

Production Optimization by Sonication- A Review

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Abstract: Oil and gas production suffer some challenges such as; decline in reservoir pressure, emulsion problems, formation damage, hydrate formation, sand production, scale formation, high water cut etc. High power (10- 10,000 Wcm⁻²) low frequency (10 kHz to 1000 kHz) ultrasound waves have been tested by many researchers as a way of optimizing oil production by mitigating the challenges mentioned above. This paper presents different findings of research works on the use of ultrasound energy as a technique for improving oil production performance. Results of the research works reported in this paper show that ultrasound energy can be used to stimulate oil production if the combination of frequency and intensity levels of the ultrasound wave has been correctly selected. Furthermore, exposure time to ultrasound irradiation is equally important for optimum performance.

I. INTRODUCTION

Sound or acoustic waves are characterized by their frequencies, amplitude, and wavelength, sound waves are classified as Sonic, Infrasonic and Ultrasonic depending on the frequency of the wavefront. Frequencies below 20 Hz are termed infrasonic while frequencies between 20 Hz to 20, 000 Hz are classified as Sonic, this is the frequency range for human hearing, while ultrasonic waves have frequencies above human hearing > 20 kHz (Martini, 2013). Ultrasound waves can be divided into two categories based on the application; ultrasound frequencies in the range 2 to 10 MHz are termed “high frequency ultrasound” and are typically used for measurement and medical diagnosis purposes while frequencies in the range of 20 to 100 kHz are referred to as “power ultrasound” and are used for cleaning, welding, and sonochemistry (Maso & Lorimer, 2002).

Ultrasonic waves have many applications in the oil and gas industries. Special characteristics of the ultrasound waves such as high-frequency intensity and performing cavitation have brought them forward as a unique tool in many oil production stimulation operations (Beresnev & Johnson, 1994).

Sound waves are longitudinal when they travel in a liquid or gas medium and transverse when the medium is solid. When a sound wave is propagated through a material, the material particles do not move from one point to another, but the particles only oscillate around their position of equilibrium (Martini, 2013). The nature of the material in which the wave travels through affects the wave velocity. If the material is liquid or gas, the velocity of the sound wave is a function of the material bulk modulus, equation (1) below shows the relationship:

$$c = \sqrt{\frac{K}{\rho}} \quad (1)$$

Where C = wave velocity/m/s

K = bulk modulus of the material N/m²

ρ = density of the material kg/m³

If the medium of travel is solid, young modulus is used instead, equation (2) shows the relationship between bulk modulus (K) and young modulus (E) (McClements, 1991)

$$E = K + \frac{4}{3}G \quad (2)$$

Where G is the shear modulus.

Optimum oil and gas production is hitherto hindered by many factors. Some of the factors include; decline in reservoir pressure, formation of an emulsion, damaged formation, scale production, hydrate formation etc. Production enhancement is basically employed to minimize the production gap between the actual and expected potentials (Ajienka, 2017). There are several methods the industry uses to mitigate those production challenges, and most of the methods have some drawbacks; e.g. most of the methods are generally expensive to use, they required a wide range of surface equipment, sometime production must be shut down before a particular method is applied, and some have an impact on the environment.

There are many researches on the use of ultrasound energy to improve production performance by reducing the challenges mentioned above. High intensity or power ultrasound (10 – 10,000 W/cm²) (Bermudez-Aguirre & Canovas, 2011; Rastogui, 2011) has been tested and was found to be effective in optimizing oil and gas production. Power ultrasound technique is highly invasive acoustic waves that can change material properties. Power ultrasound can cause the crystallization of some materials (sonocrystallization), it can induce chemical reactions (sonochemistry) and it can cause cavitation in fluids (Gedanke, 2004; Kasai et al., 2008; Wu et al., 2008; Trevena, 2006). Ultrasound energy can also change the physicochemical properties of different materials (Arzeni, et al., 2012; Ashokkumar, et al., 2009; Jambrak, et al., 2008; Martini, et al., 2010). These properties of the sound wave attributed to its ability to mitigate oil production challenges.

Sound Wave Pressure

The equation for the propagation of acoustic pressure in a viscous medium is given by equation 5 below (Ludwig & Levin, 1995).

$$\frac{\partial^2 p}{\partial x^2} - \frac{1}{V_0^2} \frac{\partial^2 p}{\partial t^2} + \tau \frac{\partial^3 p}{\partial t \partial x^2} = 0 \quad (5)$$

Where $p(x,t)$, and $\tau = [\eta_v + 4\eta_s/3]/\rho V_0^2$ are the acoustic pressure and relaxation time respectively, η_v and η_s are the bulk and shear viscosities and V_0 is the propagation velocity.

