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ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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КАЗАХСТАН
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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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REFORMING UNIT OPERATION CONTROL IN OIL AND GAS REFINING TECHNOLOGY

Abstract. The study and solution of breakdowns that arise in the decision-making process to control the operating modes of complex, fuzzy chemical-technological systems, such as a reformer, based on their models, is currently one of the topical issues of science and practice. To develop mathematical models of such systems characterized by a lack and fuzziness of the initial information and to solve decision-making problems in the process of controlling their operation modes, it becomes necessary to apply a systematic approach that allows the complex use of statistical methods, expert assessments and methods of fuzzy set theory. In this paper, on the example of a reforming unit of a catalytic reforming unit, the actual problems of complex systems characterized by a deficit and fuzzy initial information are investigated and effective methods for solving them are proposed. On the basis of a systematic approach, a technique for developing mathematical models of complex technological systems characterized by a lack of quantitative information and the fuzziness of available information is proposed. The proposed method allows solving the problems of synthesizing complex object models under conditions of uncertainty using available data and information of various nature.

A block diagram of the decision-making process has been created and described. A mathematical statement of the problem of choosing an effective operating mode of the reforming unit in a fuzzy information environment is formalized and obtained in the form of a problem of fuzzy mathematical programming. Based on the methodology of system analysis, a new, effective method for developing models of objects characterized by a lack of quantitative data and fuzzy initial information is proposed, using the available information of a different nature. The formulation of the decision-making problem under conditions of fuzziness and the heuristic approach to its solution are based on the modification of the combination of the principles of optimality of the main criterion and maximin.

Key words: reforming unit, mathematical model, system approach, decision making, fuzzy information, chemical-technological system, heuristic method.

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ГАЗ, МҰНАЙ ӨҢДЕУ ТЕХНОЛОГИЯЛАРЫНДА РИФОРМИНГ БЛОГЫ ЖҰМЫС РЕЖИМДЕРІН БАСҚАРУ

Аннотация. Риформинг блогы сияқты күрделі, айқынсыздықпен сипатталатын химиялық-технологиялық жүйелердің жұмыс режимдерін, олардың модельдері негізінде басқару үшін шешім қабылдау процесінде туындайтын мәселелерді зерттеу және оларды шешу қазіргі уақытта ғылым мен практиканың өзекті мәселелерінің бірі. Бастапқы ақпараттың тапшылығы және айқынсыздығымен сипаталатын мұндай жүйелердің математикалық модельдерін құру және олардың жұмыс режимдерін басқару процесінде тиімді шешім қабылдау есептерін шешуде статистикалық әдістер, эксперттік бағалау және айқын емес жиындар теориялары тәсілдерін кешенді пайдалануға мүмкіндік беретін жүйелік тәсілдерді қолдану қажет болады. Бұл жұмыста каталитикалық риформинг қондырғысының риформинг блогы мысалында бастапқы ақпараттың тапшылығы және айқынсыздығымен сипатталатын күрделі жүйелердің аталған өзекті мәселелер зерттеліп, оларды тиімді шешу тәсілдемелері ұсынылады. Бастапқы сандық ақпараттың жетіспеушілігі мен қолжетімді ақпараттың айқынсыздығымен сипатталатын күрделі технологиялық жүйелердің математикалық модельдерін жүйелік тәсілдеме негізінде құру әдістемесі ұсынылған. Ұсынылған әдістеме аталған анықсыздық жағдайларында қолжетімді түрлі сипаттағы деректер мен ақпараттарды пайдалу арқылы күрделі, айқын еместікпен сипатталатын нысандардың модельдерін құру мәселелерін шешуге мүмкіндік береді.

Шешім қабылдау процесінінің құрылымдық схемасы құрылып, сипатталған. Риформинг блогының тиімді жұмыс режимін айқын емес ортада таңдау үшін шешім қабылдау есебі айқын емес математикалық программалау есебі түрінде формализацияланып, математикалық қойылымы тұжырымдалған. Бастапқы сандық ақпараттың тапшылығы және айқынсыздығымын сипатталатын күрделі жүйенің моделін құру үшін жүйелік талдау методологиясы негізінде қолжетімді түрлі ақпараттарды қолданатын жаңа әдістеме ұсынылған. Айқынсыздықта шешім қабылдау есебінің қойылымы мен оны шешу үшін құрылған эвристикалық тәсіл басты критерий және максимин оптималдық принциптерін комбинациясын айқынсыздыққа модификациялауға негізделген.

Түйін сөздер: риформинг блогы, математикалық модель, жүйелік тәсілдеме, шешім қабылдау, айқын емес ақпарат, химиялық-технологиялық жүйе, эвристикалық тәсіл.

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УПРАВЛЕНИЕ РЕЖИМАМИ РАБОТЫ БЛОКА РИФОРМИНГА В ТЕХНОЛОГИИ ПЕРЕРАБОТКИ НЕФТИ И ГАЗА

Аннотация. Изучение и решение пробоем, возникающих в процессе принятия решений для управления режимами работы сложных, нечеткоописываемых химико-технологических систем, таких как установка риформинга, на основе их моделей в настоящее время является одним из актуальных вопросов науки и практики. Для разработки математических моделей таких систем, характеризующихся дефицитом и нечеткостью исходной информации, и решения задач принятия решений в процессе управления режимами их работы возникает необходимость применения системного подхода, позволяющего комплексно использовать статистические методы, экспертные оценки и методы теории нечетких множеств. В данной работе на примере блока риформинга установки каталитического риформинга исследуются актуальные проблемы сложных систем, характеризующихся дефицитом и нечеткостью исходной информации, и предлагаются эффективные методы их решения. На основе системного подхода предложена методика разработки математических моделей сложных технологических систем, характеризующихся нехваткой количественной информации и нечеткостью доступной информации. Предлагаемая методика позволяет решать задачи синтеза моделей сложных объектов в условиях неопределенности с использованием доступных данных и информации различного характера.

