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Performance Evaluation of an Additive in Formic Acid Blend for Well Stimulation

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Abstract
This study investigates and evaluates acidizing operations with a view to identifying causes of acidizing failures and develop an efficient method of incorporating Sodium Lauryl Sulphate (SLS) in acid blend for stimulation to enhance the performance of acidized oil wells. Acid blend of formic and hydrochloric acid was prepared in the concentration of 9%-12% and both calcium carbonate and sandstone rock samples were dissolved in the blend of different concentrations. SLS was incorporated in same concentrations of the acid blend and dissolution of rock samples were carried out as well. However, SLS in acid blend solution was found to be more effective than the solution without SLS. This is attributed to the fact that SLS has a strong amphiphilic property and its incorporation in acid blend would definitely be very effective in displacement of the oil out of the region to be stimulated. For the acid blend (0.3ml) with SLS in Calcium carbonate rock, 13.67% of the particles were dissolved while 8.38% were removed for sandstone in 0.1 ml acid blend concentration with same volume of SLS. For the acid blend (0.1ml) without SLS on Calcium carbonate rock, 8.74% of the particles plugging the pores were dissolved while 5.91% for 0.1 ml acid blend on sandstone were eliminated. The acid blends solution with and without SLS were applied to mud cake and they were able to dissolve the mud cake over an extended reaction time. Nevertheless, the solution with SLS proved to be more effective. 89% of the mud cake was dissolved in 0.1 ml concentration of the acid blend with SLS while 82.5% of the same mud cake was dissolved in 0.1 ml acid concentration without SLS. Since all dissolution in rocks investigated indicated positive response to contaminant reduction, it could be concluded that acidizing if properly executed will reduce or cure damage around the wellbore.

Keywords: *Formation Damage, Stimulation, Acid Concentrations, Reservoir rock.*

1.0 Introduction

Carbonate reservoirs constitute a good percentage of the remaining oil reserves across the globe. Carbonate formations show lots of heterogeneity and multiple production difficulties leading to productivity reduction of the well. Formation damage is among the problems that result to production decline in many hydrocarbon fields. This causes a flow barrier and at some point stops completely the flow of formation fluid in and out of the wellbore. The flow barrier is due to permeability reduction around the wellbore region and this eventually affects the well performance and the rate of production. This permeability reduction issue can be addressed by acidizing (a well stimulation technique). It entails an acid-based being injected into the affected zone of the formation under fracture pressure. This opens up the pores and permits fluid flow in and out of the well bore, Mohamed, *et al* [16].

The increasing use of fossil oil product, and being the main energy supply of the world, needs to be produced in large quantities. In other to meet up with this demand, firms are required to invent new technologies and approaches to enhance drilling operation at lower operative costs. Based on this need to improve production to meet world demand, certain technologies have been employed to stimulate wells. The aim of these technologies is centered on production enhancement and extension of reservoir life in different aspects such as: increase in temperature of the oil system, enhancement of the interaction between the oil system and the injected fluid, reduction of consistency behavior between the oil system and the injected fluid, among other things, Khan *et al*, [13].

For fossil oil accumulation to be economically viable, oil recoverable volume must be economically attractive. Also, the rock must be porous and permeable with feasible and strong energy to drive the reservoir fluid from the reservoir to the well bore, hence to the surface.

1.1 Formation Damage

Formation damage can be described as the loss of permeability of hydrocarbon formations. Formation damage is part of the recurring issues in the oil and gas industry in Nigeria and the world on a large scale. It is a serious problem that leads to economic and operational losses in the sector. Its major effect is permeability reduction and a serious decline in production rate of formation fluid from the subsurface to the surface facilities, Civan, *et al* [5].

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It (Damaged formation) refers to an area with low permeability surrounding the wellbore. This arises as a result of deposition of particles that plugs the reservoir rock pores through which oil migrate in and out of the well bore. Formation damage is classified into the following mechanisms, Civan, *et al*, [5] :

i. Mechanism caused chemically: (swelling of clay –deflocculating of clay and – alteration wettability).
ii. Mechanism caused my mechanical activities: (migration of fines particles – including external solids - trapping and blocking by the phase – perforation activity damage).
iii. Mechanism caused by biological activities: (plugging of pores – corrosion effect – toxicity damage).
iv. Mechanism caused thermally: (degradation of materials thermally– transformation of mineral).

These mechanisms occur during the following activities in a well: production, fracturing, drilling, work over, etc. Decline in well performance and production rate, Impairment, skin damage are among formation damage indicators used to access a well.

1.2 Causes of Formation Damage

i. **Migration of fines** occurs where there is a very high content of moveable materials (clatic formation) within the rock. These fines challenge can be taken care of by reducing production rates, improving the flow area by employing open hole completion. Chemical additives and stabilizers are sometimes used by Engineers to trap the particles in place thereby preventing their movement to the wellbore.
ii. **Chemical damage mechanisms** Chemical damage occurs in form of clay swelling, like reactive smectite (hydrophilic materials) present in formations as well as mixed layer clays, when they react with low-salinity water or fresh water. This swelling clearly affects the permeability of the formation. Most often Engineers make use of chemical inhibitors (glycols as example) to stop clays from been hydrated.
iii. **Clay deflocculation**: This occurs as a result of change in salinity or pH of clay. Clay particles mutate from a flocculated condition (a situation where little clay charged particles are attached to one another to form a delicate shape-structure) which eventually deflocculate as a result of disturbing the electrostatic forces holding the particles together, [10].

1.3 Well Stimulation Vessels (WSV's**)**

Recently, specific drilling ships identified as "well stimulation vessels" have been employed for stimulation of deep-sea wells as a result of the temporary nature of well stimulation. Offshore companies like Norshore and schlumberger operate a lot of such specialized ships. Also, referred to as 'multipurpose drilling vessels', these ships replace the conventional oil drilling rig in terms of cost.

Oil and gas well stimulation arises due to the following reasons:

i. Formation permeability is damaged and cannot permit sufficient fluid production enough for sound recovery of investment in the operation.
ii. Completed well with good permeability, but unfortunately the formation close to the wellbore has been damaged by the completion process or drilling fluid inversion.

In the first case, permeability inadequacy needs stimulation process, which could be acid fracturing, nitro-shooting or hydraulic fracturing. In the second situation, the impairment needs to be removed which is typically a matrix acidizing procedure but may involve hydraulic fracturing. However, Solvent or surfactant treatments can as well used to remove damage.

