ISSN 1907-0500

APPLICATION OF SIEVE/SCREEN ANALYSIS IN PETROLEUM INDUSTRY, DETERMINE GRAVEL AND SCREEN SIZE TO CONTROL SAND PRODUCTION

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ABSTRACT

The formation sand that produced together with oil and/or gas creates a number of potentially dangerous and costly problem (Losses in production, erosion damage, sand disposal, etc). In petroleum industries which explore and produce crude oil, sieve analysis is used/applied to describe the population of formation sand grain size. Sieve analysis became the accepted method for characterizing both the formation sand and the gravel which to be used to control sand production. Gravel Pack is currently the most used and most successful method of sand control, whereas the screen will holds the gravel in place. The main objectives of this experimental study are, describing the population of formation sand, determine the uniformity coefficient, define the gravel pack size that can minimize and/or stop formation sand movement and screen gauge that be hold the gravel in place.
The experimental study was started by coring job program. Core samples were taken from varies depth of two new wells, well A and well B that located in North Duri Field. Formation sand sample of well A came from the following depth; 521', 547', 601' and 608'. While, formation sand sample of well B taken from; 623', 637', 650', 664', 690' and 710'. Prior to sieve analysis each formation sand samples must be cleaned from any impurities substance by using Soxhlet extraction and Toluene used as solvent. It is then dried, grains separated with a mortar and pestle, being careful not to crush but only to separate individual grains. Then, the sand sample (from core) of known weight is passed through a set of sieves of known mesh sizes.
Based on data interpretations and calculations, we got some conclusions as followed: all of the sand formation samples relatively uniform, indicated by their Uniformity Coefficient (C) less than 5, The proper gravel pack size that can stop and/or minimize sand production is +20– 40 (Comparing Total Pressure drop of varies gravel sizes - Darcy's Law), whereas the screen gauge that used to hold gravel is 12 gauge (0,012 Inch)

Keywords: *Sieve Analysis, Sand Control, Coring, (Soxhlet) Extraction, Uniformity Coefficient, Screen gauge, Particle size distribution, gravel pack.*

ISSN 1907-0500

1. Introduction.

In most practical applications and chemical processing, many solid materials occur in sizes that are too large to be used and must be reduced. Size reduction of solids is most often performed to make them more reactive chemically or to permit recovery of valueable constituents. For instance one of Gold and Silver Mining Industry in Pongkor, required particles which 80% -200 mesh before feeding into extraction plant. or probably, sometimes the product requires separation into size ranges that are most suitable to their subsequent processing. Separation of mixtures of particulate solids according to size may be accomplished with a series of screens with openings of standard size, and the population of mixtured particle fully described by particle size distribution. In petroleum industries which explore and produce crude oil, sieve analysis is used to describe the population of formation sand grain size. Sieve analysis became the accepted method for characterizing both the formation sand and the gravel to be used to control sand production.

The production of formation sand with oil and or gas from sand stone formations creates a number of potentially dangerous and costly problems (Coberly and Wagner, 1938; Suman etal. 1983; Decker and Carnes, 1977). Losses in production can occur as the result of sand partially filling up inside the wellbore. If the flow velocities of the well can not transport the produced sand to the surface, the accumulation sand may shut off production entirely. If shut off occurs, the well must be circulated or the sand in casing must be bailed out before production can resume. Once produced sand is at the surface and no longer threatens to erode pipe or reduce productivity, the problem of disposal remains. Sand disposal can be extremely costly, where environmental regulations require that the produced sand must be free of oil contaminants before disposal. Sub surface safety valves can become in operable, leading to large economic loss and personal hazards. Particularly at offshore and remote locations, erosion damaged surface and sub surface equipment is expensive to replace and valuable time is lost during replacement and repair. Formation damage is another problem associated with wells that produce sand. The possible creation of void space behind the casing can leave the casing and any shaly streaks in the reservoir unsupported. Specifically, the casing can be subjected to excessive compressive loading, causing collapse or buckling.

The objectives of this study are to get a good description of the formation size as whole, and by refer to that description the gravel size is selected which can minimize and/or stop formation sand movement and optimize well productivity by minimizing formation damage. The second objective is to determine the screen liner slot or gauge, based on gravel size that selected.

