Controlling sand production from porous media for crude oil recovery

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ABSTRACT *The excessive sand production in oil wells causes impedance to crude oil production, damages downhole and surface tools and cut short economic producing life. The production of sand with crude oil is an old age problem in unconsolidated formation found worldwide. The sand ingression problems may be encountered at an early stage in some of the moderately consolidated formation suffering from high water cut production. The formation threshold pressure exceeding withdrawal rate in oil wells accelerates the untimely sand flow into the well. The gravel packing method of sand control creates in-situ blockage to the sand movement or across the perforation interval. The crude oil productivity of sand control wells may be sustained with placement of varying sized gravels in the vicinity of the wellbore that offer high conductivity channels for the well fluids to pass through it with partial or complete stoppage to the sand movements. In the present study, the porous media which are a part of Upper Assam oil field were analysed to evaluate its formation strength and to identify the sand delivering probability with cumulative production. The study also undertakes series of sieve analyses for the determination of gravel sizes considering Saucier means and other in place oil field practices for containing the sand movement into the well.*

Keywords: *sand ingression, water cut, unconsolidated formation, gravel pack, grain size*

1. Introduction

The sand associated produced well fluid causes internal damages to the downhole and surface completion as well. The functioning period of oil wells becomes short in absence of timely measures to contain the problem of sand movement to the wellbore. This is one of the frequently encountered problems in oil wells. The sand control measures i.e., mechanical and chemical are able to bring back the production state to such oil wells. However, sometimes gravel packing (mechanical) based sand control measures fail to yield high productivity because of the use of sub-standard materials and improper placement of gravels during sand control job. The shallower unconsolidated sandstone formations are primary sufferer of the sand movements due to the pore pressure depletion and failure to overcome the increasing formation stress with time. Worldwide studies by researchers at different times and their findings based on study by self and predecessors find that 70%-80% of the world reserves are from sandstone reservoirs which faces lowering of formation strength in comparison to increasing formation stresses with time resulting from actions viz., tectonic activity, pore and overburden pressure effect, drag forces draining tendency of sand grains and drilling activities on the formation or porous media. The shutting off sand movement across the perforation interval by limiting the production rate might put adverse effect on productivity of oil wells [1,2,3]. The enhancement of sand control well's productivity depends on the type of method (chemical/mechanical) selected to produce from unconsolidated formations. Researches find that study methods followed in the determination of uniform co-efficient, (C) and gravel sizes selection to be placed downhole for sand control (Gravel packing) by scientist's viz., Karpoff-Saucier-Halliburton, Schewartz, Coberly, Hill, Wagner, Gumpertz are not-uniform or standardized [4,5].

The problem of sand ingression in high water cut wells is a matter of concern for the oil wells producing under water drive mechanisms. The premature water breakthrough, declining formation strength and absence of in-place mechanism for early detection of sand free threshold pressure converts the sand production to be of severe nature with time. However the cause of sand ingression varies well to well. The threshold pressure delivery rate of oil wells is usually non-economical which makes the E&P industries often reluctant to comply with. Mechanical gravel packing is the widely practiced method of sand control in some oil fields of the Upper Assam basin. The mechanical measures include a list of techniques using gravel for cased and open hole and downhole screens placement to form physical barrier around the vicinity of the wellbore. The placement of the gravel and its size determinations with respect to the formation sand impacts the post gravel job productivity of the oil wells. The flow paths generations through the gravel sands i.e., the gravel pack permeability for the well fluids to pass through it to reach the wellbore were studied by several scientists. The gravel packing method of sand control is given priority to deal with the sand ingression problems because of its longer durability to contain the sand movements over chemical consolidation methods [6].

The determinations of sonic travel time, porosity of the porous media and its compressive strength are done to identify the type of formations viz., strong (<50 sec, <20%Φ, >1100 psi), moderate (50 to 90 sec, 20 to 30% Φ, 400 to 1100 psi), weak or unconsolidated (>120 sec, >30% Φ, <400 psi) [4] for sand ingression predictions. This assists in the timely selection of measures to lower down the probability of severe sand effects to arise in such oil wells.