If oil in a porous media has a compressibility k , a density ρ_0 at a reference pressure p_0 and a viscosity μ . In a linear theory of sound, the amplitude $|p - p_0|$ of the acoustic excess pressure waves that is generated by a simple source under the neglect of gravity and viscosity in the porous media is given by equation 6 below (Aarts, et al., 1999).

$$|p - p_0| = \frac{1}{L} \left(\frac{\rho_0 U_0 W}{2\pi} \right)^{1/2} \quad (6)$$

Where L = distance between source acoustic source and porous media

W = average power output generated by the acoustic source

$U_0 = \frac{1}{(k\rho_0)^{1/2}}$ is the speed of in the oil

Sound Wave Intensity

The intensity of a sound wave will continue to decrease when propagated through a liquid. This decrease of sound wave intensity is referred to as propagation loss, this loss occurred as a result of the contributions from two losses; spreading loss and attenuation loss (Trevena, 2006). Spreading loss occurs because of the waves divergence as they are propagated and is the intensity loss created by geometrical spreading of the waves. Fluid properties have no effects on the spreading loss. In the case of attenuation loss, the fluid properties have great effects on the wave propagation, and it is caused by the combined effects of absorption and scattering within the medium. According to Trevena (2006), for a plane wave at a given time t , the attenuation loss can be described by equation 7 below.

$$I_2 = I_1 \exp[-2 \alpha (x_1 - x_2)] \quad (7)$$

Where I_1 and I_2 are the intensities at points $x = x_1$ and $x = x_2$ respectively, and α is the absorption coefficient. Equation 7 shows that the fractional reduction of intensity per unit distance is constant, and this is what is usually found in practice.

II. ENHANCED OIL RECOVERY

Introducing high and low-frequency acoustic waves to oil reservoirs may cause an increase in oil recovery as evident from laboratory and field-scale applications (Hamida and Babadagli, 2005). Researchers have presently studied the interface existing between the displaced and displacing phases and observed significant changes at the interface and an increase in oil recovery when ultrasonic energy is introduced (Hamida and Babadagli, 2007). According to Hamida and Babadagli (2008), the exact recovery mechanism behind ultrasonic stimulation is still not clearly understood. However, this is mainly due to the superposition of several competing effects and the complexity of the process.

Recovery Mechanism Under Ultrasound Wave

There are several research publications, patents and field trials on the use of ultrasonic waves to stimulate fluid flows within a porous media. Despite the extensive works on ultrasound stimulation, the recovery mechanism is not well understood. However, the following mechanisms are believed to be the cause of the observed improved oil percolation within the porous media:

- Relative permeability increase between the phases.
- Ultrasound waves decrease the adherence of wetting films onto the reservoir rock matrix due to nonlinear acoustic effects, e.g. acoustic streaming, local pressures perturbation, cavitation and in-pore turbulence (Aarts, et al., 1999).
- Ultrasonic radiation generates heat which results to surface tension reduction and a decrease in viscosity and density, ultrasound may also decrease thixotropic fluid's viscosity (Fairbank & Chen, 1970; Oudina & Djelouah, 2010).
- Peristaltic transport of fluid to the adjacent pores is initiated as a result of pore wall mechanical vibration. (Aarts, 1999).

- Rock porosity and permeability increase because of removal of clays and fines, and deformation of pores.
- Micro-emulsification of oil due to the presence of either natural (in-situ) or introduced surfactant. (Abismail et al. 1999) and (Mikhailov & Nikolaevskii, 2000).

Many works have been done to enhance oil production using downhole mechanical vibrations. This vibration can be generated by ultrasound waves, which can facilitate oil production from the reservoir by altering the capillary forces, reducing the force of adhesion between fluid and rock, and cause oil coalescence (Hamida and Babadagli, 2005; Kouznetsov et al. 1998). An ultrasonic stimulation and waterflooding experiment were conducted by Erfan et al on an unconsolidated sand pack, the non-wetting phase used in the system were; engine oil, kerosene, and vaseline. Up to 16% oil recovery was observed. The mechanisms that contributed to the increase in recovery were identified as; cavitation and emulsification (Mohammadian et al. 2013).

Khosrow and Tyfun placed oil saturated sandstone core sample into imbibition cells, and experiments were carried out to determine oil recovery with and without ultrasonic radiation. An increase in oil recovery was observed when the ultrasonic wave was applied. However, a decrease in the recovery was noticed when oil viscosity is increased (Naderi & Babadagli, 2010).

