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Enhanced transportation of crude oil from the East Baghdad field using kerosene mixed with silica nanoparticles and the presence of surfactant

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Abstract

This study investigates the enhancement of heavy crude oil transportability from the East Baghdad Oil field through viscosity and density reduction. The proposed approach combined the use of silica (SiO_2) nanoparticles, kerosene, and the anionic surfactant SDBS. Prior to application, the silica nanoparticles were thoroughly characterized using thermogravimetric analysis (TGA), X-ray diffraction (XRD), atomic force microscopy (AFM), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (SEM-EDX). These techniques confirmed the particles' thermal stability, crystalline structure, nanoscale morphology, and elemental composition, validating their suitability for crude oil modification. A nanofluid was formulated with 18 vol% kerosene, 2 wt% SiO_2 nanoparticles, and 10wt% surfactant relative to nanoparticle mass. The mixture was dispersed ultrasonically under controlled thermal and temporal conditions. Optimal performance was achieved at 75 °C and 60 minutes of mixing, reducing viscosity from 58.15 cP to 16.53 cP and increasing API gravity from 19.67 to 28.84. Further enhancement was achieved with increased additive concentrations of 30% vol. kerosene, 3,000 ppm SiO_2, and 300 ppm surfactant, yielding a viscosity of 5.5 cP and an API gravity of 32.67. These results correspond to improvements of 90.5% and 66%, respectively. Control experiments using kerosene alone highlighted the superior efficiency of the ternary system. Given its affordability and availability, kerosene contributes to the practicality of this technique, offering a scalable and economically viable strategy for upgrading heavy crude oil in real-field applications.

Keywords: Heavy crude oil; East Baghdad field; Reducing viscosity; Density; Nanoparticles; Silica; Kerosene; Surfactant.

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1- Introduction

Transporting heavy crude oil poses persistent technical and economic challenges, particularly when the oil exhibits high viscosity and density, as is the case with crude oil extracted from the East Baghdad field [1]. These properties hinder efficient pipelines [2]. Efficient crude oil transportation is a key component of the petroleum value chain, particularly in regions where oil properties present significant flow challenges, which increase demand for energy-intensive pumping and increase the risk of sedimentation and flow instability [3, 4]. In regions with infrastructure constraints, conventional mitigation strategies such as heating or dilution are often impractical, required alternative solutions [5]. The East Baghdad oil field, one of Iraq's major but technically demanding fields, produces crude oil characterized by medium to high viscosity, elevated density, and a relatively complex composition of heavy hydrocarbons, resins, and asphaltenes [6]. These properties contribute to flow resistance during pipeline transport, increasing energy requirements and operating costs [7]. Over the past two decades, significant efforts have been made to enhance the mobility of heavy and medium crude oils through various techniques, including thermal methods, chemical additives (such as pour point reducers and drag reducers), and blending with lighter hydrocarbons [8]. However, many of these approaches face limitations, ranging from environmental concerns to economic inefficiencies and limited long-term effectiveness [9]. In response, nanotechnology has emerged as a promising alternative in petroleum engineering [10]. Nanoparticles, due to their tiny size and high surface-to-volume ratio, can interact with crude oil components at the molecular level, modifying rheological behavior [11]. Silica (SiO_2) nanoparticles have shown potential in reducing viscosity and altering surface tension by disrupting the intermolecular forces between heavy fractions [12, 13]. Iron oxide nanoparticles have also demonstrated promise, practically in respond to magnetic fields, providing controllable flow enhancement. In response to these limitations, the use of low-viscosity solvents, such as kerosene, has gained attention due to their ability to disrupt molecular interaction, especially those involving asphaltenes and resins, resulting in a reduction in overall viscosity [14, 15]. However, kerosene alone is often limited to heavier crude oils, necessitating exploration of

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complementary additives that can further enhance flow behavior [16]. Recent research has highlighted the potential of nanotechnology in this field. Due to their small size and large surface area, nanoparticles effectively interact with heavy oil components, disrupting their microstructures and enhancing dispersibility [17]. Studies, such as those conducted by El-Diasty and Aly [18], have shown that silica nanoparticles can significantly reduce the viscosity of heavy crude oil when dispersed in hydrocarbon media. Similarly, Faruk Yakasai et al. [19] reported improved flow and stability properties in emulsified systems using iron oxide nanoparticles, emphasizing their potential as rheological modifiers. Building on these insights, the present study investigates the combined use of kerosene and two nanoparticle types, silica (SiO_2) and iron oxide (Fe_3O_4) to enhance the transportability of East Baghdad crude oil. The research focuses on assessing key parameters such as viscosity and density to develop a scalable and economically viable solution for pipeline operations in Iraqi oil infrastructure.

2- Materials and methods

2.1. Feedstock

The crude oil sample used in this investigation was collected from a heavy oil field located east of Baghdad, Iraq. This oil is characterized by its high viscosity and considerable impurity content, making it a suitable candidate for upgrading studies. The kerosene obtained from Baiji refinery was selected as the diluting solvent due to its low viscosity, high API gravity, and low impurity levels, which make it practical for reducing the viscosity and improving the flow properties of heavy crude. The chemical composition and physical characteristics of the crude oil are as follows: vanadium content of 109.67 ppm, nickel content of 42.65 ppm, sulfur content of 4.4 wt.%, nitrogen ranging from 0.3 to 0.5 wt.%, and asphaltene content of 6.294 wt.%. The API gravity at 60°F was recorded as 19.63°, with a viscosity of 58.15 cP at 25°C. The water content was 2.7 vol.%, while the elemental analysis showed iron at 0.78 ppm, hydrogen at 10.11 wt.%, nitrogen at 1.53 wt.%, and carbon at 85.15 wt.%. Baiji kerosene exhibited significantly lighter properties, with a vanadium content of 0.85 ppm, nickel at 0.57 ppm, sulfur at 0.08 wt.%, and nitrogen at 30 ppm. The asphaltene fraction was minimal, at 0.16 wt.%. API gravity was measured at 47.6°, and the viscosity was found to be 1.65 cP at 25°C. The water content was only 0.036 vol.%, and elemental analysis indicated iron at 0.35 ppm, hydrogen at 13.51 wt.%, nitrogen at 0.06 wt.%, and carbon at 86.31 wt.%. Viscosity was measured using a standard capillary viscometer following ASTM D446 specifications. The API gravity and density values were determined using an automatic digital density meter (Model: DDM 2911 PLUS, Serial No: A25593), which offers high precision in density and specific gravity measurements essential for petroleum fluid analysis.

2.1.1. Silica nanoparticles (SiO2)

The silica nanoparticles utilized in this study were sourced from Skyspring Nanomaterials, Inc. (USA), with an average particle size of approximately 50 nanometers (APS: 50 nm). Elemental composition analysis of the nanoparticles was conducted using X-ray fluorescence (XRF) spectroscopy, as detailed in Table 1 and Table 2. All preparation and characterization procedures were carried out at Ibn Sina Laboratories in accordance with standardized protocols to ensure the reliability and reproducibility of the data.

Table 1. Physicochemical properties of silica nanoparticles (SiO_2)

Property	Value
Purity	>99%
Color	white
Average Particle Size	50 nm
Density	2.65 g/cm^3
Melting point	1710 ° C
Solubility	Insoluble in water and organic solvents
Chemically Stability	Highly Stable
Specific Heat Capacity	٤80 J/(Kg.K)

Table 2. Elemental composition of silica nanoparticles (SiO_2) by XRF analysis

Element	Percentage %
SiO_2	99.23
Na_2O	0.31
Al_2O_3	0.18
Fe_2O_3	0.12
CaO	0.08
MgO	0.05
K_2O	0.03

The results obtained from the XRF analysis confirm that the silica nanoparticles possess a high degree of purity, making them particularly suitable for advanced applications that require materials with stable and well-defined physicochemical characteristics. Such applications include, but are not limited to, biomedical engineering, nanocomposites, and surface modification technologies.

