

# Analytical evaluation of solid deposits recovered from water injection wells in Niger-Delta

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## ABSTRACT

**Aim:** This study was aimed to analyze the physical and chemical compositions of the solid deposits recovered from water injection wells in Niger Delta area of Nigeria.

**Method and Materials:** Solid deposit samples were recovered from five water injection wells TA1, TA2, TA3, TA4 and TA5 respectively within Niger Delta area, Nigeria at two different periods of the year ten months apart. Samples were collected with a clean plastic bottle. The chemical compositions of samples from the same well were determined at the same time.

**Results:** Solid deposit recovered from water injection well TA1 has the highest percentage weight (% wt) hydrocarbon as well as carbonate indicating the presence of Magnesium (Mg) and Calcium (Ca) scales while solid deposit from water injection well TA3 has the highest % wt SiO<sub>2</sub> indicating the presence of sand particles.

**Conclusion:** It was concluded the presence of hydrocarbons, carbonates, SiO<sub>2</sub> and acid insoluble components in different quantities.

**Keywords:** Scale, carbonate, mud, sludge, sand.

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## Introduction

Water injection wells play predominant roles in oil and gas exploration, they are essential in the adequate management of produced water to boosting reservoir pressure for enhanced oil recovery. In water injection wells, water is injected into the deep surface of the fluid thereby permeating into the reservoir to push the crude oil towards the production well, increasing the pool pressure of the reservoir in the process. The injected water and crude oil are produced at the surface from the production well with the crude oil being separated from the water by gravity separation while the water goes through series of filtration processes to remove solid deposits and then reinjected into the wells over again to maintain the production process (Khatib and Verbeek, 2003; Fakhru'l-Razi et al., 2009). Solid deposits recovered from water injection wells could be in the form of scales, sand, sludge, mud and clay.

Scale deposition in oil and gas production systems represents an aggregation of different materials within the unwanted areas of the system resulting in the plugging of the reservoir pore throats thereby hindering fluid flow by negatively affecting the reservoir porosity and permeability (Odo et al., 2009). The common inorganic scales formed in sandstone reservoirs include calcium carbonate, iron oxide and silicon oxide scales while other scales such as iron carbonate, barium sulphate, aluminum, strontium and chromium oxides represent minor scales (Njova et al., 2005). Sand can be defined as a mixture of small grains of rock and granular materials finer than gravel and coarser than silt. Shallow geological formations with little or no ability to naturally bond individual sand grains together have a higher tendency of sand production however sand challenges can also be faced in deep formations (Meseguer et al., 2009). Sand production can lead to a number of challenges including wellbore instability, formation and casing damage or collapse, downhole and surface equipment failure (Chikwe and Ngobiri, 2021). Sludge can be defined as a semi solid slurry produced from a range of industrial processes such as water treatment, waste

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or sewage water treatment, oil and gas operations etc. Sludge can be classified into primary and secondary sludge. Primary sludge is generated from chemical precipitation, sedimentation as well as other primary processes which are encountered in oil and gas exploration while secondary sludge refers to activated waste biomass arising from biological treatments (Inegbenebor et al., 2003). Mud is very close to sludge except that in most cases in oil and gas operations they are not regarded as waste due to their chemical composition which varies from sludge and their functions during drilling operations. Drilling muds can break through the reservoir to find their way into water injection wells, they can also be formed by imparts of chemical treatments (Onojake and Chikwe, 2019). Clay is a natural material from the earth, which is soft when wet and hard when dry, it is a very fine-grained material which occurs as sedimentary rocks, soils and other deposits. Clay particles are smaller than silt with a diameter less than 0.0039mm (Odo et al., 2009). The characteristics of the solid deposits recovered from a water injection well is highly dependent on the nature of the reservoir rocks accommodating the injection well. A reservoir rock is a rock that have the capacity to trap oil in porous media, they possess pores and throats that enables hydrocarbons to flow as well as an accumulating system for hydrocarbons (Li and Yan, 2007). Reservoir rocks also possess a sealing mechanism that prohibits the penetration of hydrocarbons to surface layers. Reservoir rocks can be formed from either igneous, sedimentary or metamorphic rocks provided they have the capacity to accommodate and drain hydrocarbons. However, most reservoir rocks are formed from sedimentary rocks basically because of their porosity. Examples of igneous rocks are basalt, granite, rhyolite, obsidian etc, while sedimentary rocks include limestone, chalk, clay, sandstone and shale. Metamorphic rocks include marble, quartzite, amphibolite, migmatite etc (Zhang, 2008). A pictorial view of three types of reservoir rocks labelled i, ii and iii were taken (Fig 1). Having known the basic types of solid deposits that can be recovered from water injection wells as well as a general view of their sources, causes and impart in oil and gas operations, the aim of this study therefore is to analyze the physical and chemical compositions

