



Application of Ultrasonic Waves on the Demulsification (Dehydration) of Crude Oil

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ABSTRACT

Demulsification (dehydration) of crude oil plays a crucial role in reducing oil contamination within the porous media of soil and rock structures and preventing corrosion of pipelines and surface facilities. Over the past two decades, the application of ultrasonic wave irradiation for demulsification and desalting of crude oil has gained increasing attention due to its significant environmental and economic advantages. However, a research gap exists regarding the comparison of conventional demulsification methods with ultrasonic treatment (UST). In this study, a comprehensive review was conducted to evaluate the effects of UST on crude oil demulsification. UST decreases the stability of water-in-oil emulsions, particularly when low-frequency waves are applied. Based on the findings, UST emerges as a promising method for both demulsification and desalting of crude oil. Based on the results, UST causes salt removal rates surpassing 90% and residual water content consistently under 0.3% vol., even for high-viscosity heavy crude feedstocks. When deployed in refinery pre-treatment systems, this technology enhances desalter efficacy while slashing chemical demulsifier consumption by 40-60%. The results highlight a dual benefit: robust operational performance under extreme conditions and a significant reduction in chemical dependency. The primary mechanisms of UST-driven demulsification are cavitation and wave-induced vibrations. These mechanisms alter the interfacial tension (IFT) between crude oil and water, reduce oil viscosity, increase pressure and temperature, and crack heavy crude oil components, especially asphaltene clusters. Combining UST with conventional demulsification methods can enhance performance. For instance, the simultaneous application of UST and nanotechnology presents a practical approach for efficient demulsification. Additionally, the synergistic effects of UST and chemical additives should be comprehensively investigated to identify optimal operational conditions. The results of this research provide insights for the oil industry to improve demulsification efficiency and reduce environmental contamination associated with crude oil.

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1. Introduction

UST has emerged as a groundbreaking technology revolutionizing multiple industries through its unique combination of operational efficiency and environmental benefits. In petroleum processing, UST significantly improves crude oil demulsification and desalting processes by generating controlled cavitation that effectively destabilizes water-oil emulsions [1], reduces IFT, and inhibits asphaltene aggregation in transportation pipelines [2]. The pharmaceutical and specialty chemical sectors utilize UST's precision energy delivery for critical applications, including nanomaterial dispersion, controlled drug crystallization, and clean extraction methodologies. The food industry has adopted ultrasonic technology for its ability to achieve microbial inactivation through non-thermal pasteurization [3] while simultaneously improving product homogeneity [4] and emulsion stability [5]. Environmental engineering applications demonstrate UST's versatility in advanced wastewater treatment systems, where it efficiently mineralizes organic contaminants and maintains membrane filtration efficiency, as well as in industrial precision cleaning operations for high-value components in aerospace and automotive manufacturing [6]. Perhaps most significantly, UST offers a sustainable alternative to conventional processes by dramatically reducing both energy consumption (replacing thermal methods) and chemical dependency, while maintaining cost competitiveness across industrial scales.

The application of ultrasonic waves in the petroleum industry traces its origins to the mid-20th century, when researchers began exploring non-invasive methods to enhance oil recovery and improve process efficiency [7-8]. Early studies in the 1950s-70s focused on using low-frequency ultrasound for well stimulation and permeability enhancement, leveraging

its mechanical vibrations to dislodge trapped hydrocarbons in reservoir rock [9-10]. By the 1980s, advancements in transducer design enabled higher-frequency systems, expanding applications to emulsion breaking, desalination, and contaminant removal. Notably, ultrasonic cavitation, the formation and collapse of micro-bubbles, emerged as a key mechanism for destabilizing water-oil emulsions, offering a chemical-free alternative to traditional demulsifiers [11-12].

Crude oil produced from reservoirs typically contains saltwater (brine). This water dissolves in the oil due to the drag forces of oil flow and a reduction in the IFT between oil and water. Lowering IFT plays a significant role in the formation of water-in-oil emulsions. As IFT decreases, more water emulsions form within the oil. In other words, reduced IFT enhances water's tendency to mix with the oil [13-14].

Chemical additives such as surfactants can further reduce the IFT between oil and water. Additionally, reservoir conditions including pressure and temperature along with water properties (salinity and pH) and crude oil characteristics (density, viscosity, and composition) influence the quantity and size of water emulsions in crude oil [15-16].

The presence of water-in-oil emulsions significantly affects crude oil quality. These emulsions pose challenges such as accelerated corrosion in pipelines and surface equipment within petrochemical and refinery plants. From an environmental perspective, emulsions are concerning because they can contaminate porous media in soil and rock structures. Moreover, such contamination may spread to surface water and aquifers [17-18].

Mineral deposition from high-salinity water can clog pore throats in soil and rock, leading to reduced permeability and restricted fluid flow at the pore scale. These deposits also narrow the effective diameter of pipes, altering

fluid pressure. Furthermore, mineral scaling can damage surface facilities and reduce their efficiency. This process also promotes corrosion in pipelines and equipment due to changes in the system's electrical charge [18-19]. (Figure 1) illustrates the key benefits of demulsification in the oil industry.

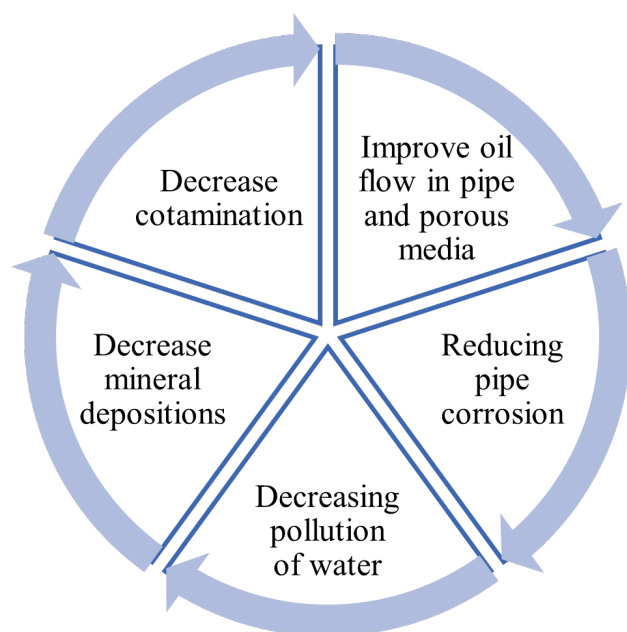


Figure 1. Advantage of Demulsification Operation in the Oil Industry

Various methods exist for demulsification and desalting of crude oil, including chemical and thermal approaches, but these conventional techniques have significant economic and environmental limitations. Recently, UST has attracted growing interest due to its lower operational costs and enhanced safety compared to traditional methods. However, a research gap remains regarding a systematic comparison between conventional demulsification methods and UST, as well as a detailed analysis of ultrasonic wave advantages.

