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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
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«ХАЛЫҚ» ЖҚ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

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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.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

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A FUZZY DECISION-MAKING METHOD FOR CONTROLLING OPERATION MODES OF A HARD-TO-FORMALISE RECTIFICATION COLUMN OF A DELAYED COKING UNIT

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Abstract. In practice, many technological objects, such as complex rectification columns, refineries and other industries are often difficult to formalise, as some parameters are not directly quantified. Such parameters as oil composition, raw material and product quality parameters are not clearly assessed in practice by experienced production personnel based on their experience, knowledge and intuition. Since the quality of operation of complex objects is assessed by many criteria, which are contradictory in the field of effective solutions, the problem of optimising their operating modes should be formulated as a decision-making problem in a fuzzy environment. A decision-making problem with fuzzy constraints for controlling the operating modes of the main rectification column of a delayed coking unit (DCU) is formulated. Based on a modification of Pareto principle of optimality, a heuristic method for solving the formulated decision-making problem in a fuzzy environment is proposed, which allows to obtain an effective solution by using experience, knowledge and intuition decision marker. The process of optimisation and selection of the best solution in the advanced heuristic method is carried out on the basis of the models of the main DCU rectification column developed by the authors. In known approaches to solving fuzzy problems, the initial problem based on the level set α is represented into a set of crisp problems, which are then solved by deterministic methods, which leads to reduced adequacy of the solution. The novelty and difference of the proposed heuristic method of solving the decision making problem from the known methods of solving fuzzy problems lies in the maximum use of available fuzzy information from decision marker, experts. This advantage of the developed method is achieved by formulating and solving the problem in a fuzzy environment by formalising the fuzziness through their accessory functions, which ensures high adequacy of the decision to be made in a fuzzy environment. The proposed heuristic method for solving decision making problem with fuzzy constraints is an iterative method based on improving the solution by exchanging information between decision marker and computer by utilising their advantages.

Keywords: decision making, fuzzy information, Pareto principle of optimality, distillation column, heuristic method

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КҮРДЕЛІ ФОРМАЛИЗАЦИЯНАТЫН БАЯУ КОКСТЕУ ҚОНДЫРҒЫСЫ РЕКТИФИКАЦИЯЛДАУ КОЛОННАСЫНЫҢ ЖҰМЫС РЕЖИМДЕРІН БАСҚАРУ ҮШІН АЙҚЫНСЫЗДЫҚТА ШЕШІМ ҚАБЫЛДАУ ТӘСІЛІ

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Аннотация. Практикада мұнай өңдеу және басқа өндірістерде қолданатын күрделі ректификациялау колонналары сияқты көптеген технологиялық объектілердің кейбір параметрлері өндірістік жағдайда сандық түрде өлшенбайтінден формализациялануы өте қиын. Мұнайдың құрамы, шикізат пен өнімнің сапа көрсеткіштері сияқты параметрлерді өндірісте тәжірибелі өндірістік қызметкерлер өз білімі, тәжірибесі мен түйсігі негізінде айқынсыз бағалайды. Күрделі объектілердің жұмыс сапасы тиімді шешімдер жиынынында қарама-қайшылықта болатын көптеген критерийлер бойынша бағаланатындықтан, олардың жұмыс режимдерін оптимизациялау есебі айқын емес ортада шешім қабылдау есебі ретінде тұжырымдалуы керек. Айқын емес шектеулермен сипатталатын шешім қабылдау есебі баяу кокстеу қондырғысының (БКҚ) негізгі ренктификациялау колоннасының жұмыс режимдерін басқару мысалында тұжырымдалған. Паретоның оптималдық принципін модификациялау негізінде айқын емес ортада тұжырымдалған шешім қабылдау есебін шешу үшін шешім қабылдаушының тәжірибесін, білімін және интуициясын пайдалану арқылы тиімді шешімді алуға мүмкіндік эвристикалық тәсіл ұсынылған. Ұсынылған эвристикалық тәсілде оптимизациау және ең тиімді шешімді таңдау процесі авторлар қатысумен әзірлеген БКҚ негізгі ректификациялау колоннасының модельдкрії негізінде жүзеге асырылады. Айқын емес есептерді шешудің белгілі тәсілдерінде α деңгейлі жиынына негізінде бастапқы есеп айқын есептер жиынтығында келтіріледі, содан кейін белгілі детерминиді тәсілдермен шешіледі, бұл шешімнің адекваттылығының төмендеуіне әкеледі. Шешім қабылдау есебін шешудің ұсынылған эвристикалық тәсілінің айқын емес есептерді шешудің белгілі тәсілдемелдерінен айырмашылығы мен жаңашылдығы шешім қабылдаушы, эксперттерден алынатын айқын емес ақпаратты максималды пайдалануында. Әзірленген тәсілдің бұл артықшылығы есепті айқын емес ортада қойып, шешуге мүмкіндік беретін айқынсыздықты тиістілік функциялары арқылы формализациялау негізінде айқын емес ортада қабылданған шешімнің жоғары адекваттылығын қамтамасызететді. Айқын емес шектеулерімен сипатталатын шешім қабылдау есебін шешудің ұсынылған эвристикалық тәсілі шешім қабылдаушы мен компьютер арасында ақпарат алмасу, олардың артықшылықтарын пайдалану арқылы шешімді жақсартуға негізделген итеративті тәсіл болып табылады.

