International Journal of Engineering & Technology, 7 (3.11) (2018) 232-236

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Effects of Ultrasonic Waves During Waterflooding for Enhanced Oil Recovery

'Aqilah Dollah*, Zakirah Zainol Rashid, Nur Hidayati Othman, Siti Nurliyana Che Mohamed Hussein, Suriatie Mat Yusuf, Nur Shuhadah Japperi

Faculty of Chemical Engineering, Universiti Teknologi MARA, Malaysia
**Corresponding author E-mail: aqilah7097@salam.uitm.edu.my*

Abstract

Ultrasonic waves is an unconventional enhanced oil recovery (EOR) technology and has been a point of interest as it is more economical and environmentally friendly. Numerous research works on ultrasonic waves application in EOR have been reported, nevertheless the studies on the effect of ultrasonic waves towards oil mobilization in porous media are still debatable. Therefore, this study aims to investigate the effect of ultrasonic waves on enhanced oil recovery of three types of oil (kerosene, engine oil and crude oil) and a brine sample at different temperatures (27°C, 35°C, 45°C, 55°C). A series of ultrasonic waterflooding experiments were conducted under controlled temperature conditions. Results demonstrated that oil recovery increases as the temperature increases during ultrasonic exposure compared to conventional waterflooding. The ultrasonic waves creates energy that increase the mobility of a displacing fluid thus reduce the viscosity of displaced fluids whereas the vibration energy produced from ultrasonic waves induced the mobility of the entrapped oil within the pores. The IR Spectra test indicates that the oil produced from ultrasonic simulated waterflooding for oils with different viscosity and density from the IR Spectra result without ultrasonic exposure due to the influence of flow behavior and sweep efficiencies of fluids. As conclusion, the ultrasonic cavitation is one of mechanism that could improve oil mobilization and enhanced oil recovery.

Keywords: *Enhanced Oil Recovery, Ultrasonic, Waterflooding*

1. Introduction

Vibration seismic and acoustic waves refer an ultrasonic wave which have been extensively studied from laboratory scale to field development to improve oil recovery (Abramov et al., 2015; Mohammed Mohsin & Meribout, 2015). It is unique and promising method operating both at surface and in well condition (Khan et al., 2017). The advantages of ultrasonic application in enhanced oil recovery are their low operating cost, easy implementation and reliability (Wang & Xu, 2015). Various cases involving ultrasonic treatment portraying positive views such reduction of viscosity, reducing the interfacial tension, increasing the fluid mobilization, reducing the capillary effect and played role as demulsification agent as well (Muhammad Mohsin & Meribout, 2015).

The pioneer study using this method to improve oil recovery was revealed by (Duhon & Campbell, 1965). However, the discussion on the effects of oil recovery induced by ultrasonic waves to improve fluid mobilization in porous medium are still evasive at present. The world conventional oil (light oil) supply rates are entering into decline due to inexorable oil production. This declination introduces the operation towards alternative and complex resources such exploration on heavy oil. Viscosity, density and interfacial tension plays as one of major important parameters specifically on the higher molecular weight of crude oil. (Fairbank & Chen, 1971) concluded the surface tension, density and viscosity of oil reduce as the liquids experienced to ultrasonic exposure. The formation of cavitation in the liquid is less favorable in high viscous oil due to strong forces acting within the liquid (Hamidi, Mohammadian, Rafati, Azdarpour, & Ing, 2015). The greater amplitude of ultrasonic waves will assist on the deterioration of strong liquid forces (Abramov et al., 2016) thus improves the mobility of fluid flow in porous medium.

The objective of this work is to investigate the effect of ultrasonic waves on enhanced oil recovery of kerosene, crude oil and engine oil and its dependence on the temperature variance. This work would contribute to a deeper understanding of the effect ultrasonic waves on oil recovery in a porous media

