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Experimental Work to Study the Behavior of Proppant Inside the Hydraulic Fractures and the Plugging Time

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Abstract

Experiments were conducted to study the behavior of the solid particles (proppant) inside the hydraulic fracture during the formation stimulation, and study the effect of the proppant concentration on the hydraulic fracturing process, which lead to bridge and screen-out conditions inside the fractures across the fracture width that restricts fracturing fluid to flow into the hydraulic fracture. The research also studies the effect of the ratio between the fracture size and the average particles diameter "proppant", on fracture bridging. In this study two ratios were considered β= 2 and 3 ,where $\beta = D_t / D_p$ where: D_t= hydraulic fracture size (width) and Dp=Average particles diameter.

This work presents experimental work to study the behavior of these particles (proppant) inside the hydraulic fractures by measuring the plugging time for different particles concentration for different conditions. The experimental data recorded for different particle concentration and one flowing forces (gravity) inside the hydraulic fracture. Most recorded experimental data obtained were analyzed by using SPSS software.

Introduction

Hydraulic fracturing is a well stimulation method where a fluid is pumped into the rock to create fractures. These fractures are intended to function as high-conductivity fluid pathways enabling increased well productivity [1].

The main goal of the hydraulic fracture treatment is to create a highly conductive flow path for hydrocarbon production.

Hydraulic fracturing is a technique used to stimulate the productivity of a well [2]. Thus the effective permeability of a reservoir remains unchanged by this process. That mean increasing the wellbore radius and increase its productivity, because a long contact surface between the well and the reservoir is created.

Hydraulic fracturing is a technique in petroleum sciences. First applied of Hydraulic fracturing was at 1947 (Hugoton gas field, Kansas) as a new technique to overcome the skin damage. Hydraulic fracturing is used mainly in reservoir stimulation, control of sand production, and other purposes. it has been used to extract gas and oil from shales and other tight reserves economically.

The well treatment by hydraulic fracturing job states that the fracture is approximately perpendicular to the axis of the least stress. Deepest reservoirs, the minimum stress is horizontal [3 and 9].

"A screenout is a blockage caused by Bridging, accumulation, clumping or lodging of the proppant across the fracture width that restricts fluid flow into the hydraulic fracture" [4].

The stimulation treatment (hydraulic fracturing job), ends when the engineers have completed their planned pumping schedule or when a sudden rise in pressure indicating that there is a screenout has taken place [4].

There is problems, that called screenout, can occur during the fracturing job. Screen-outs as defined above happen when a continued injection of fluid into the fracture requires pressure above the safe limitations of the wellbore and surface equipment. This condition happened because of high fluid leakage, high concentration of proppants, and an insufficient pad size that blocks the flow of proppants. As a result of that, pressure rapidly builds up to high value. Screen-out can cause stopping a fracturing job or operation and need to clean the wellbore before resuming fracturing job [5].

During hydraulic fracturing job, engineers need to keep a constant rate for fracture fluid injection during the job. The volume injected includes the additional volume created during stimulation (hydraulic fracturing), and the fluid loss to the formation because of leak- off into the permeable wall of the fracture [6]. However, the rate of leak off during the growing hydraulic fracture tip is extremely high. Therefore, it is not possible to initiate a hydraulic fracture with proppant in the fracturing fluid because the high fluid loss would cause the solid particles (proppant), at the fracture tip to reach the consistency of a dry solid, that lead to bridge and screen-out conditions. For that, using some volume of clean fluid (a pad), must be pumped before any proppant is pumped [4].

By using the down hole microseismic to indicate and control possible hazard during hydraulic fracturing job, i.e. fracture breakthrough to the over and underlying formation, screenout risk during pumping, etc. [7];

The concentrated proppant slurry cause plugging of the hydraulic fracture, and preventing additional growth of the hydraulic fracture length. Additional pumping of the proppant with the fluid slurry into the formation after the screenout happen causes the hydraulic fracture to balloon. For that the fracture going to grow in Width rather than length, and large concentrations of proppant per surface area will be occur in the fracture [8].

Experimental Work

Set the Apparatus to Measure the Plugging Time by using Gravity Force for β= 3

Set the apparatus as shown in Figure 1, using viscose fluid (water + 1.0% Xanthan) which prepare by mixing fresh water + Xanthan for about 30 min and then used, to carry and suspend the particles uniformly inside the cylinder, the particles represent the solid particles (ceramic proppant) from different sources in oil and gas industry.

Gravity was used to force the viscose fluid with the particles, the carrier fluid with proppant through the tube Figure 1 which represent the pore throat or hydraulic fracture were called without shift as a shape name need to study.

Filling the cylinder with the suspension about 450 cc + 27.6 solid% by volume, open the bottom valve of the cylinder to allow flow through the fracture. During the suspension flow through the fracture, digital camera recorded the cumulative weight "gm "in the graduate cylinder set above digital scale, recording the cumulative weight vs. time. This type of experiment is made for 27.6 solids % by volume, for β= 3 (the ratio between the pore throat pipe "fracture size" and the average particles diameter "proppant").

Set the Apparatus to Measure the Plugging Time by using Gravity Force for β= 3 Run No. 2

The second run of experimental is the same as the first one of experiment using gravity force to force the fluid to flow through the fracture, for same particles concentration and for same β= 3 again. During the run the experiment for the second time, there is no difference between the first and second run of experiments in experiment conditions, For the above two runs of experimental, were done at the same time for same concentration and same conditions, noticed that the plugging time "sec" was different and when the experiment was repeated for the third time, also was not similar to the previous two experiments. After that repeat the experiments for about more than 10 times for each concentration to get normal distribution for the plugging time frequency.

For that it is decided to repeat the experiment for about 10 times to check the plugging time if it is the same or not for each run, but noticed that the plugging time is not the same for the same conditions for each run. Figures 2, 3, 4 and 5 represent the relation between the plugging time (sec) and the cumulative weight (gm), for different concentration and β= 3, Figures 6, 7, 8 and 9 illustrate the normal distribution for different concentration.