of the solid deposits recovered from water injection wells in Niger Delta area of Nigeria. Results obtained will enable us to ascertain a proactive method of preventing solid deposit formation, link the data to the sources, causes as well as the imparts they may have on oil and gas exploration within the region.

### Materials and Methods

Solid deposit samples were recovered from five water injection wells TA1, TA2, TA3, TA4 and TA5 respectively within Niger Delta area, Nigeria at two different periods of the year ten months apart. Samples were collected with a clean plastic bottle. The chemical compositions of samples from the same well were determined at the same time using two methods namely:

- i. Weight difference before and after acid treatment to ascertain the acid soluble components which represents carbonate scales such as magnesium or calcium carbonates and acid insoluble components representing sand, mud, sludge and clay respectively. The hydrocarbon content of the solid deposits were also determined using this method.
- ii. The second method is by spectrophotometric techniques which specifically identifies the chemical composition of the solid deposits. This method verifies the % component of sand ( $\text{SiO}_3$ ) in the sample as determined by the first method and helps to distinguish other acid insoluble components such as mud, sludge and clay from each other by their chemical composition.

#### *Analyses of Solid Deposits by Weight Difference before/after Chemical Treatment*

Rinse a specific weight (R) of solid deposit sample thoroughly with xylene to remove all hydrocarbon components in the deposit. Dry sample in an oven at 100 °C for 12 hours, cool the sample in a desiccator and reweigh and record weight as (X). The hydrocarbon content of the deposit is calculated by the weight difference before and after treatment with xylene.

Obtain 10 grams from dried sample (X), crush in a crucible to very fine particle size. Introduce the crushed sample into a porcelain dish, add 100 mls of 15% hydrochloric acid (HCl), place on top of a heater with magnetic stirrer and stir at 80 °C for 1 hour. Filter sample appropriately and dry at 100 °C for 12 hours. Obtain dry sample after HCl treatment, cool, weigh and record as (Y).

Obtain the dry, cool sample after HCl treatment (Y) and add 100 mls of mud acid (a mixture of hydrofluoric acid and hydrochloric acid), stir at 80

°C for 1 hour, filter and dry sample at 100 °C for 12 hours. Obtain the dry sample, cool and weigh as (Z). Results can be calculated using the equations below:

$$\% \text{ Weight of Hydrocarbon} = \frac{(R-X)}{R} \times 100 \dots (1)$$

$$\% \text{ Weight of Hydrocarbon} = \frac{(X-Y)}{R} \times 100 \dots (2)$$

$$\% \text{ Weight of Hydrocarbon} = \frac{(Y-Z)}{R} \times 100 \dots (3)$$

$$\% \text{ Weight of Acid Insolubles} = \frac{Z}{X} \times 100 \dots (4)$$

(Daniel et al., 2005)

*Analyses of Solid Deposits Using Spectrometric Technique*

Solid deposit samples were activated by crushing sample into powder and sieving to a particle size of 250µm and then calcined at a temperature between 500 - 600°C. The sample was acidified using 0.2% w/w tetraoxosulphate VI acid (H<sub>2</sub>SO<sub>4</sub>) and then 200 g was placed in a beaker with 45 ml of distilled water added to make a paste slurry. Add 120 ml of dilute H<sub>2</sub>SO<sub>4</sub> to soak the paste for 1

hour at a controlled temperature range of 80 - 100 °C. Sample was later dried at 120 °C for 12 hours. The finely powdered sample was placed in a muffle furnace at 1000 °C for 2 hours to obtain the 'Loss on ignition' (LOI). The decrease in mass of the sample during the firing is the LOI according to the equation below:

$$LOI = \frac{wf-wi}{wi} \dots (5)$$

Where wf = final weight  
wi = initial weight

Quantitative determination of the chemical composition of samples was achieved using an X-ray fluorescence spectrometer (XRF) (Inegbenebor et al., 2016)