In this study, we conducted a comprehensive review of UST's effects on crude oil demulsification. The findings of this research can be applied in the oil industry to optimize demulsification efficiency and minimize oil-related contamination.

2. Demulsification Methods

Demulsification refers to the process of separating a crude oil emulsion into distinct oil and water phases. This phase separation is crucial in petroleum processing. Three primary demulsification methods exist: physical, chemical, and biological approaches, with effectiveness determined by their ability to destabilize emulsions until complete phase separation occurs.

Common demulsification (dehydration) techniques encompass several approaches, including electromagnetic or electrical heating, which applies energy to separate emulsions; hot fluid injection, where heated fluids are introduced to reduce viscosity; solvent injection, particularly using surfactants to alter IFT; and fluid pressure control, which manipulates system pressure to facilitate phase separation [20-21]. In dehydration processes, warm dry air is typically circulated over oil to extract moisture, with efficiency enhanced by oil thinning. For natural gas, dehydration involves removing water molecules through absorption or adsorption. Modern crude oil separation often employs hot furnace systems [21-22].

The demulsification process serves as a critical step in crude oil purification by effectively separating water from oil. Commonly employed demulsifiers include acid/base-catalyzed phenol-formaldehyde resins, polyamines and polyols, and specialized surfactants, each selected based on their specific interaction properties with oil-water emulsions. Chemical desalting, an essential complementary process, follows three key stages: first, introducing water and surfactant demulsifiers to the crude oil; second, heating the mixture to facilitate impurity dissolution; and finally, allowing sufficient settling time in separation tanks for complete phase separation. As the predominant industrial method, chemical demulsification effectively treats both water-in-oil and oil-in-water emulsions by accelerating

emulsion breakdown. However, formulating emulsion-specific demulsifiers remains technically challenging. For desalination, the most prevalent methods are reverse osmosis (membrane-based) and multistage flash distillation (thermal-based) [23-24].

Conventional demulsification methods present several notable limitations that hinder their effectiveness. Chemical methods are often hampered by three primary constraints: prohibitively high operational costs, significant risks of environmental contamination, and limited applicability in industrial-scale operations. Similarly, thermal methods face substantial challenges, particularly their heavy dependence on electrical energy and economic impracticality when implemented in large-scale projects [24-25]. In light of these limitations, UST has gained prominence in recent years as a viable and promising alternative for crude oil demulsification. As visually summarized in (Figure 2), UST stands among various available demulsification techniques, offering distinct advantages over these conventional approaches.

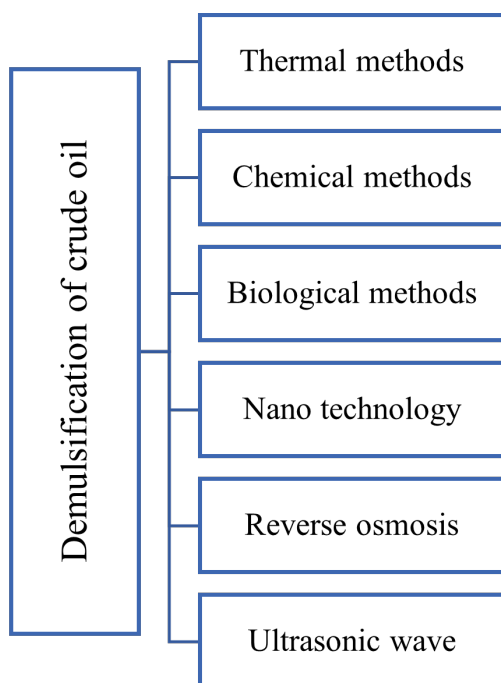


Figure 2. Various Methods for Demulsification of Crude Oil

3. Ultrasonic Treatment

Ultrasonic wave irradiation has emerged as an innovative and versatile technique for modifying key fluid properties in crude oil systems. This advanced approach effectively reduces IFT between oil and water phases, significantly decreases overall fluid viscosity, and facilitates the breakdown of heavy hydrocarbon components, particularly effective against stubborn asphaltene clusters. These simultaneous modifications work synergistically to enhance oil flow characteristics and improve separation efficiency, making UST a valuable tool for modern petroleum processing applications. Operating at frequencies above 20 kHz, ultrasonic wave power depends on the piezoelectric properties of the transducers employed [26-27]. When applied to crude oil, wave radiation generates internal bubbles due to pressure differentials. These bubbles collapse upon reaching critical size, triggering a sharp increase in oil temperature and pressure, a phenomenon known as cavitation.

Additionally, UST induces vibrational energy within the oil. Cavitation and vibration can alter the oil's molecular structure and composition. Specifically, UST breaks down heavy crude oil components through cavitation effects.

Research has identified the existence of an optimal UST condition characterized by minimized oil viscosity and significantly reduced asphaltene cluster formation [28-29], as visually demonstrated in (Figure 3), which illustrates the mechanistic impact of ultrasonic waves on asphaltene clusters within crude oil systems.

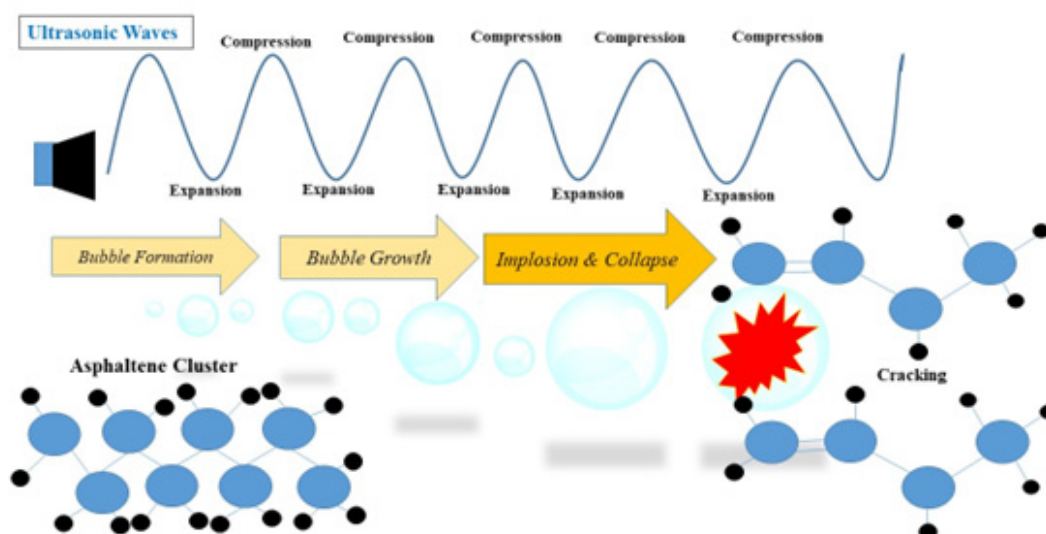


Figure 3. Schematic Image of the Ultrasonic Wave Effect on the Asphaltene Clusters in the Crude Oil