1.4 Acidizing

Acidizing can be classified into groups:

i. Acid fracturing, this entails injection of acid at rates slightly higher than those needed by the matrix, thereby fracturing the formation, and creating cracks on the face of the fractures, hence developing flow paths.
ii. Matrix acidizing, involves sending acid solution to the damaged portion at minimal rates thereby permitting timely spread of the solution into the formation without fracturing it.
iii. Acid washing makes use of acid to dissolve particles plugging the well bore by injecting acid across the affected surfaces without the acid entering the formation.

1.4.1 Expression for Determining Degree of Acid Penetration

Basic Assumptions

i. Formation is assumed to be homogenous
ii. Pores do not vary and therefore are of uniform sizes
iii. Acid is assumed to penetrates uniformly and radically
iv. Reaction rate is assumed to reduce uniformly as acid concentration decreases.
v. limestone formation width dissolved per increasing distance reduces uniformly until acid is totally spent.

Volume injected = pore volume invaded as reported by [8].

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$$q_t = \emptyset\pi h({r_a}^2 - {r_w}^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$r_a = \sqrt{\frac{q_t}{\pi h\emptyset} + {r_w}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If q = bbl/min and time is in sec,

$$r_a = \sqrt{\frac{\left(\frac{5.615ft^2}{bbl}\right)\left(\frac{qbbl}{min}\right)\left(\frac{min}{60sec}\right)t + r^2 ft^2}{\pi Ph(ft)}} \ldots\ldots\ldots \quad (3)$$

$$r_a = \sqrt{\frac{0.0936q_t}{\pi h\emptyset} + {r_w}^2} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where ra = radial distance penetrated by acid until it's totally spent, $\emptyset$ = fractional porosity, q = acid injection rate (bbls/min), r_w = wellbore radius, h = formation thickness, ft, t = the spent time, min
For linear flow, Darcy equation is expressed as;

$$q = \frac{KA}{\mu}\frac{\Delta P}{l} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where k = permeability measured in (mD) , μ = viscosity measured in (cp), q = acid injection rate with unit (bbls/min), L = equivalent to time the acid will travel (min), A = is given as cross-sectional area of flow in (cm^2) , dP = is given as pressure change (psi).

1.5 Summary of Research works on well stimulation

Some researchers Jian Chen, *et al.*, [12] Carried out a study to determine the dissolution of different reservoir rocks (micrite which represented limestone and containing calcite, dolomite and quartz; Sucrosic dolostone containing dolostone and lithic arkose representing sandstone which contains quartz, clay, feldspar, calcite and hematite) by organic acid in laboratory stimulations: implication for the effect of alteration on deep water oil reservoirs.

The dissolution of the different rocks were stimulated using acetic acid in an enclosed structure and rock grains were chosen because it would react faster with the acetic acid and show clear result. XRD (X-tray diffraction) was used to determine the mineralogical and elemental constituents. The surface structures, water chemistry differences as well as pore structure of the original and altered samples were compared. Dolostone and micrite were well dissolved (20%-30%) of their original weight of rock sample. The SEM (Scanning Electron Microscope) indicated that limestone dissolved homogeneously while dolostone displayed a honeycomb-like dissolution. The rock samples displayed development in large voids except in nanopores of different sizes which were blocked. Lithic arkose on the other hand was heterogeneously modified, lost 13% of its weight by calcite element dissipation. The nanometer-scale pores were affected but to a small degree [6].

These researchers [2] Carried out a study to develop a successful approach for stimulating high water cut wells (in Some Selected Niger Delta Reservoir) so as to improve their productivity without significantly increasing water production. Ten intervals were analyzed in this study. Eight of these had water cuts ranging between 20% and 60%. Five of these candidates for stimulation were previously modified with Mud Acid and retreated with the fresh hydrofluoric acid (HV-HF) System within the last two years. Results were obtained from the ten wells that have been treated over the past couple of years which proved performance with little or into increase in water cut (it showed over 300% economic and technical improvement using the HV-HF acid System over the previous Mud Acid treatments). This has helped to change the long negative mentality on the stimulation of high water cut wells based on failures of earlier methods.

This successful method shows the possibility of reducing water cut via drawdown reduction and also near well bore wettability alteration through the use of an effective two way diversion which are foam and high rate diversion. There was significant increase in scope for candidates selection for acid stimulation from the results obtained. The results also indicated that there is scope for reducing the cost of stimulation wells, as a result of reduced pumping time and equipment usage. The job designs, execution and post-job evaluation of some candidate wells were discussed. The Post job performance data of trial candidates displayed over 95% technical and economic success of the jobs. The candidates also showed significant improvement in production over prediction. These performances indicated that it is possible to reduce water production through wettability alteration and drawdown reduction. The Comparison between the treatment results from the new method and the previously used methods which involves the use of Unit Technical Cost, Skin factors, Productivity Index and Payback Time have proven the success and also the superiority of this new approach [2]

The researchers Albert, *et al.*, [1] presented a research on matrix acidizing preparation consisting of a salt containing monochloro acetic acid resulting in a slowed acidification and a chelating agent meant to disallow the

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precipitation of calcium salt. The outcomes of dissolved ability, test of core flood and corrosion inhibition were analyzed and contrasted with execution of 15 wt% emulsified hydrochloric acid.

Equal molar quantities of grounded limestone and dolomites were used in the dissolution ability experiments in an agitated reactor at atp. Different chelating agents (four in number) were added to test the calcium ion isolating ability. Test for corrosion were carried out as well with the aid of an autoclave reactor below nitrogen atmosphere at a pressure of 10 bars. Core flood tests were as well carried out to replicate carbonate matrix stimulation using limestone cores.

It was observed that the half-life of the hydrolysis reaction was found to be 77 min at 100 °C. Sodium gluconate and salt of sodium containing D-glucoheptonic acid were found to effectively disallow precipitation of the outcome of the reaction product (calcium glycolate) at 40°C. At optimum injection rate, computed tomography (CT) scans of the treated cores showed that a single wormhole was formed. An optimum injection rate of 1 ml/min was observed at a temperature of 150 °C, which correlates to a minimum PVBT of 6. However, no face dissolution was identified following core flooding. Rates of corrosion of different metallurgies (L80 and J55) were measured and observed to be significantly less than that reported in literature for 15wt% emulsified hydrochloric acid.

The formulation showed there is a slow migration of organic acid in the well, which enhances its depth of penetration in the concerned formation, and sodium gluconate disallows precipitation of the outcome of the reaction product. The corrosiveness of this mixture (formulation) is a bit small, thereby saving the cost of maintenance for assembly as well as the pipe work.