**Results and Discussion**

Composition of solid deposits by weight difference before/after acid treatment (Table 1&2 and Fig 2), composition of solid deposits by spectrometric techniques (Table 3&4 and Fig 3) and pictorial view of recovered solid deposits (Fig 4) were recorded.

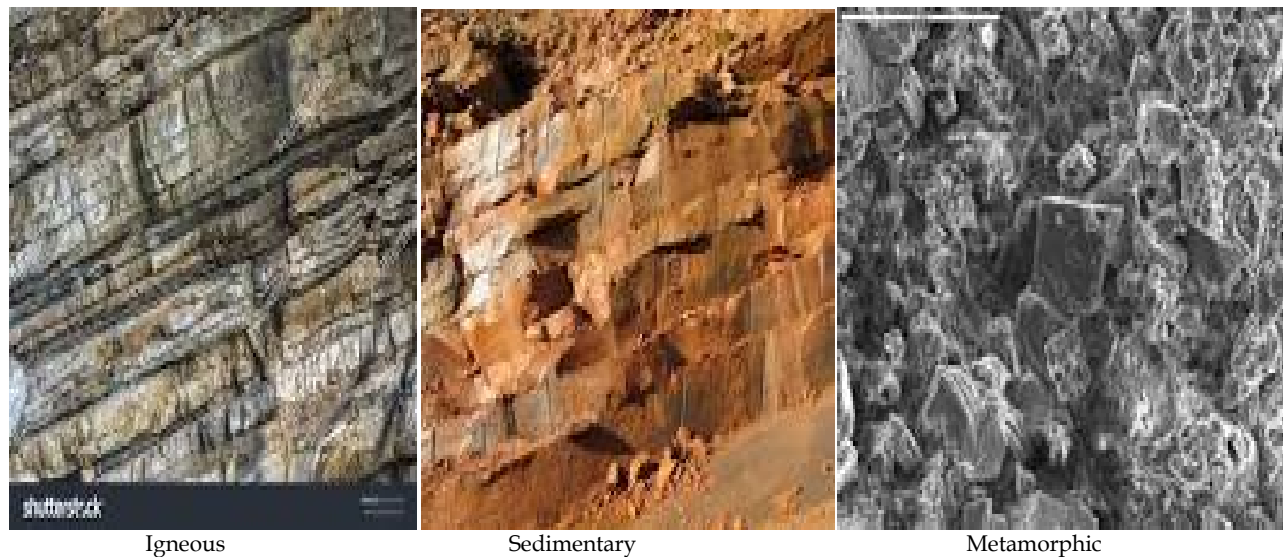


Fig 1: Pictorial View of Reservoir rocks

Table 1: Composition of solid deposits by weight difference before/after acid treatment (1st Recovery)

Parameters	TA1	TA2	Water Injection Wells		
			TA3	TA4	TA5
Sample Description	Scaly Sludge	Black Mud	Ash Sandy Mud	Black mud	Ash Sludge
% Weight Hydrocarbon	35.20	15.00	5.20	25.70	18.50
% Weight Carbonate	49.30	38.50	4.50	1.50	28.50
% Weight SiO <sub>2</sub>	7.30	20.00	66.50	3.50	20.20
% Weight Acid Insolubles	8.20	26.50	23.80	69.30	32.80
Total (%)	100.00	100.00	100.00	100.00	100.00

Table 2: Composition of solid deposits using weight difference before/after acid treatment (2nd Recovery)