Создана и описана структурная схема процесса принятия решений. Формализована и получена математическая постановка задачи выбора эффективного режима работы блока риформинга в нечеткой информационной среде в виде задачи нечеткого математического программирования. На основе методологии системного анализа предлагается новая, эффективная методика разработки моделей объектов, характеризующихся дефицитом количественных данных и нечеткостью исходной информации, использующая доступной информации различного характера. Постановка задачи принятия решений в условиях нечеткости и эвристический подход к ее решению основаны на модификации сочетания принципов оатимальности главного критерия и максимина.

Ключевые слова: блок реформинга, математическая модель, системный подход, принятия решений, нечеткая информация, химико-технологическая система, эвристический метод.

Introduction. Efficient control of the operation modes of a catalytic reforming unit like most chemical and technological systems (CTS) while satisfying the set constraints is considered to be a major and relevant issue in the refining industry (Deryugina, et al. 2020, Orazbayev, et al. 2022:1–26). In order to efficiently solve this problem, it is necessary to create a package of interrelated mathematical models, which allow the systematic simulation of the chemical and technological system. The abundance of elements of a catalytic reforming unit as a system, their relations and influence on each other, the uncertainty arising from the lack and uncertainty of initial information, and the variability of production conditions complicate the construction of the unit models. There are also difficulties in formulating and solving decision-making problems pertaining to efficient control of the reforming unit operation modes on the basis of the models being created (Orazbayev, et al. 2021:1–22).

Thus, the chemical and technological system (CTS) is characterized by scarcity and uncertainty of the initial information, such as catalytic reforming; various scientific, practical issues arise when setting and solving the problems of operation modes control based on the models. The scientific and practical significance of this research lies in the fact that the problems arising in solving the issues under consideration are studied and ways of solving them are proposed. The main issues of decision-making (DP) regarding modeling and control of operation of LG-35-11/300-95 CTS catalytic reforming unit of Atyrau oil Refinery (AOR) are considered in this paper as an example. LG-35-11/300-95 catalytic cracking unit is designed for production of high-quality automobile gasoline and hydrogen-containing gas (HCG) and raw materials necessary for petrochemical synthesis. (Pinheiro, et al. 2018).

By means of computer simulation of the reforming unit operation modes of the catalytic reforming unit it is possible to determine and control its efficient operation modes, to increase the volume of the target products produced while ensuring the required quality of the products released. In addition the process of visual mathematical modeling of the reforming unit operation applying multimedia computer capabilities, i.e. computer simulation, allows to improve the values of control criteria based on rapid determination of its efficient operation mode. Thus, computer modeling makes it possible to control the operation modes of a reforming unit by means of its mathematical models and to apply the obtained results to a specific object.

Any mathematical models should be built depending on the purpose of modeling, i.e. depending on the purpose of model application. In this regard we can point out the problem of determining the purpose of modeling as one of the problems of the development process of mathematical models of chemical and technological systems. The purpose of modeling should be determined depending on what problem the models are built to solve. For example, if modeling is used for forecasting, the requirements to the accuracy of the model will not be relatively high, and if it is used to solve a control problem, it is necessary for the models to have much higher accuracy and adequacy.

The purpose of modeling is defined in the subsequent issue, which is the issue of building the necessary model. In order to build the required model it is necessary to have the type of initial information necessary to create it, because only then the required model can be created. The next arising problem is the problem of structural and parametric identification of the required models. If the necessary amount of statistical data on the operation of the chemical and technological system is available, then the idea of serial connection of regressors (SCR) methods can be used for structural identification (Valeev 2017). And when solving parametric identification problems it is usually preferable to use the most appropriate of the known parametric identification methods, for example, the least squares method is preferred for practical application in most cases (Malev, et al. 2021). Problems arise due to the lack and uncertainty of the initial information required to create complex models of chemical and technological systems, such as reforming unit, as well as to optimize and control their operation modes. Whereas the reason for uncertainty arises basically due to the random nature of the values of measured object parameters or the uncertainty of the values of unmeasurable parameters described by the operator-technologist, decision maker (DM), experts in the natural language. It is known that methods of the theory of probability are used to solve the problems of uncertainty of measurable parameters of probabilistic nature (Sansyzbay, et al. 2020, Orazbayev, et al. 2020: 498–507). However, there are also often important parameters encountered in production, which are very difficult to measure, are economically inefficient, or cannot be measured in general. For example, parameters determined by human presence that are characterized by such uncertainty include refinery product quality indicators, environmental impacts, various constraints and requirements. Probabilistic methods are unacceptable when solving problems of uncertainty in such verbally described values of parameters, since in this case the axioms of the theory of probabilities are not fulfilled. In this case based on the methods of expert evaluation and the fuzzy sets theory apparatus the uncertainty problems can be solved by formalizing, processing and using implicit information obtained from experts (Orazbayev, et al. 2020:1–13, Sayed, et al. 2021, Sarojini, et al. 2022).

