Запропоновано модифікований θ-метод забезпечення збіжності ітераційних розрахунків процесів багатокомпонентної ректифікації згідно потарілчастому методу розрахунку колони. Значення коефіцієнта θ уточнюється на кожній ітерації шляхом піднесення до степеня, який визначається введеним настроювальним параметром алгоритму. Це дозволяє значно скоротити число ітерацій і знизити витрати часу, необхідні на розрахунки статичних характеристик досліджуваних процесів

***Ключові слова:** математичне моделювання, багатокомпонентна ректифікація, ітераційні методи, θ-метод збіжності, рухоме керування*

Предложен модифицированный θ-метод обеспечения сходимости итерационных расчетов процессов многокомпонентной ректификации согласно потарелочному методу расчета колонны. Величина коэффициента θ уточняется на каждой итерации путем возведения в степень, которая определяется введенным настроечным параметром алгоритма. Это позволяет значительно сократить число итераций и снизить затраты времени, необходимые на расчеты статических характеристик исследуемых процессов

***Ключевые слова:** математическое моделирование, многокомпонентная ректификация, итерационные методы, θ-метод сходимости, подвижное управление*

UDC 519.853.6
DOI: 10.15587/1729-4061.2016.85372

DEVELOPING A TECHNIQUE FOR IMPROVING THE EFFICIENCY OF ITERATIVE METHODS FOR THE CALCULATION OF THE MULTICOMPONENT RECTIFICATION PROCESS

A. Sheikus
Postgraduate student*
E-mail: a.sheykus@gmail.com
E. Belobrova
Senior Lecturer**
E-mail: belobrova_e_v@mail.ru
Ya. Dovgopoliy
Postgraduate student*
E-mail: Xa4ik@3g.ua
I. Levchuk
PhD, Associate professor*
E-mail: lil8192@gmail.com
V. Korsun
Doctor of Technical Sciences, Professor, Head of Department
Department of Metrology and Information-Measuring Technologies
National Mining University
Karl Marx ave., 19, Dnipro, Ukraine, 49600
E-mail: korsun@ua.fm
*Department of Computer Integrated Technology and Metrology***
Department of Economic Cybernetics*
***Ukrainian State University of Chemical Technology
Gagarina ave., 8, Dnipro, Ukraine, 49005

1. Introduction

Calculations of the processes of separation of multicomponent mixtures in the rectifying columns are characterized by high dimensionality and variety of the variants of setting the problem.

At present, thermodynamically precise methods are the main ones, based on mathematical description of the process of heat- and mass exchange, which takes place in the separate plate of rectification apparatus [1]. This model of contact device includes equations of total and component material balances, equations of thermal balance, the algorithms of vapor-liquid equilibrium and kinetic equations that quantitatively describe accepted mechanism for the distribution of material and energy fluxes between the contacting phases.

The studies carried out in papers [2, 3] are aimed at the development of a new class of control systems for the processes of rectification – the systems of mobile control [4], their mathematical, algorithmic and software provision. In order to solve the problems of static optimization of the operating regimes of rectifying columns using mobile controlling influences, the most suitable is the Lewis and Matheson method for the plate to plate calculations [5]. It allows, simultaneously with the basic design-testing calculations, the determination of the number of the optimum feeding plate. In accordance with the selected calculation method, a mathematical model of contact device was constructed, which makes it possible to consider mobility of the source of substance and energy by the height of apparatus, and the corresponding algorithms for solving the obtained system of nonlinear equations are developed.

Since all the plates of mass-exchanged apparatuses are connected together, the equations of mathematical description for particular contact devices must be aligned with each other and meet joint conditions – material and thermal balances for the column as a whole. Thus, here is a relevant task of the provision of convergence of an iterative process that makes it possible for the plate to plate calculation of the installation to be brought into line with overall balance dependences.

2. Literature review and problem statement

A calculation of the operating modes of rectifying column comes down to the solution of the system of nonlinear algebraic equations of high dimensionality that are called the MESH-equations [6]. Their solution according to the Lewis and Matheson method was performed in [7]. In these papers, the major advantages of this approach were noted, and the algorithm for the calculation of static characteristics of the installations is presented.

According to the plate to plate method, in the beginning of each iteration, the compositions of separation products are assigned [8]. At these assigned compositions, all equations that describe the process are solved for each step of separation individually. The compositions of separation products are corrected after the completion of calculations for all contact devices, and a new iterative cycle begins.