Parameters	Water Injection Wells				
	TA1	TA2	TA3	TA4	TA5
Sample Description	Scaly Sludge	Black Mud	Ash Sandy Mud	Black mud	Ash Sludge
% Weight Hydrocarbon	33.70	18.00	7.50	19.80	22.70
% Weight Carbonate	45.50	36.80	5.90	2.50	32.50
% Weight SiO <sub>2</sub>	10.50	20.20	72.20	4.00	15.50
% Weight Acid Insolubles	10.30	25.00	14.40	73.70	29.30
Total (%)	100.00	100.00	100.00	100.00	100.00

Table 3: Composition of solid deposits by spectrometric technique (2nd Recovery)

Parameters	Water Injection Wells				
	TA1	TA2	TA3	TA4	TA5
SiO <sub>2</sub> (%)	7.50	20.25	67.20	3.80	20.50
Al <sub>2</sub> O <sub>3</sub> (%)	0.70	11.00	4.20	6.50	0.60
Fe <sub>2</sub> O <sub>3</sub>	40.90	30.65	22.40	87.00	49.20
CaO (%)	27.20	17.50	2.00	1.00	16.00
MgO (%)	23.50	18.90	2.70	0.70	13.50
K <sub>2</sub> O (%)	0.20	1.70	1.50	1.00	0.20
Total (%)	100.00	100.00	100.00	100.00	100.00

Table 4: Composition of solid deposits using spectrometric technique (1st Recovery)

Parameters	Water Injection Wells				
	TA1	TA2	TA3	TA4	TA5
SiO <sub>2</sub> (%)	10.60	20.50	72.50	4.20	16.10
Al <sub>2</sub> O <sub>3</sub> (%)	0.80	10.50	4.00	6.70	0.55
Fe <sub>2</sub> O <sub>3</sub>	39.65	35.40	16.20	85.80	48.25
CaO (%)	25.50	15.20	2.50	1.50	18.50
MgO (%)	23.20	16.90	3.50	0.80	16.50
K <sub>2</sub> O (%)	0.25	1.50	1.30	1.00	0.10
Total (%)	100.00	100.00	100.00	100.00	100.00

