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Application of Ultrasonic Waves for Degassing of Drilling Fluids and Crude Oils

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Abstract

In the oil and gas industry, both the produced oil and the drilling fluids used while drilling will contain gases that are entrapped within their liquid systems. These gases are removed, or degassed, using several methods such as separator tanks (for crude oil) and vacuum degassers (for drilling mud). This project, however, proposes a novel, environment friendly and cheap method of degassing that uses ultrasonic waves to remove gas bubbles from liquid systems. This method could be incorporated with already existing degassing technologies to increase their efficiency.

The objective of this work, therefore, is to investigate the feasibility of using ultrasonic waves as a method of degassing drilling fluids and crude oil samples. The basic idea of this new method is based on the effect that ultrasonic waves generate when in contact with a liquid medium as they create repeated compressions (high-pressure cycles) and rarefactions (low-pressure cycles) in which small vacuum bubbles (voids) are formed in the liquid. Dissolved gases will migrate into these small voids which will coalesce and then rapidly grow into large size bubbles that are easily removed out of the liquid.

Hence, this method insures more effective removal of dissolved gases that are entrapped within the liquid. Also, as this whole process happens rapidly, gas bubbles will have shorter time in contact with the liquid particles which reduces the possibility of gas redissolving; especially in the case of highly viscous liquids such as oil. This further adds to the advantages of using this new method.

For the purpose of this project, several testing methods such as sonication, density, pH, Particle Size Distribution (PSD), Fourier Transform Infra-Red (FTIR), and corrosion testing were conducted. These tests aimed to evaluate the physical and chemical impacts that ultrasonic waves have on the tested systems.

The results of these tests prove, to a great extent, the effectiveness of ultrasonic waves in removing gases from water based mud and crude oil samples. The impact of ultrasonic waves on the physical and chemical properties of the tested fluid systems, however, requires further investigation.

Key words: Degassing; Gas redissolving; Ultrasonic waves; Drilling fluids and crude oils

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SIGNIFICANCE

In the subsurface, different gases are introduced to the produced crude oil and to the drilling fluids. These gases exist in the form of small suspended bubbles. The presence of gases in crude oil and drilling fluids is undesired for several reasons. For instance, some of these gases, such as oxygen and hydrogen sulfide, are highly corrosive and damaging to the surface facilities, pipes, pumps, and so forth. Also, thepresence of gases could influence some of the essential properties of the fluids, such as density and viscosity. Hence, quick and efficient removal of these gases is extremely important[1].

The process of removing these small bubbles from the containing liquid is referred to as degassing. During oil production, gases are removed from the produced crude in

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the separators which are pressure tanks that separate the produced fluids into three components: water, oil, and gas based on their different densities[2]. Drilling fluids, on the other hand, are passed through degassers (vacuum tank or atmospheric) which are special tanks designed to remove the bubbles from the drilling fluid before it is circled again into the wellbore during the drilling process[3].

This project, however, discusses the possibility of introducing a new degassing method using ultrasonic wave technology. The basic idea of this new method is based on the effect that ultrasonic waves generate when in contact with a liquid medium. These waves create repeated compressions (high-pressure cycles) and rarefactions (low-pressure cycles). During rarefactions (low-pressure cycles), large number of small vacuum bubbles (voids) are formed in the liquid. Dissolved gases will migrate into these small voids which will coalesce and then rapidly grow into large size bubbles that are easily removed out of the liquid[4]. Hence, this method insures more effective removal of dissolved gases that are entrapped within the liquid. Also, as this whole process happens rapidly, gas bubbles will have shorter time in contact with the liquid particles which reduces the possibility of gas re-dissolving; especially in the case of highly viscous liquids such as oil. This further adds to the advantages of using this degassing method[5].

Such novel attempt will be path breaking to the concept of degassing applications both in drilling and production operations, hence the significance of this research project. The technology of ultrasonicdegassing could be implemented as a substitute to existing degassing methods or incorporated with them to increase degassing efficiency. Furthermore, ultrasonic degassing technology could provide a cheaper replacement of chemical defoamers that are occasionally added to increase gas-removal efficiency. Finally, ultrasonic waves degassing system is an environment friendly system that poses no dangers to the surrounding.