The basic methods of providing for the convergence of calculations of the process of multicomponent rectification are still the Newton-Raphson method [9, 10] and the θ-method [11], as well as their various modifications. However, the Newton method is the most suitable for simple binary rectification [12], while for the multicomponent mixtures, there is high probability of different anomalies in the calculations, connected to the emergence of negative concentrations of components. Strict requirements to the quality of initial approximations of the required magnitudes predetermine low effectiveness of this approach.

Depending on the qualitative and quantitative composition of the separated mixture, as well as on the calculated operating mode of rectification installation, it is frequently necessary to conduct a considerable number of iterations. Each iterative refinement of the compositions of end products includes the plate to plate calculation of the entire rectifying column [13]. If one assumes that the calculation of operating mode of installation contains tens of iterations, then the algorithm for the calculation of contact device is carried out hundreds of times. In this case, the thousand-fold implementations of the base algorithms are necessary for the calculation of equilibrium concentrations of steam and liquid phases, for determining boiling points, condensation, for the calculation of enthalpies.

3. Aim and objectives of the research

The purpose of the work is the modification of the θ-method of convergence of iterative calculations of the multicomponent rectification process, which makes it possible to reduce the number of iterations and reduce the time, spent on the search for the solution. It is obvious that the method under development must be characterized by simplicity so that the time and resources, saved by the reduction in the number of iterations, would not be used for the realization of the method itself.

To achieve the aim, the following tasks are to be solved:

– to formulate a problem of the calculation of static characteristics of the multicomponent rectification process according to the Lewis and Matheson plate to plate method;

– to describe an algorithm for the provision of convergence of calculations of installation by the θ-method and to indicate those proposed changes in the technique that make it possible to accelerate attaining the solution;

– to conduct calculations of static characteristics of column for the separation of products of synthesis of methyl tert-butyl ether (MTBE) at various modes of its operation and to prove an improvement in quality of iterative calculations using the technique proposed.

4. The θ-method for the provision of convergence of calculations of the multicomponent rectification process and its proposed modification

4. 1. Formulation of the problem of calculation of static characteristics of the rectification process

A calculation of the established operating regime of rectifying column implies the determination of concentration and temperature profiles of the installation. In this case, we also determine the rates of material flows per each contact device of the apparatus and the thermal load of the dephlegmator:

$$\overline{L},\overline{V},\overline{x_i},\overline{y_i},Q_d,\overline{t}=f\left(W,\overline{x_w},Q_w,\overline{P},F,\overline{x_f},N_f,t_f,P_f,t_{Fl},t_d,\overline{\eta_i}\right). \quad (1)$$

When controlling a rectification column by redistributing the feeding between two plates, calculations must be carried out with regard to the dual-stream of the raw material:

$$\overline{L},\overline{V},\overline{x_i},\overline{y_i},Q_d,\overline{t}=$$
$$=f\left(W,\overline{x_w},Q_w,\overline{P},F,\overline{x_f},q,N_{f,1},N_{f,2},t_{f,1},t_{f,2},P_{f.1},P_{f,2},t_{Fl},t_d,\overline{\eta_i}\right). \quad (2)$$

As can be seen from (1) and (2), the following indices are necessary as the initial data for the plate to plate calculations of the installation: total number of plates of the column and numbers of the feeding plates, rates, compositions and temperatures of the feeding flows, pressure profile in the column, pressure in the lines of feeding supply, temperature of distillate and phlegm. As the target product is MTBE, separated from the cube, then the consumption of cubic product is selected as the first generalized variable. The second is the basic index of power consumption for conducting the process of rectification – heat consumption, supplied to the bottom of the column, which is also a controlling magnitude. The effectivenesses of mass transfer on the contact devices are the tuning parameters; if we accept them equal to 1, then the calculation of theoretical plates will be performed.

The required magnitudes are the functions of variables, which were selected as the initial data, and, in addition, concentrations of bottoms $\overline{x}_w$. These concentrations are the starting points of concentration profiles of components of the separated mixture $\overline{x}_i$ and $\overline{y}_i$. The concentration and temperature profiles of the column calculated by the plate to plate method will have forms, predetermined by the values of these set starting points.

The plate to plate design-testing calculation of a rectifying column is possible to conduct unidirectionally (from one end of the column to another) and in two directions (from the ends of the column to the control plate or vice versa). When simulating the multicomponent rectification, the use of unidirectional calculations leads to essential difficulties and it is of little effect. This is connected to the absence of accurate methods for determining the initial approximations of concentrations of components in the product that starts the calculation. These may be microimpurities, and then error in setting the values of such concentrations can reach several orders. In this case, a total calculation of the column is not carried out, and the absence of results of the calculations and the values of output magnitudes does not make it possible to conduct the refinement of the desired magnitudes. A way out from this situation is the calculations, directed toward one of the plates of the column.