Vitaly *et al.* [22] carried out a study on the stimulation of oil and gas wells in Carbonate reservoir by Using Supercharged Nanoparticles. A conventional stimulation method was taken into consideration in this research which is a one-stage production well treatment using a water solution of hydrochloric acid. This study took into account the mature carbonate formation of the Abdulovskoe oil-gas field, which is located in the Russian province of Ural-Volga oil and gas. The Abdulovskoe oil-gas field has been subjected to industrial development since 1970, and as of right now still contains highly degraded recoverable reserves. The formation rocks exhibit a relatively high net sand coefficient (0.26), low porosity (0.10) and low matrix permeability (0.02 μm^2). The development of oil-gas formation is complicated by a network of natural fractures, resulting in considerable interface between the producer-producer wells as well as the injector-producer wells.

1.6 Sodium Lauryl Sulfate (SLS)

The additive used in this research is Sodium lauryl sulfate (SLS). SLS is an anionic surfactant also known as sodium dodecyl sulfate, with the formula $CH_3(CH_2)_{11}SO_4Na$. Its molecular weight is frequently 420g/mol (288.38 + 44.05n) g/mol. SLS can be naturally derived. It can as well be synthetic. SLS can be derived from naturally occurring substances such as palm kernel oil and coconut, and may further be produced in a laboratory environment. This chemical compound is prepared by reacting lauryl alcohol obtained from hydrocarbon or plant source with sulfur trioxide to yield hydrogen lauryl sulfate, which is further neutralized with sodium carbonate to produce SLS. SLS has verities of applications such as in domestic cleaning, pharmaceuticals, food products, personal hygiene, cosmetic, and some laboratory applications and because of its efficiency in breaking oil and grease, SLS is an additive used in many industrial and commercial activities including cleaning, product formulations, engine degreasers and industrial strength detergents. SLS also facilitates the mixing of acids with other liquids as required Reutemann, *et al* [20].

The choice of Sodium Lauryl Sulfate is due to its effectiveness as a foaming agent, yielding substantial bubbles and cleaning capabilities and also its abundance, low cost and its simplicity, which makes its use in several cosmetic, dermatological, laboratory and consumer products, [3].

Toxicologically, SLS is regarded as a sustainable material due to its 100% bio-based composition, biodegradability, and limited potential for bioaccumulation. It does not introduce unnecessary risks to consumers as well as to the environment because of its composition, and if synthesized correctly, it poses no threat to the safety and health of human beings, [4].

1.7 Formic Acid

Formic acid commonly known as methanoic acid is an organic acid [HCOOH] utilized in oil and gas well stimulation treatments. Formic acid possesses an advantage over HCl as it facilitates the mitigation of pipe corrosion at temperatures reaching 400°F [204°C]

Formic acid was initially extracted from specific ants and derives its name from the Latin term *formica*, meaning "ant." It is generated when sulfuric acid react with sodium formate, which is obtained via carbon monoxide and sodium hydroxide.

$$\underset{\text{carbon monoxide}}{CO} + \underset{\text{sodium hydroxide}}{NaOH} \xrightarrow{H_2O} \underset{\text{sodium formate}}{HCOONa} \xrightarrow{H_2SO_4} \underset{\text{formic acid}}{HCOOH} \ldots\ldots(6)$$

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Formic acid can as well be produced in the form of its esters through the reaction of carbon monoxide with an alcohol which might be methanol (methyl alcohol) in the presence of a catalyst, [7]

Pure formic acid is a colourless, fuming liquid with a pungent odour; it causes irritation to the mucous membranes, blisters the skin, freezes at 8.4°C (47.1 °F) and boils at 100.7 °C (213.3 °F), (Reutemann, *et al* [20].

2.0 Materials and method

Materials used for this research include: water, barite, PAC R, bentonite, sodium carbonate, reservoir rocks, acids (formic acid and hydrochloric acid), Sodium lauryl sulfate, laboratory glass wares, etc

The equipment used were: pH meter, balance, mud balance, stirrer, sand content kit, filter press, rheometer, etc.

i. **Preparation of drilling fluid**

25g of bentonite was added to 350ml of water in a beaker and was mixed properly with a Hamilton beach stirrer for almost10 minutes until a homogeneous mixture was formed. 0.5g of Pac R was added to the mixture and further stirred for 5 minutes; this was followed by the addition of 2g of sodium carbonate with additional 5 minutes stirring before finally adding 10g of barite to the mixture and further stirred for about 10 minutes to yield drilling fluid of API standard.

ii. **Formulation of acid blend.**

Acids used to formulate this blend were Formic acid and hydrochloric acid. Volumes of formic acid and Hydrochloric acid used for the blend were prepared using the dilution theory. The dilution formula is expressed as:

$$volume = \frac{\%\ of\ fluid \times Density\ of\ mud\ acid}{\%\ of\ Initial \times Density\ of\ \ acid} \times 1000 \ldots\ldots\ldots\ldots\ldots(7)$$

Hydrochloric acid (290ml) was poured into a conical flask. 174 ml of formic acid was poured into the same conical flask and the mixture was made up to 1000ml by adding distilled water. For the acid blend of different concentrations, the solution of acid blend on the conical flask was poured into five (5) equal beakers (200ml each), thereafter, distilled water was poured into each of the beakers with 100ml increment i.e. 100ml was added to the first beaker, 200ml to the second, 300ml to the third, 400ml to the fourth and 500ml to the fifth beaker respectively.

iii. **Formulation of acid blend with Surfactant**

Surfactant was introduced into the blend solution by adding 15g of SLS into a beaker and distilled water was poured into the same beaker to 1000ml mark. The mixture was thoroughly stirred until a homogeneous solution was obtained. 200ml of the mixture (surfactant solution) was measured and added to each acid blend concentration in the five (5) beakers.

iv. **Reservoir Rock preparation for contamination and dissolution**

Reservoir rocks (Carbonate and sandstone) were crushed into pieces (10 pieces for each) having equal weight (60kg). The broken rocks were left under the sun for weeks to allow particles from the surroundings block the pores especially the freshly broken sides. This was done before the contamination with the formulated drilling fluid.

v. **Contamination of Reservoir Rock Samples and Dissolution in Different Acid Concentration**

Already contaminated rock samples were dipped inside the prepared drilling fluid for 20 minutes after which they were brought out and allowed to dry under the sun for a period of one week. The contaminated samples after drying were dipped inside the five beakers whose contents were the different acid concentrations (with and without sodium lauryl sulfate). For each concentration, the samples were left inside the solution for dissolution to take place. They were brought out, weighed and recorded at 4 minutes interval till approximated time the acid reaction was completed indicating flat figures (a total of 24 minutes).

vi. **Mud Cake Preparation**

Mud cake was also prepared for dissolution like the rock samples. Drilling mud was poured into a small dish, left for a week to dry up to form a mud cake.

vii. **Dissolution of Mud cake in Different Acid Blend Concentration**

The dried mud cake was divided into equal parts (2g each). They were dipped into the acid blend of different concentrations (with and without SLS). At an interval of 2 minutes, the cakes were brought out, weighed and recorded.