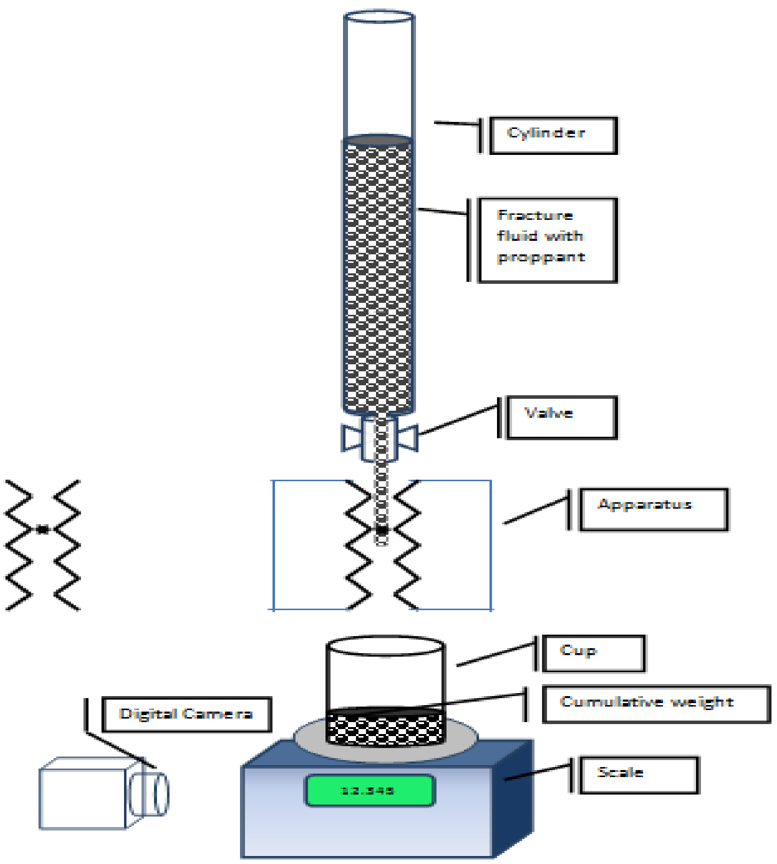

Fig. 1: the shape of the apparatus that used to represent inside the hydraulic fracture ,fracture shape without shift

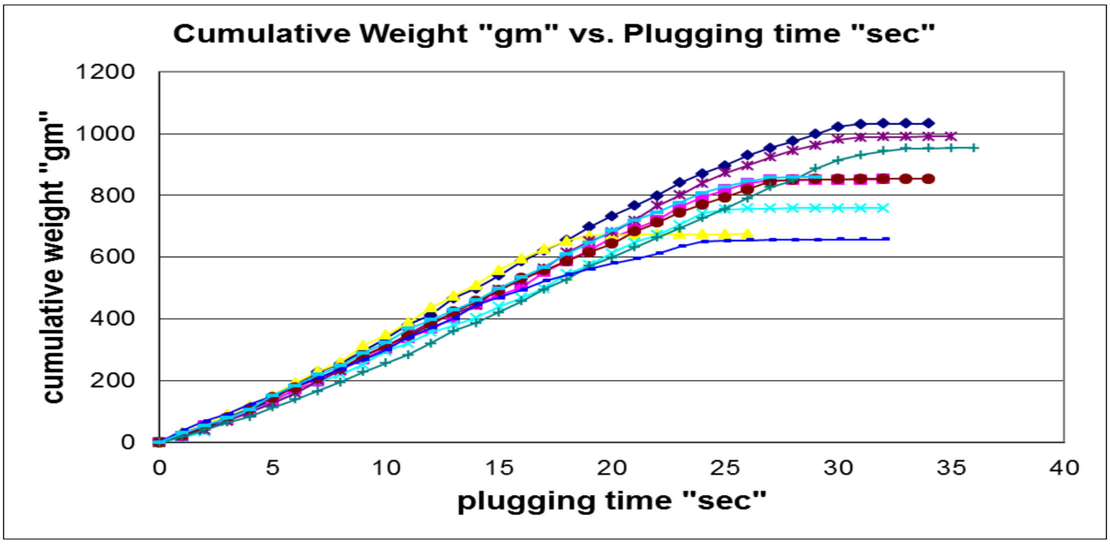

Fig. 2: Relation between the cumulative weight "gm" and the Plugging time "sec", fluid flow by gravity force for β=3, concentration 27.6 % by Volume

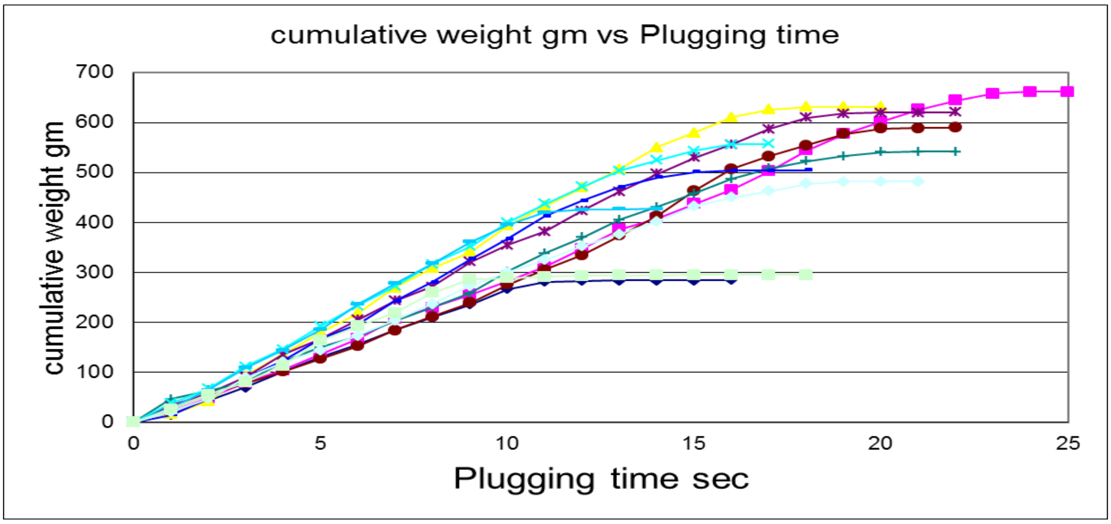

Fig. 3: Relation between the cumulative weight "gm" and the Plugging time "sec", fluid flow by gravity force for β=3, concentration 33.3 % by Volume