1. OBJECTIVES

The primary objective of this research project is to investigate the feasibility of using ultrasonic waves to remove gas bubbles from water based mud and crude oil samples. To help establish this goal, several secondary goals are also intended such as investigating the effects of ultrasonic waves on the physical and chemical properties of the samples and also determining a proper configuration that optimizes the effect of ultrasonic wave.

2. METHODOLOGY

For the purpose of this project, which is investigating the feasibility of using ultrasound as a degasser, different experimentations were conducted on water-based mud and crude oil sample. The water based mud was prepared in the lab by mixing 350 ml of 10 ppg NaCl brine (1 bbl equivalent) with 0.5 g of Flowzan, which is a biopolymer viscosifier commonly used by drilling fluids companies. The crude oil sample was provided by one of the operating companies in Qatar. The conducted tests were the following.

2.1 Sonication

Sonication is referred to the process of irradiating a sample with ultrasonic waves (frequency ≥ 20,000 Hz).

This process implicates several physical and chemical changes[6-8]. An ultrasonic wave generator model Hielscher UIP1500hd that generates 20,000 Hz frequency and 1,500 W power output was used to sonicate the water-based mud and the crude oil specimens (see Figure 1). The specimens were irradiated for time intervals of 2, 5, 10, 15, 20, 25, and 30 minutes.

Figure 1
Ultrasonic Wave Generator, Transducer, and Cell Assembly

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For safe operation, a special sound isolating cabinet was manufactured to house the ultrasonic wavegenerator. Figure 2 below shows the designschematics of the cabinet and a picture of it on the upper right corner.

Figure 2
Ultrasonic Waves Isolation Cabinet

Sonication procedure:

A. Cell Assembly:

(a) On a steady platform, set the cell on up-right position. Tighten the stem valve on the bottom lid.
(b) Fix the top cap and screw the Allen screws (3) all the way down until they push the top cap against the lid.
(c) On the other end, pour your weighed (grams) sample and fix the bottom cap followed by the rubber O-ring, the rod, an O-ring and metal locking screw accordingly.
(d) Securely tighten it by a wrench of the appropriate size.

B. Ultrasonic Wave Generator Assembly:

(a) On the top of the inverted transducer, fix the cell assembly.
(b) Set the generator to 65% amplitude.
(c) PumpNitrogen gas (N_2) continuously on the stem valve while it is closed, this operation is also called **sparging**.

C. Sonication:

(a) Open the stem valve by turning it 270° counter clockwise using a 6" wrench.
(b) Turn "ON" the generator for 5 minutes.
(c) After 5 uninterrupted minutes, close the stem valve and turn the generator off.
(d) Remove the connection between Nitrogen gas lines and stem valve.
(e) Carefully, open the stem valve and let the air to liberate.
(f) Once no more air is observed inside the system, close the stem valve.
(g) Repeat step#1-3, but this time pump Butane gas (C_4H_{10}).
(h) After 5 minutes of operation, close the stem valve and let it cool down for about 10 minutes.
(i) Carefully open the stem valve and let air to leak.
(j) Open the top cap and transfer the sample into a graduated cylinder and measure the volume.

2.2 Effect of Sonication

To analyze the effect of sonication on the tested samples, different measurements were taken. It is important here to note that some of these testing were done on both crude oil and water-based mud samples while others were done only on one of the two samples mainly due to lack of appropriate testing equipment or incompatibility with the available facilities. These measurements were the following:

2.2.1 Density

The mass density (ρ) of a substance is defined as its mass per unit volume. The density of a substance depends on pressure (directly proportional) and temperature (inversely proportional). The effect of these two parameters is more noticeable in gases than in solids and liquids.

After sonicating the water-based mud samples and the crude oil samples, density was measured. Readings were taken at temperature of 20-25 °C under atmospheric pressure using a hydrometer (see Figure 3).

