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Satbayev University

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B.B. Orazbayev[1], M.D. Kabibullin[1], K.T. Bissembayeva[2*], G.S. Sabyrbayeva[2], A.J. Mailybayeva[3]

[1]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan;
[2]Caspian University of Technology and Engineering named after Sh. Yessenov, Aktau, Kazakhstan;
[3]Kh.Dosmukhamedov Atyrau University, Atyrau, Kazakhstan.
E-mail: karlygasha.bissemd74@mail.ru

HEURISTIC APPROACH TO FUZZY CONTROL OF THE REFORMING PROCESS IN REFINING AND GEOLOGY

Abstract. In production conditions, many processes of oil geology and oil refining and other industries are often characterized by a lack of reliable statistical data and fuzzy initial information. At the same time, the lack and economic inexpediency of collecting and using quantitative information leads to the use of available fuzzy information in the form of knowledge, experience and intuition of a decision maker (DM, subject matter experts, which are available at all functioning objects. In this regard, the formulation and solution of the problem of managing fuzzy-described processes of geological exploration and refining of oil and the development of an effective method for solving it based on a heuristic approach with the involvement of decision makers is an urgent task of science and practice geological exploration geological exploration and oil refining.

A mathematical statement of the problem of controlling the processes of geological exploration and reforming in a fuzzy environment is formulated and obtained, and a heuristic method for solving the problem is developed based on the modification of various principles of optimality. The proposed fuzzy approach to solving the problem of managing the processes of geological exploration and oil refining in a fuzzy environment is based on the use of knowledge, experience and intuition of decision makers, experts in the decision-making process to manage these processes in a fuzzy environment. The mathematical formulation of the problem of managing the processes of geological exploration and reforming is specified in the case of one main criterion and a vector of fuzzy constraints. The specific problem of managing the processes of geological exploration and reforming is solved using the proposed heuristic method. The results obtained are compared with the known results obtained on the basis of a deterministic approach and real data. The advantages are shown and the effectiveness of the proposed fuzzy approach to solving the problem of control in geology and oil refining in a fuzzy environment is substantiated, which makes maximum use of the initial fuzzy information when solving the problem. The novelty of the proposed approach to the formulation and solution of the problem of managing the processes of geological exploration and refining of oil in a fuzzy environment is to increase the adequacy of the solution of practical problems of geology and oil refining based on the use of experience, knowledge and intuition of the decision maker..

Key words: Oil geology, geological exploration, reforming process, decision making, fuzzy control, heuristic method, decision maker (DM), principles of optimality.

Б.Б. Оразбаев[1], М.Д. Кабибуллин[1], К.Т. Бисембаева[3*], Г.С. Сабырбаева[2], А.Ж. Майлыбаев[3]

[1]Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан;
[2]Ш.Есенов атындағы Каспий технологиялар және инжиниринг университеті, Ақтау, Казақстан;
[3]Х. Досмұхамедов атындағы Атырау университеті, Атырау, Қазақстан.
E-mail:karlygasha.bissemd74@mail.ru

ГЕОЛОГИЯ МЕН МҰНАЙ ӨҢДЕУДЕ РИФОРМИНГ ПРОЦЕСІН АЙҚЫНСЫЗДЫҚТА БАСҚАРУДЫҢ ЭВРИСТИКАЛЫҚ ТӘСІЛДЕМЕСІ

Аннотация. Геология, мұнай өңдеу және басқа да салалардың көптеген технологиялық жүйелері көбінесе сенімді статистикалық мәліметтердің жетіс-пеушілігімен және қолжетім бастапқы ақпараттың айқынсыздығымен сипат-талады. Бұл жағдайларда сандық ақпараттың жетіспеушілігі, оны жинау мен өңдеудің экономикалық тұрғыдан тиімсіздігішешім қабылдаушының тұлғаның (ШҚТ), пәндік сала эксперттердің білімі, тәжірибесі және интуициясы түріндегі қолжетімді айқын емес ақпаратты пайдалану тиімді болып табылады. Осыған байланысты мұнай геологиясы мен мұнай өңдеуде айқынсыздықпен сипатталатын технологиялық жүйелерін басқару есебін тұжырымдау және шешу және ШҚТ-ны тарта отырып, эвристикалық тәсілге негізделген оны шешудің тиімді тәсілін жасақтау мұнай геологиясы мен өңдеудің аса өзекті ғылыми, практикалық міндеті болып табылады.

