

Investigating the impact of sieve analysis on the choice of gravel pack design for wells in unconsolidated sandstone formations in the Niger Delta

ABSTRACT

Sand production problems are as old as oil drilling itself. It is argued to be the oldest problem plaguing the oil industry. If the passive methods of sand control of selective and oriental perforations fail, the active methods which involve the chemical and mechanical methods are called into play. Gravel packs have proven to be an effective mechanical sand control technique, therefore for an effective control of produced sands, a good gravel pack design and completion is of great importance. It is important to choose an effective gravel pack design using the formation sand sample analysis data to choose an optimum gravel size and the best screen slot width. When applied in unconsolidated formations as those found in Nigeria, the optimum design from the samples used for the analysis is expected to perform favorably since the formation is loose.

Keywords: Sand Control, Sieve Analysis, Gravel Pack,

1 INTRODUCTION

Sand production mostly occurs in unconsolidated sandstone reservoirs and affects more than 70% of oil and gas reservoirs worldwide [1]. 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. 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 [2]. Sand production is one of the concerns encountered by oil and gas companies during exploration and production from unconsolidated formations.

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 [3]. 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. Failure to implement sand management techniques can result in 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 [3]. 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 [4].

For the past couple of decades, the oil and gas industry 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 [2].

The outcome of exceeding a reservoir's threshold pressure in order to produce at maximum rate from a sandstone reservoir is sand production. When the reservoir pressure exceeds the wellbore pressure, a substantial volume of fluid inflow from the sandstone reservoir occurs. As a result, finding a means to remove sand manufacturing without dramatically affecting output would be desirable. As a result, sand control technologies that reduce sand output without limiting productivity must be implemented. Sand production can be classified as transient sand production, continuous sand production, and catastrophic sand production which is essential in predicting sand production rates [5].

Sand control methods are classified as follows: production rate restriction, mechanical methods, and chemical consolidation. Mechanical sand control methods are the most widely used due to their simplicity and low cost [4] which is the focus of this study. According to [3], the most suitable mechanical sand control methods are standalone screens and gravel packs. Research has 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 [4]. The disadvantage of this method is erosion of the screen causing it to fail in performing its function of sand control. This justifies 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 [6]. It serves two purposes and is installed as a downhole filter to enable maximum fluid production and prevent production of sand. 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. 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 data for selecting a good gravel pack design.

The following three gravel pack design concepts that result in a good design that boosts productivity while reducing sand output were presented by Bouhroum & Civan [7]. The first rule is to keep the majority of the formation sand particles from migrating. 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 through sieve and laser particle size analysis [2]. 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 [8].

One of the most important aspects of gravel pack design is sieve analysis for deciding the proper gravel size [9]. 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 [10].

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 [11]. 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.

Sieve Analysis is a common laboratory procedure used to pick the right size gravel from a formation sand sample. Sieve analysis is 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.

2 Materials and Method

2.1 Materials

In this paper, four different samples (2 sandstones samples and 2 commercial gravel samples) were used and represented in the table 1.

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	Obinze	500
	Sample G2	Company X	500

2.2 Method

The records of the sandstone and gravel analyses were carefully analyzed. The concentration of the different grain sizes is a function of the weights of different weight samples.

The results are tabulated and represented in a graph of percentage percent against sieve sizes.

- i. To get the proportion of aggregate (grain sizes) flowing through each sieve, use equation 1 to compute the percentage retained in each sieve. This is given by equation 1.

$$\% \text{Retained} = \frac{W_{\text{sieve}}}{W_{\text{Total}}} \times 100\% \quad (1)$$

Where W_{sieve} = weight of aggregate in the sieve

W_{total} = total weight of aggregate

- ii. The cumulative percent of aggregate retained in each sieve is computed by adding the total quantity of aggregate retained in each sieve to the total amount retained in the preceding sieves. Subtracting the percent maintained from 100 percent yields the aggregate's cumulative percentage passing. This is given in equation 2.

$$\% \text{Cumulative passing} = 100\% - \% \text{cumulative retained} \quad (2)$$

$$\% \text{Passing} = \frac{W_{\text{Below}}}{W_{\text{Total}}} \times 100\% \quad (3)$$

W_{below} = total mass of aggregate within the sieves below the current sieve, not including the current sieve's aggregate

W_{total} = total mass of all the aggregate in the sample.