Түйін сөздер: шешім қабылдау, айқын емес ақпарат, Парето оптималдық принципті, ректификациялау колоннасы, эвристикалық тәсіл

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НЕЧЕТКИЙ МЕТОД ПРИНЯТИЯ РЕШЕНИЙ ДЛЯ УПРАВЛЕНИЯ РЕЖИМАМИ РАБОТЫ ТРУДНОФОРМАЛИЗУЕМОЙ РЕКТИФИКАЦИОННОЙ КОЛОННЫ УСТАНОВКИ ЗАМЕДЛЕННОГО КОКСОВАНИЯ

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Аннотация. Многие технологические объекты, такие как сложные ректификационные колонны, нефтеперерабатывающие заводы и другие производства, зачастую трудно формализовать, поскольку некоторые параметры не имеют прямого количественного определения. Такие параметры, как состав масла, качество сырья и продукции, на практике не получают четкой оценки опытным производственным персоналом. Поскольку качество эксплуатации сложных объектов оценивается по многим критериям, противоречивым в области эффективных решений, задачу оптимизации режимов их работы следует формулировать как задачу принятия решений в нечеткой среде. Авторами сформулирована задача принятия решений с нечеткими ограничениями для управления режимами работы главной ректификационной колонны установки замедленного коксования (УЗК). На основе модификации принципа оптимальности Парето предложен эвристический метод решения сформулированной задачи принятия решений в нечеткой среде, позволяющий получить эффективное решение, используя опыт, знания и интуицию маркера решения. Процесс оптимизации и выбора лучшего решения в расширенном эвристическом методе осуществляется на основе моделей основной ректификационной колонны, разработанных авторами. В известных подходах к решению нечетких задач исходная задача на основе множества уровня α представляется набором четких задач, которые затем решаются детерминированными методами, что приводит к снижению адекватности решения. Новизна и отличие предлагаемого эвристического метода решения задачи принятия решения от известных методов решения нечетких задач заключается в максимальном использовании доступной нечеткой информации от маркеров решения, экспертов. Данное преимущество разработанного метода достигается за счет постановки и решения задачи в нечеткой среде путем формализации нечеткости через их акцессорные функции, что обеспечивает высокую адекватность принимаемого решения в нечеткой среде. Предлагаемый эвристический метод решения задачи принятия решений с нечеткими ограничениями представляет собой итерационный метод, основанный на улучшении решения путем обмена информацией между маркером решения и компьютером за счет использования их преимуществ.

Ключевые слова: принятие решения, нечеткая информация, принцип оптимальности Парето, ректификационная колонна, эвристический метод

Introduction

Rectifying columns of oil refineries, petrochemical plants designed for separation of oil and other multiphase systems are complex and difficult to formalise, as some of their parameters are not measured. The main rectification column C-1 of the delayed coking unit (DCU) is complex and separates heavy oil refining units of complex composition (tar, fuel oil) from crude oil products (gasoline, light and heavy gas oil). In addition, fatty gases are released from this column, which are used as internal DCU fuel. As a result of heating in the rectification process light fractions of oil products are separated at low temperature in the upper part of the column, and heavy fractions at high temperature in the upper part. Thus, gas, gasoline and light gas oil are removed from the upper part and columns, and heavy gas oil and raw materials for coke production are removed from the lower part, which are sent to the coke reactors of the DCU.

