ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

№5
2025

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

5 (473)

SEPTEMBER – OCTOBER 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2025

«Central Asian Academic Research Center» LLP 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.

«Орталық Азия академиялық ғылыми орталығы» ЖШС «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. Web of 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.

ТОО «Центрально-азиатский академический научный центр» 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.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*
Мерзімділігі: жылына 6 рет.
http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.
Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*
Периодичность: 6 раз в год.
http://www.geolog-technical.kz/index.php/en/

CONTENTS

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 5. Number 473 (2025), 55–72

https://doi.org/10.32014/2025.2518-170X.550

UDC 336.77:338.43(477)

©B. Assanova[1], B. Orazbayev[2*], Zh. Moldasheva[1], Zh. Shangitova[1], 2025.
[1]Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan;
[2]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan.
E-mail: batyr_o@mail.ru

DECISION MAKING ON EFFECTIVE CONTROL OF RECTIFICATION PROCESS IN THE MAIN COLUMN OF DELAYED COKING UNIT IN FUZZY ENVIRONMENT

B. Assanova — PhD, associate professor of Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan,
E-mail: baha1981_13@mail.ru, ORCID ID: https://orcid.org/0000-0003-1029-6266;
B. Orazbayev — Doctor of Science, Professor of L.N. Gumilyov Eurasian National University, Astana, Kazakhstan,
E-mail: batyr_o@mail.ru, ORCID ID: https://orcid.org/0000-0003-2109-6999;
Zh. Moldasheva — PhD, associate professor of Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan,
E-mail: zhadira1985@mail.ru, ORCID ID: https://orcid.org/0000-0002-0559-3410;
Zh. Shangitova — PhD, associate professor of Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan,
E-mail: zhanna.shangitova@mail.ru, ORCID ID: https://orcid.org/0000-0001-7494-5208.

Abstract. The quality of petroleum products at the outlet of the main rectification column in a delayed coking unit is uncertain and typically evaluated by laboratory experts based on their experience and test results. Therefore, addressing decision-making in a fuzzy environment for controlling the rectification process and ensuring product quality is a relevant scientific and practical task. This paper aims to study and solve the decision-making problem for effective control of the rectification process in the main column of the delayed coking unit under uncertainty. The key outcome is a heuristic method developed to address decision-making under fuzzy conditions, modifying the optimality principles of the main criterion and Pareto optimality. Using this method, a fuzzy-constrained decision-making problem for rectification control is resolved. The method demonstrates advantages over conventional deterministic approaches. Its scientific novelty lies in formalizing fuzzy expert information through membership functions, enabling maximum utilization of expert knowledge. This enhances decision accuracy in fuzzy environments. The proposed approach effectively translates expert insight into structured decision

models, improving the adequacy of solutions in uncertain conditions. The practical significance is in applying this method to manage complex industrial processes where input data is vague and expert judgment is essential. The results contribute to improving the efficiency and reliability of production control in the petroleum industry and can be extended to other areas requiring fuzzy decision-making.

Keywords: decision making; fuzzy problem; principle of the main criterion; Pareto principle of optimality; heuristic method; rectification process

Funding

This work was supported the Science Committee of the Ministry of Science and Higer Education of the Republic of Kazakhstan (Grant No. fund this research AP19679897-Development of an intelligent decision-making system for controlling the petroleum coke production process).

©Б. Асанова[1], Б. Оразбаев[2*], Ж. Молдашева[1], Ж. Шангитова[1], 2025.

[1]Х. Досмұхамедов атындағы Атырау Университеті, Атырау, Қазақстан;
[2]Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан.
E-mail: batyr_o@mail.ru

АЙҚЫН ЕМЕС ОРТАДА БАЯУ КОКСТЕУ ҚОНДЫРҒЫСЫНЫҢ НЕГІЗГІ КОЛОННАСЫНДАҒЫ РЕКТИФИКАЦИЯЛАУ ПРОЦЕСІН ТИІМДІ БАСҚАРУ БОЙЫНША ШЕШІМ ҚАБЫЛДАУ

Б. Асанова — PhD, Х. Досмұхамедов атындағы Атырау университетінің қауымдастырылған профессоры, Атырау, Қазақстан,
E-mail: baha1981_13@mail.ru, ORCID ID: https://orcid.org/0000-0003-1029-6266;
Б. Оразбаев — Л.Н. Гумилев атындағы Еуразия ұлттық университетінің техника ғылымдарының докторы, профессор, Астана, Қазақстан,
E-mail: batyr_o@mail.ru, ORCID ID: https://orcid.org/0000-0003-2109-6999;
Ж. Молдашева — PhD, Х. Досмұхамедов атындағы Атырау университетінің қауымдастырылған профессоры, Атырау, Қазақстан,
E-mail: zhadira1985@mail.ru, ORCID ID: https://orcid.org/0000-0002-0559-3410;
Ж. Шангитова — PhD, Х. Досмұхамедов атындағы Атырау университетінің қауымдастырылған профессоры, Атырау, Қазақстан,
E-mail: zhanna.shangitova@mail.ru, ORCID ID: https://orcid.org/0000-0001-7494-5208.

Аннотация. Баяу кокстеу қондырғысының негізгі ректификациялық колоннасының шығысындағы мұнай өнімдерінің сапасы айқынсыздықпен сипатталады және зертхана мамандарының тәжірибелері мен білімдері негізінде зертханалық зерттеулер арқылы бағаланады. Осыған байланысты негізгі колоннадағы ректификациялау процесі мен алынатын өнімдердің сапасын басқару бойынша айқын емес ортада шешім қабылдау есебін зерттеу және шешу өзекті ғылыми-практикалық мәселе болып саналады**.** Бұл жұмыстың *мақсаты* айқын емес ортада баяу кокстеу қондырғысының негізгі колоннасындағы ректификациялау процесін тиімді бақылау үшін шешім

қабылдау мәселесін зерттеу және тиімді шешу. Зерттеудің *негізгі нәтижелері*: басты критерий және Парето оптималдық принциптерін модификациялау негізінде айқын емес ортада шешім қабылдау есебін шешудің эвристикалық тәсілі; ұсынылған эвристикалық тәсіл негізінде ректификациялау процесін басқару үшін айқын емес шектеулерлері бар шешім қабылдау есебі шешілді. Белгілі детерминирделген тәсілдермен салыстырғанда ұсынылған эвристикалық тәсілдің артықшылықтары көрсетілген. *Ғылыми жаңалығы*: айқын емес ортада шешім қабылдау есептерін шешудің әзірленген эвристикалық тәсілінің ғылыми жаңалығы айқынсыз шамалардың тиістілік функцияларын формализациялау арқылы қолжетімді сарапшы мамандардың айқын емес ақпараттарын максималды пайдалануында. Сарапшы мамандардың білімі мен тәжірибесін барынша пайдалана отырып, айқын емес есептерді шешудің бұл тәсілі айқын емес ортада қабылданған шешімдердің жоғарыадекваттығын қамтамасыз етеді. *Нәтижелердің практикалық құндылығы* күрделі өндірістік процестерді басқаруда айқын емес шешімдер қабылдау есептерін тиімді шешу үшін алынған нәтижелердің тиімді қолданылу мүмкіндігінде.