2. Methodology

The experimental setup for ultrasonic simulated water flooding (USWF) is showed in Fig.1. The experiments were carried out at room temperature with diameter and length of the sand-pack column used were 2.50 cm and 33.00 cm, respectively. Initially, the sand particles were packed uniformly in a clean tube which represents the porous media until completely filled. Pore volume (PV), the empty volume of the model, was measured by calculating the volume of brine needed to saturate the column to determine the porosity (%) of the column. The brine was then flooded into the column at a constant injection flow rate and the differential pressure across the sand-pack were recorded to measure the permeability of the sand-pack by using the brine. The porosity and permeability of the sand pack were calculated by using formula shown below:

$$\text{Pore volume}, V_p = \frac{\text{weight wet}_{\text{sandpack}} - \text{weight dry}_{\text{sandpack}}}{\text{density}_{\text{brine}}} \quad (1)$$

$$\text{Bulk volume}, V_b = \text{Area of the cylinder} = \pi r^2 h \quad (2)$$

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

$$\text{Porosity, } \emptyset = \frac{V_{pore}}{V_{bulk}} * 100\% \quad (3)$$

$$\text{Permeability, } k = \frac{Q \mu L}{A \Delta P} \quad (4)$$

where, V_p is pore volume, V_b is bulk rock volume, r is the radius of the cylinder (cm), h is the height of the cylinder (cm), k is the permeability of the sample (Darcy), Q is the flow rate (cm^3/s or m^3/s), μ is dynamic viscosity of the fluid (cp), L is the length of the tube (cm or m), A is the area of the sample (cm^2 or m^2) and ΔP is the pressure difference of fluid (dynes/cm^2 or Pa).

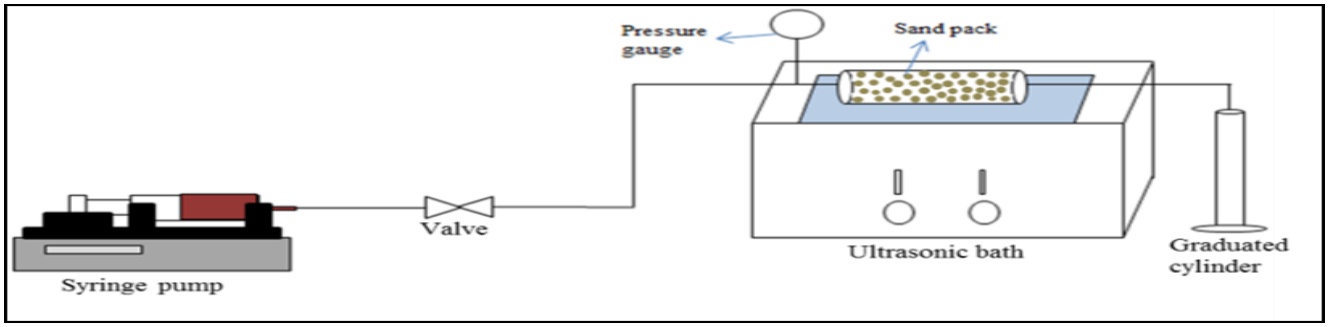


Fig. 1: Schematic diagram of ultrasonic simulated water flooding test

The porosity and permeability of the sand pack were 38.27% and 1.167 Darcy, respectively. The sand-pack column was first flooded with brine followed by the injection of oil into the sand-pack column at 2.5 cm3/min in order to replace the brine, until the residual oil saturation was reached and original oil in place (OOIP) was determined (Skauge, Thorsen, Sylte, & Asa, 2001). The first step of the experiment represented the water flooding without applying ultrasonic at temperature of 27°C was used as a base case. On the other hand, the ultrasonic bath provided a fixed frequency and output power of 37 kHz and 150 Watts respectively and applied when the sand-pack was immersed in the ultrasonic bath at the residual oil saturation in order to mobilize the additional oil. The experiment began simultaneously with the injection of water as the volume of water injection was same as in water flooding experiment and the recovery then was calculated (Mai & Kantzas, n.d.) with 35°C, 45°C and 55°C of the temperature of the ultrasonic bath. The results of the recovery with and without ultrasonic treatment were compared and plotted in the graphs while the oil recovered after water flooding were measured and used for calculating the residual oil saturation. The calculation for residual oil saturation is shown below:

$$\text{Residual oil volume, } N_r = (S_{oi} * PV) - N_p \quad (5)$$

$$\text{Recovery factor, } RF = \frac{N_p}{N} \quad (6)$$

$$\text{Residual oil saturation, } S_{or} = RF * S_{oi} \quad (7)$$

$$\text{Residual oil saturation, } S_{or} = \frac{N_r}{PV} \quad (8)$$

where, N_r is residual oil volume (cm^3), N is initial oil in place (cm^3), N_p is cumulative oil produced (cm^3), RF is recovery factor, S_{or} is residual oil saturation and PV is pore volume. The recovered oil was analysed by Fourier Transform Infrared (FTIR) to determine the functional groups.

