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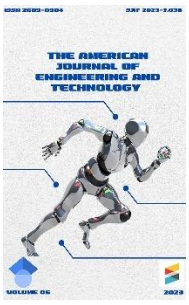

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Research Article

CURRENT STATE OF MODELING PROBLEMS AND MANAGEMENT OF RECTIFICATION PROCESSES

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Jalolitdin Mukhitdinov
Prof., Doc. Technical Sciences, Tashkent State Technical University, Uzbekistan Tashkent Region, Tashkent City, Uzbekistan

Ildar Sultanov
Art. Teacher, Doctoral Student, Andijan Machine Building Institute Uzbekistan Andijan Region, Andijan, Uzbekistan

ABSTRACT

Distillation and rectification processes are common in the chemical, petrochemical, and food industries. All these processes are complex and very energy-intensive. Since the rectification process directly affects the quality of the final product, the problem of energy efficiency and resource saving remains relevant. The main tasks in solving this problem are mathematical modeling of the technological process, optimization of the design and technological parameters of the process based on its modernization. A special place in solving this problem is given to process management. This is explained by the nonlinearity and multiplicity of the process, nonstationarity of behavior and the influence of various disturbing influences on the process.

KEYWORDS

Rectification, process, mathematical modeling, control, modernization, scheme.

INTRODUCTION

Static nonlinearity manifests itself in the asymptotic approach to zero of the level of impurity components in the selected product flows.

Considering a mixture of two components, the level of impurity in the distillate is the concentration of the low-boiling component, and the level of impurity in the bottom product is the concentration of the heavy-boiling component. Nonlinearity and process dynamics, i.e., changes in time constants with volume and changes in the input signal, and static nonlinearity are much more pronounced for distillation columns producing high-purity products.

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Multiplicity is important when the composition of both the upper and lower products is controlled.

Columns are subject to various disturbances, especially changes in the composition of raw materials and power consumption. Unsteady behavior is associated with variations in tray efficiency caused by uneven vapor and liquid flows in the column or by contamination. The efficiency of the distillation column is influenced by the parameters of temperature and pressure in the column, as well as the type of raw materials being processed, the technological mode, and the operation of the automatic control system, etc.

Let's consider a scheme for separating a mixture consisting of 2 components (binary rectification). A binary distillation scheme with one input stream and two separated products is shown in Figure 1:

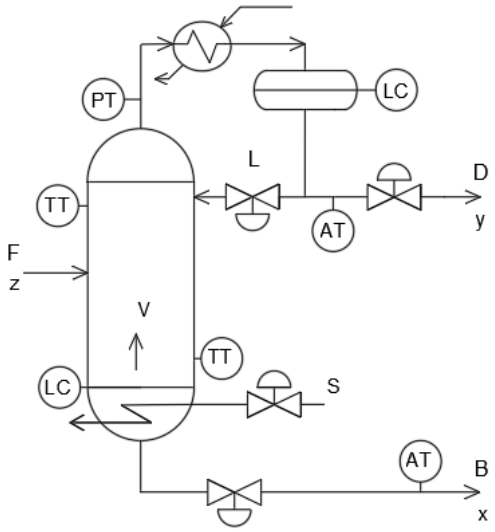

Fig. 1. Rectification scheme with two components.

Based on the material and energy balances, combining the general steady-state material balance with the balance for the highly volatile component with two separation components, we can write:

$$\frac{D}{F} = \frac{z - x}{y - x}$$

where: *F* – power consumption

D – distillate consumption

y – concentration distillate in the vapor phase

x – concentration of bottoms in the liquid phase

z – concentration of components in food

Regrouping leads to :

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$$y = x + \frac{z - x}{\frac{D}{F}}$$

This equation shows that as the distillate flow rate D decreases while maintaining constant *F* _ ***z*** and x the purity of the upper product *y* increases. Likewise, as the selection value *D increases* , its purity decreases.

Since in a steady state the sum of the selected product flows must equal the food flow, one of the separation products becomes cleaner relative to the other (Figure 2). This example clearly demonstrates the effect of material balance , in which the concentration of impurities in the selected product directly depends on the flow rate of the corresponding product.