Түйін сөздер: шешім қабылдау, айқын емес есеп, негізгі критерий принципі, Парето оптималдық принципі, эвристикалық тәсіл, ректификациялау процесі

© Б. Асанова[1], Б. Оразбаев[2*], Ж. Молдашева[1], Ж. Шангитова[1], 2025.
[1]Атырауский Университет имени Х. Досмухамедова, Атырау, Казахстан;
[2]Евразийский национальный университет имени Л.Н. Гумилева,
Астана, Казахстан.
E-mail: batyr_o@mail.ru

ПРИНЯТИЕ РЕШЕНИЙ ПО ЭФФЕКТИВНОМУ УПРАВЛЕНИЮ ПРОЦЕССОМ РЕКТИФИКАЦИИ В ОСНОВНОЙ КОЛОННЕ УСТАНОВКИ ЗАМЕДЛЕННОГО КОКСОВАНИЯ В НЕЧЕТКОЙ СРЕДЕ

Б. Асанова — PhD, ассоциированный профессор Атырауского университета имени Х. Досмухамедова, Атырау, Казахстан,
E-mail: baha1981_13@mail.ru, ORCID ID: https://orcid.org/0000-0003-1029-6266;
Б. Оразбаев — доктор технических наук, профессор Евразийского национального университета имени Л.Н. Гумилева, Астана, Казахстан,
E-mail: batyr_o@mail.ru, ORCID ID: https://orcid.org/0000-0003-2109-6999;
Ж. Молдашева — PhD, ассоциированный профессор Атырауского университета имени Х. Досмухамедова, Атырау, Казахстан,
E-mail: zhadira1985@mail.ru, ORCID ID: https://orcid.org/0000-0002-0559-3410;
Ж. Шангитова — PhD, ассоциированный профессор Атырауского университета имени Х. Досмухамедова, Атырау, Казахстан,
E-mail: zhanna.shangitova@mail.ru, ORCID ID: https://orcid.org/0000-0001-7494-5208.

Аннотация. Качество нефтепродуктов на выходе основной ректификационной колонны установки замедленного коксования характеризуется нечеткостью и оценивается с участием специалистов-экспертов лаборатории

на основе их опыта и знаний путем лабораторных исследований. В этой связи исследование и решение задачи принятия решений в нечеткой среде для управления процессом ректификации и качеством получаемой продукции основной колонны является актуальной научно-практической задачей. Целью данной работы является исследование и разработка эффективного решения задачи принятия решений для управления процессом ректификации в основной колонне установки замедленного коксования в условиях нечеткости. Основными результатами исследования являются: разработка эвристического метода решения задач принятия решений в нечеткой среде на основе модификации принципов оптимальности главного критерия и Парето-оптимальности; применение предложенного метода для решения задачи с нечеткими ограничениями при управлении процессом ректификации. Показаны преимущества предложенного эвристического метода по сравнению с известными детерминированными подходами. Научная новизна метода заключается в максимальном использовании доступной нечеткой информации от специалистов-экспертов за счёт её формализации через функции принадлежности. Такой подход обеспечивает более высокую адекватность принимаемых решений в нечеткой среде. Практическая ценность результатов заключается в возможности применения разработанного метода для решения задач управления сложными производственными процессами.

Ключевые слова: принятие решений; нечеткая среда; принцип главного критерия; принцип Парето-оптимальности; эвристический метод; процесс ректификации

Introduction. Currently, increasing the depth of oil refining and increasing the range of more valuable products is an important task for oil refineries, as this indicator characterizes the efficiency of using hydrocarbon raw materials (Shelekhova, 2019). Currently, after the modernization of oil refineries (ORs) in the Republic of Kazakhstan, the average refining depth has exceeded 85%, but lags behind the refining depth of many other countries. Therefore, for Kazakhstan, further increasing the depth of oil refining is a very urgent scientific and practical task. The Government of the Republic of Kazakhstan plans to increase the depth of oil refining at refineries to 90-95% in the coming years through scientific research, development and implementation of high-tech, high-tech projects.

The currently used processes of deep oil refining at catalytic cracking and reforming units using catalysts in the presence of catalysts at high temperatures and pressures do not ensure complete removal of sulfur and other harmful compounds in gasoline. These refining technologies do not allow to achieve the required depth of oil refining, providing a depth of refining 20% below the level of industrialized countries. One of the approaches to solving the problems of increasing the depth of oil refining is the qualitative organization of the processing of oil refining residues: tar and fuel oil contained in the composition of oil up to 20%. In addition, this

approach to increasing the depth of refining makes it possible to increase the range of petroleum products with more valuable petroleum products, such as high-quality petroleum coke, benzene, petrochemical raw materials, etc. Technological processes of delayed coking occurring in delayed coking units (DCUs) Refineries provide the most efficient way to produce high-quality petroleum coke, which is in high demand in the domestic and global markets (Sawarkar et al., 2020).

One of the main units of the DCU is the main distillation column C-1, which is designed to produce additional petroleum products of the unit: gasoline, light and heavy gas oils, as well as heavy residues of the rectification process to produce petroleum coke. Thus, the main C-1 DCU distillation column is designed to isolate various fractions of petroleum products (gasoline, light and heavy gas oils) from raw materials (fuel oil or tar), which are commercial products of the plant and raw materials for the production of petroleum coke. Due to the development of mathematical methods and computer technology in comparison with column irrigation technology (Bochkarev, 2019), mathematical modeling and decision-making methods have become more effective and promising methods for optimizing the rectification process. These methods allow the decision maker (DM) to make the best decision to manage the operating modes of complex distillation columns, such as the C-1 DCU column, depending on the current production situation and market demand for manufactured products. The main C-1 DCU distillation column, which is the object of research in this work, like many complex distillation columns, is characterized by a lack and vagueness of the initial information necessary for modeling and decision-making. In this regard, this study develops a heuristic method for effectively solving decision-making problems in a fuzzy environment based on the use of intelligence (experience, knowledge and intuition) of DM, domain experts. The proposed heuristic approach is based on the application of the models of the main rectification C-1 DCU of Atyrau refinery developed by the authors in the work (Assanova, et al, 2024) and is included in the mathematical support of the developed intelligent decision support system (IDSS).