3. Results and Discussion

Water flooding experiments were conducted horizontally both without and with ultrasonic exposure. Fig. 2 demonstrates oil recovery versus injected fluid of water flooding for kerosene before and after applying ultrasonic waves. In the case of kerosene, the recovery for waterflooding was 40.4% and the recovery improved 6.6% with the aids of ultrasonic waves at 35°C. However, the recovery increased gradually at 45°C and 55°C which were 10.4% and 14.6%, respectively. Kerosene is a low viscosity, hence the recovery of waterflooding was high due to high sweep efficiency. The general shape of these curves approaches the straight water flood curves thus, it can concluded that more oil produced during the ultrasonic effect (Duhon & Campbell, 1965). In crude oil case, the recovery for normal water flooding is 38.4% and the recovery for ultrasonic stimulated water flooding at 35°C is 41.24%. Fig.3 depicts oil recovery versus injected fluid of water flooding for crude oil after applying ultrasonic waves. The recovery of crude oil was increased slightly after applying ultrasonic as the temperature of ultrasonic bath increased to 45°C and 55°C. Primarily, the ultrasonic waves generate heat during the propagation of waves through the rock layers. The thermal effect of ultrasonic waves depends on the frequency and power of ultrasonic system (Mohammadian, Junin, Rahmani, & Idris, 2013) whereas the temperature effect in this experiment shows a significant induce on the increasing percentage of oil recovery. The heat from ultrasonic bath temperature probably contribute to enhanced oil recovery as has been discovered by Poesio, Ooms, Barake, & van der Bas, 2002. As the temperature kept constant, the cavitation mechanism is less effective. Therefore, the natural cohesion forces acting within the liquid can be resolved by applying the ultrasonic waves with temperature gradient (Junin et al., 2014). The results show that the oil mobilization in porous media is dependent on ultrasonic frequency and the reduction of residual oil is more significant with ultrasonic treatment than without ultrasonic (Hamidi, Rafati, Junin, & Manan, 2012).

Engine oil was chosen due to its high viscosity at ambient temperature. The amount of oil produced by water flooding was 34.12%. Fig.4 shows recovery increases up to 1.53% after ultrasonic treatment applied at 35°C. According to (Alhomadhi, Amro, & Almobarky, 2014), the oil droplets that are trapped in the small pores of the medium can be displaced by vibration which leads to additional oil recovery. Furthermore, the ultrasonic waves will generate vibration energy hence improve the intensity of coalescence of water droplets. The vibration energy will also reduce the adherence of water droplet on rock surfaces thus increase oil recovery. For crude oils with a high n-alkane content ultrasonic treatment is not effective due to the intensification of the crystallization of high molecular n-alkanes (Mullakaev, Volkova, & Gradov, 2015).

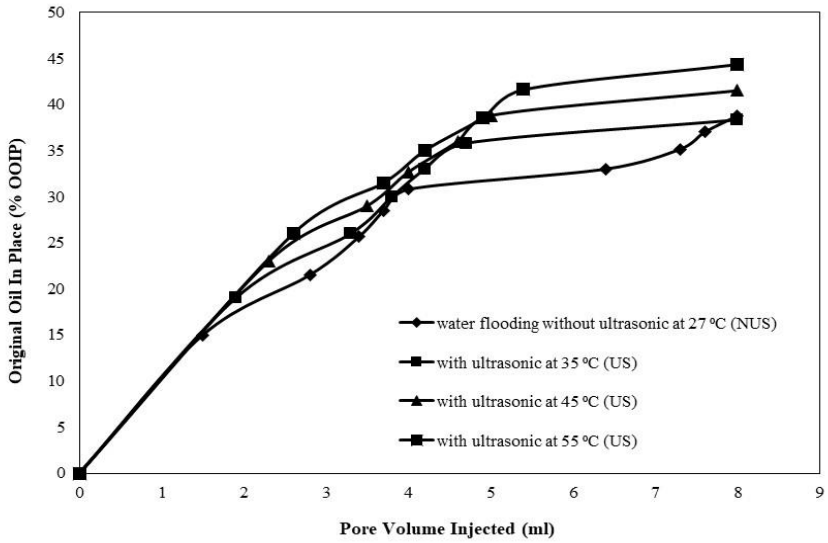


Fig.2: Oil recovery (% OOIP) versus injected pore volume (mL) of water flooding for kerosene before and after applying ultrasonic.