The main scopes of this experimental study are to get distribution of the population of each formation sand samples which came from different source and/or depth. Particle size distribution data and plot will be used to determine sorting degree or uniformity coefficient (C), grain size at some cumulative level and select gravel size that can minimize and/or stop sand production. Pressure drop or drawdown pressure that is represented as equivalent to a permeability reduction is considered as parameter in gravel size selection. The Screen slot size / gauge will be determined based on selected gravel size.

2. Basic Theory

Gravel packs are currently the most widely used and most successful method to reduce or avoid sand production from unconsolidated formations. Gravel must be sized so that the pore openings between gravel grains are small enough to stop passage of the formation sand. It should also be placed in a dense packing arrangement over the entire completion interval, and must be held in place by screen or liner. Placing gravel around a screen enhances both sand control and productivity of wells as gravel stops formation sand movement. Some of techniques in calculating and selecting the optimum of gravel size that will reduce or avoid produced sand, already performed over the years by many experts. . Sieve analysis became the accepted method for characterizing both the formation sand and the gravel to be used to control sand production. Sieving gives a mass distribution and a size known as the sieve diameter.

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The sieve analysis plot can be used to get an indication of the degree of sorting (Uniformity Coefficient/Uc) in a particular formation sand samples. A sorting factor or uniformity coefficient (Uc) can be calculated as follows (recommended by Schwartz)

$$Uc = \frac{d_{40}}{d_{90}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

Where: Uc = sorting factor or uniformity coefficient
d_{40} = grain size at the 40% cumulative level from sieve analysis plot.
d_{90} = grain size at the 90% cumulative level from sieve analysis plot.

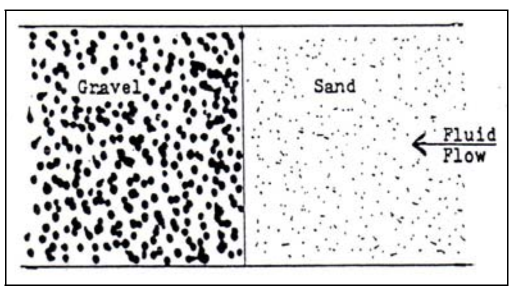
Uc<3 - sand is highly uniform

3<Uc<5 - sand is uniform

5<Uc>10 - sand is non-uniform

Uc >10 - sand is highly non-uniform

The technique most widely used for selecting a suitable sized gravel to control the production of formation sand was developed or recommended by Saucier. **Figure 1** is a schematic of Saucier's experiment on gravel. The tests were done in a linier flow cell with the formation sand in one end and the gravel on the other end. Fluid was flowed through the formation sand into the gravel and the pressure drop through the gravel was measured at various flow rates. Several ratios of gravel to sand sizes were tested.



*Ref: William Ott,P.E., Sand Control Technology, 1996

Figure 1: Saucier's Experiments

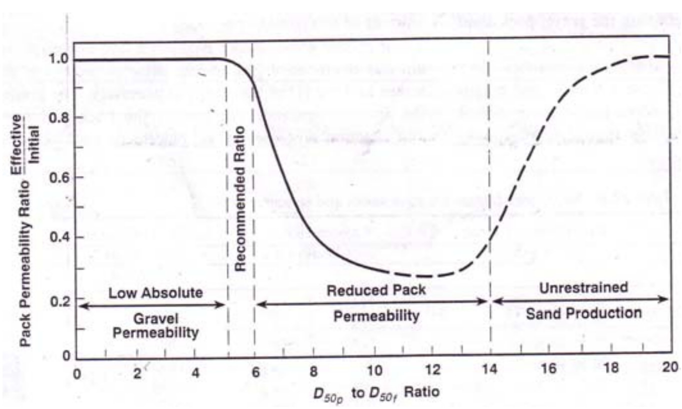


Figure 2: Saucier's Experiments Results

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The final results of Saucier's experiment are shown in **Figure 2**. No reduction in pack permeability was measured up to median gravel/sand ratios of 5.5; but above a gravel/sand ratio of 6,5, invasion into the gravel caused the permeability ratio to decrease significantly. Above a gravel/sand ratio of 14, the formation sand was not stopped at. This indicates that gravel/sand size ratio between 6 and 14 should stop sand movement but yield low production rates from gravel packed wells.