Currently, an effective method of controlling and increasing the productivity of the rectification process is decision-making methods for choosing effective operating modes of rectification columns based on their models (Tsirlin et al., 2021: 483-491; Chuzlov et al., 2022: 236–243). Thus, effective control of the operation modes of complex rectification columns requires the development of their mathematical models, on the basis of which multicriteria optimisation problems are solved (Assanova et al., 2023: 1–7). Since the optimisation criteria in the field of effective solutions are contradictory, these problems of multicriteria optimisation are solved as decision-making problems, allowing to choose an effective, compromise solution. The decision-making task of selecting effective operating modes of rectification columns is complicated in practice due to the vagueness of some initial information.

Below are the results of the analysis of works devoted to the development of models of rectification columns and to the optimisation of the rectification process. The studies (Anisimov et al., 2017: 225; Duyfjes et al., 2019: 537–547; Khazeev et al., 2022: 23–42;

Palancz, 2022: 247–270) consider the issues of modeling and optimization of simple distillation columns. These and many other well-known works have investigated the development of mathematical models for optimising the separation process in simple rectification columns for the separation of feedstock into two phases. In this case, mathematical models of the rectification process are developed on the basis of methods of calculation of the separation process from plate to plate. Khazeev et al. Models of the process of rectification of crude methanol into two phases have been proposed. The state of the issue of optimizing the rectification process on simple rectification columns is analyzed in the work (Savelyev, 2022: 25–28). The author (Anikin, 2019: 55–58) analysed the issues of modelling simple distillation columns with the use of freeware. In the article (Nadir et al., 2021: 379–389), an algorithm and software for optimal design of simple distillation columns are proposed.

The analysed and other known works on the subject investigate the issues of modelling based on plate-to-plate methods and optimisation of the rectification process. The proposed models and methods of rectification process optimisation are applicable for modelling and optimisation of operation modes of simple rectification columns separating liquids into two phases depending on the boiling point. But these approaches for complex rectification columns designed to separate multiphase systems like oil into multiple petroleum products are not efficient or suitable.

In the works (Sheikus et al., 2020: 33–40; Shakeri et al., 2021: 36–57) the authors considered the issues of modeling, optimization and management of raw material separation processes in complex distillation columns of petrochemistry and other industries. However these and other similar works do not sufficiently investigate and address the issues of model development, optimisation and control of complex rectification columns under conditions of deficiency and vagueness of initial information.

When developing models of complex rectification columns as the main rectification column DCU, designed for the separation of oil, or its refined products into several petroleum products in practice, there are often problems of deficiency and vagueness of the initial information. The main reasons for these problems include: unmeasurability or difficult measurement of some important parameters of the rectification process such as raw material composition, qualitative parameters of separation products and others. Even with the theoretical possibility of measuring such parameters, in practice, their measurement is economically impractical. In practice, a more effective assessment of the value of immeasurable or difficult to measure parameters, indicators is a fuzzy assessment based on the experience, knowledge and intuition of decision marker (DM), experts, in their natural language (Orazbayev et al., 2019: 182–194; Chen, 2020: 1–9). Under such conditions of scarce and unclear background information, experienced DMs can effectively manage the operating modes of complex facilities like the main DCU rectification column based on their knowledge, experience and intuition. Currently, an effective and promising approach to the development of models, optimization and control of modes of operation of complexly formalized objects is the use of expert assessment methods and fuzzy set theories (Orazbayev et al., 2021: 1–22).

Thus, the results of the analysis of the work on the research topic substantiates the relevance of decision-making methods for managing the operating modes of complex distillation columns as the main DCU distillation column and motivates this study. In connection with this, the aim of the study is to develop a decision-making method for controlling the modes of operation of complex, difficult to formalise objects on the example of the main distillation column DCU.