2.2.1 Grain Size Statistics

2.2.1.1 Mean

The mean, also called arithmetic mean or average is the central value of a finite set of numbers: specifically, the sum of the values divided by the number of the values.

$$MR = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3} \quad (4)$$

Φ_{16} , Φ_{50} and Φ_{84} are the sizes at the 16th, 50th and 84th percent of the sand sample by weight. It is also measured in phi (Φ) units.

2.2.1.2 Median

The median is the value separating the higher half from the lower half of a data sample

$$M = \Phi_{50} \quad (5)$$

Φ_{50} corresponds to the 50 percentile on a cumulative curve.

2.2.1.3 Standard Deviation

The standard deviation is a measure of how much a group of numbers varies or disperses. A low standard deviation implies that the values are close to the set's mean, whereas a large standard deviation suggests that the values are spread out across a greater range. Sorting is another term for it.

$$SD = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{94} - \Phi_5}{6.6} \quad (6)$$

Φ_{84} , Φ_{16} , Φ_{94} and Φ_5 are the sizes at the 84th, 16th, 94th and 5th percent of the sand sample by weight. It is also measured in phi (Φ) units.

2.2.1.4 Mode

The mode is the grain size with the greatest frequency.

2.2.1.5 Skewness

Skewness measures the degree to which a cumulative curve approaches symmetry and it is presented mathematically by equation 7.

$$SK = \frac{\Phi_{16} + \Phi_{84} - 2(\Phi_{50})}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_5 + \Phi_{95} - 2(\Phi_{50})}{2(\Phi_{95} - \Phi_5)} \quad (7)$$

2.2.1.6 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.

$$KG = \frac{\Phi_{95} - \Phi_5}{2.44(\Phi_{95} - \Phi_{25})} \quad (8)$$

2.2.2 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:

$$C_U = \frac{D_{40}}{D_{90}} \quad (9)$$

- 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.

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. Figures 1 and 2 shows plots of % Passing versus Grain size for samples S1 and S2 respectively.