Saucier recommended the median grain size of gravel be less than six times larger than the median grain size of formation sand. Most design recommendations today use this criterion. In practice, the recommended gravel size is determined by multiplying the median grain size of the formation sand (from a sieve analysis) by four to eight, and using the next smaller commercially available gravel.

$$D_{50} = (4 \approx 8)d_{50} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where
D_{50} = Median gravel size / 50% cumulative weight (Inch)
d_{50} = Median sand size / 50% cumulative weight (Inch)

The commonly available gravel commercially are shown in **Table 1**,

Gravel Size (in.)	U.S. Mesh Size	Approximate Median Diameter (in.)	Approximate Median Diameter (µm.)
0.006 x 0.017	-40 +100	0.012	300
0.008 x 0.017	-40 +70	0.013	330
0.010 x 0.017	-40 +60	0.014	350
0.017 x 0.033	-20 +40	0.025	630
0.023 x 0.047	-16 +30	0.035	880
0.033 x 0.066	-12 +20	0.050	1260
0.039 x 0.066	-12 +18	0.053	1340
0.033 x 0.079	-10 +20	0.056	1410
0.047 x 0.079	-10 +16	0.063	1590
0.066 x 0.094	-8 +12	0.080	2020
0.079 x 0.132	-6 +10	0.106	2670

Table 1: Commonly Available Gravel Commercially

The table unit convertion for particle size from Inch to mesh is attached as **attachment 1**, and in this study U.S. Mesh standard is used.

Since the permeability of gravels are so high compared with formation sands, their effect on productivity will be negligible. Using too large gravel will increase permeability significantly, however, will permit invasion of the formation sand into the gravel and result in lower permeability (often to less than the native reservoir's permeability), restricted productivity, and increase draw dawn pressure /Pressure drops. Pressure drop is represented as equivalent to a permeability reduction, and in this study, pressure drop used as one parameter to select proper gravel size.Darcy's law was used for calculating total pressure drop around well bore. . The pressure drops in cased hole gravel pack completion type will be occurred in some place around the well bore; through formation reservoir, outside pipe (gravel – sand interface), perforation tunnels and inside pipe/casing.

2.1. General Darcy's Equation

For laminar flow in packed beds shows that the flow rate is proportional to Δp and inversely proportional to the viscosity μ and length ΔL. This is the basis for Darcy's law as follows for purely viscous flow in porous media.

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$$v = \frac{q}{A} = -\frac{K}{\mu}\frac{\Delta p}{\Delta L} \qquad \text{.....................} \quad (3)$$

Where v is superficial velocity based on the empty cross section in *ft/s*, q is flow rate *B/d*, A is empty cross section in ft^2, μ is viscosity in cp, Δp is pressure drop in psi, ΔL is length in ft, and k is permeability are often given in Darcy or in millidarcy (1/1000 Darcy). This equation is often used in measuring permeability and pressure drop / drawdown pressure of underground oil reservoirs.

The most common geometries in the petroleum industry are linier and radial.

2.1.1. LINEAR FLOW

Linear flow systems are ones where the flow is in only one direction. That is, in a Cartesian coordinate system, flow occurs either in the x-direction, y-direction, or z-direction only. Physically, these systems include propped fractures, perforation tunnels, filter beds (such as sand bridging in production tubing), and others. The simplest form of Darcy's law for a linear, horizontal system is given in equation (4).

$$q_L = \frac{1.127\,KA\Delta P}{\mu L} \qquad \text{.....................} \quad (4)$$

Where, q_L = fluid flow rate at reservoir conditions, res bbl/day
A = cross sectional area for flow, ft2
K = permeability, darcies
μ = fluid viscosity, cp
L = the horizontal distance over which ΔP occurs, ft
ΔP = pressure drop in direction of flow, psi

2.1.2. RADIAL FLOW

The other major geometry of importance is radial flow. Fluids flow from a large outer radius to a smaller inner radius. In this case, the cross sectional area varies with location. This geometry handles general reservoir situations, as well as production situations such as gravel packing and well bore damage. Again simplest form for radial, horizontal flow is given in equation (5).

$$q = \frac{7.08KH(P_2 - P_1)}{\beta\mu \ln(r_2 / r_1)} \qquad \text{....................} \quad (5)$$

For well productivity calculations, points 1 and 2 are usually replaced with the wellbore and the drainage radius, respectively. This substitution leads to equation (6).

$$q = \frac{7.08KH(P_r - P_{wf})}{\beta\mu \ln(r_e / r_w)} \qquad \text{.....................} \quad (6)$$