Recently, UST has been utilized for the demulsification and desalting of crude oil. During this process, cavitation and wave vibrations decrease the stability of water-in-oil emulsions and promote the aggregation of water droplets [29-30]. The primary mechanisms driving demulsification include: 1) A rise in fluid temperature resulting from cavitation, and 2) Energy distribution within the oil caused by wave vibrations. Additionally, increased oil temperature reduces IFT between oil and water and alters their interactions [31-32].

Experimental results demonstrate that UST significantly reduces both the quantity and size of water emulsions in crude oil. Furthermore, an optimal irradiation time exists, which depends on the properties of crude oil, reservoir rock, and irradiated wave parameters. Thus, identifying optimal ultrasonication conditions is critical for large-scale projects to enhance oil flow efficiency.

For surface facilities and transport pipelines facing challenges such as inorganic (mineral) deposition, these optimal UST conditions must be thoroughly investigated and precisely determined to ensure operational efficacy [33-35].

4. Advantages of UST

Compared to conventional methods such as chemical, mechanical, or biological approaches, UST offers significant economic and environmental advantages. Unlike these methods, UST avoids damage and pollution in pipelines, equipment, and porous rock media while eliminating the need to inject chemical additives (e.g., solvents or demulsifiers) into the system. Moreover, UST is inherently safer, posing no health hazards to personnel during operations [36-39].

Economically, UST requires no costly pumping systems, specialized materials, or advanced equipment. Instead, only a transducer powered by electricity is needed. Additionally, UST can target specific sections of pipelines or porous media (rock/soil) to mitigate damage and prevent organic/inorganic deposition. Critically, UST operates continuously during oil production, avoiding economic losses associated with shutdowns [40-42].

Mechanistically, UST reduces oil viscosity through cavitation phenomena, significantly improving oil flow rates post-treatment. Alterations in pressure and temperature during

UST modify fluid properties, including IFT and wettability. Experimental evidence confirms UST's efficacy in both demulsification and desalting of crude oil [43-45].

Synergistic integration of UST with conventional methods such as chemical solvent injection, thermal treatments, nanotechnology, or gas injection enhances outcomes while minimizing system damage. In summary, combining UST with other techniques optimizes demulsification efficiency [46-49]. (Figure 4) highlights the key benefits of UST.

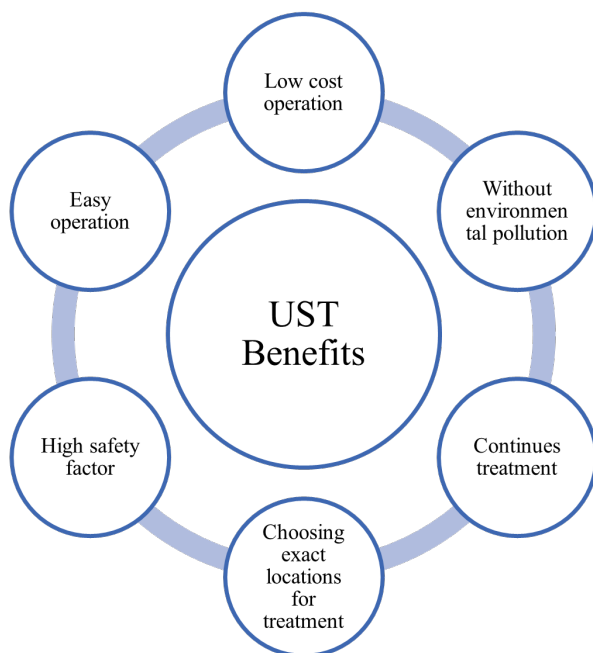


Figure 4. Benefits of Ultrasonic Technology as a Well-Stimulation Method

5. Challenges of UST

The primary limitation of UST is its limited penetration depth. Ultrasonic waves can only affect a small portion of a rock or pipe and cannot treat large-scale systems. Consequently, UST is unsuitable for addressing large-scale issues such as pipeline blockages. For high-production-rate crude oil demulsification, UST faces significant limitations and must be integrated with conventional methods like thermal or chemical treatments. Another key challenge involves identifying optimal operating conditions [50-53].

As noted earlier, determining the optimal irradiation duration is crucial and must be tailored to each crude oil's specific properties. This process requires extensive experimental analysis of the crude oil's physical and rheological characteristics. Such analyses can prolong operational timelines, posing practical constraints for industrial applications.

6. Summary of Experimental Results

Numerous studies have explored the demulsification and desalting of crude oil using UST. Researchers have demonstrated that ultrasound irradiation alters crude oil properties, reducing emulsion stability and promoting water droplet aggregation [54-56]. UST is an effective method for both desalting and demulsification, offering significant environmental benefits, such as minimizing oil pollution in soil porous media and preventing pipeline corrosion caused by brine. Economically, UST lowers costs associated with repairing or replacing surface and subsurface equipment through efficient demulsification. A summary of key studies on UST's impact on crude oil demulsification is provided in (Table 1).

Ultrasonic wave irradiation induces phase separation in water-oil emulsions by elevating fluid temperature and generating vibrational energy. This process relies on viscosity reduction in crude oil post-irradiation, enabling water droplets to coalesce and form distinct oil and water phases [42-45]. Low-frequency ultrasonic waves are highly effective for demulsification, whereas high frequencies prove ineffective due to induced emulsion instability [14-16].

Ultrasonic demulsification is critical in the oil industry as it rapidly separates water from crude oil without chemical additives and operates at relatively low temperatures. Furthermore, ultrasonic waves disrupt adhesion forces between particles by transferring energy, leading to their disintegration.