A number of studies have been devoted to the issues of multi-criteria optimization, with contradictory criteria in the field of effective solutions, i.e. the problem of decision-making based on models of the rectification process. For example, the author of the article (Savelyev, 2022) reviewed the state of issues related to the optimization of rectification plants. The authors of the paper (Yang et al, 2024) investigated the problems of optimizing the rectification process based on models. In the works (Sheikus, et al, 2024; Duyfjes, et al, 2024), an approach to optimizing the distillation process using a mobile control device was proposed and the issues of control and optimization of distillation columns based on their models were investigated. However, when optimizing complex distillation columns such as the C-1 DCU column, there are problems of shortages of the necessary information for the mathematical description and formalization of the distillation process. In well-known works on the modeling and optimization of distillation columns, these

problems have not yet been sufficiently investigated and solved.

In works (Orazbayev, et al, 2023; Orazbayev, et al, 2015; Matveykin, et al, 2019) devoted to modeling and optimizing the parameters of distillation columns and other aggregates with the fuzziness of some of the available information, an approach is used to transform the initial fuzzy problem to a set of clear problems based on the set of level α of the theory of fuzzy sets (Abbas, et al, 2019). However, this approach allows us to solve the problem of fuzzy optimization only at the specified α levels. In other areas, the problem of fuzziness is not solved, i.e. the collected fuzzy information is lost in these areas, which is knowledge, experience and intuition are not used, which reduces the adequacy of solving a fuzzy problem. This situation motivates this research, which is aimed at making full use of the collected fuzzy information and ensuring the high adequacy of the decision made to manage vaguely described production facilities in a fuzzy environment.

The purpose of this study is to develop a heuristic method for solving the decision-making problem for controlling the operating modes of complex vaguely described objects and, based on it, effectively controlling the rectification process in the C-1 DCU column in a fuzzy environment. The following research objectives are set and solved to achieve this goal:

– formalization and obtaining a mathematical formulation of the decision-making problem in a fuzzy environment for controlling the operating modes of vaguely described technological facilities and specifying the resulting formulation of the problem for the main distillation column C-1 DCU of Atyrau refinery;

– based on the modification of various principles of optimality for working in a fuzzy environment, the development of a heuristic method for solving a formulated fuzzy decision-making problem that makes maximum use of available fuzzy information and ensures high adequacy of the decision;

– effective solution of the decision-making problem for controlling the rectification process occurring in the C-1 DCU column in a fuzzy environment using the proposed heuristic method based on the involvement of DM, experts in the decision-making process.

The proposed heuristic method for solving the problem of decision-making based on a systematic application of expert assessment methods and theories of fuzzy sets of other methods has a synergetic effect and makes it possible to effectively solve decision-making problems in a fuzzy environment.

Object, materials and methods. The object of the study is the main rectification column C-1 DCU 21-10/6 of Atyrau refinery, designed to produce fatty gas, gasoline, light and heavy gas oils from tar by separation depending on the boiling point (Tuleuov, et al, 2010). The structure of the C-1 DCU 21-10/6 rectification column is shown in Figure 1.

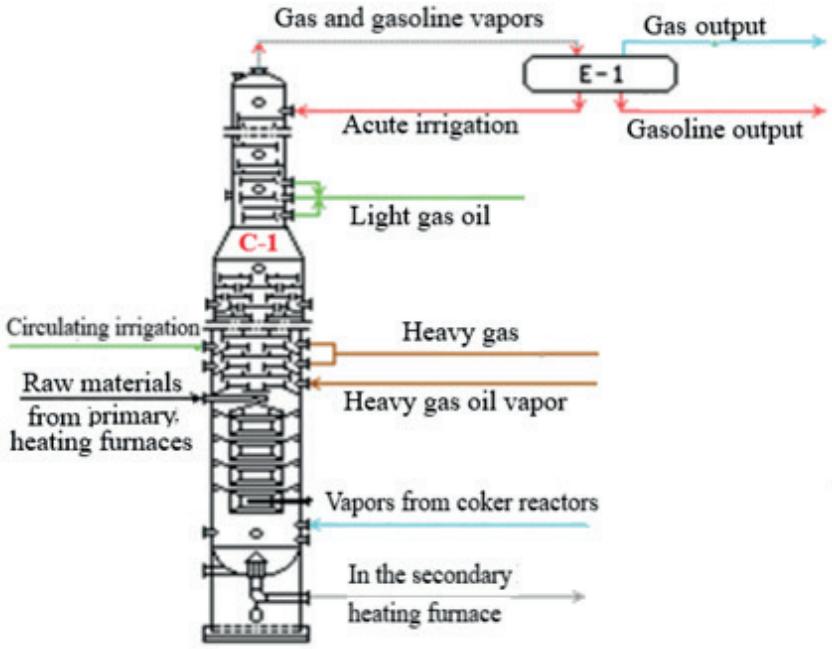


Figure 1. Scheme of the rectification column C-1 DCU 21-10/6

As a raw material, tar heated in DCU primary heating furnaces is fed into the C-1 distillation column. Vapors of gases and gasoline are released from the top of the distillation column, which are separated into gases and gasoline in the E-1 tank. Gas is used as an internal fuel, and gasoline is one of the commercial products of DCU. Further, depending on the boiling point, light and heavy gas oils are separated, which are removed from the corresponding plates of the columns. Secondary raw materials are removed from the bottom of the column, which are heated in furnaces of secondary raw materials and then fed into coke reactors for the production of petroleum coke. The coking reactors undergo a delayed coking process, which results in petroleum and petroleum vapors, which are fed into the distillation columns to intensify the distillation process.

The materials of the research are the technological scheme of rectification column C-1 DCU 21-10/6 of Atyrau refinery, experimental and statistical data on its operation modes and expert information describing the dependence of qualitative indicators of produced petroleum products on the input, mode parameters of the investigated column C-1.

The choice of the best operating mode of the column when controlling the rectification process is iterative and is implemented on the basis of the C-1 DCU column models, which describe the dependence of the volume ($y_j, j = \underline{1,4}$) and quality of products ($\tilde{y}_j, j = \underline{5,7}$) on the values of the output, operating parameters of the column ($x_i, i = \underline{1,6}$). At the same time, the qualitative indicators of the

column's commodity products (gasoline, light, heavy gas oil and combustion raw materials) are characterized by vagueness, since they are not measured in practice and are evaluated by DM, experts based on their experience and knowledge and laboratory studies. In this regard, fuzzy models ($y_j, j = \overline{1,m}$) are used to evaluate the quality of C-1 DCU products, which we synthesized in our work (Assanova, et al, 2024).

To obtain a mathematical formulation of the decision-making problem for controlling the modes of operation of complex objects in a fuzzy environment, we present the following formalization.

