Experimental Investigation of Microwave Radiation on the Reservoir Rock Wettability and Oil Viscosity

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Abstract
Oil production from unconventional oil reservoirs is facing many problems, such as high oil viscosity and low oil recovery. So, there is a need to apply modern technologies to improve oil production. Nowadays, electromagnetic heating is a new method that attracted researchers' attention. Despite the studies that have been done so far, this technique still has many challenges to use in field applications, such as the effect of electromagnetic radiation on the reservoir rock wettability and oil viscosity. Therefore, in this study, the effect of microwave radiation on rock wettability and oil viscosity is investigated experimentally. The relation between irradiation time, contact angle and oil viscosity is also presented. Results showed that the carbonate rock wettability changes from 159º to 75º, and there is an optimum irradiation time to decrease the oil viscosity and contact angle simultaneously. It was proved that microwaves could reduce oil viscosity from 840 cP to 745 cP until 10 minutes irradiation. Then oil viscosity begins to increase.

Keywords: Microwave, Wettability, Contact Angle, Oil Viscosity.

Introduction
The efficient oil production from unconventional reservoirs, such as oil shale, heavy oil reservoirs, and tar sands, is a major problem in the oil industry. These types of reservoirs have minimal production due to the high viscosity of their oil. Among the oil extraction methods, thermal recovery methods are the best way to apply in these reservoirs. However, these methods have low performance because of the depth limitation, the high costs of production and fluid injection into the formation, and the very low penetration in the low permeable porous medium. Nowadays, a new thermal method, electromagnetic heating technology, has attracted the attention of researchers and experts in the oil industry [1-3]. Electromagnetic waves are not dependent on the formation depth, permeability, and size of the pores, as well as the additional costs involved in other thermal methods. Applying this method to an oil well is such that a wave generator is sent into the oil well in front of the pay zone. As the waves emit, the fluid in the formation begins to warm, and the reservoir temperature rises. As the reservoir temperature increases, the viscosity of the oil decreases, resulting in an increase in oil production.
Taheri-Shakib et al. [4-7] performed a thorough experimental investigation on the effect of microwave on oil upgrading, rock wettability changes, and the effect of additives such as nanoparticles on oil properties. They showed that oil properties improve until an optimum

irradiation time, and after that viscosity increases. Viscosity increment is because of the liberation of oil light components. This phenomenon does not appear in the reservoir because of high confining pressure and prevents light components from liberation. So, the optimum irradiation time in the reservoir differs from the laboratory. Although several researches have been conducted, the effect of microwave radiation time, type of oil and nanoparticle, etc. on the wettability alteration of reservoir rock and oil viscosity is not well defined.
Therefore, in this study, the effect of microwave radiation on the carbonate reservoir rock wettability, the oil viscosity and the relation between them are investigated. Previous studies placed the rock directly inside the microwave. In this study, unlike previous studies, the rock is first immersed in water and then is exposed to microwave radiation to bring conditions closer to the real reservoir conditions.

Materials and Method

The oil used in this study was obtained from one of the southern Iranian oilfields. The characteristics of used oil are presented in table 1. Also, the prepared calcite rock has 38% porosity and 94% purity.

Table 1. Oil properties used in this research

Parameter	Viscosity(cP)	Density (g/cc)	API
Value	840	0.9658	15.01

The rocks were first cut into thin sections with a diameter of 3.8 cm and a thickness of 2 mm. These rock sections are then washed several times with deionized water to dissolve any ions or impurities on the surface or inside them. The rocks were then put into the seawater sample and heated at 75 ° C for two weeks. The seawater is then separated from the sample, and the rock samples are immersed in the oil for five weeks at 90 ° C [8] .
A commercial microwave oven with a frequency of 2450 MHz and a power of 450 watts was used to conduct electromagnetic radiation tests. These tests are divided into two parts. In the first, the thin rock sections are immersed into 25 ml deionized (DI) water and then are exposed with microwaves at different time intervals and finally the oil contact angle on them is measured by the sessile drop method. In the second section, a specific volume of oil is placed in the microwave and then the oil contact of this irradiated oil at different times is measured with a thin section rock by the sessile drop method.