Pendant drop method was used by Tarek and Tayfun to investigate the effect of ultrasonic wave on flow through a capillary. A capillary tube was submerged in different mineral oils and kerosene. Several ultrasonic intensities were applied and an average drop rate per minute was measured in each case. They observed a peak drop rate at a particular intensity, and this depends on the interfacial tension between water and oil and oil viscosity. The results obtained show a reasonable change in the interfacial tension between water and oil, and this could be the evidence for the improvement of oil recovery when the ultrasonic waves were applied (Hamida & Babadagli, 2008).

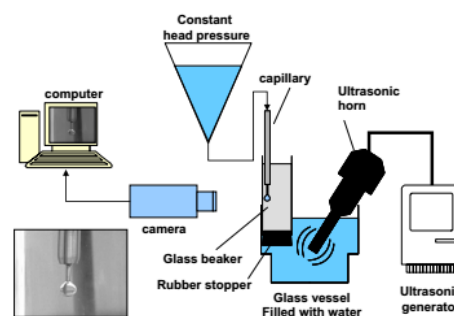


Fig.1: Pendant Drop Experimental Setup (Hamida & Babadagli, 2008)

Another technology for ultrasonic enhancement of oil recovery from depleted wells was described by Vladimir et al. in this technology, a source of power ultrasound is lowered to the bottom of the well either as a permanent placement to be used intermittently or for short term treatment before removal. They concluded that; oil production can be increased up to 50% with ultrasonic treatment particularly for wells with permeability and porosity above 20mD and 15% respectively. However, for lower permeability and porosity wells, ultrasonic treatment alone is less effective. But the introduction of chemicals to the ultrasound can yield a better result (Vladimir et al., 2013).

Emad et al carried-out laboratory experiment on reservoir rock core samples to investigate the ability of ultrasound waves to

improve oil production. The ultrasound wave was applied to the core samples after performing initial waterflooding. The experiment was conducted at original oil in place and at residual oil saturation. The results of this work show that; oil recovery factor is more favorable in the case of residual oil saturation than the case of original oil in place (Alhomadhi et al., 2014).

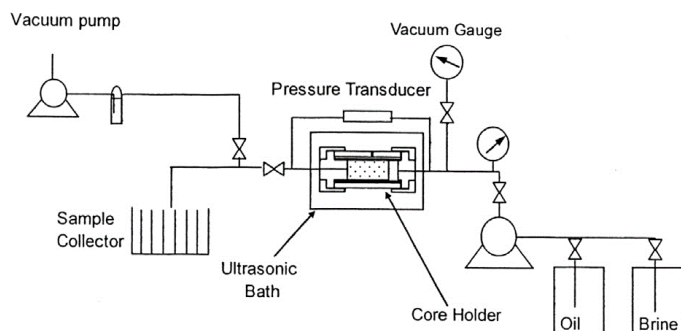


Fig. 2: Experimental setup used for ultrasound enhanced oil recovery(Alhomadhi et al., 2014)

According to Mullakaev et al. (2015), after ultrasound stimulation was conducted on three wells, an average increase of 32.6 barrels of oil per day was observed, and the effect of the treatment on oil production was about six months. During the treatment, fluid was injected to aid wave propagation.

EMULSION CONTROL (DEMULSIFICATION)

Ultrasonic irradiation can demulsify any type of emulsion because it has a good conductivity in both oil and water (Sun et al., 2000, 1999). According to Teipel (2002), the heating effect of ultrasonic energy can increase the temperature of the emulsions and thus, results in viscosity reduction and coalescence. Stoke's law can be used to determine the settling velocity of the dispersed phase through the continuous phase(Ajienka, 2017;Teipel, 2002).

$$v_w = \frac{D^2(\rho_w - \rho_o)g}{18\mu_o} \quad (3)$$

Where v_w is water droplets velocity
 ρ_w, ρ_o water and oil densities respectively
 D is the water droplet diameter
 g is the gravitational acceleration
 μ_o is the oil viscosity

Equation 1 above can be applied for rising velocity of oil droplets if water is the continuous phase. Many researchers (Stack et al., 2005; Gautam & Donald, 2004; Yu et al., 2002; Qi & Lu, 2001) have worked on this new technology and reported its advantages. Yang et al. (2009) conducted an experiment to investigate the demulsification of crude oil emulsion using an ultrasonic and chemical method. Figure 3 below shows the experimental setup used.