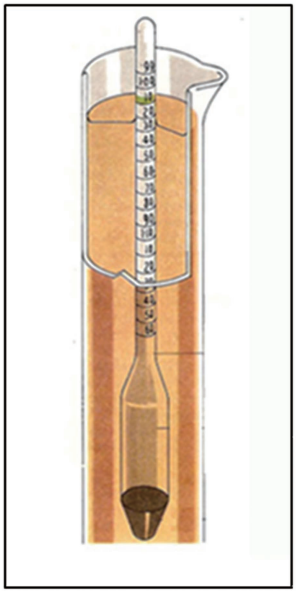

Figure 3
Hydrometer for Density Measurement

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2.2.2 Fourier Transform Infra-Red (FTIR) Analysis

Fourier Transform spectroscopy analysis of the crude oil was performed to a sonicated and a non-sonicated specimen to determine whether any alteration in the composition of the crude oil has taken place when ultrasonic waves are applied. This test was not performed on the water based mud samples as materials that contain high water percentages do not generate meaningful spectra due to the large peaks that water molecules generates. This analysis is based on the fact that when a specimen is subjected toradiation (infra-red waves, in this case), the molecules of the specimen will absorb particular wavelengths that are characteristic to their structure and, hence, will create a spectrum that can be analyzed to determine molecular "finger prints" of that specimen. The generated spectrum is then compared to standard spectrums to identify functional molecular groups[9].

The equipment that was used to conduct this test was the Perkin Elmer Spectrum-one VB spectrometer (see Figure 4).

Figure 4
Perkin Elmer Spectrum-One VB Spectrometer

2.2.3 pH (Power of Hydrogen)

pH tests indicates the acidity or the alkalinity of the substance. pH readings were taken for the water based mud before and after sonication.

Figure 5
Digital pH Meter

Apparatus:

(a) 3 Glass beakers.
(b) Calibration Fluids.
  a) pH 4 (red),
  b) pH 7 (yellow),
  c) pH 10 (blue).
(c) Digital pH Meter (see Figure 5).

Calibration Procedure:

The probe should at all times, when not in use, be stored in calibration fluid pH 4 if the 3M KCl is not available. The container is refilled when needed.

(a) Fill each of the beakers with one of the calibration fluids.
(b) Press "ON."
(c) Rinse the electrode with deionized water and shake gently to remove any excess water.
(d) Put the probe in the calibration fluid pH 7 and press CAL/MEAS. Once the "READY" indicator is displayed in the left-hand corner, press "ENTER."
(e) Repeat steps 3-4 using calibration fluids pH 4 & 10 without pressing the CAL/MEAS, it will automatically detect which pH solution is at use.
(f) Once all 3 pH solutions have been tested, the meter will automatically return to "pH measurement mode". Results are noted.

Testing Procedure:

(a) Immerse the probe into the solution (mud) before subjecting it in sonication.
(b) Avoid any contact with the tip of the container.
(c) The pH concentration will be shown in the screen, record the reading as it stabilizes.
(d) Remove the probe and rinse it with deionized water.
(e) After sonication, repeat step 1 to 3.
(f) After testing, rinse the probe with deionized water and store it in a pH 4 buffer.

2.2.4 Particle Size Distribution Analysis (PSD)

Figure 6
Particle Size Distribution Analyzer (Model MALVERN Mastersizer V2.19)

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This test indicates the size of the radii of the particles of the material being tested. The equipment used in this project (see Figure 6) has the ability to detect sizes from 0.5 μm to 550 μm. The working concept this equipment uses for measuring is laser diffraction and characterization through scattering[10].

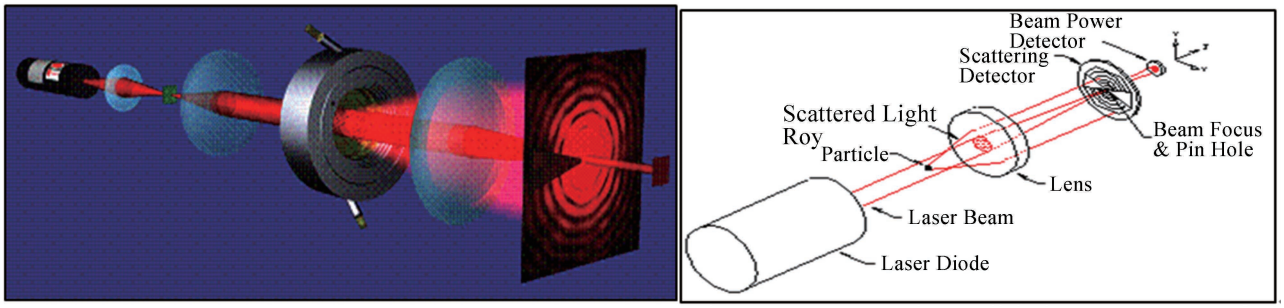

Figure 7
Drawings Showing the Working Concept of a Particle Size Distribution Analyzer

In simple words, the equipment detects the intensity of the scattered light when a laser beam is passed through the tested suspension (see Figure 7).