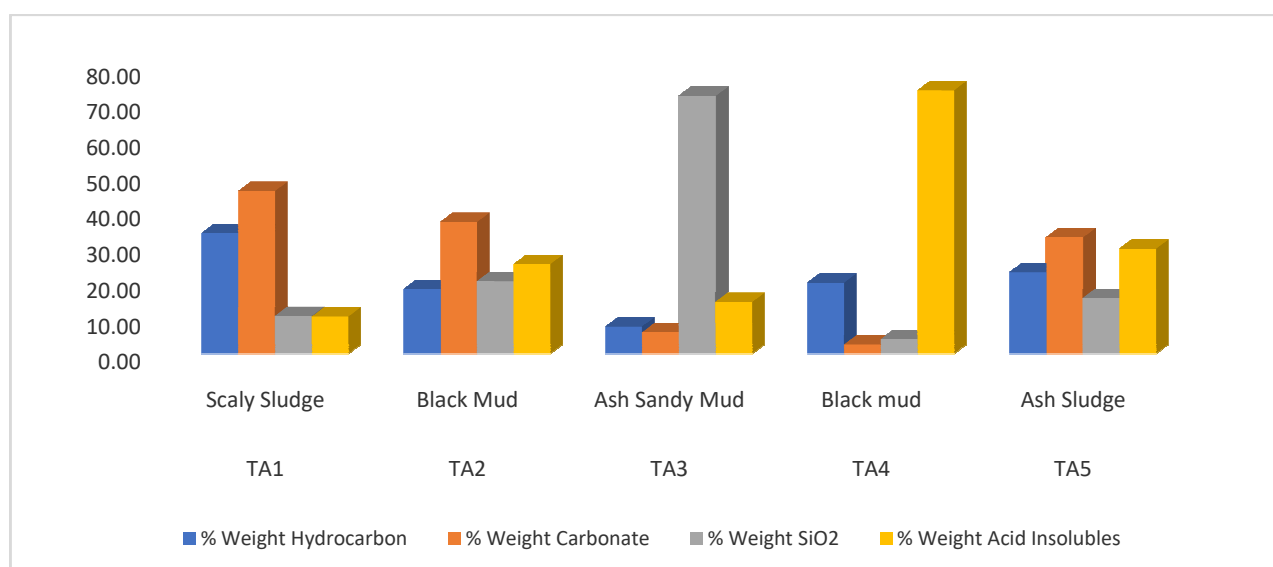


Fig 2: Bar chart of solid deposits composition by weight difference

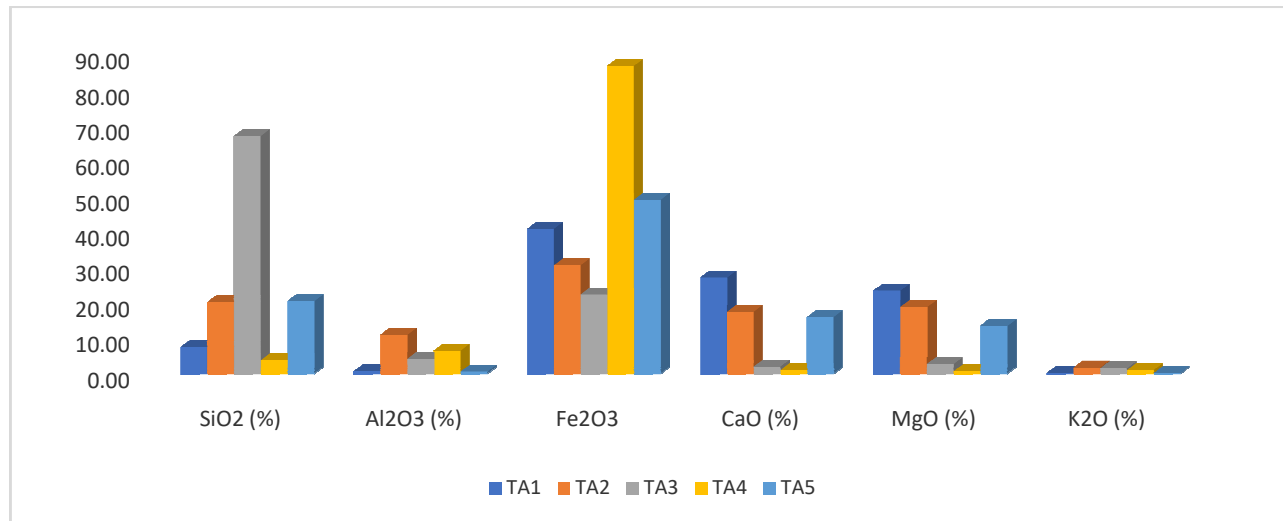


Fig 3: Bar chart of solid deposits composition by spectrometric technique

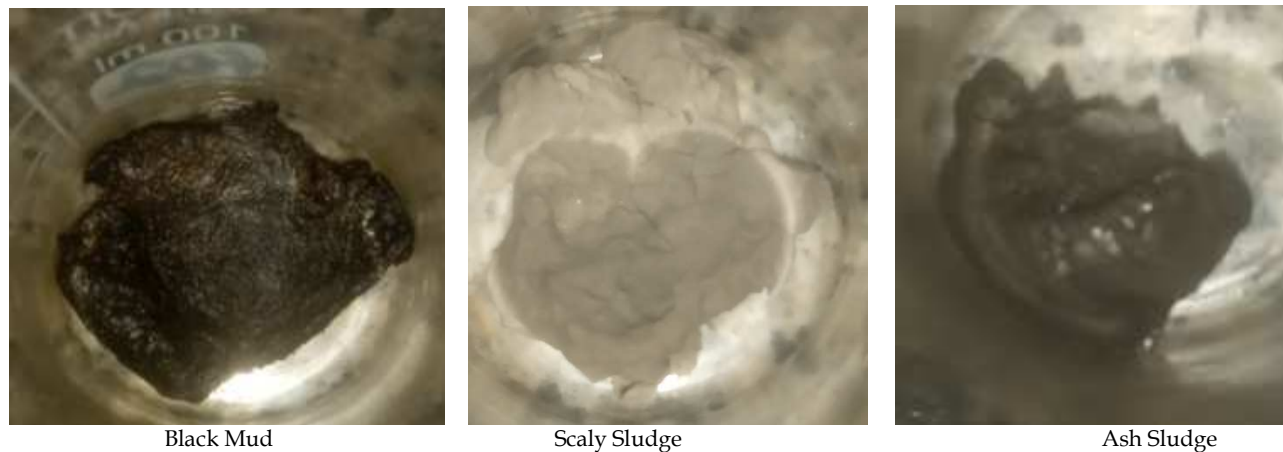


Fig 4: Pictorial view of recovered solid deposits

The formation of solid deposits in water injection wells can be attributed to several factors such as chemical reaction between oil field treatment chemicals and the produced water, presence of heavy metal ions or scale forming metals in the produced water due to the geochemical composition of the reservoir producing the crude, perforations within the reservoir leading to penetrations of unwanted debris within the injection wells amongst several other factors (Fakhru'l-Razi et al., 2009). Scale formation in water injection wells in offshore locations could be as a result of the reaction between incompatible waters from the sea and the produced water. The sea with high concentration of sulphate ( $\text{SO}_4^{2-}$ ) reacts with produced water with high concentration of calcium and barium to form precipitate scales of barium and calcium sulphates respectively (Inegbenebor et al., 2016) Water injection wells possess sand screens of

specified mesh sizes to prevent penetration of unwanted debris and solid particles within the reservoir into the well columns, however lack of maintenance and adequate replacement as at when due could leave the injection wells exposed to deposits inversion (Chikwe and Ngobiri, 2021). The chemical reaction between the produced water and surrounding fluids, chemicals as well as substances forming the solid deposits is determined by the chemical composition of the produced water and this determines the chemical composition of the formed deposits (Sirivedhin et al., 2004). Table 1 shows the chemical composition of solid deposits recovered from five water injection wells. Results obtained indicates the description of the deposits which was done by physical identification. A strong effervescence was observed on reacting solid deposits from TA1, TA2 and TA5 with hydrochloric acid which explains the high percentage (%) weight (wt) of carbonate in the solid deposits, however,

