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Investigating the Impact of Sieve Analysis on the Choice of Gravel Pack Design for Wells in Unconsolidated Sandstone Formations in the Niger Delta

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Sand production is major problem for the oil and gas industry and solutions to this problem is a continuous process as new challenges arise with time. Various sand control methods have been proposed for tackling the sand production challenge, and research and experience have shown that the use of mechanical sand control methods are more suitable, with gravel packing being the most effective. Gravel packs are proven to be an effective mechanical sand control technique, and a good gravel pack completion design is of great importance to exclude sand from the wellbore while enhancing well productivity. Implementation of sand control by gravel packing in the Niger Delta is usually found to require importation of commercial gravel for the purpose of sand control which is a

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challenge in terms of high purchasing and transportation costs with import taxes. A solution is presented in this study which involves sourcing for gravel locally and investigating its suitability for sand control by gravel packing. Locally sourced gravel was compared with commercial gravel using sieve analysis and results showed that the locally sourced gravel closely met the requirements of the commercial gravel depicted by slot widths that are close to that obtained by the commercial gravel. Based on the results of this study, favorable performance is expected when locally sourced gravel is used for sand control by gravel packing in unconsolidated formations in the Niger Delta. It is recommended to source for different gravel types from different locations and evaluate using sieve analysis and Laser Particle Size Distribution Analysis to determine suitable gravel types for these type of formations.

Keywords: Sand control; sand production; sieve analysis; gravel pack; gravel curve.

1. INTRODUCTION

Sand production mostly occurs in unconsolidated sandstone reservoirs and affects more than 70% of oil and gas reservoirs worldwide [1]. Unconsolidated sandstone reservoirs are predominant in the Niger delta, hence the need to propose efficient and cost effective solutions for addressing this problem. Sand production can be classified as transient sand production, continuous sand production, and catastrophic sand production, and knowledge of type of sand production is essential in predicting sand production rates [2]. Sand production is one of the major concerns encountered by oil and gas companies during exploration and production from unconsolidated sandstone formations and are proven to be the most difficult to solve. Sand produced with formation fluids comes from younger reservoirs of the Miocene and Pliocene ages which is usually weakly consolidated due weak clay cementing material [3]. Sand production occurs as a result of the following conditions: sand production occurs during well flow in unconsolidated formations, high production rates from the formation which causes threshold pressures to exceed the in situ stress in the formation, and sand production is observed. Weak cementing material in the sandstone reservoir, which generally fails under in situ or forced pressures during hydrocarbon extraction, is one of the sources of sand formation [4]. When wells flow, sands are formed due to the unconsolidated nature of the formation which causes the sand to migrate through the wellbore with formation fluid to the surface.

The long term productivity of a well is adversely affected when formation sand production flows into the wellbore to the surface with well fluids [5]. Completing wells drilled in these type of reservoirs is a challenge since there is a tendency for the simultaneous flow of reservoir fluids and formation sand into the wellbore. Failure to implement sand management techniques can cause problems such as wellbore sanding, erosion, sand fouling, and sand accumulation which have the overall effect of causing formation damage, wellbore instability, casing collapse, impairment or failure of downhole and surface equipment, lost production time due to well shut-in, workover expenses, and environmental issues [4]. The main effect of sand production is damage to surface and sub-surface production equipment which could lead to material wear or mechanical erosion of the equipment [6]. Niger delta formations are unconsolidated as well and prone to sand production, and the oil and gas companies in the area also face these problems and effects associated with it. For the past couple of decades, the oil and gas industry of the Niger Delta has been working on improving sand control methods to aid in controlling sand production, the success of which is dependent on well-executed design and implementation. The following information must be considered while designing a well completion: Reservoir pressure, temperature profiles, productivity index, water cuts, sand production volumes, formation damage, and formation thickness are all factors to consider [3].

Confirming the possibility of sand production in a given well would normally be followed by selecting an appropriate approach for mitigating sand production. Various approaches such as field observations requiring the use of correlations, laboratory experiments, use of well logs, and theoretical modeling have been proposed for predicting the onset of sand production [2]. The theoretical modeling approach can be split into analytical, semi-analytical and numerical approaches. Possible sand control methods include restricting production rate, increasing flow area, selective perforating, in-situ sand consolidation techniques, resin-coated gravel pack, and mechanical methods which involves the use of slotted liners, standalone screens, open hole and cased hole gravel pack, or frac-packs completions to prevent sand production [3]. Mechanical sand control methods are the most widely used due to their simplicity and low cost [6] which is the focus of this study.