Parameters of all contact devices are determined during calculations from bottom to top, starting from the cube of the column and up to the control plate. Consumptions and compositions of steam and liquid phases in the control section of the installation are the end results. Parameters of all contact devices are determined during calculations from top to bottom, starting from the dephlegmator and to the control plate inclusively. In this case, parameters of the distillate are determined based on the balance equations of the entire rectification installation. All the same consumptions and compositions of steam and liquid phases in the control section of the installation are the end results.

The task of calculating static characteristics of the rectification process is the iterative determination of such concentrations of components in the bottoms, based on which the calculations of the upper and lower parts of the columns, directed toward the control section, make it possible to obtain identical results.

The process that we examine in the paper is the separation of a ten-component mixture, which consists of products of the MTBE synthesis. The rectifying column, which is used for obtaining pure MTBE, contains 51 plates. In the feeding we examined 10 basic components whose concentrations exceed 0,1 %: propane (0,010053 mol. share), n-butane (0,079121), isobutane (0,54908), butylene (0,088858), cis-butene (0,04048), trans-butene (0,070099), isobutylene (0,004375), pentane (0,006143), methanol (0,041645) and methyl tert-butyl ether (MTBE). The starting data that determine normal operating regime of the installation: F=144,95 kmol/h; W=14,14 kmol/h; Q_w=3 GJ; $t_f=t_{boil}$, $t_{Fl}=t_{boil}$, $t_d=t_{boil}$; P_w=5,2 kgs/cm^2, P_d=3,7 kgs/cm^2, P_f= =9,3 kgs/cm^2, N_f=34, η=0,1232. The following initial approximations of concentrations in the bottom product were used for all calculations: propane ($1\cdot10^{-15}$ mol. share), n-butane ($1\cdot10^{-5}$ mol. share), isobutane ($1\cdot10^{-5}$ mol. share), butylene ($1\cdot10^{-5}$ mol. share), cis-butene ($1\cdot10^{-5}$ mol. share), trans-butene ($1\cdot10^{-5}$ mol. share), isobutylene ($1\cdot10^{-5}$ mol. share), pentane ($1\cdot10^{-3}$ mol. share), methanol ($1\cdot10^{-5}$ mol. share).

4. 2. Theoretical base of the modified θ-method of convergence

According to the set problem of the calculation of static characteristics of the rectification process, the concentrations of components of bottoms $x_{w,i}$ are necessary to refine until numerical values of basic indices of vapor phase $v^{\uparrow}_{N_r,i}$ and $v^{\downarrow}_{N_r,i}$ in the control section of the column, determined based on the plate to plate calculation of the installation, coincide with the required accuracy. A pointer indicates direction of the calculations of rectifying column when determining these magnitudes.

In accordance with the classic θ-method of convergence of calculations of the rectification processes, the refining of concentrations of the components in the bottoms is necessary to perform based on the following dependence:

$$x_{w,i}=\frac{F\cdot x_{f,i}}{W\cdot\left(1+\theta\cdot\frac{d_i}{w_i}\cdot\frac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}\right)}. \qquad (3)$$

Coefficient θ in (3) ensures the equality to unity of the sum of new approximations of concentrations. Based on this, each iterative refinement of concentrations of the components of bottom includes iterative calculations of magnitude θ:

$$f(\theta)=\sum_{i=1}^{n}\frac{F\cdot x_{f,i}}{1+\theta\cdot\frac{d_i}{w_i}\cdot\frac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}}-W=0. \qquad (4)$$

The calculation is conveniently conducted using the Newton method as it is possible to analytically determine the function of first-order derivative f´(θ):

$$f'(\theta)=-\sum_{i=1}^{n}\frac{F\cdot x_{f,i}\cdot\frac{d_i}{w_i}\cdot\frac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}}{\left(1+\theta\cdot\frac{d_i}{w_i}\cdot\frac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}\right)^2}. \qquad (5)$$

Fig. 1 displays graphic interpretation of the iterative calculation of normal operating mode of the column with the help of the classical θ-method of convergence: a change in the value of coefficient θ is shown, as well as the decrease in summary discrepancy of components consumption in the liquid phase in the control section as we approach solution:

$$S=\sum_{i=1}^{n}\left|l^{\uparrow}_{N_r+1,i}-l^{\downarrow}_{N_r+1,i}\right|=\sum_{i=1}^{n}\left|L^{\uparrow}_{N_r+1}\cdot x^{\uparrow}_{N_r+1,i}-L^{\downarrow}_{N_r+1}\cdot x^{\downarrow}_{N_r+1,i}\right|. \qquad (6)$$