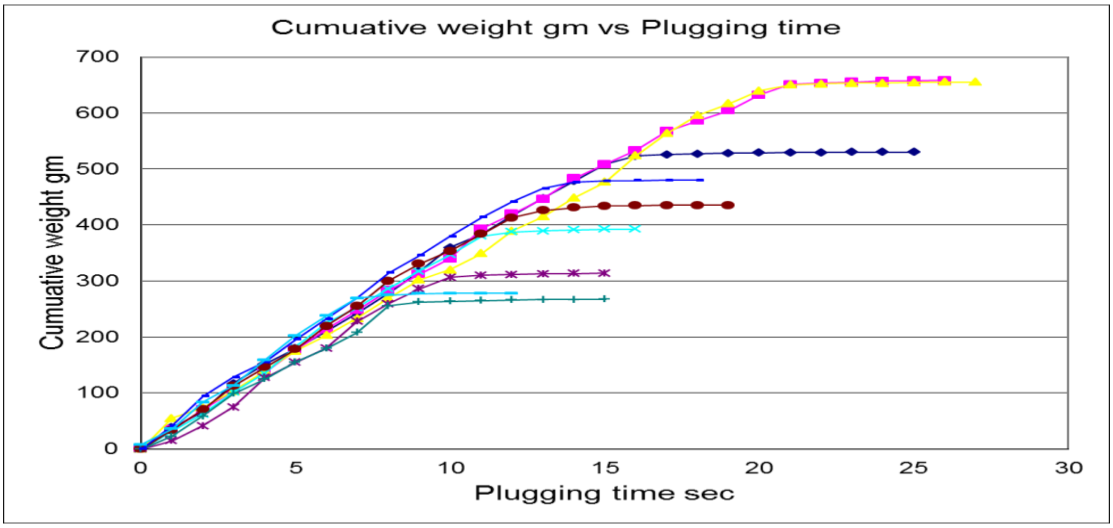

Fig. 4: Relation between the cumulative weight "gm" and the Plugging time "sec", fluid flow by gravity force for β=3, concentration 38.9 % by Volume

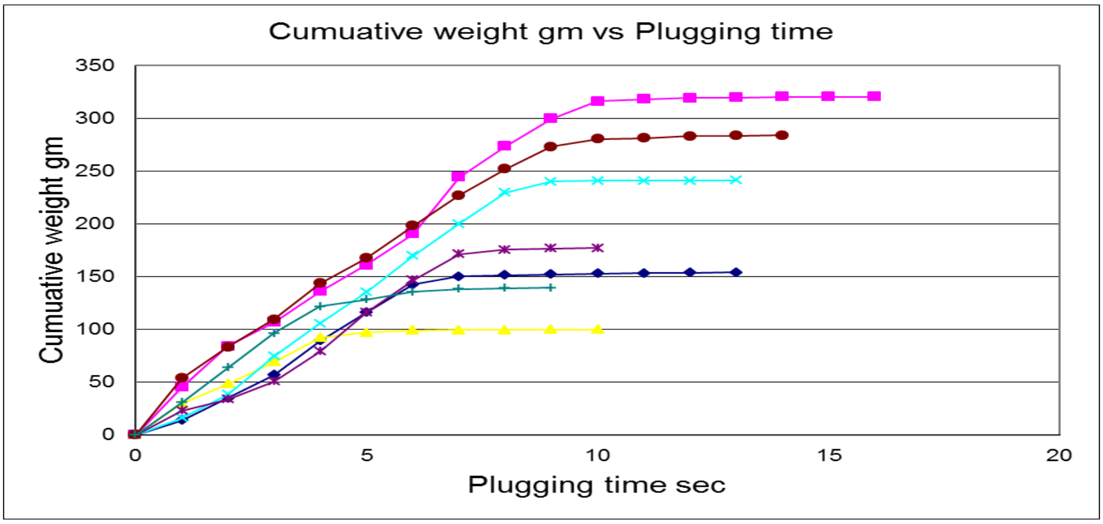

Fig. 5: Relation between the cumulative weight “gm” and the Plugging time “sec”, fluid flow by gravity force for β=3, concentration 44.12 % by Volume

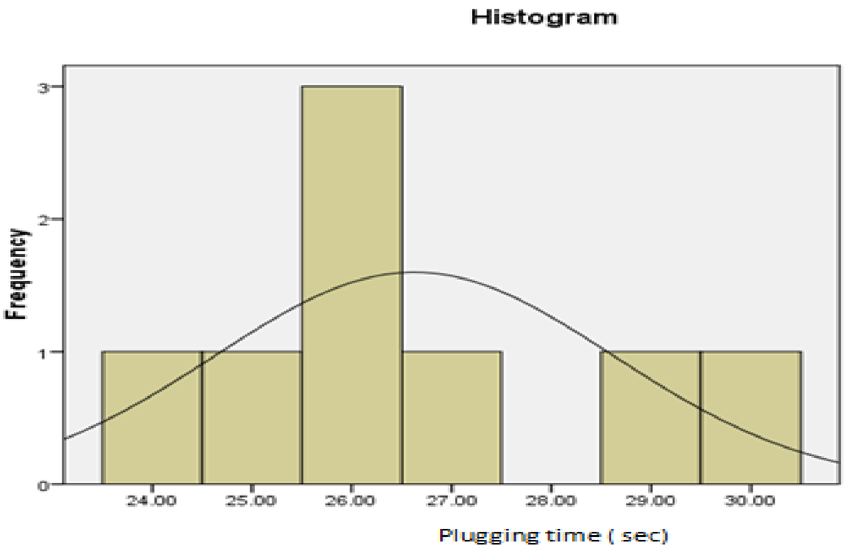

Fig. 6: Normal distribution chart for plugging time “sec” vs. frequency of 27.6 % particles concentration by Volume, β=3