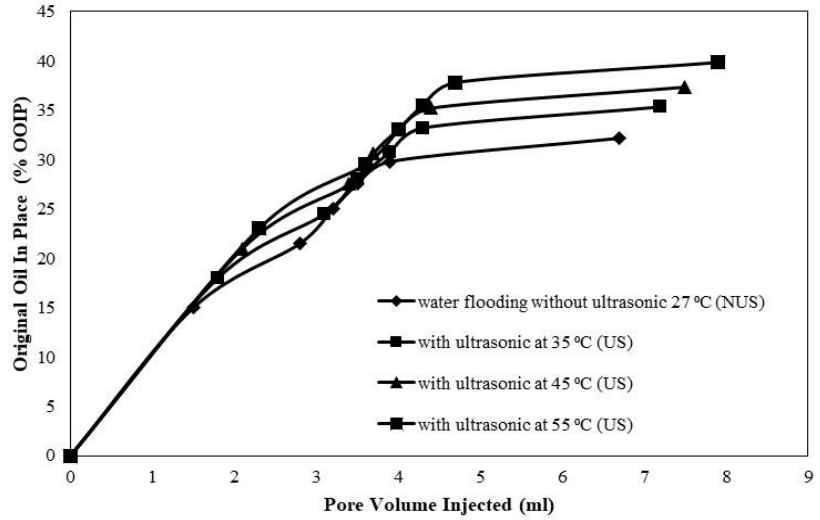


Fig.3: Oil recovery (% OOIP) versus injected pore volume (mL) of water flooding for crude oil before and after applying ultrasonic.

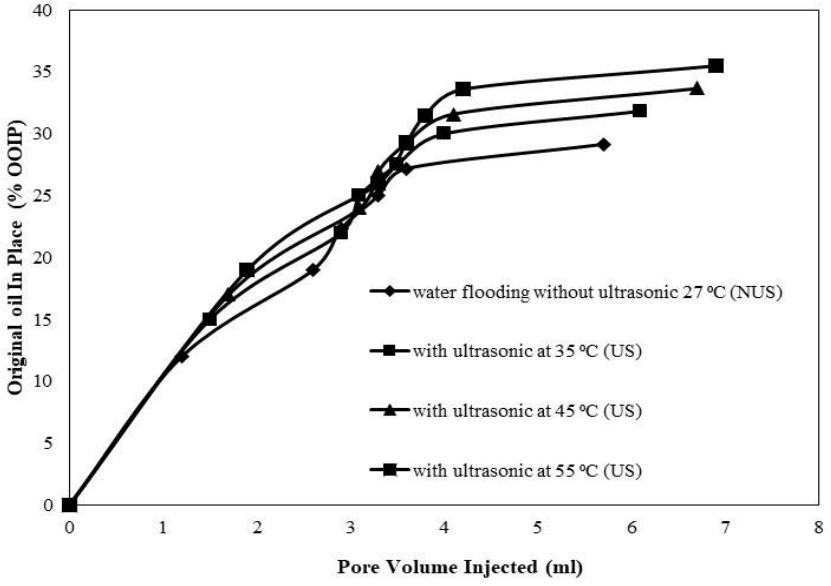


Fig.4: Oil recovery (% OOIP) versus injected pore volume (mL) of water flooding for engine oil before and after applying ultrasonic.

Several studies claimed that the effect of ultrasonic on oil recovery is less significant in a porous medium with higher oil viscosity which certainly have higher molecular liquids (Hamidi, Mohammadian, Rafati, & Azdarpour, 2013). The results shows that the oil recovery increased under ultrasonic is higher for lighter molecular liquids compare to heavier liquids which temperature effect is pertinent to break this heavy chains. Therefore, the application of ultrasonic waves improves the oil recovery for kerosene, crude and engine oil.