Table 2: Results on the Sieve Analysis on Sample S1

Sieve Size	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

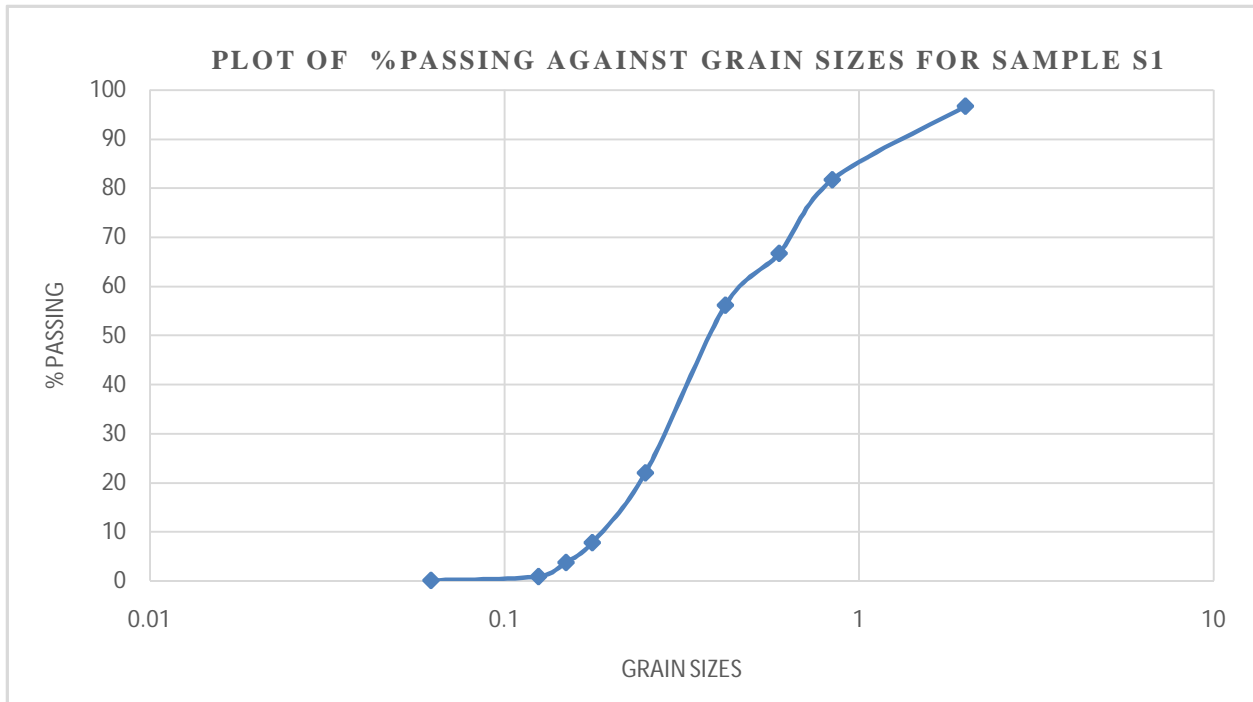


Figure 1: Plot of % passing against grain size for sample S1

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

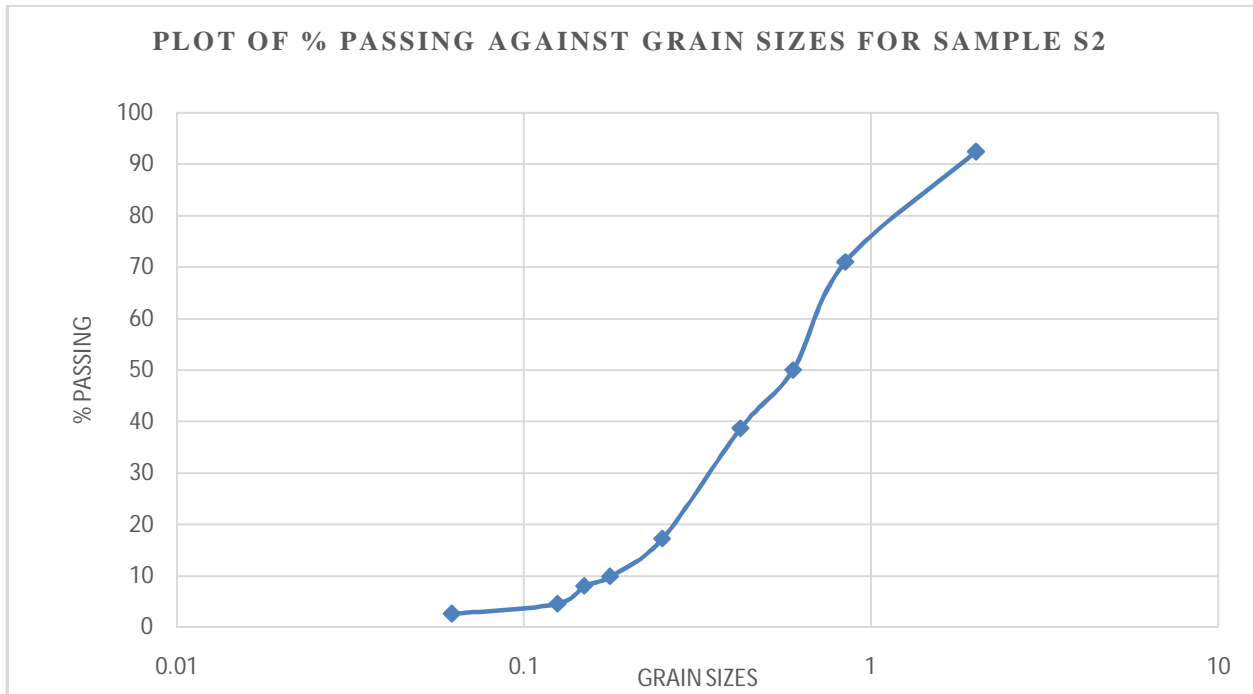


Figure 2: Plot of % passing against grain size for Sample S2

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

3.1.2 Sieve Analysis for Gravel Samples G1 and G2

Tables 5 and 6 shows the Sieve Analysis on Gravel samples G1 and G2 respectively. Figures 3 and 4 shows the plot of % passing versus Grain size for samples G1 and G2 respectively. Table 7 shows the gravel sample analysis for Samples G1 and G2.