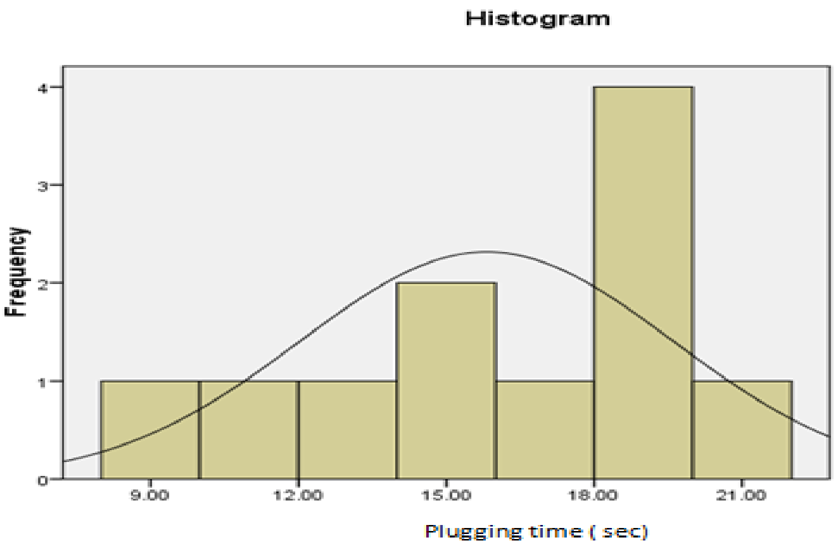

Fig. 7: Normal distribution chart for plugging time “sec” vs. frequency of 33.3 % particles concentration by Volume, β=3

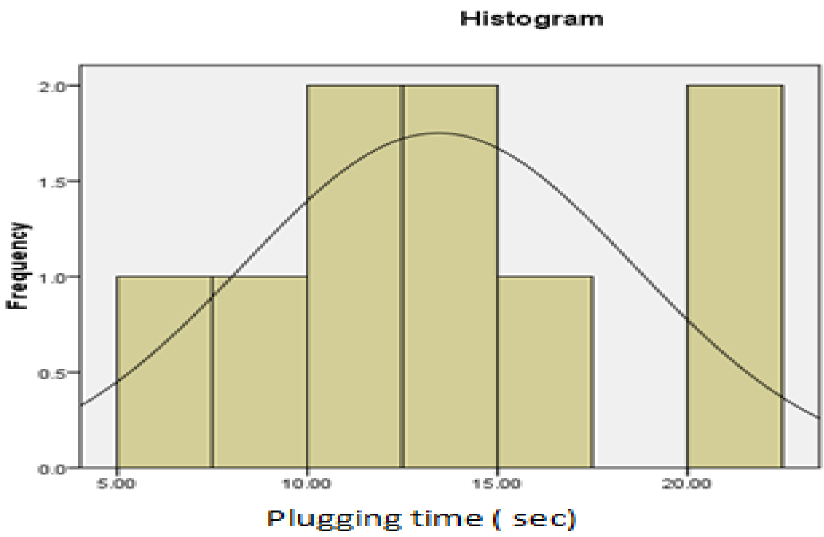

Fig. 8: Normal distribution chart for plugging time “sec” vs. frequency of 38.9 % particles concentration by Volume, β=3

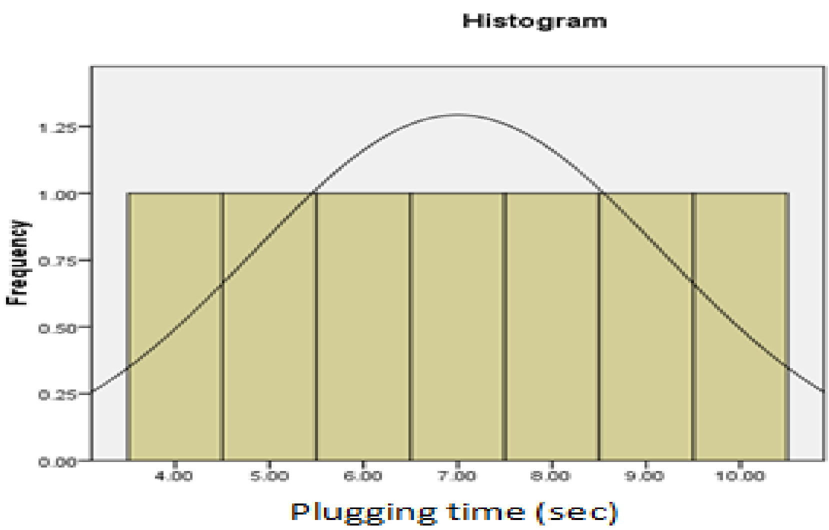

Fig. 9: Normal distribution chart for plugging time “sec” vs. frequency of 44.1 % particles concentration by Volume, β=3

Set the Apparatus to Measure the Plugging Time by using Gravity Force for β= 2

Set the apparatus as shown in Figure 1, using viscose fluid (water + 1.0% Xanthan) which prepare by mixing fresh water + Xanthan for about 30 min and then used, to carry and suspend the particles uniformly inside the cylinder, the particles are represent the solid particles from different sources in oil and gas industry, effectively.

To force the viscose fluid with the particles to flow, gravity was used to flow through the fracture, Figure 1 which represent the pore throat or hydraulic fracture. Fill the cylinder with the suspension about 450 cc + solid % by volume; open the bottom valve of the cylinder to allow flow through the fracture. During the suspension flow through the fracture, digital camera was recorded the cumulative weight “gm“ in the graduate cylinder, recording the cumulative weight "gm" vs. time "sec". This type of experiment is made for different particles concentration (16.8, 21.66, 24 and 29.6) solids % by volume, for β= 2, Figures 10, 11, 12 and 13 represent the experiments, Figures 14, 15, 16 and 17 represent the normal distribution for different concentration.

