UNIVERSITY OF NOVI SAD
Technical Faculty "Mihajlo Pupin"
Zrenjanin, Republic of Serbia

IIZS Conference

PROCEEDINGS

of the XIV International Conference on

Industrial Engineering and Environmental Protection IIZS 2024

Zrenjanin, Serbia, October 3-4, 2024.

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INTRODUCTION

Department of mechanical engineering and Department of environmental protection of Technical Faculty "Mihajlo Pupin", Zrenjanin, has organized the XIV International Conference Industrial Engineering and Environmental Protection – IIZS 2024.

The topics of scientific conference «IIZS 2024», cover the fields of Industrial Engineering and Environmental protection: Mechanical Engineering, Energetics and process technique, Designing and maintenance, Oil and gas engineering, Health and environmental protection, Environmental management, Occupational safety and Engineering management.

The main goals of the conference are: fostering innovation and expanding knowledge for engineers in industry and environmental protection; supporting researchers in presenting their current research results; establishing new contacts with premier national and international institutions and universities; popularizing the Faculty and its leadership role in our society and immediate environment, to attract a high-quality young individuals to study at our Faculty; cooperating with other organizations, public companies, and industry; initiating the collection of ideas for solving specific practical problems; interconnecting and establishing business contacts; introducing professional and business organizations to the results of scientific and technical research; and presenting scientific knowledge and exchanging experiences in industrial engineering.

We would like to express our gratitude to the partners of the IX International Conference "IIZS 2024" – Aurel Vlaicu University of Arad, Faculty of Engineering, Arad, Romania; University St. Kliment Ohridski, Technical Faculty, Bitola, Macedonia; University Politehnica Timisoara, Faculty of Engineering, Hunedoara, Romania; University of East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo, B&H, Republic of Srpska; and University of Giresun, Faculty of Engineering, Giresun, Turkey – for their support in organizing this event. We are also grateful to all the authors who have contributed their papers to the scientific meeting "IIZS 2024".

We would like to extend our special thanks to the Ministry of Education, Science and Technological Development, Republic of Serbia, and the management of Technical Faculty “Mihajlo Pupin”, University of Novi Sad, for supporting the organization of the Conference "IIZS 2024".

The IIZS Conference has become a traditional annual meeting for researchers from around the world. We are open to and grateful for any useful suggestions that could help make the next, XV International Conference on Industrial Engineering and Environmental Protection even better, both organizationally and programmatically.

Chairman of the Organizing Committee
Asst. Prof. Jasna Tolmač, PhD

Zrenjanin, October 3-4, 2024.

CONTENTS

PLENARY SESSION

Session 1: Mechanical Engineering

Doi: 10.46793/IIZS24.071K

MECHANICAL CENTRIFUGATION AND PYROLISIS AS A COMBINED PROCESS FOR EFFICIENT MANAGEMENT OF OIL REFINERY SLUDGE

Research paper

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Abstract: This work presents a review of mechanical centrifugation and pyrolysis, two prominent techniques used for the efficient management of oil refinery sludge. The petrochemical industry produces large quantities of hazardous oily sludge, which demands complex and costly treatment methods due to its diverse composition. However, a major component of this sludge is crude oil, which holds significant recycling potential. As a result, various technologies, including combined processes, have been developed to recover crude oil from sludge. This study evaluates the effectiveness of combining mechanical centrifugation and pyrolysis, specifically focusing on their oil recovery capabilities. The primary objective is to explore the development of these recycling technologies while summarizing and comparing their mechanisms, advantages, and limitations.
Key words: Oil sludge, centrifugation, pyrolysis, recycling.