deposit from TA1 has the highest % wt of Carbonates amongst the five water injection wells. Carbonates basically from Calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) are responsible for scale formation. Results also shows that TA3 has the highest % wt of Silicate ( $\text{SiO}_2$ ) which confirms a high concentration of sand. TA4 has the highest % wt of acid insoluble compounds which indicates a high concentration of clay, mud and sludge. Results obtained from Table 1 also shows that TA1 has the highest % wt of hydrocarbon, this could be because the oil in water component of the produced water in the water injection well is high or as a result of breakthroughs from the surrounding reservoir and/or oil wells into the water injection well (Zhang, 2008). A bar chart showing the chemical composition of solid deposits recovered from each water injection well by weight difference before and acid treatment is shown in Figure 2. A second recovery was carried out 10 months after the first recovery to ascertain the impact of oil and gas exploration activities within the facility on the chemical composition of the solid deposits recovered from the water injection wells. Results obtained from Table 2 indicates the following relationship in the solid deposit composition between the first and second recovery

- i. A reduction in % wt hydrocarbon and carbonate. An increase in %wt  $\text{SiO}_2$  and acid insoluble components in TA1
- ii. An increase in % wt hydrocarbon and reduction in % wt carbonate, acid insoluble components, with the % wt  $\text{SiO}_2$  relatively the same in TA2
- iii. An increase in % wt hydrocarbon, carbonate,  $\text{SiO}_2$  and a reduction in % wt acid insoluble components in TA3
- iv. A reduction in % wt hydrocarbon and an increase in % wt carbonate,  $\text{SiO}_2$ , acid insoluble components in TA4
- v. An increase in % wt hydrocarbon and % wt carbonate. A reduction in % wt  $\text{SiO}_2$  and acid insoluble components in TA5.

An increased hydrocarbon content in produced water in the water injection well obviously leads to a high concentration of total oil and grease (TOG) and total petroleum hydrocarbon (TPH) in water and this can be treated using adequate concentration of flocculant (Daniel et al., 2005). An increased carbonate content in the solid deposit implies a high concentration of calcium and magnesium ions in

produced water which can be treated with adequate concentration of scale inhibitors. An increased concentration of  $\text{SiO}_2$  in the solid deposit represents the predominance of high quantity of sand and in such cases the sand screens within the water injection columns should either be replaced with a screen that has a smaller mesh size or adequately maintained for optimal performance (Fakhru'l-Razi et al., 2009; Chikwe and Ngobiri, 2021).