This paper evaluates the strength of the porous medium under study which is a part of Upper Assam basin based on its porosity determination. The porosity of the porous samples were measured through measurement of its grain volumes using TPI-219 Teaching Helium Porosimeter, Coretest systems, INC, USA of Morgan [7]. This follows the sieve analysis of the part of oil producing porous media in order to fix sizes of the gravels to be set to contain the sand movement while facilitating in-situ permeable flow paths for the crude oil to move into the well. In addition, the comparative study of the gravel sizes determination methods for appropriate gravel selection was done to evaluate and understand the performance of the sand control measures to be taken up.

2. Methods

The porous media of depth ranges (X1) 2483m, (X2) 2485.5m, (X3) 2487m, (X4) 2506m, (X5) 2504m were analysed for porosity determination by measurement of its grain volume. In the experimental study, the primary cleaning of the porous medium was done in a Soxhlet apparatus using oil soluble solvents i.e., toluene and methanol mixtures at 50:50 by volume. The solvent mixtures in the round bottom flask of the distillation unit were heated in a mantle at 60^0C. The instrument works on Dean-Stark distillation extraction method to remove water from the pore spaces of the porous media by vaporization process. Following this, the ultrasonic cleaning was carried out passing high frequency ultrasounds of 20-400 LHz to the porous samples for removal of relatively tightly adhering core plug surface contaminants. Each such cleaned sample was then dried in a humidity control oven till the samples became dried under humidity set at 40% for the entire process. The cleaned and dried samples were then put into the TPI-219 Helium Porosimeter Coretest systems for evaluation of the strength of the formation and its potential for sand releasing. After determination of the porosity, the sand grains in each of the samples were disintegrated through a series of procedures viz., pouring each sample into water for acceleration of disintegration of the grains with ease of finger and the relatively tough part with mortar. The procedure was repeated for all the samples belonging to a part of oil producing porous media under study. The wet disintegrated samples were then dried in the Humidity control oven with humidity set at 40% for the process and recorded the initial weights. The dried sand grains weighing 100gms disintegrated from each porous sample were then put separately on the coarsest sieve at top bearing ASTM no. 45(0.35M, 1.5Φ) on the mechanical sieve shaker machine. The sieve machine is driven by an inductor motor of frequency 50Hz, 220/240volts, 2.6 AMPS and 1425 R.P.M rating to provide vibration to the stacked of sieves consisting of the coarsest at the top and finest at the bottom viz., ASTM nos. 60(0.25M, 2Φ), 80(0.177M, 2.5Φ), 120(0.125M, 3Φ), 170(0.088M, 3.5Φ), 230(0.0625M, 4Φ), 325(0.044M, 4.5Φ) arranged in descending sequence. At the end of the analysis, the weights of the retained samples at the sieves were recorded to be used to generate sieve cures for gravel size selections.

2.1 Porosity determination

The determination of the grain volume of the porous media in TPI-219 Helium Porosimeter was done by measuring the system reference and grain volume following Boyle's law and instrument (TPI-219) operating procedures [6]. During the experiment, care was taken while determining the maximum allowable core plug sample height to be inserted within the grain volume chamber cup i.e., 1.5 inch Matrix cup with attached billets. A total of five numbers of 1.5 inch diameter billets volumes ranging from viz., A (7.209163 cc), B (14.40692 cc), C (21.57046 cc), D (28.86337 cc), E (43.41468 cc) and heights (A: 0.6320 cm, B: 1.2630cm, C: 1.8910cm, D: 2.5330cm and E: 3.8060cm) were used for the full cup reference pressure measurements. For the determination of system reference and grain volume in the experiments, series of the system references and cup pressures with billets inside or outside the matrix cup were recorded.