INTRODUCTION

The petroleum industry generates substantial amounts of oily sludge through various stages of oil production, including crude oil exploration, transportation, storage, and refining, [1]. Crude oil production generates approximately 0.1% to 0.5% of oily sludge annually. On average, the petroleum industry produces around 0.3% sludge from crude oil, amounting to an estimated 228.29 million tons per year globally as of 2020, [2].
The waste oil sludge generated includes drilling fluid, petroleum wastewater, sludge from petroleum effluent treatment plants, and bottom tank sludge, [3]. The quantity and characteristics of oily sludge are influenced by factors such as the type of crude oil, storage conditions, downstream processing methods, and the design of refining equipment.
Globally, various techniques are employed for the treatment and disposal of petroleum sludge, including thermal, mechanical, biological, and chemical methods. However, these approaches are generally not economically sustainable.
In addition to the costs associated with the removal, transportation, and landfilling of petroleum sludge, the sludge itself contains numerous toxic compounds. These contaminants include petroleum hydrocarbons, such as aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), with over 33% total petroleum hydrocarbons (TPH) and 550 mg/kg of PAHs present in the sludge. It also contains polychlorinated biphenyls (PCBs) and heavy metals like barium, lead, zinc, mercury, chromium, arsenic, and nickel, [4]. Also, oily sludge contains substantial amounts of oil emulsions, water, heavy metal ions, and other recyclable resources composed of hydrocarbons and refractory petroleum hydrocarbons, which are a renewable energy with high potential value, [5]. The resource utilization of oily sludge can not only effectively reduce the disposal volume and pollution degree of hazardous waste solids but can also reduce the use of nonrenewable resources, [1].

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In recent years, physical recovery and treatment technologies, such as mechanical centrifugation and pyrolysis, as well as combined physical and chemical processes, have been increasingly applied in engineering. These technologies not only enable the efficient recovery of crude oil from oily sludge but also significantly reduce its harmful impact on human health and the surrounding environment.

MATERIAL AND METHODS

Mechanical centrifugation

Mechanical methods for processing oily sludge primarily focus on pretreatment and the separation of oil derivatives (such as oil, fuel oil, paraffin, and bitumen) from water, thereby reducing the water content in the waste. Typically, waste separation involves heating and the addition of reagents (demulsifiers and coagulants), carried out in multiple stages using specially designed centrifuges and decanters, as illustrated in Fig. 1. Phase separation is achieved through the application of centrifugal forces.
Centrifugal separation is influenced by several factors, with the most critical being the viscosity of the oily sludge and sediment, particle size, and centrifugation speed. Additionally, the larger the separation zone during centrifugation, the easier and more efficient the separation process, [1].