Айқын емес ортада геологиялық барлау, риформинг процесін басқару есебінің математикалық қойылымы тұжырымдалып, түрлі оптималдық принциптерін модификациялау негізінде қойылған есепті шешудің эвристикалық тәсілі жасалған. Айқын емес ортада геологиялық барлау, мұнай өңдеу процесстерін басқару есебін шешуге ұсынылған айқын емес тәсілдеме ШҚТ-ның, эксперттердің айқынсыздықта нысан жұмыс режимін басқару бойынша шешім қабылдау процесінде білімін, тәжірибесін және интуициясын пайдалануға негізделген. Геологиялық барлау, риформинг процесін басқару есебінің математикалық тұжырымы бір негізгі критерий және айқын емес шектеулер векторы жағдайында

нақтыланған. Мұнай геологиясы мен риформинг процесін басқарудың нақтыланып, қойылған есебі ұсынылған эвристикалық тәсілді қолдану арқылы шешілген. Алынған нәтижелер детерминирді тәсілмен алынрған нәтижелермен және өндірістік нақты деректер негізінде алынған мәліметтермен салыстырылған. Салысыру негізінде айқын емес ортада геологияды, мұнай өңдеу нысандары жұмыс режимдерін басқару есебін шешуге ұсынылған эвристикалық тәсілдің тиімділігі мен артықшылықтары негізделген, олар есепті шешу барысында қолжетімді айқын емес ақпаратты толықтай пайдалану есебінен қамтамасыз етеді. Айқын емес ортада мұнайды геологиялық барлау мен өңдеу процесстерін басқару есебін қою мен шешуге ұсынылған тәсілдің жаңашылдығы ШҚТ тәжірибесін, білімін және интуициясын пайдалану негізінде өндірістік есептерді айқынсыздықта шешудің адекваттылығын арттыру болып табылады.

Түйінді сөздер. Мұнай геологиясы, геологиялық барлау, **р**иформинг процесі, шешім қабылдау, айқын емес басқару, эвристикалық тәсіл, шешім қабылдаушы тұлға (ШҚТ), оптималдық принциптері.

Б.Б. Оразбаев[1], М.Д. Кабибуллин[1], К.Т. Бисембаева[3*], Г.С. Сабырбаева[2], А.Д. Майлыбаева[3]

[1]Евразийский национальный университет имени Л.Н. Гумилев, Астана, Казахстан;
[3]Каспийский университет технологии и инжиниринга им. Ш. Есенова, Актау, Казахстан;
[3]Атырауский университет им. Х. Досмухамедова, Атырау, Казахстан.
E-mail: karlygasha.bissemd74@mail.ru

ЭВРИСТИЧЕСКИЙ ПОДХОД К НЕЧЕТКОМУ УПРАВЛЕНИЮ ПРОЦЕССОМ РИФОРМИНГА В НЕФТЕПЕРЕРАБОТКЕ И ГЕОЛОГИИ

Аннотация. В производственных условиях многие процессы геолологии нефти и нефтепереработки и других производств часто характеризуются дефицитом достоверных статистических данных и нечеткостью исходной информации. При этом дефицит и экономическая нецелесообразность сбора и использования количественной информации приводит к использованию доступной нечеткой информации в виде знания, опыта и интуиции лица, принимающего решения (ЛПР), экспертов предметной области, которые имеются на всех функционирующих объектах. В связи с этим формулировка и решение задачи управления нечетко описываемыми процессами геологоразведки и перераюботки нефти и разработка эффективного метода ее решения на основе эвритстического подхода с привлечением ЛПР является актуальной задачей науки и практики нефтеперерабатывающего производства.