The distinctive feature of the catalytic reforming unit of AOR – LG-35-11/300-95, which has been operated for more than 70 years, is that the control process is basically carried out by the person who makes direct decisions on control thereof, i.e. DM, experienced operators. Thus, the control process of operation modes of this unit is characterized in most cases by non-formalized action of the DM's participating in the control chain. And DM's on the basis of experience, knowledge and intuition causes implicitness of some part of the initial information being transmitted in the natural language. Due to this studying and solving the problems of modeling, control of chemical and technological systems characterized by fuzziness is currently a relevant and important scientific and technical task.

Despite the significant development of mathematical approaches and computer technologies, the application of traditional methods of building models of chemical and technological systems characterized by the indicated uncertainty does not allow to achieve the expected results. In a real case scenario the objects characterized by such uncertainty are well controlled by an experienced operator, DM, who due to his experience, knowledge and intuition can successfully carry out the control process under the uncertainty of the initial information (Orazbayev, et al. 2019: 182-194). Whereas as opposed to the computer the DM uses non-obvious concepts and in the case of arising uncertainty he can efficiently control the operation modes of the chemical and technological system.

The decision-making process of reforming unit operation modes control is based on the mathematical models of the object and by the way of selecting an efficient operation mode of the unit with consideration of the intelligence and priority of the DM. In this case a specific formal and creative decision is combined, i.e. the decision is made on the basis of mathematical models, creative capabilities and human intelligence. Decision making support systems (DMSS) are developed for prompt and efficient decision making by means of a computer. The DMSS combines human and computer capabilities and iteratively implements the process of efficient decision making by the DM by applying object models. (Thomas. 2020).

The decision-making procedure pertaining to control of the catalytic reforming unit operation modes, like many chemical and technological systems, is characterized by fuzziness, and is characterized as follows:

– with the purpose of making a decision, which should be achieved in the decision-making process. In the absence of a goal the need to make a decision does not arise;

– with alternative ways to achieve the goal, because the decision is made only if there are several ways to achieve the formulated goal of decision making. In addition, each alternative to achieve the goal is characterized by a different probability of its achievement and requires different costs;

– the limiting factors subdivided into groups are economic factors (money, labor, time resources and other), technical, process factors (mode of operation of the chemical and technological system, reliability, energy consumption and other); social factors, which take moral requirements into consideration.

The problems arising in the decision-making process can be divided into conceptual and formal-mathematical ones. Conceptual problems are characterized by the complexity of formal-mathematical methods and logical form, which cannot be solved by a computer. Such problems are basically solved on the basis of experience, knowledge and intuition of experienced experts-specialists on the basis of methods of expert evaluation and heuristic methods. Besides, formal methods are used as aids that organize and facilitate the implementation of heuristic procedures by DM, and formalization of heuristic activities is performed on the basis of decision-making theories. Formal-mathematical problems are solved on the basis of formal methods of mathematics and with the help of computation tools.

The aim of this paper is to study the problems of modeling and decision-making in control of chemical and technological systems by the example of reforming unit and the development of approaches to solving thereof based on the methodology of systems analysis, methods of expert evaluation and approaches of fuzzy sets.

Research materials and methods. Methods of the theory probabilities and mathematical statistics are used to collect, process statistical data of input, mode-related and output values of reforming unit parameters in different modes of operation (Orazbayev, et al. 2020:53–65), whereas collection, design and use of fuzzy information about the state and operation of the object is performed on the basis of expert evaluation methods and mathematical apparatus of fuzzy set theories (Sayed, et al. 2021, Orazbayev, et al. 2020:1235–1241).

Construction of models of the own interrelated units of the catalytic reforming system uses hybrid model construction methods based on system analysis methodology and on application of available information of different nature (Orazbayev, et al. 2019:182–194, Pavlov, et al. 2016). Temperature, pressure, output volume of products and other process parameters of the reforming process are measured quantitatively by means of appropriate measuring instruments. If the uncertainty problem arises due to the random nature of the measured parameters, these problems can be solved using the methods of the theory of probabilities.

Some important parameters that characterize product quality, such as octane number of gasoline, its fractional composition and the proportion of other sulfur impurities in gasoline, are not directly measured under production conditions, they are determined in the presence of specialized experts and are described in uncertain terms. The quality of unit operation, requirements to quality indicators of products can be described by DM with the help of fuzzy instructions: for example "it should not be less", "it should not be more", etc. Therefore, when building mathematical models of the reforming unit it is necessary to take into account these non-obvious instructions, which evaluate the influence of input, mode-related parameters, production indicators characterized by uncertainty.

Since the decision-making process based on fuzzy sets theory approaches must take into account the uncertainty of constraints, quality indicators of the target products, the solution is found in the form of a fuzzy mathematical programming (FMP) problem, which uses heuristic approaches to solve decision-making problems (Orazbayev, et al. 2021:1–22, Valiakhmetov, et al. 2018).

Results. To solve the problems of uncertainty arising due to randomness of parameters, which are quantified by measuring instruments, or the uncertainty of available information, a methodology for building models of complex systems based on information of different nature in the process of building CTS models, such as reforming unit, has been proposed. The proposed method is based on the methodology of system analysis, approaches of probabilistic and mathematical statistics, approaches of expert evaluation and theory of fuzzy sets and allows building models of chemical and technological systems using available information of different nature.