2.1.2. Surfactant

Sodium dodecylbenzene sulfonate (SDBS) was utilized in this study as an anionic surfactant to enhance the dispersion and stability of nanoparticles within aqueous media. This compound belongs to the sulfonate group and is characterized by the molecular formula $C_{18}H_{29}NaO_3S$, with a molar mass of 348.48 g/mol. Under standard conditions, SDBS appears as a solid substance with a melting point exceeding 300 °C. It is highly soluble in water and remains thermally stable up to approximately 100 °C. These properties make it particularly effective in maintaining homogeneous nanoparticle suspensions and preventing agglomeration during processing and characterization.

2.1.3. Nanoparticles characterization

Comprehensive testing of the silica nanoparticles was conducted at the University of Kashan's laboratories in Iran. These evaluations aimed to characterize the fundamental properties of the nanoparticles, with a particular focus on their thermal stability, size distribution, and structural features. A series of advanced analytical techniques were employed, including Thermogravimetric Analysis (TGA) to assess thermal tolerance, X-ray Diffraction (XRD) to investigate crystalline structure, and Atomic Force Microscopy (AFM) for surface morphology and particle size analysis. Additionally, surface area and porosity characteristics were determined through specific surface area measurements and pore size distribution analyses. These tests provided a detailed understanding of the nanoparticles' physical and thermal behavior, essential for optimizing their performance in targeted applications.

2.2. Experimental setup and procedure

This study aimed to evaluate the effect of a composite of kerosene, silica nanoparticles, and a surfactant (SDBS) on the rheological properties of heavy crude oil from the East Baghdad field, specifically in terms of reducing viscosity and density, and improving the API. Initially, the composite was prepared by adding 0.2% by weight of silica nanoparticles and 0.02% by weight of SDBS to 100 ml of kerosene. This mixture was thoroughly mixed using a magnetic stirrer to ensure complete homogeneity between the three components. The composite was then added at a rate of 18% by volume to the 82% crude oil, and the resulting mixture was thoroughly mixed. The resulting samples were treated using an ultrasonic bath to study the effect of temperature and exposure time on the physical properties of the system. The experiments were conducted at four different temperatures: 20, 40, 60, and 75°C, and for four sample dwell times: 15, 30, 45, and 60 minutes. After treatment, the samples were allowed to cool to room temperature and then subjected to viscosity and density measurements to evaluate the effect of the compound addition on the crude oil properties. All measurements were performed using precise, pre-calibrated equipment, in accordance with approved ASTM standards. These experiments aimed to determine the optimal operating conditions (temperature and time) that achieve the maximum viscosity reduction and the highest API value improvement, as indicators of the effectiveness of the compound in improving the properties of heavy crude oil. Viscosity was measured at 25°C using a capillary viscometer in accordance with ASTM D446. Each measurement was repeated three times to ensure repeatability and accuracy. API gravity and density for each blend were measured using an automatic digital density meter (Model: DDM 2911 PLUS, Serial No: A25593). The instrument was calibrated before each session using certified standard fluids to maintain data reliability. All data were recorded, and the results were analyzed to determine the effectiveness of kerosene in reducing the viscosity and modifying the flow behavior of the heavy crude oil. The changes in API gravity and other physical properties were also evaluated to assess the potential for upgrading through the dilution process. Fig. 1 illustrates a schematic of the process for enhancing heavy crude oil using the compound (kerosene, SiO_2, and surfactant).

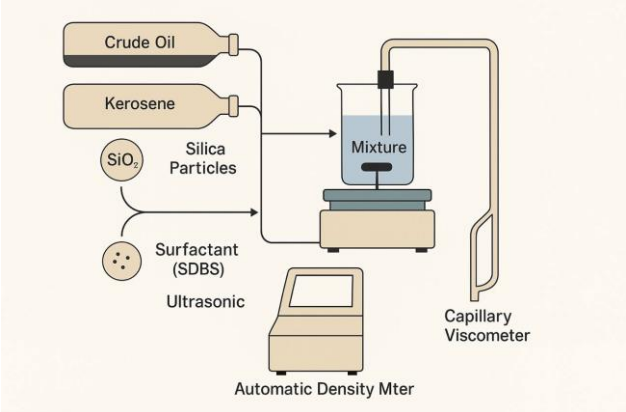

Fig. 1. Schematic clarification of the process of upgrading heavy crude oil using a composite (kerosene, SiO_2, and surfactant SDBS)

2.2.1. Viscosity measurement and analysis

Viscosity is a critical physicochemical property of crude oil and its derivatives, serving as a key indicator of quality and processability. Light crude oils, which typically exhibit lower viscosity, are considered to be of higher quality due to their ease of transport through pipelines, reduced energy requirements, and lower operational costs. Moreover, their refining processes are generally less complex and more energy-efficient compared to those required for heavier, high-viscosity crude oils. In light of this, one of the central objectives of the present study was to investigate methods for reducing the viscosity of heavy crude oil, thereby enhancing its flow behavior and refining efficiency. To achieve this, silica nanoparticles (SiO_2) were added to kerosene in the presence of a surfactant (SDBS), and the resulting mixtures were subjected to ultrasonic treatment to ensure proper dispersion and interaction among the components. The treated samples were then exposed to a series of controlled temperatures and time intervals. At each stage, viscosity measurements were performed to assess the influence of the SiO_2-surfactant-kerosene combination on the crude oil's rheological properties. Viscosity measurements were carried out in accordance with the ASTM D446 standard using a calibrated capillary viscometer. The principle of measurement involves recording the time required for the sample to flow under gravity through a calibrated capillary tube. The kinematic viscosity (μ) was calculated by multiplying the measured flow time (t) by the viscometer constant (k), as shown in Eq. 1.

$$\text{Kinematic Viscosity} = (T * K) \quad (1)$$

Where: T: flow time in seconds, K: viscometer constant = 0.0372 mm^2/s^2.

This method allowed for precise monitoring of viscosity changes resulting from various treatment conditions, offering valuable insight into the efficiency of nanoparticle-assisted upgrading.

2.2.2. API density treatment

Crude oil density represents a fundamental physical property that significantly influences both the classification and processing of petroleum and its derivatives. The API gravity, a standardized measure of density established by the American Petroleum Institute, is widely used to assess the quality of crude oil. Higher API values indicate lighter, more desirable crude oils, which are favored due to their efficiency in yielding greater quantities of valuable light fractions such as gasoline and other distillates during refining. Consequently, API gravity plays a critical role in refinery operations by guiding decisions regarding process design, equipment selection, and overall operational strategy. In contrast, heavier crudes pose greater technical and economic challenges, often necessitating advanced and cost-intensive upgrading technologies. Additionally, lighter oils offer logistical advantages, including reduced energy requirements and lower transportation costs through pipeline systems. This study aims to enhance API gravity by introducing specific additives, namely, kerosene, silica nanoparticles, and surfactants, into crude oil samples. These samples are subjected to ultrasonic treatment under varying time and temperature conditions. Following treatment, the density of each sample is measured, and the corresponding API values are calculated. The collected data are then analyzed to determine the extent to which each additive influences the improvement of API gravity.