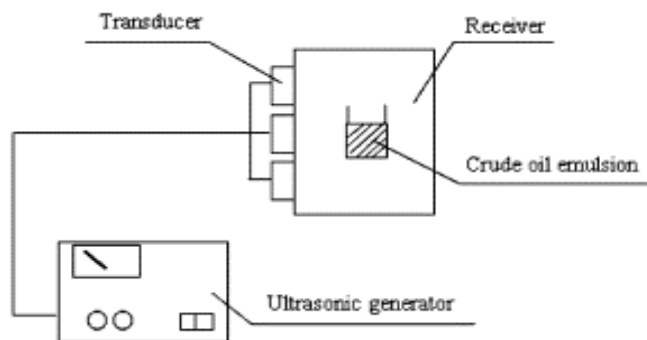


Fig. 3: Ultrasonic chemical demulsifier Experimental Setup(Yang et al., 2009)

The results of Yang experiment show that up to 97.7% v/v dehydrating ratio can be achieved if the right combination of ultrasonic out power, irradiation time and the concentration level of chemical demulsifier were applied i.e. 100 W, 10 min, and 50 mg/L respectively.

Ultrasonic waves' effect on the stability of asphaltene emulsion was investigated by Zhang et al. (2010), they observed that the colloidal stability of asphaltene improves after ultrasound waves application and it is primarily a physical process.

III. FORMATION DAMAGE CONTROL

Asphaltene Formation Damage

The molecular weight of asphaltenes can be changed by ultrasound radiation. About 35% of asphaltenes was successfully converted into resin and gas oil fractions by Dunn & Yen (2001) using the ultrasound power and its cavitation feature. Lin et al. (1994) cracked refinery oil residue containing high amount of asphaltenic components by applying ultrasonic waves in the presence of abundant hydrogen. Experimental results show that there is no direct relationship between the effects of ultrasound frequency and its ability to change the average molecular weight of asphaltene content (Kang et al. (2006). The asphaltenic oil viscosity can be changed by radiating ultrasonic waves. Islam et al. (1994) conducted experiments to determine the relationship between bitumen viscosity and asphaltene content molecular weight. The results show that oil viscosity increases significantly if it contains more asphaltenic heavy components. Accordingly, by accepting that ultrasound can crack the asphaltene molecular chains, it can also decrease the oil viscosity. About fifteen percent (15%) decrease in viscosity of heavy asphaltenic oil samples was reported by Chakma & Berruti (1991) after radiating ultrasonic waves. According to Hamidi et al. (2014) the mechanism behind oil viscosity reduction by ultrasound waves are heat generation and cavitation within the fluid.

The effect of ultrasonic irradiation on asphaltene particle size distribution (APSD) was observed in an experiment conducted by Najafi et al. (2011) and it was found that exposure of asphaltene particles to ultrasonic waves for a specific time, can mitigate the particles average sizes. A model was developed by Rad et al. (2013) to describe asphaltene flocculation kinetics behavior, and the results show that, the asphaltene flock size is reduced after exposure to ultrasonic waves for an optimum sonication time.

Rabbani et al. (2015) conducted an experiment using a bundle of tubes model to determine the effect of ultrasound waves on permeability impairment caused by asphaltene deposition. Equation (4) below shows flow permeability in porous media using bundle of tubes experiment (Rabbani et al. 2015).

$$k = \frac{n_p \cdot \pi r_p^4}{8\tau A} \quad (4)$$

Where k = is permeability
 r_p = average pore radius
 n_p = total number of tubes
 A = cross sectional areal
 τ = tortuosity of the medium

The results of the experiment show that, permeability impairment caused by asphaltene deposition can be remediated by application of ultrasound waves which affect the asphaltene particles size distribution.