Procedure:

(a) Mix the prepared mud with 30 grams of barite to incorporate a solid particle in the system.

(b) Feed the mud sample in the PSD machine to verify the mean diameter (A) of the solid before degassing.

(c) After the test, prepare the same mud sample for sonication.

(d) After the sonication, retest the mud sample in the PSD.

(e) Confirmed mean size diameter in the PSD after sonication will be labeled as B.

2.2.5 Corrosion Ring Test

Figure 8
Corrosion Test Apparatus

Corrosion is a chemical reaction that consumes metals. Some of the most common corrosive substances that are encountered in the oil and gas are oxygen and hydrogen sulfide[11]. These gases are present in crude oil and drilling fluids. Degassing is aimed to remove these gases and, hence, corrosion rings test could give a direct indication of the removal of these corrosive gases after the samples are degassed using our ultrasonic waves system. Therefore, corrosion tests were conducted for water based mud samples before and after sonication.

Corrosion rings are metal rings that are specially designed to sensitively interact with corrosive materials. The rings are pre-weighed and after exposing them to the targeted environment (at least for 40 hours), they are re-weighed to determine the loss in weight which is directly related to the corrosion rate (reported in lb/ft^2/yr or mils per year (MPY)).

This particular test will determine the corrosion rate and the cavitation for two controlled samples (before and after sonication mud samples) in a high pressure and high temperature state:

(a) Weigh coupon to the nearest 0.001 g and record the reading.

(b) Check ageing cell seals for damage. Replace all rubber "O" rings and pressure test. Place Teflon inserts in ageing cell and fill it to approximately 300 ml with treated brine.

(c) Place coupon in test mud using clean rubber gloves or tweezers, ensuring coupon is fully immersed.

(d) Replace lid on ageing cell and purge headspace with nitrogen gas for 5 seconds. Pressurize the cell to 100 psi with nitrogen.

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(e) Check cells for leaks by immersing completely in water. If gas bubbles appear, trace source of leak, release pressure and repair. Pressurize the cell and check for leaks.
(f) Place ageing cell(s) in oven at 300 °F as required temperature until test duration is complete. Test time can be set between 40 hours and 100 hours as recommended.
(g) Once the test is complete, rinse corrosion coupon in acetone to remove the protective oil applied on location.
(h) Clean corrosion coupon with a detergent solution and a stiff fiber brush.
(i) It may be necessary to dip the corrosion coupon for 5 to 10 seconds in 10%-15% hydrochloric acid (HCl) one or more times to remove corrosion products. The ring should be scrubbed with detergent solution after each acid dip. Rinse thoroughly with clean water.
(j) Rinse with acetone or methanol.
(k) Evaluate type of corrosion (general and/or pitted). Allow the corrosion coupon to dry prior to weighing (nearest milligram).
(l) Record weight loss and calculate corrosion rate.

3. RESULTS & DISCUSSION

The results of all the measurements were analyzed as the following:

3.1 Sonication

Before sonication, we were targeting a 100% recovery of our "bubbly" sample including the liquid in foam formation. For this reason, we initially measured the weight of each part of the cell assembly; the values are tabulated in Table 1. Then, the volume of the sample in the cell by weight (g) was calculated using mass and density values. Direct measurement of the volume of the sample being tested was not made as it would give huge marginal error due to the presence of bubbles in the system.

Table 1
Weights of Different Cell Assembly Parts

Parts	Weight, grams
Cylindrical Cell	1,520.00
Cell O-Ring (2x)	4.55
Lid+Stem Valve+2x O-Rings	596.96
Top Cap	1,152.00
Bottom Cap	1,730.00
Rod+2x O-Rings	587.00
Metal Ring	3.06
Metal Locking Screw	218.00
Total Weight, grams	5,811.57

Initial Weight of the Sample = **170.40 grams**.