D.D. Sparlin recommended the average permeability of radial flow from a large outer radius (formation sand) to a smaller inner radius (gravel pack)

$$K_{avg} = \frac{\ln(\frac{r_e}{r_w})}{(\frac{1}{K_g})\ln\frac{r_g}{r_w} + (\frac{1}{K_r})\ln\frac{r_e}{r_g}} \qquad \text{.....................} \quad (7)$$

Production rate of fluid that flow through gravel pack is:

$$q_g = \frac{7.08h(P_r - P_{wf})}{\beta\mu(\frac{1}{K_g}\ln\frac{r_g}{r_w} + \frac{1}{K_r}\ln\frac{r_e}{r_g})} \qquad \text{.....................} \quad (8)$$

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So, the productivity ratio of initial production rate (with out gravel) to production rate with gravel, formulated as followed:

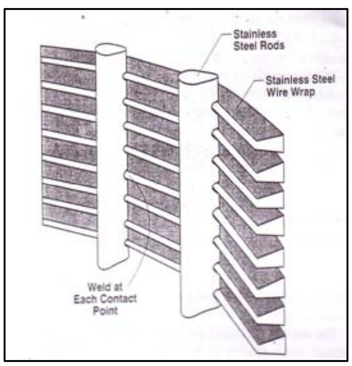
$$\frac{q_g}{q} = \frac{\ln(\frac{r_e}{r_w})}{K_2(\frac{1}{K_g}\ln\frac{r_g}{r_w} + \frac{1}{K_r}\ln\frac{r_e}{r_g})} \quad \text{.....................} \quad (9)$$

Where: q_g = Gravel – Production rate, B/D
q = Production rate without gravel, B/d
H = Depth, ft
β = Formation Volume Factor, = 1, 0220 RB/STB
K_g= Gravel permeability, md
K_r= Reservoir permeability, md
r_g = radius gravel in place, ft
r_e = Drainage radius, ft
r_w = well radius, ft

2.2. SCREEN SELECTION CRITERIA

Manufacturers or wire wrapped screens express the space between the wires in units of 0.001 in., which is referred to as the gauge of the screen. The correct screen gauge is chosen according to the grade of the pack sand that the screen will have to retain. Since 100% retention of all the pack sand is essential during all phases of well life.

The smallest pack sand grains are represented by the highest mesh number in the grade designation. The spacing between the wires should be 0.5 to 0.9 times the diameter of the smallest pack sand grains. (**Figure 3**)



*Ref: Cole, R.C., and Ross, C., Halliburton Energy Services

Figure 3: Details of Well Screen Wires Slot Relative to the Vertical Rods

3. Methodology

The experimental study was started by coring job program. Core samples were taken from varies depth of two new wells, well A and well B that located in North Duri Field. Formation sand sample of well A came from the following depth; 521', 547', 601' and 608'. While, formation sand sample of well B taken from; 623', 637', 650', 664', 690' and 710'. Prior to sieve analysis each formation sand samples must be cleaned from any impurities substance by using Soxhlet extraction and Toluene used as solvent. It is then dried, grains separated with a mortar and pestle, being careful not to crush but only to separate individual grains. Then, the sand sample (from core) of known weight is passed through a set of sieves of known mesh sizes. The Soxhlet extraction and set of vibrated sieve/screen are illustrated in **Figure 4** and **5.**

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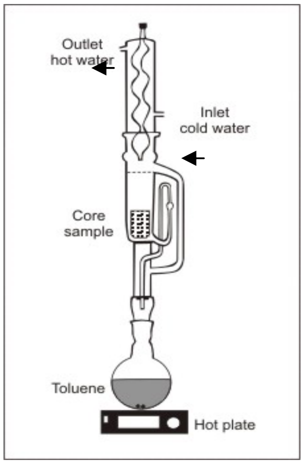

Figure 4: Soxhlet Extraction

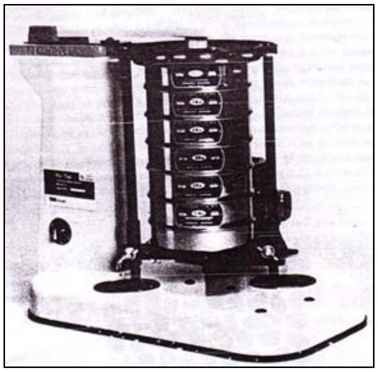

Figure 5: Ro-Tap Sieve Shaker

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3.1. CONSTANT PARAMETERS AND ASSUMPTIONS