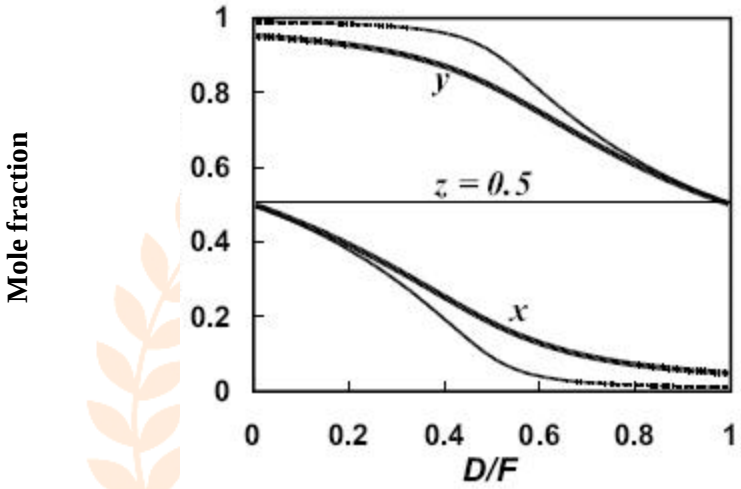

Fig. 2. *D* / *F* influence (distillation product and feed flow rate) and energy for product purity. The thin line corresponds to an increase in energy costs.

Another key factor affecting product purity is the temperature in the bottom of the column, which determines the rate of movement of steam *V* up the column. As the temperature in the column cube increases, its separation capacity increases (Fig. 2), the indicator of which is the separation coefficient *S* , determined by the equation:

$$S = \frac{y}{1 - y}\frac{1 - x}{x}$$

As the level of impurities in products decreases, S increases.

Let us consider in more detail the effect of increasing temperature in the cube of the column. To do this, consider the movement of vapor and liquid inside the column. If the flow *V* is increased and the distillate withdrawals *D* and bottoms *B remain constant, the* reflux flow *L* increases by the same amount as the vapor flow *V. As a result,* the reflux ratio increases . An increase in vapor and liquid flows inside the column causes a decrease in the amount of impurities in the separation products at the same *D/F ratio* (Fig. 2). When evaluating the response of a column at a control point, it must be remembered that the energy input into the column generally determines the degree of separation that the column can achieve, while the material balance determines how the separated products are distributed between the two product streams.

Let us consider changes in vapor and liquid flows, which influence changes in the dynamics of the

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composition of components along the height of the column. For all columns except very high pressure columns, i.e. columns operating near the critical pressure of the highly volatile component, a change in the magnitude of the steam flow *V* in the reboiler is felt at the top of the column in just a few seconds, while to achieve a change in the reflux flow rate takes a few minutes. The hydraulic response of the tray depends on the accumulation or depletion of fluid on it. The hydraulic time constant for fluid flow from the tray typically ranges from 3 to 10 seconds. As a result, for a column with 50 or more trays, the total hydraulic response time in the form of an electrical signal is on the order of several minutes.

As an example showing the difference between the effects of vapor and liquid dynamics, consider the effect of increasing temperature in a cube.

An increase in temperature in the bottom of the column causes an increase in the speed of steam rising up the column , while the flow of liquid falling down the column remains relatively constant, since the reflux flow rate is set by the level controller on the reflux separator .

In each section between the trays of the distillation column, the *L/V* ratio determines its separation capacity. As a result of an increase in steam flow in column *V* , the impurity concentration in the sample stream initially increases. An increase in steam flow causes an increase in the level in the reflux separator , which causes an increase in the reflux flow *L*. As the increased amount of reflux moves relatively slowly down the trays of the column, the *L/V ratio increases* , resulting in a decrease in the level of impurities in the overhead product. Thus, the difference in liquid and vapor dynamics results in an increase in the purity of the overhead product.