The objective of FTIR study was to observe any changes of functional groups in the oil samples before and after ultrasonic treatment. It is found that the crude oil and engine oil obtained to verify the structural changes during water flooding with ultrasonic exposure and compare the results with the without ultrasonic exposure.

Fig. 5 shows the chemical composition difference between before (a) and after (b) ultrasonic radiation of kerosene. Kerosene consists predominantly of C6H14 which means it has carbon-carbon (C-C) and carbon-hydrogen (C-H) bonds only. In addition, it also does not have high electron density at any region due to no double bond. The C-C bond in the kerosene was weakened when ultrasonic treatment was introduces as the compound absorbed more energy which causes molecular motions that create a net change in the dipole moment as ultrasonic generated heat. A sharp signal at 2922.31 cm-1 in (a) indicates the strong adsorption by C-H stretching frequency. The peak at 1738.62 cm^{-1} in (b) corresponds to asymmetric C-H stretching vibrations that occurred when the C-C bond of weak alkane was degrade due to ultrasonic vibration. The peak shift move towards higher wave number side, thus shows the mass of that molecule is reduced. Since the frequency of vibration is inversely proportional to mass of vibrating molecule thus the lighter the molecule, the more vibration frequency and higher the wave numbers.

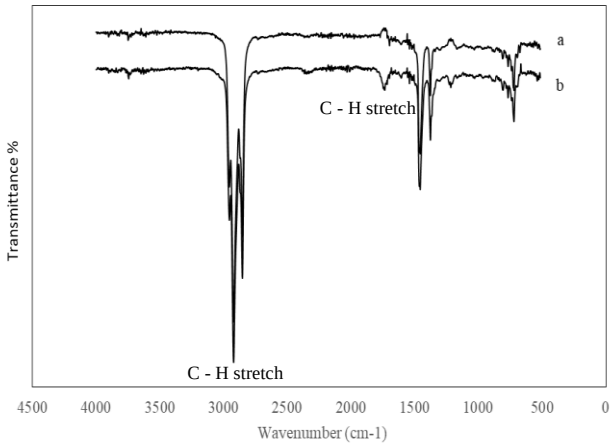


Fig.5: FTIR spectra of kerosene (a) before and (b) after the ultrasonic radiation.

Fig. 6 shows the FTIR spectra before and after ultrasonic treatment for crude oil. Crude oil consists predominantly of C5H12 which indicates it has carbon-carbon (C-C) and carbon-hydrogen (C-H) bonds only. This spectrum shows a similar shape of bands with kerosene. The alkanes C-H stretching absorption shows strong and sharp peaks at 2953.83 cm^{-1}, 2921.81 cm^{-1} and 2852.37 cm^{-1} in (a) indicating saturated carbons evolution (Verşan Kök, Varfolomeev, & Nurgaliev, 2017). On the other hand, the C-C bond in the Crude oil was weakened due to the compound more absorbed energy caused by molecular motions that create a net change in the dipole moment as ultrasonic generates heat. The peak at 1735.61 cm^{-1} in (b) corresponds to asymmetric C-H stretching vibrations which did not occur at initial condition. Some strong vibration bands shows at 1457.46 cm^{-1} and 1376.84 cm^{-1} indicating the C-H bending of alkanes due to heat generated by ultrasonic effect.

Engine oil consists predominantly of C7H16, it has carbon-carbon (C-C) and carbon-hydrogen (C-H) bonds only. Fig. 7 shows the chemical composition difference between before (a) and after (b) ultrasonic radiation of engine oil. The dominant peaks at 2954.88 cm-1, 2921.58 cm-1 and 2852.94 cm-1 belongs to C-H stretch alkane groups (Kök, Varfolomeev, & Nurgaliev, 2017). High energy absorption causes the C-C bond in the engine oil weakened caused by molecular motion created a net change in the dipole moment when the ultrasonic generates heat. The peak at 1735.55 cm^{-1} in (b) corresponds to asymmetric C-H stretching vibrations. It is observed that the peak shifts toward higher wave number due high frequency of vibration caused by reduction of molecule mass. Overall, the spectrum of kerosene, Crude oil and engine oil before ultrasonic treatment is slightly differ from after ultrasonic treatment. Therefore it can be concluded that ultrasonic effect is less noticeable in IR spectra for both crude and oil fraction (Volkova, Anufriev, & Yudina, 2016). However, further investigation to verify the study need to be done.