After sonication, we measured the amount by volume of the sample, wherein no sign or presence of foam and bubbles are observed.

Final Volume = **142 ml**.

Considering that the mud sample was formulated to be 1.2 g/ml (density): Therefore, 100% was recovered: **(170.4 g / 1.2 g/ml) = 142 ml**.

This just proves that the total components from the immeasurable initial volume of sample and foam were converted into a solution free of entrapped air without any loss. Figure 9 below shows two pictures of the same water based mud sample before and after sonication. The foamy sample turned into clear liquid after only five minutes of sonication.

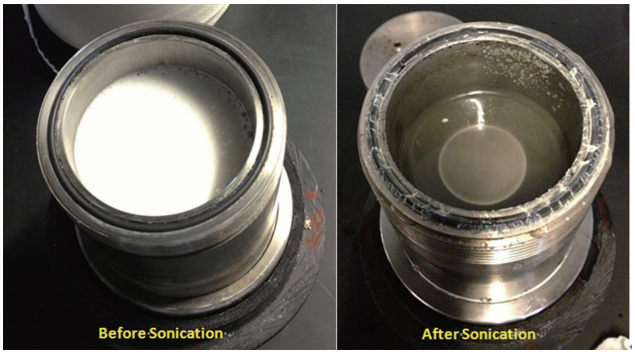

Figure 9
Water Based Mud Sample Before and After Sonication

3.2 Density

Figure 10 below shows the density readings, taken at ambient temperature, of the water-based mud sample and the crude oil sample at different sonication times. The graph indicates that there is a remarkable increase in the density of the water-based mud (WBM) when the sample was subjected to ultrasonic waves. Five minutes of sonication increased the density from 1.07 g/ml to almost 1.20 g/ml. This was mainly due to the fact that the bubbles in the original sample resulted in a lower density reading and, subsequently, removing these bubbles by ultrasonic waves increased the density readings. Also, it is important to note that 5 minutes of sonication were sufficient to remove the larger bulk of the bubbles and that sonication for longer times only contributed to a very slight change in density.

The density of the crude oil sample, however, has not undergone a noticeable change when subjected to ultrasonic waves. The presence of gas bubbles in crude oil is less pronounced due to the fact that gases are more likely to be dissolved in oil than in water; therefore, ultrasound did not alter the density of the crude oil sample.

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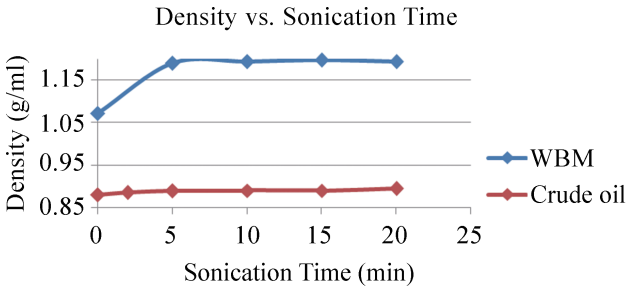

Figure 10
Density Measurements at Different Sonication Times

3.3 FTIR Analysis

Figure 11 below shows the Fourier Transform Infra-red (FTIR) spectra for the crude oil before sonication (blue curve) and after sonication (five minutes) (red curve). The graph shows almost identical spectra (absorption peaks are the same) after and before sonication which means that no alteration has occurred to the composition of the crude oil. This suggests that using ultrasonic waves as a means of degassing will not expose the composition of the crude oil to any noticeable change.