Results and discussion

According to Fig.s 1 and 2, the oil contact angle has a decreasing trend with increasing radiation time. The initial contact angle was 159 ° and after 45 min microwave radiation, reduced to 75 ° which is showed a reduction of 52.8 %. This indicates a change in the wettability from strongly oil-wet to water-wet. Water with high polarity and dielectric constant of 80.2 at 20 °C [9] is a good absorbent of electromagnetic waves. Radiated waves cause a dipolar momentum in water molecules, which increases molecular collision and frictional force between them. Therefore, the kinematic energy of the system and as a result, the temperature increases. The incremental temperature has many effects on the system such as lowering the oil viscosity. In a similar work [5], the oil contact angle reduces from 120 to 90 degrees after 35 minutes of microwave radiation. Microwave increases the system temperature which is a driving force to reduce the oil contact angle on the carbonate rock [10, 11]. This is due to fine detachment from the surface of the oil-coated solid. Consequently, formatting a new clean rock surface with water wet behavior. In microwave-free mode, the rock wettability could not change at short times, such as one hour. Different additives like surfactants, nanoparticles and so on need more time to effect on the surface of the rock. Previous researches can confirm this subject. For example, Jarrahian et al. [12] showed that DI-water has no effect and C12TAB has the highest (changing from 138 to 64 degree) effect after 24 hours on the wettability. Also, Rezvani et al. [13] reported that Fe_3O_4 nanoparticles at 750 ppm concentration in formation water reduced 63° of oil contact angle on the rock after 24 hours.

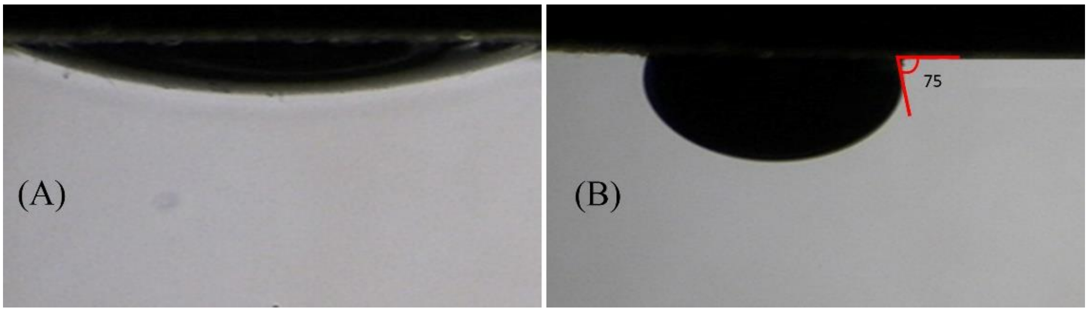

Fig.1. Contact angle of oil droplet with rock. A) 0 min irradiation and B) 45 min irradiation.

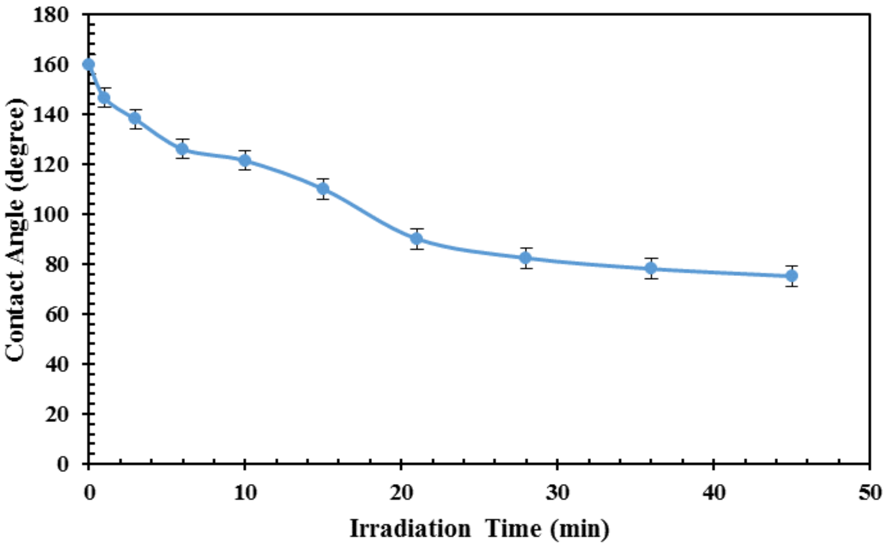

Fig. 2. Oil contact angle with rock versus irradiation time.

