Lecture 11 «Rectification. Calculation of plates number of a rectifying column. Rectification with different pressure»

Aim: Give a definition of the rectification process. Give the calculation equations of the number of plates of the rectification column. Characterize the rectification under different pressures.

Lecture summary: The rectification is the process of separating liquid homogeneous mixtures into constituent substances as a result of the counter-current interaction of a mixture of vapors and a liquid resulting from the condensation of vapors.

When the vapor rising in the column with the downward flowing liquid partially condensed vapor and partial evaporation of the liquid take place.

In this case, the high-boiling component (HBC) predominatly is condensed from the vapor phase, and the low-boiling component (LBC) evaporates from the liquid. Thus, the flowing liquid is enriched with a high-boiling component, and the vapors are enriched by the LBC. At the top of the column (Fig. 1) there are vapors consisting of one LBC, and with their condensation a rectificate is formed.

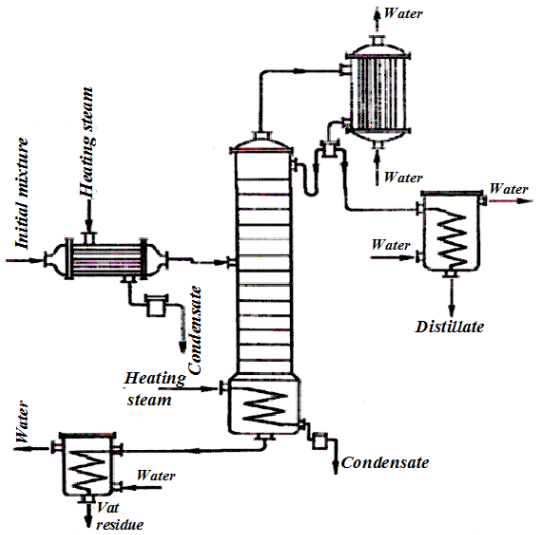

Fig. 1. Scheme of rectification column

Part of the rectificate enters the top of the column for irrigation and is called *phlegm*. From the bottom of the column a liquid flow, consisting mainly of the HBC, it is called *the vat residue*. The interaction of vapor and liquid on the distillation column plate can be followed on the *t–x–y* diagram for the binary mixture (Fig. 2).

The vapors *A* from the bottom plate *n*–1 are mixed on the overlying plate *n* with the liquid (phlegm) *B*. Par *A* and phlegm *B* are not equilibrium, and therefore their figurative points do not lie on the isotherm.

The temperature of the steam t_A is above the phlegm temperature t_B, so the steam is partially condensed when mixed with reflux, and due to the heat of condensation, part of the liquid evaporates. The LBC predominantly evaporates from the liquid, but from the vapor mainly the HBC condenses. The steam is enriched by the LBC, and the figurative point *A* is shifted along the condensation line and at the moment of equilibrium it will take the position *D*.

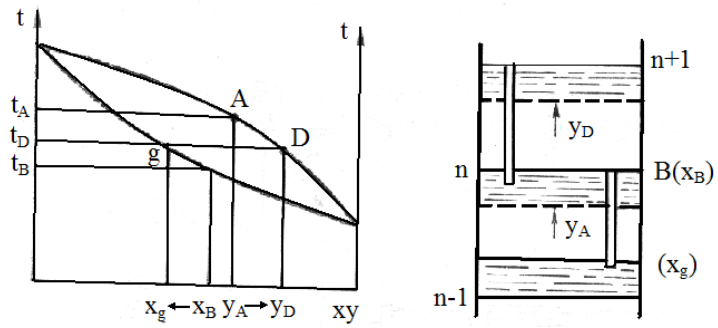

Fig. 2. To the analysis of the process of rectification on a plate: diagram *t–x–y* for a binary mixture

At the moment of equilibrium, the temperature of the vapor and liquid is the same, then the figurative phlegm point, equilibrium to vapor of composition *D*, is located on the isotherm t_D, which is denoted by *g*. On the considered plate, *n* vapors will be enriched with a volatile component, changing their composition from y_A to y_D, and phlegm will be enriched by a higher-boiling component, according to which its composition changes from x_B to x_g.

Calculation of the number of plates of the rectification column of continuous action for separation of binary liquid mixtures

The degree of separation of the liquid mixture into constituent components and the purity of the resulting distillate and vat residue depend on the phase contact surface. The surface of the phase contact is determined by the amount of irrigated phlegm and the design of the apparatus. The number of phlegm fed for irrigation is determined by the number of theoretical plates in the column.

Several methods for calculating the number of theoretical plates have been developed, of which the graphical method of Mac Cab and Thiele (since 1925) is widely used for binary mixtures.