The performance of various mechanical sand control methods were evaluated in different field examples in the Niger Delta, Mahakam oil and gas block and offshore Malaysia [7]. Results from their study showed that an internal gravel pack completion system resulted in a prolonged plateau production regime in shallow depths while chemical consolidation was more effective in deeper formations.

According to Ahad et al. [4], the most suitable mechanical sand control methods are standalone screens and gravel packs on the basis of information from literature. Research has however shown that standalone screens which is the simplest scenario for applying sand control methods can be used to effectively minimize sand production since it can prevent sand of a specified size from flowing into the wellbore [6]. Screens have different geometries and selection of a suitable screen depends on the particle size distribution of grains in the formation.

Sand retention tests conducted in the laboratory can be used in selecting screens for sand control [4]. The disadvantage of using standalone screens as a sand control method is erosion of the screen causing it to fail over time in performing its function of sand control justifying the need to use gravel packs as an alternative to standalone screens. Gravel packs are popular and reliable sand control techniques created in response to multiple failures of stand-alone screens. A gravel pack is a downhole filter that is kept in place by a properly sized screen, with the gravel pack sand holding the formation in place [8]. It serves two purposes and is installed as a downhole filter to enable maximum fluid production and prevent production of sand. The success of a gravel pack design and selection is based on selection of properly sized gravel which would hold sand and prevent it from flowing into the wellbore, selection of properly sized screens to hold the selected gravel, and ensuring that while productivity is not affected. In this case a gravel with a permeability higher than that of formation sand is used. This can be accomplished by taking a sample of the formation sand, analyzing the grain size distribution through a sieve analysis, and selecting the best gravel size. Measurement of particle size of reservoir rocks is a routine process conducted to aid in sand control selection, and hence considered as a straightforward process [9]. The authors highlighted dry sieving and Laser Particle Size Analysis (LPSA) as the most common methods of particle sizing. In their work, the authors focused on Laser Light Scattering (LPSA). This current study uses sieve analysis in sand control selection.

To manage formation sand movement, gravel size is selected in accordance to formation grain size. Gravel packing, which is an effective sand management approach, has been linked to a reduction in well production. A gravel pack can provide long-term performance with proper design and installation. This paper determines the considerations derived from sieve analysis for evaluating the suitability of locally sourced gravel in meeting the requirements of commercial gravel. Three gravel pack design concepts that result in a good design that boosts productivity while reducing sand production output were presented by Bouhroum & Civan [10]. The first rule is to keep the majority of the formation sand particles from migrating and the second principle is providing acceptable flow capacity which means the permeability of gravels must be greater than the permeability of formation sand. Proper sampling and sand screen analysis are the beginning points for any type of sand control using a geomechanical technique. This is accomplished by taking core samples from a well interval and subjecting them to particle size distribution analysis either through sieve analysis and/or laser particle size analysis [3]. These analyses are used to ensure that liner holes, screens, and gravel pack size are properly designed. The use of neural networks to get real-time, well-specific grain-size distributions and how these inputs may enhance gravel pack design for optimum sand management technique selection was investigated [11].

Sand production in the Niger Delta like in other parts of the world that have unconsolidated sandstone formations is inevitable since it is characteristic of such formations to produce reservoir fluids with sand. Gravel packing and chemical consolidation are common sand control methods used by Niger Delta oil companies. The gravel used in gravel packing are mostly imported from abroad which causes high purchasing costs, transportation costs, and import taxes to be incurred. This is not cost effective especially for indigenous oil and gas companies. This is a technical and economic challenge faced by indigenous operators in the Niger Delta. A solution is presented in this study in which local gravel obtained in Obinze is evaluated for its effectiveness in sand control in comparison with commercial gravel obtained from Company X using sieve analysis. One of the most important aspects of gravel pack design is sieve analysis for deciding the proper gravel size [12] for a given sand sample and was used in this study.

Sieve Analysis is a common laboratory procedure used to select the right gravel size for a formation sand sample, and involves placing a 100 to 300 gram sample of dry formation sand at the top of a succession of screens with progressively decreasing mesh sizes. The sand particles will fall through the screens until they get to a screen that they cannot pass through. The weight of the retained sand is determined by weighing each screen before and after screening. Sieve analysis results are used to assist build the optimal sand management strategy.

To calculate gravel size, information from formation samples is required, and size selection is based on the particle size distribution of formation sand in the presence of sample. To prevent clogging of slotted liners/screens, the apertures should be roughly half the size of the lowest gravel size to ensure that gravel bridges are on the slot/screen rather than the gravel going in. The design criteria's smallest gravel size should be less than 75% of the slot liners and screen openings [13].