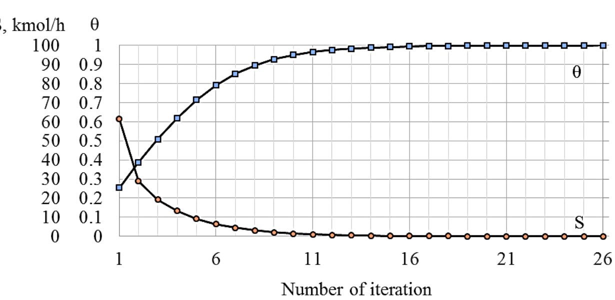

Fig. 1. Iterative calculation of static characteristics of normal operating mode of the rectifying column with the use of the classic θ-method

As can be seen from Fig. 1, approaching the solution is characterized by monotony and low speed. Values of coefficient θ, identical for all components, calculated based only on the requirement about the equality to 1 of the sum of concentrations, are far from optimal.

In connection with the indicated shortcoming of the classical θ-method, it is recommended to modify it, which makes it possible to reduce the number of iterations and to reduce the time, spent on the search for the solution. The main change is the exponentiation of values of coefficient θ, calculated at each iteration, which is determined by the introduced tuning parameter of algorithm b:

$$\theta = \theta^{b}. \qquad (7)$$

It is obvious that at the value b=1, the modified θ-method is analogous to the classical one.

An effectiveness of the proposed change is possible to theoretically substantiate in the following way. If using dependence (3) does not allow us to ensure high approach speed to the solution, then, at each iteration, it is necessary to more significantly change the concentrations of components in the bottom. This is achievable by an increase in the exponent b of coefficient θ. In this case, the corrected value θ is located at the larger distance from 1, than that calculated based on (4), which increases efficiency of the θ-method.

But if convergence is of divergent or periodic character and using the classical θ-method does not provide for the solution, then the application of correction (7) and values b<1 enables us to use in calculations values θ, close to 1, and to accomplish a smoother change in the concentrations of the bottom.

An algorithm for the calculation of static characteristics of the multicomponent rectification process with the use of the modified θ-method includes the following actions.

1) Vector of initial approximations of concentrations of the bottoms $\overline{x}_{W}$ is assigned. The plate for plate calculations of column (1) or (2) are conducted, and the ratios of the component-by-component consumptions of components in the vapor phase through control section are determined – $v^{\uparrow}_{N_r,i}$ and $v^{\downarrow}_{N_r,i}$.

As the control one, it is proposed to select the plate with number $N_r=N_f-1$, which is connected with the occurrence of negative concentrations during the calculations of the feeding plate from bottom to top. Then the control section is the section of column, located between feeding plate N_f and the lower-placed control plate N_r.

2) We enter internal iterative cycle of algorithm and perform calculations of coefficient θ.

As can be seen from Fig. 2, there are several roots of equation (4). In connection with this, initial approximation θ must be assigned equal to 0, since other approximations may as a result lead to obtaining negative or other result, out of touch with reality. The represented dependence was calculated for initial approximations of concentrations of the bottom and the initial data that are in line with normal operating mode of the column. The desired θ in this case is equal to 0,25431.

Equation for the iterative search for θ using the Newton method and dependences (4) and (5) takes the form:

$$\theta = \theta - \frac{\dfrac{W}{F} - \sum\limits_{i=1}^{n} \dfrac{x_{f,i}}{1+\theta \cdot \dfrac{d_i}{w_i} \cdot \dfrac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}}}{\sum\limits_{i=1}^{n} \dfrac{x_{f,i} \cdot \dfrac{d_i}{w_i} \cdot \dfrac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}}{\left(1+\theta \cdot \dfrac{d_i}{w_i} \cdot \dfrac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}\right)^2}}. \qquad (8)$$