The method is based on the following assumptions:

1. The molar heat of evaporation of both components is the same. 1 *kmol* of condensed vapor evaporates 1 *kmol* of liquid. Therefore, the amount of vapor and liquid in the column height does not change, but only their composition changes.

2. The initial mixture and phlegm have a temperature equal to their boiling point.

3. The composition of phlegm is equal to the composition of steam rising from the top of the column, i.e. in the dephlegmator there is no change in the composition of the vapor.

4. The composition of the liquid draining from the last plate and the bottom column is equal to the composition of the steam rising from the boiler, i.e. the cube does not produce a separating action.

The equations of the working lines of the rectification process, necessary for calculating the number of theoretical plates, are deduced, as for the mass exchange process, from the equation of material balance.

In general, the equation has the form:

$$Gdy = -Ldx \qquad (1)$$

In the case under consideration, we express the quantities *G* and *L*.

The amount of steam rising up the column *V* after the reflux condenser gives a liquid to the top of the column (phlegm) *P* and the distillate G_r

$$V = P + G_r \tag{2}$$

By introducing dimensionless relations, we obtain

$$\frac{V}{G_r} = \frac{P}{G_r} + \frac{G_r}{G_r} = R + 1 = G \tag{3}$$

The dimensionless ratio $\frac{P}{G_r} = R$ is – called the reflux ratio.

Thus, the equation (1) takes the form:

$$(R + 1)dy = -Rdx \tag{4}$$

In the continuous column, the amount of vapor and the amount of liquid remain unchanged, so we take the quantities *R + 1* and *R* out of the integral sign and for any plate in the upper part of the column with which the vapor with composition *y* leaves and on which the liquid has composition *x*, taking into account the presence of a counterflow, we get

$$(R + 1)\int_y^{y_r} dy = -R\int_{x_r}^{x} dx, \tag{5}$$

whence

$$(R + 1)(y_r - y) = R(x_r - x) \tag{6}$$

and after the transformation, taking into account by the condition $y_{eq} = x_{eq}$,

$$y = \frac{R}{R+1}x + \frac{x_r}{R+1} \tag{7}$$

The resulting equation establishes a relationship between the composition of the vapor and the composition of the liquid in any section of the upper part of the column for given irrigation values (phlegm ratio *R*) and composition of rectificate x_r. Dependence (7) is the equation of the working line of the upper (strengthening) part of the rectification column.

Similarly, we obtain the equation of the working line of the lower part of the column, taking into account that the amount of flowing liquid in this part of the column increases by the amount of feed *F*.

We write the equation of material balance for the lower part of the column:

$$(R + 1)dy = -(R + F)dx \tag{8}$$

We integrate it within the limits of the change in the vapor composition from y_w to y and the liquid from *x* to x_w:

$$(R+1)\int_{y_w}^{y} dy = -(R+F)\int_{x}^{x_w} dx, \quad (9)$$

whence

$$(R+1)(y-y_w) = (R+F)(x-x_w), \quad (10)$$

where y_w – the composition of steam rising from the boiler, x_w – the composition in mole fractions of the bottom liquid.

After the transformation, taking into account the condition that x_w=y_w, we obtain

$$y = \frac{R+F}{R+1}x - \frac{F-1}{R+1}x_w \quad (11)$$

Dependence (11) is the equation of the working line of the lower (exhaustive) part of the distillation column.

For a continuous column, the following quantities remain constant:

$$\frac{R}{R+1} = A, \frac{x_r}{R+1} = B, \frac{R+F}{R+1} = A_1, \frac{F-1}{R+1} = B_1, \quad (12)$$

then the equations of the working lines of the process are the equations of straight lines [2, 3]:

$$y = Ax + B, \quad (13)$$

$$y = A_1x - B_1 \quad (14)$$

Rectification under different pressures

Depending on the boiling point of the separated liquids, the rectification is carried out under various pressures. At t_{boil} = 30-150 °C, the rectification is usually carried out at atmospheric pressure.

When the high-boiling liquids are separated to reduce their boiling points, the rectification is carried out under vacuum.

Pressure rectification is carried out in the separation of liquids with a low boiling point, when the separated mixture is at atmospheric pressure in the gaseous state (an example is the separation of liquefied gases).

The pressure in the cube is always greater than the pressure at the top of the column by the amount of its hydraulic resistance. Therefore, the hydraulic resistance of columns operating under vacuum should be as small as possible.

Questions to control:

1. Expand the principle of rectification. Draw a diagram of the distillation column and indicate the flow of liquid and vapor on it.
2. What physical content is contained in the equations of working lines of the process of continuous rectification?

3. Give the assumptions of the graphic method of Mac Cab and Thiele to calculate the number of theoretical plates.
4. How does the phlegm number affects the number of required theoretical plates?
5. What factors determine the required diameter of the rectification column?
6. When is rectification performed under pressure?

Literature

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