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Development of Mathematical Model of the Main Apparatus of the Oil Fractionation Unit

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Abstract

Currently, due to the rapid growth in demand for fuel and energy resources in the world, there is an increase in the depth of processing and an improvement in quality indicators at technological installations that carry out oil fractionation at the oil refineries of our republic. Increasing their economic efficiency by reducing energy costs during oil refining is of national economic importance. Ensuring the implementation of this technological process in both safe and optimal modes, as a rule, directly depends on the level of construction of its automation system. For development high-quality automation systems and implement enterprise management in an optimal mode, it is necessary to develop mathematical models that can adequately describe the operating modes of its main technological devices. In the article a mathematical model was developed that ensures the optimal operating mode of the K-2 column, which is the main fractionating device of a primary oil refining installation and its quality was evaluted.

Keywords: oil refinery, K-2 column, regression equation, mathematical model, adequacy.

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Neftin fraksiyalandırılması qurğusunun əsas aparatının riyazi modelinin işlənilməsi

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Xülasə

Hazırda dünyada yanacaq-enerji ehtiyatlarına tələbatın sürətlə artması ilə əlaqədar olaraq respublikamızın neft emalı zavodlarında neftin fraksiyalaşdırılmasını həyata keçirən texnoloji qurğularda emal dərinliyində artım, keyfiyyət göstəricilərində yaxşılaşma müşahidə olunur. Neftin emalı zamanı enerji xərclərini azaltmaqla onların iqtisadi səmərəliliyinin yüksəldilməsi milli iqtisadi əhəmiyyətə malikdir. Bu texnoloji prosesin həm təhlükəsiz, həm də optimal rejimlərdə həyata keçirilməsinin təmin edilməsi, bir qayda olaraq onun avtomatlaşdırma sisteminin qurulması səviyyəsindən birbaşa asılıdır. Yüksək keyfiyyətli avtomatlaşdırma sistemlərini qurmaq və qurğunun idarə edilməsini optimal rejimdə həyata keçirmək üçün onun əsas texnoloji apparatlarının iş rejimlərini adekvat təsvir edə bilən riyazi modellərinin işlənilməsi tələb olunur. Məqalədə neftin ilkin emalı qurğusunun əsas fraksiyalama apparatı olan K-2 kalonunun optimal iş rejimini təmin edən riyazi modeli işlənib hazırlanmış və onun keyfiyyəti qiymətləndirilmişdir.

Açar sözlər: neft emalı zavodu, K-2 sütunu, reqressiya tənliyi, riyazi model, adekvatlıq.

Разработка математической модели основного аппарата установки фракционирования нефти

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Аннотация

В настоящее время в связи с быстрым ростом спроса на топливно-энергетические ресурсы в мире происходит увеличение глубины переработки и улучшение качественных показателей на технологических установках, осуществляющих фракционирование нефти на нефтеперерабатывающих заводах нашей республики. Повышение их экономической эффективности за счет снижения энергозатрат при переработке нефти имеет народнохозяйственное значение. Обеспечение реализации данного технологического процесса как в безопасном, так и в оптимальном режимах, как правило, напрямую зависит от уровня построения системы его автоматизации. Для разработки качественных систем автоматизации и реализации управления предприятием в оптимальном режиме необходима разработка математических моделей, способных адекватно описывать режимы работы его основных технологических устройств. В статье разработана математическая модель, обеспечивающая оптимальный режим работы колонны К-2, являющейся основным ректификационным аппаратом установки первичной переработки нефти, и оценено ее качество.

Ключевые слова: нефтеперерабатывающий завод, колонна К-2, уравнение регрессии, математическая модель, адекватность.

Introduction

"Black box" and "gray box" methods can be used in the modeling of systems, including the development of mathematical models of technological processes. In the modeling based on the "black box" method, only the initial statistical information collected on the basis of passive experiments on the input and output parameters of the technological process is used. At the next stage, as in other methods, the parameters of the selected models are determined. They are widely used in the development of deterministic and probabilistic models of technological processes [1].

