapor flow rate required to give equilibrium drum condensate temperature with condensate entering the drum at water supply temperature. This produces a state change from dew point vapor to bubble point condensate in the condenser. This line is assumed to have no or low friction loss since the drum is essentially 'floating' on the overhead system pressure.
3. Insulation for the drum and balance line should be the same as for the tower. The purpose of this insulation is to reduce pressure control upsets caused by ambient changes (rain, wind).
4. Vent connections for removal of inerts are provided on the drum and on the outlet end of the condenser.

Hot Gas Bypass Method - The hot gas bypass method of tower pressure control has been used over a long period on time. In

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most cases, it is employed when elevation of the condenser is not achievable which is a requirement of the preferable flooded condenser method...There are many variations of the method, some of which are shown in [Figures 7](#). Field experience with these arrangements has varied. However, roughly one-third to two-thirds of the [Figure 7 A, B, C](#) applications have had serious problems. A systems analysis and operation of computer models confirm the inherent lack of stability of these arrangements and inability to predict in advance which designs will be stable. Therefore, in general the hot gas bypass method is not recommended for use in current designs.

This general rule may not apply when a large incentive exists to submerge the condenser below a drum. Large air fin condensers that, if elevated, would need an expensive support structure, can and have caused such situations. The decision to provide a drum precludes the use of the Drumless condenser method depicted in [Figures 4 and 5](#). The decision to submerge the condenser precludes the use of the flooded condenser depicted in [Figure 6](#). For such a case, when the added costs can be justified, the method of [Figure 7D](#) is recommended. Experience with this equipment configuration is limited, but satisfactory. It is seen to be in principle, a variation of [Figure 6](#), which is in wide use.

One of the difficulties and a major contributor to the lack of consistent success for the hot gas bypass control is the sizing of the bypass control valve. Proper sizing requires a complex analysis of the overhead conditions, such as; exchanger pressure drop assuming condensing, variations in cooling rates, expected composition and rate turndown, and stability of the downstream drum pressure.

Cautionary Note - In all of these total-condensation configurations, build-up of unanticipated non-condensables can cause operational disturbances. The designer needs to consider appropriate means to dispose of non-condensable under varying conditions of operations. Typical considerations include:

- Start-up venting of blanket gas
- Entrained inert
- Light end break through from upstream unit
- High point where non-condensable can accumulate
- Expected frequency of build-up

In most cases manual venting is sufficient, but in some cases, automatic venting may be desired. Non-condensable build-up may result in uncontrollable pressure increase, which will require venting to allow for return to normal pressure control. Control schemes such as split range, or staggered set-point pressure control can be considered. Venting rate, and/or controller tuning, will need to be addressed to avoid tower disturbance during the venting process.

CONTROL OF PRODUCT QUALITY

When the pressure control method has been chosen, the method of controlling the quality of the fractions is then selected. This is a two-part problem that, with respect to automatic control, quickly reduces to one part for most towers. The two parts are control of the degree of separation between two adjacent fractions and control of the point at which the cut is made.

The degree of separation between adjacent fractions for a given tower will depend on the extent to which the actual liquid and vapor rates in the tower approach the maximum allowable rates. These rates will usually be set by heat input control (e.g., steam rate to the reboiler) or heat removal control (e.g., reflux flow rate) performed by a flow controller.

Thus, separation capability is seen to be primarily a tower design matter and seldom leads to control problems. The major tower control problem is that of cut point. In choosing the method of control, it should be kept in mind that the purpose of automatic control is to: (1) restabilize conditions after a disturbance in feed rate, feed composition, heat input or heat output, (2) maintain stable operations during slow changes of the above items, and (3) give the operator proper tools to change the fractionation and cut points as required by changes in feed or product demand.

TOWERS WITH OVERHEAD AND BOTTOMS PRODUCTS ONLY

Control By Tray Temperature - The majority of two-product towers have the quality of one of the products set by control of temperature at a point in the tower. The quality of the other product is then a function of the tower's separation efficiency, and any adjustment of this quality would be made by adjustment of the degree of fractionation. [Figures 8 A/B](#) show the two typical tower control systems based on temperature. This method, which controls product quality by adjusting heat input (e.g., [Fig 8A](#), reboiler steam rate) or the heat removal (e.g., [Fig 8B](#), reflux rate), is called energy balance control.