Research object, materials and methods

The object of research of this work is the main rectification column DCU of Atyrau refinery, which is complex and difficult to formalise for optimisation and control of operating modes. The main distillation column DCU of Atyrau refinery is designed for the rectification of tar and oil vapor from coking reactors for additional petroleum products: gasoline, light and heavy gas oils (Tuleuov et al., 2018: 217). In addition, fatty gases are extracted from the top of this column to be used as the internal fuel of the plant, and from the bottom - heavy fractions to be sent to the coking reactors for the production of high quality petroleum coke. Thus, a complex rectification process takes place in the main distillation column DCU, as a result of which gases, gasoline, light and heavy gas oils, as well as raw materials for coke production are released from the raw materials, depending on the boiling point.

The research materials are the technological regulations and schemes of the DCU of Atyrau refinery (Tuleuov et al., 2018: 217), the results of the study, experimental and statistical data on the work of the research object (Gafner et al., 2018: 24–35; Sunyaev, 2019: 307). In addition, the selected operating schedules of DCU of Atyrau refinery over the past 2 years were used as materials in the research process.

In order to achieve the formulated research goal, at the end of the Introduction section, the development of a decision-making method for controlling the operating modes of the main DCU distillation column, the following research tasks are set and solved:

1. Selection or development of mathematical models of the main rectification column DCU, determining the influence of input, mode parameters of the column on its optimisation criteria and constraints in controlling the operating modes of the column.

2. Formulation of the mathematical formulation of the decision-making problem, taking into account fuzzy constraints for controlling the modes of operation of the object of study.

3. Development of a heuristic method for solving the formulated problem of decision-making in a fuzzy environment to control the modes of operation of the object under study.

The following research methods were used in the process of conducting the study:

– for the application of available or accessible information of various types, methods of system analysis (Radin et al., 2017: 378; Dieter et al., 2018: 267; Doumeingts et al., 2018: 201–224; Pavlov et al., 2019: 117–133);

– methods of mathematical planning of experiments and mathematical statistics for the collection and processing of experimental statistical data (Dvorkin et al., 2019: 5–16; Douglas et al., 2021: 784–794; Karmanov et al., 2019: 187; Melnikova et al., 2022: 132);

– methods of expert assessments and fuzzy set theories for collecting, processing and using expert and fuzzy information (Boiko, 2018: 9–11; Jorgensen, 2019: 37–60; Ryzhov, 2017: 178; Zimmermann, 2018: 525).

In the formulation and development of a method for solving the decision-making problem, multicriteria optimization methods were used (Odu, 2019: 1–14; Volin et al., 2017: 165–178; Kahraman, 2018: 592–608) and Pareto principle of optimality (Ng, 2020: 26–46; Mornati, 2020, 65–82; Lovison, 2022: 1–23).

Results

The quality of operation of complex technological objects such as the main DCU rectification column is usually evaluated by several criteria, which are contradictory on the set of effective solutions. When optimizing and managing the operating modes of such objects, it is necessary to take into account various limitations and the vagueness of some of the initial information. In this regard, the task of multi-criteria optimization in managing their modes of operation in a fuzzy environment can generally be formulated as a fuzzy decision-making problem. To control the operating modes of the main distillation column, the statement of the problem of acceptance for controlling the operating modes of the main distillation column C-1 DCU c with fuzzy constraints can be written as follows:

$$\max_{\bar{x}_1 \in X} \mu_C^i(\bar{x}_1), i = \overline{1,4}, \quad (1)$$

$$X = \{\bar{x}_1, \bar{x}_2 : \bar{x}_1, \bar{x}_2 \in \Omega \wedge \varphi(\bar{x}_2) \lesssim b_q, q = \overline{1,3}\}, \quad (2)$$

where $\mu_C^i(\bar{x}_1), i = \overline{1,4}$ – local criteria evaluating the volume of petroleum products produced ($\mu_C^1(\bar{x}_1)$ – gasoline, $\mu_C^2(\bar{x}_1)$ – light gas oil, $\mu_C^3(\bar{x}_1)$ – heavy gas oil and $\mu_C^4(\bar{x}_1)$ – heavy residue used for coke production); $\varphi(\bar{x}_2) \lesssim b_q, q = \overline{1,3}$ – fuzzy restrictions on the quality of gasoline, light and heavy gas oil; $\bar{x}_1 = (x_1, x_2, x_3)$ – vector of input, regime parameters affecting local criteria; $\bar{x}_2 = (x_4, x_5)$ – vector of input, regime parameters affecting quality indicators of the main gasoline products, i.e. gasoline, light and heavy gas oil. The components and vectors of these vectors are: x_1 – the volume of raw materials (tar) at the inlet of column C-1; x_2 and x_3 – the temperature and pressure in column C-1; x_4 and x_5 – the temperature and pressure of the output of petroleum products from column C-1; Ω – the initial set of alternatives to the input, regime parameters of the distillation column; X the range of acceptable solutions subject to restrictions.