As it is known, primary oil processing facilities are designed for the production of light-colored oil products and various oil fractions that meet modern requirements with their quality. The main equipment of these technological facilities are rectification columns operating under atmospheric and vacuum conditions, which perform the decomposition of crude oil and fuel oil into various product fractions. Generally, the quality indicators of product fractions produced in these columns are provided by stabilizing the temperature modes at certain points (plates) of these or rectification columns by regulating the irrigation consumption supplied to those plates. Requirements for the quality indicators of various oil products produced through these technological facilities require the creation of more modern and perfect control systems [2, 3].

Experience in modeling technological processes shows that when developing mathematical models of control objects of this class, experience is needed in using experimental mathematical models built on the basis of statistical data collected in normal operating modes of technological processes or collected as preliminary information. These facilities widely use the results of specially organized passive experiments. When modeling modern technological processes of oil refining, taking into account the physical and chemical laws in these processes is one of the main conditions that ensures, as a rule, obtaining adequate mathematical models. On the other hand, the use of mathematical models constructed by this method in a control system has great advantages compared to other methods. The most important of them is the elimination of uncertainty, which cannot always be detected due to the assumed variables of reflux number and steam number in mathematical models of the quantity and quality indicators of fractions obtained in the K-2 rectification column, which is considered the main device of this technological process from the point of view target production of products [4, 5].

For this purpose, a plan and softüare for a passive experiment was developed to collect preliminary statistical information, which could become the basis for bilding more adequate mathematical models in a technological installation for primary oil refining. One of the main advantages of this plan is that there is no disruption to the normal operation of the device during the experiment.

The experiment was conducted in each column separately. At this time, stabilization of existing regimes in other columns was ensured. The quality indicators were based on the results of laboratory analyses. During the experiment the registration frequency of mode parameters was done once per hour, and the results of the quality indicators of the fractions in each stable mode were recorded twice.

Purpose of the work

Development of mathematical models that can adequately describe the real technological situations occurring in the operating modes of the K-2 column of oil fractionation unit on its input, control and controlled output coordinates.

Problem statement

The mathematical formulation of the modeling problem, which expresses the regression dependence between unstable gasoline yield (volume consumption) of the K-2 column of atmospheric section and other parameters, and the sequence of solving the problem according to the formulation are as follows. The diagram of the structural form of K–2 column as a modeling facility for the building of a mathematical model is depicted in Fig. 1.

Constraint conditions set for input and control parameters. The linear mathematical model of K-2 column is written as follows (with unknown coefficients):

$$y = b_0 + \sum_{i=1}^{n} b_i x_i .$$

Here b_i – unknown regression coefficients. x_i is input and y_i is output.

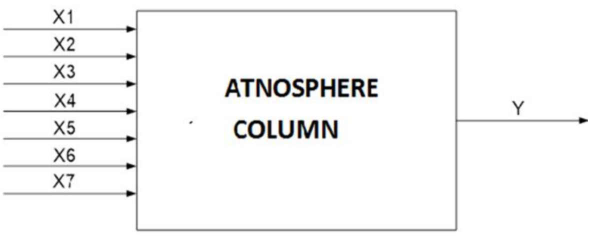

Figure 1 – Structural diagram of K-2 column as a modeling facility

Where X1 – volume consumption of raw material given to K-2; X2 – specific weight of row material; X3 – temperature above K-2; X4 – temperature below K-2; X5 – temperature below K-1; X6 – temperature in flow K-6; X7-- temperature in flow K-7; y – volume consumption of unstable gasoline.

There are many ways to find the unknown regression coefficients of a mathematical model, one of which is to find the regression coefficients using the least squares method. This method is based on the fact that the square of the difference between the calculated value and the experimental one is very small. The initial statistical data obtained from the passive experiments required for modeling are as shown in table 1.

