ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD)
in the educational program 8D07107 – "Chemical Engineering of Hydrocarbon Compounds"

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INNOVATIVE TECHNOLOGIES FOR EXTRACTING SULFUR COMPOUNDS AND NON-FERROUS METALS FROM HEAVY HYDROCARBON FEEDSTOCK USING A NEW GENERATION OF ENERGY-ACCUMULATING SUBSTANCES

Relevance of the Research Topic

The current state of the petrochemical industry and the energy sector is driving increased interest in the efficient and environmentally friendly processing of heavy hydrocarbon feedstock. With the depletion of light oil reserves and the transition to utilizing fields rich in heavy hydrocarbons, such as Karazhanbas, the development of innovative processing technologies becomes critically important.

Heavy oil is characterized by high density, viscosity, and content of asphaltenes, resins, sulfur compounds, as well as metallorganic complexes of nickel and vanadium. These properties significantly complicate production, transportation, and processing, reducing economic efficiency and increasing environmental impact. The sulfur content in the feedstock leads to the formation of hydrogen sulfide and other toxic compounds, increasing SO_2 emissions into the atmosphere and negatively affecting ecosystems. High metal content deactivates catalysts and causes equipment corrosion, leading to increased production costs.

Existing methods of demetallization and desulfurization, including physical, chemical, and biological approaches, have limitations such as high energy and resource requirements, scalability challenges, and insufficient environmental safety. In this context, technologies based on energy-accumulating materials, such as activated aluminum alloys, open new perspectives for creating effective solutions. These materials can simultaneously act as reactive and sorbent agents, enabling high sulfur and metal extraction efficiency with minimal environmental impact.

The relevance of the topic is further enhanced by global trends in decarbonization and stricter environmental standards for sulfur and metal content in petroleum products. Implementing such technologies will contribute to reducing the carbon footprint and meeting international sustainability commitments. The development of environmentally friendly and resource-efficient processing technologies for heavy hydrocarbon feedstock also aligns with Kazakhstan's strategic priorities for modernizing the petrochemical industry and implementing the "green economy" transition concept.

Thus, this study holds significant scientific, technical, and socio-economic relevance, offering a solution to a critical task—creating a competitive and environmentally safe technology for processing heavy oil in compliance with modern industry requirements.

Research Objective:

To develop an environmentally safe, economically efficient, and high-performance technology for the demetallization and desulfurization of heavy hydrocarbon feedstock from the Karazhanbas field using activated aluminum alloys, aimed at improving oil quality and reducing its environmental impact.

Research Tasks:

1. Conduct a detailed analysis of existing demetallization and desulfurization technologies for heavy hydrocarbons, identifying their limitations and opportunities for improvement.
2. Develop and characterize new composite formulations using activated aluminum alloys for the removal of sulfur and non-ferrous metal compounds from heavy hydrocarbon feedstock.
3. Investigate the capture process of sulfur, nickel, vanadium, and other metal compounds on the surface of activated aluminum alloys.
4. Simulate the thermogasochemical processing of heavy hydrocarbon feedstock under laboratory conditions, studying the effects of temperature and reagent composition on process efficiency.
5. Perform a physicochemical analysis of the properties of crude oil before and after treatment with various solvents and activated aluminum alloys, evaluating changes in sulfur, metal, and other component contents.

Research Objects:

Crude oil from the Karazhanbas field, with high concentrations of sulfur and metals, and energy-accumulating compositions based on activated aluminum alloys.

Research Methods:

The research was conducted using modern high-precision equipment (accuracy class 0.25–0.5). All analytical methods comply with GOST standards, and the experimental results were verified for reproducibility through three repetitions. Methods applied included X-ray fluorescence and elemental analysis, thermogravimetric analysis (TGA-DTA), scanning electron microscopy (SEM), EDX, IR spectroscopy, UV absorption, and fluorescence.

Scientific Novelty:

The concept of using activated aluminum alloys for the demetallization and desulfurization of heavy hydrocarbon feedstock was proposed and scientifically substantiated for the first time. A thermogasochemical processing method for heavy oil was developed and experimentally validated, ensuring deep purification of hydrocarbon feedstock and improving its physicochemical properties.

Key Points for Defense:

1. Activated aluminum alloys demonstrate effectiveness in the processes of removing sulfur compounds and heavy metals from oil.
2. The use of the activated aluminum alloy composition Rau-85 and toluene ensures a reduction in the content of sulfur, nickel, and vanadium in hydrocarbon feedstock by 77%, 75%, and 68%, respectively.
3. A technological process for oil treatment was developed, ensuring high levels of demetallization and desulfurization, as well as improvements in its physicochemical properties.
4. The ecological safety of the proposed method was substantiated by its ability to reduce emissions of sulfur and metal compounds.

Compliance with Scientific Development Directions and Government Programs:

This study was conducted within the framework of grant-funded research projects of the Ministry of Education and Science of the Republic of Kazakhstan (IRN AR09260008) related to the development of environmentally safe technologies for hydrocarbon feedstock processing, including collaborative studies with enterprises in Kazakhstan's petrochemical industry. Parts of the research were carried out at the LRGP (Laboratoire Réactions et Génie des Procédés) in Nancy, France, during a scientific internship.

Author's Personal Contribution, Publications, and Validation of Practical Results:

The author’s personal contribution includes the analysis of literature, conducting the experimental part of the work, performing physicochemical analysis methods, and summarizing and interpreting the obtained experimental data and conclusions.

Validation of the Work:

The dissertation materials were presented and discussed at the following scientific and practical conferences: "Satbayev Readings-2021" (April 11–12, 2021, Almaty, Kazakhstan); The International Russian-Azerbaijani Scientific Conference dedicated to the 880th anniversary of the great Azerbaijani poet and educator Nizami Ganjavi. **Publications:**

The main results of the dissertation were published in 7 papers, including 2 articles in international scientific journals with a 42nd percentile indexed in Scopus, 1 publication in the "Oil and Gas" journal, and 4 papers in the proceedings of international and national scientific conferences.

Structure and Volume of the Dissertation:

The dissertation consists of normative references, abbreviations, and definitions, an introduction, three chapters, a conclusion, and a list of references. The work is presented on 119 pages and includes 20 tables and 72 figures. The list of references contains 117 sources.