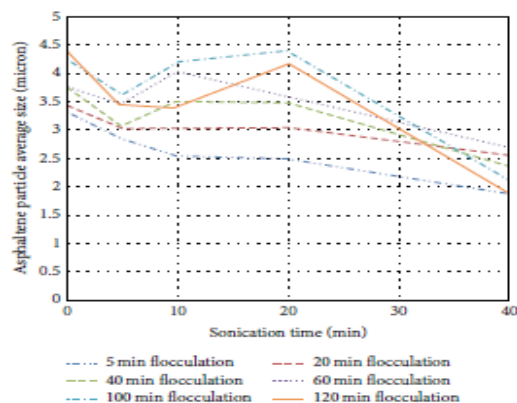


Fig. 4: Asphaltene Particle size versus time of ultrasonic

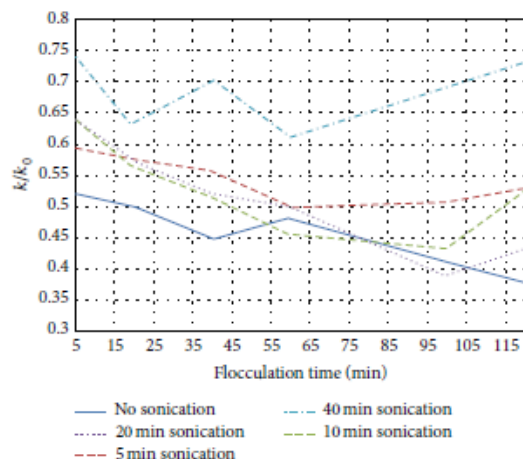


Fig. 5: Changes in predicted permeability ratio versus

Radian (Rabbani et al. 2015) flocculation time for different sonication periods. Results of the experiment also show that mobility reaches minimum value when the sonication time is about 20 minutes, as shown in figure six below.

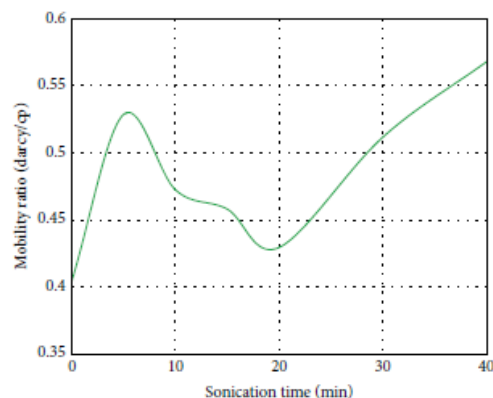


Fig. 6: Mobility changes for different times of sonication(Rabbani et al. 2015)

Near Wellbore Damage Caused by Mud solids and Fines

Venkitarama et al. (1995) conducted laboratory experiments to investigate the possibility and effectiveness of using ultrasonic waves to mitigate formation damage caused by fines and mud solids. During the experiments, core samples were damaged with drilling muds in a dynamic filtration cell to simulate mud solid damage. Freshwater was injected into the core sample to simulate damage caused by fines migration. The damaged core samples were then treated with ultrasonic energy at different frequencies and intensities. The setup for the experiment is shown in figure seven.

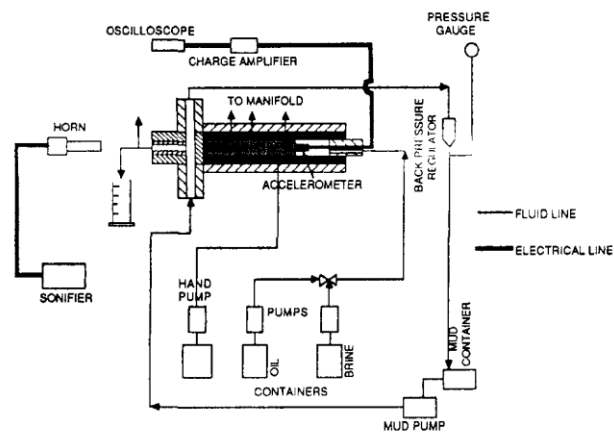


Fig. 7: Experimental Setup Schematic (Venkitarama et al., 1995)

The results of this experiment show that application of ultrasonic energy is capable of partly removing wellbore damage caused by the invasion of mud particles. The treatment is effective in both oil phase as well as water phase. The method can be used to treat mud-particle invasion damage for both sandstone and limestone formations. The sonication effectiveness depends on the frequency intensity, the power, the flow rate, and the duration of sonication. The challenges of formation damage by fines can also be solved by ultrasonic treatment. Permeability increase in these experiments was observed by as much as a factor of six. The treatment effectiveness is enhanced if it is conducted under static conditions followed by back flushing. Acoustic streaming is most likely the dominant mechanism for cleaning both fines and mud damages. However, in the mud damage case the removal of near-surface particles may be contributed by cavitation (Venkitarama et al., 1995). The results of the experiment are graphically presented in figures 8 to 11.

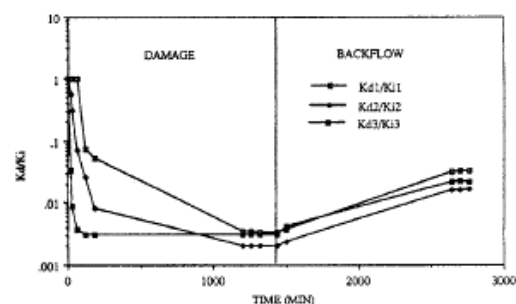


Fig. 8: Formation damage caused by freshwater injection in brine

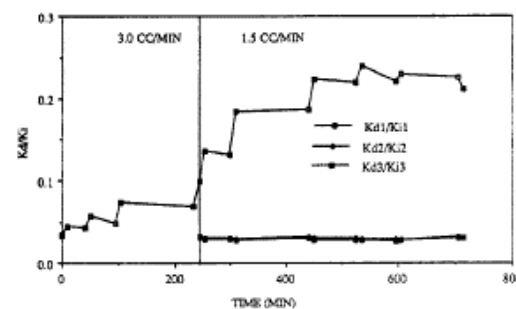


Fig. 9: Acoustic cleaning of core damaged saturated Berea sandstone (Venkitarama et al., 1995) by freshwater injection (Venkitarama et al., 1995)