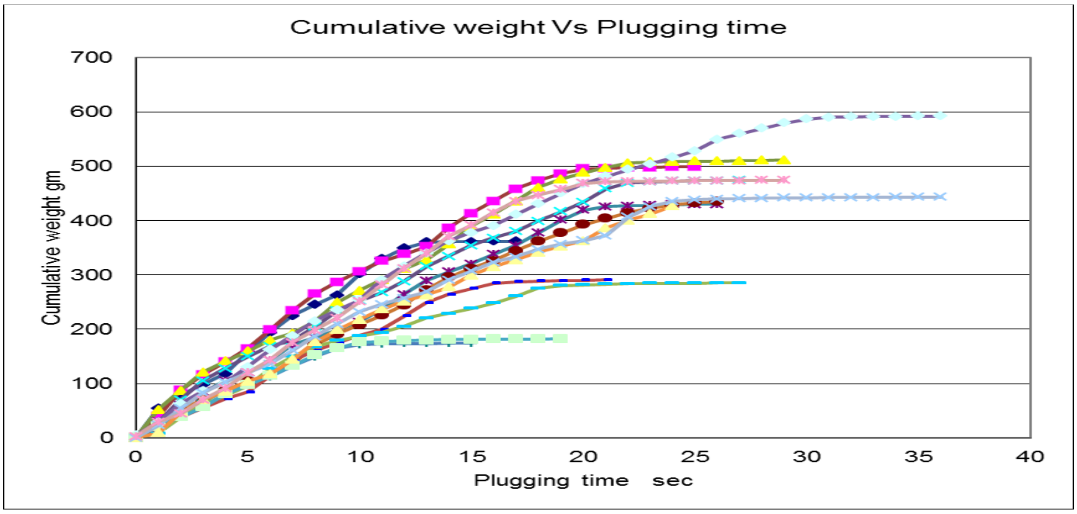

Fig. 10: Relation between the cumulative weight “gm” and the plugging time “sec”, fluid flow by gravity force for β=2, concentration 16.8 % by Volume

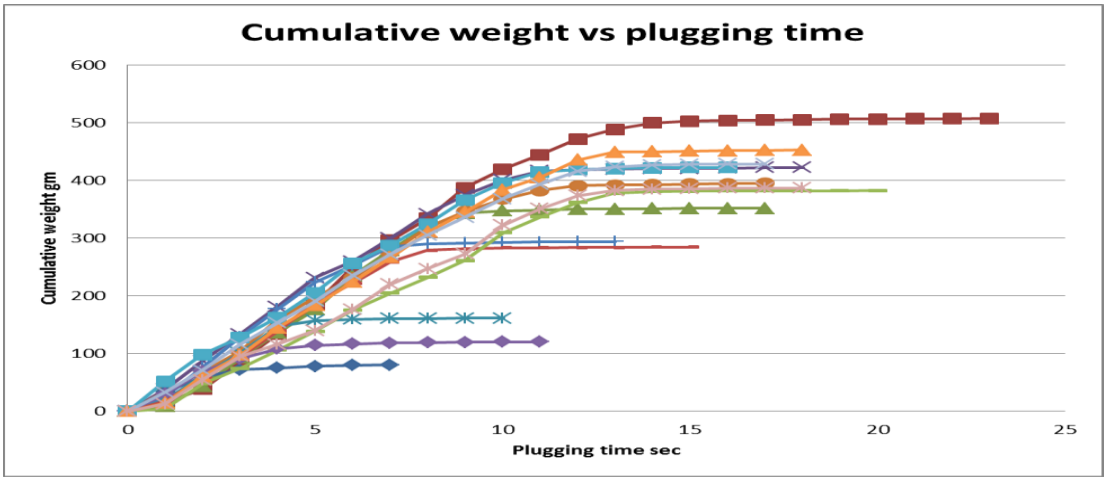

Fig. 11: Relation between the cumulative weight “gm” and the plugging time “sec”, fluid flow by gravity force for β=2, concentration 21.66 % by Volume

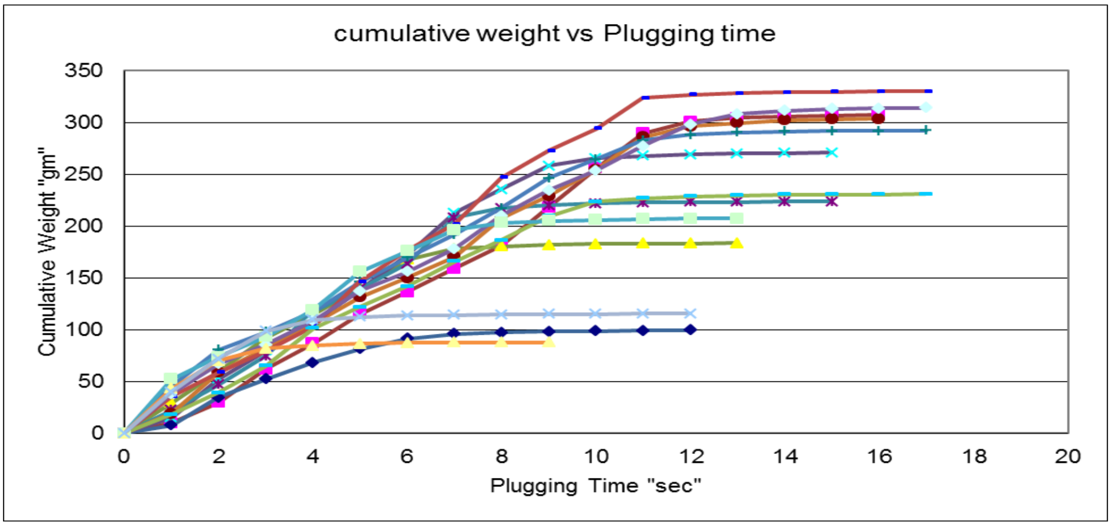

Fig. 12: Relation between the cumulative weight “gm” and the plugging time “sec”, fluid flow by gravity force for β=2, concentration 24 % by Volume

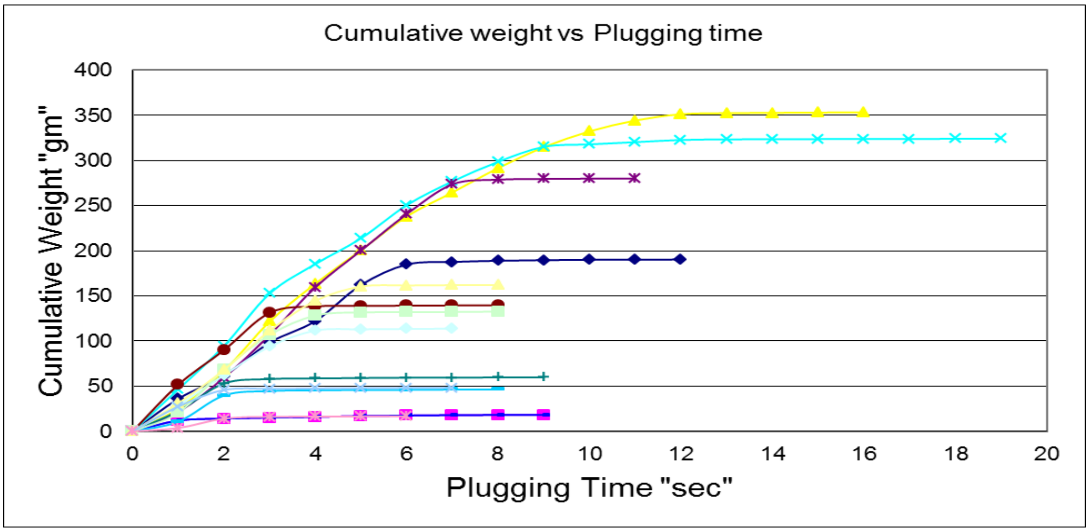

Fig. 13: Relation between the cumulative weight “gm” and the plugging time “sec”, fluid flow by gravity force for β=2, concentration 29.6 % by Volume

