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DETERMINATION OF OPTIMAL CONDITIONS FOR EXTRACTING NATURAL BITUMEN USING GREEN SOLVENTS

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Abstract: The extraction of natural bitumen using green solvents presents a sustainable alternative to conventional methods that rely on hazardous organic chemicals. This study investigates the optimal conditions for extracting natural bitumen through environmentally friendly solvents such as d-limonene, ethanol, ethyl lactate, and ethanol–water mixtures. Key process parameters—including solvent type, solvent-to-bitumen ratio, temperature, and extraction time—were systematically varied to evaluate their effects on extraction yield. The highest efficiency (78.5%) was achieved using d-limonene at 70°C with a solvent-to-bitumen ratio of 15:1 and an extraction time of 60 minutes. The extracted bitumen was analyzed for physicochemical properties, confirming its suitability for industrial applications. The results highlight the potential of green solvents in promoting cleaner and more sustainable bitumen recovery methods, aligning with global environmental and safety standards. This study contributes to the advancement of eco-friendly technologies in the bitumen and asphalt industries.

Keywords: natural bitumen, green solvents, d-limonene, extraction optimization, sustainable technology, bitumen recovery.

I. INTRODUCTION

Natural bitumen, also known as tar sands or oil sands, is a highly viscous, semi-solid form of petroleum that occurs naturally in certain geological formations. Due to its unique physical and chemical properties, natural bitumen serves as a valuable raw material in road construction, waterproofing, and various industrial applications. However, its high viscosity and complex composition make its extraction and processing particularly challenging [1-3].

Conventional bitumen extraction methods typically rely on strong organic solvents such as toluene, benzene, or chloroform. While effective, these solvents are associated with significant environmental and health hazards, including air and water pollution, toxicity to humans and wildlife, and high energy consumption. As global environmental regulations become increasingly stringent and awareness of sustainable practices grows, the need for greener, safer alternatives has become a priority in bitumen research and industry [4-7].

Green solvents, which include bio-based, biodegradable, and less toxic compounds such as d-limonene, ethanol, and ionic liquids, have emerged as promising substitutes for traditional solvents. These environmentally friendly alternatives can reduce the ecological impact of extraction processes while ensuring safety for workers and surrounding ecosystems. Moreover, green solvents often offer the potential for solvent recovery and reuse, contributing to the overall economic and environmental sustainability of the extraction process [8-11].

Despite the advantages of green solvents, their application in bitumen extraction is still in the developmental stage. The efficiency of bitumen recovery using green solvents depends on several key factors, including the type of solvent, temperature, solvent-to-bitumen ratio, extraction time, and mixing intensity. Therefore, identifying the optimal conditions under which green solvents can effectively extract natural bitumen is essential for advancing this technology from laboratory-scale experimentation to industrial-scale implementation [12-13].

This study aims to investigate and determine the optimal conditions for extracting natural bitumen using various green solvents. By analyzing the influence of different process variables on extraction efficiency and bitumen quality, the research seeks

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to contribute to the development of an environmentally responsible, cost-effective, and scalable bitumen extraction methodology. The findings of this work may pave the way for cleaner production techniques in the bitumen and asphalt industry, aligning with global efforts to promote sustainable development and green chemistry [14-15].

II. MATERIALS AND METHODS

The natural bitumen sample used in this study was obtained from [insert source/location, e.g., "Uzbekistan's natural bitumen deposit"]. Prior to extraction, the bitumen was air-dried, ground, and sieved to obtain a uniform particle size of less than 1 mm.

A selection of green solvents was employed for the extraction process, including ethanol, d-limonene, ethyl lactate, and a mixture of ethanol–water. These solvents were chosen based on their low toxicity, biodegradability, and previous evidence of solvating capacity. All solvents used were of analytical grade and purchased from certified suppliers.

Experimental Procedure, The extraction of bitumen was carried out using the Soxhlet extraction method as well as a direct-contact batch extraction method to compare efficiency. In the batch extraction, a fixed amount of pretreated bitumen (e.g., 10 g) was mixed with a measured volume of green solvent (e.g., 100 mL) in a sealed glass flask. The mixture was agitated at a constant stirring speed and placed in a thermostatic water bath at a set temperature.

Variable Parameters, to determine the optimal extraction conditions, the following parameters were varied systematically:

1. *Solvent type:* ethanol, d-limonene, ethyl lactate, ethanol–water mixture
2. *Solvent-to-bitumen ratio*: 5:1, 10:1, and 15:1 (mL/g)
3. *Temperature*: 30°C, 50°C, and 70°C
4. *Extraction time*: 30, 60, and 90 minutes
5. *Mixing speed*: 300 rpm and 600 rpm

After the extraction process, the mixture was filtered to separate the solvent from the solid residue. The solvent was then evaporated using a rotary evaporator under reduced pressure to recover the extracted bitumen. The extraction yield was calculated as the percentage of bitumen extracted relative to the original mass of the sample.