The block diagram of the generalized and refined method of building complex models of chemical and technological systems characterized by lack and uncertainty of the initial information, is presented below in Figure 1.

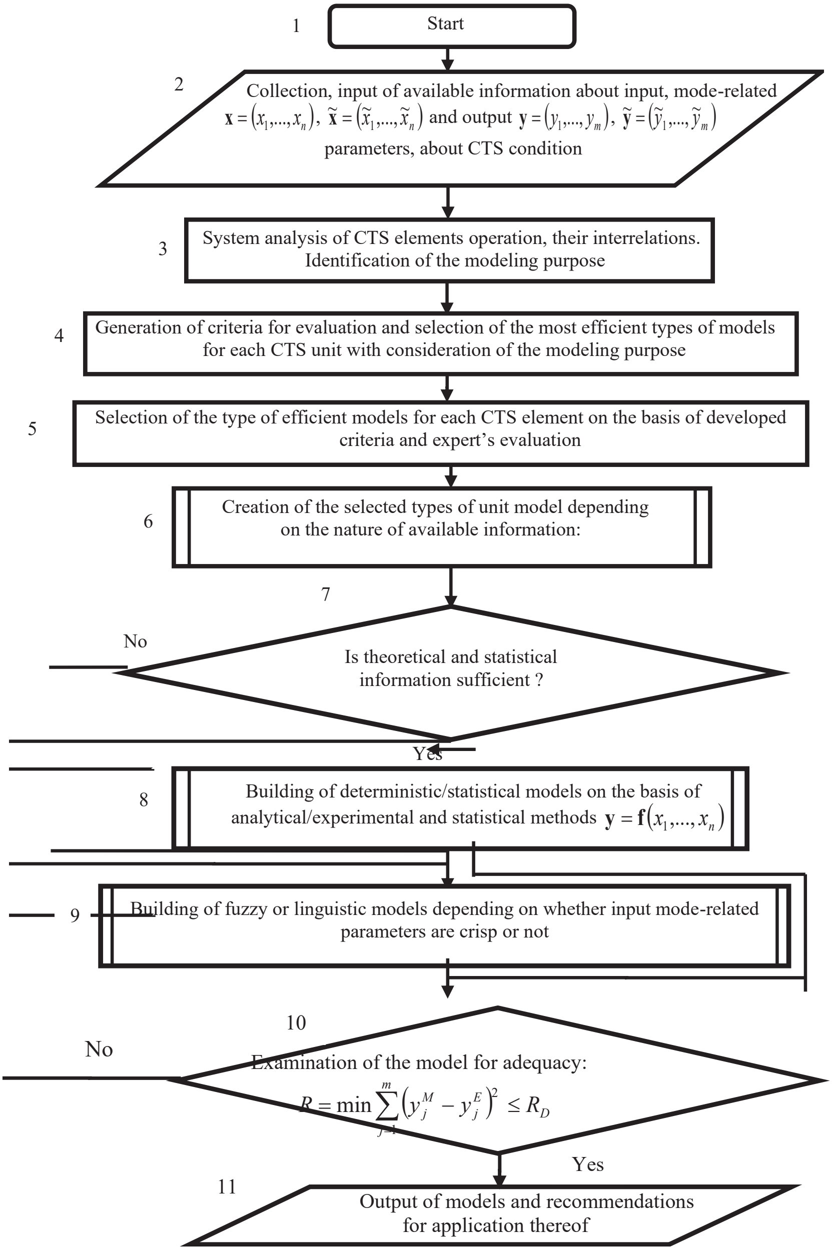

Figure 1. Block diagram of the generalized approach to the construction of complex CTS models, characterized by scarcity and uncertainty of the initial information

Let us consider the description of the basic blocks of the block diagram of the generalized approach in the figure below. In block 2 the simulated state of the chemical and technological system and the available values of its input, mode-related and corresponding output parameters are summarized and implemented. In blocks 3, 4 and 5 a systematic analysis of operation of CTS units and of the relations between them is carried out, the purpose of modeling is determined and based on expert evaluation the type of model is selected, the construction of which is appropriate for each unit depending on the purpose. From block 6 the procedure of building the aggregate selected models starts depending on the nature of the information available to the expert.

If theoretical/statistical information is sufficient to build a model, and by the value of the integrating criterion the greatest value is the construction of deterministic/statistical model of the chemical and technological system, then in block 8 the procedure of construction of deterministic/statistical model based on analytical/statistical methods is performed respectively. Then a transition to block 10 is made to check the adequacy of the model.

In cases where theoretical/statistical information is insufficient to build a model and construction of implicit/linguistic model of the CTS has the greatest value on the value of the integrating criterion, the procedure of creating an implicit/linguistic mold using methods of expert evaluation and implicit sets respectively is performed in block 9. Then the adequacy of the created models will be checked for the purpose of modeling in block 10. If the adequacy of the created model is sufficient according to the modeling goal, the model is recommended for deployment and application (block 11). And if the adequacy of the model is low at the required level, its cause will be determined, and the cycle will be repeated by returning to the appropriate block (8 or 9) in order to increase the adequacy of the model to the required level.

The procedure for creating a deterministic/statistical model in block 8 of the described block diagram is based on the deterministic/statistical model building approach. In the procedure of deterministic/statistical model construction the deterministic model of the object will be constructed on the basis of analytical approaches to construction of such model under maximum balganic conditions of this type of model according to sufficiency value of theoretical data and criterion being integrated.