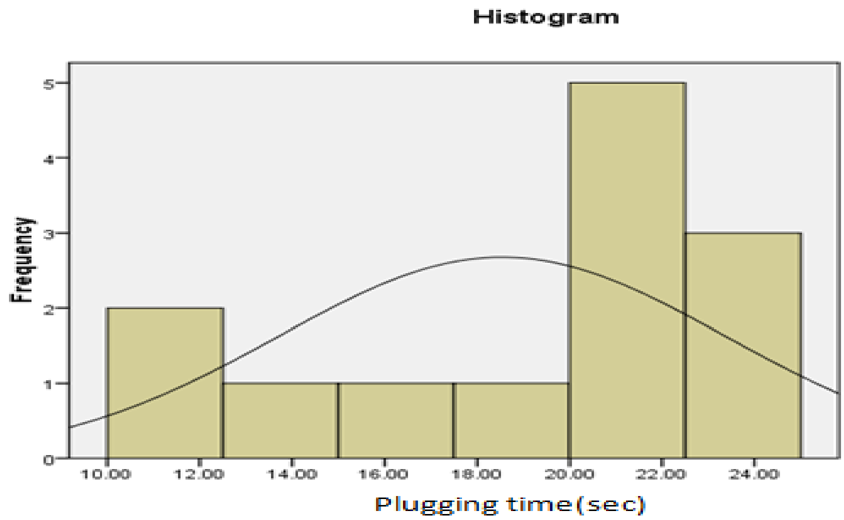

Fig. 14: Normal distribution chart for plugging time “sec” vs. frequency of 16.8 % particles concentration by Volume, β=2

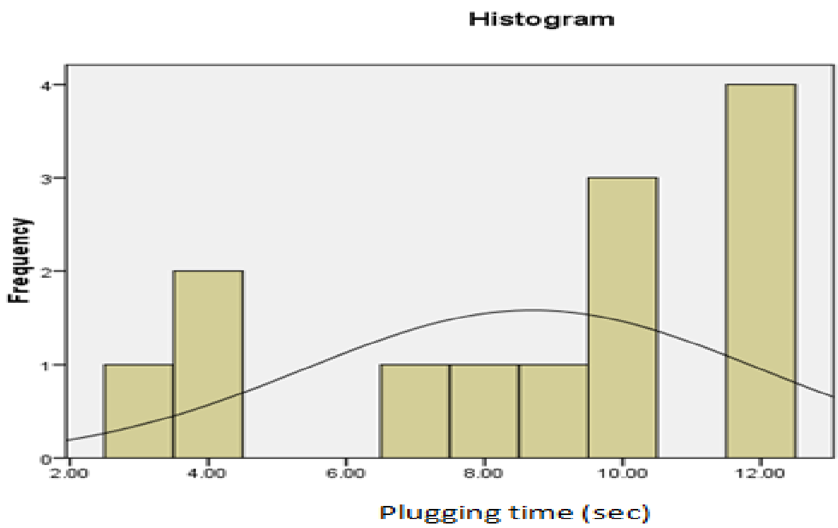

Fig. 15: Normal distribution chart for plugging time “sec” vs. frequency of 21.66 % particles concentration by Volume, β=2

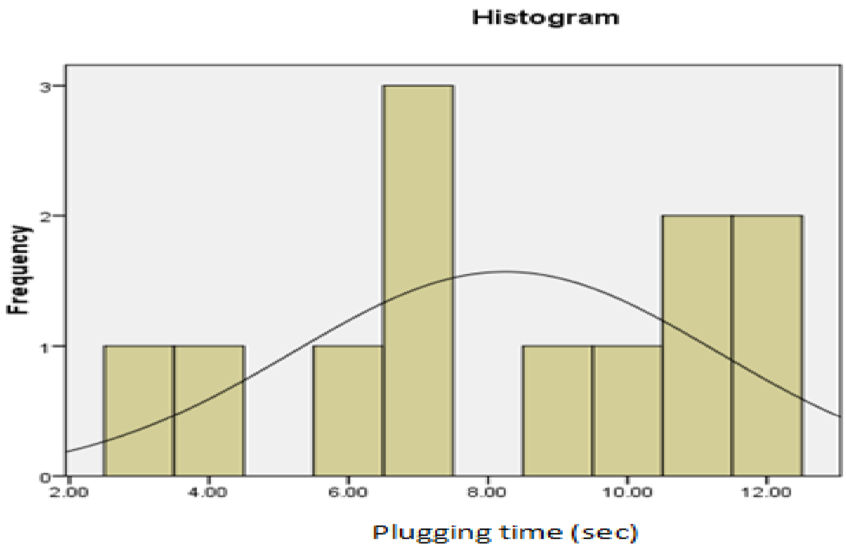

Fig. 16: Normal distribution chart for plugging time "sec" vs. frequency of 24 % particles concentration by Volume, β=2