In addition to the dynamics of steam and liquid flows inside the column, the quality of the selected products is affected by changes in the feed composition, its flow rate and enthalpy, subcooling of the reflux flow, pressure loss in the bottom, and pressure disturbances in the column.

Changes in the power composition are the main disturbing factor for the control system. A change in the feed composition leads to a change in the concentration profile along the height of the distillation column, leading to significant changes in the composition of the selected distillate products .

Due to the lack of continuous analyzers in most distillation units, changes in feed composition are treated as unmeasured disturbance signals. Therefore, the development of control systems sensitive to variable supply composition is a significant challenge.

The power consumption of a static column model with constant tray efficiency is similar to the power consumption of a real column. A change in power consumption leads to a change in the sweat inside the column, which removes the separation mode from the steady state and changes the efficiency of the plate [1 , p . 5] . To eliminate the effects of changes in power consumption in the control system, it is possible to use *L/F, D/F, V/F* or *B/F ratios*

Dynamic compensation is usually required to account for the dynamic mismatch between product composition to changes in feed flow and the response to changes in MVs . When certain ratios (eg *L/D, V/B*) are used as MV $_S$, these ratios in combination with the level controller automatically compensate for changes in feed flow.

Changes in the enthalpy of the feed stream in low reflux ratio columns can significantly alter the vapor and liquid velocities within the column, causing a significant change in the internal concentration profile across the height of the column and therefore a significant deviation from the desired product composition. Enthalpy deviation is difficult to identify , since even the presence of a power flow temperature

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sensor does not allow determining the change in enthalpy of two-phase power supply [2 . c . 47]. A change in enthalpy without a detailed study can be taken as a change in the composition of the diet. To maintain a constant enthalpy of the feed flow into the column, it is possible to install an additional heat exchanger to heat or cool the feed flow.

Subcooling of the reflux flow in the absence of internal control can lead to serious disruptions in the operation of the column caused by significant changes in the concentration profiles of the components along the height of the column [5, p . 6].

With a sharp drop in steam pressure in the column , a sharp drop in the reboiler load occurs . This results in a dramatic increase in impurity levels in product streams. When the vapor pressure in the column returns to normal levels, the column height control system attempts to return the product to normal purity. If the column composition control system is not configured properly, the mismatch may be amplified by it. In this case, operator intervention is required to stabilize the column, including turning off and reconfiguring the control system.

Column pressure has a direct effect on the relative volatility of the key components in the column, therefore changes in column pressure can significantly affect the composition of the product streams. A properly implemented pressure control circuit maintains the column pressure close to the set point, with only short-term and low-amplitude excursions. A large class of columns (such as oil refinery columns) are operated at maximum condenser load to maximize column separation, which minimizes steam use. In these cases, the column pressure increases during the day when the cooling water or ambient air temperature is highest and decreases at night, but the resulting pressure changes must be slow enough for the composition control system to effectively correct this variation.

Improperly functioning flow, level or pressure controllers can compromise the effectiveness of product flow controllers. Therefore, to control product flows, systems are used to control the flow of products, reflux and coolant used in the boiler. Their settings are determined by various level and composition controllers.

Level regulators are used to maintain the level in the separating vessel, the boiler. In work [7, p . 153] it is shown that separate level control in the separating vessel and the reboiler worsens the problem of composition control. When controlling *D* or *B* , the internal flow of steam and liquid is changed only after the corresponding level controller acts as a result of changing *D* or *B*. _ On the other hand, if the level controller contains a differential component, this may cause oscillations to be transmitted back to the column and contribute to unstable operation. When the operating mode of the reboiler is set by the level regulator, it can also cause oscillations in the reboiler and cyclic pressure in the column.