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			

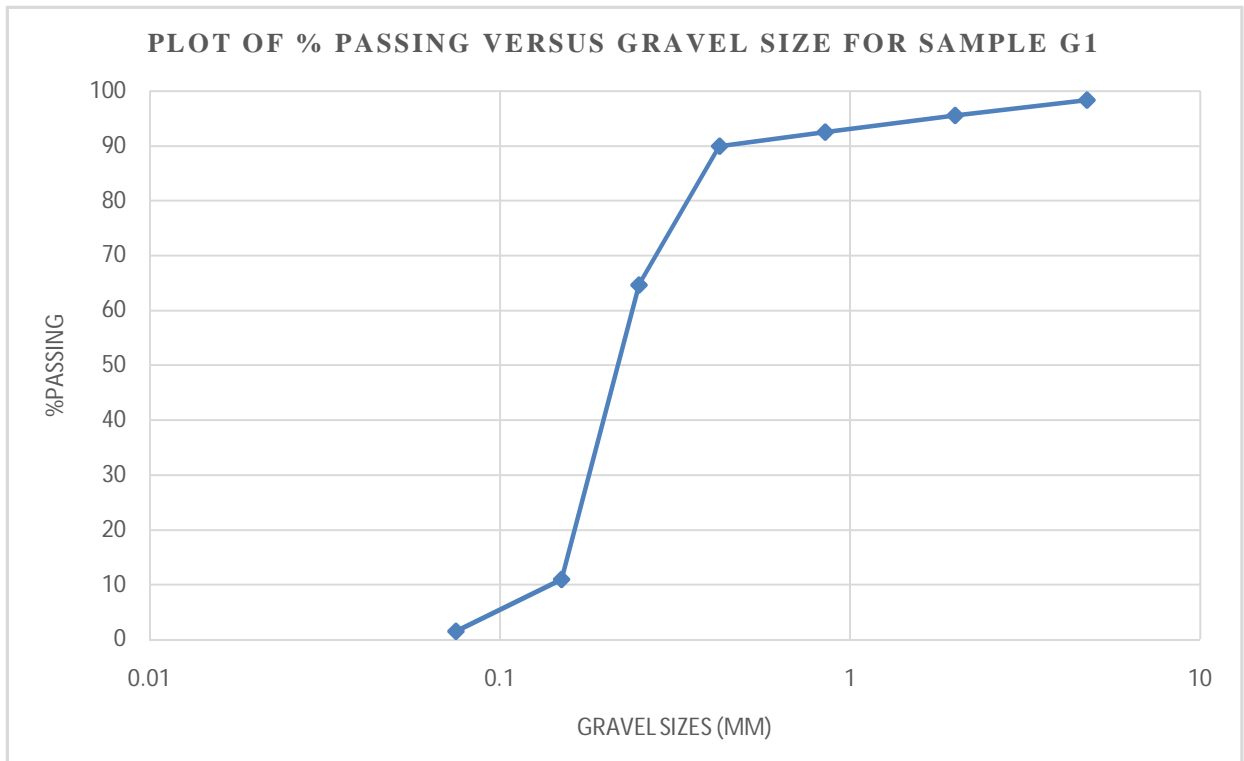


Figure 3: Plot of % passing against gravel size for sample G1.