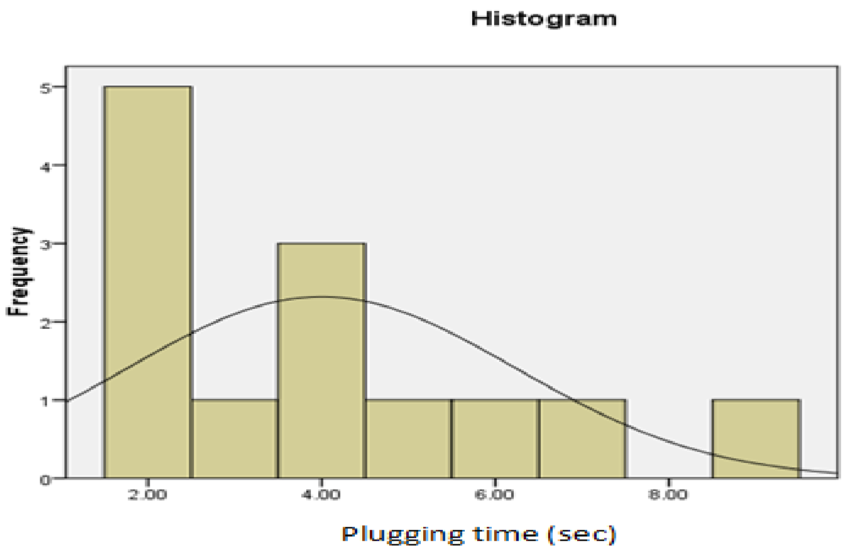

Fig. 17: Normal distribution chart for plugging time "sec" vs. frequency of 29.6 % particles concentration by Volume, β=2

Material Used in this Work

The apparatus designed to meet the fracture or pore throat by using irregular tube representing the pore throat or hydraulic fracture, and the particles represent the solid particles from different sources including water flooding, drilling fluid, perforation, work over, and fracture fluid (viscose fluid) as shown in Figure 1.

Material for Measuring Plugging Time by Gravity Force

Carrier fluid used was prepared form fresh water 450 cc + Xanthan (1.0 %) + Carbo prop (20/40), ceramic proppant, specific gravity =2.76 gm/cm^3, as solid particles. Using 1.0 % Xanthan to get suitable viscosity to carry the particles through the pipe and suspend the particles uniformly inside the cylinder , as shown in Figure 1, and the force to let the viscose fluid to flow was gravity. The ratio between the fracture diameter to average particles diameter was β =3 and 2.

Experimental Results

Plugging Time by Gravity Force Repeated for about 10 Times

These experiments done for the same concentration and conditions for β=3, repeated for 10 time to get the plugging time (screen out).

Using the SPSS software to get the confidence interval for plugging time for each concentration, we can get normal distribution for plugging time.

Figure 2 illustrates the relation between the plugging time and the cumulative weight for solid concentration 27.6% by volume particles concentration, Figure 3 for 33.3% by volume particles concentration, Figure 4 for 38.9% by volume particles concentration, and Figure 5 for 44.1% by volume particles concentration.

We can notice from these figures that for the same condition and for the same concentration the plugging time was different for each run of the experiments. The force used to force the fluid to flow was by gravity.

Plugging Time by Gravity Force

After the experiments were done for about 10 times, for β=3 and the same condition but different concentration and for fracture shape (without shift) Figure 1, to get the plugging time by taking the average value for plugging time for different concentration.

Figures 2, 3, 4 and 5 illustrate the results for the fracture shape without shift for β=3 for various particles concentration by volume percent, and Figures 6, 7, 8 and 9 illustrate the normal distribution for the results for β=3 for various particles concentration % by volume.

For β=2 for the same fracture shape for different particles concentration we can see the results in Figures 10, 11, 12 and 13 without shift represent the results for the relation between the plugging time (sec) vs cumulative weight (gm), and Figures 14, 15, 16 and 17 illustrate the normal distribution for different particles concentration solid % by volume.

Analysis of the Data

Data Results from Plugging Time Measurement by using Gravity Force and β=3

We can see in Figures 2 through 5 which represent the relation between the Plugging time (sec) vs Cumulative weight (gm), that the plugging time represented by the sharp deflection in the curve for each of the concentrations (27.6, 33.3,38.9 and 44.12) % by volume. These plugging time correlated with the concentration % by volume and get the correlation for different concentration % by volume, as shown before, using the gravity force to allow the suspension to flow through the fracture Equation 1 and Figure 18, and the R^2 =0.9808, exponential relation between the concentration and the plugging time for β=2

$$y=203.35\ e^{-0.075x} \qquad \dots(1)$$

Where: y= plugging time “sec”, x=concentration of the particles in the suspension % by volume.

Data Results for Plugging Time Measurement by using Gravity Force Repeated for each Concentration when β=2

Using the SPSS software to analyze the results gotten for the different runs of experiments. The experiments were repeated because of the results of the plugging times were varied when the experiments were repeated for the same concentration and same conditions, because the plugging times depend on the probability of the particles to be in the same place at the same time. For that the experiments were repeated for about 10 times to get normal distribution for the frequency of the time vs. the plugging times "sec", Figures 6, 7, 8 and 9 represents the normal distribution of 27.6, 33.3, 38.9 and 44.12% by volume particles concentration. Analyzing these data by SPSS getting 95% the confidence interval of plugging times Table 1, we can see from Table 1 that the plugging time for 27.6% by volume of particles concentration, the plugging time between 24.95 – 28.29 sec, that what we call it confidence interval of the plugging times with 95% correct and 5% error.

Table 1 represent the results from analyzed data, for 33.3, 38.9 and 44.12 respectively, using the SPSS software to get the confidence interval and the mean value of plugging time for each concentration with 95% correct and 5% error.

Table 1: represent confidence interval for different β and concentration % by volume

Plugging time (sec) conditions		95% Confidence Interval for Mean	
B	concentration	Lower Bound	Upper Bound
3	27.6	24.9567	28.2933
3	33.3	13.2721	18.3643
3	38.9	9.5041	17.3848
3	44.12	5.0021	8.9979

The mean value of the plugging times "sec" from the results illustrated in Figure 10 represents the relation between the solids concentration % by volume and the plugging time for β=3.