An increased % wt of acid insoluble components in the solid deposit represents a high concentration of mud, clay and sludge which often times are formed by the reaction between the produced water from the crude and treatment chemicals or penetrations through permeable layers around the water injection columns (Inegbenebor et al., 2003). Results obtained (Table 3) showed composition of solid deposits from the same water injection wells using spectrometric technique. Spectrometric analyses by X-ray fluorescence spectrometer gives more detailed chemical composition of the solid deposit by enabling an inference that helps in determining the chemical constituents of the acid insoluble components (Inegbenebor et al., 2016). It can be deduced that the highest chemical constituent in the solid deposit from TA1, TA2 and TA4 and TA5 was  $\text{Fe}_2\text{O}_3$  with TA4 having the highest value (Table 3). Solid deposits from TA2 have the highest % concentration of alumina ( $\text{Al}_2\text{O}_3$ ) while TA3 have the highest % concentration of sand ( $\text{SiO}_2$ ). A bar chart showing the chemical composition of solid deposits recovered from each water injection well by spectrometric technique was recorded (Fig 3). Results obtained (Table 4) indicated the chemical constituents of the solid deposits recovered 10 months after the first recovery. Results obtained showed that the trend (Tables 3 and 4) using spectrometric technique was the same as weight difference by acid treatment (Tables 1 and 2). The % concentration of calcium oxide ( $\text{CaO}$ ) and Magnesium oxide ( $\text{MgO}$ ) can be related to the % wt of carbonates, respectively as water injection wells with relatively high carbonate content seem to have corresponding high concentrations of  $\text{CaO}$  and  $\text{MgO}$  due to the predominance of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions. The % wt of  $\text{SiO}_2$  were relatively the same within acceptable limit. Both sludge and mud are rich in  $\text{Fe}_2\text{O}_3$  however mud has a higher concentration of alumina and heavy metal than sludge (Costa et al., 2021). The % concentration of

Al<sub>2</sub>O<sub>3</sub> in the solid deposits recovered from the water injection wells as recorded (Tables 3 and 4) that the deposits recovered from TA2, TA3 and TA4 are more of mud with the % concentration of Al<sub>2</sub>O<sub>3</sub> >3.0 while TA1 and TA5 are more of sludge with a % concentration <1.0. The mud properties of the solid deposit recovered from TA2, TA3 and TA4 can also be verified from the % concentration of K<sub>2</sub>O which is relatively higher than those from deposits recovered from TA1 and TA5. The heavy metal in mud which can be related to % concentration of K<sup>+</sup> and Al<sup>3+</sup> is higher than what is obtainable in sludge. Getting rid of heavy metal ions in the produced water contained in the water injection wells by methods such as reverse osmosis, coagulation and flocculation, floatation packages as well as electric based separation will go a long way in reducing the probability of reactions leading to mud formation in these wells (Zimmerman and Weindorf, 2013; Hardi et al., 2019). Ensuring that there are no interactions and permeations between drilling muds used in drilling operations and the water injection well is also key in preventing mud formations in the water wells (Onojake and Chikwe, 2019). The description of the recovered deposits was obtained by physical examination however it is important to note that the description may not align with results obtained after analytical evaluation (Xiaoqing, 2008). A pictorial view of some solid deposits recovered from the water injection wells were recorded (Fig 4).

### Conclusion

Formation of solid deposits in water injection wells can be due to a number of factors such as chemical reactions between the produced water in the well and treatment chemicals used within the oil/gas installation, intrusions from the reservoir to the water injection well columns, interference of drilling mud used during drilling operations etc. The chemical composition of the produced water determines the possibility and type of chemical reactions between it and the environment and by extension the composition of the formed deposits. Solid deposits recovered from water injection wells in the Niger Delta Nigeria showed the presence of hydrocarbons, carbonates, SiO<sub>2</sub> and acid insoluble components in different quantities. Further characterization of the acid insoluble components confirmed that most of the deposits have mud and sludge properties. Solid deposits in water injection wells can cause a number of

challenges such as wellbore instability, formation and casing damage or collapse, downhole and surface equipment failure as well as plugging of reservoir pore throats which can adversely affect the reservoir porosity and permeability.