3- Results and discussion

3.1. Nanoparticles characterization

Thermogravimetric Analysis (TGA) is a reliable used technique for studying the thermal behavior of materials by monitoring changes in their mass as temperature increases over time [20]. During this process, nanoparticles are heated in a controlled environment, allowing for continuous observation of their weight response to thermal stress [21]. This method is essential for evaluating the thermal stability and decomposition patterns of nanomaterials. In this study, TGA was employed to investigate the thermal stability of silica nanoparticles by examining the changes in their mass when subjected to elevated temperatures [22]. As shown in Fig. 2, the silica nanoparticles exhibited excellent thermal stability, with only minimal weight loss detected as the temperature increased. At the reference temperature of 16°C, the particles retained 100% of their initial mass. Upon heating to 75 °C, the mass retention was 97.8%, indicating a modest loss of 2.2%. Further heating to 200 °C resulting in a weight retention of 95%, confirming a slight additional decrease. These results reflect the strong thermal resistance of the Silica nanoparticles under elevated temperatures. Considering that the maximum temperature used in the experimental procedures was 75 °C, the observed stability ensures that the silica nanoparticles retain their effectiveness throughout the testing process.

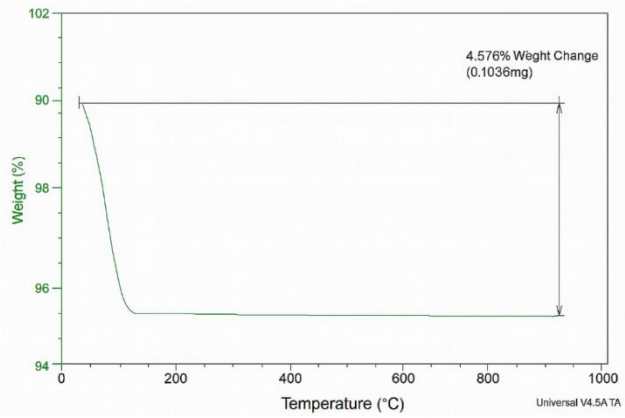

Fig. 2. Thermal weighing analysis (TGA) of silica (SiO_2)

X-ray diffraction (XRD) analyzer is employed to analyze the structural properties of silica nanoparticles by measuring the diffraction of X-rays as they interact with the particles [23]. During the procedure, silica nanoparticles are subjected to a controlled heating environment, while an X-ray beam is directed at the sample. When the X-rays encounter the atoms in the silica structure, the electrons begin to oscillate, emitting electromagnetic waves [24]. These emitted waves are then measured to reveal detailed information about the internal structure of the nanoparticles. This method, known as X-ray diffraction (XRD), is widely used to determine the crystalline and physical structure of nanomaterials [25]. Through this analysis, the key properties of silica nanoparticles, including thermal stability, mechanical strength, and hardness, can be assessed (Shown Fig. 3). XRD is considered one of the most essential techniques for nanoparticle characterization, as the structural and crystalline properties of nanoparticles play a critical role in their effectiveness, particularly in applications such as upgrading heavy crude oil [25].

Atomic Force Microscopy (AFM) is a powerful, high-resolution imaging technique used to examine the surface morphology and structural features of nanoparticles at the nanoscale [26]. This method operates by scanning a sharp probe, often referred to as a nanoneedle, across the surface of the nanoparticles, allowing for the precise characterization of their topographical and mechanical properties [27]. In this study, AFM was utilized to investigate the surface characteristics of silica nanoparticles. The significance of this technique lies in its ability to reveal critical information about surface roughness and texture, which are key factors influencing nanoparticle behavior in various applications. As illustrated in Fig. 4, the surface of the silica nanoparticles exhibits remarkably low roughness, which contributes to

their enhanced stability when combined with kerosene. Moreover, the mechanical properties of the silica particles, as observed through AFM, demonstrate excellent hardness and elasticity, along with strong resistance to chemical degradation. Additionally, the particle size distribution shown in Fig. 4 reveals a predominance of small-sized particles, while the proportions of medium and large particles remain minimal. This distribution suggests a high degree of uniformity and efficiency, as smaller particles offer a significantly larger surface area, enhancing their overall performance and reactivity in the experimental processes carried out in this study.

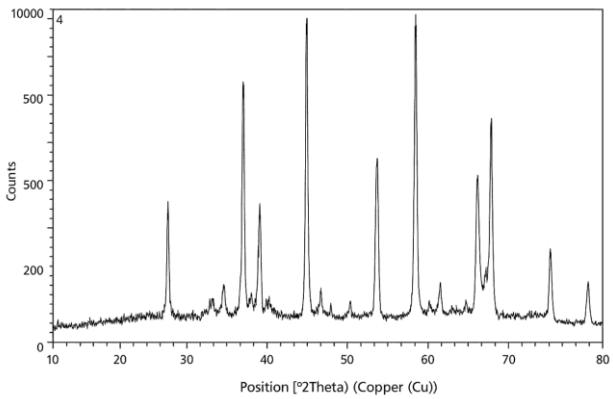

Fig. 3. X-ray analysis (XRD) of silica (SiO_2)

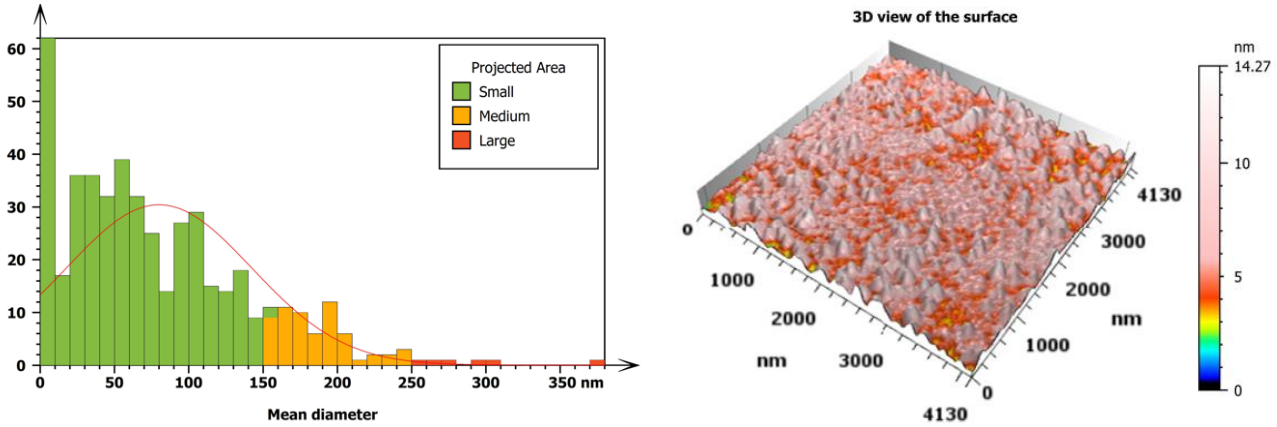

Fig. 4. Atomic force microscopy (AFM) analysis of silica (SiO_2)

A scanning electron microscope (SEM) was employed to investigate the structural and surface characteristics of silica nanoparticles using advanced microscopic techniques [28]. High-resolution imaging revealed critical insights into particle size, spatial distribution, and potential agglomeration [29]. The nanoparticles exhibited a uniform size range and an approximately spherical morphology. To further assess the elemental composition, energy-dispersive X-ray spectroscopy (EDX) was conducted in conjunction with scanning electron microscopy (SEM) [30]. The resulting images, as presented in Fig. 5, confirmed that the elemental constituents were present in ratios closely matching the theoretical expectations, indicating a high level of material purity and consistency in the synthesis process. The integration of SEM and EDX analyses offered a thorough understanding of the chemical and structural attributes of the silica nanoparticles [31].