Figure 1: Contaminated Rock samples

Figure 2: Rock sample in acid blend concentration for dissolution

Figure 3: Dried mud cake.

3.0 Results and Discussion

i. Performance Analyses of Dissolution in Acid Blend without SLS

Well stimulation is a remedy given to an oil well in order to remove impairment and improve production. There are so many ways of removing the impaired or damaged portion of the formation to improve formation permeability. Among these methods is acidizing which is the subject matter in this research. An acid blend (formic acid and hydrochloric acid) containing an additive (SLS) was used in this research to dissolve the particles that blocked reservoir rocks so as to improve the oil permeability as stated earlier.

Figure 4 is a plot of time (minute) against mass of calcium carbonate (g) as shown on table 1. The table was generated after 24 minutes of dissolution when the acid has been completely spent. The table showed the values obtained for the five different concentrations which were prepared for the dissolution. 0.1 ml was able to dissolve the sample (reservoir rock) from 61.97 g to 56.55 g, 0.2 ml dissolved from 60.79 g to 56.86 g, 0.3 ml dissolved from 62.46 g to 60.89g, 0.4 ml dissolved from 61.83 g to 61.37 g and 0.5 ml dissolved the sample from 62.38 g to 61.14 g respectively. The plot also buttresses the fact that the more the time given for the dissolution, the more the particles were dissolved out of the sample and the more the pores through which oil flows open up.

Looking at the table 1 generally, concentration of 0.1ml gave the best result followed by 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml in that order. 0.1 ml and 0.2 ml concentrations dissolved most with percentages of 8.74% and 6.46% respectively. The percentages as calculated showed the level of contamination surrounding the carbonate rock which has been dissolved to allow more flow of hydrocarbon.

Figure 5 is a plot of time (minute) against mass of sandstone (g) as shown on table 2. The plot disclosed that the higher the time given for the dissolution process, the more the particles on the sandstone surface were dissolved, in other words it's a linear relationship. After 24 minutes of treatment, 0.2 ml was able to dissolve the particles on the surface of the sample from 63.44 g to 61.28 g, 0.3 ml dissolved from 63.74 g to 61.82 g, 0.4 ml dissolved from 62.95 g to 61.26 g and 0.5 ml dissolved the sample from 63.75 g to 62.53 g respectively. The result

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obtained was commendable as formic acid (an organic acid) that hardly dissociate totally in water acts as an enhancer in well stimulation. 0.1ml and 0.2ml concentrations dissolved most with percentages of 5.91% and 3.40% respectively. The percentages showed the level of sandstone contamination which has been dissolved to make way for formation permeability improvement.

The impact of acid blend on the dissolution of mud cake was also investigated in this research. A plot of time (minute) against mud cake weight (g) across the five concentrations as shown in figure 6 extracted from table 3 was made. The plot presented is a linear graph with a negative slope showing downward trend for mud cake weight with increasing time. From the plot, the concentration (0.1 ml) was found to be more effective in the dissolution of the mud cake than 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml in that order. 0.1 ml and 0.2 ml made most dissolution with percentages of 82.5% and 81% respectively. This also indicated how efficient and encouraging the acid blend could be in well stimulation.

ii. **Analyses of Dissolution of Samples in Acid Blend in the Presence of an Additive (SLS)**

Remarkable reductions in the dissolution of samples (calcium carbonate, sandstone and mud cake) were achieved as can be seen on tables 4, 5 and 6 respectively.

For calcium carbonate, 0.1 ml (concentration) was able to dissolve the particles on the rock surface from 61.52g to 55.32g, 0.2 ml dissolved from 60.53g to 54.25g. 0.3 ml dissolved from 61.17g to 52.81g, 0.4 ml dissolved from 61.67g to 57.43g and 0.5 ml was able to dissolve the sample from 62.24 g to 59.84 g.

The difference between the initial and final value in each concentration indicated that 0.3 ml performed better, followed by 0.2 ml, 0.1 ml, 0.4 ml and 0.5 ml in that order. The values showed that contaminated calcium carbonate sample in 0.3 ml and 0.2 ml concentrations dissolved most with percentages of 13.67% and 10.37% respectively. The percentages reviewed the level of contaminants on the carbonate sample that blocked the pores which were eventually dissolved in the acid blend containing SLS. The plot of time (minute) versus mass of carbonate rock (g) in figure 7 followed the same trend of decrease in mass of contaminated rock sample with increase in time of dissolution. The removal of those contaminants from the rock surface open up the pores for easy flow of crude oil.

For sandstone, after the acid has been completely spent, the weight of the contaminated sample (sandstone) decreased from 63.4g to 58.14g, 63.29g to 59.69g, 63.36g to 60.12g, 63.00g to 60.10g, and 62.97g to 60.39g for 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml concentrations respectively with 0.1 ml having the best result followed by 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml in that order. For the contaminated sandstone sample, 0.1 ml and 0.2 ml concentrations dissolved most with percentages of 8.38% and 5.69% respectively. This showed a great improvement in removal of impairment from a damaged oil well especially when a surfactant like SLS is incorporated into an acid blend. A linear plot of time of dissolution (minute) against mass of sandstone (g) shown in figure 8 supported the fact that time is needed to ensure proper removal of the contaminants from the reservoir rock surface. It was also established that when the acid was completely spent, increase in time did not had much effect again on the dissolution process and at this point, the weight of the rock remained constant.

From the table 6, five different concentrations were prepared for the dissolution of mud cake. At the 24th minute, the acid reaction got completed with no further dissolution of the cake. 0.1 ml could dissolve the mud cake from 2 g to 0.22 g, 0.2ml dissolved from 2g to 0.25g, 0.3ml dissolved from 2g to 0.40 g, 0.4ml dissolved the mud cake from 2 g to 0.56 g and 0.5 ml dissolved from 2 g to 0.64 g respectively. 0.1 ml gave a good result followed by 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml in that order. 0.1 ml and 0.2 ml with the highest dissolution values gave percentages of 89% and 87.5% respectively.