Table 1. A Summary of the Recent Studies on the Effect of Ultrasonic Waves on the Demulsification of Crude Oil

Authors/Year	Ultrasonic Waves Characteristics	Emulsion Blocking	Mixed Deposition
Yang et al (2009) [13]	20 kHz 100 W	Measure demulsifying velocity	<ul style="list-style-type: none"> Result was a dehydrating ratio of 97.7% under the condition of 10 min of irradiating time, 50 mg/L of demulsifier, and 75°C of water bath temperature..
Yi et al (2017) [14]	20-40 kHz 50-150 W	Microscopic imaging	<ul style="list-style-type: none"> Combined method of UST and chemical demulsifier has the best demulsification effect, followed by chemical demulsifier. UST without using a chemical demulsifier has the least demulsification effect. Final demulsification rate increases with the increase of temperatures and wave power and almost does not change with the increase of wave irradiation time.
Pedrotti et al (2018) [15]	35 kHz 200 W	Particle size analysis and Droplet size distribution (DSD) analyzing	<ul style="list-style-type: none"> Demulsification efficiency up to 93% was obtained with 15 min of UST (100% amplitude) using a few amounts of chemical demulsifier. Reactors positioned in the most intense acoustic regions provided a much higher efficiency of demulsification in comparison with the ones positioned in the less intense acoustic field region.
Xu et al (2019) [16]	10 kHz, 15 kHz, 20 kHz, 25 kHz, 30 kHz 200 W	Imaging and record the total volumes of the dehydrated water and the whole mixed sample	<ul style="list-style-type: none"> Demulsification rate increases with the increase of sound intensity, but the demulsification rate will decrease when wave intensity reaches a certain level; the demulsification rate decreases with the increase of wave frequency. The demulsification rate increases with the increase of sedimentation time, but the increasing extent of the dehydration rate tends to be reduced with the increase of sedimentation time. With the increase in temperature, the effect of UST on the demulsification of crude oil is decreased, or the advantages of UST can be fully displayed only at low temperatures.
Romanova et al (2022) [17]	40 kHz 1000 W	Microscopic imaging	<ul style="list-style-type: none"> Destruction above 99% of all the studied emulsions is achieved by UST with 1.0 kW power together with the addition of nanopowder AIN suspension in acetone. Application of this approach leads to a significant decrease in oily waste formation. The exposure time was 0.5-3 min, and the additive amount was 4-8 %vol. The proposed method applies to destroying regular and gel-containing emulsions.
Song et al (2024) [18]	40 kHz	Measuring the volume of separated oil and water	<ul style="list-style-type: none"> The combined UST and pyrolysis of the crude oil shows a dehydration rate of 61 %, beneficial for the green transformation and utilization of subsequent demulsification products.
Gao et al (2024) [19]	20 kHz 650 W	Microscopic and particle size analyses	<ul style="list-style-type: none"> Oil samples achieve demulsification and dehydration under UST, with a maximum dehydration rate of 98 %. UST destabilizes the oil-water interfacial membrane and causes droplets of different sizes to collide, agglomerate, and settle.

To refine and desalt crude oil, salt removal is essential. A common desalting method involves electrical processes; however, research indicates that combining UST with electrical methods significantly enhances desalting and dewatering efficiency. For example, crude oil with high initial salt concentrations retained elevated salinity after two-stage electrical refining, but applying UST-electrical hybrid technology under optimal conditions reduced salt content from 68 mg/L

to 4 mg/L in a single stage, with water content dropping below 0.3% by volume [54].

These results demonstrate that UST outperforms standalone electrical methods for desalting high-salinity crude oil. In a 2013 experimental study, UST achieved an 80% desalting rate under optimal parameters (10kHz frequency, 5-minute irradiation time) [55]. A summary of key studies on UST's desalting efficacy is provided in (Table 2).

Table 2. A Summary of the Recent Studies on the Effect of Ultrasonic Waves on the Desalting of Crude Oil

Authors/Year	Ultrasonic Waves Characteristics	Type of Experiments	Main Findings
Guoxiang et al (2008) [56]	20 kHz 100 W	Measuring TDS	<ul style="list-style-type: none"> The salt content of crude oil can be reduced from 67.5 mg.L⁻¹ to 3.97 mg.L⁻¹ after UST and the water content falls below %0.3 (by volume). Ultrasonic-electric united process is more effective than the electric process in high salt-contenting oil desalting. This technology should be useful in the refinery process.
Ye et al (2010) [57]	10 kHz 0.38 W/cm	Measure of salt content	<ul style="list-style-type: none"> The combined application of a standing wave field and demulsifier demonstrated superior performance compared to the use of demulsifier alone. Specifically, the desalting and dewatering rates were 11.5% and 4.3% higher, respectively, in the hybrid treatment.
Check et al (2014) [58]	30 kHz 75 and 50 W	Measure of salt content and depositions	<ul style="list-style-type: none"> The dehydration rate was more than 95% and the final salt content was up to 2.5 PTB, which can meet the need for refineries. This proposed technique managed to reduce the settling time to 5(×2) min after UST.
Hu et al (2014) [59]	75 W	Investigation of oil recovery and salt removal	<ul style="list-style-type: none"> In general, ultrasonic irradiation could be an effective method in terms of oil recovery and salt removal from refinery oily sludge, but the separated wastewater still contains relatively high concentrations of PHCs and salt, which requires proper treatment.
Wang et al (2018) [60]	10 kHz, 15 kHz, 20 kHz, 25 kHz, 30 kHz	Sedimentation Analysis and Imaging	<ul style="list-style-type: none"> Dehydration rate will decrease when sound intensity reaches a certain level. Water ratio has a heavy and complex influence on ultrasonic dehydration rate. The effect of ultrasonic dehydration becomes better with the increase of temperature.
Pedrotti et al (2018) [15]	35 kHz	Average droplet size distribution analysis	<ul style="list-style-type: none"> Demulsification efficiency up to 93% was obtained with 15 min of sonication (100% amplitude) using few amount of chemical demulsifier.
Xu et al (2019) [16]	100 W and 250 mg/L	Comparison of demulsifying and dehydrating crude oil	<ul style="list-style-type: none"> Sonochemical technique has the best effect for crude oil demulsification/dehydration. The demulsification effect varies with the increase of ultrasonic radiation time. Ultrasonic wave acts as demulsifying agents, and with the increase of power, the dehydration rate of the crude oil emulsion increases.
Sadatshojaie et al (2021) [61]	20 kHz 80 W to 1000 W	Microscopic imaging	<ul style="list-style-type: none"> Water separation under UST was effective and occurred rapidly. As the intensity of the ultrasonic waves increased, the amount of water segregated from crude oil also increased. UST offers environmentally friendly alternatives to treatments using chemical demulsifiers as they reduce the desalination requirements of wastewater.
Ronchi et al (2021) [62]	35, 45, and 130 kHz	Imaging of water droplets	<ul style="list-style-type: none"> Low-frequency UST is also a practical method for treating the produced water to remove oil. Oil removal efficiency is about 77%.
Chen et al (2022) [63]	40 kHz 260 W	Imaging of water droplets	<ul style="list-style-type: none"> The most effective operation parameters are temperature, followed by acoustic power intensity, ultrasonic irradiation time and demulsifier concentration. Water droplets in heavy oil undergo less aggregation than those in light crude oil.
Bahmani et al (2024) [64]	40 kHz 100 W	Response surface methodology (RSM)	<ul style="list-style-type: none"> Desalting of crude oil was achieved successfully in a remarkable number of experiments. The maximum desalting of 80% was obtained when the flow rate and water content were 18 ml/s and 20%, respectively.