As presented in Table 3, the elemental analysis of the silica nanoparticles confirms the chemical identity of the sample used in this study as silicon dioxide (SiO_2). The analysis reveals that the nanoparticles are primarily composed of two key elements, silicon (Si) and oxygen (O), which together constitute the fundamental structure of silica. This compositional purity is a critical factor in ensuring the consistency and reliability of the experimental results. The absence of significant impurities or foreign elements further supports the high quality of the nanoparticles, which is essential for applications that demand precise chemical behavior. In addition to confirming the material's identity, such elemental analysis provides insight into the stoichiometric ratio between silicon and oxygen, typically close to 1:2, which is characteristic of high-purity silica. This ratio directly influences the physicochemical properties of the nanoparticles, including thermal stability, surface reactivity, and compatibility with other materials used in the study, such as kerosene and surfactants. Therefore, the data presented in Table 3 not only validates the use of silica nanoparticles in experimental procedures but also highlights their suitability for advanced applications requiring high material integrity.

Table 3 presents the elemental composition of the nanostructured silica (SiO_2) particles used in this study, as determined by energy-dispersive X-ray spectroscopy (EDS). The results clearly indicate that the sample is composed almost exclusively of two elements: oxygen (O) and silicon (Si), which are the primary constituents of silicon dioxide. The weight percentages of oxygen and silicon were found to be approximately 39.69% and 60.31%, respectively, corresponding to atomic percentages of 53.60% and 46.40%. These values are consistent with the theoretical stoichiometry of SiO_2, further confirming the material's purity and suitability for the intended experimental applications. The absence of detectable impurities in the elemental spectrum reinforces

the high quality of the silica nanoparticles, which is essential for ensuring consistency in their physical, chemical, and thermal behavior. The high peak-to-background ratios (Pk/Bg) and classification confidence levels (LConf, HConf) indicate the reliability and accuracy of the elemental detection and quantification.

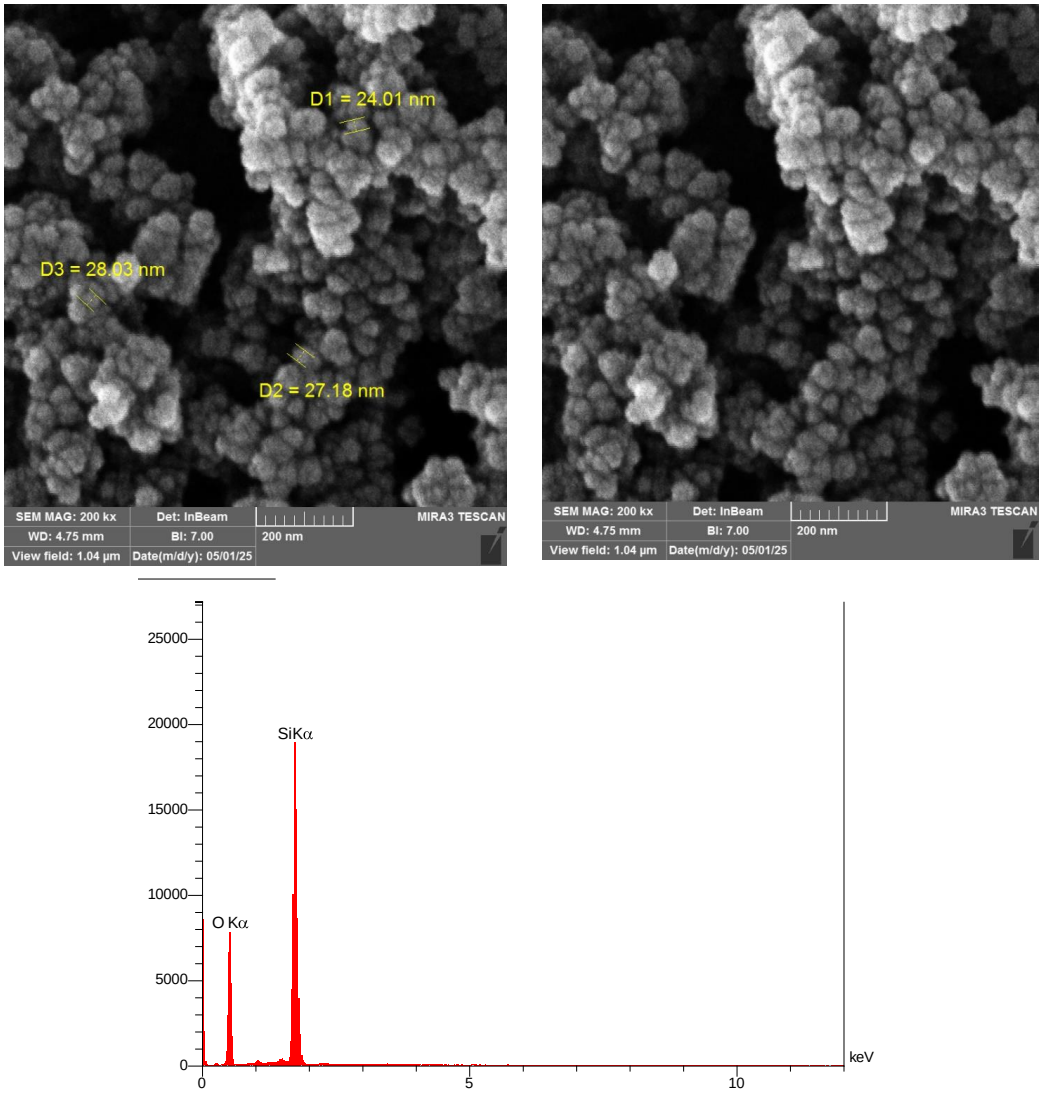

Fig. 5. SEM-EDX results for SiO_2

Table 3. Structural composition of nanostructured silica (SiO_2) particles

Elt	Line	Int	Error	K	Kr	W%	A%	ZAF	Ox%	Pk/Bg	Class	LConf	HConf	Cat#
O	Ka	543.7	660.27	0.1718	0.1047	39.69	53.60	0.2637	0.00	1734.2	A	39.10	40.28	0.00
Si	Ka	2428.8	51.452	0.8282	0.5045	60.31	46.40	0.8365	0.00	811.16	A	59.88	60.74	0.00
				1.0000	0.6092	100.0	100.0		0.00					0.00

3.2. Effect of novel composite on viscosity

Fig. 6 illustrates the impact of incorporating silica nanoparticles into kerosene, in the presence of the surfactant sodium dodecylbenzenesulfonate (SDBS), on the viscosity of the mixture at various temperatures (20°C, 40°C, 60°C, and 75°C). The results indicate a noticeable reduction in viscosity as the duration of ultrasonic treatment increases. Additionally, a further decline in viscosity is observed with increasing temperature. The most significant viscosity reduction was observed at 75°C after 60 minutes of ultrasonic exposure, where the viscosity decreased to 16.53 cP, representing an improvement rate of approximately 72%. To isolate the specific contribution of the silica nanoparticles, a control experiment was conducted in which only kerosene (without nanoparticles) was added to crude oil under identical conditions. Fig. 7 also presents the effect of adding kerosene alone on viscosity at the same temperature intervals. As with the nanoparticle-enhanced samples, viscosity decreased with prolonged ultrasonic exposure and rising temperatures. However, the lowest recorded viscosity in the kerosene-only sample was 33.98 cP at 75°C after 60 minutes, yielding a viscosity reduction

of only 45%. These findings demonstrate the significant role of silica nanoparticles, in synergy with surfactants and ultrasonic treatment, in enhancing the rheological properties of crude oil by achieving greater reductions in viscosity compared to the use of kerosene alone.