The column top pressure acts as an integrator and is determined by the net accumulation of material in the vapor phase. Column pressure is controlled by directly changing the amount of material in the vapor phase of the top layer or by changing the rate of condensation of the top layer, which converts low-density vapor to high-density liquid. Various approaches can be used to control column pressure, including:

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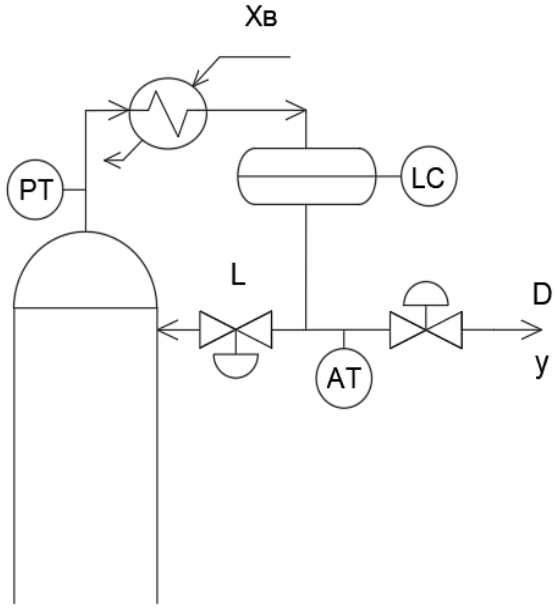

Fig.3. Operating at minimum column pressure with maximum cooling water flow

1. Using maximum cooling water flow and ensuring that the column pressure is maintained at a minimum pressure level (Fig. 3).

2. Regulation of refrigerant flow into the condenser (Fig. 4).

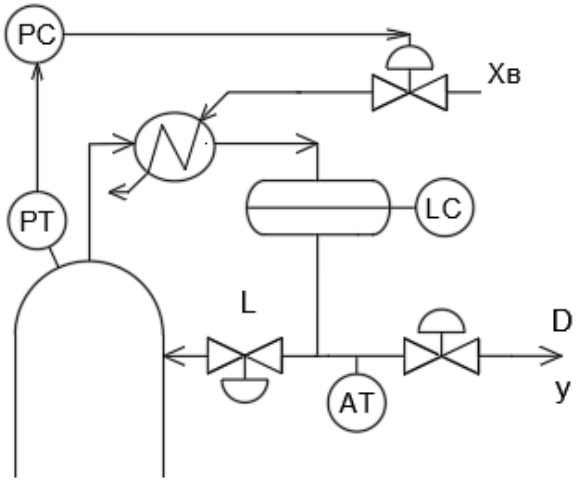

Fig.4. Column Pressure Control Configuration Using Refrigerant Flow as MV

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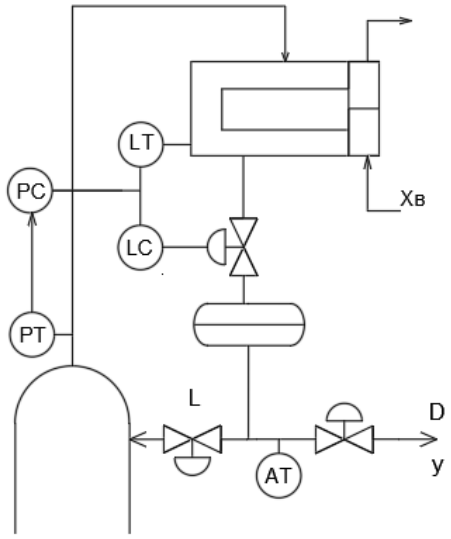

Fig.5. Setting Column Pressure Using Condenser Liquid Level Setpoint as MV for Pressure Regulator

3. Adjusting the liquid level in the condenser to change the effective heat transfer area (Fig. 5).
4. By regulating steam flow using shut-off valves (Fig. 6).