Let $\mu_C(\mathbf{x}) = \left(\mu_C^1(\mathbf{x}),...,\mu_C^m(\mathbf{x})\right)$– be a normalized vector of local criteria, if the criteria are fuzzy, then their membership functions; $\mathbf{x} = \left(x_1,...,x_n\right)$– be a vector of input, mode parameters affecting the operating modes and output parameters of the control object; $\varphi_q(\mathbf{x}) \tilde{\geq} b_q, q = \overline{1,L}$– be fuzzy constraints specified in the form of fuzzy instructions. Let's assume that the $\mu_q(\mathbf{x}), q = \overline{1,L}$ membership functions describing the degree of fulfillment of the requirements of fuzzy constraints are constructed with the help of DM and experts. We believe that the weight vectors assessing the mutual importance of fuzzy constraints are $\boldsymbol{\beta} = (\beta_1,...,\beta_L)$ set or determined by DM and experts.

Then the general statement of the decision-making problem for controlling the modes of operation of an object in a fuzzy environment can be written as:

$$\max_{\mathbf{x}\in X} \mu_C^i(\mathbf{x}), i = \overline{1,m}$$

$$X = \left\{\mathbf{x} : \arg\max_{\mathbf{x}\in X} \mu_q(\mathbf{x}), q = \overline{1,L}\right\}.$$

In this formulation, it is required to maximize the vectors of *m* criteria at one point, taking into account the requirements of $\mu_C^i(\mathbf{x}), i = \overline{1,m}$ L constraints $\mu_q(\mathbf{x}), q = \overline{1,L}$, which cannot be solved with contradictory criteria. Therefore, in order to obtain an effective (compromise) solution to the problem, it is necessary to apply various principles of optimality (compromise schemes) to a fuzzy environment. For example, by modifying and combining the principles of the main criterion (for criteria) and Pareto optimality (for constraints), the correct formulation of the decision-making problem in a fuzzy environment can be written as follows:

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

$$X = \{\mathbf{x} : \mathbf{x} \in \Omega \wedge \arg(\mu_0^i(\mathbf{x}) \geq \mu_R^i) \wedge \arg\max_{\mathbf{x}\in\Omega} \sum_{q=1}^{l} \beta_q \mu_q(\mathbf{x}) \wedge$$

$$\wedge \sum_{q=1}^{L} \beta_q = 1 \wedge \beta_q \geq 0, i = \overline{2,m}, q = \overline{1,L}\}. \tag{2}$$

In the resulting problem (1)–(2): $\mu_0^1(\mathbf{x})$– the main criterion chosen by DM, which is optimized; $\wedge$– the sign of the logical "and", which requires the truth of all

conditions associated through it; $\mu_R^i, i = \overline{2,m}$ – the boundary values of local criteria set by DM for local criteria $\mu_0^i(\mathbf{x}), i = \overline{2,m}$ that are included in the constraints.

By changing the values of the boundary values of the local criteria $\mu_R^i, i = \overline{2,m}$ and the weight coefficients of the vector, we $\boldsymbol{\beta} = (\beta_1, ..., \beta_L)$can obtain a family of solutions to the problem (1)–(2) $\mathbf{x}(\mu_R^i, \boldsymbol{\beta})$: Then, the choice of the best solution from the set of solutions obtained is carried out by the DM based on his preference and taking into account the current situation in production and the market for the sale of manufactured products.

In this study, a heuristic method is developed to solve the problem of decision–making with fuzzy constraints in the formulation (1)-(2) to select the effective mode of operation of the research object based on the modification of the principles of the main criterion and Pareto optimality.

In the proposed approach to solving the problem (1)–(2), the DM defines the main criterion that needs to be optimized, and sets boundary values for the remaining local criteria and they are taken into account as constraints. The degree of fulfillment of fuzzy constraints in optimizing the main criterion is assessed by their membership functions. The $\mu_0^i(\mathbf{x}), i = \overline{2,m}.$ flowchart of the proposed heuristic method is shown in Figure 2.

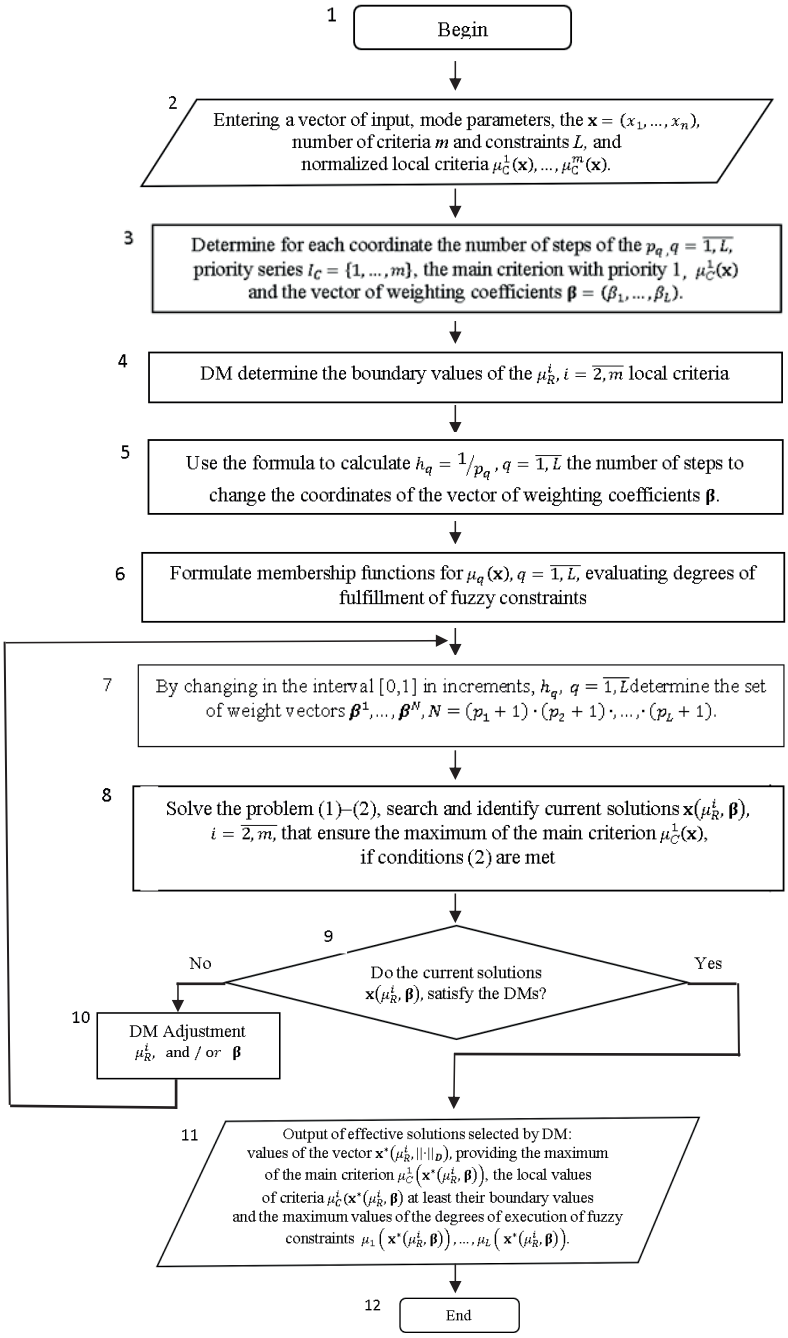
We briefly describe the main blocks of the developed heuristic method based on the modification of the principles of the main criterion and Pareto optimality for working in a fuzzy environment.