2.2 Sieve analysis

Sieves curves i.e., grain size Vs cumulative weight percentage were plotted for gravel size determination for each of the porous media based on the recorded weights of the sand grains that had been retained in the series of stack of sieves on the sieve shaker machine. Several studies by scientist's viz., Gumpertz, Saucier, Schwartz and Maly suggested different methods for determination of gravel-sand size ratios to provide permeable flow channels in place which are not standardized [5]. In the present study, the uniformity co-efficient (C) i.e., the ratio (D_{40}/D_{90}) was calculated to evaluate the sorting of sand i.e., the uniform, non-uniform and very non-uniform. Based on these results, the selection of gravel sizes to be considered as fit to contain the sand movement were done. In the present study, the findings of the Schwartz and Saucier were considered to select the gravel sizes under the conditions i.e., uniform and non-uniform sand sorting [5]. In addition, the experimental study incorporated the widely practice oil field method of gravel size selection i.e., the smallest and largest to contain sand movement into the wellbore considering 50 percentile points (D_{50}) as the reference grain size diameter.

3. Results & Discussion:

3.1 Porosity

Table 1 below shows the results of the porosity values of the representative core plug samples received from a part of Upper Assam oil field, obtained through laboratory investigations with TPI-219 Helium Porosimeter, Coretest Systems of USA. In the experimental study, the porosity (Φ) values obtained in the analysis are found to be within the ranges of 16.65% to 23.21%. The results find the formation strength to be as strong and at strong to moderately state of consolidations [4]. It is obvious that the layers i.e., close to 30% porosity or more (X3, X4) will deliver sand earlier than other sand producing intervals (X1,X2,X5). The sand breakthrough problems from such porous media with time might become severe due to absence of timely measures to contain the sand ingression. In addition, the probable causes of sand movement for the porous media at its moderate to strong consolidated state of the formation may be due to the dissolution of cementing materials by increasing high volume of water production. In addition, the build up of high well fluid withdrawal rate might raise the drag forces resulting sand production. However, further conclusive study has to be done in this regard considering production history and reservoir analysis to arrive at the cause of the same.

Table 1

Porosity & formation strength determination

Sample ID (depth, m)	**Without core plug sample into the matrix cup**			**With core plug sample inside the matrix cup**	**V_{grain} (cc)= $V_{Billetsremoved}+[(P_{reffull}/P_{cupfull})-(P_{refsample}/P_{cupsample})] x V_{ref}$**	**V bulk (cc)**	**Porosity (%) Φ**	**Strength of formation**
	Pressure data(psi)	**Volume data (cc)**	V_{ref} (cc)=$V_{Billetsremoved}$/ [(P_{refrem}/P_{cuprem})-($P_{reffull}/P_{cupfull}$)]	**Pressure data (psi)**				
X1(2483)	$P_{reffull}$: 92.56	$V_{Billets}$:115.464593	4.14609	$P_{refsample}$:92.40	59.068	73.717	19.87	Strong
	$P_{cupfull}$: 38.53	$V_{Billets}$: 115.464593		$P_{cupsample}$:12.65				
	P_{refrem}:93.10	$V_{Billetsremoved}$: 79.39206						
	P_{cuprem}: 4.32	$V_{Billetsremoved}$:79.39206:						
X2(2485.50)	$P_{reffull}$: 94.23	$V_{Billets}$:115.464593	4.14339	$P_{refsample}$:94.15	56.263	70.315	19.98	Strong
	$P_{cupfull}$: 39.43	$V_{Billets}$: 115.464593		$P_{cupsample}$:11.81				
	P_{refrem}:93.10	$V_{Billetsremoved}$: 79.39206						
	P_{cuprem}: 4.32	$V_{Billetsremoved}$:79.39206:						
X3 (2487)	$P_{reffull}$: 92.46	$V_{Billets}$:115.464593	4.14594	$P_{refsample}$:92.40	54.899	71.449	23.16	Moderate
	$P_{cupfull}$: 38.50	$V_{Billets}$: 115.464593		$P_{cupsample}$:11.12				
	P_{refrem}:93.10	$V_{Billetsremoved}$: 79.39206						
	P_{cuprem}:	$V_{Billetsremoved}$:79.						