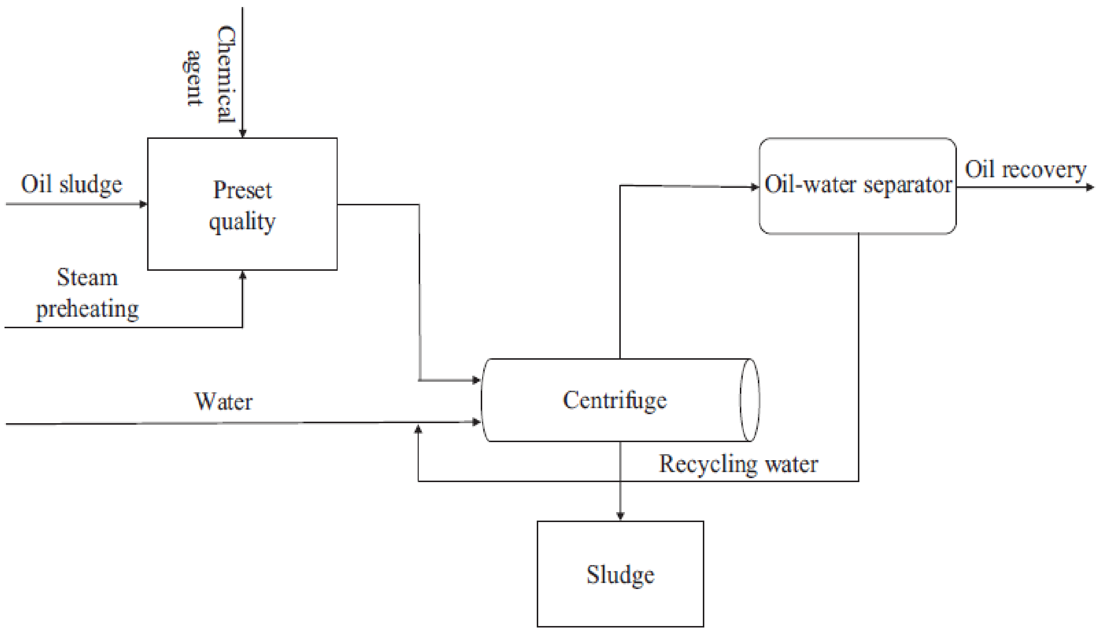

Fig. 1. *Flowchart of recovery of crude oil by mechanical centrifugation [1]*

To enhance centrifugation efficiency and reduce energy consumption, the viscosity of waste oily sludge must be lowered through pretreatment methods such as the addition of organic solvents, demulsifiers, surfactants, steam injection, or direct heating. After mechanical centrifugation, the oily sludge is separated into a solid phase (about 8%), wastewater (about 80%), and a liquid phase (about 12%) that is returned to the processing cycle. The wastewater is sent for further treatment, while the solid phase undergoes additional processing. Water is used during the treatment process and is recirculated, while steam is used to heat the raw input material.

Pyrolysis process

Pyrolysis technology involves heating oily sludge in an oxygen-free environment under slight positive pressure. This process separates oil and organic matter, breaking down the sludge into three components: pyrolysis residue, liquid, and gas. The resulting products, which vary based on the procedural conditions, include char, liquid fuels, and gases. This method is used to convert waste into usable resources, optimizing the recovery of valuable materials from the sludge, [7].

Liquid pyrolysis products contain organic acids, bases, phenols, asphaltenes and hydrocarbons. It can be used as a raw material to produce gasoline, kerosene, oil or liquid boiler fuel.

Pyrolytic oil can also be used as a fuel substitute for furnaces. There are options for applying solid residues (as a filler for rubber-bituminous mastics, paints, etc.).

Heavy metals and other pollutants in oily sludge can be enriched and fixed into a solid residue, which greatly reduces the degree of environmental pollution. The liquid product produced by the pyrolysis process has a good capacity reduction effect and is suitable for storage and transportation; the resulting oil can be directly used for diesel engines; the carbon-containing solid residue can also be reused as an adsorbent, flocculent, soil improver, and so on. However, pyrolysis can be limited by numerous factors, such as temperature, heating rate, characteristics of the sludge and chemical additives.

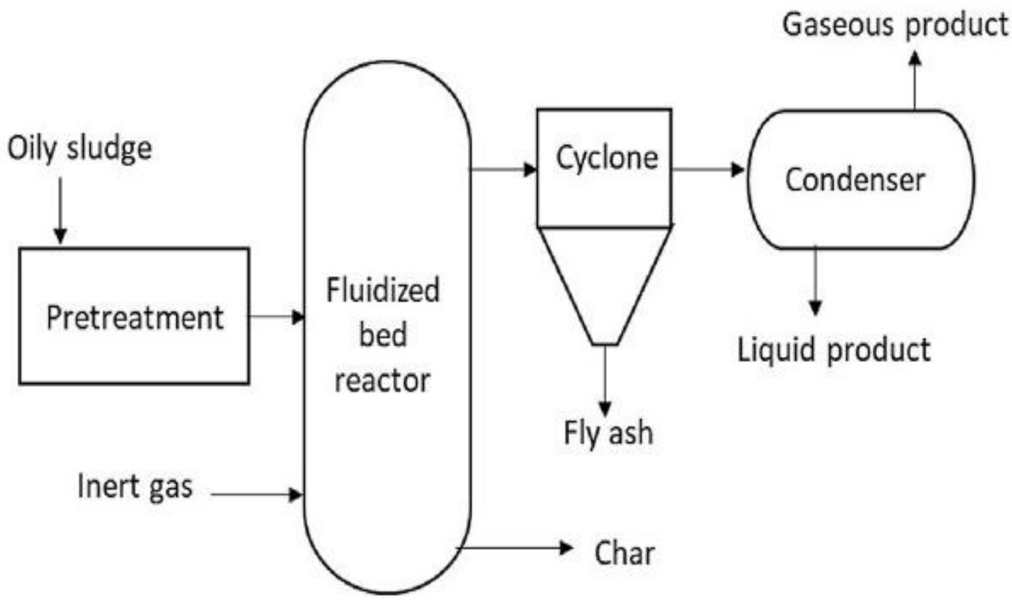

Fig. 2. *Fluidized bed system for oily sludge pyrolysis [8]*

Pyrolysis methods can be roughly categorized into three types, namely ordinary pyrolysis, catalytic pyrolysis, and microwave pyrolysis.