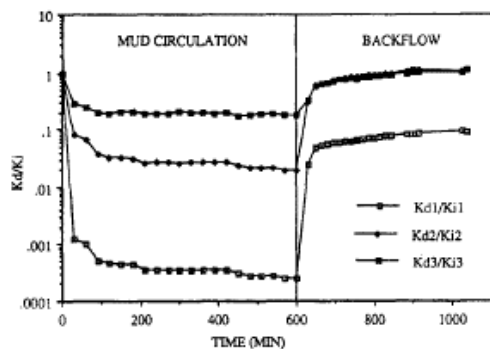
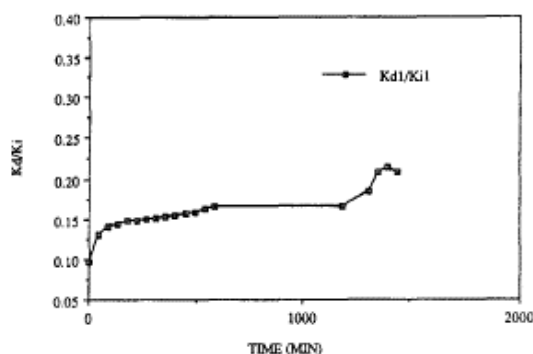


Fig. 10: Formation damage caused by drilling mud in Berea

Fig. 11: Acoustic cleaning of Berea sandstone at S_{wi} and stone at irreducible water saturation (S_{iw}) damaged by drilling mud (Venkitarama et al., 1995)

Near Wellbore Damage Caused by Organic Deposits and Polymer

Experiments were conducted by Roberts et al.(2000) aimed at investigating the effectiveness of using ultrasonic energy to reduce the degree of formation damage caused by paraffin precipitation and HEC polymer infiltration in core samples obtained from Berea sandstone. Previously reported work by Venkitarama et al. (1995) indicated that ultrasonic waves are capable of significantly reducing damage induced by drilling mud infiltration and in-situ fines migration. Equally, positive cleaning results were obtained for paraffin and polymer damage. About 1.4 kJ of acoustic energy at a frequency of approximately 20 kHz removed all precipitated paraffin from the first core section of 6.35 cm length and increased the permeability in the second section of 5.08 cm length by 100%. The experimental setup for both paraffin and polymer cases are shown in figure 12 and 13 respectively.

The results of the experiments show that, to significantly clean damage caused by polymer infiltration, more acoustic energy is required, and only about 50% net permeability increase was observed in both core sections. Ultrasonic cleaning seems to be a feasible technique for treating paraffin problems, especially

if it is combined with solvent soaks. Table 1 below shows the summary of ultrasonic cleaning simulation results and the parameters used in the experiments.

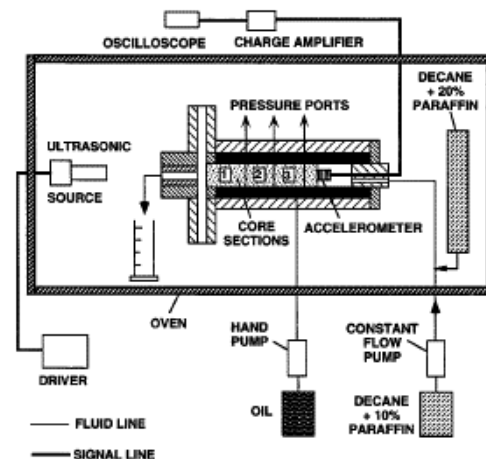


Fig. 12: Experimental setup used for the polymer damage case

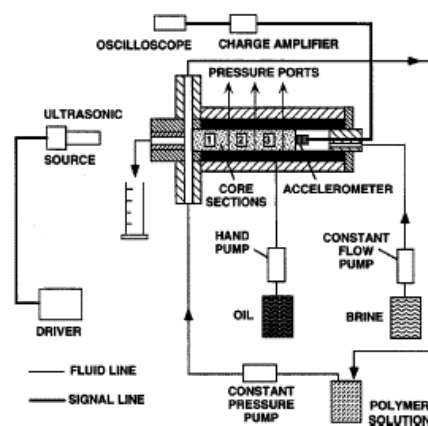


Fig. 13: Experimental setup used for the Paraffin damage case

The dominant physical mechanisms for the cleaning process seem to be increased re-suspension or dispersion of paraffin caused by mechanical agitation. Polymer infiltration is much tougher to remove acoustically than any other form of damage investigated. The feasibility of using ultrasonic waves to remove polymer damage without complementary chemical treatments is uncertain at best.