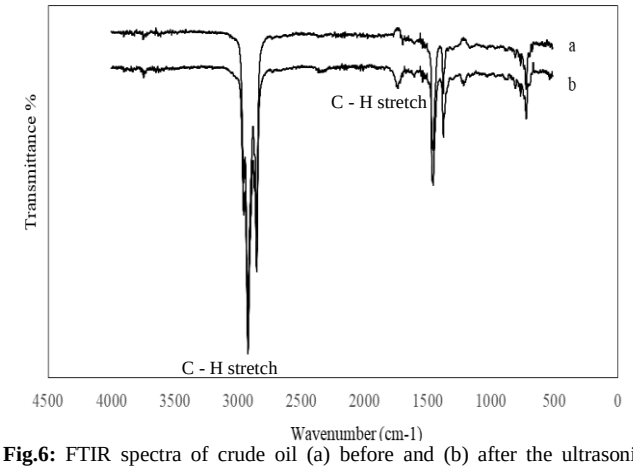


Fig.6: FTIR spectra of crude oil (a) before and (b) after the ultrasonic radiation.

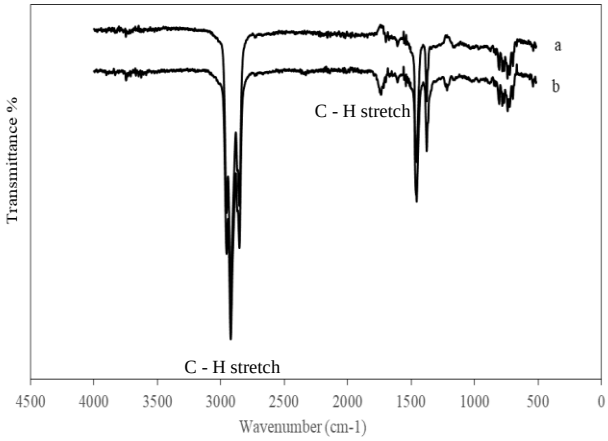


Fig.7: FTIR spectra of engine oil (a) before and (b) after the ultrasonic radiation.

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

4. Conclusion

The recovery of waterflooding with ultrasonic vibration improved compared to conventional water flooding without the ultrasonic assistance. The improved oil recovery as a result of ultrasonic wave treatment success for all cases. The recovery of waterflooding assisted by ultrasonic wave was higher in kerosene compared to crude oil and engine oil. The increment could be due to reduction of viscosity, density and interfacial tension.

Acknowledgement

The authors gratefully acknowledge the Universiti Teknologi MARA (UiTM) for providing the Aras Fund (102015160002) research grant and the Faculty of Chemical Engineering, UiTM Shah Alam for the provision of the laboratory facilities to complete this work.

References

[1] Abramov, V. O., Abramova, A. V., Bayazitov, V. M., Altunina, L. K., Gerasin, A. S., Pashin, D. M., & Mason, T. J. (2015). Sonochemical approaches to enhanced oil recovery. Ultrasonics Sonochemistry, 25(1), 76–81. https://doi.org/10.1016/j.ultsonch.2014.08.014

[2] Abramov, V. O., Abramova, A. V, Bayazitov, V. M., Mullakaev, M. S., Marnosov, A. V, & Ildiyakov, A. V. (2016). Ultrasonics Sonochemistry Acoustic and sonochemical methods for altering the viscosity of oil during recovery and pipeline transportation. Ultrasonics - Sonochemistry. https://doi.org/10.1016/j.ultsonch.2016.10.017

[3] Alhomadhi, E., Amro, M., & Almobarky, M. (2014). Experimental application of ultrasound waves to improved oil recovery during waterflooding. Journal of King Saud University - Engineering Sciences, 26(1), 103–110. https://doi.org/10.1016/j.jksues.2013.04.002

[4] Duhon, R. D., & Campbell, J. M. (1965). The Effect Of Ultrasonic Energy On The Flow Of Fluids In Porous Media. Second Annual Eastern Regional Meeting, 1–15. https://doi.org/10.2118/1316-MS

[5] Hamidi, H., Mohammadian, E., Rafati, R., & Azdarpour, A. (2013). A role of ultrasonic waves on oil viscosity changes in porous media. CEAT 2013 - 2013 IEEE Conference on Clean Energy and Technology, 1–6. https://doi.org/10.1109/CEAT.2013.6775589