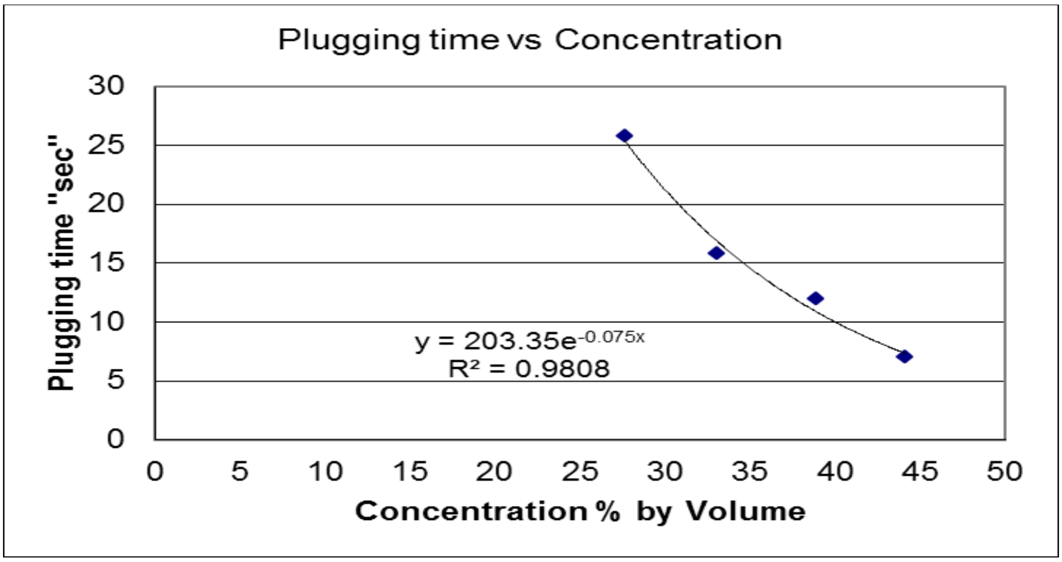

Fig. 18: The relation between the concentration % by volume and the plugging time "sec", the flow by gravity, β=3 , without shift

Also using the SPSS software to analyze the results gotten for the different runs of experiments for β=2. The experiments were repeated because of the results of the plugging times were varied when the experiments were repeated for the same concentration and same conditions, the results with the set of conditions for β=2 because the plugging times depend on the probability of the particles to be in the same place at the same time. For that the experiments were repeated also for more than 10 times to get normal distribution for the frequency vs. the plugging times "sec", Figures 10 through 13 represents the relation between the plugging time "sec" and the cumulative weight "gm" each figure represent the same condition repeated more than 10 times to get the confidence interval for the plugging time sec. Figures 14, 15, 16 and 17 represents the normal distribution of 16.8, 21.66, 24 and 29.5 solids % by volume particles concentration. Analyzing these data by SPSS getting 95% the confidence interval of plugging times Table 2, we can see from Table 2 that the plugging time for 16.8% by volume of particles concentration is (15.61 21.46) sec, that what we call it confidence interval of the plugging times with 95% correct and 5% error.

The mean value of the plugging times "sec" from the results illustrated in Figure 19 represents the relation between the concentration % by volume and the plugging time for β=2.

Table 2 represent the results from analyzed data, for 16.8, 21.66 , 24 and 29.6% respectively, using the SPSS software to get the confidence interval and the mean value of plugging time for each concentration with 95% correct and 5% error.

Table 2: represents the confidence interval for different β and concentration % by volume

Plugging time (sec) conditions		95% Confidence Interval for Mean	
B	concentration	Lower Bound	Upper Bound
2	16.8	15.6130	21.4639
2	21.66	6.7128	10.6718
2	24	6.3129	10.1871
2	29.6	2.6488	5.3512

Table 3 list the values of R– square, and the equations for different conditions (proppant concentration, plugging time (sec) and β).

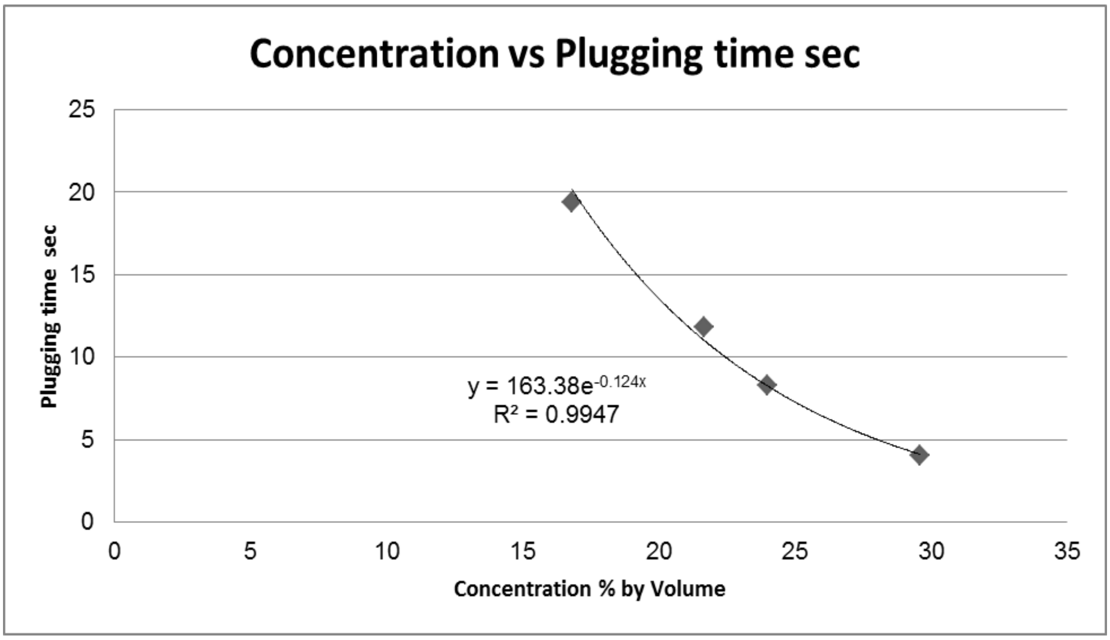

Fig. 19: The relation between the Concentration % by Volume and the plugging time "sec", the flow by gravity, β=2 , without shift

Table 3: represent the values of R –square and the equation

experiments No.	Fracture shape	β value	R^2	Correlation	Figure No.
1	Without shift	3	0.9808	$y = 203.35e^{-0.075x}$	18
2	Without shift	2	0.9947	$y = 163.38e^{-0.124x}$	19

Conclusion

The two Figures 18 and 19 above, illustrates that the region below the curve line that indicate the conditions for non-screen out whereas the region above the curve indicate the screen -out region, because of that fracture engineer need to avoid the conditions above the curves and make an optimization between the fracture width, proppant concentration and the proppant size for success fracture job.

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