As can be seen, the results indicated that dissolution of calcium carbonate, sandstone and mud cake improved favorably with the addition of SLS as shown on tables 4, 5 and 6 as well as in figures 7, 8 and 9 respectively. This showed that sodium lauryl sulfate is a good surfactant in dissolution of contaminated reservoir rocks as it was found to contain strong amphiphilic properties. This remarkable achievement in dissolution of contaminated reservoir rocks in the presence of SLS could be commercially explored as SLS is abundant and cost effective in Nigeria. In summary, it has been established from this research that dissolution of reservoir rocks (calcium carbonate and sandstone) as well as mud cake were strongly observed in formic acid blend with the surfactant (SLS) than in the acid blend without SLS. This is because SLS has a high lubricating and dissolution ability than ordinary acid blend.

Table 1: Table showing effect of formic acid blend on Calcium Carbonate

Time (Min)	**Calcium Carbonate mass (g)**				
	0.1 Conc.(ml)	**0.2 Conc.(ml)**	**0.3 Conc.(ml)**	**0.4 Conc.(ml)**	**0.5 Conc.(ml)**
0	61.97	60.79	62.46	61.83	62.38
4	61.02	58.53	61.21	61.66	61.45
8	59.11	57.91	61.19	61.63	61.4
12	58.45	57.4	61.06	61.46	61.27

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Time (Min)	Calcium Carbonate mass (g)				
	0.1 Conc.(ml)	0.2 Conc.(ml)	0.3 Conc.(ml)	0.4 Conc.(ml)	0.5 Conc.(ml)
16	57.6	57.1	61.01	61.45	61.22
20	56.57	56.9	60.94	61.4	61.16
24	56.55	56.86	60.89	61.37	61.14

Table 2: Effect of formic acid blend on Sandstone

Time (Min)	Mass of Sandstone (g)				
	0.1 Conc. (ml)	0.2 Conc. (ml)	0.3 Conc. (ml)	0.4 Conc. (ml)	0.5 Conc. (ml)
0	63.6	63.44	63.74	62.95	63.75
4	63.52	63.3	63.12	61.51	63.56
8	62.8	62.41	62.31	61.38	63.46
12	61.43	61.77	62.04	61.36	62.84
16	61.28	61.55	61.99	61.32	62.7
20	59.86	61.32	61.86	61.29	62.55
24	59.84	61.28	61.82	61.26	62.53

Table 3: Effect of formic acid blend on Mud cake

Time (Min)	Mass of Mud cake(g)				
	0.1 Conc.(ml)	0.2 Conc.(ml)	0.3 Conc.(ml)	0.4 Conc.(ml)	0.5 Conc.(ml)
0	2	2	2	2	2
4	1.6	1.66	1.7	1.72	1.74
8	1.23	1.36	1.38	1.46	1.44
12	1.05	1.13	1.18	1.22	1.24
16	0.71	0.76	0.86	0.92	0.97
20	0.37	0.42	0.51	0.67	0.76
24	0.35	0.38	0.48	0.65	0.73

Table 4: Table showing effect of SLS in formic acid blend on Calcium Carbonate

Time (Min)	Mass of Calcium Carbonate (g)				
	0.1 Conc.(ml)	0.2 Conc.(ml)	0.3 Conc.(ml)	0.4 Conc.(ml)	0.5 Conc.(ml)
0	61.52	60.53	61.17	61.67	62.24
4	58.26	57.53	56.94	59.67	60.85
8	57.55	56.09	55.41	59.06	60.59
12	56.2	55.46	54.65	58.54	60.38
16	55.68	54.41	53.57	58.26	60
20	55.38	54.28	52.84	57.48	59.88
24	55.32	54.25	52.81	57.43	59.84

Table 5: Table showing effect of SLS in formic acid blend on Sandstone

Time (Min)	Mass of Sandstone(g)				
	0.1 Conc.(ml)	0.2 Conc.(ml)	0.3 Conc.(ml)	0.4 Conc.(ml)	0.5 Conc.(ml)
0	63.46	63.29	63.36	63	62.97
4	63.28	63.13	62.39	62.35	62.51
8	62.99	62.82	61.94	61.55	61.88
12	61.84	61.62	61.61	60.95	61.24
16	60.29	60.02	60.73	60.63	60.68
20	58.22	59.79	60.18	60.14	60.47
24	58.14	59.69	60.12	60.10	60.39

Table 6: Table showing effect of SLS in formic acid blend on Mud cake

Time (Min)	Mass of Mud cake(g)				
	0.1 Conc.(ml)	0.2 Conc.(ml)	0.3 Conc.(ml)	0.4 Conc.(ml)	0.5 Conc.(ml)
0	2	2	2	2	2
4	1.56	1.61	1.65	1.64	1.68
8	1.2	1.24	1.32	1.28	1.38
12	0.92	0.9	0.94	0.97	1.04

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Time (Min)	Mass of Mud cake(g)				
	0.1 Conc.(ml)	0.2 Conc.(ml)	0.3 Conc.(ml)	0.4 Conc.(ml)	0.5 Conc.(ml)
16	0.57	0.55	0.6	0.77	0.76
20	0.28	0.32	0.45	0.62	0.69
24	0.22	0.25	0.40	0.56	0.64