In block 2, the values of the vector of input and mode parameters, the $x = (x_1, \dots, x_n)$, number of criteria *m* and constraints *L,* as well as normalized local criteria are entered. $\mu_C^1(x), \dots, \mu_C^m(x)$.

In blocks 3 and 4, the DM determines the number of steps $p_q, q = \underline{1, L,}$ for each coordinate of the constraints, a number of priority criteria, $I_C = \{1, \dots, m\}$ and selects the main criterion with priority 1: $\mu_C^1(x),$ assigns the values of the weighting coefficients of the vector. In $\beta = (\beta_1, \dots, \beta_L)$ addition, the DM determines the boundary values of the $\mu_R^i, i = \underline{2, m}$ local criteria (except the main one) that are taken into account in the constraints.

In block 5, the values of the steps for changing the coordinates of the vector of weighting coefficients are calculated using β the formula $h_q = \frac{1}{p_q}, q = \underline{1, L.}$

In block 6, changing in the interval [0,1] with a step to h_q, $q = \underline{1, L}$ determine, a set of weight vectors $\beta^1, \dots, \beta^N, N = (p_1 + 1) \cdot (p_2 + 1) \cdot, \dots, \cdot (p_L + 1)$ is determined in which the optimal solution is sought.



Begin

Figure 2. A flowchart of a heuristic method for solving decision-making problems in a fuzzy environment based on a combination and modification of the principles of optimality of the main criterion and Pareto optimality

The construction of a function $\mu_q(x), q = \underline{1, L,}$ that allows estimating the degrees of fulfillment of fuzzy constraints is $\varphi_q(x) \lesseqgtr b_q, q = \underline{1, L,}$ performed in block 7 of the proposed heuristic method.

In block 8, a solution is found to the decision-making problem in a fuzzy environment (1)–(2), current solutions are determined $x(\mu_R^i, \beta), i = \underline{2, m}$ that can provide the maximum of the main criterion $\mu_C^1(x)$, if conditions (2) are met. In this block of searching for an effective solution, after reducing the initial multi-criteria problem to a single-criterion one based on the principle of the main criterion and formalizing fuzzy constraints through their membership functions, constructed in block 6, suitable conditional optimization methods can be applied.

As a result of solving the problem, current solutions are determined $x(\mu_R^i, \beta), i = \underline{2, m,}$ that provide the corresponding values of the main criterion $\mu_C^1\left(x(\mu_R^i, \beta)\right)$; the remaining local criteria that satisfy the condition: $\mu_C^i\left(x(\mu_R^i, \beta)\right) \geq \mu_R^i, i = \overleftarrow{2, m}$ and the corresponding $x(\mu_R^i, \beta)$ values of the accessory function. The $\mu_1\left(x(\mu_R^i, \beta)\right), \dots, \mu_L\left(x(\mu_R^i, \beta)\right)$ current solutions obtained in the next block are presented to the DM for analysis and selection of the best solution.

In block 9, the condition obtained in block 8 and the presented current solutions is checked whether the DM satisfies or not. If the DM does not satisfy the current solutions, then the values of the boundary values of the weight vector are adjusted to improve $\mu_R^i, i = \overleftarrow{2, m}$ *and / or* the solution β (block 10). Then control is transferred to block 8 for the next iteration of the search for the best solution. This iteration is repeated until the DM is satisfied with the solutions obtained. If the DM is satisfied with the current solutions presented to him, then the DM makes the final, best decision based on his preferences, taking into account the current production situation, quality requirements and market demand for manufactured products.

Block 11 displays the selected DM, the final, best solution: $x^*(\mu_R^i, \beta), i = \underline{2, m}$ – providing the maximum value of the main criterion $\mu_C^1\left(x^*(\mu_R^i, \beta)\right)$; the values of the remaining local criteria $\mu_C^i\left(x^*(\mu_R^i, \beta)\right), i = \overleftarrow{2, m}$ satisfying the specified boundary values $\mu_R^i, i = \overleftarrow{2, m}$ and the maximum values of the accessory function $\mu_1\left(x^*(\mu_R^i, \beta)\right), \dots, \mu_L\left(x^*(\mu_R^i, \beta)\right)$, providing the degrees of fulfillment of fuzzy constraints.

In addition to the proposed and described method, this study uses methods of expert assessment (Boiko, 2018) and fuzzy set theory (Romanov, 2019; Orazbayev, et al, 2018) to collect, formalize and use fuzzy information in the search and decision-making process in a fuzzy environment. In addition, the methodology of system analysis (Reverberi, et al, 2020) and methods of conditional optimization (Bhatnaga, et al, 2022; Crown, et al, 2019) are used in the work.

Results. Based on the research results obtained in the previous section, i.e. the general formulation of decision-making problems in a fuzzy environment and

the developed heuristic method for solving it, the problem of decision-making for controlling the modes of operation of the object of study is concretized and formulated, and the problem of decision-making is solved. In the process of preparation and decision-making, models of the main C-1 DCU distillation column were used to control the operating modes of the C-1 DCU column.

We concretize the general formulation of the decision-making problem in a fuzzy environment (1)−(2) for the decision-making problem for controlling the operating modes of the distillation column of the C-1 DCU of Atyrau refinery column in the form of the following fuzzy mathematical programming problem:

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

$$X = \{\mathbf{x} : \mathbf{x} \in \Omega \wedge \arg(\mu_0^i(\mathbf{x}) \geq \mu_R^i) \wedge \arg\max_{\mathbf{x}\in\Omega} \sum_{q=1}^{3} \beta_q \mu_q(\mathbf{x}) \wedge$$

$$\wedge \sum_{q=1}^{3} \beta_q = 1 \wedge \beta_q \geq 0, i = \overline{2,4}, q = \overline{1,3}\}, \tag{4}$$

where $\mu_C^1(x)$ – is the main criterion, the yield of gasoline from column C-1; $\mu_C^i(x), i = \underline{2,4}$ – are other local criteria that evaluate, respectively, the yields of light $\mu_C^2(x)$ and heavy $\mu_C^3(x)$ gas oils, as well as the yield of raw materials for coke production $\mu_C^4(x)$; set by DM; $\mu_q(x), q = \underline{1,3}$– are accessory functions that evaluate the degrees of fulfillment of vague restrictions on quality indicators − is the boiling point of gasoline ($\mu_1(x)$), light ($\mu_2(x)$) and $\mu_3(x)$ the $x = (x_1, \ldots, x_6)$ vector of input, operating parameters of the C-1 DCU distillation column: the volume of raw materials supplied to the column x_1; x_2, x_3, x_4 *and* x_5 the outlet temperatures of gasoline, light and heavy gas oils, respectively, as well as the outlet of raw materials for the production of petroleum coke; x_6– the pressure in the main C-1 DCU distillation column; $\mu_R^i, i = \underline{2,4}$ – the boundary the value of the local criteria $\mu_R^i(x), i = \underline{2,4}$ set by the DM.