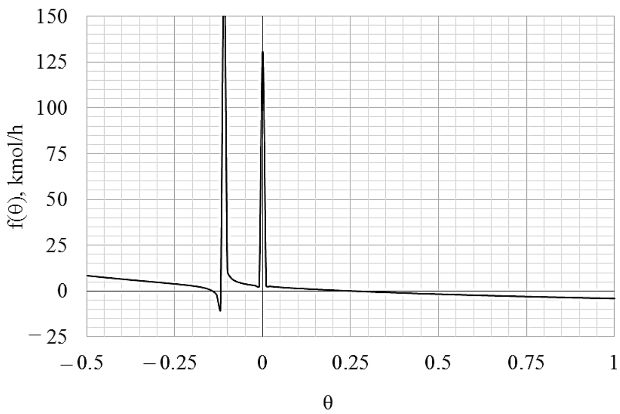

Fig. 2. Graphic determination of magnitude θ

In the first iteration, the value of function f(θ), its first-order derivative and the next approximation θ are equal to:

$$f(0) = F \cdot \sum_{i=1}^{n} x_{f,i} - W = F - W = D, \qquad (9)$$

$$f'(0) = -F \cdot \sum_{i=1}^{n} \left(x_{f,i} \cdot \frac{d_i}{w_i} \cdot \frac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}} \right), \qquad (10)$$

$$\theta = \frac{D}{F \cdot \sum\limits_{i=1}^{n} \left(x_{f,i} \cdot \dfrac{d_i}{w_i} \cdot \dfrac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}} \right)}. \qquad (11)$$

3) The value of θ obtained with the help of the Newton method is corrected and is used for calculating new approximations of the desired concentrations of the bottom product.

However, results, obtained using correction (7) and classical equation (3), do not satisfy basic condition:

$$\sum_{i=1}^{n} x_{w,i} = 1. \qquad (12)$$

When using the modified θ-method, iterative refinements of concentrations of the bottom product must be conducted based on the following expression:

$$x_{w,i} = \frac{x_{w,i}}{\sum\limits_{i=1}^{n} x_{w,i}} = \frac{x_{f,i}}{\left(1+\theta^{b} \cdot \dfrac{d_i}{w_i} \cdot \dfrac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}\right) \cdot \sum\limits_{i=1}^{n} \dfrac{x_{f,i}}{1+\theta^{b} \cdot \dfrac{d_i}{w_i} \cdot \dfrac{v^{\uparrow}_{N_r,i}}{v^{\downarrow}_{N_r,i}}}}. \qquad (13)$$

Dependence (13) makes it possible to reduce to 1 the sum of refined concentrations using any value of parameter b.

If necessary, an increase in the stability of work of the algorithm is proposed to achieve by using different values b in cases when θ>1 and when θ<1.

Actions 1)–3) are repeated; the condition of terminating iterative calculations is equality 0 (with the required accuracy $\varepsilon=10^{-2}$) of magnitude S.

5. Results of calculations of the multicomponent rectification process using the modified θ-method

A proof of effectiveness of the proposed approach is the extreme dependence of the number of necessary iterations on the degree b of coefficient θ (Fig. 3) for the examined operating regime of the column.

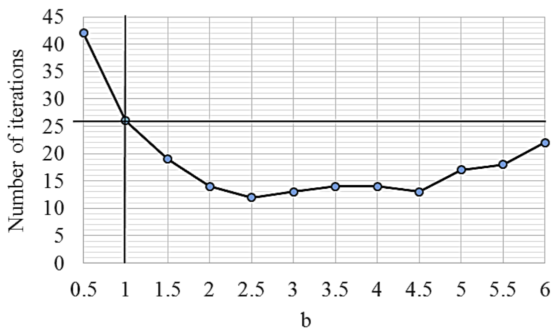

Fig. 3. Reduction in the number of iterations by changing the exponent of coefficient θ

With an increase in the value of b, iterative search acquires convergent oscillatory character (Fig. 4, *b*). However, high exponent not only leads to an increase in the number of the plate for plate calculations, but, for the majority of the operating regimes of the column, does not allow finding the solution at all. For the examined column, the key iteration is the 2nd iteration: if, after the first refinement of composition of the bottom product, further calculations are performed, then the solution will be found (Fig. 4, *a*).