If the data necessary for construction of statistical model of an object is sufficient and by criterion being integrated the statistical model has maximum value, then on the basis of experimental-statistical approaches the statistical model of object will be constructed.

In case theoretical/statistical information is insufficient for construction of the model and the greatest value by the value of the integrating criterion has the construction of fuzzy/linguistic model of the CTS, expert evaluation and fuzziness $\tilde{y}_j = \tilde{f}_j(x_1,...,x_n,\tilde{a}_0,\tilde{a}_1,...,\tilde{a}_n), j=\overline{1,m}$ $(x_i \in A_i, i=\overline{1,n}$ crisp, and $\tilde{y}_j \in \tilde{B}_j$, $j=\overline{1,m}$ if fuzzy) or linguistic models *IF* $\tilde{x}_1 \in \tilde{A}_1(\tilde{x}_2 \in \tilde{A}_2(,...,(\tilde{x}_n \in \tilde{A}_n))$, and *THEN* $\tilde{y}_j \in \tilde{B}_j, j=\overline{1,m}$ $(x_i \in A_i, i=\overline{1,n}$ if fuzzy) expert evaluation will be constructed based on fuzzy sets approaches. Whereas the structure of the implicit model can be defined based on the method of successive addition of regressors in the form of implicit regression equations:

$$\tilde{y}_j = \tilde{a}_{0j} + \sum_{i=1}^{n} a_{ij} x_{ij} + \sum_{i=1}^{n} \sum_{k=i}^{n} a_{ikj} x_{ij} x_{kj,}\ j = \overline{1,m}\,.$$

Fuzzy parametric identification after structural identification, i.e. fuzzy $\tilde{a}_{0j}, \tilde{a}_{ij}, \tilde{a}_{ikj}$, $, i = \overline{1,n}, k = \overline{i,n}, j = \overline{1,m}$ solves the problem of estimating the regression coefficients. This problem can be solved using sets of α - level by converting the implicit equation into several explicit equations, and then using least squares methods.

When constructing linguistic models, firstly, we should pay attention to the fuzzy output of the object $\tilde{y}_j \in \tilde{B}_j, j = \overline{1,m}$ the input, mode-related parameters, described fuzzy impacts $\tilde{x}_i \in \tilde{A}_i, i = \overline{1,n}$ are selected. These parameters are necessary for construction of linguistic model and are linguistic variables: $\tilde{A}_i \in X, \tilde{B}_j \in Y$ – fuzzy sets, X, Y – the universe of input and output parameters. Then with participation of DM, experts the value of □-parameters and indicators characterizing fuzzy object parameters is determined, and membership functions shall be built for each term: $\mu_{A_i}(\tilde{x}_i)$, $\mu_{B_j}(\tilde{y}_j)$.

Based on the experience of modeling technological objects of oil refining facility in a fuzzy environment we can imagine the construction of the following membership function with the adaptation coefficients:

$$\mu_{B_j}^{p}(\tilde{y}_j) = \exp(Q_{B_j}^{p} \left| (y_j - y_{mdj})^{N_{B_j}^{p}} \right|),$$

here $\mu_{B_j}^{p}(\tilde{y}_j)$ -is the membership function describing the fuzzy output parameters of the object; p -is the quantum number; $Q_{B_j}^{p}$ - is the adaptive coefficient defining the uncertainty level determined when determining the membership function; $N_{B_j}^{p}$ are the adaptive coefficients defining the domain of the membership function of implicit parameters and allowing to change the shape of the membership function; y_{mdj}^{p} p is the implicit variable corresponding to a given term in the quantum. This variable is defined from the following condition $\mu_{B_j}(y_{mdj}^{p}) = \max_j \mu_{B_j}(y_j)$

After that the relations between the input $\tilde{x}_i$ and $\tilde{y}_j$ output linguistic variables are defined, i.e. $\tilde{R}_{ij}$ a fuzzy image is created. To make the use of the fuzzy representation acceptable, a matrix of relations with the membership functions is defined in the course of computation:

$$\mu_{R_{ij}}(\tilde{x}_i, \tilde{y}_j) = \min\left\lfloor \mu_{A_i}(\tilde{x}_i), \mu_{B_j}(\tilde{y}_j), i = \overline{1,n}, j = \overline{1,m} \right\rfloor$$

The overall structure of the linguistic model based on the generalization rules of the logical condition, can be written as follows:

$$IF\ \tilde{x}_1 \in \tilde{A}_1(\tilde{x}_2 \in \tilde{A}_2(,\ldots,(\tilde{x}_n \in \tilde{A}_n)),\ THEN\ \ \tilde{y}_j \in \tilde{B}_j,\ j = \overline{1,m}$$

On the basis of the compositional conclusion rule $\tilde{B}_j = \tilde{A}_i \circ \tilde{R}_{ij}$ the fuzzy values of the output parameters of the investigated CTS are determined, afterwards the numerical values of the output parameters can be determined from the implicit solutions. In addition by means of the compositional conclusion rule the output parameters determining the quality of the object operation, such as the maximum output volume or quality, are determined. Whereas $\widetilde{x}_i^*$ – represents the fuzzy values of the input parameters of the object estimated by the experts. In this case the set of current values of input parameters is defined as a fuzzy set, in which the membership functions of the input parameters are the highest, as follows: $\mu_{A_i}(\widetilde{x}) = \max(\mu_{A_i}(\widetilde{x}_i^*))$.