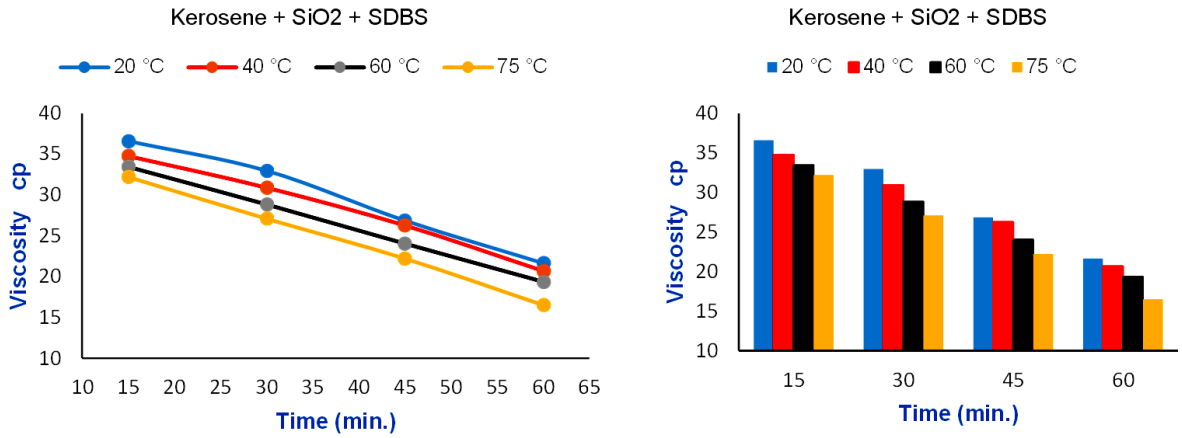

Fig. 6. Effect of SiO_2 addition to kerosene on crude oil viscosity

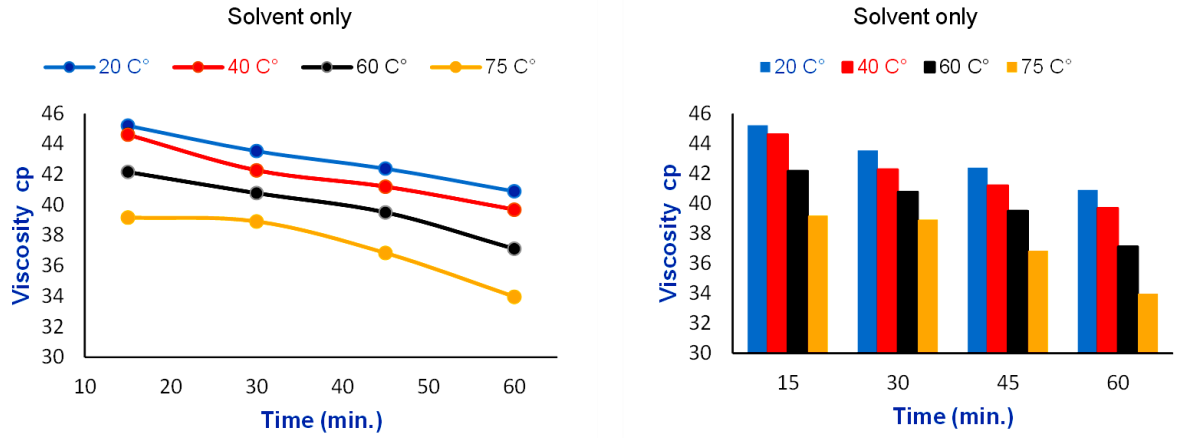

Fig. 7. The effect of kerosene addition alone on the viscosity of crude oil

Fig. 8 presents a comparative analysis of the impact of using kerosene alone versus kerosene combined with silica nanoparticles and a surfactant (SDBS) on the viscosity of crude oil. Based on the findings shown in Figs. 6 and 7, the optimal experimental conditions, 75°C and 60 minutes of ultrasonic treatment, were selected for this comparison, as they yielded the lowest values in both cases. Under these conditions, the use of kerosene alone resulted in a viscosity reduction to 33.98 cP, corresponding to a 45% improvement in flow behavior. In contrast, the addition of silica nanoparticles along with the surfactant led to a significantly greater reduction in viscosity, reaching 16.53 cP, which represents a 72% improvement. The comparative results in Figure 8 clearly demonstrate that the incorporation of silica nanoparticles enhances the effectiveness of kerosene and surfactant in reducing the viscosity of crude oil. The observed 30% increase in viscosity improvement highlights the substantial role played by silica nanoparticles in improving the efficiency of the viscosity reduction process. This enhancement is particularly relevant for optimizing flow characteristics in the treatment of heavy crude oil.

From the previous figures, it is clear that the optimum conditions for obtaining the lowest viscosity value were 75°C and 60 minutes. The viscosity improvement rate achieved using silica with the previously mentioned additives (18% kerosene, 2000 ppm, and 200 ppm SDBS from kerosene) resulted in a 72% improvement in viscosity. To increase this improvement rate, the concentrations of the materials were changed as follows: kerosene (100 ml), silica (3000 ppm or 0.3% wt. from kerosene), and SDBS (300 ppm or 0.03% wt. from kerosene). This mixture was then added to the crude oil (a 30% volume mixture of fluid and 70% volume crude oil) to reduce its viscosity. Fig. 9 shows a comparison between the effect of the first concentrations used in the viscosity improvement process and the second concentrations used at the best conditions of the study experiments, which are 75°C and 60 minutes. The figure shows that the lowest viscosity value obtained was 5.5 cP when 30% of the mixture consisting of kerosene, silica, and surfactant (SDBS) was added to 70% by volume of crude oil. Note that the mixture consists of 100 ml of kerosene, 0.3% by weight of SiO2, and 0.03% by weight of SDBS. The improvement in viscosity was 90.6%.

3.3. Effect of novel composite on API

Fig. 10 presents the influence of incorporating silica nanoparticles into kerosene, in the presence of the surfactant SDBS, on the API gravity at various temperatures: 20°C, 40°C, 60°C, and 75°C. The data shown in Fig. 10 indicates a consistent increase in API values as the duration of ultrasonic treatment was extended. Moreover, a further enhancement in API gravity was observed with rising temperatures. According to Fig. 10, the maximum API value achieved was 28.87 at 75°C after 60 minutes of treatment, marking a 48% improvement compared to the baseline.

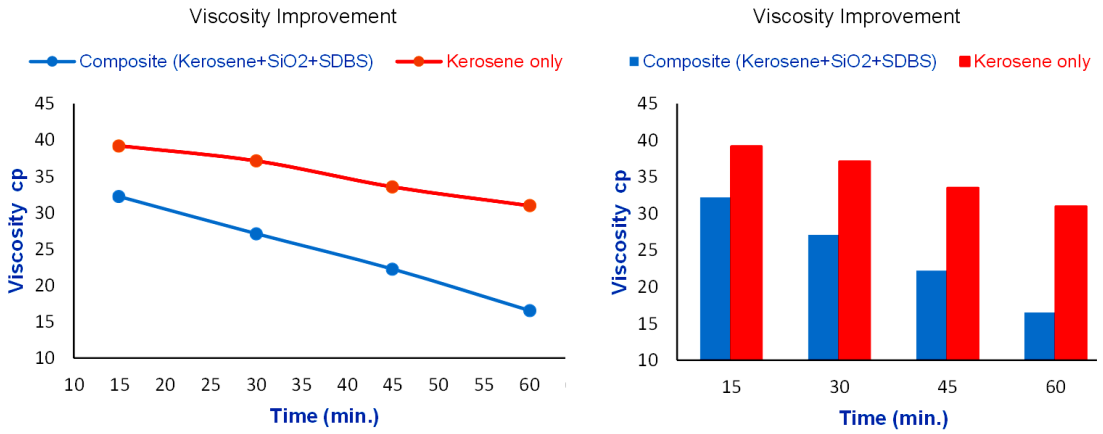

Fig. 8. A comparative analysis was conducted to evaluate the influence of pure kerosene versus kerosene enhanced with SiO_2 nanoparticles on the viscosity of crude oil