Сформулирована и получена математическая постановка задачи управления процессами геологоразведки и риформинга в нечеткой среде и на основе модификации различных принципов оптимальности разработан эвристический метод решения поставленной задачи. Предложенный нечеткий подход к решению задачи управления процессами геологоразведки и переработки нефти в нечеткой среде основан на использование знания, опыта и интуиции ЛПР, экспертов в процессе принятия решений по управлению этими процессами в нечеткой среде. Математическая постановка задачи управления процессами геологоразведки и риформинга конкретизирована на случае одного главного критерия и вектора нечетких ограничений. Конкретизированная задача управления процессами геологоразведки и риформинга решена с применением предложенного эвристического метода. Полученные результаты сравнены с известными результатами, полученными на основе детерминированного подхода и реальными данными. Показаны преимущества и обоснована эффективность предложенного нечеткого подхода к решению задачи управления в геологии и нефтепереработки в нечеткой среде, который при решении задачи максимально использует исходную нечеткую информацию. Новизна предлагаемого подхода к постановке и решению задачи управления процессами геологоразведки и переработки нефти в нечеткой среде заключается в повышении адекватности принимаемого решения практических задач геологии и нефтепереработки на основе использования опыта, знания и интуиции ЛПР.

Ключевые слова: Геология нефти, геологоразведка, процесс риформинга, принятия решений, нечеткое управление, эвристический метод, лицо, принимающее решение (ЛПР), принципы оптимальности.

Introduction. In oil refining and other industries the chemical process systems, where various physical and chemical processes take place, are referred to sophisticated systems and are often characterized by many parameters simultaneously affecting the process and by fuzziness of some of the source information. In this regard the formulation and solving of the problem of controlling the modes of operation of such chemical process systems in a fuzzy environment and improving their performance based on fuzzy control systems are currently very relevant scientific and technological tasks (Demin et al., 2016, Orazbayev et al., 2019, Gumen, 2018). To diversify and further develop Kazakhstan's economy it is necessary to increase the share of processing industries, primarily oil refining and petrochemical industry. As it is known, one of the most important processes of oil refining and petrochemical industries is the process of catalytic reforming.

The catalytic reforming process is designed to produce high quality motor fuels - high-octane motor road vehicle gasoline, household gas and raw materials for petrochemical synthesis (Orazbayev, et al., 2022). A number of papers are known on the development and improvement of modeling and control approaches for the catalytic reforming process (Gumen, 2018, Orazbayev, et al., 2022, Panchenkov, 2018, Rubekin, 2018, Zhorov, 2017, Nazarova, et al., 2020). The following is implemented in the known systems of the catalytic reforming process control: optimal temperature distribution at the inlet of reforming reactors (Rakhmetov, et al., 2022); optimization of process modes of the reforming unit operation (Bekibayev, et al., 2022), catalyst quality control in the stabilization unit of the catalytic reforming unit (Dzhambekov, et al., 2022); situational control of the reforming process (Moldasheva, et al., 2022). These and other works insufficiently study and solve the issues of modeling and optimization of the reforming process in a fuzzy environment.

The research paper (Matveykin, et al., 2019) formulates the problem of controlling the catalytic reforming process and develops the control system of the catalytic reforming process with consideration of fuzziness. Whereas this work applies the well-known Bellman-Zadeh principle to account for fuzziness of target and constraints. But various production situations arising in practice require development of other approaches and principles, which solve the problems of fuzziness more efficiently.

In this regard, the goal of this work is to set the problem of reforming process control in a fuzzy environment depending on the given production situation and available information and to develop a heuristic method for solving thereof with the involvement of human operators-technologists. In this case operators-technologists are the decision makers (DM) in the process control based on their experience, knowledge, intuitions and preferences depending on the production situation.

To achieve the formulated goal the following research tasks are solved:

– formalization and mathematical formulation of the problem of reforming process control based on reforming unit models under multicriteria and fuzziness conditions;

– development of a heuristic method for solving the formulated reforming process control problem taking into account the fuzziness constraints;

– analysis and comparison of the results of fuzzy approach and non-probability method for the solution of the reforming process control problem.

Research materials and methods. Materials for the study are experimental-statistical data and expert information on the object of research - LG-35-11/300-95 catalytic reforming unit of Atyrau oil refinery (AOR). This technological unit is designed for production of high-quality gasoline with an octane number up to 95 points as per research method and of hydrogen-containing gas (HCG) as well as for production of aromatic hydrocarbons to be used as feedstock for petrochemical synthesis (Toleuov, 2018).