The best solution to the decision-making problem (3)−(4) with fuzzy constraints is the value of the vector of input mode parameters $x^* = (x_1^*, x_2^*, x_3^*, x_4^*, x_5^*, x_6^*)$ in which the following is achieved:

— the maximum of the main criterion, i.e. gasoline output $\mu_C^1(x^*)$;

— the remaining criteria will not be less than the specified boundary value. $\mu_C^i(x^*) \geq \mu_R^i, i = \underline{2,4}$;

— the maximum values of the accessory function, estimating the degrees of fulfillment of fuzzy constraints $\mu_q(x), q = \underline{1,3}$.

Next, we will present the results of solving the problem of decision-making on the effective management of the rectification process in C-1 DCU 21-10/6 of Atyrau refinery. The main blocks of the proposed heuristic method for solving this problem (figure 2) and the learned results:

1. The values of the vector of input, mode parameters, the $x = (x_1, \ldots, x_6)$,

number of criteria m=4, constraints L=3, and normalized local criteria are entered $\mu_C^1(x), \dots, \mu_C^4(x)$.

2. The number of steps and a $p_q, q = \underline{1,3}$: $p_1 = 4;\ p_2 = 2; p_3 = 2,$ number of priority criteria are determined for each coordinate $I_C = \{1,2,3,4\}$, respectively, for the volumes of gasoline (1), light gas oil (2), raw materials for the production of coke (3) and heavy gas oil (4), and the values of the vector of weighting coefficients are set $\beta = (0.5, 0.3, 0.2)$.

3. DM $\mu_R^i, i = \underline{2,4,}$ boundary values for local criteria are defined and specified: $\mu_R^2 = 60\ oC; \mu_R^3 = 180\ oC; \mu_R^2 = 240\ oC$.

4. The values of the steps for changing the coordinates of the vector of weighting coefficients are calculated using β the formula $h_q = \frac{1}{p_q}, q = \underline{1,L}$: $h_1 = \frac{1}{p_1} = \frac{1}{5} = 0.2;$ $h_2 = \frac{1}{4} = 0.25;\ h_3 = \frac{1}{p_1} = \frac{1}{5} = 0.2.$

5. Membership functions of $\mu_q(x), q = \underline{1,3,}$ estimating degrees of fulfillment of fuzzy constraints are constructed:

— "the temperature of the beginning of the boiling of gasoline $\mu_1(x) \lesssim 60$;

— "the boiling point of light gas oil $\mu_2(x) \lesssim 180$;

— "the boiling point of heavy gas oil $\mu_3(x) \lesssim 240$.

For a vague description of the quality indicators of gasoline, light and heavy DM gas oils, the following term set $T(Y)$ is selected={"much less", "less", "equal"}. The following exponential dependence (8) is chosen as the structure of the membership function for estimating the degrees of fulfillment of fuzzy constraints:

$$\mu_q^t(x) = exp\left(Q_t|\tilde{y}_j - y_j^m|^{N_t}\right),$$

where q is the number of the fuzzy constraint, t is the number of the current term; Q_t and N_t are the identified parameters used respectively for rough and accurate identification of the type of function; $\tilde{y}_j, y_j^m$ – is the fuzzy parameter and its most corresponding numerical value (with the maximum value of the membership function).

The following membership functions are constructed that evaluate the degrees of fulfillment of fuzzy constraints $\mu_q^t(x), t = \underline{1,3}, q = \underline{1,3}$:

$$\mu_1^1(x) = exp(0.6|\tilde{y}_5 - 50|^{0,4});\ \mu_1^2(x) = exp(0.6|\tilde{y}_5 - 55|^{0,4});\ \mu_1^3(x) = exp(0.6|\tilde{y}_5 - 60|^{0,4});$$

$$\mu_2^1(x) = exp(0.5|\tilde{y}_5 - 160|^{0,5});\ \mu_2^2(x) = exp(0.5|\tilde{y}_5 - 170|^{0,5});\ \mu_2^3(x) = exp(0.5|\tilde{y}_5 - 180|^{0,5});$$

$$\mu_3^1(x) = exp(0.4|\tilde{y}_5 - 220|^{0,3});\ \mu_3^2(x) = exp(0.6|\tilde{y}_5 - 230|^{0,3});\ \mu_3^3(x) = exp(0.6|\tilde{y}_5 - 240|^{0,3}).$$

The fuzzy values of $\tilde{y}_5, \tilde{y}_5$ and are $\tilde{y}_5,$ determined by fuzzy models that evaluate the quality of gasoline, light and heavy gas oils depending on the operating parameters x_2, x_3, x_4 and of the x_6 distillation column C-1 DCU of Atyrau refinery, developed by us in [8].

6. To find the best solution with a change in the interval [0,1] with a step

h_1, h_2 and h_3, defined in the previous paragraph, a set of weight vectors is defined $\beta^1, \ldots, \beta^N, N = (p_1 + 1) \cdot (p_2 + 1) \cdot (p_3 + 1) = (4 + 1) \cdot (2 + 1) \cdot (2 + 1) = 5 \cdot 3 \cdot 3 = 45.$

7. The problem of decision-making (3)–(4) is solved, i.e. maximizing the main criterion $\mu_C^1(x)$ (3) in the field of acceptable solutions (2). As a result, a solution was chosen that $x(\mu_R^i, \beta), i = \underline{2, m,}$ provides the current values of the main criterion of $\mu_C^1\left(x(\mu_R^i, \beta)\right)$, local criteria $\mu_C^i\left(x(\mu_R^i, \beta)\right), i = \underline{2,4}$ and degrees of fulfillment of fuzzy constraints $\mu_q\left(x(\mu_R^i, \beta)\right), q = \underline{1,3}$. The current solutions to the problem are presented to the DM for analysis and final decision-making.

8. The condition has been verified: do the current solutions $x(\mu_R^i, \beta)$, satisfy the DM? If the current solutions presented to the DM do not satisfy him, he corrects them in order to improve the current solutions μ_R^i, *and / or* β (block 10) and repeats the next iteration of the search for the best solution starting from block 7. In the case of a satisfactory current solution, the DM, based on his preference and taking into account the current production situation and market demand for manufactured products, makes the best decision that is the best in these situations. The best decision made by the DM at the 5th iteration is transferred for output to the next point.