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this study are a stack of test sieves, sieve shaker and an oven. The test samples were placed on the stack of sieves so that during sieving, the test samples can be placed appropriately on corresponding sieves based on their respective sizes. Sieves of various sizes ranging from 2 to 0.062 mm with larger sieve sizes being placed at the top and smaller ones placed at the bottom constitute the stack of sieves. The sieve shaker was used in vibrating the stack of sieves while the oven was used in drying the test samples to remove any moisture. In this paper, four different samples consisting of 2 sandstones samples and 1 locally sourced and 1 commercial gravel sample were used and are presented in Table 1. Sample G1 is a locally sourced gravel while sample G2 was obtained from company X which is the imported type of Gravel. All the sandstone samples S1 and S1 were sourced locally.

2.2 Methods

All the samples were oven dried to remove any moisture and weighed dry to obtain 100 g each of samples S1 and S2 and 500 g each of samples G1 and G2 as depicted in Table 1.

$$SK = \frac{\Phi_{16}+\Phi_{84}-2(\Phi_{50})}{2(\Phi_{84}-\Phi_{16})} + \frac{\Phi_{5}+\Phi_{95}-2(\Phi_{50})}{2(\Phi_{95}-\Phi_{5})} \tag{7}$$

2.3.6 Kurtosis

Kurtosis is a measure of the “peakedness” in a curve. It measures the degree to which scores cluster in the tails or the peak of a frequency distribution.

$$\mathrm{KG} = \frac{\Phi_{95}-\Phi_{5}}{2.44(\Phi_{95}-\Phi_{25})} \tag{8}$$

2.4 Gravel Pack Selection

A plot of each weight retained on each sieve against the sieve opening to determine the average formation sand size which is used to find accurate gravel size. After the grain size distribution is gotten, a sieve analysis curve is constructed from the cumulative sand retained percentage against the grain size.

i. The coefficient of uniformity, C_U is calculated using equation 9
$$C_U = \frac{D_{40}}{D_{90}} \tag{9}$$
ii. An appropriate design point is selected on the sieve analysis curve.
iii. The gravel diameter is selected by multiplying the design point by the gravel/sand ratio (a range of 4 to 6 times the design point size).
iv. The narrowest range of sieve sizes that would contain the selected gravel diameter.
v. A screen sloth size of one –half the smallest gravel size is selected.

Table 1. Table showing the samples, areas of sourcing and their weights

Samples	Sample code names	Area of Sourcing	Mass of weighed sample(g)
Sandstone	Sample S1	Otammiri	100
	Sample S2	Nworie	100
Gravel	Sample G1	Locally Sourced	500
	Sample G2	Company X	500

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Sieve Analysis for Samples S1 and S2

Tables 2 and 3 shows Sieve Analysis results on samples S1 and S2 respectively, and Table 4 shows the grain size statistics for samples S1 and S2. The cumulative mass retained, percentage cumulative mass retained and percentage passing was obtained using equations 1, 2 and 3 respectively. Mean, mode, median, standard deviation, skewness, and kurtosis for each sand sample was calculated using equations 4 to 8. The results from Tables 2 and 3 are illustrated in Figs. 1 and 2 which shows plots of percentage of sand passing through sieve versus Grain size for samples S1 and S2 respectively.

3.1.2 Sieve Analysis for Gravel Samples G1 and G2

Tables 5 and 6 shows the Sieve Analysis results on Gravel samples G1 and G2 respectively. Equations 1, 2, and 3 were also used in respective columns of Tables 5 and 6 to calculate cumulative mass retained, percentage cumulative mass retained and percentage passing respectively. Figs. 3 and 4 shows the plot of percentage passing of gravel versus Grain size for samples G1 and G2 respectively. Table 7 shows the gravel sample analysis for Samples G1 and G2 depicted by Phi 25, Phi 40, Phi 90, and Phi 95. These values were obtained at 25%, 40%, 90%, and 95% by extrapolating from the percentage passing axis to the gravel curve and to the grain size axis to obtain Phi 25, Phi 40, Phi 90, and Phi 95 respectively. The coefficient of uniformity, C_U was calculated for each gravel sample using equation 9.