UST has emerged as an innovative and efficient technology for crude oil desalting and dehydration, leveraging unique physico-chemical mechanisms to overcome limitations of conventional methods. The technology operates through three synergistic effects: (1) intense cavitation generates localized microjets and shockwaves that rupture stabilizing films at oil-water interfaces, (2) high-frequency vibrations promote droplet coalescence through enhanced collision frequency, and (3) controlled thermal effects reduce viscosity while preserving heat-sensitive components. This multi-modal action achieves remarkable processing efficiencies, with field demonstrations showing salt reduction exceeding 90% and residual water content below 0.3% vol., even for challenging heavy crude applications. Modern implementations combine UST with electrostatic separation in refinery pre-treatment systems, where it significantly enhances desalter performance while reducing chemical demulsifier requirements by 40-60%. The technology's compact footprint and rapid processing (typically 5-15 minutes versus hours for conventional systems) make it particularly valuable for offshore platforms and pipeline terminals. Current research focuses on intelligent process optimization through machine learning algorithms that dynamically adjust ultrasonic parameters based on real-time crude quality monitoring, while nanotechnology integration shows promise for further efficiency gains. Despite its demonstrated advantages in energy efficiency (30-50% reduction versus thermal methods) and environmental benefits, scale-up challenges persist, particularly in maintaining uniform acoustic fields in large-volume processing vessels, an area where phased-array transducer configurations are showing potential solutions. These ongoing advancements position UST as a transformative technology in the petroleum industry's transition toward more sustainable

and cost-effective processing solutions.

7. Future Direction and Suggestions

Based on the findings, we recommend integrating UST with conventional demulsification methods to enhance efficiency. For instance, combining UST with nanotechnology offers a practical approach. Specifically, Fe_2O_3 NPs or CDs exhibit enhanced demulsification efficiency in crude oil. Future studies should explore magnetic NPs, as a research gap exists regarding their synergy with UST.

Another viable strategy is coupling UST with chemical demulsification. Combining solvent injection (e.g., toluene) with chemical demulsifiers can alter IFT between oil and water, thereby destabilizing water-in-oil emulsions. We propose investigating the synergistic effects of UST and surfactants to identify optimal conditions for maximum demulsification efficiency.

Additionally, integrating UST with thermal methods (e.g., hot fluid injection) could improve water separation and desalting. Notable research gaps remain in exploring UST's synergies with chemical and thermal methods, urging researchers to rigorously evaluate these combinations for novel solutions. (Figure 5) summarizes proposed future research directions for UST hybrid methodologies.

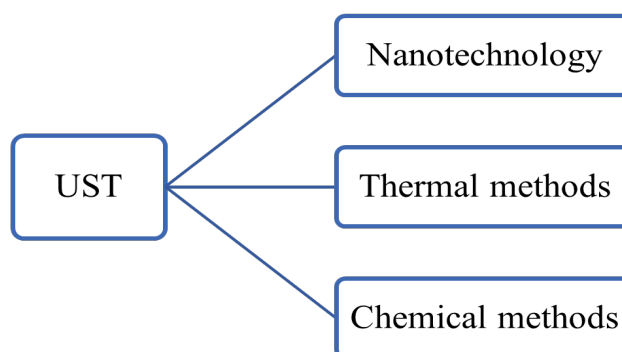


Figure 5. Combination of Ultrasonic Treatment with other Methods

8. Discussion

UST revolutionizes crude oil demulsification and desalting through three core mechanisms: cavitation, vibration, and thermal effects. Cavitation generates microbubbles that collapse violently, disrupting interfacial films between oil and water, while vibrational shear forces accelerate droplet coalescence. Simultaneously, localized heating reduces oil viscosity and fractures heavy components like asphaltene clusters, enhancing phase separation. These mechanisms collectively reduce IFT and improve salt dissociation, achieving >90% desalting efficiency and <0.5% residual water content in optimized systems. The technology's benefits include rapid processing (minutes vs. hours), reduced chemical dependency, and lower energy consumption compared to thermal methods, making it particularly effective for viscous or heavy crude oils. However, limitations persist: UST's limited penetration depth restricts scalability in large tanks, and optimal parameters (e.g., frequency, irradiation time) require crude-specific calibration. Additionally, high-frequency waves may destabilize emulsions unpredictably. Despite these challenges, UST's environmental and economic advantages drive its adoption in refineries and offshore platforms. Future advancements in hybrid systems (e.g., UST + nanotechnology) and AI-driven process optimization promise to overcome current constraints, positioning UST as a cornerstone of sustainable petroleum processing.

9. Conclusion

In this study, the impact of UST on crude oil demulsification and desalting was comprehensively investigated. Key findings from this review include:

1. UST offers significant advantages over conventional demulsification methods

(e.g., thermal or chemical approaches). It is an environmentally friendly, high-safety, and cost-effective solution for dehydration projects.

2. UST destabilizes water-in-oil emulsions, particularly under low-frequency wave conditions. Experimental evidence confirms its efficacy for both demulsification and desalting of crude oil.
3. The primary mechanisms driving UST demulsification are cavitation and wave-induced vibrations. These physical phenomena modify the IFT between crude oil and water, while simultaneously reducing oil viscosity, elevating system pressure and temperature, and breaking down heavy hydrocarbon components - particularly asphaltene clusters.
4. One significant limitation of UST is its limited penetration depth, which restricts its effectiveness for crude oil demulsification. Furthermore, UST achieves optimal efficiency only under specific conditions that must be individually determined for each crude oil type. These ideal operating parameters are directly influenced by multiple factors, including ultrasonic wave power, the crude oil's density and viscosity, and the system's pressure and temperature.
5. The integration of UST with conventional demulsification methods can significantly enhance overall performance. Specifically, combining UST with nanotechnology represents a particularly promising approach for efficient demulsification. Moreover, a thorough investigation of the synergistic effects between UST and various chemical additives could help establish optimal operational parameters for maximum effectiveness.