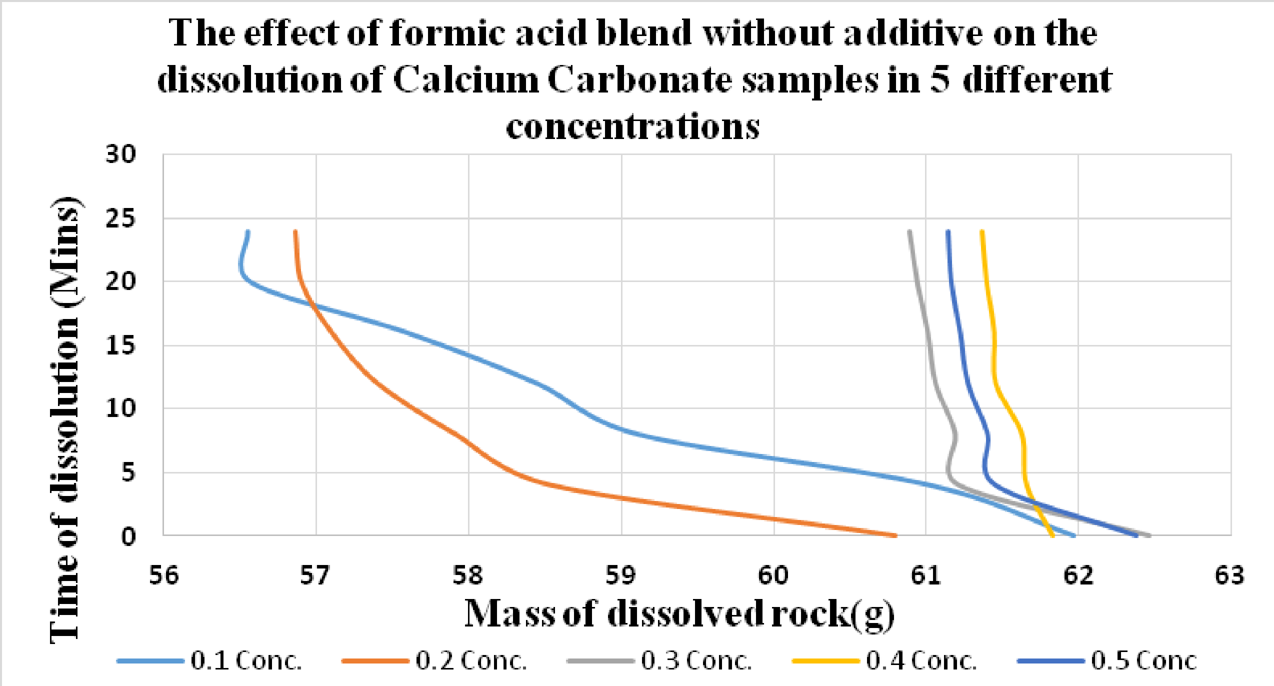

Figure 4: Graph of Time against mass of calcium carbonate dissolved

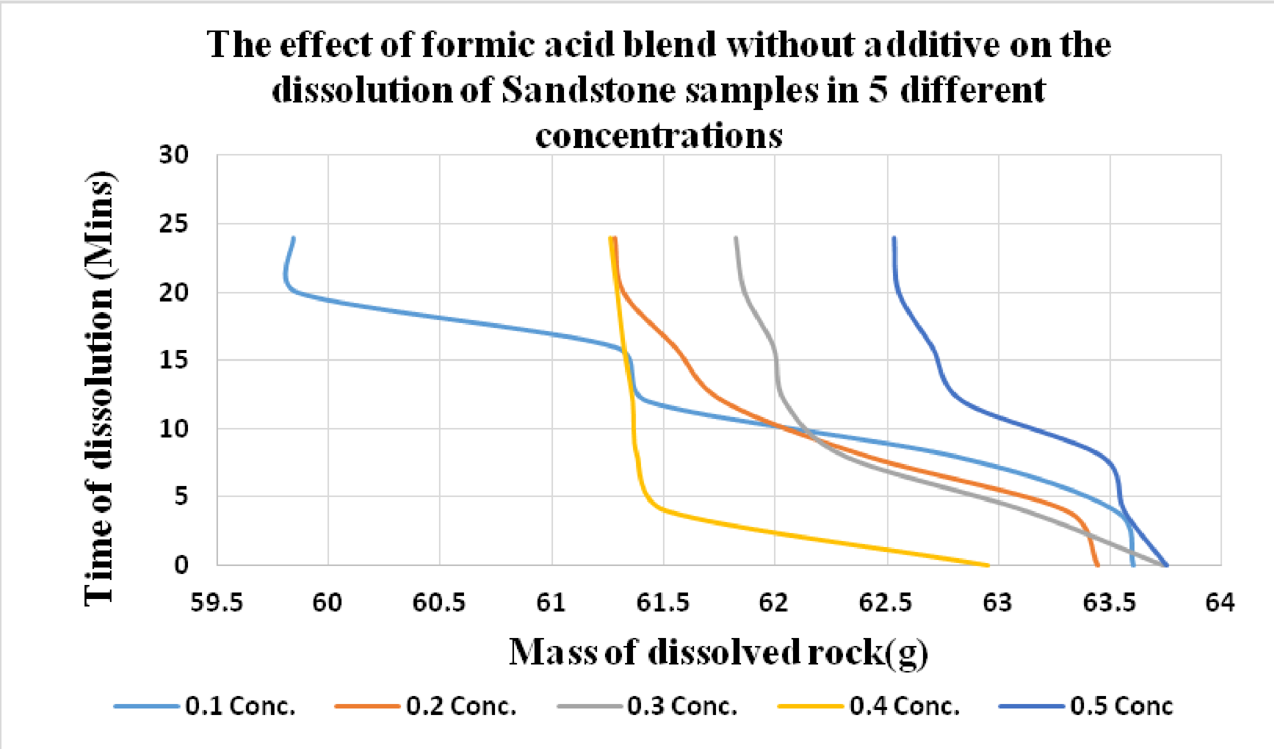

Figure 5: Graph of Time against mass of sandstone dissolved

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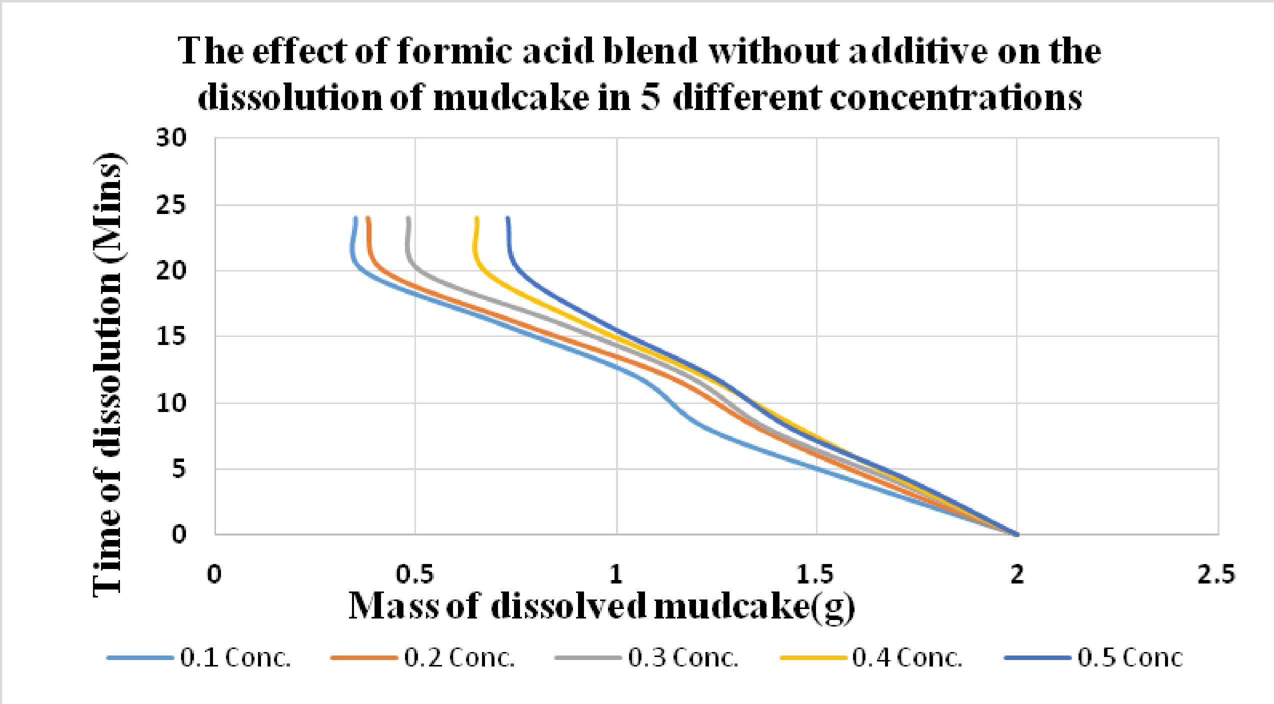