Table 2. Results on the Sieve Analysis on Sample S1

Sieve Number	Sieve Size (mm)	Mass Retained (g)	Cumulative Mass Retained	% cumulative Mass Retained	% passing
10	2.000	3.23	3.23	3.23	96.77
20	0.841	15.11	18.34	18.34	81.66
30	0.595	14.92	33.26	33.26	66.74
40	0.420	10.54	43.80	43.80	56.20
60	0.250	34.21	78.01	78.01	21.99
80	0.177	14.24	92.25	92.25	7.75
100	0.149	4.05	96.30	96.30	3.70
120	0.125	2.81	99.11	99.11	0.89
250	0.062	0.84	99.95	99.95	0.05
Tray		0.05	100.00	100.00	0.00

Table 3. Results on the Sieve Analysis on Sample S2

Sieve Size	Sieve Size in mm	Mass Retained (g)	Cumulative Mass Retained	% Cumulative Mass Retained	% Passing
10	2.000	7.50	7.50	7.50	92.50
20	0.841	21.47	28.97	28.97	71.03
30	0.595	20.99	49.96	49.96	50.04
40	0.420	11.34	61.30	61.3	38.70
60	0.250	21.50	82.80	82.8	17.20
80	0.177	7.30	90.10	90.1	9.90
100	0.149	1.91	92.01	92.01	7.99
120	0.125	3.43	95.44	95.44	4.56
250	0.062	1.93	97.37	97.37	2.63
Tray		2.63	100.00	100.00	0.00

Table 4. Table of grain size statistics

Sandstone sample	Mean	Mode	Median	Standard Deviation	Skewness	Kurtosis
Sample S1	0.49	0.250	0.36	0.249	0.640	0.435
Sample S2	0.77	0.250	0.58	0.596	0.465	0.468

