On Choosing Multicomponent Multiphase System Separation Progress Optimization Criteria

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Abstract. The article describes the existing criteria of separation processes optimization. The possibility of application of the general theory of separation for calculation of technological schemes is being justified. The technological, thermodynamical, statistical and economic criteria of separation processes, methods of their analysis and comparison are briefly described. The method of selection of optimization process criteria with technology research, installation engineering schemes and under automatic control of separation processes, as well as statistical planning of extreme experiments was offered.

1. Introduction

Recently, an issue of efficiency criteria and parameters technological processes optimization has been widely discussed. Evaluation of the technological process results is usually carried by several criteria. The interest to general criterion, clearly expressing efficiency of the process, at the first stage was associated with the natural human desire to evaluate the results of their activities.

With the formulation of the problem of optimal automatic control of technological processes and development of cybernetic methods of research, the overall efficiency criterion becomes technically necessary, since it formally defines the direction and point of optimization, the essence of the study.

The approach to the object of study enables us to apply statistical methods of planning of extreme experiments for the prompt identification of optimal process conditions and obtaining its mathematical model.

The validity of this approach is proved by complexity and probabilistic nature of most separation processes.

Figure 1. Criteria for technological processes optimization.

In some ways, the choice of optimization criterion determines the results of the study. Because these results, at the beginning of the study, are the question of the future and it is impossible to imagine clearly enough all the consequences of optimization, the choice of criteria is very difficult. It is connected not only with erudition, level of knowledge on the subject under study, but also with the psychology of researcher. Naturally, the criterion may vary during the study. In the final part of the article the authors attempted to provide a general approach to the selection criteria consistent in solving individual problems of the separation process.

Technological, thermodynamical, statistical and economic optimization criteria can be referred to as the most frequently used. At the thermodynamic approach to the separation process using the theory of separation it is possible to develop the application of the principle of minimality of dilution to a wide range of separation processes. This approach makes it possible to select the optimization criteria...
of separation schemes in terms of distribution and circulation of intermediate products calculation the number of stages and their efficiency in the separation cascade of operations.

Criteria for differences of physical and chemical properties of the separated materials or environments (wettability, density, magnetic permeability, melting point, boiling point, and others), associated with the concept of separability, should be considered together with a description of the relevant processes. Criterion of separation perfection on a particular device and kinetic criteria are also very important by themselves or in combination with other criteria.

Figure 2. Criteria for technological processes optimization.

Industrial exploitation of natural resources is somehow associated with the separation process. The vast majority of materials used by mankind does not exist in nature in finished form, and to obtain
them, it is necessary to allocate all of their components in the form of the simplest chemical elements or compounds. There is a variety of separation processes based on physical, chemical and physico-chemical properties of elements and their compounds; screening - by size separation, gravity - by density, flotation - by water wettability, magnetic and electric separation, hydrometallurgy - by solubility, liquid extraction, ion exchange, distillation, pyrometallurgical processes, diffusion isotope separation, etc... The separation processes are used in a variety of industries: mineral processing, metallurgy, oil, food, chemical, nuclear and others.

2. Research
Industrial exploitation of natural resources is somehow associated with the separation process. The vast majority of materials used by mankind does not exist in nature in finished form, and to obtain them, it is necessary to allocate all of their components in the form of the simplest chemical elements or compounds. There is a variety of separation processes based on physical, chemical and physico-chemical properties of elements and their compounds; screening - by size separation, gravity - by density, flotation - by water wettability, magnetic and electric separation, hydrometallurgy - by solubility, liquid extraction, ion exchange, distillation, pyrometallurgical processes, diffusion isotope separation, etc... The separation processes are used in a variety of industries: mineral processing, metallurgy, oil, food, chemical, nuclear and others.

A common feature of all separation processes is the mass character: the number of basic units to be separated (e.g., mineral particles, molecules of chemical compounds, atoms of elements or grains, etc.), are presented in countless numbers. In separation processes, particularly thin and complex in its technology, there is always some probability that even with a clear distinction, some of separated particles properties, some of them do not get in their product and hence there will be some contamination of cleaned substance with alien particles on the one hand, and under-recovery particles of substance into the product - on the other.

At these probabilistic characteristics of the separation process, assessing the quality and extraction, more errors caused by imperfections in separation units are imposed, as well as the existence of particles with intermediate properties - isomorphic atoms minerals splices and others.

Thus, as a result of an industrial separation process, from the initial mixture, not pure substances are obtained, but only enriched or depleted products. Although the term "enrichment" is used only to refer to the separation of minerals, it can be used equally well for all industrial separation processes, since in all cases, at least two of the above three reasons for the impossibility of clear separation play an important role. The random nature of these causes and mass character make it necessary to use probabilistic characteristics to evaluate the separation. All the technological characteristics of separation processes are therefore not more than integrated or averaged characteristics of the corresponding probabilities.