The effect of ultrasound irradiation on fluids viscosity was reported by Bjorndalen & Islam (2004) from their experiment. During the experiment, three different fluids; crude oil, asphaltene and paraffin were exposed to ultrasound irradiation at different exposure times i.e 30, 60 and 120 seconds. Figure fourteen below shows the graphical representation of the experiment's results.

Table 1: Results summary for ultrasonic cleaning simulation and parameters

Type of Damage	Core Section 1 (6.35 cm)		Core Section 2 (5.08 cm)		Input rms Intensity (W/m^2)	Input rms Power (W)	Total Input Energy (kJ)
	k_d/k_i Before Sonication	k_d/k_i After Sonication	k_d/k_i Before Sonication	k_d/k_i After Sonication			
Mud	0.07	0.32	1.0	1.0	1500 to 4500	0.76 to 2.28	1.3
Fines	0.03	0.18	0.03	0.03	1200 to 3000	0.61 to 1.51	0.7 to 1.4
Paraffin	0.40	1.20	0.40	0.85	300 to 1800	0.15 to 0.91	0.9 to 1.4
Polymer	0.22	0.37	0.53	0.78	5700	2.89	12.0 to 14.0

k_d & k_i core sample permeability after & before induced damage respectively.

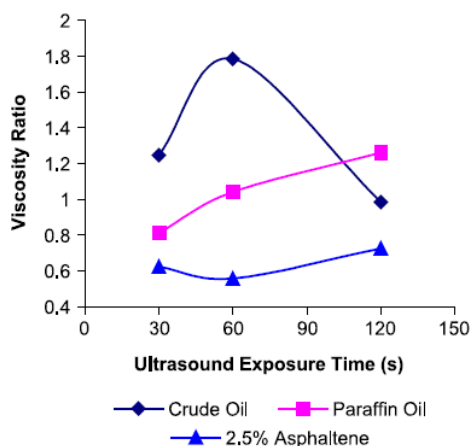


Fig. 14: Fluid Viscosity change for different Ultrasound Exposure Times(Bjorndalen& Islam, 2004)

Before 60 seconds, the viscosity of crude oil increases and that of asphaltene decreases, beyond 60 seconds the viscosity of crude oil decreases while that of asphaltene begins to increase. The viscosity of paraffin oil decreases from 30 seconds and is less than unity. But the slope's nature shows that the ultrasound can increase the viscosity of the paraffin oil over time. The results observed by Bjorndalen & Islam (2004) is similar to what Chackma et al.(1994) observed and was also reported by Islam (1995). These observations were attributed to two counteracting factors: an increase in ultrasound exposure time causes an increase in temperature which results to viscosity reduction, an increase of the exposure time also causes the re-orientation of the fluid's molecular structures.

IV. SCALE REMOVAL

A Scale is one of the common problems during oil production, and it can result to significant decline in production by reducing production flow path and may even lead to well abandonment (Akaranta, 2017). Types of scale commonly found in the oil and gas field are the sulfates and carbonates of calcium salts, Barium and Strontium.

The normal practice by the industry to mitigate scale production is by the use of chemicals solutions which are referred to as scale inhibitors. And scale dissolvers are used to remove that is formed already.

Kunanz et al. (2014) conducted an experiment on scale removal using ultrasonic energy. During the experiment, Sulfates of calcium salts (gypsum) base scale was simulated. The gypsum samples for the laboratory test were generated artificially using a setup that was designed to ensure the sample is defined and reproducible. Commercially available G1 70 Murexin type gypsum was used in the experiment. A pipe sample was formed using low-grade steel pipe with 28 mm diameter. The pipe was cut into 70 mm long pieces and each piece was cut into two equal halves along their longitudinal axes.

The sonification of the gypsum samples was done using DG 200 type ultrasonic generator. During the laboratory tests, twelve (12) experiments were run and the ultrasonic frequency was kept constant at 20 k Hz while the power was varied between 279 W minimum and 810 W maximum. Figure fifteen below shows the setup that was used to conduct the experiment.