Nomenclature

Abbreviation	Full Term
<i>AI</i>	Artificial Intelligence
<i>CDs</i>	Carbon dots
<i>IFT</i>	Interfacial Tension
<i>kHz</i>	kilohertz
<i>NPs</i>	Nanoparticles
<i>UST</i>	Ultrasonic wave treatment
<i>W</i>	Watt

References

- Romanova, Y. N., Koroleva, M. Y., Musina, N. S., & Maryutina, T. A. (2025). Ultrasonic demulsification of water-in-crude oil emulsions: Influence of rheological properties. *Chemical Engineering and Processing-Process Intensification*, 211, 110242.
- Razavifar, M., Yunusov, T., Mukhametdinova, A., Bakulin, D., Qajar, J., Cheremisin, A., & Riazi, M. (2025). Improving oil recovery with ultrasound: mitigating asphaltene-induced formation damage. *Journal of Petroleum Exploration and Production Technology*, 15(4), 78.
- Wen, H., Cheng, D., Chen, Y., Yue, W., & Zhang, Z. (2024). Review on ultrasonic technology enhanced biological treatment of wastewater. *Science of The Total Environment*, 925, 171260.
- Singla, M., & Sit, N. (2021). Application of ultrasound in combination with other technologies in food processing: A review. *Ultrasonics Sonochemistry*, 73, 105506.
- Lü, Y., Zhu, S., Lin, G., Wang, M., & Wang, C. (2025). Research on Ultrasonic Demulsification Characteristics and Parameter Optimization of Condensate Oil Emulsion. *Chemical Engineering and Processing-Process Intensification*, 110185.
- Lyu, F., Zhou, X., Ding, Z., Qiao, X., & Song, D. (2024). Application research of ultrasonic-guided wave technology in pipeline corrosion defect detection: A review. *Coatings*, 14(3), 358.
- Nikolaevskii, V. N. (1992). Rock vibration and finite oil recovery. *Fluid dynamics*, 27(5), 689-696.
- Huh, C. (2006, August). Improved oil recovery by seismic vibration: a preliminary assessment of possible mechanisms. In *SPE International Oil Conference and Exhibition in Mexico* (pp. SPE-103870). SPE.
- Naderi, K., & Babadagli, T. (2008, October). Effect of ultrasonic intensity and frequency on oil/heavy-oil recovery from different wettability rocks. In *SPE International Thermal Operations and Heavy Oil Symposium* (pp. SPE-117324). SPE.
- Westermarck, R. V., Brett, J. F., & Maloney, D. R. (2001, March). Enhanced oil recovery with downhole vibration stimulation. In *SPE Oklahoma City Oil and Gas Symposium/ Production and Operations Symposium* (pp. SPE-67303). SPE.
- Gunal, O. G., & Islam, M. R. (2000). Alteration of asphaltic crude rheology with electromagnetic and ultrasonic irradiation. *Journal of Petroleum Science and Engineering*, 26(1-4), 263-272.
- Beresnev, I. A. (1993, June). Review of using acoustic and seismic waves for stimulation of oil reservoirs-Methods and results. In *55th EAEG Meeting* (pp. cp-46). European Association of Geoscientists & Engineers.
- Yang, X. G., Tan, W., & Tan, X. F. (2009). Demulsification of crude oil emulsion via ultrasonic chemical method. *Petroleum Science and Technology*, 27(17), 2010-2020.
- Yi, M., Huang, J., & Wang, L. (2017). Research

- on crude oil demulsification using the combined method of ultrasound and chemical demulsifier. *Journal of Chemistry*, 2017(1), 9147926.
- 15- Pedrotti, M. F., Enders, M. S., Pereira, L. S., Mesko, M. F., Flores, E. M., & Bizzi, C. A. (2018). Intensification of ultrasonic-assisted crude oil demulsification based on acoustic field distribution data. *Ultrasonics sonochemistry*, 40, 53-59.
- 16- Xu, X., Cao, D., Liu, J., Gao, J., & Wang, X. (2019). Research on ultrasound-assisted demulsification/dehydration for crude oil. *Ultrasonics sonochemistry*, 57, 185-192.
- 17- Romanova, Y. N., Maryutina, T. A., Musina, N. S., & Spivakov, B. Y. (2022). Application of ultrasonic treatment for demulsification of stable water-in-oil emulsions. *Journal of Petroleum Science and Engineering*, 209, 109977.
- 18- Song, Z., Ren, F., Wang, S., Pang, Y., Zhao, X., Sun, J., ... & Su, Y. (2024). Factors influencing demulsification of refinery oily sludge via ultrasonic treatment. *Chemical Engineering and Processing-Process Intensification*, 204, 109936.
- 19- Gao, J., Zhu, J., Gao, Q., Zhao, X., Yu, L., Zhao, J., ... & Guo, J. (2024). Mechanism study of aging oil demulsification and dehydration under ultrasonic irradiation. *Ultrasonics Sonochemistry*, 105, 106859.
- 20- Faizullayev, Saidulla, et al. "Recent demulsification methods of crude oil emulsions–Brief review." *Journal of Petroleum Science and Engineering* 215 (2022): 110643.
- 21- Shah Buddin, Meor Muhammad Hafiz, et al. "A review of demulsification technique and mechanism for emulsion liquid membrane applications." *Journal of Dispersion Science and Technology* 43.6 (2022): 910-927.
- 22- Saad, M. A., et al. "An overview of recent advances in state-of-the-art techniques in the demulsification of crude oil emulsions." *Processes* 7.7 (2019): 470.
- 23- Hadi, Ahmed Abdulrazzaq, and Ali Abdulkhabeer Ali. "A review of petroleum emulsification types, formation factors, and demulsification methods." *Materials Today: Proceedings* 53 (2022): 273-279.
- 24- Issaka, Souleyman A., Abdurahman H. Nour, and Rosli Mohd Yunus. "Review on the fundamental aspects of petroleum oil emulsions and techniques of demulsification." *Journal of Petroleum & Environmental Biotechnology* 6.2 (2015): 1.
- 25- Abdulredha, Murtada Mohammed, Hussain Siti Aslina, and Chuah Abdullah Luqman. "Overview on petroleum emulsions, formation, influence and demulsification treatment techniques." *Arabian Journal of Chemistry* 13.1 (2020): 3403-3428.
- 26- Hamidi, Hossein, et al. "Recent applications of ultrasonic waves in improved oil recovery: A review of techniques and results." *Ultrasonics* 110 (2021): 106288.
- 27- Ehsani, MohammadAmin, Mohammadreza Akbari, and Yasin Khalili. "A Comprehensive Review of Ultrasonic-Assisted Oil Recovery: Principles, Applications, and Future Prospects." *Journal of Chemical and Petroleum Engineering* (2025).
- 28- Zhang, Huan, et al. "Revisiting the Application of Ultrasonic Technology for Enhanced Oil Recovery: Mechanisms and Recent Advancements." *Energies* 17.14 (2024): 3517.
- 29- Wang, Zhenjun, and Yuanming Xu. "Review on application of the recent new high-power ultrasonic transducers in enhanced oil recovery field in China." *Energy* 89 (2015): 259-267.