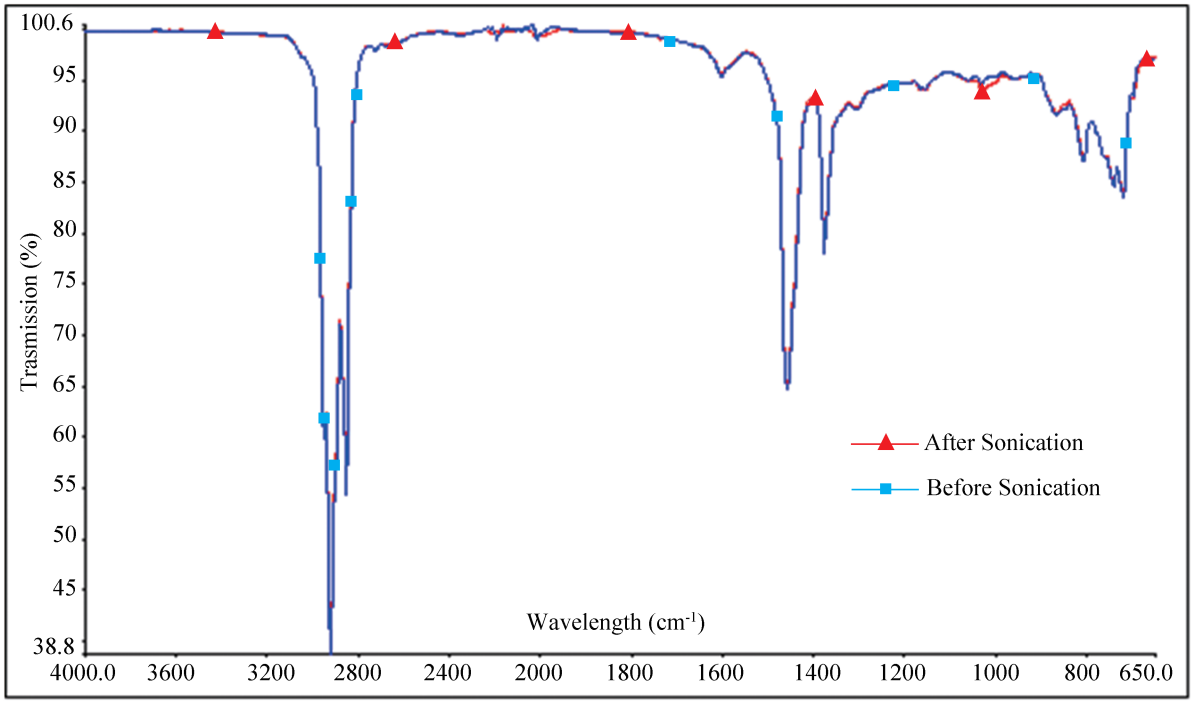

Figure 11
Fourier Transform Infra-Red (FTIR) Spectra for Sonicated and Non-Sonicated Crude Oil

Table 2
pH Test Values for the Water Based Mud Sample

pH Level at 25 °C	
Before sonication	After sonication
7.9	8.3

3.4 pH Test

The pH value of the tested water based mud sample increases after the sonicationtest, as indicated in Table 2, because Nitrogengas (N_2) was pumped into the system replacing the dissolved oxygen and CO_2. Hence, the system now contains a low-soluble gas that will inhibit the re-adsorption of gases and start to ionize producing a more alkaline solution.The removal of the corrosive CO_2 gas from the system upon sonication reduces the amount of Carbonic acid in the solution and hence increases its pH value.

3.5 Particle Size Distribution Analysis

Based on the test results illustrated in Figure 12, the size of the solid Barite particles in the water based mud sample was reduced by 24.53%. This was due to the strong agitation of the ultrasonic waves at a power of 1,500 W, 65% amplitude, and a frequency of 20,000 Hz. The cavitational collapse that sonication had on the solid particles led to microjet and shock wave impacts on the surface which, together with the inter-particle collisions and breakage ofintermolecular structure, resulted in reduction in particle sizes[12].

The results of corrosion ring test are illustrated in Figure 13 which shows pictures of two different corrosion rings: One tested in a non-sonicated water based mud sample (denoted as “Before” ring) while the second was tested in a sonicated water based mud sample (denoted as “After” ring). At similar conditions of temperature, pressure, and exposure time (100 hours), the “Before” ring has undergone more

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severe corrosion, as the pictures show. The effervescence that can be seen on the "Before" ring could be attributed to the formation of carbonic acid in the non-sonicated solution due to the presence of CO_2. The sonicated (After) sample contained less corrosive materials due to the removal of corrosive gases by the ultrasonic waves.

In addition to these observational conclusions, weight-loss calculations were made to quantify the corrosion rate before and after sonication. The corrosion rate for the non-sonicated sample was 0.7 lbs/sq-ft-year which dropped to only 0.2 lbs/sq-ft-year when the same sample was sonicated for fiveminutes.