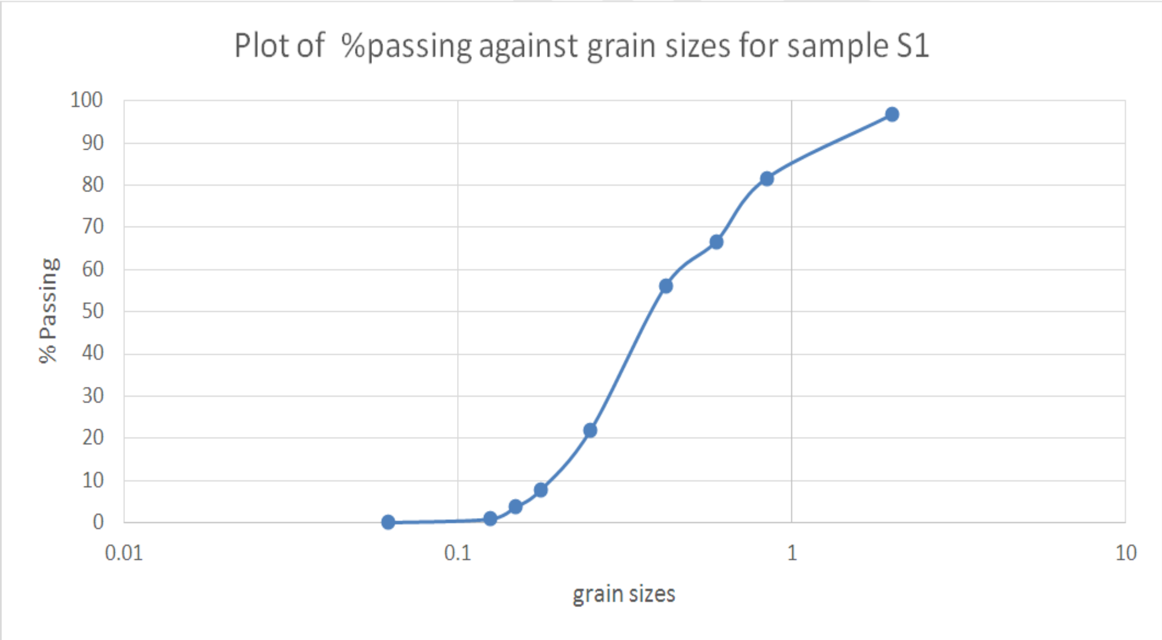

Fig. 1. Plot of % passing against grain size for sample S1

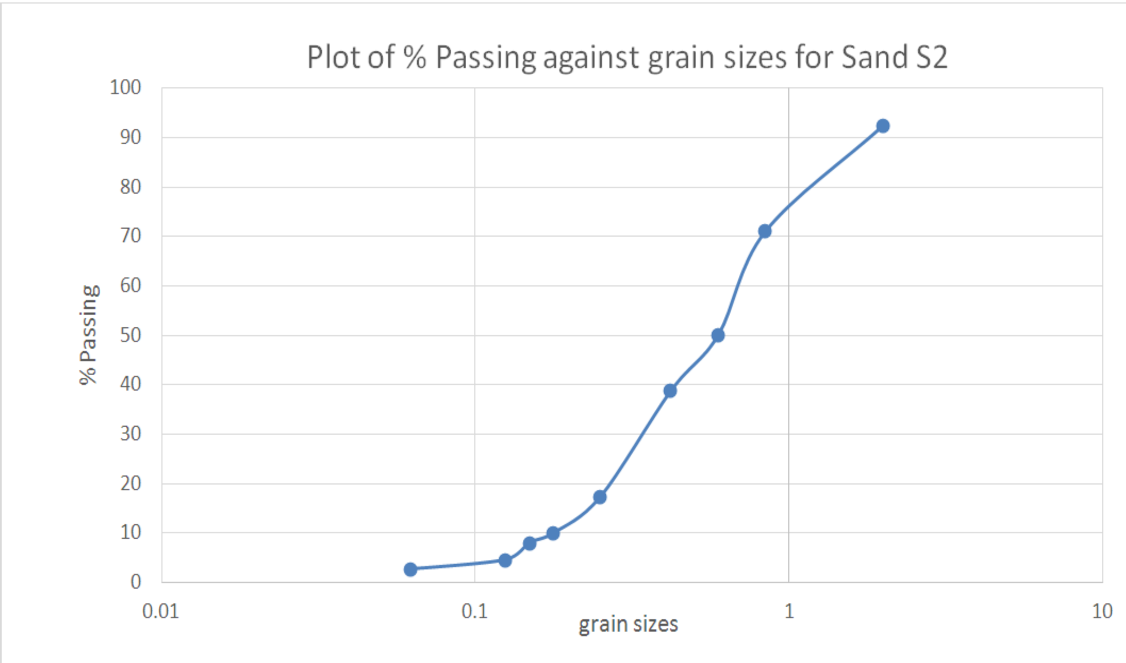

Fig. 2. Plot of % passing against grain size for Sample S2

Table 5. Results on the Sieve Analysis on Sample G1

Sieve Size	Sieve Size in mm	Mass Retained (g)	Cumulative Mass Retained (g)	% Cumulative Mass Retained	% Passing
4	4.750	8.28	8.28	1.68	98.32
10	2.000	13.97	22.25	4.51	95.49
20	0.850	14.83	37.08	7.51	92.49
40	0.425	37.26	74.34	15.06	84.94
60	0.250	100.20	174.54	35.35	64.65
100	0.150	265.37	439.91	89.09	10.91
200	0.075	46.79	486.70	98.57	1.43
Tray		7.06	493.76	100.00	0.00
Total		493.76			

Table 6. Results on the Sieve Analysis on Sample G2

Sieve Size	Sieve Size in mm	Mass Retained (g)	Cumulative Mass Retained (g)	% Cumulative Mass Retained	% Passing
4	4.750	19.04	19.04	3.81	96.19
10	2.000	48.88	67.92	13.58	86.42
20	0.850	43.10	111.02	22.20	77.80
40	0.425	40.74	151.76	30.35	69.65
60	0.250	75.62	227.38	45.48	54.52
100	0.150	207.68	435.06	87.01	12.99
200	0.075	60.11	495.17	99.03	0.97
Tray		4.45	499.62	99.92	0.08
Total		499.62			

Table 7. Table of Gravel Sample Analysis

Gravel sample	Phi 25	Phi 40	Phi 90	Phi 95	C_U
G1	0.176	0.204	0.435	1.812	0.460
G2	0.179	2.46	3.008	4.423	0.817