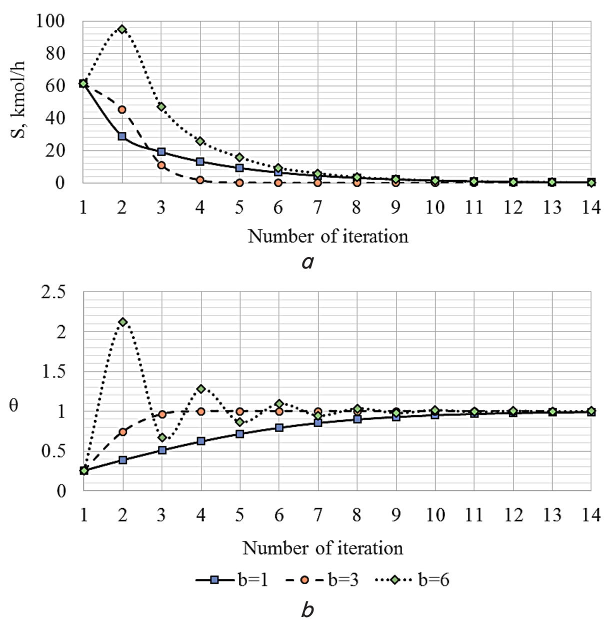

Fig. 4. Convergence of iterative calculations when using the classic (b=1) and modified θ-methods: *a* — dependences of summary discrepancies of concentrations in the control section of the installation on the number of iteration; *b* — calculated values of coefficient θ

As can be seen from Fig. 3, 4, the optimum value of degree b in the course of simulation of the column performance for the separation of products of the MTBE synthesis is equal to 2. Further increase in the value of this tuning index does not lead to perceptible improvement in the quality of convergence, but in this case the risk of errors at the plate for plate calculations of the column grows as a result of a sharp change in the composition of the bottom product.

Results, represented in Fig. 3, are related to the normal operating mode of the column. For the purpose of confirming the effectiveness of the proposed method, we carried out research into operating regimes of the installation at the change in the input magnitudes in wide ranges (Fig. 5).

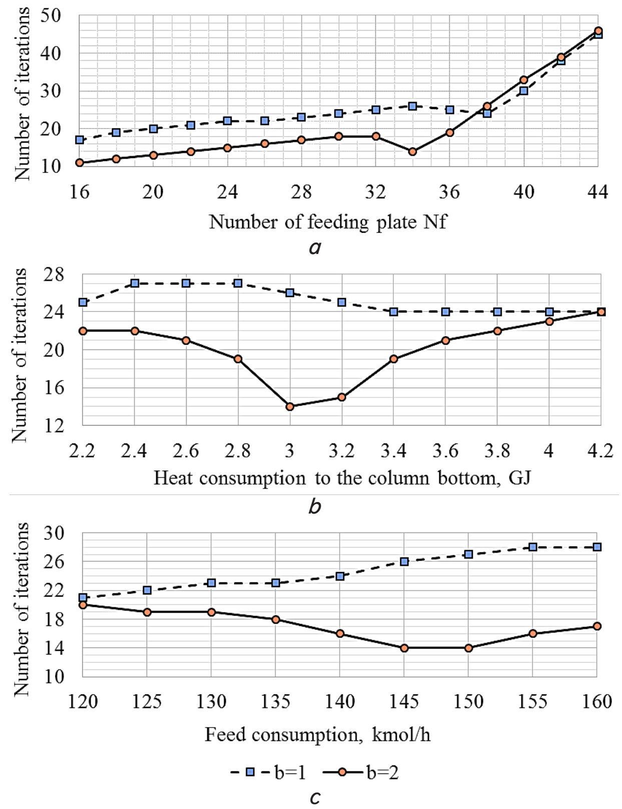

Fig. 5. Required number of iterations for calculating the rectifying column using the classic and modified θ-methods: *a* — with different numbers of the feeding plate; *b* — with different thermal load of the boiler of the column bottom; *c* — with different feeding consumptions to the column

According to the method of mobile control of the rectification processes, controlling influences are manifested by the change in the heat consumption to the column bottom and in the number of the feeding plate. Fig. 5 displays dependences of the number of necessary iterations on the values of data of controlling influences and the basic disturbing magnitude – a change in the consumption of raw material. In this case, we examined the classic θ-method and the modified one, with tuning coefficient b, equal to 2.

6. Discussion of results of calculations of the multicomponent rectification process using the modified θ-method

Results of calculations represented in Fig. 3 prove that the proposed modification allows us, when calculating normal operating mode of the installation, to reduce the number of iterations from 26 to 13. In this case, reduction in the cost of time is 50 %.

In all of those examined operating regimes of the column, the modified θ-method makes it possible to substantially reduce the number of necessary calculations (Fig. 5). The exception is the calculations of rectifying column at high numbers of the feeding plate. A change in the number of the feeding plate is combined with a change in the position of control section, to which the plate to plate calculations are conducted. This explains a considerable increase in the number of iterations, when both classic and the modified (at b=2) θ-methods of convergence are characterized by identical quality indicators. In this case, the reduction of magnitude b to the values lower than 1 proves to be effective.

For each calculated operating regime of the column, there is an optimum value of tuning coefficient b.