As already mentioned, in the industrial separation processes, it is impossible to achieve complete separation, only enriched and depleted in any product component are obtained. With the increase in the completeness of separation, cost of the process greatly increases and performance of the device significantly reduces. Therefore, at some point, it becomes more profitable to recycle an additional amount of raw materials to produce the same output of finished products which can be obtained at a lower total extraction of the initial amount. Completeness in the extraction of valuable component into concentrate (or its losses in the waste) is one of the most important characteristics of the separation process.

Since the extraction efficiency is associated with separating installation, and ultimately it is only required to obtain a specific output of finished products, then the final product performance is the second most important criterion of separation. It is economically connected to the first one by prime cost of raw material and finished products and technologically, these two criteria are in antagonistic contradiction to each other: with productivity growth, extraction falls and vice versa.

The third characteristic of the separation process is the quality of concentrate (content of valuable component) becomes especially important in those processes (mostly intermediate), which allow wide
variations in this parameter. The quality of the concentrate can be the higher, the lower the performance (or prime cost of processing) and extraction is. Quality and recovery are related to each other through the function extracting content from initial raw material in processes of adjustment or further processing of concentrate.

Thus, all three main criteria of separation process are interconnected so that increase in process efficiency in terms of any of them reduces, to some extent, the efficiency the other two. This greatly complicates the evaluation of the efficiency of the separation process. Additional difficulties arise when evaluating separation of multicomponent systems with obtaining several products, the value of which is different. In comparing experiments or optimization of the separation process of complex products, it is necessary to consider several parameters, which have a difficult economic and technological dependency. Automatic adjustment of a process or statistical planning of the experiments in such conditions is impossible, if the functional connections between optimization criteria are unknown.

In this regard, the problem of choosing the optimization criterion or efficiency of the separation process arises. A significant number of papers, relating not only to the separation process, and to a variety of fields - from economics to systems engineering, are dedicated to the choice of efficiency criteria. Initially, these studies were of a purely informative value and corresponded to the natural human need to somehow evaluate the results of their work.

With the development of mathematics, and then automating, the choice of optimality criterion has become a technical necessity, determining not only the accuracy of setting a specific task, but also the speed of its solution. Mathematical optimization unit is developed quite fully: mathematical analysis, calculus of variations, functional analysis and dynamic programming allow finding extreme values in any tasks, if you know the criterion of efficiency.

The efficiency criterion, designed for technology research or process control, in particular the separation process, should meet several requirements:

1. It should characterize the process efficiency in terms of the ultimate goal of this production. It is clear that the recovery cannot be a criterion for the separation excluding quality of concentrate, as on such criteria it is the most profitable not to enrich the ore, extraction in this "process" is equal to 100%. But at constant quality of concentrate, extraction can be considered as a criterion of separation, with reservations.

2. The criterion should be quantitative and one-figure, i.e., expressed in by one number. The numeric values of the criterion are not necessarily have to be in a proportional or other dependence from each other: in the simplest case numbers expressing the efficiency may indicate just ordinal number of separation process mode when the ranking of technological parameters on several grounds. However, this criterion is not very convenient, since the statistical operations with such numbers are quite limited. Ideally, the numerical values of the criterion should be proportional to the efficiency and uniformly distributed over the entire range of changes of a criterion. As it will be shown below, this property is possessed only by economic criteria, and separation entropy.

3. The fullness or universality of the efficiency criterion. For example, economic criteria (without corresponding corrections) do not have this property, since they do not allow or restrict processes which are unprofitable but necessary in terms of technology, strategic considerations and technical policy. On the contrary, technological criteria often do not take into account the important economic reasons.

4. Statistical efficiency of a criterion is to some extent antagonistic to demand of sensitivity to changes in process parameters. The physical meaning of statistical efficiency - insensitivity to small random fluctuations, of mathematical evaluation - dispersion, standard deviation of criterion values for the same tests characterizing the scatter about the average result.

5. The criterion should have a physical meaning, not just be an abstract number. It can express the cost, amount of valuable components (absolute or relative) in the products of separation and others. When considering the efficiency criteria, it is necessary to specify their physical meaning. Convenience of criteria that have physical meaning is in less probability of serious errors in their
application, as well as the possibility of rationing. For such a criterion one can always find its value for an ideal division, compare it to the actual and thus find out what are the areas of improvement of the separation unit work. Rationing, which consists of calculating the ratio of the real and the ideal separation, allows to identify the interval of criterion changes from zero, corresponding to the absence of separation to unity (or 100%), corresponding to the ideal division, which gives greater visibility to criterion.

6. Simplicity of calculation criterion is required only in the case when it does not contradict with fullness and uniqueness.

Obviously, the greatest number of requirements satisfies the economic criteria, although in many cases there are no sufficient data for calculation, since it is impossible to establish the price of all the intermediate products produced in one or another manufacturing operation. Moreover, economic efficiency is subject to strong changes associated with technological progress. Nevertheless, the economic evaluation is the most complete, universal and accurate, and in some cases - the only possible one.