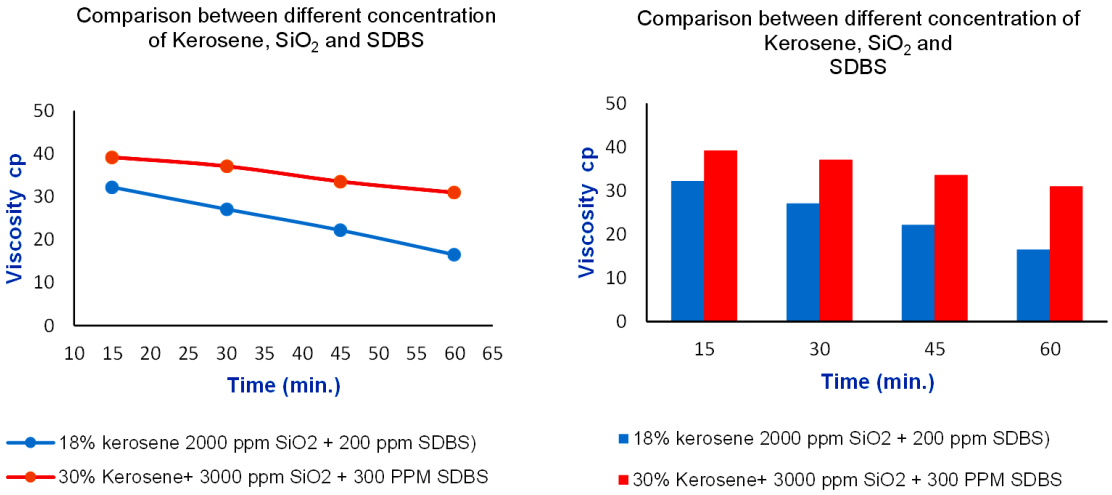

Fig. 9. Comparison between different concentrations of kerosene, SiO_2, and SDBS in improving viscosity

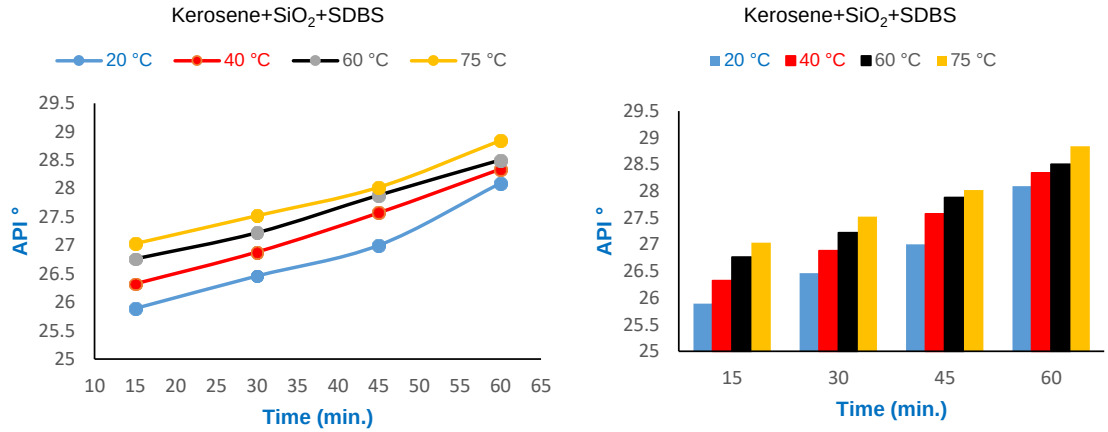

Fig. 10. Effect of kerosene modified with SiO_2 and SDBS on the API gravity of crude oil

To isolate the effect of the silica nanoparticles, a control experiment was conducted in which kerosene alone, without the silica nanoparticles, was mixed with crude oil under identical conditions. This allowed for a clearer understanding of the specific role played by the silica nanoparticles in altering the API gravity. Fig. 11 illustrates the impact of adding kerosene alone, without any nanoparticle additives, on API gravity at various temperatures: 20°C, 40°C, 60°C, and 75°C. The results indicate a gradual increase in API values as the duration of ultrasonic exposure increases. Additionally, a positive correlation was observed between temperature and API gravity, with higher temperatures yielding improved results. The maximum API value recorded was 25.61 at 75°C after 60 minutes of ultrasonic treatment, corresponding to an API improvement of just 31%. These findings underscore the comparatively limited effect of kerosene alone on enhancing API gravity under the studied conditions.

Fig. 12 presents a comparative analysis of the effects of using kerosene alone versus incorporating silica nanoparticles into kerosene in the presence of a surfactant on API gravity. Based on the results from Fig. 10 and Fig. 11, the optimal conditions, 75°C and 60 minutes of ultrasonic treatment, were selected for this comparison. As shown in Fig. 12, the use of kerosene alone yielded an API value of 25.61, indicating a modest improvement of approximately 30%. In contrast, the formulation containing silica nanoparticles and a surfactant yielded a significantly higher API value of 28.87, corresponding to a 48% enhancement. The difference in improvement between the two approaches, as illustrated in Fig. 12, is 18%, highlighting the notable contribution of silica nanoparticles and surfactants (SDBS) in enhancing API gravity under the specified conditions.

When crude oil was treated to improve its API values by adding 18% kerosene, 2000 ppm silica nanoparticles, and 200 ppm liquid sodium carbonate, a 60% improvement rate was achieved. The API increased from 19.67 to 28.6. To further improve the improvement rate, the concentrations of the additives were varied as follows: kerosene (30%), silica (3000 ppm), and liquid sodium carbonate (300 ppm). This mixture was then added to the crude oil to reduce its viscosity. Fig. 13 compares the effects of the first concentrations used in the viscosity improvement process with those of the second concentrations under the optimal experimental conditions of 75°C and 60 minutes. The figure shows that the highest API value obtained was 32 when 30% kerosene, 3000 ppm silicon dioxide, and 300 ppm solid bitumen resins were added. The improvement rate was 65%.