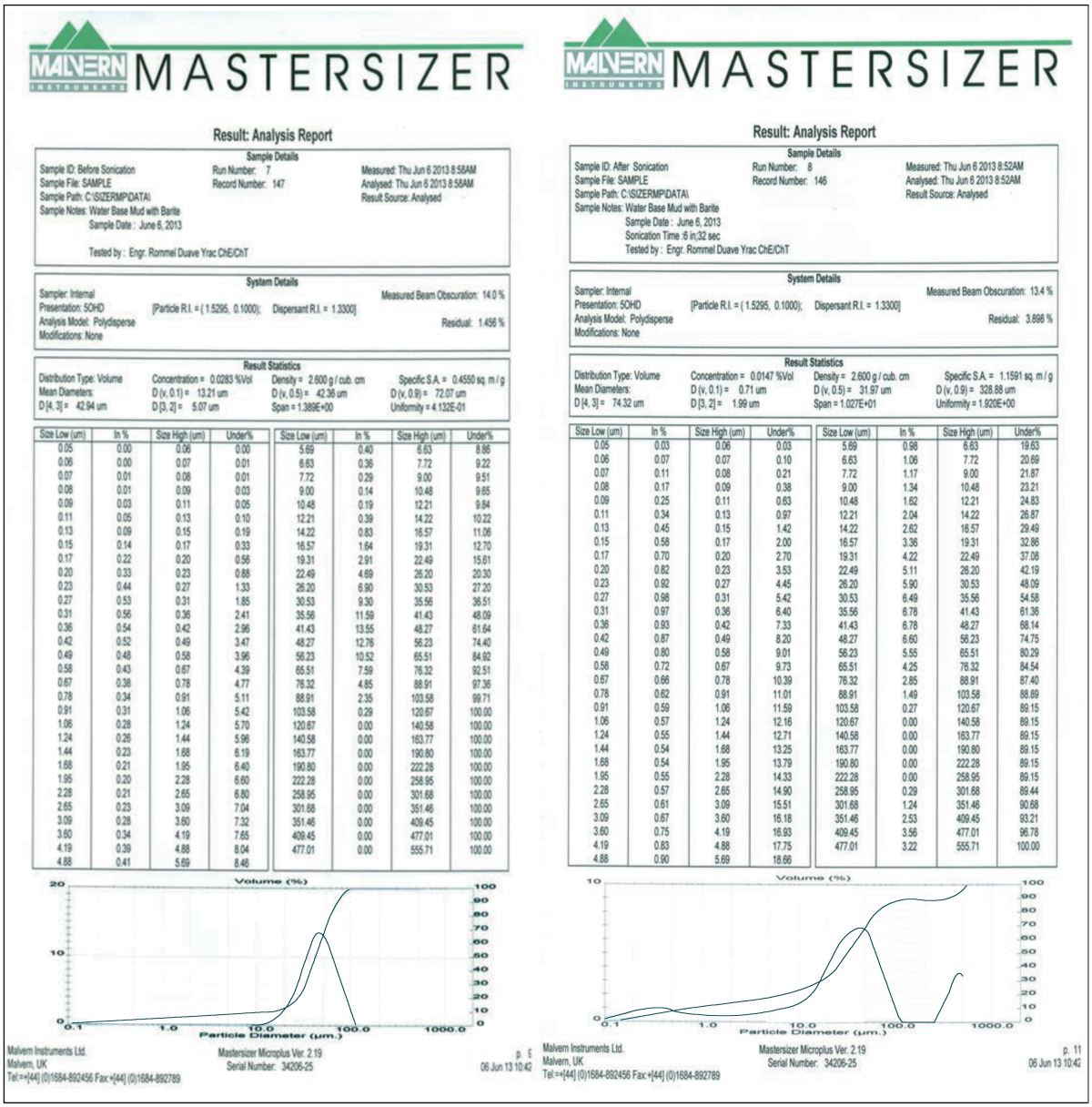

Figure 12
Particle Size Distribution Test Results

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3.6 Corrosion Ring Test

Before Sonication Corrosion Report — TEXAS A&M UNIVERSITY at QATAR

Treatment Reference	Before Sonication	specs	Date	15-Jun-13	specs
Mud Type	NaCl Brine/Polymer		Flow Line Temp.(F)	250F	
MW ppg	10		API Filtrate	-	-
Funnel vis.	-		HTHP ,ml	-	
pH	-		Calcium, mg/L	-	
Pf/Mf	-		Chlorides mg/L	-	