Based on speed of response, there is a small incentive to temperature control heat input if the tower temperature point is in the bottom section of the tower. Similarly, there is a small incentive to temperature control the reflux (with constant heat input) if the tower temperature point is in the upper section of the tower. The method for determining which trays are suitable for temperature control is covered later in this subsection. The method also determines whether temperature is a suitable control variable.

No mention has been made of the feed stream because, due to fraction considerations, the contribution of the feed stream to the heat input of the two-product tower is usually much less than that of the reboiler. However, it may be necessary to control the temperature of the feed stream if it would otherwise be sufficiently variable to cause frequent tower disturbances.



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Control by Material Balance - The class of two-product towers known as superfractionators usually cannot be controlled from tray temperature, because tower operation is too sensitive to temperature. For example, a change of 1°F in the temperature on the optimum tray for control will usually cause more of a change in product quality (cut point) than is allowable. (In case of doubt, the method described under selection of tower temperature control point in this subsection can be used to establish whether control from temperature will be satisfactory or not.)

For such towers, control is by material balance, as illustrated by the two optional configurations in Figure 9. The overhead product is removed on flow control and the remainder of the feed must go out the bottom on level control. As discussed in the flooded condenser pressure control method, material balance control requires that the operator have some tool to use in setting the product flow rate. Where use of the material balance method is based on tower operation being too sensitive to temperature, tray temperature would be unsuitable as a tool. For such services, a feed tank analysis or a product stream analysis (periodically from the laboratory or continuously on-line) is used.

It should be apparent that control by material balance may also be applicable to situations other than the superfractionator application discussed here.

For example, material balance control is preferred when there is a high reflux (R) to distillate (D) ratio and there is a reflux drum. For R/D greater than or equal to 5, manipulating reflux flow should give better sensitivity and rangeability for drum level control.

When the bottoms is a small percentage of the feed stream, changes in the overhead rate can cause large changes in bottoms flow rate. Where this can be anticipated as a problem (bottoms product quality or disturbance to a downstream process), the bottoms product would be put on flow control and the tower level used by the operator to indicate needed changes in the overhead rate.

When the material balance method is used on a tower for which the feed rate is not held constant, consideration should be given to advanced control methods that adjust product rate, rather than leaving this task to the operator (feed rate, feedforward controls). Likewise, in order to reduce tower upsets and response times after feed rate change when the energy balance method is used, feed rate feedforward control adjusts heat input or reflux rate in anticipation of the feed rate change.

Selection of Tower Temperature Control Point - The method covered here for selecting the tower temperature control point was developed for light ends towers having only overhead and bottoms products. This method has now been in use long enough to be considered proven for such services. If extrapolated to other services, the basic points discussed here should be considered carefully in setting up the procedure to follow and the changes to examine.

- It should be emphasized that only a small percentage of the towers in new plant designs would be examined using the method outlined. The method will be most useful for cases where:
 - Uncertainty exists on whether or not temperature is a satisfactory control variable, due to a small delta T across the tower and where there is no available experience with similar separations and feeds.
 - The job being done by the tower is sufficiently different from available experience that the proper tray to control from is not obvious.
- There are large classes of towers that would not require the use of the method, including:
 - Towers handling such wide cuts that a good correlation between temperatures and cut points is known to exist. Naphtha fractionators are an example of this class.
 - Towers, which handle narrow cuts, but are so close to known operations that a direct extrapolation from other jobs is possible. The ethane-ethylene splitter of a stream cracker fractionation train is an example of this class.

To be satisfactory, a method for selecting a tower temperature from which to control must answer the following question: Will product quality remain within allowable limits when tower upsets and disturbances occur, if the temperature at this point is held constant as limited by the ability of the measurement and control system? The method outlined is set up to answer this question. The ability of the measuring and control system to respond is taken as $\pm 1^\circ\text{F}$ ($\pm 0.6^\circ\text{C}$). The types and sizes of upsets or disturbances to examine are covered in the discussion.

The method requires that four additional tower computer simulations be run, in addition to the design case, in order to examine a suitable range of operating conditions. Any available information on the actual upsets and disturbances that the tower will undergo should be used for selecting the range of operating conditions to examine. However, since such information is rarely available prior to operation, the following changes are suggested. They are large, but realistic.

Step 1 Determine which product stream is most critical. A check of the towers' function and product specification will usually suffice for this.

Step 2 Select the light key (LK) and heavy key (HK) components which govern tower operation.