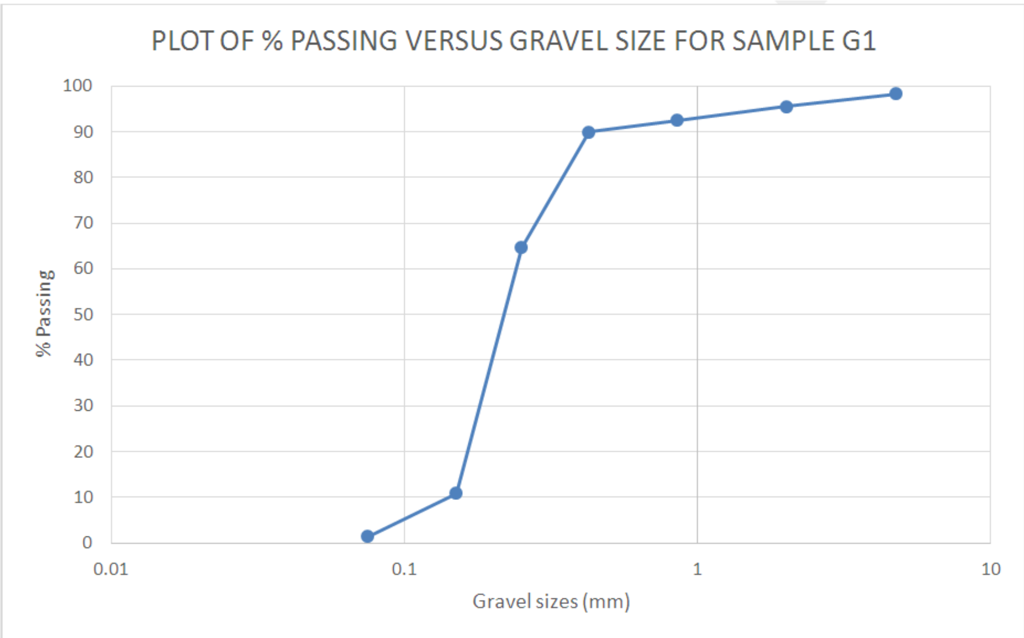

Fig. 3. Plot of % passing against gravel size for sample G1

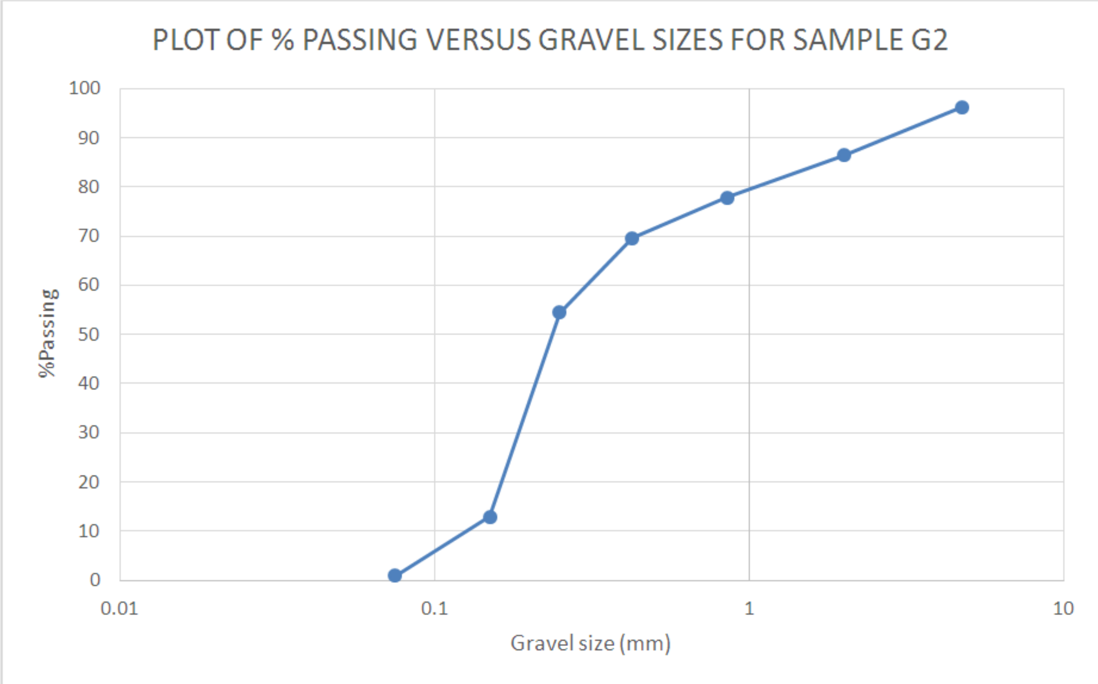

Fig. 4. Plot of percentage passing against gravel sizes for sample G2

3.1.3 Gravel Pack Plot for different Sand and Gravel sample combinations

Figs. 5, 6, 7, and 8 shows gravel plot for gravel G1 and sand S1, gravel G1 and sand S2, gravel G2 and sand S1, and gravel G2 and sand S2 respectively. The median grain sizes for sand samples S1 and S2 are 0.388 mm and 0.594 mm respectively obtained by extrapolating from the percentage passing axis to the sand curve and to the grain size axis.