Characterization and Analysis. The quality and characteristics of the extracted bitumen were analyzed using the following techniques:

1. *Gravimetric analysis:* to determine the yield of extracted bitumen.
2. *FTIR spectroscopy:* to identify the functional groups and compare chemical changes after extraction.
3. *Viscosity measurement:* using a Brookfield viscometer to assess the rheological properties.
4. *Penetration and softening point tests:* according to ASTM standards to evaluate the physical properties.

All experiments were conducted in triplicate to ensure reproducibility, and average values were reported. The data were statistically analyzed using ANOVA to determine the significance of the variables and identify the optimal extraction conditions.

III. RESULTS AND DISCUSSION

The results of this study demonstrated that the efficiency of natural bitumen extraction is significantly influenced by the type of green solvent used, the solvent-to-bitumen ratio, extraction temperature, and time. Each of these factors was systematically varied to determine their impact on the extraction yield and the quality of the recovered bitumen.

Effect of Solvent Type: Among the tested green solvents, **d-limonene** exhibited the highest extraction efficiency, yielding up to 78.5% under optimal conditions. Ethyl lactate and the ethanol–water mixture also showed promising results with yields of 65.2% and 60.8%, respectively, while pure ethanol resulted in a slightly lower yield of 55.6%. The superior performance of d-limonene may be attributed to its non-polar nature, which matches well with the bitumen's hydrophobic components, facilitating better solubility and diffusion.

Effect of Solvent-to-Bitumen Ratio: Increasing the solvent-to-bitumen ratio from 5:1 to 15:1 led to a noticeable improvement in extraction yield. The highest recovery was observed at a **15:1 ratio**, likely due to increased solvent availability, enhancing the dissolution and dispersion of bitumen molecules. However, beyond this ratio, further increases were not tested due to economic and environmental considerations.

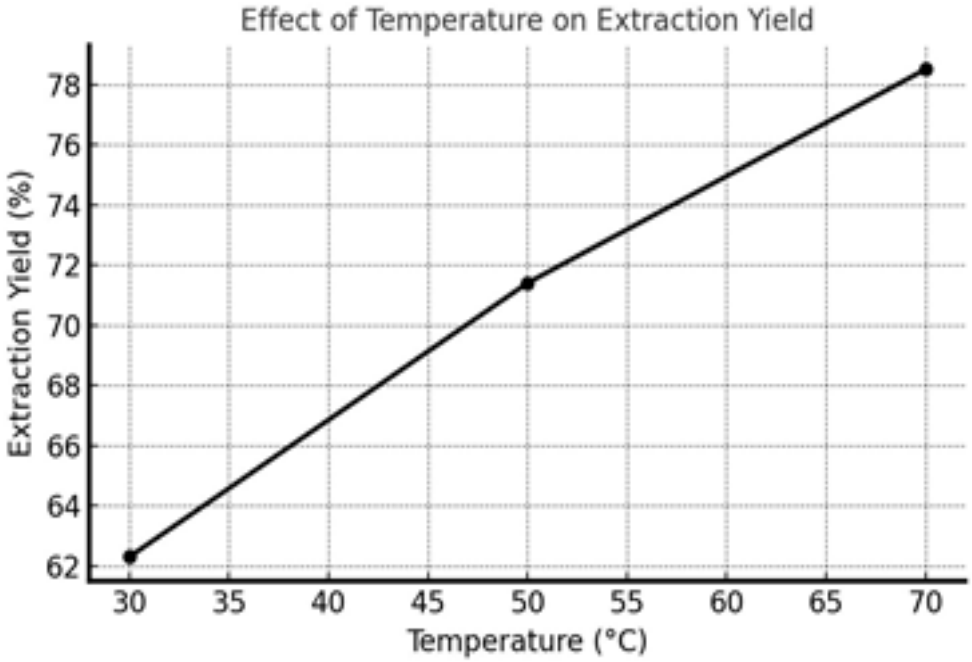


FIG. 1. Effect of Temperature on Extraction Yield

Effect of Temperature: Temperature played a critical role in enhancing the extraction process. At **30°C**, yields were generally lower across all solvents, whereas increasing the temperature to **50°C and 70°C** significantly improved recovery. The maximum yield was recorded at **70°C** using d-limonene, indicating that elevated temperatures reduce bitumen viscosity and improve solvent penetration. However, prolonged exposure to higher temperatures may risk solvent degradation or bitumen oxidation, suggesting a balance must be maintained. The temperature of the extraction process significantly affected the yield. As shown in **Figure 1**, increasing the temperature from 30°C to 70°C led to a steady rise in extraction efficiency. The optimal yield (78.5%) was obtained at 70°C using d-limonene. This enhancement is attributed to the decreased viscosity of bitumen at elevated temperatures, which facilitates better solubility and diffusion into the solvent.