Step 3 Run two computer cases as follows:

RUN NO.	TOWER VARIABLES	FEED COMPOSITION	CRITICAL PRODUCT AS % OF FEED
1	Feed rate: Design Reflux rate: Design	Design	Design % +5 Percentage Points

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	Cut point: Variable 2nd product rate: Decrease to compensate for critical product increase		
2	Ditto except increase 2nd product rate	Design	Design % -5 Percentage Points

Note: This size change has been used for hydrocarbon fractionators with the critical product rate a large part of the feed rate (above 50%). Where the critical product rate is a smaller part of the feed, the change may have to be less than the 5 percentage points in order to keep the operation within reasonable limits.

Likewise, for many chemical plant towers with high purity products, a change of 5 percentage points would probably result in the product being seriously off specification. In such cases, it is suggested that the changes to examine be:

Run 1 Increase distillate rate so that the amount of the heavy key in the distillate is 1.5 times the design value.

Run 2 Decrease distillate rate so that the amount of the light key or the important impurity) in the bottoms is 1.5 times the design value.

It is obvious that for many towers some judgment will be needed in choosing the changes to examine.

Step 4 Plot the tower temperature profile for the design case and the two cases of Step 3. [Figure 10](#) gives an example of this.

Step 5 Select possible control trays for each section of the tower using these criteria:

- Stay a minimum of 4 actual (as opposed to theoretical) trays away from the feed tray.
- Choose trays from each tower section that have the largest temperature spread between the profiles.
- Choose trays where the design case temperature is about mid-way between the other two. This is a judgment matter, since the design case is seldom exactly centered. A ratio of more than 2 or 3 to 1 in the delta T from the design case should be cause for suspicion.

✦ **Note:** From the example of [Figure 10](#), and just for illustrative purposes, trays 6 and 18 were chosen for further examination as possibilities. To show the variation between trays, Trays 2 and 9 are also plotted in [Figure 11](#) (see Step 6 below) and can be compared to Tray 6.

Step 6 Plot the temperature of the selected trays against the percentage heavy key in the distillate ([Figure 11](#)) and light key in the bottoms ([Figure 12](#)). Even though only one end of the tower is critical with its product specification governing the tower operation, it is desirable to make both plots in order to check the effect of control on product recovery as well as product quality.

Step 7 Run two additional computer cases, as follows:

RUN NO.	TOWER VARIABLES	FEED COMPOSITION	CRITICAL PRODUCT AS % OF FEED
3	Feed rate: Design Reflux rate: Design	LK 25% over design case amount. Compensate for increase by decreasing 3 components each side of LK in proportion to their mole fraction in the feed.	Allow this to vary in order to obtain constant tray temperature called for. Specify temperature of most logical tray (Tray 18 in the Example 0) to be the same as for the design case.
4	Same as Run No. 3	HK 25% over design case amount. Compensate similar to Run 3.	Same as Run No. 3

Step 8. Add points from Runs 3 to 4 to the plots of Step 6. Draw curves through these added points parallel to the base curves of Step 6. In reality these curves are not necessarily parallel. However, the tray design temperature points are correct and by using them as the starting points for the curves one minimizes any error.

✦ It might be expected that the design case would be the middle curve in each family of 3 curves on [Figures 11 and 12](#). This is seldom found to be true, however, and curves such as those in [Figures 11 and 12](#) appear to be typical.

For Trays 6 and 18, a construction is shown for examining the effect on product quality of a $\pm 1^\circ\text{F}$ variation in tray temperature, for the design feed alone, and for all three feeds. The quality change indicated should closely approximate reality (steady state) for the changes in tower operation examined. However, variability due to other possible changes such as in feed composition

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and during the transient period between two steady states, will not be known. Thus, some "safety factor" based on experience and judgment is necessary before one can conclude how close product quality will be held for a specific tower.

This method should be satisfactory for determining if temperature is suitable for control of product quality and for comparison of trays in selecting the one to use for control. On this basis, Tray 6 would be selected for best maintenance of bottoms product quality. Tray 18 could be examined in an actual design job (such as was done in the stripping section with Trays 2 and 9) if there were a need to be sure that the best tray was selected.

Because of unforeseen changes in tower operations that frequently occur, it is prudent to install a minimum of two to four additional temperature points (thermowell) on trays near the selected control tray.