- Single phase fluid flow: Oil
- Commercial gravel permeability (darcy)
- Constant Parameters

Depth (H)	ft	334
Gradient Pressure	psi/ft	0.433
Tubing/casing pressure (P_{tf})	psi	20
Reservoir Pressure (P_r)	psi	260
Drainage Radius (r_e)	ft	442.913
Length of interval (h)	ft	80
# of shots	4 spf	320
% of opened perforation	%	50
holes	$Inch^2$	0,5
Perforation Diameter (D_{perf})	ft^2	0,0035
	Inch	12
Well Diameter (D_w)	ft	1
	Inch	6
Well radius (r_w)	ft	0,5
	ft	2
Length of Gravel that past the		
borehole	ft	5
Diameter gravel in place (D_g)	ft	2,5
Radius Gravel in place (r_g)	Inch	6-5/8 or 6,625
Screen Outside Diameter (D_s)	ft	0,55
	Inch	3,3125
Screen Radius (r_s)	ft	0,276
	Inch	10-3/4 or 10,75
Casing OD (D_c)	ft	0,896
	Inch	5,375
Casing radius (r_c)	ft	0,448
	mD	1600
Permeability (K_f)	Deg.	20,5
Specific Gravity, Oil (Sg)	API	150
Viscosity (μ)	cP	35
Porosity (□)	%	

Table 2: Constant Parameters

Detail description about those constant parameters (assumptions) are illustrated and attched as **attachment 2.**

for selecting a suitable sized gravel to control the production of formation sand, initially started by creating particle size distribution curve for all formation sand samples (group by Well A, Well B, Well A+B), each of group separated into Max, medium and minimum particle, to get fully desriptions about distribution range of formation sand size of each group. Then, determining the grain size of every 10% cummulative weight (d10, d20, d30,etc) and calculate degree of sorting, multiplying the median grain size (d_{50}) of the formation sand by four to eight to get description about ranges of gravel size being used. Calculate the total pressure drop that occurred around well bore by using Darcy's law for every available commercial gravel. Calculate and compare Q (with gravel and with out gravel) and average permeability for every commercial gravel.

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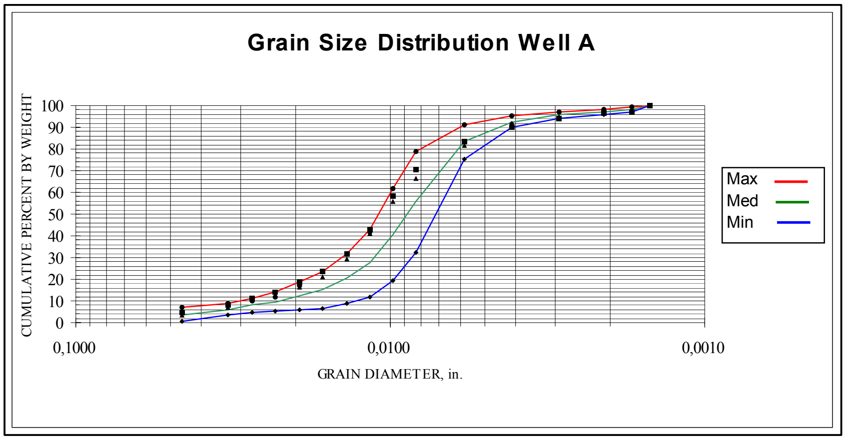
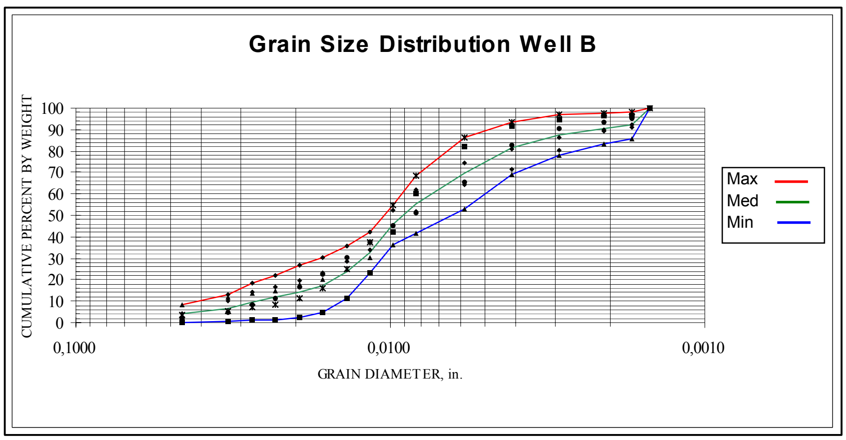
4. Data Analysis and Interpretation,