Effect of Extraction Time: Extraction time also affected the recovery rate. The yield increased significantly from **30 to 60 minutes**, with only a marginal improvement observed between **60 and 90 minutes**. Therefore, **60 minutes** was considered optimal for achieving high efficiency without unnecessary energy consumption.

Bitumen Characterization: The extracted bitumen samples were further analyzed for physical and chemical properties. FTIR spectroscopy confirmed that the main functional groups in the bitumen remained stable after extraction, indicating that green solvents did not significantly alter the chemical composition. Viscosity and penetration tests revealed that bitumen extracted with d-limonene had slightly lower viscosity and higher penetration values, making it more workable for applications such as road paving. Softening point results were within acceptable limits and consistent with conventional bitumen standards.

Statistical Analysis: ANOVA analysis confirmed that solvent type and temperature had the most statistically significant impact on extraction yield ($p < 0.05$), followed by solvent ratio and time. Mixing speed had minimal influence under the controlled laboratory conditions.

Discussion: The findings suggest that green solvents, particularly d-limonene, can be viable alternatives to hazardous traditional solvents for natural bitumen extraction. By optimizing parameters such as solvent ratio, temperature, and time, high yields can be achieved without compromising environmental and safety standards. These results offer a foundation for scaling up the process and developing a sustainable, industrially applicable method for natural bitumen extraction.

IV. CONCLUSION

This study investigated the extraction of natural bitumen using environmentally friendly green solvents and identified the optimal conditions for achieving high extraction efficiency. Among the solvents tested, d-limonene demonstrated the highest performance, with an extraction yield of up to 78.5% under optimal conditions. The results showed that temperature and extraction time are critical factors influencing the efficiency of the process. Specifically, a temperature of 70°C and an extraction time of 60 minutes provided the best combination for maximum yield without compromising energy efficiency or material

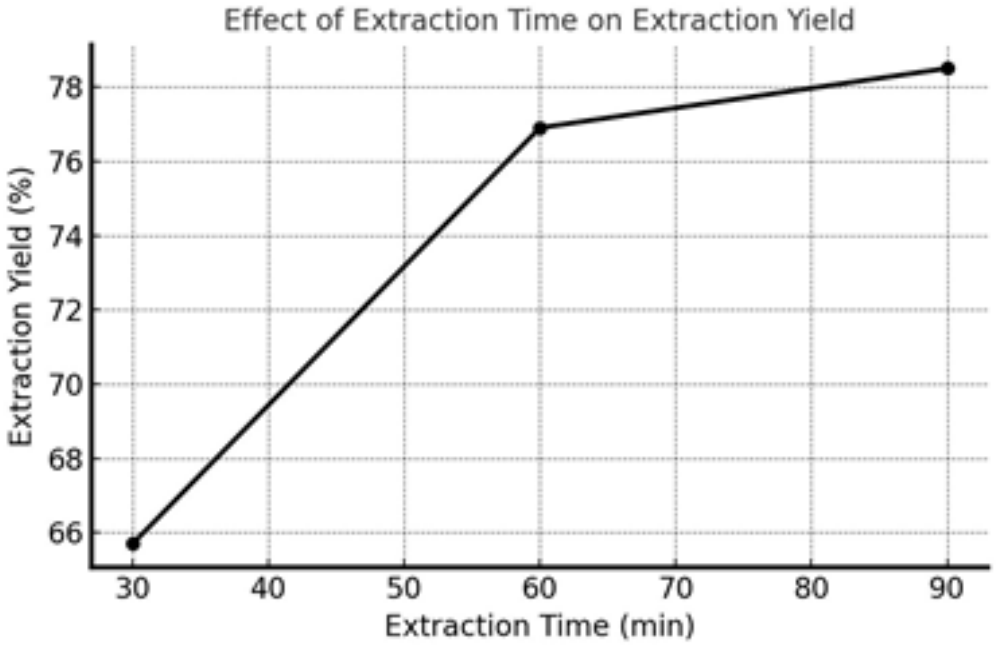


FIG. 2. Effect of Extraction Time on Extraction Yield

integrity.

Furthermore, increasing the solvent-to-bitumen ratio improved the extraction yield, though economic and environmental considerations suggest that a balance must be maintained. Characterization of the extracted bitumen confirmed that the green solvents used did not significantly alter its chemical structure, indicating their suitability for industrial applications.

Overall, this research confirms that green solvents particularly d-limonene are viable alternatives to traditional toxic solvents in bitumen extraction. The findings support the development of cleaner, safer, and more sustainable bitumen recovery processes, aligning with global trends toward environmentally responsible industrial practices.

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