- 30- Adeyemi, Idowu, Mahmoud Meribout, and Lyes Khezzar. "Recent developments, challenges, and prospects of ultrasound-assisted oil technologies." *Ultrasonics Sonochemistry* 82 (2022): 105902.
- 31- Shafiai, Siti Habibah, and Adel Gohari. "Conventional and electrical EOR review: the development trend of ultrasonic application in EOR." *Journal of Petroleum Exploration and Production Technology* 10.7 (2020): 2923-2945.
- 32- Luo, Xiaoming, et al. "Research on mechanism and characteristics of oil recovery from oily sludge in ultrasonic fields." *Journal of Hazardous Materials* 399 (2020): 123137.
- 33- Hafezi, Asieh, et al. "Experimental investigation on the synergetic effect of low salinity water and ultrasonic wave on crude oil flow in porous media." *Petroleum Science and Technology* (2024): 1-20.
- 34- Thilakarathna, R. C. N., et al. "A review on application of ultrasound and ultrasound assisted technology for seed oil extraction." *Journal of Food Science and Technology* 60.4 (2023): 1222-1236.
- 35- Taheri-Shakib J, H Naderi, Y Salimidelshad, A Teymouri, A Shekarifard. Using ultrasonic as a new approach for elimination of inorganic scales (NaCl): an experimental study. *Journal of Petroleum Exploration and Production Technology*. 8 (2018) 553-64.
- 36- Chunsheng P, S Daohan, Z Shushan, X Hongxing. Technology of removing near wellbore inorganic scale damage by high power ultrasonic treatment. *Petroleum Exploration and Development*. 38 (2011) 243-8.
- 37- Mousavi SM, A Ramazani, I Najafi, SM Davachi. Effect of ultrasonic irradiation on rheological properties of asphaltenic crude oils. *Petroleum science*. 9 (2012) 82-8.
- 38- Hamidi H, E Mohammadian, R Junin, R Rafati, M Manan, A Azdarpour, M Junid. A technique for evaluating the oil/heavy-oil viscosity changes under ultrasound in a simulated porous medium. *Ultrasonics*. 54 (2014) 655-62.
- 39- Hamidi H, E Mohammadian, M Asadullah, A Azdarpour, R Rafati. Effect of ultrasound radiation duration on emulsification and demulsification of paraffin oil and surfactant solution/brine using Hele-shaw models. *Ultrasonics sonochemistry*. 26 (2015) 428-36.
- 40- Mullakaev M, G Volkova, O Gradov. Effect of ultrasound on the viscosity-temperature properties of crude oils of various compositions. *Theoretical Foundations of Chemical Engineering*. 49 (2015) 287-96.
- 41- Wang Z, Y Xu, Y Gu. Lithium niobate ultrasonic transducer design for enhanced oil recovery. *Ultrasonics Sonochemistry*. 27 (2015) 171-7.
- 42- Aliev F, I Mukhamatdinov, A Kemalov. The influences of ultrasound waves on rheological and physico-chemical properties of extra heavy oil from Ashalcha field. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*. (2017) 941-8.
- 43- Dehshibi RR, A Mohebbi, M Riazi, F Danafar. Visualization study of the effects of oil type and model geometry on oil recovery under ultrasonic irradiation in a glass micro-model. *Fuel*. 239 (2019) 709-16.
- 44- He S, X Tan, X Hu, Y Gao. Effect of ultrasound on oil recovery from crude oil containing sludge. *Environmental technology*. 40 (2019) 1401-7.
- 45- Karami S, AHS Dehaghani, SAHS Mousavi. Condensate blockage removal using microwave and ultrasonic waves: Discussion on rock mechanical and electrical properties. *Journal of Petroleum Science and Engineering*. 193 (2020) 107309.