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			

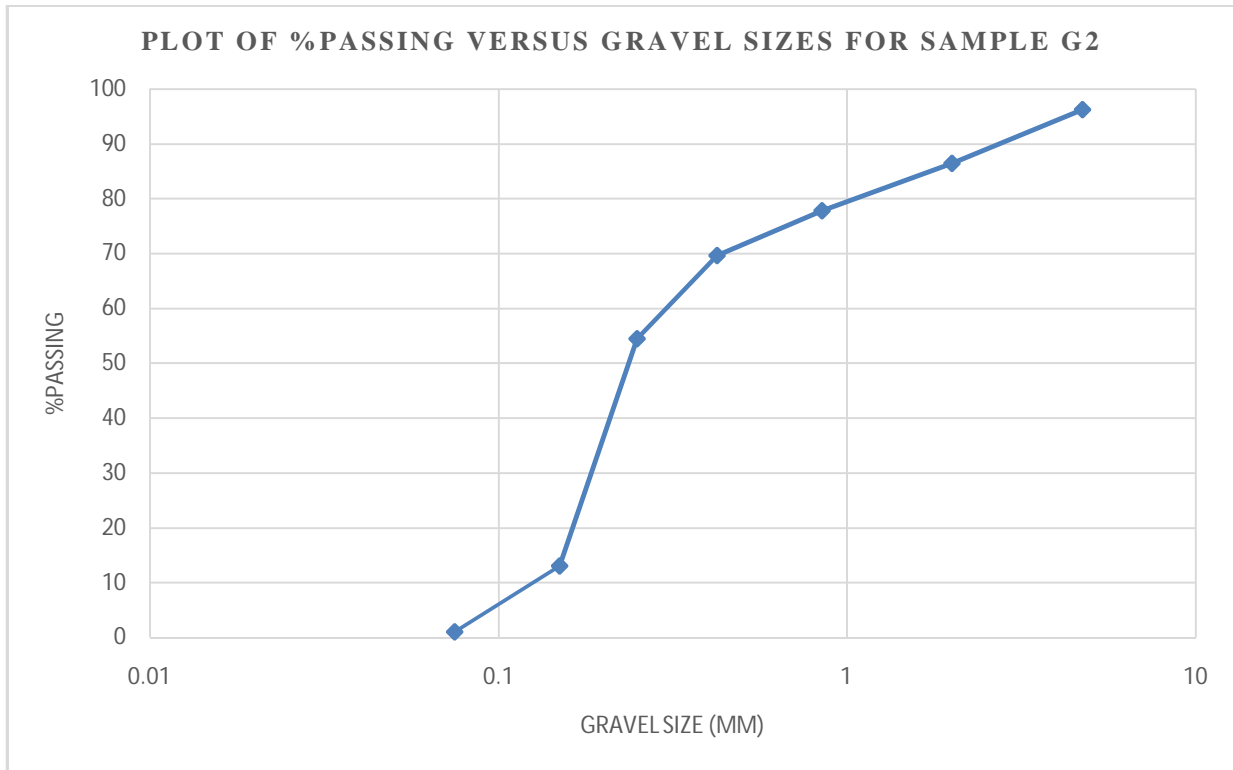


Figure 4: Plot of % passing against gravel sizes for sample G2

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

3.1.3 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 the screen slots.

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

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

3.1.4 Gravel Pack Plot for different Sand and Gravel sample combinations

Figures 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 sample S1 and S2 is 0.388 mm and 0.594 mm respectively.