	4.32	39206:						
X4 (2506)	$P_{reffull}$: 93.21 $P_{cupfull}$: 38.78 P_{refrem}:93.10 P_{cuprem}: 4.32	$V_{Billets}$:115.464593 $V_{Billets}$: 115.464593 $V_{Billetsremoved}$: 79.39206 $V_{Billetsremoved}$:79.39206:	4.14637	$P_{refsample}$:92.66 $P_{cupsample}$:11.14	54.869	71.449	23.21	Moderate
X5 (2504)	$P_{reffull}$: 94.86 $P_{cupfull}$: 38.63 P_{refrem}:93.10 P_{cuprem}: 4.32	$V_{Billets}$:115.464593 $V_{Billets}$: 115.464593 $V_{Billetsremoved}$: 86.60122 $V_{Billetsremoved}$:86.60122	4.53521	$P_{refsample}$:94.52 $P_{cupsample}$:13.58	66.171	79.388	16.65	Strong

3.2 Sieve analysis:

The Fig. 1 to Fig. 5 present the sieve analysis curves which were plotted based on sand grain sizes study. In this study, the selection of gravel sizes to be used for sand control measure with reference to representative porous medium under study were carried out following Saucier means and D50 reference grain diameter points.

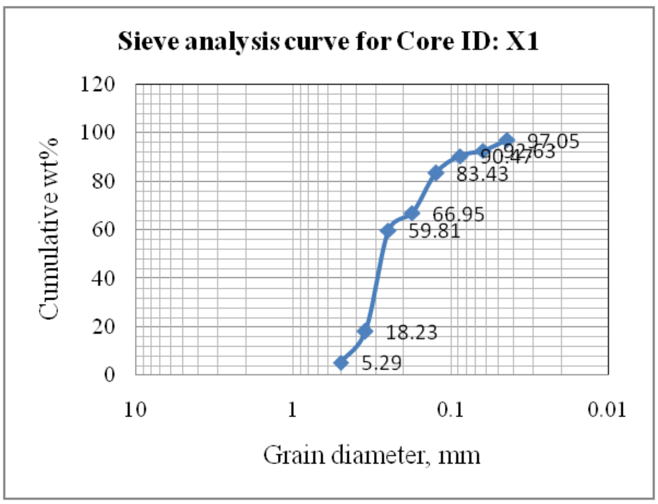

Fig.1. Sieve curve for X1

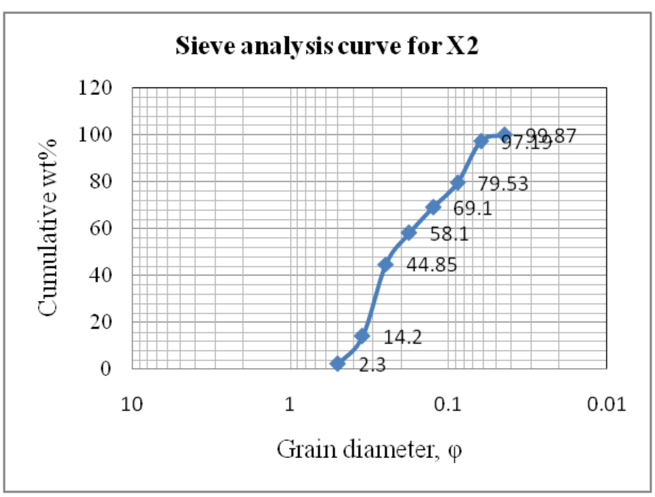