9. The effective solutions of the selected DM are derived: the value of the vector $x^*(\mu_R^i, \|\cdot\|_D), i = \underline{2,4,}$ providing: the maximum of the main criterion $\mu_C^1(x^*(\beta))$, the values of the local criteria $\mu_C^2(x^*(\mu_R^2, \beta), \mu_C^3(x^*(\mu_R^3, \beta), \mu_C^4(x^*(\mu_R^4, \beta),$ not less than their boundary values $\mu_R^i, i = \underline{2,4}$ and the maximum values of the degrees of fulfillment of fuzzy constraints, $\mu_1\left(x^*(\mu_R^i, \beta)\right), \mu_2\left(x^*(\mu_R^i, \beta)\right), \mu_3\left(x^*(\mu_R^i, \beta)\right),$ $i = \underline{2,4.}$ These results are listed in Table 1.

Table 1. The results of multi-criteria optimization of the operating modes of the C-1 DCU distillation column based on well-known deterministic optimization methods (Shumsky, et al, 2019), the proposed heuristic method and real data obtained at the research facility.

Results of multi-criteria optimization (decision-making) of C-1 DCU parameters, determination of volumes of produced petroleum products and their quality	Deterministic optimization method (Shumsky, et al, 2019)	The proposed heuristic method	Real (experimental data
$\mu_C^1(x^*(\beta))$ – volume of gasoline, t /h;	11,3	13,2	12,3
$\mu_C^2(x^*(\mu_R^2, \beta)$ – volume of light gas oil, t/h;	34,7	35,3	35,2
$\mu_C^3(x^*(\mu_R^3, \beta)$ – volume of heavy gas oil, t/h;	26,5	22,3	24,6
$\mu_C^4(x^*(\mu_R^4, \beta)$ – volume of raw materials for coke production, t/h;	34.0	34.1	34.1
$\mu_1\left(x^*(\mu_R^i, \beta)\right)$ – boiling point of gasoline, °C	–	54.7	$(55,5)^L$

$\mu_2\left(x^*(\mu_R^i,\beta)\right)$ – boiling point of light gas oil, °C	–	175	$(178)^L$
$\mu_3\left(x^*(\mu_R^i,\beta)\right)$ – boiling point of heavy gas oil, °C	–	253	$(240)^L$
$x^* = (x_1^*, x_2^*, x_3^*, x_4^*, x_5^*, x_6^*)$ – optimal value of the vector of selected input and mode parameters: x_1^* – volume of raw materials supplied to the C-1 column;	104	104	104
x_2^* – temperature of gasoline withdrawal from column C-1;	180	178	179
x_3^* – output temperature of light gas oil from C-1;	230	228	230
x_4^* – output temperature of heavy gas oil from C-1;	280	280	280
x_5^* – temperature of the output of raw materials for the production of coke from the bottom of C-1;	327	327	327
x_6^* – pressure in the C-1 DCU column.	4.5	4.4	4.6

Note: – means that these parameters that evaluate the quality of gasoline, light and heavy gas oils are not determined by this method; $(^*)^L$ means that these parameters are evaluated by specialists based on laboratory tests.

Discussion of results. In the formulated decision–making problem with fuzzy constraints (1)-(2) and in the developed method for solving it, the principles of the main criterion, Pareto optimality, are modified for fuzziness and used. At the same time, the principle of the main criterion is used to reduce a multi-criteria problem to a single-criterion one, and the Pareto optimality principle, modified on the basis of the apparatus of fuzzy set theories, is used to solve problems of constraint fuzziness. In the specified C-1 DCU (3)–(4) column, the volume of gasoline, which is the most important product of the column, is maximized as the main criterion. And the remaining local criteria, which assess the volumes of light and heavy gas oils produced and the residue from the bottom of the column, which is the raw material for coke production, supplied to coke reactors, are taken into account as restrictions, taking into account their boundary values set by DM $\mu_R^i, i = \underline{2,4}$. The problem is solved in the field of feasible solutions, in which it requires the fulfillment of fuzzy constraints, maximizing the function of accessories describing the degrees of their fulfillment.

In the solved problem (3)–(4) c, vague restrictions are imposed on the quality indicators at the output of C-1 DCU − of the temperatures of the beginning of accumulation of gasoline, light and heavy gas oils, which are not directly measured, determined with the participation of humans, specialists through laboratory research and based on their experience, knowledge, i.e. are estimated vaguely.

The problem of making decisions on the effective management of operating modes (3)–(4) was solved using the proposed heuristic method with the participation of DM, and the solution was improved sequentially from iteration to iteration. The

best solutions were obtained and selected by the DM at the fifth iteration and are listed in the 3rd column of Table 1. The proposed and used heuristic method for solving decision-making problems in a fuzzy environment by formalizing fuzzy constraints in the form of a function for their implementation makes maximum use of available fuzzy information −, experience, knowledge and intuition of DM, expert specialists. Based on the comparison and discussion of the results obtained in Table 1, the following advantages of the proposed and used heuristic method can be noted:

1. Based on the results of comparing the results of the heuristic method with the known one, it is noticeable that the results of the proposed method are more adequate to real, experimental data, compared with the results of the compared method.

2. The proposed eusristic method provides an effective solution to decision-making problems with fuzzy constraints, based on the control of their degrees of fulfillment in the form of a function of accessories describing their degrees of fulfillment.

3. Comparing the results of the fuzzy, deterministic methods, it can be seen from Table 1 that the proposed heuristic method increases the volume of the more important products: gasoline and light gas oil, by 1.9 t/h (16.8%) and 0.6 t/h (1.73%), respectively, by reducing the less demanded product − heavy gas oil. This provides a significant economic effect, as the DCU is a continuous production unit and allows for an additional 45.6 tons of gasoline and 14.4 tons of light gas oil per day, which are more expensive and in demand. In addition, the proposed heuristic method makes it possible to find and ensure a more efficient operating mode of the C-1 DCU column in a more energy-efficient mode, i.e. lower temperatures.

Conclusions. Based on the modification and combination of the principles of the main criterion and Pareto optimality, the formulation of the decision-making problem for controlling the rectification process in a fuzzy environment is formulated and a heuristic method for its solution is proposed. These results have been tested to solve the problem of decision-making on the control of the distillation process taking place in the main column C-1 DCU of Atyrau refinery.

Thus, based on the main results of the study, conclusions can be drawn:

– the formalization was carried out and the mathematical formulation of the decision - making problem with fuzzy constraints in the form of a fuzzy mathematical programming problem was obtained;

– a flowchart of a method for solving the formulated problem has been created and described, developed by combining and modifying the principles of the main criterion and Pareto optimality for fuzziness;

– based on the models of the main C-1 DCU distillation column and the proposed heuristic method, the problem of decision-making with fuzzy constraints for controlling the distillation process in the C-1 DCU of Atyrau refinery has also been solved.