Then the solution to the decision-making problem (1) – (2) is such values of vectors $\bar{x}_1^* = (x_1^*, x_2^*, x_3^*)$ and $\bar{x}_2^* = (x_4^*, x_5^*)$, providing optimal values of local criteria $\mu_C^i(\bar{x}_1^*), i = \overline{1,4}$ when fulfilling the condition of all fuzzy constraints $\varphi(\bar{x}_2^*) \lesssim b_q, q = \overline{1,3}$. When solving this problem, the optimization process is carried out on the basis of mathematical models that allow us to determine the dependence of criteria (product volumes) and restrictions (product quality) on the input, operating parameters of the C-1 column: x_1, x_2, x_3, x_4 and x_5. In this work, the following mathematical models of the main DCU distillation column developed by the authors of the work are selected and used as such models (Orazbayev et al., 2023: 1–17).

Mathematical models determining the dependence of local criteria, respectively, on the volumes of gasoline, light gas oil, heavy gas oil and raw materials for coking, on the vector of input, operating parameters of the C-1 DCU column:

Mathematical models determining the dependence of local criteria, $\mu_C^1(\bar{x}_1), \mu_C^2(\bar{x}_1), \mu_C^3(\bar{x}_1)$, respectively, on the volumes of gasoline, light gas oil, heavy gas oil and raw materials for coking, on the vector of input, operating parameters of the $\bar{x}_1 = (x_1, x_2, x_3)$ C-1 DCU column:

$$-\mu_C^1(\bar{x}_1) = 11.805 + 0.625x_1 + 0.842x_2 - 0.434x_3 + 0.003x_1^2 + 0.0022 - 0.0002x_3^2 + + 0.006x_1x_2 - 0.001x_2x_3, \quad (3)$$

$$-\mu_C^2(\bar{x}_1) = 54.999 + 1.533x_1 + 1.991x_2 - 0.832x_3 + 0.008x_1^2 + 0.002x_2^2 - 0.005x_3^2 + + 0.002x_1x_2 - 0.019x_2x_3, \quad (4)$$

$$-\mu_C^3(\bar{x}_1) = 6.788 + 1.046x_1 + 3.167x_2 + 0.981x_3 + 0.006x_1^2 + 0.002x_2^2 - 0.006x_3^2 + + 0.003x_1x_2 - 0.002x_2x_3, \quad (5)$$

$$-\mu_C^4(\bar{x}_1) = 165.665 + 0.082x_1 + 0.359x_2 - 0.265x_3 + 0.002x_2^2 + 0.001x_3^2 - 0.001x_3^2 + + 0.007x_1x_2 - 0.005x_2x_3. \quad (6)$$

Models describing fuzzy restrictions on the quality of commercial petroleum products (boiling point): $\varphi(\bar{x}_2) \lessapprox b_1 -$ gasoline, $\varphi(\bar{x}_2) \lessapprox b_2 -$ light and $\varphi(\bar{x}_2) \lessapprox b_3 -$heavy gas oil, depending on the value of the vector of operating parameters $\bar{x}_2 = (x_4, x_5)$:

$$-\varphi(\bar{x}_2) = 27.50000 + 0.02750x_4 + 3.66667x_2 + 0.00014x_1^2 \le 55\ ^{o}\text{C}, \quad (7)$$

$$-\varphi(\bar{x}_2) = 87.50000 + 0.05469x_4 + 11.66667x_2 + 0.00017x_1^2 \le 175\ ^{o}\text{C}, \quad (8)$$

$$-\varphi(\bar{x}_2) = 97.50000 + 0.07344x_4 + 15.66667x_2 + 0.00023x_1^2 \le 235\ ^{o}\text{C}. \quad (9)$$