In most particular cases, quite satisfactory criteria of separation efficiency can be recommended. They can be used for various purposes related to technology, economics, automation, process research theory, reproducibility of experiments and so on. It is not necessary that the same criteria are applied to the entire system in general and each of its parts.

According to justification of the withdrawal and purpose, all of the proposed separation criteria for our purposes are convenient to classify into the following groups: technological, thermodynamical, kinetic, statistical, economic, of automatic control, of natural separability, instrumental.

Introduce the following notations:
α - content of valuable component in the raw material;
β - the same in enriched product (concentrate, matte, distillate, etc...);
υ - the same in the depleted product (tails, wastes, slag, etc...);
βт - theoretically possible maximum content of valuable component;
γ - output of the enriched product;
(1-γ) - output of depleted product;
e - extraction of valuable components,

\[
e = \frac{\gamma \beta}{\alpha}
\]  (1)

R - extraction of non-useful part into the concentrate,

\[
R = \frac{\gamma (1 - \beta)}{1 - \alpha}
\]  (2)

εн — extraction of nonuseful part into the ends,

All values are expressed in decimals, not in percentage.

The following relations are derived from the conditions of the balance of valuable component in raw materials and separation products:

\[
\varepsilon \alpha = \gamma \beta
\]  (4)

\[
\alpha = \gamma \beta + (1 - \gamma) \delta
\]  (5)

For the case of allocation of \( n \) of separation products and wastes

\[
\alpha = \sum_{i=1}^{n} \gamma t \beta t + \left(1 - \sum_{i=1}^{n} \gamma t\right) \delta
\]  (6)

The degree of reduction

\[
\tau = \frac{1}{\gamma} = \frac{\beta}{\varepsilon \alpha}
\]  (7)

The degree of enrichment
When carrying out a large number of parallel experiments we can calculate mean square deviation (dispersion) and coefficients of variation for the different criteria. Obviously, the criterion is statistically the more effective, the smaller the coefficient of variation is. Using a variety of experiments, it is possible to build a distribution and calculate the dispersion and coefficient of variation for a number of criteria, as well as the main parameters of separation. The coefficient of variation in this case indicates the sensitivity of the criterion: the greater is the sensitivity, the greater the coefficient of variation is, if the reproducibility error on this criterion is not too large. It is necessary to take into account the sensitivity and the statistical efficiency of separation criteria during the following choosing them for research process.

The task of establishing a minimum number of criteria, completely characterizing the process, arises from the fact that some of the basic criteria can be correlated. In this case, it can turn out that with a change in separation conditions, any two indicators, such as isolation and kinetics of the process or the quality of concentrate and economic efficiency, are measured in the studied ranges in the same direction with symbatic curves. To establish this fact, it is necessary to calculate all the known criteria for a large number of experiments (at least 20-30) and to conduct the correlation analysis, by calculating pair correlation criteria coefficients for each pair. One should select one from each pair of correlated criteria and discard the second.

3. Conclusion

Experimental studies of the separation process, as well as the study of the work of industrial separation unit provide material for the expression of the test parameters of the process in the form of various separation criteria. According to the same parameters, e.g. $\alpha$, $\beta$, $\gamma$, $\upsilon$ different criteria are calculated - technological and thermodynamic; kinetic and economic criteria are calculated by duration of the process or cost of materials, respectively.

The calculation of the various criteria is associated with a specific purpose or stage of a research. Since there is no universal common separation criterion, the experiments should be analyzed in terms of several, although contradicting, parameters. This approach involves the use of the experience of researcher and his subjective evaluations. Considering the number of indicators, a researcher in many cases can quite accurately give preference to the results of one experiment to the results of another. In some cases this can be done more confidently and objectively, otherwise - intuitively. As a result of the pairwise comparison, of all the experiments conducted they can be arranged in a series of consecutive increasing or decreasing of the separation process quality. Experiment number in order of size is thus a kind of general separation criterion.

It should be noted that the use of such a criterion is associated with certain inconveniences. Statistical processing of results in this case is impossible, and the accuracy of the criterion is quite small, which is predetermined by the subjective approach to the ranking of experiments. Therefore, the degree of approximation to the optimal mode is not known and can not be assessed. Analysis of statistical efficiency (sensitivity) and the choice of a minimum number of criteria are produced by methods of mathematical statistics.

References

[1] Bakhmat G V 1981 Investigation degassing prcess of multicomponent gas saturated liquids. NTS. Development and exploitation of gas and offshore oil fields (Moscow; VNIEGazprom) 34-7
[2] Zemenkov Yu D, Markov L M, Prokhorov AD and Dudin S M 2009 Collection and preparation of oil and gas (Moscow; Academy)
[3] Sinai E G, Lapiga E Ya, Zaitsev YuV 2002 Separation of multiphase multicomponent systems (Moscow; Nedra) 620
[4] Trivus N A and Seidali-zade B M 1974 Optimum modes of condensate degassing stepped or efficiency Development and exploitation of gas and gas condensate fields VNIEGazprom 6 17-22