RESULTS AND DISCUSSION

Hazardous waste management option in oil refineries which include application of mechanical centrifugation as a pretreatment technology and pyrolysis as a final treatment has been analyzed. A theoretical scenario has been examined with the application of material flow analysis. The following picture shows the material flow analysis for the assumed scenario, depicting the percentage of oily sludge throughout the entire treatment system.

It is assumed that the efficiency of water phase separation during the mechanical centrifugation process is approximately 80% which depends on the material characteristics but it is in accordance with the literature data, while the remaining fraction comprises two

phases: the liquid fraction (approximately 12%), which can be returned to the processing of crude oil, and the solid fraction that requires final treatment (8%), [8,9]. The remaining solid fraction is further treated through the pyrolysis process.
The pyrolysis of oily sludge yields three main products: oil, gas, and char. When conducting the pyrolysis process, it is crucial to control both the quantity and quality of these products. Among these three products, char still contains a significant amount of organic matter, resulting in a higher char yield compared to ash content. Given the substantial presence of inorganic materials in oily sludge, char yields tend to be relatively high. Throughout the pyrolysis process, a majority of the organic components are released as gaseous products. Oil, distinguished by its high calorific value and ease of storage, is the most desirable product for recycling.
However, without the use of catalysts and additives, only a small quantity of oil is typically obtained at high temperatures, [10-12]
During the pyrolysis process, the assumption is that 70% of the material is converted into pyrolytic oil, 10% of the material transforms into a solid phase (coke) and 10% of input material is transformed to inert residue which requires adequate final disposal, and the remaining 10% is converted into the gaseous phase known as pyrolytic gas, respectively, [13].