Based on data that got as experimental results, create particle size distribution curve for all formation sand sample as shown in **Figure 6**, the experimental data are attached as **Attachment 3** & **4.**





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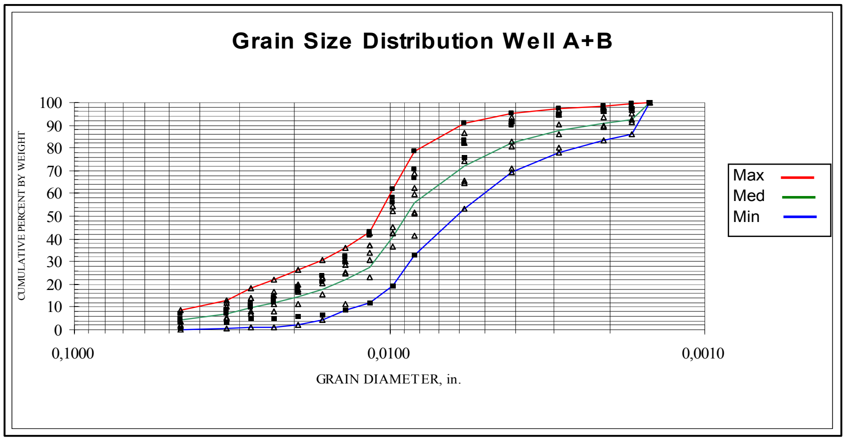

Figure 6: Particle Size Distribution Curve all group of formation sand samples

Determining the grain size of every 10% cummulative weight (d10, d20, d30,etc) for respective group (Well A, Well B and Well A+B) is important for further data analysis and interpretation in this study. The grain size per 10% cummulative weight data can get from interpolation of experimental data, the results for each group are shown in **Table 3**

Cum Weight (d) [%]	Maximum Size [Inches]			Minimum Size [Inches]			Medium Size [Inches]		
	Well A	Well B	Well A+B	Well A	Well B	Well A+B	Well A	Well B	Well A+B
d10	0,0301	0,0417	0,0417	0,0129	0,0143	0,0129	0,0225	0,0267	0,0267
d20	0,0187	0,0255	0,0255	0,0097	0,0122	0,0097	0,0139	0,0153	0,0150
d30	0,0144	0,0168	0,0168	0,0086	0,0107	0,0086	0,0112	0,0123	0,0112
d40	0,0122	0,0124	0,0125	0,0079	0,0088	0,0074	0,0099	0,0106	0,0099
d50	**0,0109**	**0,0105**	**0,0109**	**0,0073**	**0,0065**	**0,0062**	**0,0089**	**0,0091**	**0,0089**
d60	0,0100	0,0092	0,0100	0,0067	0,0051	0,0051	0,0079	0,0075	0,0076
d70	0,0091	0,0081	0,0091	0,0061	0,0040	0,0040	0,0070	0,0058	0,0061
d80	0,0080	0,0067	0,0080	0,0053	0,0026	0,0026	0,0061	0,0043	0,0045
d90	0,0060	0,0049	0,0060	0,0041	0,0016	0,0016	0,0046	0,0022	0,0023
d100	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015
Uc	2,0314	2,5101	2,0873	1,9238	5,3487	4,5081	2,1718	4,7469	4,2883

Table 3 : Grain Size of Every 10 % Cummulative Weight

Most of population of formation sand samples relatively uniform, thats can be defined by their uniformity coefficient that are less than 5 (Uc < 5), the Uc can be calculated by using Schwart method that explained in the previous chapter.