Further, based on the above models describing the dependence of criteria and fuzzy constraints on the vectors of input, mode parameters (3) – (9), it is possible to solve the problem of making decisions with fuzzy constraints (1) – (2). To solve decision-making problems in a fuzzy environment (1) – (2) modifying the Pareto principle of optimality, we rewrite the problem in a convenient way by formalizing fuzzy constraints through their accessory functions:

$$\max_{\bar{x}_1 \in X} \sum_{i=1}^{4} \gamma_i \, \mu_C^i(\bar{x}_1), \quad (10)$$

$$X = \left\{ \bar{x}_2 : \max_{\bar{x}_2 \in \Omega} \sum_{q=1}^{3} \beta_q \mu_q(\bar{x}_2) \wedge \sum_{q=1}^{3} \beta_q = 1 \wedge \beta_q \ge 0, q = \overline{1,3} \right\}, \quad (11)$$

where $\gamma_i, i = \overline{1,4} -$ are the weighting coefficients of local criteria; $\beta_q, q = \overline{1,3} -$ are the weighting coefficients of fuzzy constraints set by DM, experts; $\mu_q(\bar{x}_2), q = \overline{1,3}$ – are membership functions evaluating the degree of fulfillment of fuzzy constraints.

Based on the modification and adaptation of Pareto principle of optimality for working in a fuzzy environment, a heuristic method for solving the problem of decision-making in a fuzzy environment (10) – (11) has been developed. The proposed PO+PO heuristic method is iterative and is based on the use of DM's experience, knowledge and intuition in the process of improving and choosing the best solution and is specified to control the operating modes of the main DCU distillation column

The PO+PO heuristic method:

1. DM, experts set the values of the vector of weighting coefficients $\bar{\gamma} = (\gamma_1, \gamma_2, \gamma_3, \gamma_4)$, determining the mutual importance of local criteria based on the condition: $\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4 = 1, \gamma_i \geq 0, i = \overline{1,4}$.

2. The value of the vector of weight coefficients $\bar{\beta} = (\beta_1, \beta_2, \beta_3)$ for constraints is set: $\beta_1 + \beta_2 + \beta_3 = 1, \beta_q \geq 0, q = \overline{1,3}$.

3. The number of steps for each qth coordinate of constraints is determined: $p_q, q = 1,3$.

4. To change the coordinates of the weight vector, the $\bar{\beta} = (\beta_1, \beta_2, \beta_3)$ values of the steps are calculated using the formula: $h_q = {}^{1}/_{p_q}, q = \overline{1,2}$.

5. Changing in the interval [0,1] with the increments calculated in the previous paragraph, a set of weight vectors is determined: where $\bar{\beta}^1, \bar{\beta}^2, \dots, \bar{\beta}^N$, $N = (p_1 + 1) \cdot (p_2 + 1) \cdot (p_3 + 1)$.

6. If the criterion, weight vectors are fuzzy, then term sets are defined for them and membership functions are constructed that vaguely describe them.

7. For each fuzzy constraint, a term set is defined, and an affiliation function is constructed that $\mu_q(\bar{x}_2), q = \overline{1,3}$, evaluates the degree of its fulfillment.

8. The problem of maximizing the integrated criterion (10) obtained by summing the product of local criteria $\mu_C^i(\bar{x}_1), i = \overline{1,4}$ by their weight coefficients $\gamma_i, i = \overline{1,4}$ to the set of acceptable solutions X(11), c, taking into account the condition of fuzzy constraints, is solved. As a result of the solution, the current solutions are determined: $\bar{x}_1(\bar{\gamma}, \bar{\beta}), \bar{x}_2(\bar{\gamma}, \bar{\beta})$ providing the appropriate values of the integrated criterion $\sum_{i=1}^{m} \gamma_i \mu_C^i(\bar{x}_1(\bar{\gamma}, \bar{\beta}))$ and the values of the membership functions of fuzzy constraints $\mu_q(\bar{x}_2(\bar{\gamma}, \bar{\beta})), q = \overline{1,L}$.

9. The current decisions obtained in the previous paragraph are submitted to the DM for analysis of making the final best decision. If the current solutions do not satisfy the DM, then in order to improve the solution, he changes the values of the vectors and/or and the search for a solution is repeated starting from point 4. If the current solutions obtained satisfy the DM, then he chooses the final best solutions based on his preference and proceeds to the next point.