TOWERS WITH SIDESTREAMS

A considerable amount of work has been done on quality control methods for multiple sidestream crude pipestills. The work has included field test and experiment, model test and experiment, analysis of results, and implementation of conclusions on commercial units.

Sidestream Drawoff Tray Type - Drawoff trays may be of two types, either partial or total drawoff of the liquid coming down the tower. The choice between partial and total drawoff depends on overall fractionation considerations and is not an automatic control matter. However, the choice of drawoff tray type will heavily influence the quality control method, as detailed here. [Figures 13 and 14](#) show the common equipment arrangements for the two types of drawoff trays.

Tower Temperature - Product Quality Correlation - For crude oil fractionation, which is characterized by cuts with a wide range of boiling points and with only two trays between cuts, tower temperature does not necessarily correlate with the product qualities of interest.

With partial drawoff trays, per [Figure 13](#), it was found that constant temperature of the vapors entering the drawoff tray does not mean constant product quality of the sidestream (e.g., flash point, end point, viscosity). Feedback control of the vapor temperature by manipulation of the drawoff rate was found to be easy to accomplish. However, this temperature did not correlate with the overhead stream on vapor line temperature control and a series of sidestreams on flow control from partial withdrawal trays. The endpoint of each sidestream will depend primarily on what part of the crude it represents, which is set by the flow rate controllers, rather than by a tray temperature.

In contrast to this with total drawoff trays per [Figure 14](#), the temperature of the vapors entering a drawoff tray correlates well with sidestream quality for most types of upsets. This would be expected, since the temperature governs the amount of material removed by the sidestream.

Control of Partial Drawoff Sidestreams - Partial drawoff sidestreams are flow controlled. When a stripper is involved, flow control on the stripper outlet is usually preferred since this rate sets the cut point; by locating the orifice plate for the flowmeter in the outlet, one minimizes the delta P on the inlet. The stripper inlet control valve is then controlled from stripper level.

Precaution is needed in setting the stripper elevation, the inlet line size and the control valve size. Many such inlets have turned out to be bottlenecks by requiring more head than the arrangement provides.

- With this arrangement, note that any change in the quantities removed by the tower overhead or sidestreams above the sidestream being considered will change the product cut of the crude and thus its qualities. This influence of one stream's control on the qualities or control of another stream is known as interaction. Interaction between partial drawoff sidestreams during changes in feed or in product specifications makes the job of rebalancing the unit for the new conditions time consuming when done by manually resetting the flow controllers and almost impossible to accomplish with individual stream analyzer closed loop control.

To overcome the interaction problem, it is necessary to adjust more than one valve when reacting to a change in one sidestream. This tie-in of more than one measurement to more than one control valve in order to compensate for the interaction of the process is known as multivariable control and is described later in this subsection.

When the overflow from a partial drawoff tray is depended on to prevent dry trays below the drawoff, there will be a minimum percent overflow required for dependability. If less than this minimum is expected, it is necessary to use total withdrawal and to pump the required liquid back to the tower under flow control. The acceptable minimum design percent overflow depends on the expected variations in the overflow rate (caused by changes in tower operation above this point). Selection of normal overflow depends on the seriousness of dry tray operation and the presence or absence of a means of detecting dry trays. An overflow of less than 25 percent of the liquid coming to the drawoff tray would be questionable. Tower profiles for the cases identified above for "Selection of Tower Temperature Control Point" should be evaluated to ensure that liquid overflow occurs in all operating cases.

- Control of Total Drawoff Sidestreams** - Primary control of a total drawoff sidestream must be by drawoff pan level, to prevent withdrawing more (temporarily) or less liquid than the amount coming down the tower. Flow control is possible but this is usually uneconomical because of the added tower height required to provide the needed holdup time and more operator attention would be required to ensure tray level during variations in liquid traffic within the tower.

Of more importance is the control of sidestream quality; initial boiling point, end point, viscosity, pour point, etc. This is accomplished from a measurement of vapor temperature entering the drawoff tray or from direct measurement of product quality with a sidestream analyzer. The manipulated variable would be pump-back reflux or adjustment of heat removal in a

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pumparound circuit. Note that the interaction between sidestreams discussed under partial drawoff sidestreams is minimized with total drawoff, since the individual draw rates are controlled independently to achieve some quality target. Thus, control of towers is simpler and easier with total drawoff sidestreams than with partial drawoff sidestreams.

Control of Tower Pumparound Streams - Comparisons have been made of three methods of controlling tower pumparound streams. These are flow control alone, flow control plus control of the return temperature, and heat removal control (flow rate $\times \Delta T$).