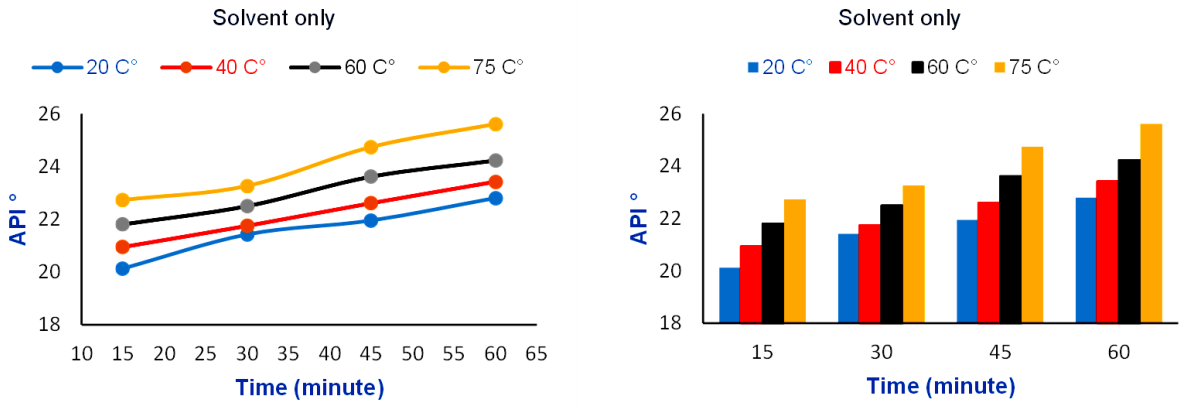

Fig. 11. Effect of kerosene addition alone on crude oil API values

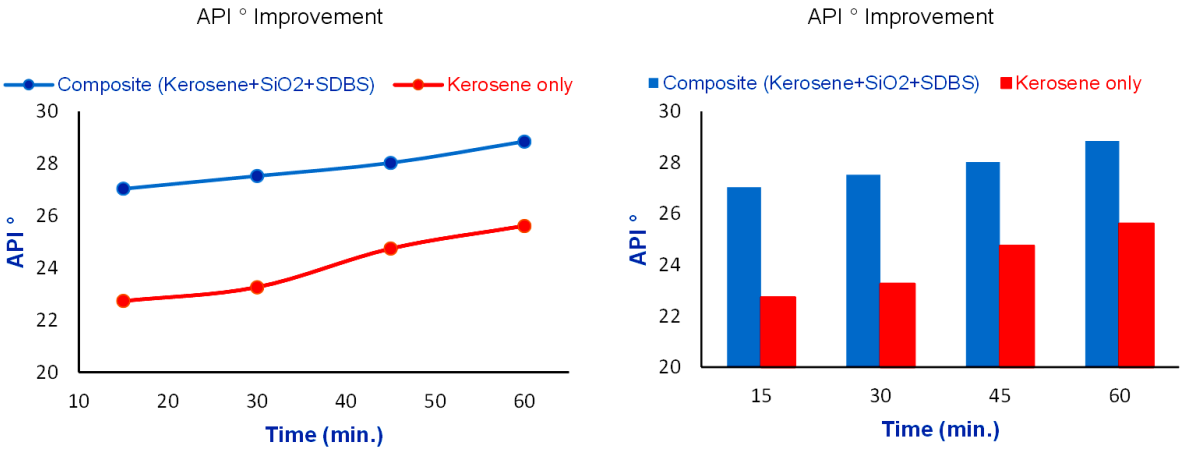

Fig. 12. Comparison between the effect of kerosene alone and kerosene modified with SiO_2 and SDBS on the API gravity of crude oil

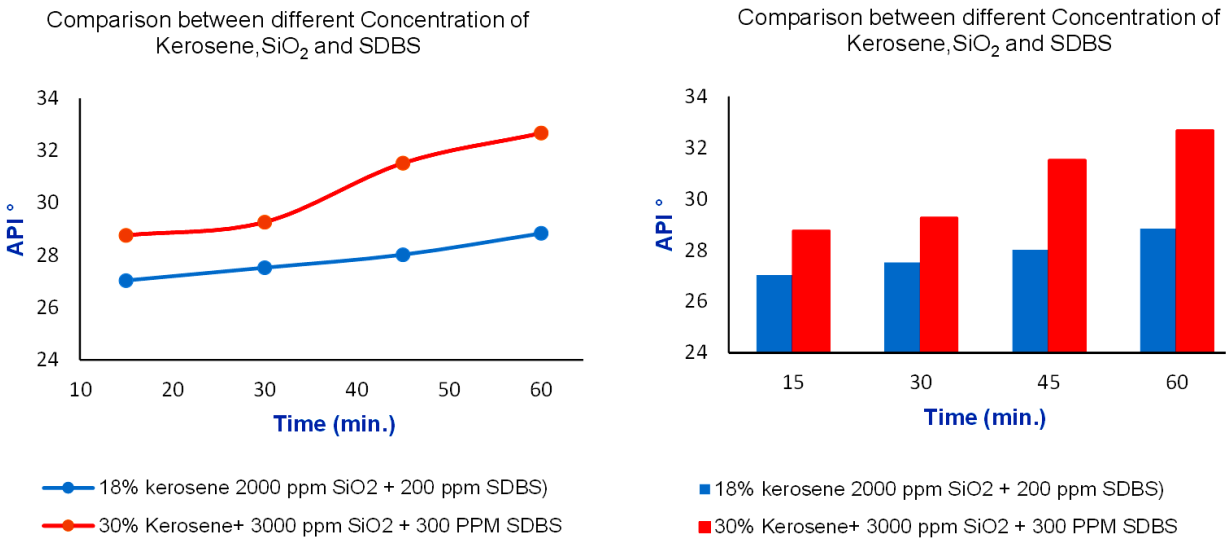

Fig. 13. Comparison between different concentrations of kerosene, SiO_2, and SDBS in improving viscosity

4- The mechanism and kinetic behavior of kerosene modified with SiO_2 nanoparticles and SDBS surfactant

The incorporation of silica nanoparticles, surfactants, and kerosene into East Baghdad heavy crude oil has demonstrated a synergistic and highly effective role in enhancing flow characteristics, resulting in significant reductions in viscosity and density [32]. Kerosene functions as a light solvent, facilitating the dissolution of high-molecular-weight constituents, such as asphaltenes and resins, which are major contributors to the high viscosity of heavy crude oils. This solvation process disrupts intermolecular associations within the oil matrix, resulting in enhanced fluidity and improved transport properties [33]. The effect of kerosene is markedly enhanced by the addition of silica nanoparticles, which contribute to the enhancement through both physical and chemical mechanisms [34]. Due to their high specific surface area and reactive surface chemistry, these nanoparticles are capable of adsorbing heavy polar components and promoting the disaggregation of asphaltene micelles [35]. This interaction is believed to weaken π–π stacking and other non-covalent bonds within asphaltene aggregates, facilitating their dispersion and, in some cases, partial breakdown. Such mechanisms are crucial for modifying the rheological behavior of heavy oil, especially under thermal or ultrasonic treatment. Surfactants complement this process by serving as stabilizing agents that enhance the colloidal stability of the nanoparticle-crude oil mixture [36]. They reduce interfacial tension and prevent nanoparticle agglomeration, thus promoting a more uniform and effective dispersion throughout the crude. Additionally, surfactants encapsulate heavy molecular clusters, increasing their surface exposure to reactive nanoparticles and further supporting disaggregation and viscosity reduction [37]. In systems where emulsion stability and nanoparticle mobility are critical, the role of surfactants becomes essential for sustaining prolonged interactions between all components. Overall, the combined action of kerosene, silica nanoparticles, and surfactants yields a multifaceted enhancement in the treatment of heavy oil. Each additive plays a distinct but complementary role: kerosene improves solubility and diffusivity, silica nanoparticles engage in adsorption and structural disruption of the heavy fractions, and surfactants stabilize the system and facilitate dispersion (as shown in Fig. 14). When applied under optimized thermal and mechanical conditions, such as elevated temperatures or ultrasonic agitation, this integrated approach provides a highly effective strategy for upgrading heavy crude oil, making it more suitable for transportation and refining.