The proposed method of the provision of convergence, as well as the classic one, makes it possible to calculate a rectifying column at a change in the input magnitudes in wide ranges, it is characterized by high stability, even taking into account the fact that the initial approximations of the desired magnitudes were intentionally selected with errors of several orders.

The use of the modified θ-method and the algorithmic provision designed on its basis allows us to determine concentration profiles of the rectifying column, temperature profile, rates of steam and liquid phases by the height of the column. Changes in the number of the feeding plate or coefficient of redistribution q in the process of imitation studies make it possible to track and prove an expediency of using mobile controlling influences for the multicomponent rectification processes control.

7. Conclusions

1. We substantiated the selection of independent variables and initial data for the calculation of a rectifying column according to the Lewis and Matheson method taking into account mobile controlling influences. The formulation of the problem for the calculation of the multicomponent rectification process is completed: it is necessary to iteratively determine such concentrations of components in the bottoms so that the calculations of the upper and lower parts of the column, based on them, and directed toward the control section, provide identical results.

2. We proposed changes to the technique of solving the set problem with the use of the θ-method, which consist in the exponentiation of coefficient θ that is determined by the introduced tuning parameter of the algorithm. An algorithm for the calculation of static characteristics of the rectifying column is developed: concentrations of components in the bottoms are determined based on the modified θ-method of convergence, and the Newton method is applied for the calculations of coefficient θ in each iteration.

3. We carried out the calculations of static characteristics of a rectifying column for the separation of products of the MTBE synthesis at different modes of its operation and different exponents of coefficient θ. The extreme dependence of the number of iterations on the introduced tuning coefficient of the algorithm is proven. We noted essential (to 50 %) reduction in time, necessary for the search for the solution, including under condition of change in the input magnitudes in wide ranges. It is proven that the iterative calculations of the multicomponent rectification processes with the use of the modified θ-method are characterized by high stability, even taking into account the fact that initial approximations of the desired magnitudes were intentionally selected with errors of several orders

References

1. Laptev, A. G. Osnovy rascheta i modernizatsiya teplomassoobmennykh ustanovok v neftekhimii [Text]: monografiya / A. G. Laptev, M. I. Farakhov, N. G. Mineev. – Kazan': Kazanskii gosudarstvennyi energeticheskii universitet, 2010. – 574 p.
2. Belobrova, E. V. Automatic control of heat-mass exchange processes with movable distributed regulatory impact [Text] / E. V. Belobrova, A. R. Sheikus, V. I. Korsun // Eastern-European Journal of Enterprise Technologies. – 2014. – Vol. 5, Issue 2 (71). – P. 51–55. doi: 10.15587/1729-4061.2014.28037
3. Levchuk, I. L. Sposob upravleniya protsessom rektifikatsii s pomoshch'yu raspredelennykh upravlyayushchikh vozdeistvii [Text] / I. L. Levchuk, A. R. Sheikus, V. Ya. Trishkin // Herald of the National Technical University "KhPI". Subject issue: New solutions in modern technologies. – 2015. – Issue 14. – P. 100–105.
4. Rapoport, E. Ya. Analiz i sintez sistem avtomaticheskogo upravleniya s raspredelennymi parametrami [Text] / E. Ya. Rapoport. – Moscow: Vyssh. shk., 2005. – 292 p.
5. Castner, W. R. The Lewis-Matheson method on computer [Text] / W. R. Castner. – New Jersey Institute of Technology, 1983. – 272 p.
6. Bansal, S. Theoretical investigation on the performance of multicomponent distillation column for the separation of hydrocarbon mixture using inside out approach [Text] / S. Bansal, S. D. Manjare // International Journal of Chemical Engineering and Applications. – 2016. – Vol. 7, Issue 4. – P. 282–288. doi: 10.18178/ijcea.2016.7.4.590
7. Banka, S. R. Computer aided design of distillation column [Text] / S. R. Banka // Journal of Applied Sciences Research. – 2015. – Vol. 11, Issue 17. – P. 8–12.
8. Komissarov, Y. A. Multicomponent distillation calculations using computer simulation principles [Text] / Y. A. Komissarov, D. Q. Sang // Theoretical Foundations of Chemical Engineering. – 2014. – Vol. 48, Issue 3. – P. 280–287. doi: 10.1134/s0040579514030087
9. Buryakov, V. G. Razrabotka odnogo klassa matematicheskikh modelei rektifikatsii mnogokomponentnykh smesei [Text] / V. G. Buryakov, A. N. Khodzinskii // Komp'yuternaya matematika. – 2008. – Issue 2. – P. 13–24.
10. Monroy-Loperena, R. A simple, reliable and fast algorithm for the simulation of multicomponent distillation columns [Text] / R. Monroy-Loperena, M. Vacahern // Chemical Engineering Research and Design. – 2013. – Vol. 91, Issue 3. – P. 389–395. doi: 10.1016/j.cherd.2012.09.005
11. Olafadehan, O. A. Mathematical modelling and simulation of multicomponent distillation column for acetone-chloroform-methanol system [Text] / O. A. Olafadehan, V. O. Adeniyi, L. T. Popoola, L. Salami // Advanced Chemical Engineering Research. – 2013. – Vol. 2, Issue 4. – P. 113–123.