The basic criteria for reforming process control are maximization of the volume of produced gasoline y_1 and HCG y_2 and improvement of gasoline quality indicators taking into account the imposed constraints. Practically these criteria (quantity and quality of gasoline) are contradictory in the area of efficient solutions. Since gasoline quality indicators - octane number ($\tilde{y}_2$); gasoline fractional composition, i.e., 10% distillation ($\tilde{y}_3$)and 50% distillation ($\tilde{y}_4$)are not directly measured, but are determined with human participation (DM), are not clearly expressed, for example, with the term «at least» ($\tilde{\geq}$).Thus, the problem of reforming process control should be formulated taking into account fuzziness and it is necessary to develop a heuristic method for its solution, which would take into account and use the experience, knowledge and intuition of the DM, his preferences when choosing any solutions.

Since the problem of controlling the modes of the research object operation is characterized by multi-criteria and fuzziness of constraints the methods of modeling, multi-criteria optimization and decision making (Orazbayev et al., 2019:, Orazbayev, et al., 2022, Nazarova, et al., 2020, Bekibayev, et al., 2022, Makhazhanova, et al., 2020, Ospanov, et al., 2016), methods of fuzzy set theories and expert evaluations (Orazbayev, et al., 2022, Dzhambekov, et al., 2022, Orazbayev, et al., 2020:, Turekulova, et al., 2022, Jovanovic, et al., 2022, Gutsykova, et al., 2017) are applied for formulation and solution of this problem in a fuzzy environment.

Results. In accordance with the goal and objectives of the study the following basic findings were obtained:

Formalization and formulation of the problem of reforming process control based on the models of the reforming unit under the conditions of multi-criteria and fuzziness.

Let $F(x)=(f_1(x), f_2(x))$ be the criteria vector evaluating the quality of the reforming unit: the yield of gasoline $f_1(x)$ and HCG $f_2(x)$; $\varphi_q(\mathbf{x}) \tilde{\geq} b_q, q=\overline{1.3}$ fuzzy restrictions imposed on the quality indicators of gasoline: on the octane number "more than $\tilde{\geq}$ 92"; fractional composition according to GOST 2177-82 - 10% distillation «no higher than $\tilde{\leq}$ 75»; and 50% distillation «no higher than $\tilde{\leq}$ 115» (Toleuov, 2018). The $\tilde{}$ sign denotes the fuzziness of the constraints.

Each of the local criteria $f_i(x), i=1,2$ and constraints $\varphi_q(\mathbf{x}), q=\overline{1.3}$ depends on the vector of input, mode (controlling) parameters $x=(x_1,x_2,x_3,x_4,x_5)$, where x_1 – feedstock flow rate; x_2,x_3 and x_4 – respectively - the volume rate, temperature and pressure in the reformer reactor P-4,4a; x_5 – H_2/feedstock ratio). Input, mode parameters used to control the reforming process have their boundary values, which are set by the technological regulations of the unit: $x_j \in \Omega \supset X, X=\left[x_j^{\min}, x_j^{\max}\right], j=\overline{1,5}$., where $x_j^{\min}, x_j^{\max}$ – lower and upper limits of $x_j, j=\overline{1,5}$. parameters variation. These limits, variation intervals might also be fuzzy ($\tilde{>}, \tilde{<}, \cong$).

A number of priorities of local criteria and a vector of importance of fuzzy constraints is considered to be set or is defined.

Under such conditions it is required to determine and select such a mode of the reforming unit operation, which provides the best value of the criteria vector under the given constraints and fuzziness of some part of the source information and with consideration the DM preference.

The formalized problem of decision-making as to control of the reforming unit operation modes under conditions of multi-criteria and fuzziness can be written in the form of the following decision-making problem:

$$\max_{\mathbf{x}\in X} f_i(\mathbf{x}), i=1,2, \quad (1)$$

$$X=\left\{\mathbf{x}\in\Omega,\ \varphi_q(\mathbf{x}) \tilde{\geq} b_q, q=\overline{1,3}\right\} \quad (2)$$

Solution to this problem is a value of control vector $\mathbf{x}^*=(x_1^*,x_2^*,x_3^*,x_4^5,x_5^*)$, which ensures such values of local criteria, which are acceptable for DM and ensure meeting the fuzzy constraints conditions.