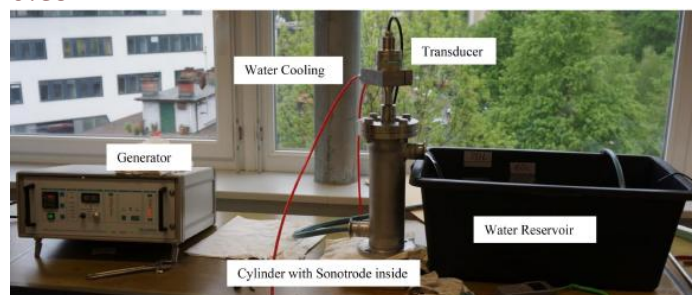


Fig. 15: Experimental Setup (Kunanz et al. 2014)

The results of the experiment show that about 100% purification can be achieved if the right combination of ultrasonic frequency, amplitude, and power are used. Figures 16 and 17 below show the effect of the ultrasonic energy on scale removal.



Fig. 16: Sample before Treatment(Kunanz et al. 2014)



Fig. 17: Sample after treatment(Kunanz et al. 2014)

An experiment to simulate inorganic scales (NaCl) removal using ultrasonic waves was conducted by Taheri-Shakib et al. (2017). During the experiment, twenty core samples of different permeabilities were used. The results of the experiment show that better permeability restoration was achieved when water injection is augmented with ultrasound wave. Core samples with the following permeabilities: below 20, 30 – 100, 100 – 700 and 1000 mD and above; ultrasonic waves application improves the permeabilities to; 80, 42, 87 and 81% respectively. However, water injection alone restores the permeabilities to; 29, 18.5, 65 and 77% respectively. Figure 18 below shows the experimental setup used.

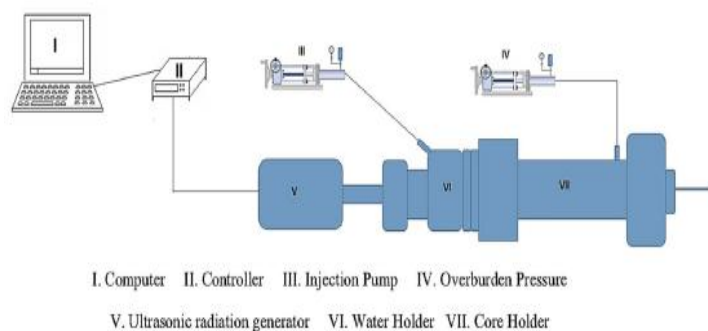


Fig. 18: NaCl removal Experimental setupTaheri-Shakib et al. (2017)

According to Xu et al. (2009) the solubility of inorganic scale is accelerated by the passage of ultrasound wave through the core sample. The solubility is increased because of raising in temperature. Ultrasound waves caused the distortion of the crystal of NaCl and crushes the bonding energy between the particles and rock matrix (Fakhru'l-Razi et al. 2009).

V. HYDRATE REMOVAL AND CONTROL

O'Malley et al. (2009) discussed in their patent the application of high amplitude vibration to control hydrates formation. Agitation or perturbation of water and gas molecules will continuously break up gas hydrates agglomerates that are formed and support the formation of smaller particles that are soluble in the flow stream.

Some researchers think it is necessary to have a system which could monitor and detect initial hydrate formation which would serve as a backup to any hydrate prevention strategy. Application of ultrasound waves to detect and monitor hydrates formation was investigated in an experiment conducted by Mazloun et al. (2011). The results of the experiment show that ultrasound wave speed can be used to detect early signs of hydrate formation.

CONCLUSION

This paper presents various research works on the application of ultrasonic energy to enhance oil production. Results of the research works reported show that low-frequency and high intensity ultrasound which is an invasive technique can reduce production challenges. High-frequency ultrasound waves if applied to stimulate oil production may be attenuated after propagating a short distance.

Despite the extensive research works on the application of ultrasound to stimulate oil production, the mechanisms that contributed to oil recovery improvement were still not clearly understood due to some competing factors. However, the following mechanisms are believed to contribute in stimulating the oil production: rock porosity and permeability increase, temperature rise as a result of ultrasound radiation which causes viscosity and surface tension reduction, chemical reaction, acoustic streaming, fluid cavitation local pressure perturbation and change in physicochemical properties of materials.

To achieve optimum performance of ultrasound energy as a means of stimulating oil production, the right combination of frequency, intensity and exposure time of ultrasound should be applied. For cases where solvents are required to augment the ultrasound waves, right volume should be used.

Most of the research works are at laboratory scale with few field pilot tests. Therefore, more work has to be done to obtain an in-depth knowledge on the application of ultrasound technology to optimize oil and gas production to allow large-scale field application and commercialization.

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