Fig. 3 shows the viscosity of irradiated oil and its contact angle with an unirradiated aged rock. As it can be observed for up to 10 minutes of irradiation, the oil viscosity decreases from 840 cP to 745 cP. Also, as it is shown in Fig. 4, the contact angle is reduced from 151° to 114°. For more than 10 minutes irradiation, the viscosity begins to increase as well as the contact angle. It should be mentioned that by altering the physical and chemical properties of the oil during thermal recovery methods such as microwave irradiation, the tendency of the oil to spread on the rock surface reduced. Hence, the other effective parameters on oil production like relative permeability, surface tension, and capillary pressure changed.

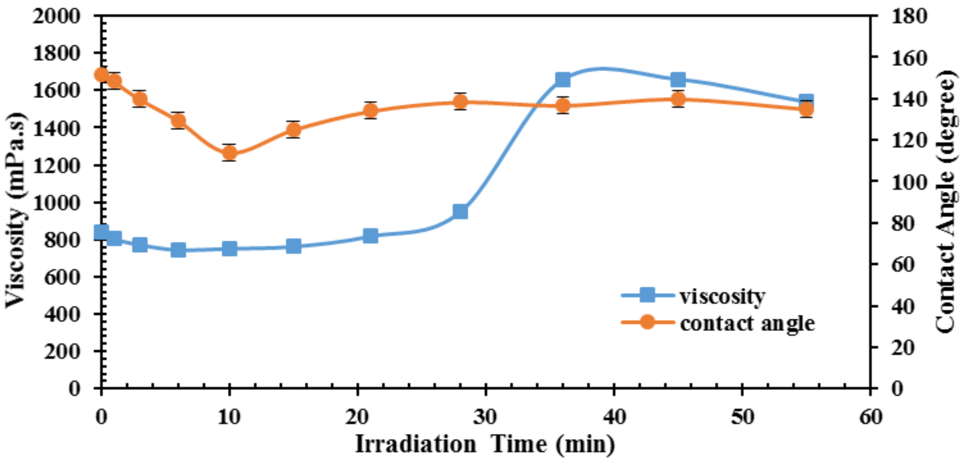

Fig. 1. Irradiated Oil viscosity vs. Irradiated Oil contact angle.

From Fig. 3, it can be found that the initial viscosity reduction can be due to the breakdown of large hydrocarbon chains to smaller and lighter components [4]. The inverse trend of viscosity after 10 min irradiation could be referred to the evaporation of light components or the formation of large chains and polymerization.

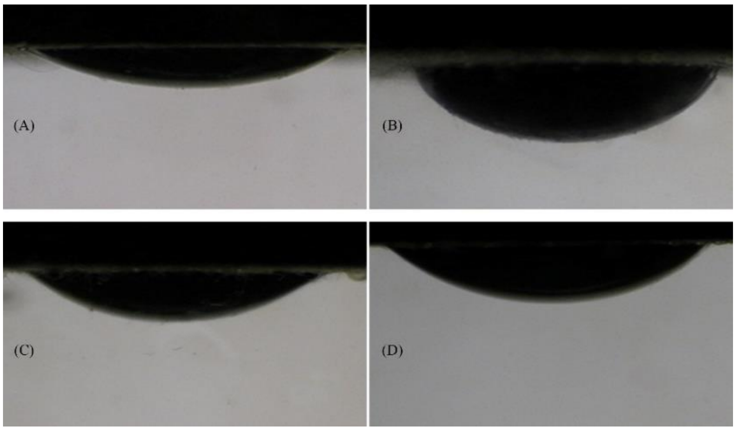

Fig. 2. Irradiated Oil Contact angle with rock. A) 0 min B) 10 min C) 15 min D) 55 min.

This is consistent with the previous results [3, 14]. Mozaffari and Nasri [15] showed that after 5 minutes half-power level of microwave irradiation, the viscosity diagram shows a reverse trend. They stated that after this time, light molecules are combined to form heavy components. As shown in Fig. 3, the contact angle has more tendency to reach equilibrium condition sooner in comparison with viscosity diagram. It emphasizes that the microwave radiation has a complex effect on the oil viscosity into a porous medium. Nevertheless, conducting more studies and researches on the effect of microwave radiation on the fluid-rock and rock-rock interactions into a porous medium seems necessary.

Finally, it is worth mentioning that the best irradiation time for reducing viscosity is 10 minutes (as shown in Fig. 3). Nevertheless, this time is increased to 45 minutes for the wettability (according to Fig. 2). Therefore, the time of microwave irradiation should be optimized to have maximum oil recovery factor in a filed operation.