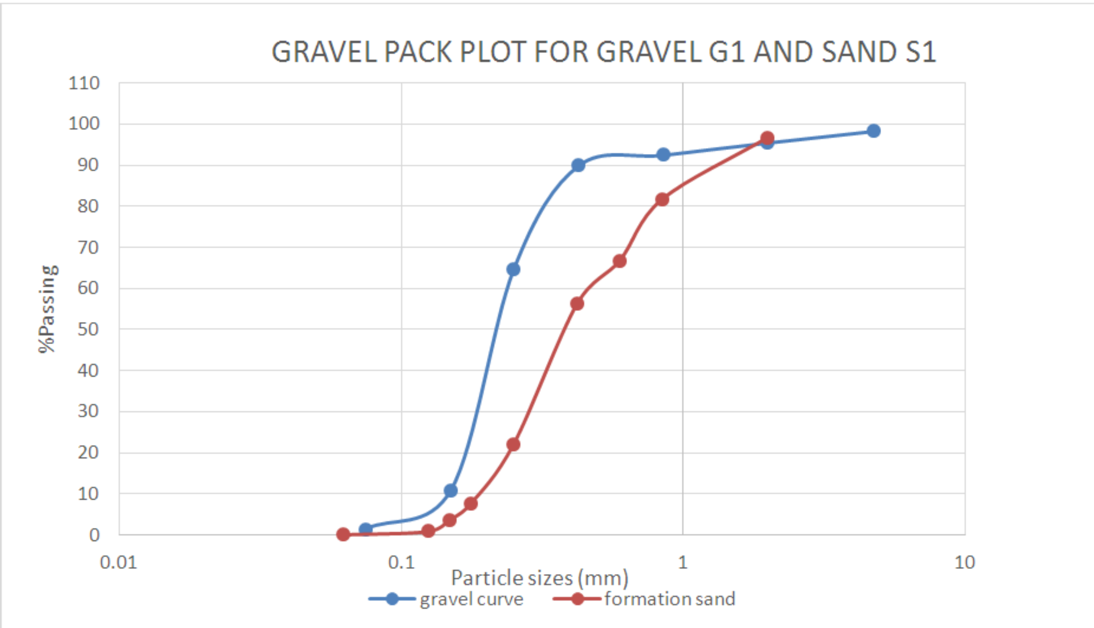

Fig. 5. Gravel Pack plot for Gravel G1 and Sand S1

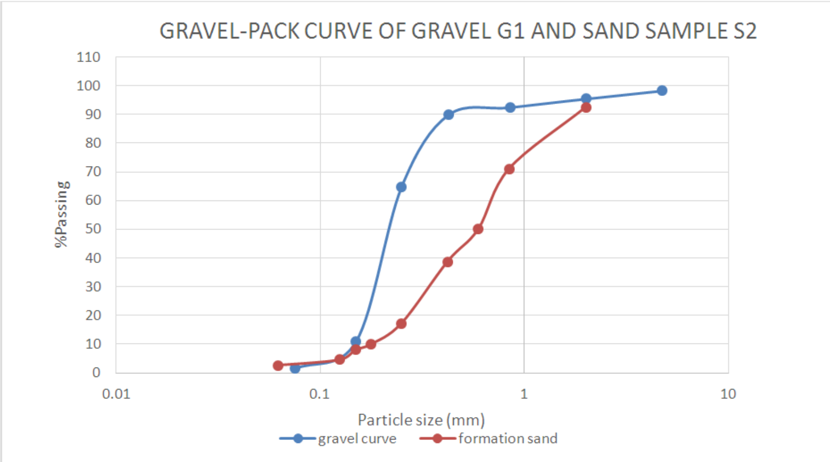

Fig. 6. Gravel Pack plot of Gravel G1 and Sand S2

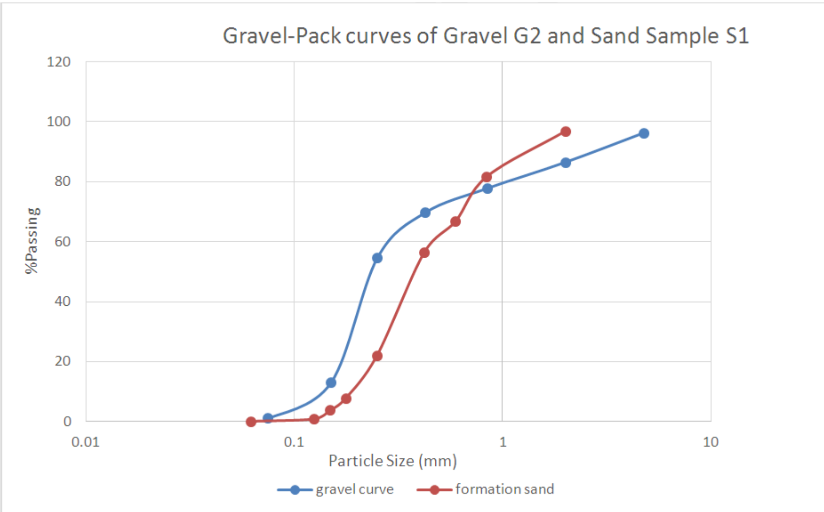

Fig. 7. Gravel Pack plot of Gravel G2 and Sand Sample S1

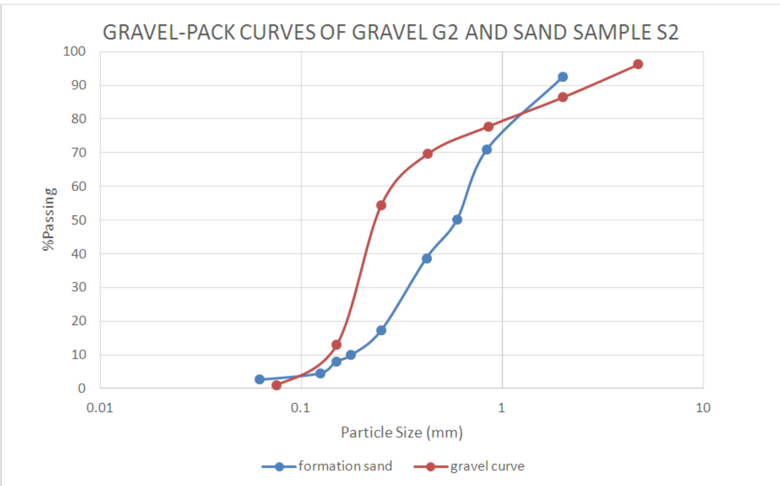

Fig. 8. Gravel Pack plot of Gravel G2 and Sand Sample S2

Table 8. Screen slot width calculations for sand and gravel sample combination

Sand sample	Median grain size of sand (mm)	Gravel Sample	Smallest Gravel sieve size (mm)	C_U	Slot width (mm)	Gravel type (US mesh sieves)
S1	0.388	G1	0.075	0.460	2.53	4/8
S2	0.594	G1	0.075	0.460	3.874	3/5
S1	0.388	G2	0.075	0.817	1.425	7/14
S2	0.594	G2	0.075	0.817	2.181	5/10

3.1.4 Screen Slot Width Calculations and Selection of Gravel Type

Table 8 shows screen slot width calculations for each sand and gravel sample combination presented in this paper with the recommended gravel type suitable for preventing migration of the smallest sand grains through the screen slots.

4. DISCUSSION

Tables 2 and 3, and Tables 4 and 5 shows sieve analysis results for sands S1 and S2, and gravels G1 and G2 respectively. The percentage of grain sizes passing the sieves was plotted against the sieves sizes which constitute the stack of sieves for each of S1, S2, G1, and G2 and the results are presented in Figs. 1, 2, 3, and 4 respectively. The percentage passing versus grain size for each sand and gravel combination was conducted and the results are presented in Figs. 5, 6, 7, and 8 for S1 and G1, S2 and G2, S2 and G1, and S2 and G2 respectively. The median of sand S1 shows that it has a medium fined texture while that of sand S2 indicated a coarse texture. Both sand samples S1 and S2 have low standard deviations of 0.249 and 0.596 respectively showing that they are relatively well sorted. The two sand samples are positively skewed (skewed to the right) meaning that they are finer than coarse grains, and have very little concentrations of very fine and very coarse particles