Figure 6: Plot of Time against mass of mud cake dissolved

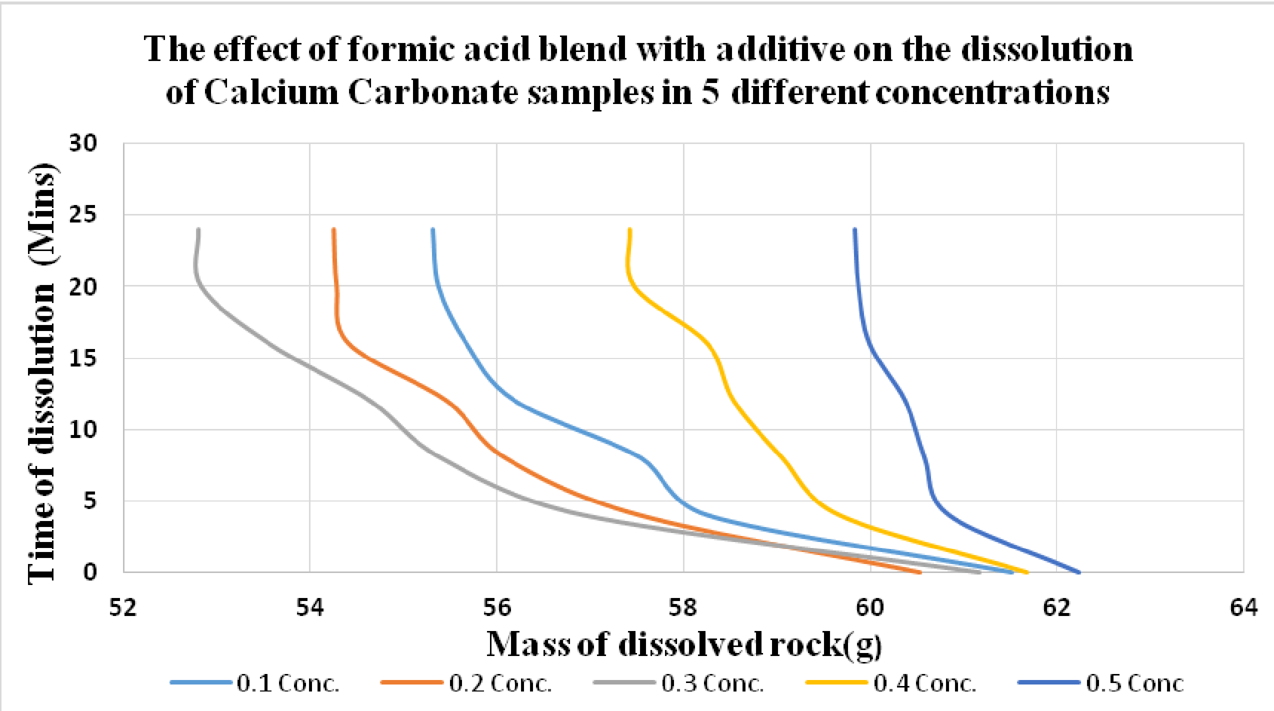

Figure 7: Plot of Time versus mass of calcium carbonate dissolved

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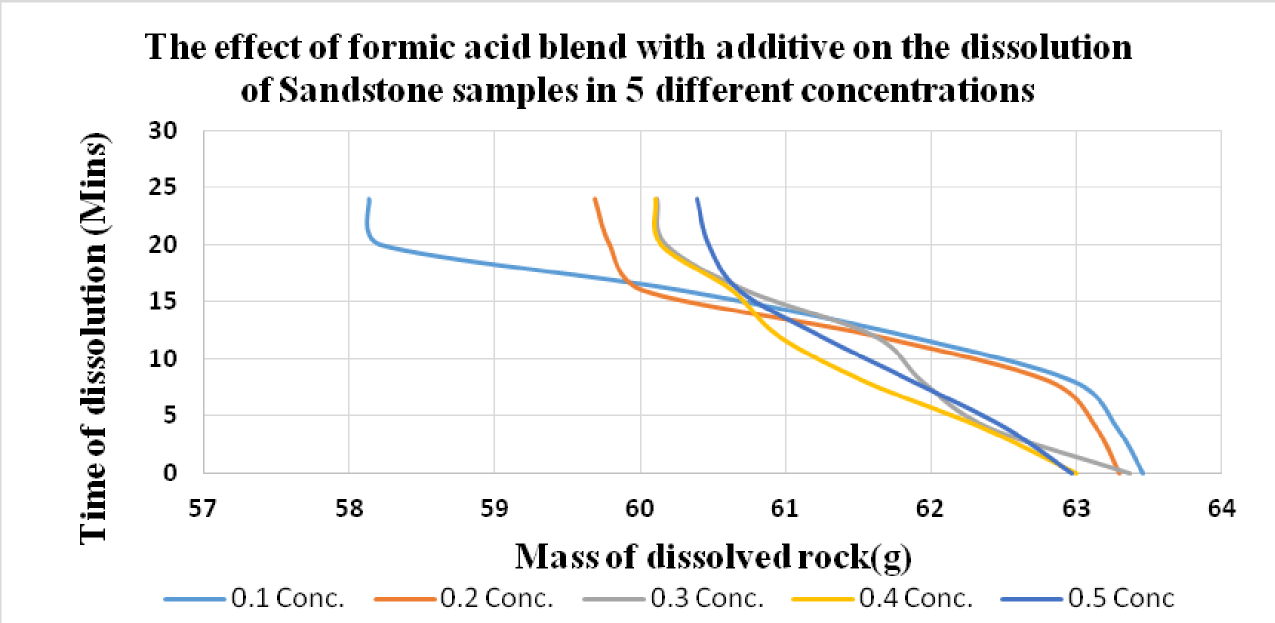