10. Conclusion of the final solutions chosen by the DM, which are the best in the current situation in the production and sales market of manufactured products:

– the best values of the vectors of input and mode parameters $\bar{x}_1^*(\bar{\gamma}, \bar{\beta}), \bar{x}_2^*(\bar{\gamma}, \bar{\beta})$;

– the maximum value of the integrated criterion $\sum_{i=1}^{4} \gamma_i \mu_C^i(\bar{x}_1(\bar{\gamma}, \bar{\beta}))$ when $\bar{x}_1^*(\bar{\gamma}, \bar{\beta})$;

– maximum degrees of fulfillment of fuzzy constraints $\mu_q(\bar{x}_2^*(\bar{\gamma}, \bar{\beta})), q = \overline{1,3},$ when $\bar{x}_2^*(\bar{\gamma}, \bar{\beta})$.

The proposed heuristic method for solving the problem of decision-making in a fuzzy environment is based on a modification of the Pareto principle of optimality for use in a fuzzy environment and will work effectively if DM is possible, experts will determine the weighting coefficients of criteria and constraints. In other situations, similarly to the proposed approach to solving the problem of decision-making in a fuzzy environment, other principles of optimality can be modified and their combinations applied depending on the availability and accessibility of the initial information. This justifies the universality of the proposed approach to solving decision-making problems in a fuzzy environment.

Discussion

The proposed approach is universal for solving the problems of decision-making on controlling the modes of operation of complex, difficult to formalise objects in a fuzzy environment, because depending on the current situation and available information allows to choose and apply different principles of optimality. For convenience, the methods of fuzzy set theory are used to normalize the criterion so that their values vary in the range [0, 1]. And fuzzy constraints are formalized through their accessory functions, which assess the degree of their fulfillment.

The formulation of the problem of decision-making in a fuzzy environment (10) (11) and the proposed heuristic method for solving it are specified to control the operating modes of the main distillation column DCU, with m=4 criteria and L=3 fuzzy constraints. The values of these criteria and constraints in solving this problem are determined on the basis of models (3)(9) developed with the participation of the authors in the work (Orazbayev et al., 2023: 1–17). To apply an advanced approach to the formulation and solution of decision-making problems in a fuzzy environment, it is necessary to take and In the points of the method, where the membership functions of terms describing fuzziness are constructed, Gaussian-type functions can be used using the Fuzzy Logic Toolbox of the MATLAB system, which more adequately describe the fuzzy representations of DM, experts.

The developed heuristic method by modifying Pareto principle of optimality is an iterative method that allows consistently improving solutions based on the use of human and computer capabilities. In (8), the proposed heuristic method for solving a single-criteria problem in which the fuzziness is formalised through membership functions is solved by more appropriate well-known conditional optimisation methods, such as the penalty function method. In the process of solving the problem, the DM analyses the current solutions obtained by the computer and, in order to improve the solution at the next iteration, changes the values of the relevant parameters based on his experience and preference. The final best decisions that satisfy the DM are made by him depending on the current production situation and market demand for the products produced.

If the situation arises that the application of Pareto principle of optimality is difficult and inefficient, it is possible to modify other principles of optimality (principal criterion, maximin, ideal point, equality and others) for fuzzy, similarly develop an appropriate heuristic method to solve the decision making problem in fuzzy environment.

Conclusion

The problem of decision making in a fuzzy environment to manage the modes of operation of ore-formalised technological objects on the example of the main rectification column DCU is formulated and a heuristic method for its effective solution is developed. The obtained formulation of the decision-making problem in fuzzy environment and the proposed method of its solution are based on the modification of Pareto principle of optimality to work in fuzzy environment.

The main conclusions based on the results obtained include:

1. The mathematical models of the main DCU rectification column developed by the authors are selected, allowing to determine the dependence of criteria and constraints on its input, mode parameters.

2. The mathematical formulation of the decision-making problem with fuzzy constraints for controlling the operating modes of the main distillation column DCU is formalised and obtained.

3. A heuristic method for solving the formulated decision-making problem in a fuzzy environment for controlling the operating modes of the object under study based on a modification of Pareto principle of optimality is proposed and described.

In further research of the authors it is planned to formulate decision-making problems in fuzzy environment and to develop heuristic methods of their solution on the basis of modification of other optimality principles. In addition, software implementation of the proposed heuristic methods and creation of computer decision support systems for controlling the operating modes of complex, difficult to formalise objects are planned.

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