Through applying and modifying the principles of the main criterion (MC, for criteria) and Pareto optimality (PO, for constraints) for fuzziness, in general terms for m criteria and L constraints we can obtain the following mathematical statement of the decision making problem:

$$\max_{\mathbf{x}\in X} \mu_0^1(\mathbf{x}), \quad 3)$$

$$X = \left\{ \mathbf{x} : \mathbf{x} \in \Omega \wedge \arg\left(\mu_0^i(\mathbf{x}) \geq \mu_R^i\right) \wedge \right.$$

$$\left. \wedge \arg\max_{\mathbf{x}\in\Omega} \sum_{q=1}^{L} \beta_q \mu_q(\mathbf{x}) \wedge \sum_{q=1}^{L} \beta_q = 1 \wedge \beta_q \geq 0, i = \overline{2,m}, q = \overline{1,L} \right\} \quad (4)$$

where $\wedge$ – the sign of logical «and», which requires that all statements related thereby are true; $\boldsymbol{\gamma} = (\gamma_1,...,\gamma_m)$ **and** $\boldsymbol{\beta} = (\beta_1,...,\beta_L)$ – respectively are weight vectors reflecting the mutual importance of the criteria and constraints; $\mu_q(\mathbf{x}),\ q = \overline{1,L}$ – the membership functions (MF) describing the degrees of fuzzy constraints.

2) A heuristic method for solving the decision-making problem of reforming process control taking into account the fuzziness of constraints.

To solve the problem of decision-making as to control of operation modes of a multi-criteria process with fuzzy constraints (3)-(4) a heuristic method of MC+PO is proposed, which consists of the following main steps:

the DM shall define the main criterion and introduce a number of priority of local criteria: $I = \{1,2,...,m\}$. Whereas the main criterion is assigned priority 1, the second most important criterion - 2, etc.

If criteria are described by fuzziness a T(X.У) – term set is defined for them and membership functions are built up.

The term set describing fuzzy constraints is defined.

Membership functions are built up that estimate the degree of observing the fuzzy constraints. $\mu_q(\mathbf{x}), q = \overline{1,L}.$

DM introduces the value of the weight vector of constraints $\boldsymbol{\beta} = (\beta_1,...,\beta_L)$, which takes into account the importance of local constraints.

The task of criterion maximization with consideration of the imposed fuzzy constraints is solved. Current solutions are determined: the value of the control vector $\mathbf{x}(\mu_K^i, \boldsymbol{\beta})$, providing the current values of the $\mu_0^1(\mathbf{x}(\boldsymbol{\beta}))$, main criterion, values of other criteria to be taken into account as constraints $\mu_0^i(\mathbf{x}(\mu_R^i, \boldsymbol{\beta})),\ i = \overline{2,m}$ and the degree of observation of fuzzy constraints $\mu_q(\mathbf{x}), q = \overline{1,L}.$

The solution is presented to DM. If the current results are not acceptable to DM, the $\boldsymbol{\beta}$ vector values and/or boundary values of local criteria are corrected by him, then return to paragraph 2 is carried out in order to improve the solution. Otherwise go to paragraph 8.

Searching for a solution is stopped, results of DM's final choice are displayed: values of control vector $\mathbf{x}^*(\boldsymbol{\beta})$; which provides maximum value of main criterion $\mu_0^1(\mathbf{x}^*(\boldsymbol{\beta}))$

, fulfillment of conditions of local criteria $\mu_0^i(\mathbf{x}^*(\mu_R^i,\boldsymbol{\beta})), i=\overline{2,m}$ and maximum degrees of observing the constraints $\mu_1(\mathbf{x}^*(\boldsymbol{\beta})),...,\mu_3(\mathbf{x}^*(\boldsymbol{\beta}))$. To make decision making problem on reforming process control in fuzzy environment more specific and convenient we accept the following assumptions and designations.