— the proposed heuristic method based on the maximum use of the experience, knowledge and intuition of DM, expert specialists allows us to obtain effective and highly adequate solutions to the problem being solved in a fuzzy environment, which is confirmed by comparing the results of the deterministic method, the proposed method and real data.

References

Abbas S.H., Hussain Z., Hussain S., Sharif, R., Hussain S. (2021) Intuitionistic fuzzy entropy and its applications to multicriteria decision making with IF-TODIM. Journal of mechanics of continua and mathematical sciences. — Vol. 16. — no 7. — P. 99-119 (in English).

Assanova B., Orazbayev B., Moldasheva Zh., Makhatova V., Tuleuova R. (2024) A fuzzy decision-making method for controlling operation modes of a hard-to-formalise rectification column of a delayed coking unit. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. 1. — P. 17-30. https://doi.org/10.32014/2024.2518-170X.362 (in English).

Bhatnagar S., Prasad H., Prashanth L. (2022) Algorithms for Constrained Optimization. In: Stochastic Recursive Algorithms for Optimization. Lecture Notes in Control and Information Sciences, 434. Springer, London. https://doi.org/10.1007/978-1-4471-4285-0_10 (in English).

Bochkarev V.V. (2019) Optimization of chemical technological processes; Publishing House Yurayt, Krakow, Poland. — P.. 337. ISBN: 978-5-9916-6546-9 (in English).

Boiko Y. (2018) Methods of forming an expert assessment of the criteria of an information system for managing projects and programs. Computer sciences, 5. — P. 9-11 (in English).

Crown W., Buyukkaramikli N., Thokala P., Ijzerman M.J, Wong P.K., Pasupathy K.S. (2019) Constrained Optimization Methods in Health Services Research – An Introduction: Report 1 of the ISPOR Optimization Methods Emerging Good Practices Task Force. Research Article., 20(3). — P. 310-319. https://doi.org/10.1016/j.jval.2017.01.013. (in English)

Duyfjes G., Grinten P.M. Application of a mathematical model for the control and optimization of a distillation plant. Automatica, 2019. — vol. 9. — №5. — P. 537-547. https://doi.org/10.1016/0005-1098(73)90040-X (in English).

Matveykin V.G., Dmitrievsky B.S., Kokuev A.G., Dzhambekov A.M. (2019) Problem of control of catalytic reforming and method of its solutions. Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering. 330(6). — P. 59-65 (in English).

Orazbayev B., Dyussembina E., Uskenbayeva G., Shukirova A., Orazbayeva K. (2023) Methods for Modeling and Optimizing the Delayed Coking Process in a Fuzzy Environment. Processes, 11(2), 450. — P. 1-19. https://doi.org/10.3390/pr11020450 (in English).

Orazbayev B.B., Orazbayeva K.N., Kurmangaziyeva L.T., Makhatova V.E. (2015) Multi-criteria optimisation problems for chemical engineering systems and algorithms for their solution based on fuzzy mathematical methods. EXCLI Journal, 2015. — Vol. 14. — P. 984-998**.** https://doi.org/10.17179/excli2015-266 (in English).

Orazbayev B., Zhumadillayeva A., Kabibullin M., M. James C. Crabbe, Orazbayeva K., Yue X.G. (2023) A Systematic Approach to the Model Development of Reactors and Reforming Furnaces with Fuzziness and Optimization of Operating Modes. IEEE Access. 11. — P. 74980-74996 https://doi.org/10.1109/ACCESS.2023.3294701 (in English).

Reverberi A.P., Kuznetsov N.T., Meshalkin V.P., Salerno M., Fabiano B. (2020) Systematical Analysis of Chemical Methods in Metal Nanoparticles Synthesis. Theoretical Foundations of Chemical Engineering. Vol. 50, №1. — P. 63-75 (in English).

Romanov V.N. (2019) The use of fuzzy arithmetic in decision-making problems. SN Applied Sciences. 1:367 https://doi.org/10.1007/s42452-019-0384-9 (in English).

Savelyev M.Yu. (2022) Optimization of the operation of a rectification plant: review of the state of the issue. Bulletin of Omsk State Technical University. — Vol. 330. — N. 7. — P. 25-28 (in Russian).

Sawarkar A.N., Pandit A.B., Samant Sh., Joshi B.J. (2020) Petroleum Residue Upgrading Via

Delayed Coking: A Review. The Canadian Journal of Chemical Engineering. — Vol. 85(1): 1-24. DOI: 10.1002/cjce.5450850101 (in English).

Sheikus A., Kovalenko V., Kotok V., Levchuk I., Bilobrova O., Darovskih L. (2020) Optimization of rectification process using mobile control action with. EUREKA: Physics and Engineering. 6. — P. 33-40. https://doi.org/10.21303/2461-4262.2020.001503 (in English).

Shelekhova P.S. (2019) Tudy of the effect of depth of oil processing on the economy of the industry. Global and regional research. 2. — P. 464−470. https://elibrary.ru/item.asp?id=41226323 (in English).

Shumsky V.M., Zyryanova L.A. (2019) Inzhenernye problemy neftepererabotki i neftekhimii [Engineering problems of oil refining and petrochemistry]. MPK: Moscow, Russia, 2nd ed. — P. 478. (in Russian).

Tuleuov Zh.N. (2020) Tekhnologicheskij reglament ustanovki zamedlennogo koksovaniya DCU 21-10/6 Atyrauskogo neftepererabatyvayushchego zavoda [Technological regulations for the delayed coking unit DCU 21–10/6 of the Atyrau Oil Refinery]. Atyrau, Kazakhstan. — 220 p. (in Russian).

Yang L. Chen Y., Wang J., Luo Y., Zhou P., Zhang X. (2024) The Simulation and Optimization of the Tetrafluoroethylene Rectification Process. Separations. 11, 37. — P. 11-14. https://doi.org/10.3390/separations11020037 (in English).

Publication Ethics and Publication Malpractice
in the journals of the Central Asian Academic Research Center LLP

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the journals of the Central Asian Academic Research Center LLP implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier. com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The Central Asian Academic Research Center LLP follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics. org/files/ u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/ or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the Central Asian Academic Research Center LLP.

The Editorial Board of the Central Asian Academic Research Center LLP will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:
www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Ответственный редактор *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Т. Апендиев*
Верстка на компьютере: *Г.Д. Жадырановой*

Подписано в печать 15.10.2025.
Формат 70x90$^{1}/_{16}$. 20,5 п.л.
Заказ 5.

«Central Asian Academic Research Center» LLP
Алматы, Қонаев к-сі, 142