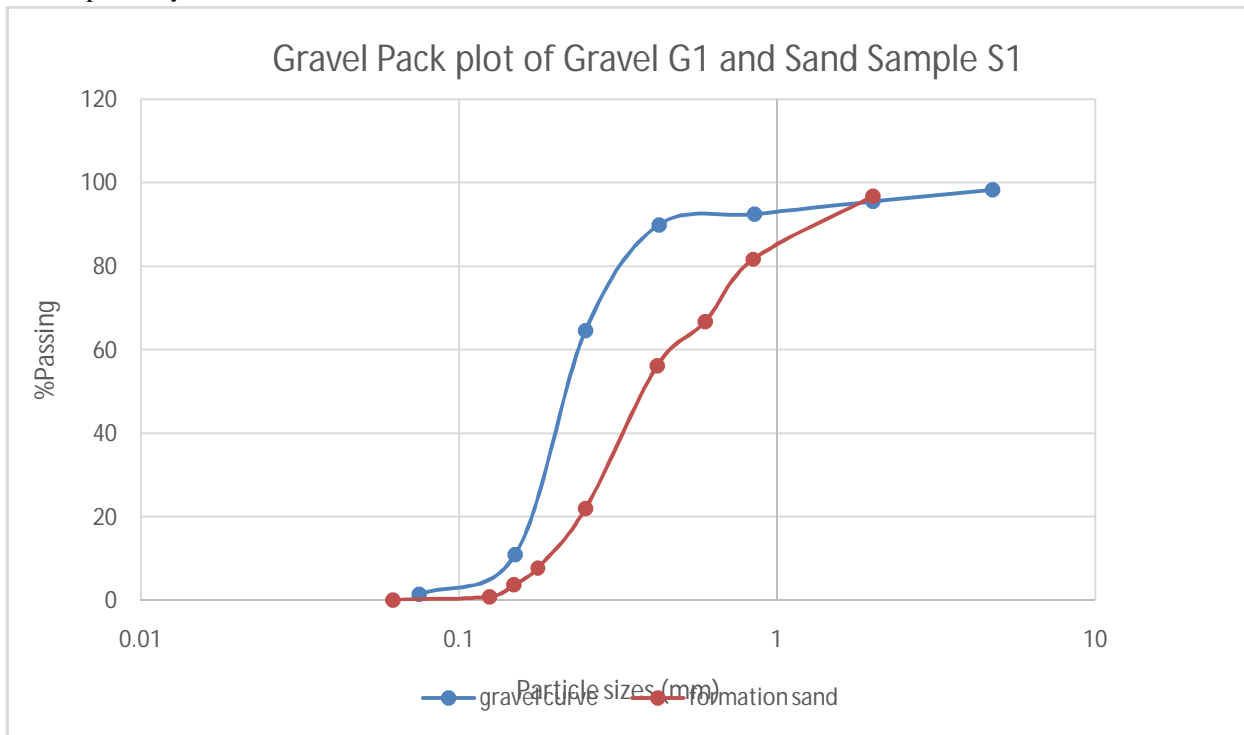


Figure 5: Gravel Pack plot of Gravel G1 and Sand S1

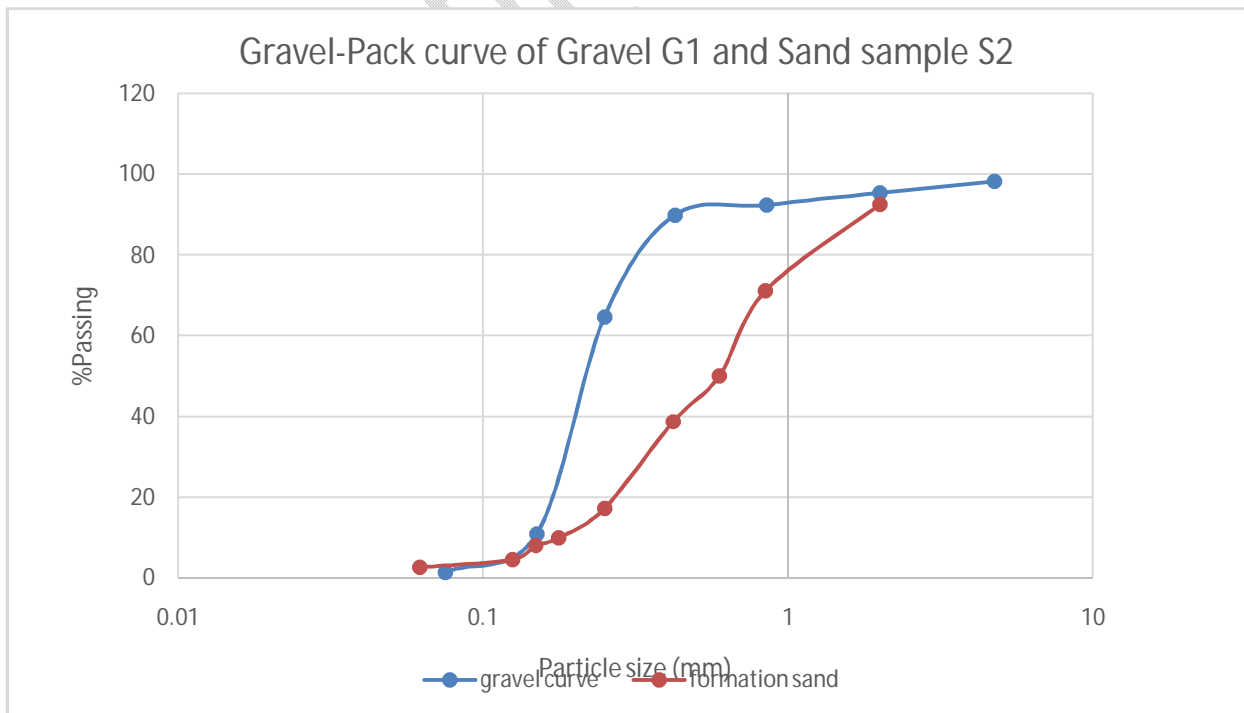


Figure 6: Gravel Pack plot of Gravel G1 and Sand S2

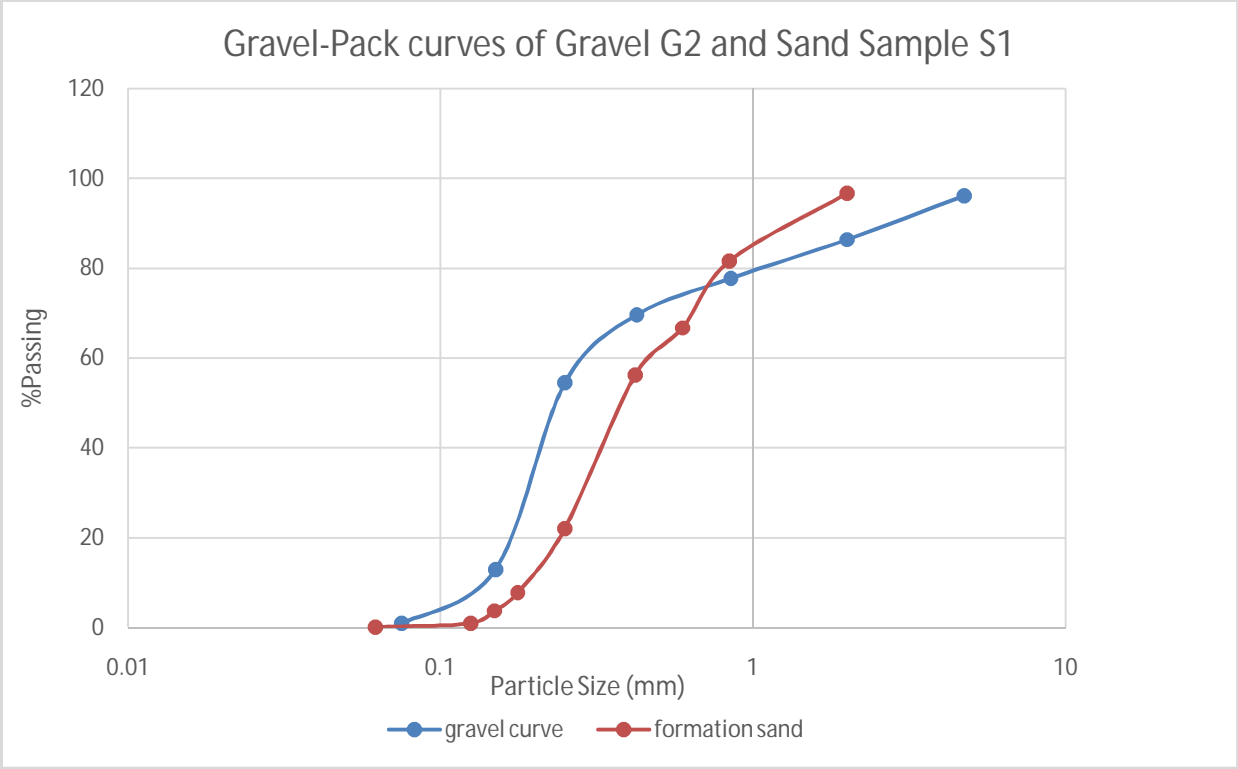


Figure 7: Gravel Pack plot of Gravel G2 and Sand Sample S1

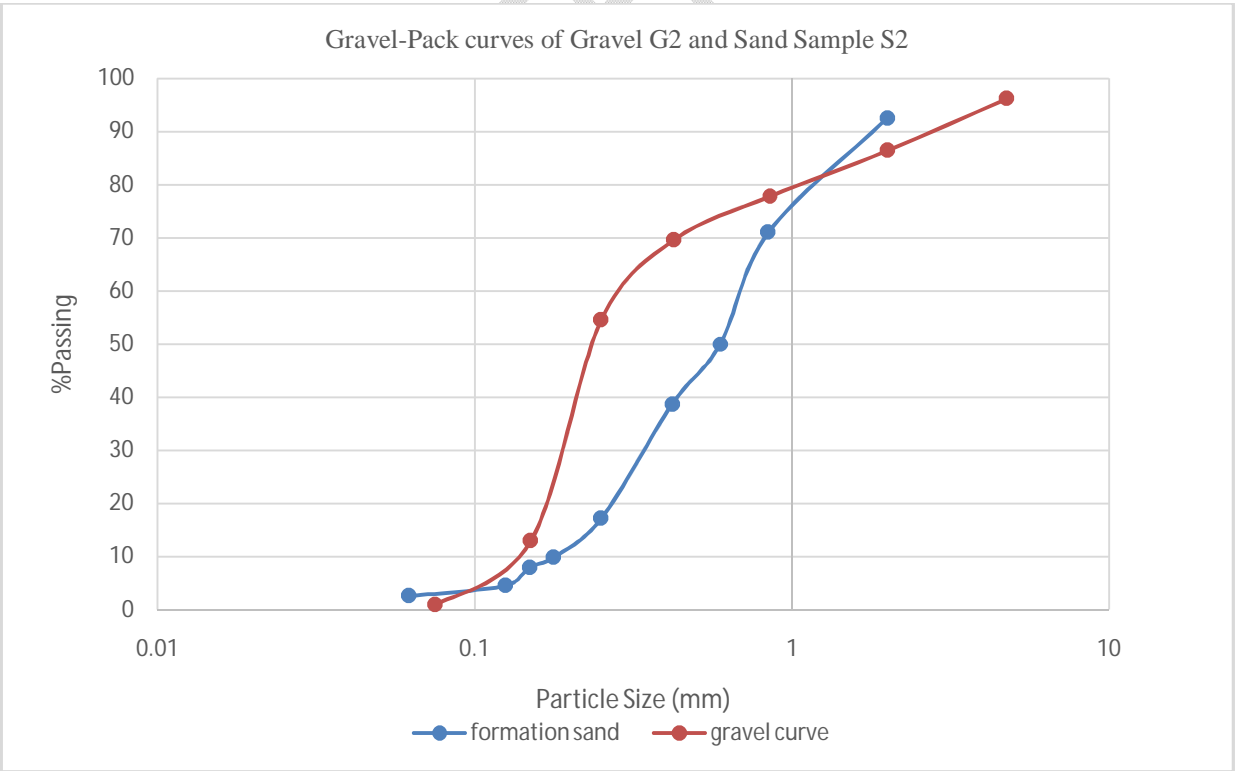


Figure 8: Gravel Pack plot of Gravel G2 and Sand Sample S2

3.2 Discussion

The above plots and results were obtained after the gravel packing curves were plotted for each gravel and sand sample combination. Each sample was alternated for another creating four different combinations of sand sample and gravel samples. Table 9 shows a summary of the results of the gravel packing plots.

Table 9: Table of sample combination, screen slot width and gravel type for each combination

Sample combination	Screen slot width (mm)	Gravel type
G1 + S1	2.530	4/8
G1 + S2	3.870	3/5
G2 + S1	1.425	7/14
G2 + S2	2.181	5/10

The grains of S1 are medium fine while those of S2 are a little coarser, their modes are the same. The median of S1 shows that its medium fine while that of S2 indicated that it's coarser, with their low standard deviations, it showed that they are relatively sorted. They both samples are positively skewed i.e. skewed to the right, meaning that there are finer than coarse grains. They are both platykurtic i.e. there are very little concentrations of very fine and very coarse particles. From the above table, sample combination of Gravel sample G2 and Sand sample S1 provided the best sand control capability. The slot width is the smallest which means that the aggregates of the gravel have the highest probability to control sand. On the other hand, sample combination of Gravel sample G1 and Sand sample S2 gave the worst results as it relates to sand control. The calculated slot width is too large 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. However, this means that sand particles below the slot sizes can be produced whilst producing hydrocarbons.

4 Conclusion

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

- Sieve analysis is a practical and easy way to determine particle size distribution of aggregates.
- The sand samples obtained showed that the samples were medium fines.
- 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.
- 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.

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