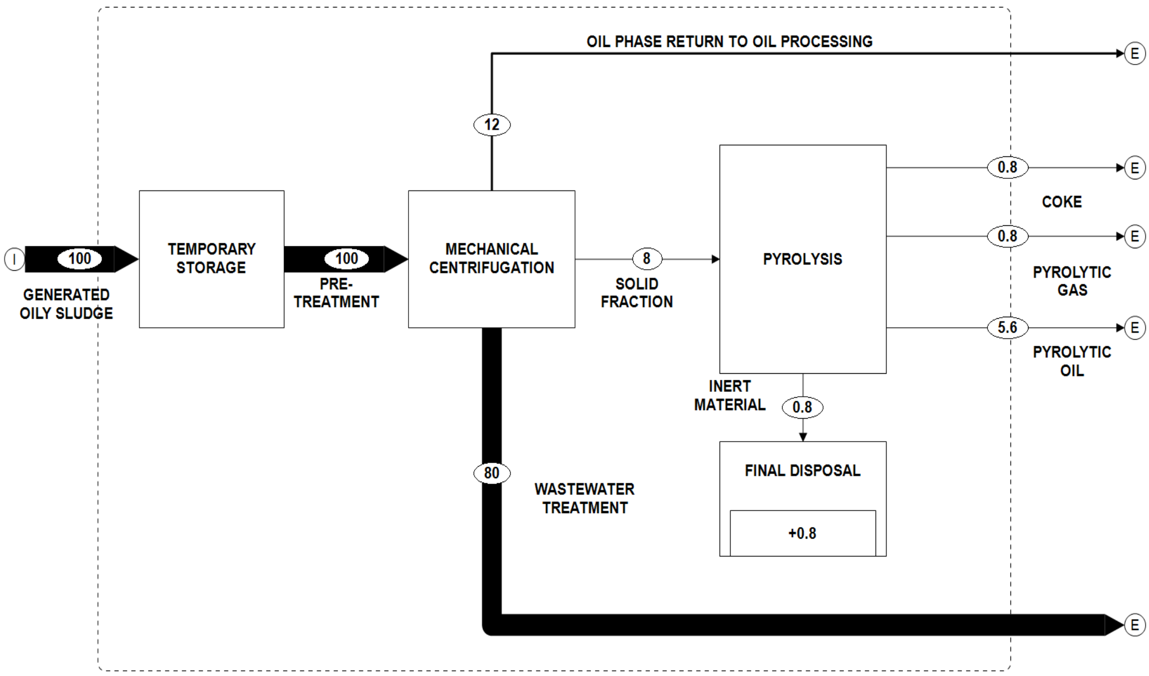

Fig. 3. *Material flow analysis of theoretical scenario*

By applying material flow analysis, it can be concluded that the management system for oily sludge, which involves pretreatment through centrifugation and final treatment through pyrolysis, is highly efficient. At the end of the process, only 0.8% of the initial mass of material require final disposal, achieving a system efficiency of nearly 99%.
There are certain limitations to the use of the analyzed technologies. Before the centrifugation process, the material being treated should ideally be in a minimally liquid form, with a maximum particle size of less than 50 mm before mixing. After mixing and passing through a vibrating screen, the maximum particle size should be 20 mm before entering the decanter centrifuge. Mechanical centrifuges can be used to treat oily sludges and sediments with suspended material concentrations of up to 15%. However, it is necessary to add additional water during the mixing and heating phase for effective separation. Heating the incoming oily sludge and sediment to a temperature of 60-70°C using steam is essential to

introduce the required reagents and achieve efficient phase separation. Some limitations for pyrolysis technology include: pyrolysis process requires an input moisture concentration below 50%, necessitating pretreatment, also applying pyrolysis leads to significant emissions of pollutants into the atmosphere which requires the use of expensive equipment for gas cleaning and finally secondary waste disposal needs to be addressed.
The advantages of using mechanical pretreatment through centrifugation include: Effective Separation: Centrifugation efficiently separates different phases of a mixture, allowing for the extraction of valuable components; Improved Efficiency: It enhances the overall efficiency of subsequent treatment processes by reducing the initial concentration of impurities and contaminants. Reduced Environmental Impact: By removing contaminants before further processing, it helps minimize environmental pollution and ensures compliance with regulatory standards. Cost Savings: Mechanical pretreatment can lower operating costs by reducing the burden on downstream equipment and processes. Enhanced Product Recovery: It aids in the recovery of valuable materials and energy from waste streams, maximizing resource utilization. Process Optimization: It contributes to the overall optimization of the treatment process, resulting in improved product quality and yield. Reduced Maintenance: Centrifuges are known for their robustness and durability, reducing the need for frequent maintenance and downtime. Versatility: Centrifugation can be applied to various industries and processes, making it a versatile option for waste treatment and material recovery.
The advantages of using pyrolysis include:

- Efficiency in Hydrocarbon Removal: Pyrolysis is effective in removing hydrocarbons, with removal rates ranging from 50% to 90%;
- Swift and Efficient Process: Pyrolysis is known for its speed and efficiency in breaking down complex materials;
- Utilization of Pyrolytic Gas: The pyrolytic gas generated can be utilized within the plant's processes, contributing to resource optimization;
- Low Operational Costs: Pyrolysis often involves lower operational costs compared to alternative methods;
- Reuse of Pyrolytic Oil: The obtained pyrolytic oil can be reused in oil processing, leading to cost savings and profit generation.