Coupon No.	3372
Coupon Size	3.5" I.F. & 3.5" X Hole
Date in	12-Jun-13
Time In	1600H
Date out	16-Jun-13
Time Out	0800H
Total Hours (Exposure)	100.0
Initial weight grs	66.8866
Final weight, gr	66.5930
Weight loss	0.2936
Corrosion rate Lbs/Sq.Ft-Year	**0.7**
Corrosion Rate	**LOW**
K - factor	253
Type of corrosion attack	**Generalized**
Scale	No
Oxygen corrosion	No
Carbon dioxide corrosion	Yes
Hydrogen sulfide corrosion	No

OBSERVATIONS:

Carbon dioxide corrosion was observed from the formation of effervescence which indicates the presence of carbonates from dissolved gas using a Hydrogen Sulfide Test Solution which contains 15% HCl.

BEFORE | AFTER

Tested by: Engr. Rommel Duave Yrac ChE/ChT

After Sonication Corrosion Report — TEXAS A&M UNIVERSITY at QATAR

Treatment Reference	After Sonication	specs	Date	15-Jun-13	specs
Mud Type	NaCl Brine/Polymer		Flow Line Temp.(F)	250F	
MW ppg	10		API Filtrate	-	-
Funnel vis.	-		HTHP ,ml	-	
pH	-		Calcium, mg/L	-	
Pf/Mf	-		Chlorides mg/L	-	

Coupon No.	3427
Coupon Size	3.5" I.F. & 3.5" X Hole
Date in	12-Jun-13
Time In	1600H
Date out	16-Jun-13
Time Out	0800H
Total Hours (Exposure)	100.0
Initial weight grs	66.8015
Final weight, gr	66.7420
Weight loss	0.0595
Corrosion rate Lbs/Sq.Ft-Year	**0.2**
Corrosion Rate	**LOW**
K - factor	253
Type of corrosion attack	**Generalized**
Scale	No
Oxygen corrosion	No
Carbon dioxide corrosion	No
Hydrogen sulfide corrosion	No

OBSERVATIONS:

BEFORE | AFTER

Tested by: Engr. Rommel Duave Yrac ChE/ChT

Figure 13
Results of Corrosion Ring Tests

CONCLUSION

Conducting this research project led to the following conclusion:

Ultrasonic waves are conceptually effective and environment-friendly means for removing gases from liquid systems. Different tests were conducted on water based mud and on crude oil samples to investigate this claim and affirming results were attained.

Direct observational results simply show that ultrasonic waves agitate the sample particles leading to fast and effective release of gases entrapped or dissolved in the liquid systems.

Thorough tests were conducted to evaluate the chemical and physical impact that ultrasonic waves have on the tested samples. Such tests included density, pH, particle size distribution, FTIR, and corrosion testing.

In terms of physical changes, particle size distribution analysis of the water based mud sample (containing solid Barite particles) showed reduction in particle size by almost 25%. This reduction was the mere result of the powerful agitation caused by ultrasonic waves that led to inter-molecular breakage and inter-particular collisions and, hence, consequent particle size reduction. The effect of such size reduction on the properties of the drilling fluids needs to be further evaluated.

In terms of chemical changes, pH and corrosion tests gave direct indications that corrosive gases (which usually tend to have an acidic effect) were effectively removed from the systems.

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Direct changes in the chemical composition of the crude oil did not take place as the FTIR results spectra showed. FTIR testing for water based mud, however, was not possible because of the large peaks water molecules would generate which make the spectrum meaningless.

To sum up, the concept of removing gases using ultrasonic waves was proven to be successful and efficient. The tests that were conducted to support this assertion yielded mostly favorable results. Nonetheless, the impact of the ultrasonic waves on the physical and chemical properties of the tested samples is yet to be determined and requires further investigation.

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