Figure 8: Graph of Time against mass of sandstone dissolved

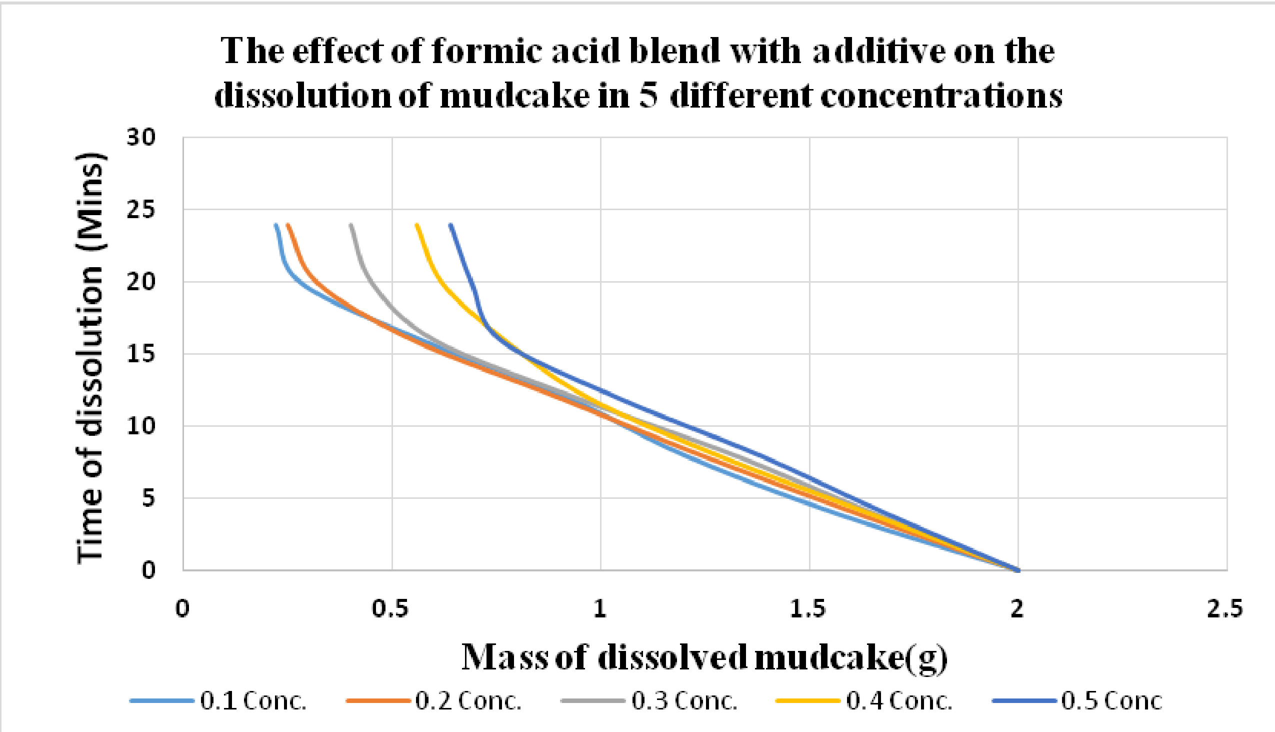

Figure 9: Plot of Time versus mass of mud cake in formic acid blend with SLS

4.0 Conclusion

Well stimulation practices have grown tremendously in recent years and have proven to be very effective in improving reservoir fluid recovery. This research introduces readers to a concise overview of formation damage and its associated mechanisms. Formation damage poses a significant challenge in the oil business, necessitating the implementation of procedures to mitigate and prevent any actions that could contribute to it. This is very important because when a formation is damaged, permeability is affected and productivity is reduced.

This report studied the evaluation of the effectiveness of an additive (SLS) in formic acid blend for well stimulation. Sandstone and carbonate reservoir rocks were used to carry out this study as a significant proportion of the oil reserves worldwide are found in the reservoir rocks mostly carbonate reservoirs. Thus, there has been a growing demand for different innovative and efficient stimulation treatment for reservoir rocks especially carbonate.

Results presented in this research indicated that additive (SLS) in formic acid blend was very effective more than that without additive in dissolving particles plugging the pores through which oil flows. This, to a large extent removed the impairment and enhanced the permeability of sandstone and calcium carbonate. Dissolution in mud cake was also carried out and good result similar to those of sandstone and calcium carbonate was obtained.

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However, it was observed that increasing the surfactant concentration to some extent would definitely be more efficient and effective. These results reviewed the potential of dissolution systems using the acid blend to enhance production from a damaged well.

In general, SLS in formic acid blend has proven to be a technical alternative to be applied in well stimulation to enhance productivity.

5.0 Recommendations

From the results obtained, these recommendations could be made:

i. Parameters like temperature and dosage should be considered during the dissolution process.
ii. More research on this topic should focus on the development of formulations of acid blend with low additive concentration.
iii. Acidizing activities should be restricted to wells with sufficient remaining reserves in the reservoir where economic benefit is assured.
iv. Other available additives should be looked into.
v. Corrosion problem should be burning in mind when choosing acids and additives for well stimulation.

6.0 Contribution to Knowledge

i. Formic acid blend can be an alternative in the absence of the commonly used mud acid and other acids in well stimulation.
ii. Surfactant like SLS is valuable for formation damage treatment and as well could retard the rate of corrosion on the down hole equipment
iii. Damaged wells could be restored after the treatment.
iv. SLS and other similar surfactants are cost effective, very affordable and readily available.

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