Let $f_1(\mathbf{x}))=\mu_0^1(\mathbf{x})$ – be the normalized main criterion, i.e., the volume of produced gasoline (catalyst). Suppose that membership function $\varphi_q(\mathbf{x})\tilde{\geq} b_q, q=\overline{1,3}$ of observing a fuzzy constraint was built up for each fuzzy constraint describing the qualitative parameters of gasoline $\mu_q(\mathbf{x}), q=\overline{1,3}$. We consider that either a priority row for the constraints $I_R=\{1,2,3\}$, or a weight vector reflecting the mutual importance of the constraints $\boldsymbol{\beta}=(\beta_1,\beta_2,\beta_3)$ are known. As it has been already noted the criterion and constraints depend on the parameters $x_i, j=\overline{1,5}$. These dependencies describe the mathematical models of the reforming reactor obtained in the research paper (Orazbayev, et al., 2022).

By modifying the MC and PO principles under the conditions of one criterion and several fuzzy constraints we can write down the following mathematical statement of the reforming process control problem in the form of a decision-making problem with fuzzy constraints:

$$\max_{\mathbf{x}\in X}\mu_0^1(\mathbf{x}), \tag{5}$$

$$X=\left\{\mathbf{x}:\mathbf{x}\in\Omega\wedge\arg\max_{\mathbf{x}\in\Omega}\sum_{q=1}^{3}\beta_q\mu_q(\mathbf{x})\wedge\sum_{q=1}^{3}\beta_q=1\wedge\beta_q\geq 0, q=\overline{1,3}\right\}. \tag{6}$$

In the obtained problem (5)–(6), since there is no special requirement for the HCG output in production, the second criterion is neglected in order to simplify the problem.

To solve the given specific problem of decision-making on controlling the operation modes of the reforming unit (5)–(6) we modify and apply the above proposed heuristic MC+PO method based on involvement of the DM, i.e. his knowledge and experience when choosing a solution.

The main stages of solving the problem (5)–(6) by applying the heuristic MC+PO method:

1. Since there is one criterion under consideration, there is no need to define the main criterion, a number of criteria and to assign boundary criteria for local criteria except for the main criterion.

2. In the given task the $\mu_0^1(\mathbf{x})$ criterion is clear, that is why T(X.У) – term set for it is not defined and membership function is not built up.

3. The term set is defined, which describes fuzzy constraints. By involving DM, experts to describe fuzzy constraints the term set is defined: from terms «less», «more» (for octane number) and «lower» and «not higher» (for fractional composition), and also their derivatives which are received by means of various modifiers can be used.

4. The membership functions for observing the fuzzy constraints $\mu_q(\mathbf{x}), q=1,3$ are built up. On the basis of research results the following membership functions for observing the constraints are built up: $\mu_1(\mathbf{x})=\exp\left(82.0\,|\,y_2-95\,|^{0.78}\right)$; $\mu_2(\mathbf{x})=\exp\left(72.0\,|\,y_3-70\,|^{0.85}\right)$; $\mu_3(\mathbf{x})=\exp\left(110.0\,|\,y_4-115\,|^{0.50}\right)$

where y_2, y_3, y_4 – are numerical values of fuzzy indicators of catalyst quality obtained on the basis of =1 level set;

82.0, 72.0, 110.0 – parameters, which are determined at identification and determine the fuzziness level at =0.5;

95, 70, 115 – parameters that determine the fuzzy variable that corresponds to the selected term the most, for which the membership function takes the maximum value;

0.78, 0.85, 0.50 – coefficients for changing the area of definition of terms and the shape of the graph of the membership function of fuzzy parameters.

5. DM has introduced values of weight coefficients of $\boldsymbol{\beta} = (\beta_1, \beta_2, \beta_3)$, vector constraints, which takes into account the importance of local constraints. In the process of solving the given task at the 5th cycle the DM has introduced the following final values $\beta = 0.6, \beta = 0.2, \beta = 0.2$, ie $\boldsymbol{\beta} = (0.6, 0.2, 0.2)$.

6. The problem of criterion maximization is solved, i.e. the problem of catalyst yield max $\mu_0(x)$ taking into account the imposed fuzzy constraints. The current solutions are determined: $\mathbf{x}(\boldsymbol{\beta})$; $\mu_0^1(\mathbf{x}(\boldsymbol{\beta}))$ and $\mu_1(\mathbf{x}(\boldsymbol{\beta}))$, $\mu_2(\mathbf{x}(\boldsymbol{\beta}))$, $\mu_3(\mathbf{x}(\boldsymbol{\beta}))$.