Then implicit values of the output variables are defined as the membership functions representing the largest set:

$$\mu_{B_j}(\widetilde{y}_j^*) = \max\{\min_{x_i \in X_i}[\mu_{A_i}(\widetilde{x}_i^*), \mu_{R_{ij}}((x_i^*, \widetilde{y}_j)]\} \cdot$$

The quantitative values of the output parameters can be determined using the following expression: $y_j^c = \arg\max_{\widetilde{y}_j^*} \mu_{B_j}(\widetilde{y}_j^*)$, that is, the values of the output parameters whose membership functions reach the maximum value, are selected.

If both theoretical and statistical data describing the operation of the CTS and fuzzy information are insufficient or their collection is economically inefficient or impossible, and the integrated criterion according under the hybrid model has a maximum value, a hybrid model will be built using the hybrid approach [Orazbayev, et al. 2019:182−194]. In this case the hybrid (composite) model is developed on the basis of available (theoretical, statistical, expert fuzzy information) of different nature.

The adequacy of the models can be tested under the following conditions:

$$R = \min \sum_{j=1}^{w} (y_j^M - y_j^E)^2 \le R_D,$$

here y_j^M calculated values of output parameters obtained by means of the model; y_j^E – experimental values of output parameters of the object; R_D – y_j^M and y_j^E are the permissible value of deviation of values. If the condition of adequacy is met, then it is recommended to model the model and determine the optimal operation modes of the object, i.e., the reforming unit. Otherwise, the causes of model inadequacy will be identified, and model building cycles will be repeated to eliminate them and improve model adequacy to the required level.

Let us describe the process of decision-making on the basis of their models during control of operation modes of chemical technological system and mathematical statement of the decision-making problem in a fuzzy environment and the way of solving it.

In a fuzzy environment, for example, when the constraints are not obvious, let us formalize and give a mathematical formulation of the decision-making problem for choosing the optimal mode of operation of reforming reactors and let us consider a heuristic approach to its solution.

LG-35-11/300-95 from the reforming unit of the unit produces a catalyst with a higher octane number, i.e., high-quality automotive gasoline, as the target product. In addition, technical hydrogen, which is valuable for petrochemical synthesis, is produced from the reforming unit. The choice of the optimal operating mode of the reforming reactors assumes an increase in the volume of products produced as criteria, i.e. values 1y and 2y, as well as an improvement in the quality indicators of the target product, meeting the requirements of the various imposed constraints. These criteria such as volume and quality of gasoline in the aggregate of efficient solutions in practical application are in conflict.

Quality indicators of gasoline produced in reforming reactors, namely its octane number – $\widetilde{y}_1$, fractional composition of gasoline, i.e. 10% distillation – $\widetilde{y}_2$, 50% distillation – $\widetilde{y}_3$ are not measured directly, they are characterized by uncertainty in the presence of a person, DM, for example by means of terms such as "not less" ($\widetilde{\geq}$), "approximately" ($\approxeq$) or "not more" ($\widetilde{\leq}$).For these reasons the decision-making calculation for selecting the optimal mode of operation of reforming reactors should be formulated with uncertainty in mind, and it is advisable to use a heuristic approach to solve it in an implicit environment. In this case, the dependencies of the criteria and constraints in the implicit form, the indications are determined by the object models built on the basis of the methodology for building models of CTS in a deficit and uncertainty of the input information provided above. $F(\mathbf{x})=(f_1(\mathbf{x}), f_2(\mathbf{x}))$ vector of criteria, on which the reforming reactors assess the quality of performance, that is, the volume of gasoline and technical hydrogen, and $\varphi_q(\mathbf{x}) \gtrsim b_q, q=\overline{1.3}$ – fuzzy restrictions on quality indicators of gasoline: 92 octane number "not less", and fractional composition, that is – 10% distillation "not more than 75$\lesssim$», 50% distillation will be "not less than 115$\widetilde{\leq}$». The $\sim$ sign means the uncertainty of the restrictions.

The given criteria and values of implicit restrictions depend on the vector of input, mode-related parameters used to control the reforming process $x=(x_1,x_2,x_3,x_4,x_5)$ varies, here x_1– the volume of the feedstock at the reforming; x_2,x_3 и x_4– reactor inlet, R-4, R-4a is volume rate, temperature and pressure in the reforming reactor, a x_5– H_2/ ratio of the feedstock. These parameters in the limiting values defined by the technological regulations of the unit: $x_j \in \Omega \supset X, X=\left[x_j^{min}, x_j^{max}\right], j=1{,}5,$ varies, x_j^{min}, x_j^{max} – the minimum and maximum values of variation of the specified parameter. The intervals of change of these limits can also be fuzzy.