Flow control alone has some self-regulation of tower heat balance. For example, an increase in the coil outlet temperature of a crude pipestill will tend to increase tower temperatures. This will increase the LMTD of the pumparound exchangers, resulting in more heat being removed in the pumparound circuit. With the addition of a controller to hold the return temperature constant, it is seen that an added amount of heat is removed in the pumparound circuit, giving some added self-regulation.

- Analysis of these three configurations clearly shows that heat removal control of the pumparound is inferior to the combination of flow control and control of return temperature. These comments relate to tower considerations alone. The heat sink side of the pumparound circuit will often dictate the best choice. For example, some readily understood sink side considerations are: A heat sink stream with frequent large changes in flow rate or temperature would generate tower upsets unless return temperature control were included. A pumparound exchanger serving as the reboiler for another tower may require a constant duty or a duty set by some condition in the other tower. Such external demands would need compensation within the pumparound circuit to prevent them from causing tower upsets.

Control of Towers With One Sidestream - In light ends services, single sidestream towers are sometimes used as an alternative to two towers, as shown in [Figure 15](#). Both arrangements result in three products.

Single sidestream towers have some of the product quality and product recovery characteristics of multiple sidestream crude oil fractionators. In crude oil fractionators, quality and recovery of a product are improved with sidestream strippers. For single sidestream light ends towers, such liquid sidestream strippers (or the equivalent vapor sidestream light ends rectifiers) are usually not used in ExxonMobil designs.

Thus, one of the two separations performed by the tower is expected to be relatively "rough" or poor. With a sidestream above the feed (usually a liquid stream to take advantage of relative volatilities to minimize the amount of sidestream light key and lighter components in the sidestream), the upper split is the rough one; and the stripping section functions much like a two-product tower. Similarly, with a sidestream below the feed (usually a vapor stream to take advantage of relative volatilities to minimize the amount of heavy key and heavier components in the sidestream), the lower split is the rough one, and the rectifying section functions much like a two-product tower.

Because of the above considerations, plus the interaction between control loops that can exist (see multivariable control in this subsection), the control and operation of single sidestream towers is not as simple as that of a two-product tower.

- The following is one example of the type of control complexity that can be encountered - interaction between the sidestream and the external reflux. The arrangement of controls for the reflux drum circuit shown in [Figure 16](#) is commonly found in articles and in some designs. This arrangement is unsatisfactory. Note that a high level in the reflux drum, for example, increases sidestream flow. This decreases internal reflux below the sidestream but there is no reduction of vapor going overhead and no increase in flow from the drum. Consequently, there is no immediate feedback through the process, the level continues to rise, and unless the drum is unusually large the level limit is soon reached. Other controls on the tower, such as a temperature controller in the stripping section manipulating heat input, could eventually create a balance but product quality excursion during the transient period can be long and severe.

- Control of Internal Reflux Below Sidestream** - One way to make the above arrangement operate satisfactory is to compute the internal reflux below the sidestream and use the computed value as a primary control of tower operation. [Figure 17](#) shows the basic concept in the simplest situation, where there is no condensate subcooling.

The internal reflux computations depicted in [Figures 17-19](#) is accomplished through the use of a computer applications program which is usually part of the overall unit process control system. The control block included in the figure is for illustration only.

The computation of the internal reflux (internal reflux = external reflux - sidestream) flow rate is readily done in Digital Control Systems currently available. It is possible to make the computation with conventional instrument-type elements (analog computing relays), but the number of elements involved can become quite complex and may require space. DCS computation can also be more easily configured to alert operators to keep track the internal reflux.

Operating experience and theoretical analysis show that the internal reflux below the sidestream is basic to tower operation. Thus, the recommended tower control methods shown in [Figures 18](#) make use of this process variable in various tower configurations and services. **Recommended Control Methods** - [Figures 18B - 18D](#) gives the control method recommended for towers with one liquid sidestream. Because designs show much variation in process equipment configuration, four such overhead and two bottom configurations are shown in [Figures 18](#). The basic method of control is seen to be the three adjustments (fraction and two cut points) that are available to the operator to control three of the four product quality variables (overhead final boiling point, sidestream initial and final boiling points and bottoms initial boiling point). [Figure 19A - 19B](#) similarly covers towers with one vapor sidestream.