CONCLUSION

In the petroleum industry, the generation of oily sludge is inevitable, and this presents a global challenge in its treatment and management due to its hazardous nature.
The choice of the most suitable treatment method may be influenced by various factors, including the composition of the oily sludge, treatment capacity, costs, and the applicable disposal standards.
The management of oily sludge generated during the storage and handling of crude oil necessitates the implementation of suitable procedures to minimize its volume and extract valuable materials and energy from it. Efficient management strategies aim to mitigate the toxicity of oily waste and minimize potential negative environmental impact.
Management options for both oil recovery and reducing the volume of sludge for disposal encompass various techniques. The choice of the most suitable technology depends on the characteristics of the oily sludge, treatment capacity, operational and maintenance costs, and the geographical location. In some cases, an appropriate management decision may involve integrating different processes. In this case the management system for oily sludge, which involves pretreatment through centrifugation and final treatment through pyrolysis, is highly efficient with numerous advantages.
Utilizing a combination of mechanical centrifugation and pyrolysis can result in significantly higher efficiency compared to using each technology individually. Moreover, this approach helps mitigate the limitations and drawbacks associated with individual technologies, making it a viable management option for handling hazardous oily sludge generated in oil refineries.

REFERENCES

[1] Hui, K., Tang, J.,Lu H., Xi, B., Qu, C., Li, J., Status and prospect of oil recovery from oily sludge:A review, Arabian Journal of Chemistry, No 13, pp. 6523–6543, 2020.
[2] Jagaba, A.H., Kutty, S.R.M., Lawal, I.A., Birniwa A.H., Affam A.C., Yaro N.S.A., Usman, A.K., Umaru I., Abubakar S., Noor A., Soja U.B., Yakubu A.S., Circular economy potential and contributions of petroleum industry sludge utilization to environmental sustainability through engineered processes - A review, Cleaner and Circular Bioeconomy, vol 3, 100029. 2022.
[3] Affam, A.C., Petroleum sludge treatment and disposal: A review, Environmental Engineering Research 24(2), pp 191-201, 2019.
[4] Bojes, H.K., Pope P.G., Characterization of EPA’s 16 priority pollutant polycyclic aromatic hydrocarbons (PAHs) in tank bottom solids and associated contaminated soils at oil exploration and production sites in Texas, Regul. Toxicol. Pharmacol.47:pp. 288-295, 2007.
[5] Hu, G., Feng, H., He, P., Li, J., Hewage, K., Sadiq, R., Comparative life-cycle assessment of traditional and emerging oily sludge treatment approaches. J. Clean. Prod, vol 251, 119594, 2020.
[6] Philemon, Z.B., Benoit, N.M., Treatment of conditioned oily sludge from Cameroon petroleum refinery by centrifugation. Int. J.Environ. Sci, vol 3, pp. 1373–1382, 2013.
[7] Fonts, I., Gea, G., Azuara, M., Ábrego, J., Arauzo, J., Sewage sludge pyrolysis for liquid production: A review. Renew. Sust. Energ.Rev., vol 16, pp. 2781-2805, 2012.
[8] Hochberg, S., Y., Tansel, B., Laha, S., Materials and energy recovery from oily sludges removed from crude oil storage tanks (tank bottoms): A review of technologies, Journal of Environmental Management, vol 305, 114428, 2022.
[9] Zhao, Y., Yang, Z., Niu, J., Du, Z., Federica, C., Zhu, Y., Yang, K., Li, Y., Zhao, B., Helmer Pedersen, T. H., Liu, C., Emmanuel, M., Systematical analysis of sludge treatment and disposal technologies for carbon footprint reduction, Journal of Environmental Sciences, vol 128, pp. 224–249, 2023.
[10] Wang, Z., Gong, Z., Wang, Z., Fang, P., Han, D. A., TG-MS study on the coupled pyrolysis and combustion of oil sludge. Thermochim. Acta, vol 663, pp.137-144, 2008.
[11] Song, Q., Zhao, H., Jia, J. Characterization of the products obtained by pyrolysis of oil sludge with steel slag in a continuous pyrolysis-magnetic separation reactor. Fuel, vol 255, pp. 115711, 2019.
[12] Gong, Z., Liu, C., Wang, M., Wang, Z., Li, X., Experimental study on catalytic pyrolysis of oil sludge under mild temperature. Sci. Total Environ, vol. 708, pp. 135039, 2020.
[13] Wang, Z., Gong, Z., Wang, Z., Li, X., Chu, Z., Application and development of pyrolysis technology in petroleum oily sludge treatment, Environ. Eng. Res. 26(1), pp. 190460, 2021.