Thus, the optimal value of the criteria vector, which ensures the fulfillment of the specified constraints, should be determined and the efficient mode of operation of reforming reactors should be selected under conditions of uncertainty of some initial information and taking into account the priorities of the DM. In case of uncertainty and ambiguity the refined optimization report can be written as the following decision making report:

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

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

(1)-(2) solution of the problem of making the implicit bounded decision, which meets all conditions of implicit constraints and provides maximum values of local criteria and satisfies the DM $x^*=(x_1^*, x_2^*, x_3^*, x_4^*, x_5^*)$

Now, to get the correct mathematical statement of the above problem based on the approaches of fuzzy sets theory, we introduce the following notations: $\mu_0(\mathbf{x})=(\mu_1(\mathbf{x}),\mu_2(\mathbf{x}))$ – $f_i(\mathbf{x}), i=1,2$ vector of local criteria evaluating the volume of gasoline and hydrogen produced, whose value is normalized in the interval [0, 1], and $\mu_q(\mathbf{x}), q=\overline{1,3}$ – gasoline quality indicators characterized by the expression $\varphi_1(\mathbf{x}) \gtrsim b_1$ $\varphi_q(\mathbf{x}) \gtrsim b_q, q=2,3$ let the membership function evaluate the fulfillment. A row of priorities for local criteria and constraints $I_C=\{1,2\}$ and $I_R=\{1,2,3\}$ suppose that it is known or is determined or it determines the mutual significance of criteria and constraints: $\boldsymbol{\gamma}=(\gamma_1,\gamma_2)$ and $\boldsymbol{\beta}=(\beta_1,\beta_2,\beta_3)$. – let the vectors of weights be given.

Then for main criteria (MC) we can write the problem (1)-(2) in the form of the following problem using the Maximin Optimality Principle (MM) and modifying the MM principle to fuzziness:

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

$$X=\left\{\mathbf{x}:\mathbf{x}\in\Omega \wedge \arg\left(\mu_0^2(\mathbf{x}) \geq \mu_R^2\right) \wedge \arg\left(\max_{\mathbf{x}\in\Omega}\min_{q\in L}\left(\beta_q\mu_q(\mathbf{x})\right)\right), q=\overline{1,3}, L=(1,2,3)\right\} \tag{4}$$

here $\mu_0^1(\mathbf{x})$– the target product chosen by the DM, i.e. the main criterion for assessing the volume of gasoline; $\wedge$ – the logical “and” sign, it requires that all statements associated with it are true; μ_R^2 – the DM, experts determining the $\mu_0^1(\mathbf{x})$ limiting value of the local criterion, it represents the limiting value of technical hydrogen as a constraint. The fulfillment of the limiting requirements is ensured on the basis of the guaranteeing principle of the maxim.

(3)-(4) when solving the problem of choosing an efficient mode of operation of reforming reactors under uncertainty in the representation of the limiting value 2 of the criterion μ_R^2 and / or limiting vector of limiting weight coefficients $\boldsymbol{\beta}=(\beta_1,\beta_2,\beta_3)$, by changing we can get different solutions to the problem $-\mathbf{x}(\mu_R^2,\boldsymbol{\beta})$. From the resulting set of solutions the best decision is taken by DM through dialogue depending on his priority and the prevailing production, market situation. To solve the problem of decision-making in the mathematically formulated environment (3) – (4) we provide the main steps of the proposed heuristic approach developed on the basis of MC and MM principles.

MC+MM heuristic method.

1) Experts compute numbers of steps by coordinate of each q- restriction $p_q, q=\overline{1,3}$ and row of priorities for local criterion $I_C=\{1,2\}$, here 1 is the main criterion $\mu_0^1(\mathbf{x})$ priority, definition.

2) Determination of the vector value of weighting coefficients, at which the experts evaluate the mutual importance of the constraints by means of evaluation: $\boldsymbol{\beta}=(\beta_1,\beta_2,\beta_3)$.

3) Assigning the limiting value of the local criterion to be considered as DM constraints.

4) determined at step 1 to change the coordinates of the $\boldsymbol{\beta}$ weight vector, $p_q, q=\overline{1,3}$ calculation of the step value using the following formula $h_q = \frac{1}{p_q}, q=\overline{1,3}$

5) in the section [0,1] using the step h_q $p_q, q=\overline{1,3}$ creating a set of weight vectors of constraints with the change of their coordinates $\boldsymbol{\beta}^1, \boldsymbol{\beta}^2, ..., \boldsymbol{\beta}^N$, here $N=(p_1+1)\cdot(p_2+1)\cdot(p_3+1)$.

6) Choosing the term-menu T(X,У), which characterize the fuzzy parameters and indicators of the object.

7) Creating the membership functions that estimate the degree of their fulfillment for the uncertain constraints $\mu_q(\mathbf{x}), q=\overline{1,3}$. These membership functions are recommended to build from the Fuzzy Logic Toolbox application by selecting Gaussian-type functions or using the formula with the adjustment coefficients in the structure (1).

8) Determine the current solution by solving the maximization problem of the main criterion in the set (5) of allowed solutions X, to be defined by the maximin principle $\mathbf{x}(\mu_R^2, \boldsymbol{\beta})$. Determined solutions $\mathbf{x}(\mu_R^2, \boldsymbol{\beta})$ of local criterion embedded in the constraints $\mu_0^2(\mathbf{x}(\mu_R^2, \boldsymbol{\beta}))$ of the limit value (μ_R^2) and fulfilment of fuzzy constraints must provide the maximum values of membership functions characterizing them $\mu_1(\mathbf{x}(\mu_R^2, \boldsymbol{\beta})), \mu_2(\mathbf{x}(\mu_R^2, \boldsymbol{\beta}))$, $\mu_3(\mathbf{x}(\mu_R^2, \boldsymbol{\beta}))$.