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For the vapor sidestream tower, the comparable process variable is the internal vapor above the sidestream, as shown in the recommended control method of [Figure 19A](#). In this case, the computation involves translating the reboiler heat input (Btu/h) into vapor flow (lb/h); depending upon the reboiler heating medium and service, this may not be straightforward

- Bottom Level Control for Purge Towers - [Figures 18A & E](#) and [Figure 19A](#) show a normal level control situation with automatic control of level by manipulation of bottoms outflow. When the bottoms outflow rate is small compared to the boilup rate, such as when the bottoms is a purge stream, the outflow rate would be a poor variable to manipulate for control of level. For this situation, an alternative control valve location is required.

Manipulation of boilup (heat Input to the reboiler) appears to be a first obvious choice. However, with an increase in boilup, some towers have an initial increase in level, rather than the expected decrease. This is considered to be due to the increased vapor rate causing an increased overflow on some trays. The types of trays and range of operating conditions that lead to this inverse response are not well defined. Because the phenomenon can cause long periods of instability, the manipulation of boilup for level control should be avoided. It may be reasonable to consider this method, if the opportunity of first trying it is available such as in a field troubleshooting or design revamping situation.

- The alternative to manipulating boilup is to manipulate reflux; internal reflux for the control arrangements of [Figure 18](#) or external reflux for the control arrangement of [Figure 19B](#).

Because the process portion of the control loop then includes the liquid on most or all of the tower trays, this method is obviously slow to respond. The tower bottom holdup must be made large enough to compensate for this. A value of 10 minutes based on bottoms outflow plus boilup is suggested. This could be reduced to 5 minutes, if the tower is fed from a 15-minute holdup or is otherwise stabilized.

Note that for a vapor sidestream tower with an internal vapor flow computer control, the control of level by adjusting sidestream or internal vapor flow is equivalent to control of level by adjusting boilup.

Tray Temperature Control: Selection and Suitability - The method given for selecting a tower temperature control point for two-product towers on [Page 6](#) and in [Figure 12](#) is applicable, with little change, to single-sidestream towers. For a liquid sidestream above the feed, it has been mentioned that the upper split is rough while the stripping section functions much like a two-product tower. The portion of the tower between the sidestream and the bottom would therefore be the one to consider for temperature control. Thus, for the four computer runs, one should make no change to the upper part of the tower and substitute internal reflux below the "sidestream" for "reflux." The sidestream becomes the overhead product. The heavy key component is the sidestream heavy key, and the light key component is the bottoms light key.

Similarly, for a vapor sidestream below the feed, the portion of the tower between the sidestream and the top would be considered for temperature control. Thus, for the four computer runs, no change is made to the bottom part of the tower and the sidestream becomes the bottoms product.

ADVANCED CONTROL

Conventional feedback control provides the basic regulatory controls required to maintain process operability and stability despite process disturbances and unit operation changes. However conventional feedback control is in some cases inadequate and more-involved control schemes are required. In the above discussion of material balance control of two-product towers, feedforward control was referred to as a means of compensating for large or frequent changes in feed rate or composition. Similarly, in the above discussion on material balance control of multiple sidestream towers, multivariate control was referred to as a means to overcome the control problems caused by the downward interaction between sidestreams.

Feedforward and multivariable control are two examples of a class of controls that is called Advanced Control. Whereas complex combinations of basic control hardware can implement advanced controls, they are traditionally implemented using a digital process control system (DCS or special application modules). In today's digital control system environment, there can be a wide variety of advanced controls implemented for fractionators. These are more complex than conventional feedback controls and are developed, implemented and maintained by advanced control specialists (control application engineers).

FEEDFORWARD CONTROL

- The name is descriptive of the control action. In feedforward control, a measurement is made of the upstream variables that are known to be the cause of major upsets to the process unit. For fractionation control, these changes would most commonly be in feed rate and feed composition.

Measurements of such feed system disturbances are used to adjust the fractionator's controls to allow them to compensate for the disturbances before they upset the tower. Satisfactory compensation can sometimes be accomplished with simple ratio settings. For most fractionator applications, however, the rate of changing the product flow rates to maintain the ratios, called dynamic compensation, must be synchronized with the tower's response in order to keep product quality within satisfactory limits during the transient. Any effects of the disturbance that is not eliminated by the feedforward loop will be trimmed by the feedback loop. Therefore, feedforward controls supplement the feedback controls and should never be implemented without feedback.