Fig.2. Sieve curve for X2

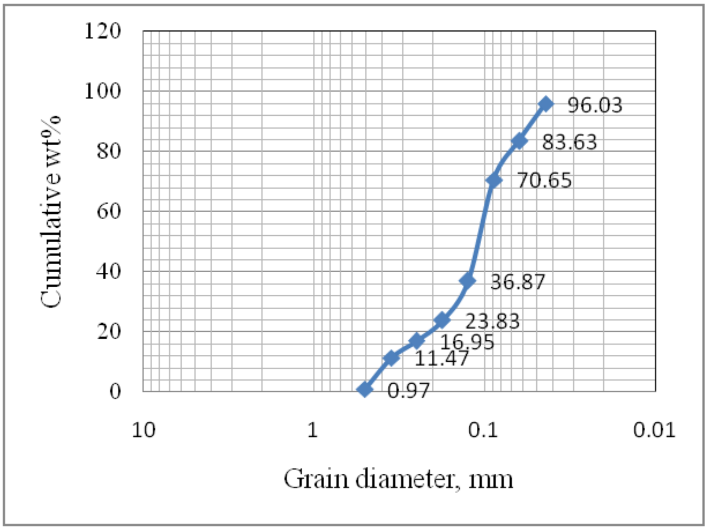

Fig.3. Sieve curve for X3

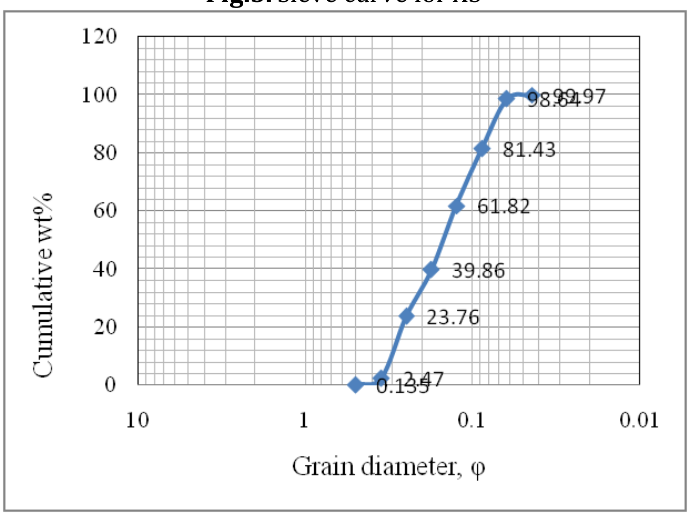

Fig.4. Sieve curve for X4

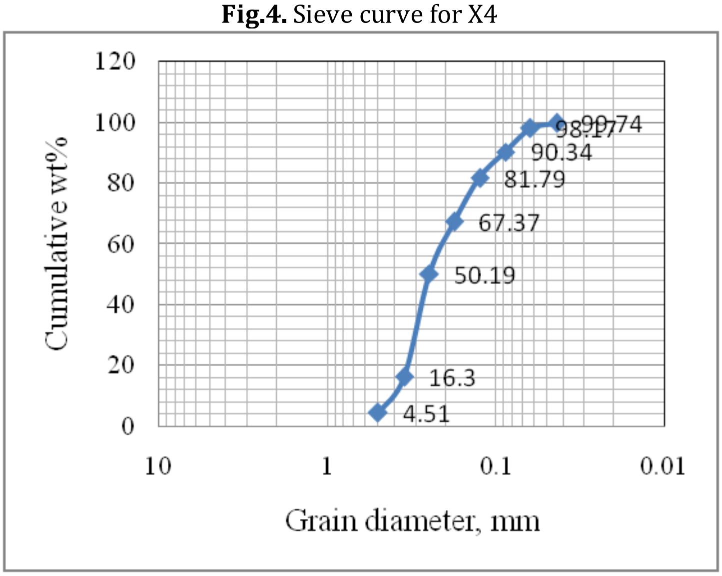

Fig.5. Sieve curve for X5

Table 2: Gravel size determination

Core ID	D_{10}(10 % percentile size)	D_{40}(40 percentile size)	D_{50}(50 percentile size)	D_{90}(90 percentile size)	Uniformity co-efficient, $C=(D_{40}/D_{90})$	Saucier means:			Field practice		
						Sand type (Uniform/ non-uniform)	G-S ratio: D_{10} gravel=6 xD_{10} sand, mm	G-S ratio: D_{40} gravel=6 x D_{40} sand	D_{50} percentile smallest gravel size (4x), mm	D_{50} percentile largest gravel size(8 x)	Screen Slot opening (3/4 times the smallest gravel)
X1	0.429	0.300	0.180	0.091	3.29	uniform	2.574	-	0.720	1.440	0.54
X2	0.380	0.270	0.250	0.092	2.93	Uniform	2.280	-	1.000	2.000	0.75
X3	0.390	0.125	0.137	0.054	2.31	Uniform	2.340	-	0.548	1.096	0.411
X4	0.340	0.184	0.178	0.076	2.42	Uniform	2.040	-	0.712	1.424	0.534
X5	0.441	0.273	0.264	0.090	3.03	uniform	2.646	-	1.056	2.112	0.792