Conclusion

This study investigated the effect of electromagnetic waves on the reservoir rock wettability and oil viscosity. From this study, it can be concluded that:

- Electromagnetic waves effect on the fluid properties and the rock surface properties, simultaneously.
- These waves can change the wettability of the rock from strongly hydrophobic to hydrophilic. For example, the oil contact angle on the rock reduced from 159° to 75° after 45 min irradiation.
- Oil viscosity changes from 840 to 745 after 10 minutes irradiation, and after that, it begins to increase.
- The contact angle of irradiated oil with a thin section has a descending trend before 10 minutes, and after that, a reverse trend was achieved.
- The time of microwave irradiation should be optimized to have maximum oil recovery factor in a filed operation.

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References

[1] Stanley, R. K. ," Methods and results of inspecting coiled tubing and line pipe", in SPE/IcoTA Coiled Tubing Roundtable: Society of Petroleum Engineers (2001).

[2] Ashton, S., Cutmore, N., Roach, G., Watt, J., Zastawny, H. and McEwan, A. ," Development and trial of microwave techniques for measurement of multiphase flow of oil, water and gas", in SPE Asia Pacific Oil and Gas Conference: Society of Petroleum Engineers (1994).

[3] Gunal, O. G. and Islam, M. ," Alteration of asphaltic crude rheology with electromagnetic and ultrasonic irradiation", Journal of Petroleum Science and Engineering, vol. 26, no. 1-4, pp. 263-272 (2000).

[4] Taheri-Shakib, J., Shekarifard, A. and Naderi, H. ," The experimental study of Effect of microwave heating time on the heavy oil properties: Prospects for heavy oil upgrading", Journal of Analytical and Applied Pyrolysis, vol. 128, pp. 176-186, (2017).

[5] Taheri-Shakib, J., Shekarifard, A. and Naderi, H. ," The study of influence of electromagnetic waves on the wettability alteration of oil-wet calcite: Imprints in surface properties", Journal of Petroleum Science and Engineering, vol. 168, pp. 1-7, (2018).

[6] Taheri-Shakib, J., Shekarifard, A. and Naderi, H. ," Inhibiting asphaltene precipitation using microwave irradiation: experimental investigation", in Saint Petersburg, (2018).

[7] Taheri-Shakib, J., Shekarifard, A. and Naderi, H. J. F. ," Heavy crude oil upgrading using nanoparticles by applying electromagnetic technique", vol. 232, pp. 704-711, (2018).

[8] Ruidiaz, E., Winter, A. and Trevisan, O. ," Oil recovery and wettability alteration in carbonates due to carbonate water injection", Journal of Petroleum Exploration and Production Technology, vol. 8, no. 1, pp. 249-258, (2018).

[9] Archer, D. G. and Wang, P. ," The dielectric constant of water and Debye- Hückel limiting law slopes", Journal of physical and chemical reference data, vol. 19, no. 2, pp. 371-411, (1990).

[10] Wang, W. and Gupta, A. ," Investigation of the effect of temperature and pressure on wettability using modified pendant drop method", in SPE Annual Technical Conference and Exhibition: Society of Petroleum Engineers (1995).

[11] Schembre, J., Tang, G. Q. and Kovscek, A. ," Wettability alteration and oil recovery by water imbibition at elevated temperatures", Journal of Petroleum Science and Engineering, vol. 52, no. 1-4, pp. 131-148, (2006).

[12] Jarrahian, K., Seiedi, O., Sheykhan, M., Sefti, M. V. and Ayatollahi, S. ," Wettability alteration of carbonate rocks by surfactants: a mechanistic study", Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 410, pp. 1-10, (2012).

[13] Rezvani, H., Khalilnejad, A. and Sadeghi-Bagherabadi, A. A. ," Comparative experimental study of various metal oxide nanoparticles for the wettability alteration of carbonate rocks in EOR processes", in 80th EAGE Conference and Exhibition, (2018).

[14] Britten, A., Whiffen, V. and Miadonye, A. ," Heavy petroleum upgrading by microwave irradiation", WIT Transactions on Modelling and Simulation., vol. 41, (2005).

[15] Mozafari, M. and Nasri, Z. ," Operational conditions effects on Iranian heavy oil upgrading using microwave irradiation", Journal of Petroleum Science and Engineering, vol. 151, pp. 40-48, (2017).