7. The solution is presented to DM. If the current results are not acceptable to DM, the $\boldsymbol{\beta} = (\beta_1, \beta_2, \beta_3)$ vector values are corrected by him and the return to step 2 is carried out to improve the current solutions. Otherwise, go to step 8.

8. The search for solution is stopped, the results of final DM's choice are displayed: values of the control vector $\mathbf{x}^*(\boldsymbol{\beta})$; $\mu_0^1(\mathbf{x}^*(\boldsymbol{\beta}))$ criterion value and the degree of constraint observation $\mu_1(\mathbf{x}^*(\boldsymbol{\beta}))$, $\mu_2(\mathbf{x}^*(\boldsymbol{\beta}))$, $\mu_3(\mathbf{x}^*(\boldsymbol{\beta}))$. The obtained best solutions acceptable to DM after the 5th cycle of problem solving are recorded in Table 1 (see Table 1).

3. Analysis and comparison of results of fuzzy approach and non-probability method of solving the problem of reforming process control.

The final, best results of solving the given specific decision-making problem of modes control acceptable to the DM obtained on the basis of the heuristic method, the results obtained on the basis of the non-probability approach and the real data obtained from the production under these conditions are provided in Table 1 for the purpose of comparison.

Table 1 - Comparison of the results of solving problem (5)-(6) based on the proposed heuristic method, non-probability solution method (Zhorov, 2017) and real production data

Criteria and constraints	Non-probability method	Proposed heuristic method (MC+PO)	Real data (AOR)
Gasoline yield – criterion $y_1 = f_1(\mathbf{x})$, m³/hour	77.0	79.0	78.5
Gasoline octane number, $\tilde{y}_2 = \varphi_1(\mathbf{x})$	85	86,5	(86)^л
Fractional composition of catalyst; 10% distillation, °C, $\tilde{y}_3 = \varphi_2(\mathbf{x})$;	70	70	(70)^л
50% distillation, °C, $\tilde{y}_4 = \varphi_3(\mathbf{x})$.	115	114	(114)^л
Membership function of observing fuzzy constraint 1, $\mu_1(\mathbf{x}^*(\boldsymbol{\beta}))$	-	1.0	-
Membership function of observing fuzzy constraint 2, $\mu_2(\mathbf{x}^*(\boldsymbol{\beta}))$	-	1.0	-
Membership function of observing fuzzy constraint 3, $\mu_3(\mathbf{x}^*(\boldsymbol{\beta}))$	-	0.98	-

Optimal values of input, mode-based parameters $\mathbf{x}^* = (x_1^*, x_2^*, x_3^*, x_4^*, x_5^*)$: x_1^* – feeding rate of raw materials, m³/hour;	80	80	80
x_2^* – volumetric velocity in reactors, hour^{-1};	1.7	1.3	1.5
x_3^* – temperature in reactors P-4,4a, °C;	500	493	495
x_4^* – pressure in reactors P-4,4a, kg/cm²;	26	25	25
x_5^* – hydrogen/hydrocarbons ratio	415	400	400

Note: MF – membership function; ()[1] means that the corresponding qualitative indicators are not measured directly, they are determined by a laboratory method with human participation; (-) means the corresponding indicators are not determined by this method. The time for finding a solution in the compared methods is almost the same: about one minute taking into account the time of entering or correcting the required data.

Discussion. In the formulated decision-making problem, the fuzzy constraints $\varphi_q(\mathbf{x}) \tilde{\geq} b_q, q = \overline{1,3}$ allow to take into account the qualities of gasoline (octane number and fractional composition) in the process of maximizing the volume of gasoline produced. In case of fuzziness of criteria or weight coefficients for them it is necessary to define a term set and build membership functions that allow to take into account fuzziness thereof. In the proposed formulation of the control problem (5)-(6) in form of a decision-making problem the criterion is presented in normalized form. This allows to ensure convenience of applying fuzzy sets methods, since the criterion as well as membership functions take value in the range of [0, 1]. The criterion value is determined on the basis of mathematical models of the reforming reactor, which models are built up with consideration of the fuzziness of the source information (Orazbayev, et al., 2022).