Table 2 shows the selected sizes of gravels for each of the representative porous media i.e., X1 to X5. From the sieves curves in Fig. 1 to Fig.5, it is observed that 10 percentile, 40 percentile, 50 percentile and 90 percentile formation sand sizes are lower than the uniform co-efficient (c) values. This finding infers that the porous medium under study to be of porous and permeable to allow well fluid movement through it. Table 2 shows that based on methodology followed by the researchers for gravel sizes selection i.e., G-S (Gravel-Sand) ratios, the sand control measures would have obvious impact on the productivity of the sand control wells. In absence of standardized method, care should be exercised following trial and error approach to validate the sand gravel sizes to have permeable flow paths available for the well fluids to flow and to contain the sand movements. Inappropriate selection of G-S ratio might impact the productivity of the gravel packed wells through permeability reduction. In the present study the Saucier means and D50 gravel size diameter method were used for comparative evaluation of the G-S ratio to understand its impact on the oil wells productivity. From the results of the Table 2 it is observed that the gravel selected to contain the formation sand following Saucier means is slightly larger in sizes than the gravels selected using 50 percentile reference formations sand grain sizes. In the present study, four (4x) and eight (8x) times of the D_{50} sand sizes were considered to be the smallest and largest gravel sizes (Table 2) for the 50 percentile formation sand grains. Several studies reveal that the 50 percentile reference formation sand size based gravel size selection offer complete stoppage to sand movements into the well. In addition, result analysis (Table 2) infers that the screen slot sizes to contain the gravel movement into the well following 10 percentile grain sizes (Saucier means) would require 3 to 4 times larger slots than the 50 percentile reference based selection.

4. Conclusion:

The sustenance of permeable flow channels that existed for well fluid transportation prior to gravel placement is of prime importance to enhance the productivity of oil wells under sand control measures. The causes of sand breakthrough in excess amount than the allowable at early, late or any stages of crude oil production may vary from well to well. The consolidated formations are less prone to the unwanted and untimely sand influx problems. In the present study the porous media under analysis are found to be in the moderate to strongly consolidated state of the formation. The release of sand grains in the wellbore may be caused by the resulting increasing drag forces due to exceeding threshold pressure driven withdrawal rate of the well fluid. The high water cut suffering porous media results lowering of formation strength with cumulative production in oil wells. The probability of the moderate to unconsolidated formations with 20% to 30% porosity or more has fair chances of sand producing at older stage of producing life. The mechanical sand control measures with placement of varying gravels sizes assist in holding the sands flowing into oil wells. However, it depends on the selection of gravel sizes to enhance the productivity in sand control wells by virtue of in-situ flow paths generation through sand bridging allowing well fluid transportation but partial or complete blockage to the sand movements through it. In the present study, the selection methodology and its comparative evaluation for the gravel sizes to contain the sands flowing through it were done considering Saucier and other known field practices. The laboratory scale gravel size selection experiments were performed with reference to a part of oil producing porous media which is suffering from water cut. The evaluations of the comparative study under Table 2 find that depending on the gravel packed chosen i.e., loose or tight for sand control, the varying state of permeable flow channels settle downhole across the wellbore. In absence of standard uniform methodology for gravel sizes selection, each well has to be evaluated as a separate case of sand control requirement to sustain the permeable flow channels thereby accelerating productivity and longer durability of sand control measures.

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6. References:

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Nomenclature:

Φ: Porosity
C: Uniformity co-efficient
ASTM: American Society for Testing and Materials
G-S ratio: Gravel to Sand ratio
E&P: Exploration and Production