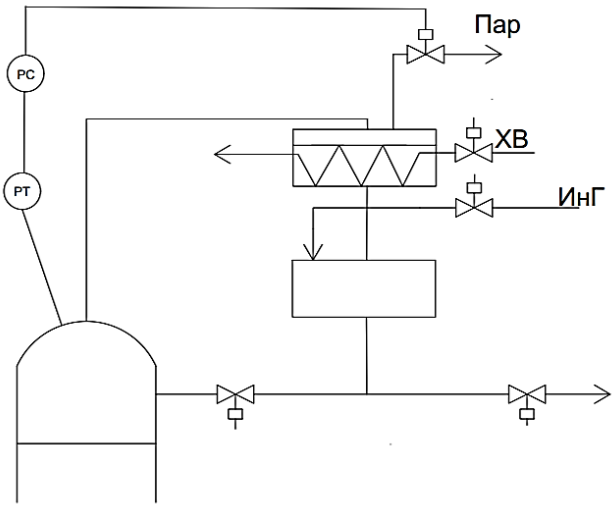

Fig.6. Column Pressure Control Option Using Output Stream as MV

5. Release steam from the outlet stream or inject inert gas into the steam space in the separation vessel (Fig. 7).

It is noteworthy that approaches 1 – 3 directly affect the steam condensation rate for pressure control, while approaches 4 and 5 directly control the amount of steam at the top of the column for pressure control.

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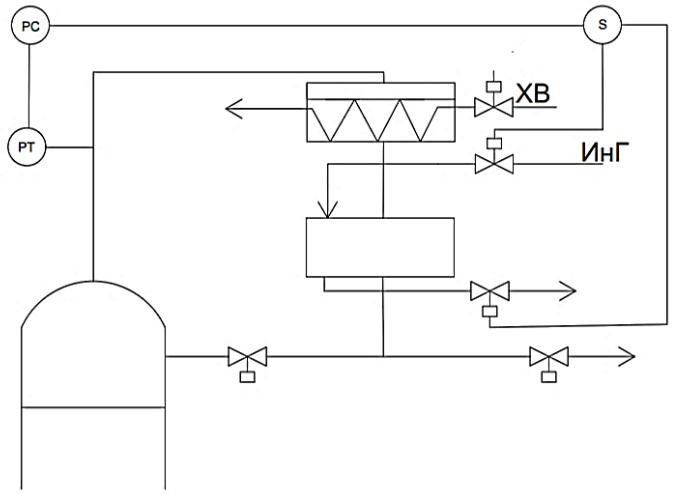

Fig.7. Column pressure control configuration using effluent or inert gas injection as MV

The most responsive pressure control schemes (i.e., the approaches that should provide the tightest control to a set point) are outlet flow (Figure 6) and outlet vent or inert gas injection (Figure 7).

The interlock or select controller in Figure 7 uses air flow when the measured pressure is above the set point and uses inert gas injection when the pressure is below the set point.

The speed of pressure control loops based on manipulating the refrigerant flow (Figure 4) and controlling the effective heat transfer area (Figure 5) responds much more slowly because both of these approaches introduce changes in the heat transfer rate to change the pressure in the column.

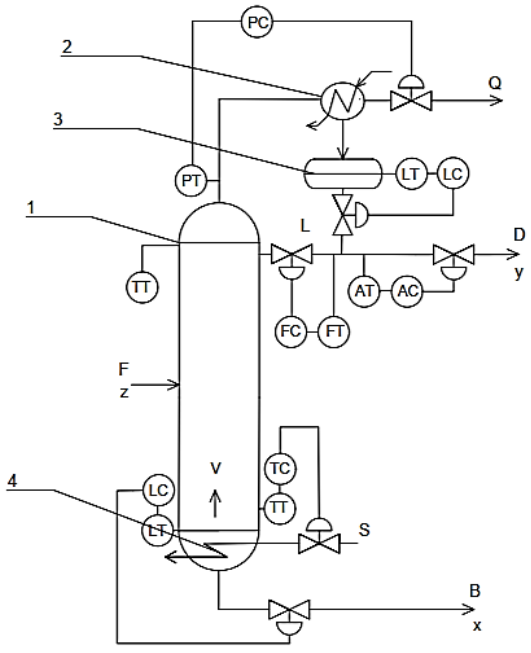

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Fig. 8. General view of the control of a two-component distillation column

1- Distillation column
2- Capacitor
3- Reflux separator
4- Evaporator (boiler)

Even the best high-level approach to distillation process control (such as model predictive control) will generally be ineffective unless the process is fully understood and the process is properly controlled.

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