12. Belobrova, E. V. Matematicheskoe modelirovanie protsessa rektifikatsii. Issledovanie tekhnologicheskikh osnov podvizhnogo upravleniya [Text] / E. V. Belobrova, V. I. Korsun, O. P. Mysov, V. Ya. Trishkin // Herald of Khmelnytskyi national university. – 2007. – Vol. 1, Issue 3. – P. 36–37.
13. Asadi, S. Simulation of the multicomponent distillation of spearmint essential oil by a predictive Soave-Redlich-Kwong equation of state and comparison with experiments [Text] / S. Asadi // Chemical Industry and Chemical Engineering Quarterly. – 2014. – Vol. 20, Issue 3. – P. 417–423. doi: 10.2298/ciceq130208024a

UDC 681.523
DOI: 10.15587/1729-4061.2016.85366

DEVELOPMENT OF THE SYSTEM OF AUTOMATIC CONTROL OF STEAM BOILERS AT ELECTRIC POWER PLANTS DURING COMBUSTION OF LOW QUALITY FUEL

G. Kanyuk
Doctor of Technical Science, Professor*
A. Mezerya
PhD, Associate Professor*
E-mail: mezzer@mail.ru
I. Suk
Postgraduate student*
I. Babenko*
E. Bliznichenko
PhD, Associate Professor*
E-mail: art-studio_diana_@ukr.net
*Department of heat energy and energy-saved
Ukrainian Engineering and Pedagogical Academy
Universitetskaya str., 16, Kharkiv, Ukraine, 61003

Наведено загальний принцип енергозберігаючого керування паровими котлами теплових електростанцій. У функціональні залежності та вихідні моделі керування котельною установкою включені параметри активатора горіння, що поліпшують процес спалювання низькосортних палив. Показано спосіб підвищення точності виміру і регулювання подачі твердого палива в топку котла теплових електростанцій. Розроблено систему автоматичного регулювання подачі активаторів горіння, яка заснована на визначенні якості та кількості подаваного палива. Показано можливий техніко-економічний ефект застосування активаторів горіння

Ключові слова: паровий котел, теплова електростанція, енергозбереження, енергетичні втрати, активатор горіння

Приведен общий принцип энергосберегающего управления паровыми котлами тепловых электростанций. В функциональные зависимости и исходные модели управления котельной установкой включены параметры активатора горения, улучшающих процесс сжигания низкосортных топлив. Показан способ повышения точности измерения и регулирования подачи твердого топлива в топку котла тепловых электростанций. Разработана система автоматического регулирования подачи активаторов горения, основанная на определении качества и количества подаваемого топлива. Показан возможный технико-экономический эффект применения активаторов горения

Ключевые слова: паровой котел, тепловая электростанция, энергосбережение, энергетические потери, активатор горения

1. Introduction

Basic thermal equipment of thermal power plant (TPP) is a steam boiler (SB) [1, 2]. Technological parameters of the SB operation significantly influence specific fuel consumption and prime cost of the manufactured thermal and electrical energy, thus determining performance efficiency of plant as a whole.

An increase in the cost of organic fuel and physical wear of boiler equipment lead to the need for the identification of possible reserves for energy saving, their scientific substantiation and integration of energy-saving algorithms for controlling boiler units into existing ACS of technical process (TP). At the same time, an increase in the volume of the burned solid fuel, the rising cost of its exploration, with simultaneous worsening of quality of obtained fuel, are some of the basic problems of contemporary thermal power industry and coal mining industry. This renders relevant the tasks of considerable increase in the effectiveness of its use both due to the improvement of traditional combustion methods and due to the development of new promising technologies [3–6].

One of such ways implies the creation of energy saving systems of control, which ensure minimum energy losses under all basic modes of operation of power equipment, including the process of combustion of low quality fuels.

A promising trend of increasing the effectiveness of operation of boilers in the process of combustion of low-bus-