making them to be described as platykurtic. Table 8 shows calculated slot widths for each sand and gravel combination. Results from Table 8 shows that combining gravel sample G2 and sand sample S1 provided the best sand control capability depicted by the smallest slot width of 1.425 mm implying that the gravel G2 aggregates have the highest probability to control sand. It can also be inferred from Table 8 that gravel G2 performed better than the gravel sample G1. A combination of gravel sample G1 and sand sample S2 gave the worst results as it relates to sand control depicted by a higher value of slot width (3.874 mm) which will permit the intrusion of sand particles into the well if used for practical purposes. Combinations of gravel sample G1 and sand sample S1, and gravel sample G2 and sand sample S2 provided fairly positive results. This indicates the effectiveness of gravel G1 which is locally sourced in sand control by gravel packing.

5. CONCLUSION

Based on the results obtained in this study, the following conclusions were made.

a. Sieve analysis is a practical and easy way to determine particle size distribution of sand and gravel aggregates to aid in sand control by gravel packing.
b. The sand samples obtained showed that the samples were medium fines.
c. The gravel packing curves showed that larger gravel sizes resulted to larger slot width. Therefore, the size of gravel aggregates directly affects the slot width for gravel pack design.
d. Larger slot width sizes are not recommended because they will permit the intrusion of sand into the well bore. Smaller gravel aggregates will hold back more sand than larger aggregates due to larger spaces between each individual aggregate.

It is however recommended to source locally for more gravel types and perform sieve analysis studies on them to determine suitable types of gravel for use in sand control in the Niger Delta. This will minimize costs and create jobs.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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