- 46- Razavifar, Mehdi, and Jafar Qajar. "Synergistic effects of ultrasonic irradiation and α -Fe₂O₃ nanoparticles on the viscosity and thermal properties of an asphaltenic crude oil and their application to in-situ combustion EOR." *Ultrasonics* 120 (2022): 106655.
- 47- Nguele R, H Okawa. Effect of ultrasound irradiation on asphaltene aggregation and implications to rheological behavior of bitumen. *Ultrasonics Sonochemistry*. 80 (2021) 105811.
- 48- Razavifar, Mehdi, and Jafar Qajar. "Experimental investigation of the ultrasonic wave effects on the viscosity and thermal behaviour of an asphaltenic crude oil." *Chemical Engineering and Processing-Process Intensification* 153 (2020): 107964.
- 49- Otumudia E, H Hamidi, P Jadhawar, K Wu. Effects of reservoir rock pore geometries and ultrasonic parameters on the removal of asphaltene deposition under ultrasonic waves. *Ultrasonics sonochemistry*. 83 (2022) 105949.
- 50- Nguele R, AO Saheed, H Okawa, K Sasaki. Insights Into Bitumen Viscosity Reduction Using Ultrasound-Assisted EOR. SPE Western Regional Meeting. SPE2023. pp. D021S01R03.
- 51- Qajar J, M Razavifar, M Riazi. A mechanistic study of the synergistic and counter effects of ultrasonic and solvent treatment on the rheology and asphaltene structure of heavy crude oil. *Chemical Engineering and Processing-Process Intensification*. 195 (2024) 109619.
- 52- Galimzyanova AR, RN Gataullin, YS Stepanova, EA Marfin, MA Khelkhal, AV Vakhin. Elucidating the impact of ultrasonic treatment on bituminous oil properties: A comprehensive study of viscosity modification. *Geoenergy Science and Engineering*. 233 (2024) 212487.
- 53- Razavifar, Mehdi, Jafar Qajar, and Masoud Riazi. "Experimental study on pore-scale mechanisms of ultrasonic-assisted heavy oil recovery with solvent effects." *Journal of Petroleum Science and Engineering* 214 (2022): 110553.
- 54- Ye, Guoxiang, et al. "Application of ultrasound on crude oil pretreatment." *Chemical Engineering and Processing: Process Intensification* 47.12 (2008): 2346-2350.
- 55- GR. Check, D. Mowla. "Theoretical and experimental investigation of desalting and dehydration of crude oil by assistance of ultrasonic irradiation". *Ultrasonics sonochemistry* (2013) 20(1):378-85.
- 56- Guoxiang, Y., Xiaoping, L. Ü., Fei, P., Pingfang, H., & Xuan, S. H. E. N. (2008). Pretreatment of crude oil by ultrasonic-electric united desalting and dewatering. *Chinese Journal of Chemical Engineering*, 16(4), 564-569.
- 57- Ye, G., Lu, X., Han, P., & Shen, X. (2010). Desalting and dewatering of crude oil in ultrasonic standing wave field. *Journal of Petroleum Science and Engineering*, 70(1-2), 140-144.
- 58- Check, G. R. (2014). Two-stage ultrasonic irradiation for dehydration and desalting of crude oil: a novel method. *Chemical Engineering and Processing: Process Intensification*, 81, 72-78.
- 59- Hu, G., Li, J., Thring, R. W., & Arocena, J. (2014). Ultrasonic oil recovery and salt removal from refinery tank bottom sludge. *Journal of Environmental Science and Health, Part A*, 49(12), 1425-1435.
- 60- Wang, Z., Gu, S., & Zhou, L. (2018). Research on the static experiment of super heavy crude oil demulsification and dehydration using ultrasonic wave and audible sound wave at high temperatures. *Ultrasonics Sonochemistry*, 40, 1014-1020.
- 61- Sadatshojaie, A., Wood, D. A., Jokar, S. M., &

- Rahimpour, M. R. (2021). Applying ultrasonic fields to separate water contained in medium-gravity crude oil emulsions and determining crude oil adhesion coefficients. *Ultrasonics Sonochemistry*, 70, 105303.
- 62- Ronchi, R. P., Negriz, L., Melo, B. N., Pereira, L. S., Vicente, M. A., Flores, E. M., & Santos, M. D. F. P. (2021). Removal of oil from synthetic heavy crude oil-in-water emulsions by the association of glass raschig rings and ultrasound. *Journal of Dispersion Science and Technology*, 43(1), 22-32.
- 63- Chen, W. S., Chen, Z. Y., Chang, J. Y., Chen, C. Y., & Zeng, Y. P. (2022). Ultrasound-assisted desalination of crude oil: The influence of mixing extent, crude oil species, chemical demulsifier and operation variables. *Ultrasonics Sonochemistry*, 83, 105947.
- 64- Bahmani, H., Hojjat, Y., Yazdian, A., & Shirkosh, M. (2024). Ultrasonic-assisted dewatering of crude oil under various transient flow regimes: an experimental and simulation study. *Petroleum Science and Technology*, 1-17.

مکاربرد امواج فراصوت در امولسیون زدایی (آب‌گیری) از نفت خام

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چکیده

امولسیون زدایی (آب‌زدایی) نفت خام نقش مهمی در کاهش آلودگی نفتی در محیط متخلخل خاک و سازه‌های سنگی و جلوگیری از خوردگی خطوط لوله و تأسیسات سطحی دارد. در طول دو دهه گذشته، استفاده از تابش امواج مافوق صوت برای امولسیون زدایی و نمک‌زدایی نفت خام به دلیل مزایای زیست‌محیطی و اقتصادی قابل توجهی که دارد، توجه روزافزونی را به خود جلب کرده است. با این حال، یک شکاف تحقیقاتی در مورد مقایسه روش‌های متداول امولسیون زدایی با درمان اولتراسونیک (UST) وجود دارد. در این مطالعه، یک بررسی جامع برای ارزیابی اثرات UST بر امولسیون زدایی از نفت خام انجام شد. UST پایداری امولسیون‌های آب در نفت را کاهش می‌دهد، به‌ویژه هنگامی که امواج فرکانس پایین اعمال می‌شود. بر اساس یافته‌ها، UST به‌عنوان یک روش امیدوارکننده هم برای امولسیون زدایی و هم نمک‌زدایی نفت خام مطرح شده است. بر اساس نتایج، UST باعث می‌شود که میزان حذف نمک بیش از ۰۹ درصد و محتوای آب باقیمانده به‌طور مداوم زیر ۰/۳ درصد حجم باشد، حتی برای مواد اولیه خام سنگین با گرانروی بالا. هنگامی که این فناوری در سیستم‌های پیش‌تصفیه پالایشگاه مستقر می‌شود، کارایی نمک‌زدایی را افزایش می‌دهد و در عین حال مصرف دمولسیفایر شیمیایی را ۰۴ تا ۰۶ درصد کاهش می‌دهد. نتایج یک مزیت دوگانه را برجسته می‌کند: عملکرد عملیاتی قوی در شرایط سخت و کاهش قابل توجه وابستگی شیمیایی. مکانیسم‌های اولیه امولسیون زدایی مبتنی بر UST کائوچو و ارتعاشات ناشی از موج هستند. این مکانیسم‌ها کشش سطحی (IFT) بین نفت خام و آب را تغییر می‌دهند، گرانروی نفت را کاهش می‌دهند، فشار و دما را افزایش می‌دهند و اجزای نفت خام سنگین، به‌ویژه خوشه‌های آسفالتین را می‌شکنند. ترکیب UST با روش‌های متداول امولسیون زدایی می‌تواند عملکرد را افزایش دهد. به‌عنوان مثال، کاربرد هم‌زمان UST و نانوتکنولوژی یک رویکرد عملی برای امولسیون زدایی کارآمد ارائه می‌دهد. علاوه بر این، اثرات هم‌افزایی UST و افزودنی‌های شیمیایی باید به‌طور جامع بررسی شود تا شرایط عملیاتی بهینه شناسایی شود. نتایج این تحقیق بینش‌هایی را برای صنعت نفت به‌منظور بهبود راندمان امولسیون زدایی و کاهش آلودگی محیطی مرتبط با نفت خام ارائه می‌کند.

واژگان کلیدی: امواج فراصوت، نفت خام، امولسیون، امولسیون زدایی، آب‌گیری