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On refining by distillation or crystallization in processes with flow of refined substance

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By analogy with distillation refining of a flowing liquid, the possibility of refining by pulling a crystal from a melt stream is considered. The technological parameters of the named processes are (in addition to the effective separation coefficient) the evaporation rate or crystallization rate, respectively, and the evaporation surface area or crystal cross-section, respectively, and the flow of refined substance. The fundamental possibility of implementing continuous crystallization refining using a thin layer of melt to increase the purification efficiency is noted.
Keywords: distillation, crystallization, refining.

Про рафінування дистиляцією або кристалізацією у процесах з потоком речовини, що рафінується. *О.І. Кравченко.*

За аналогією з дистиляційним рафінуванням поточної рідини, розглянуто можливість рафінування витягуванням кристала з потоку розплаву. Технологічними параметрами названих процесів є (крім ефективного коефіцієнта поділу) швидкість випаровування або швидкість кристалізації, відповідно, і площа поверхні випаровування або перерізу кристала, відповідно, а також потік речовини, що рафінується. Відзначено принципова можливість здійснення безперервного кристалізаційного рафінування з використанням, для підвищення ефективності очищення, тонкого шару розплаву.

1. Introduction

Distillation and crystallization are the main methods of obtaining high-purity substances. The theory of these refining methods has been developed (the similarity of their mathematical description is noted) and extensive experience has been accumulated in their application [1-9] – including the creation of industrial continuous distillation apparatus [10], in which the refining process can be carried out using a thin layer of the refined substance, i.e. with increased refining efficiency. There are three known factors that determine the efficiency of refining [8, 9]: the separation coefficient, the product yield g (the ratio of the mass of the condensate to the initial mass of the distilled substance or the part of crystallized material) and the Peclet number $Pe = X(v/D)$, where v is the velocity of the phase separation surface, D is the diffusion coefficient of the impurity in the refined material, X is the size factor of the material, the role of which in processes with a flow of the refined substance is played by the thickness of the flow. In general, using the effective separation factor, the dependence of the refining efficiency on g (or on the fraction of the residue $r = 1 - g$) is described by the equations

$$\frac{C_c}{C_0} = \frac{1-\left(1-g\right)^{\beta}}{g}$$

and

$$\frac{C_r}{C_0} = r^{\beta-1},$$

where C_c and C_r are the average concentrations of impurity in condensate or in crystal and in the residue, respectively, C_0 is the concentration of impurity in the starting material, and ß is the effective separation factor for distillation or the effective distribution coefficient for crystallization (commonly referred to as k) [6-9].

Meanwhile, the possibility of creating a crystallization analogue of continuous distillation has not been considered. Consideration of this possibility was the purpose of this work.

2. Product yield in the processes with flow of refined liquid

Scheme of crystallization process with a flow of refined liquid is shown in Figure. (It is possible to grow a crystal with a rectangular cross-section using Stepanov's method [4].) The Figure 1 can also be considered as a scheme of a continuous distillation process if we consider that a stationary capacitor, and not a crystal, is depicted above the liquid flow.

In the processes under consideration, the flow Q of the refined substance in a certain section partially evaporates from the surface with area s, turning into condensate, or partially crystallizes by pulling a crystal with a cross-sectional area s.

In the distillation process under consideration

$$g = \frac{\mathrm{w}s}{\mathrm{Q}},$$

where w is the rate of evaporation of a substance from a unit surface per unit time.

In the crystallization process under consideration (taking into account that $w = \rho v$, and assuming that the density of the crystal is equal to the density ρ of the melt)

$$g = \frac{\rho \mathrm{v} s}{\mathrm{Q}},$$

where v is the crystallization growth velocity.

3. Results and discussion

The yield g (and the refining efficiency C/C_0) in the processes under consideration is determined by the values of s and Q. The values of w, v, s and Q must be such that the constraint $g < 1$ is not violated.

It is not difficult to establish the flow rate V of the refined liquid at the entrance to the evaporation or condensation region. If the flow has a cross-sectional area S, then g can be represented as:

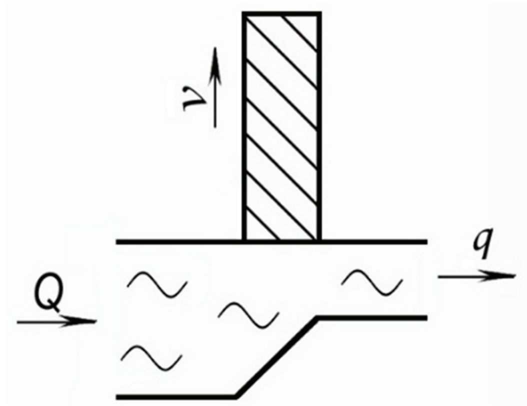

Fig. 1. Scheme of pulling a crystal from a melt stream

$$g = \frac{\mathrm{w}/\rho}{\mathrm{V}} \cdot \frac{s}{S}$$

or

$$g = \frac{\mathrm{v}}{\mathrm{V}} \cdot \frac{s}{S}$$

for distillation and crystallization correspondently, from where V can be found for given values of the other quantities. And if the flow in the crystallization process has a rectangular cross-section of height h and width H, and the crystal has a rectangular cross-section with dimensions l and H in the directions along and across the flow, respectively, then

$$g = \frac{\mathrm{v}}{V} \cdot \frac{l}{h}.$$

(The formula for g for distillation with a rectangular evaporation surface has a similar form.)

Obviously, an uneven distribution of impurities in the transverse direction along the melt flow can form in the crystal (similar to how an uneven distribution of impurities is formed along a crystal obtained by normal directional crystallization [4]). In this case, the value of C/C_0 should remain constant in both the distillation and crystallization processes under steady-state conditions.

The considered crystallization method of refining allows for processes to be carried out using a thin layer of the substance being refined – to increase the efficiency of refining.

4. Conclusion

By analogy with distillation refining of a flowing liquid, the possibility of refining by pulling a crystal from a melt stream is considered. It is shown that the efficiency of refining in these processes is determined (in addition to the effective separation coefficient) by the values *w* or *v*, respectively, and the evaporation surface area or crystal cross-section, respectively, and by a flow of refined substance (or by the relations *w*/*V* or *v*/*V* and *s*/*S*). The fundamental possibility of implementing continuous crystallization refining using a thin layer of melt to increase the purification efficiency is noted.

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