If we replace these values of unknown coefficients bi in the model, then the linear mathematical model for the consumption of the unstable gasoline fraction of column K-2 in terms of density constraint is as follows:

The regression equation in a linear form:

Y= 337,7733+0,023212X1-- 611,846X2 +0,448617X3+0,212763X4 - 0,00532X5 +0,076568X6+0,290111X7 (1)

It should be noted that after the development of the mathematical model of the considered technological apparatus, it is required to check its adequacy [6-8]. The Fisher criterion was used to check the adequacy of the mathematical model.

The experimental value of Fisher criterion (Fexp) must be greater than its table value (Ftab) for the mathematical model to be adequate:

$$F_{exp} < F_{tab}. \quad (2)$$

When checking the adequacy according to set correlation coefficient, the closer the coefficient R is to the unit ($0 \leq R \geq 1$), the more adequate the mathematical model is.

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Table 1 – Statistical data table

№	X1	X2	X3	X4	X5	X6	X7	Y
1	515	0,8526	114	345	141	171	300	45
2	530	0,8527	118	350	143	169	265	44
3	555	0,853	110	320	138	160	300	42
4	550	0,8533	117	350	143	165	297	51
5	531	0,8537	116	345	137	163	298	56
6	520	0,8536	115	341	142	164	303	58
7	515	0,854	117	332	134	169	305	54
8	600	0,8541	116	341	143	168	307	53
9	610	0,8547	116	342	135	165	309	44
10	640	0,855	118	345	150	168	298	58
11	530	0,8551	114	346	130	163	292	40
12	640	0,8553	116	347	149	162	296	60
13	530	0,8559	115	343	136	165	301	59
14	640	0,856	113	350	134	166	303	57
15	535	0,8561	112	349	130	173	304	56
16	585	0,8562	116	345	138	176	307	52
17	530	0,8563	115	348	137	160	308	51
18	580	0,8564	114	350	149	168	309	49
19	530	0,8567	113	346	148	169	298	46
20	625	0,8566	112	339	143	171	299	49
21	580	0,8567	126	340	139	150	289	48
22	585	0,857	118	350	138	160	285	47
23	515	0,854	117	332	134	169	305	54
24	640	0,856	113	350	134	166	303	57
25	531	0,8537	116	345	137	163	298	56

In order to check the adequacy of the developed linear mathematical model, its analysis should be carried out, which can also be performed using Excel.

The results of the analysis include residual error, set correlation coefficient, Fisher criterion are shown in table 2.

Experimental value of Fisher adequacy index: Fexp=1.92.

Experimental value of set correlation coefficient: R=0.87

Table 2 – Adequacy indicators of the mathematical model

Adequacy index of the mathematical model		The value obtained from the analysis
1	Fisher criterion (F)	1,92
2	Set correlation coefficient (R)	0.87
3	Residual error ε	0.103

Table value of Fisher adequacy index corresponding to a mathematical model consisting of 25 experiments with 7 factors: Ftab=1.11

Thus, since the numerical value of Fisher coefficient adequacy index of the mathematical developed model is greater than its table value (Fexp>Ftab), set correlation criterion R is close to the 1 and residual error ε is very small, the developed mathematical regression model is adequate.

Conclusion

The article deals with the research in terms of the control object of the atmospheric unit of oil refining technological complex and revealing the change of its input, controlling and controlled output coordinates according to random rules in production conditions.

A passive experiment was conducted through the equipment to collect the initial data of the object in order to develop mathematical models that can adequately record the real technological situations occurring in the operating modes of fractionation unit. Based on the statistical data collected as a result of the passive experiment for the main apparatus of the unit, a mathematical model was developed in the form of a linear regression equation on the main output coordinate of K-2 rectification column and its adequacy was checked on the basis of mathematical statistics. The obtained result confirmed the adequacy of the mathematical model.

Conflict of Interests

The author declares there is no conflict of interests related to the publication of this article.

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