As a result of the analysis of the results shown in Table 1 the following can be noted:

– the proposed heuristic method is more efficient in comparison with the non-probability method;

– when solving the control problem on the basis of the proposed method the adequacy of solving the operational problem increases, because additional qualitative information (experience, knowledge of the DM, experts) is taken into account, which describes the real situation more fully without idealization.

– the proposed and applied heuristic method allows to determine and take into account the degrees of observing the fuzzy constraints.

The proposed heuristic method based on modification of the main criterion and Pareto optimality principles is applied more efficiently in case of possibility to determine the main criterion and to apply Pareto optimality principle (number of objects in the range of 7±2). In other situations it is recommended to set and solve the problem on the basis of other principles of optimality, which are more suitable for the current production situation.

Conclusion. The task of reforming process control under the conditions of fuzziness of some part of source information has been formulated as a problem of decision-making in a fuzzy environment. In order to solve the formulated problem of control under the conditions of multi-criteria and fuzziness on the basis of modification of the main criterion and Pareto optimality principles the heuristic method has been developed. The developed heuristic method is based on involving DM, i.e. applying his knowledge, experience and intuition in the decision making process as to reforming process control.

As a result of the conducted research the following main results were obtained:

the mathematical formulation of the problem of reforming process control based on reforming unit models under multi-criteria and fuzziness conditions was worked out and obtained;

a heuristic method has been developed for solving the decision-making problem as to reforming process control taking into account fuzziness of constraints;

the analysis and comparison of the results of the proposed fuzzy approach and non-probability method for solving the reforming process control problem have been carried out; the efficiency of the proposed heuristic method for solving fuzzy production problems has been shown.

The novelty and advantage of the proposed fuzzy approach to solving the problem of control in fuzzy environment lies in setting and solving the problem in fuzzy environment without replacing the original problem with clear equivalents. As a result of full application of the original, collected fuzzy information the adequacy of solving production problems in fuzzy environment is significantly increased.

To a disadvantage or limitation of the proposed heuristic approach to solving the problems of decision-making we may refer the need to involve DM, experts in the process of collecting, processing of source fuzzy information. But this problem is easily solved when there are experienced DM, subject matter experts involved, which is often the practical case at many operating facilities.

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Information about authors:

Batyrbai Bidaibekovich Orazbayev – Professor of the Department of System Analysis and Control, Gumilyov Eurasian National University, Doctor of Technical Sciences, Professor, Republic of Kazakhstan, Nur-Sultan city, st. Pushkin, 11, tel: +77017819639, e-mail: batyr_o@mail.ru, ORCID: https://orcid.org/0000–0003–2109–6999;

Madyar Daniyarovich Kabibullin – Doctoral student of the Department of System Analysis and Control of the Gumilyov Eurasian National University, Republic of Kazakhstan, Nur-Sultan city, st. Pushkin, 11, tel: +77077351057, e-mail: madyar_kabibullin@mail.ru , ORCID https://orcid.org/0000-0002-3972-7894;

Karlygash Tanbayevna Bissembayeva – Associate Professor of the Department of Oil-chemical engineering of Caspian University of Technology and Engineering named after Sh. Yessenov, Republic of Kazakhstan, Aktau city, 32 micro district, tel.:

+77013666072, ,e-mail: karlygasha_bissemb74@mail.ru, ORCID 0000-0002-8213-7128;

Gulzhan Sanalbayevna Sabyrbayeva – Associate Professor of the Department of Oil-chemical engineering of Caspian University of Technology and Engineering named after Sh. Yessenov, Republic of Kazakhstan, Aktau city, 32 micro district, tel.: +77015666218, e-mail: gulzhans-a@mail.ru@mail.ru, ORCID 0000-0001-7998-6711;

Aiman Jadgereevna Mailybayeva – Associate Professor of the Department of Informatics of the Atyrau University named after Kh. Dosmukhamedov, Candidate of Physical and Mathematical Sciences, Republic of Kazakhstan, Atyrau city, Studenchesky Ave., 1, tel.: +77789330801, e-mail: mjkka@mail.ru, ORCID: https://orcid.org/0000-0003-0598-4806.

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