9. The current solutions obtained will be offered to select the best solution. If the current results do not satisfy the DM he proceeds to step 5 in order to improve the results by changing the threshold value of the local criteria to be considered as constraints, i.e. μ_R^2 values of weight coefficients of constraints and/or restrictions $\boldsymbol{\beta}=(\beta_1, \beta_2, \beta_3)$. Otherwise, i.e., when the specialist is satisfied with the current solutions, he chooses the final solution that will be efficient depending on his priority and the given situation. We proceed to the next step to derive the efficient solutions adopted.

10. Output of the best solutions chosen by the specialist, namely the maximum value of the main criterion $\mu_0^1(\mathbf{x}^*(\mu_R^2, \boldsymbol{\beta}))$, the value of the local criterion not less than the limit criterion μ_R^2 $\mu_0^2(\mathbf{x}^*(\mu_R^2, \boldsymbol{\beta}))$ and the maximum membership function of the fuzzy constraint fulfillment $\mu_1(\mathbf{x}^*(\mu_R^2, \boldsymbol{\beta})), \mu_2(\mathbf{x}^*(\mu_R^2, \boldsymbol{\beta}))$, $\mu_3(\mathbf{x}^*(\mu_R^2, \boldsymbol{\beta}))$ the control vector (input, mode-related parameters) $\mathbf{x}^*(\mu_R^2, \boldsymbol{\beta})$,

Discussion. The proposed methodology for building complex CTS models characterized by the absence and uncertainty of initial information is based on application of systems analysis methodology and application of available information of different nature. The methodology based on analytical methods, methods of mathematical statistics, expert assessments and the apparatus of the theory of fuzzy sets allows to build models of different types of CTS elements on the basis of theoretical data, experimental-statistical data and expert, fuzzy information. In the course of applying the methodology the question may arise as to how models of different types can be integrated into a unified system of models for system simulation of chemical and technological systems. To solve this problem it is proposed to unify the input and output data of different types of models and relate them to each other on the basis of the processes occurring in the chemical and technological system.

Decision-making report on selection of the optimal mode of operation of the CTS in a fuzzy environment of the Atyrau Oil Refinery LG-35-11/300-95 unit is formulated within the example of the problem of selecting the efficient operation mode of the reforming unit. To solve the formulated decision-making problem a heuristic method based on the main criterion and modification of principles of maximin optimality in fuzziness was developed and described. Here we can find other optimality principles related to occurring situations and to available information, such as Pareto optimality principle, ideal point, equality, etc., and note that their combinations can be used. The proposed heuristic MC+MM method for determining the efficient operation mode of a reforming unit can be easily extended and applied to chemical and technological systems characterized by other m criteria and L constraints.

The proposed heuristic method of solving the decision-making problem on the choice of an efficient operation mode of the controlled object is iterative and based on the use of creativity and intelligence of the person (DM) and the speed and capabilities of the computer in the decision-making process.

To efficiently perform the last 10 steps of the MC+MM heuristic scheme proposed for solving the decision-making problem one can organize an additional dialog procedure that allows you to determine their impact on the criteria by changing the parameters and to find the optimal solution.

Conclusion. The paper studies the problems of decision making on their modeling and control in the process of CTS control characterized by complexity, fuzziness. With the example of a reforming unit the problem of optimization of the CTS operation modes characterized by the deficit and fuzziness of the initial information has been formulated and the heuristic method for solution of the posed problem on the basis of modification of various optimal principles has been offered. To solve the problem of fuzziness in decision-making processes as to construction of complex mathematical models of CTS characterized by fuzziness and as to the choice of an efficient operation mode in control thereof, the methodology of systems analysis, approaches to theory of probabilities and expert evaluation, the mathematical apparatus of the theory of fuzzy sets are used.

As a result of the research carried out in accordance with the purpose of the study, the following results were obtained by this paper:

– On the basis of the system approach the methodology of building complex CTS models characterized by fuzziness allowing the use available information of different nature is proposed;

– With the example of reforming unit the mathematical statement of the decision-making as to the choice of the efficient operation of CTS in a fuzzy environment has been formulated in the form of the fuzzy mathematical programming problem;

–The heuristic method has been proposed for solving the decision-making problem formulated on the basis of modification of the main criterion for operation under the condition of fuzziness and on the basis of the principles of maximin optimality.

The novelty of the proposed methodology for the construction of CTS models characterized by complexity, fuzziness under the conditions of deficit of quantitative information is the integrated application of the methodology of system analysis and various approaches to model building and application of available information of different nature [Sansyzbay, et al. 2020, Pinheiro, et al. 2018, Sarojini, et al. 2022] and known methods for solving fuzzy problems considered in other papers, based on their transformation into a system of explicit problems using sets of α levels and then solving in the known ways. This approach leads to loss of some of the collected non-obvious information and, accordingly, reduces the adequacy of the solution. The advantage of the proposed heuristic scheme of solving a decision-making problem in an implicit environment and its difference from the mentioned known approaches is that in the presented implicit approach the implicit problem is set as implicit and is solved heuristically on the basis of experience, knowledge, intelligence of the DM. That is, as a result of the complete application of fuzzy information fixed in the proposed method the adequacy and efficiency of the decision made under the condition of fuzziness is increased.

The practical value of the research lies in providing the possibility of building efficient models under conditions of scarcity and fuzziness of source information and in providing sufficiently adequate and efficient decisions as to the choice of an efficient operation mode of the chemical and technological system in a fuzzy environment.

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