### Reference

- Chikwe TN and Ngobiri N (2021). Monitoring of Sand Concentration in Some Oil Wells in the Niger Delta Area of Nigeria. *International Journal of New Chemistry*, 8(4): 413-424.
- Costa HP de S, da Silva MGC and Vieira MGA (2021). Biosorption of Aluminum ions from Aqueous Solutions using Non-Conventional Low-Cost Materials: a review. *Journal of Water Process Engineering*, 40: 1-21.
- Daniel AJ, Langhus BG and Patel CP (2005). Technical Summary of Oil & Gas Produced Water Treatment Technologies. *International Journal for Innovation Education and Research*, 2411-2933.
- Fakhru'l-Razi A, Pendashteh A and Abdullah LC (2009). Review of Technologies for Oil and Gas Produced Water Treatment. *Journal of Hazardous Materials*, 170: 530-51.
- Hardi M, Siregar YI, Anita S and Ilza M (2019). Determination of Heavy Metals Concentration in Produced Water of Oil Field Exploration in Siak Regency. *Journal of Physics Conference Series*, 1156: 1-6
- Inegbenebor AO, Bamgbade A and Inegbenebor AI (2003). A study of Chemical Composition of Some Clays Deposits in Borno State for Refractory Production Science Forum: *Journal of Pure and Applied Sciences*, 6: 98 - 103.
- Inegbenebor AI, Inegbenebor AO, Mordi RC, Kalada N, Falomo A and Sanyaolu P (2016). Determination of the Chemical Compositions of Clay Deposits from Some Part of Southwest Nigeria for Industrial Applications. *International Journal of Applied Sciences and Biotechnology*, 4(1): 21-26.
- Khatib Z and Verbeek P (2003). Water to value Produced water management for sustainable Field development of mature and green Fields. *Journal of Petroleum Technology*, 26 -28.
- Li J and Yan ZH (2007). Classification of Oil

- Reservoirs in the Lasa Xing Oilfield during the Ultra-High Water Bearing Period. *Daqing Petroleum Geology and Development*, No. 6: 21-32.
- Meseguer S, Sanfeliu T and Jordan MM (2009). Classification and Statistical Analysis of Mine Spoils Chemical Composition from Oliete Basin (Teruel NE Spain). *Environmental Geology*, 56: 1461 - 1466
- Njoya A, Nkoumbou C, Grosbois C, Njopwouo D, Njoya D, Courtin-Nomade A, Yvon J and Martin, F. (2005). Genesis of Mayouom Kaolin Deposit (Western Cameroon). *Applied Clay Science*, 32: 125-140.
- Odo JU, Nwajaga CO and Nnuka EE (2009). Characterization of Ezebunage Clay Deposit and its Potential for Industrial Application. *Journal of Modern Management and Entrepreneurship*, 4: 31 - 37.
- Onojake MC and Chikwe TN (2019). Rheological Properties Of Some Oil Based Muds Used In Reservoirs In The Niger Delta, Nigeria. *Global Journal of Applied Sciences*, 25: 39-44.
- Sirivedhin T, McCue J and Dallbauman L (2004). Reclaiming Produced Water for Beneficial use: Salt Removal by Electrodialysis. *Journal of Membrane Science*, 243 (pg. 335-430
- Xiaoqing L (2008). Study on Improving the Degree of Utilization of Non-Major Sand Reserves in the North Zone. *Inner Mongolia Petrochemicals*, (10): 112-114.
- Zhang S (2008). Exploration of problems related to the process of stratified injection and gathering in the Sazhong Development Zone of Daqing Oilfield. *Petroleum Geology and Engineering*, (01): 156-158.
- Zimmerman AJ and Weindorf DC (2013). Heavy metal and Trace Metal Analysis in soil by sequential Extraction: A review of Procedure. *International Journal of Analytical Chemistry*, 10: 1105 - 1112.

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