[6] Hamidi, H., Mohammadian, E., Rafati, R., Azdarpour, A., & Ing, J. (2015). The effect of ultrasonic waves on the phase behavior of a surfactant-brine-oil system. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 482, 27–33. https://doi.org/10.1016/j.colsurfa.2015.04.009

[7] Hamidi, H., Rafati, R., Junin, R. Bin, & Manan, M. A. (2012). A role of ultrasonic frequency and power on oil mobilization in underground petroleum reservoirs. Journal of Petroleum Exploration and Production Technology, 2(1), 29–36. https://doi.org/10.1007/s13202-012-0018-x

[8] Junin, R., Manan, M., Hamidi, H., Mohammadian, E., Rafati, R., Junid, M., & Azdarpour, A. (2014). A technique for evaluating the oil/heavy-oil viscosity changes under ultrasound in a simulated porous medium. Ultrasonics, 54(2), 655–662. https://doi.org/10.1016/j.ultras.2013.09.006

[9] Khan, N., Pu, C., Li, X., He, Y., Zhang, L., & Jing, C. (2017). Permeability recovery of damaged water sensitive core using ultrasonic waves. Ultrasonics Sonochemistry, 38, 381–389. https://doi.org/10.1016/j.ultsonch.2017.03.034

[10] Kök, M. V. K., Varfolomeev, M. A., & Nurgaliev, D. K. (2017). Crude oil characterization using TGA-DTA, TGA-FTIR and TGA-MS techniques. Journal of Petroleum Science and Engineering, 154, 537–542. https://doi.org/10.1016/j.petrol.2016.12.018

[11] Mai, A., & Kantzas, A. (n.d.). Heavy Oil Waterflooding : Effects of Flow Rate and Oil Viscosity, (9).

[12] Mohammadian, E., Junin, R., Rahmani, O., & Idris, A. K. (2013). Effects of sonication radiation on oil recovery by ultrasonic waves stimulated water-flooding. Ultrasonics, 53(2), 607–614. https://doi.org/10.1016/j.ultras.2012.10.006

[13] Mohsin, M., & Meribout, M. (2015). An extended model for ultrasonic-based enhanced oil recovery with experimental validation. Ultrasonics Sonochemistry, 23, 413–423. https://doi.org/10.1016/j.ultsonch.2014.08.007

[14] Mohsin, M., & Meribout, M. (2015). Oil-water de-emulsification using ultrasonic technology. Ultrasonics Sonochemistry, 22, 573–579. https://doi.org/10.1016/j.ultsonch.2014.05.014

[15] Mullakaev, M. S. ., Volkova, G. I. ., & Gradov, O. M. . (2015). Effect of ultrasound on the viscosity-temperature properties of crude oils of various compositions. Theoretical Foundations of Chemical Engineering, 49(3), 287–296. https://doi.org/10.1134/S0040579515030094

[16] Poesio, P., Ooms, G., Barake, S., & van der Bas, F. (2002). An investigation of the influence of acoustic waves on the liquid flow through a porous material. The Journal of the Acoustical Society of America, 111(5), 2019. https://doi.org/10.1121/1.1466872

[17] Skauge, A., Thorsen, T., Sylte, A., & Asa, N. H. (2001). RATE SELECTION FOR WATERFLOODING OF INTERMEDIATE WET CORES, 1–14.

[18] Verşan Kök, M., Varfolomeev, M. A., & Nurgaliev, D. K. (2017). Thermal characterization of crude oils in the presence of limestone matrix by TGA-DTG-FTIR. Journal of Petroleum Science and Engineering, 154, 495–501. https://doi.org/10.1016/j.petrol.2017.02.001

[19] Volkova, G. I., Anufriev, R. V., & Yudina, N. V. (2016). Effect of ultrasonic treatment on the composition and properties of waxy high-resin oil. Petroleum Chemistry, 56(8), 683–689. https://doi.org/10.1134/S0965544116080193

[20] Wang, Z., & Xu, Y. (2015). Review on application of the recent new high-power ultrasonic transducers in enhanced oil recovery field in China. Energy, 89, 259–267. https://doi.org/10.1016/j.energy.2015.07.077