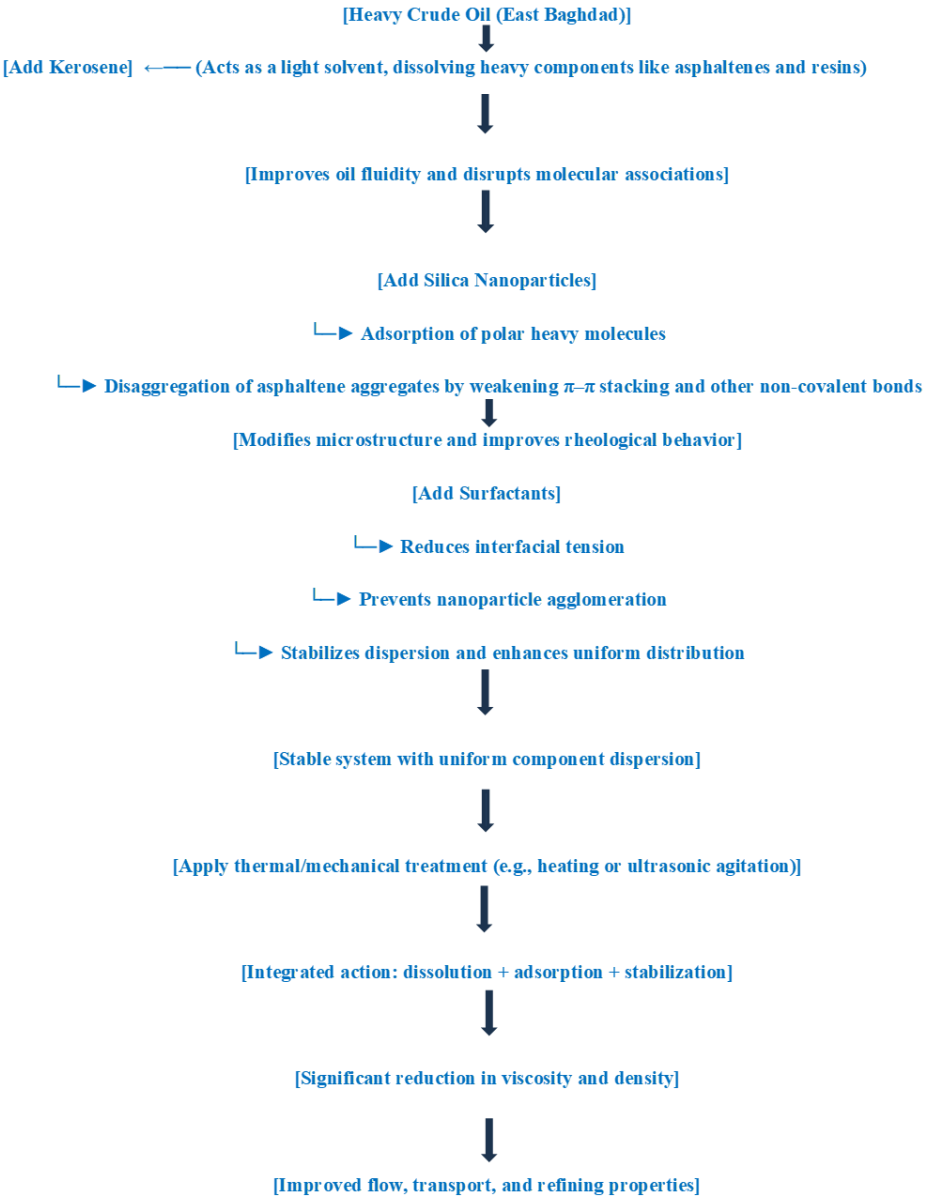

Fig. 14. A diagram illustrates the mechanism by which viscosity and density are reduced by adding kerosene, silica (SiO_2), and a surfactant (SDBS)

5- Conclusion

This study successfully developed a practical and cost-effective method for improving the quality of East Baghdad heavy crude oil. By employing a ternary system consisting of kerosene, silica nanoparticles (SiO_2), and the anionic surfactant SDBS, the research demonstrated significant improvements in crude oil properties, most notably, a substantial decrease in viscosity and a considerable increase in API density. Experimental results confirmed that the optimized conditions (75°C, 60 min) using 18% vol. kerosene, 0.2% silicon dioxide, and 0.02% surfactant (relative to the mass of nanoparticles) resulted in an 86% viscosity decrease and a 45% increase in API density, successfully converting the crude oil from a heavy to light crude. Comparative tests showed that the nanofluid system significantly outperformed kerosene alone, highlighting the synergistic effect of nanoparticles and surfactants. Further refinement using higher concentrations (30% vol. kerosene, 0.3% silicon dioxide, and 0.03% sodium hydroxide) yielded even greater improvements, achieving a 90.5% reduction in viscosity and a 65% increase in API density. These results highlight the critical role of nanoparticle concentration and surfactant interaction in controlling the rheological behavior of heavy crude oil. Beyond its technical performance, this approach has proven to be economically viable. The use of low-cost and widely available kerosene, priced at approximately $1 per liter in Iraq, represents a powerful alternative to conventional refiners, such as methyl solvents, which can cost more than $80 per liter. The affordable cost, combined with the method's effectiveness and scalability, makes the proposed nanofluidic system a promising solution for improving

crude oil quality in real-world settings, particularly in resource-limited environments. In conclusion, the integrated use of kerosene, silica nanoparticles, and SDBS represents an effective and field-applicable strategy for improving the properties of heavy crude oil. This method meets industry needs by offering simplicity, efficiency, and cost-effectiveness, thus achieving the primary objectives of the study.

Acknowledgment

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تعزيز نقل النفط الخام لحقل شرق بغداد باستخدام الكيروسين الممزوج بجسيمات السيليكا النانوية وبوجود السيرفكتانت

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الخلاصة

تتناول هذه الدراسة تحسين قابلية نقل النفط الخام الثقيل المستخرج من حقل شرق بغداد من خلال تقليل اللزوجة والكثافة. وقد اعتمد النهج المقترح على استخدام نظام ثلاثي يتكون من جسيمات نانوية من السيليكا (SiO_2)، والكيروسين، والمادة الفاعلة بالسطح الأنيونية .SDBS. قبل التطبيق، خضعت جسيمات السيليكا لتحليل شامل باستخدام تقنيات التحليل الحراري الوزني (TGA) ، حيود الأشعة السينية (XRD) ، المجهر الذري (AFM) ، المجهر الإلكتروني الماسح (SEM) ، والتحليل الطيفي بالأشعة السينية المشتتة للطاقة (SEM–EDX). أكدت هذه التقنيات ثبات الجسيمات الحراري، وبنيتها البلورية، وشكلها النانوي، وتركيبها العنصري، مما يثبت ملاءمتها لتعديل خصائص النفط الخام. تم تحضير سائل نانوي يحتوي على ١٨% حجماً من الكيروسين، و٢% وزناً من جسيمات السيليكا، و١٠% وزناً من المادة الفاعلة بالسطح نسبةً إلى كتلة الجسيمات النانوية. خضع الخليط لعملية تشتيت بالموجات فوق الصوتية تحت ظروف حرارية وزمنية مضبوطة. وقد تحقق الأداء الأمثل عند درجة حرارة ٧٥ °م ومدة خلط ٦٠ دقيقة، حيث انخفضت اللزوجة من ٥٨,١٥ سنتي بواز إلى ١٦,٥٣ سنتي بواز، وارتفعت الكثافة النوعية (API) من ١٩,٦٧ إلى ٢٨,٨٤.

تم تحقيق تحسين إضافي عند زيادة تركيز المواد المضافة إلى ٣٠% حجماً من الكيروسين، و٣,٠٠٠ جزء في المليون من السيليكا، و٣٠٠ جزء في المليون من المادة الفاعلة بالسطح، مما أدى إلى انخفاض اللزوجة إلى ٥,٥ سنتي بواز وارتفاع الكثافة النوعية إلى ٣٢,٦٧. تمثل هذه النتائج تحسناً بنسبة ٩٠,٥% و٦٦% على التوالي. أظهرت التجارب الضابطة باستخدام الكيروسين فقط كفاءة أقل مقارنة بالنظام الثلاثي، مما يبرز التأثير التآزري بين الجسيمات النانوية والمادة الفاعلة بالسطح. ونظراً لتوفر الكيروسين وانخفاض تكلفته، فإنه يعزز من جدوى هذا الأسلوب، مقدماً حلاً قابلاً للتطبيق ومجدياً اقتصادياً لتحسين جودة النفط الخام الثقيل في التطبيقات الحقلية الواقعية.

الكلمات الدالة: النفط الثقيل، حقل شرق بغداد، تقليل اللزوجة، الكثافة، النانو جزيئات، السيليكا، الكيروسين، مادة خافضة للتوتر السطحي.