Reffering to **Table 3**, we can also indicate median sand size for each distribution size category of each group. The median grain size of formation sand samples will be multiplied by 4 thru 8 to determine initial suitable range of gravel size. The multiplying results for each distribution category of each group are shown in **Table 4;**

Multiplied by (Saucier's Law)	Well A						Well B						Well A+B					
	MAX		MIN		MED		MAX		MIN		MED		MAX		MIN		MED	
	Inch	Mesh	Inch	Mesh	Inch	Mesh	Inch	Mesh	Inch	Mesh	Inch	Mesh	Inch	Mesh	Inch	Mesh	Inch	Mesh
4	0.0437	18	0.0292	25	0.0355	20	0.0419	18	0.0259	30	0.0364	20	0.0437	18	0.0247	30	0.0355	20
5	0.0546	16	0.0364	20	0.0443	18	0.0523	16	0.0324	25	0.0455	18	0.0546	16	0.0309	25	0.0443	18
6	0.0656	14	0.0437	18	0.0532	16	0.0628	14	0.0388	20	0.0546	16	0.0656	14	0.0371	20	0.0532	16
7	0.0765	12	0.0510	16	0.0621	14	0.0733	12	0.0453	18	0.0637	14	0.0765	12	0.0432	18	0.0621	14
8	0.0874	10	0.0583	14	0.0709	12	0.0838	10	0.0518	16	0.0729	12	0.0874	10	0.0494	16	0.0709	12
Range of Gravel Size	10-18 mesh or next smaller		14-25 mesh or next smaller		12-20 mesh or next smaller		10-18 mesh or next smaller		16-30 mesh or next smaller		12-20 mesh or next smaller		10-18 mesh or next smaller		16-30 mesh or next smaller		12-20 mesh or next smaller	

Table 4 : d_{50} Multiplyed by 4 to 8

 ISSN 1907-0500

Comparison between median formation sand size (d_{50}) to median available gravel size (D_{50}) is required to validate initial gravel size selection. The comparison results are shown in the following **Table 5**.

Well A

Gravel Size	U.S.	Approximate Median Diameter		D50/d50			Remarks
(in.)	Mesh Size	(in.)	(µm.)	MAX	MIN	MED	Kg/Kr>6 -- Sand Invation
0.017	40/100	0.012	300	1.0982	1.6465	1.3531	No Sand Invation
0.017	40/70	0.013	330	1.1897	1.7837	1.4658	No Sand Invation
0.017	40/60	0.014	350	1.2812	1.9209	1.5786	No Sand Invation
0.033	20/40	0.025	630	2.2879	3.4302	2.8189	No Sand Invation
0.047	16/30	0.035	880	3.2030	4.8023	3.9465	No Sand Invation
0.066	12/20	0.05	1260	4.5757	6.8604	5.6378	gravel invaded by sand (Min)
0.066	12/18	0.053	1340	4.8503	7.2720	5.9761	gravel invaded by sand (Min)
0.079	10/20	0.056	1410	5.1248	7.6836	6.3143	Med)
0.079	10/16	0.063	1590	5.7654	8.6441	7.1036	Med)
0.094	8/12	0.08	2020	7.3212	10.9766	9.0205	gravel invaded by sand
0.132	6/10	0.106	2670	9.7005	14.5440	11.9521	gravel invaded by sand

Well B

Gravel Size	U.S.	Approximate Median Diameter		D50/d50			Remarks
(in.)	Mesh Size	(in.)	(µm.)	MAX	MIN	MED	Kg/Kr>6 -- Sand Invation
0.006 x 0.017	40/100	0.012	300	1.1462	1.8536	1.3177	No Sand Invation
0.008 x 0.017	40/70	0.013	330	1.2418	2.0081	1.4275	No Sand Invation
0.010 x 0.017	40/60	0.014	350	1.3373	2.1625	1.5373	No Sand Invation
0.017 x 0.033	20/40	0.025	630	2.3880	3.8617	2.7452	No Sand Invation
0.023 x 0.047	16/30	0.035	880	3.3432	5.4063	3.8432	No Sand Invation
0.033 x 0.066	12/20	0.05	1260	4.7760	7.7233	5.4903	gravel invaded by sand (Min)
0.039 x 0.066	12/18	0.053	1340	5.0625	8.1867	5.8198	gravel invaded by sand (Min)
0.033 x 0.079	10/20	0.056	1410	5.3491	8.6501	6.1492	gravel invaded by sand (Min)
0.047 x 0.079	10/16	0.063	1590	6.0177	9.7314	6.9178	gravel invaded by sand (Min & Med)
0.066 x 0.094	8/12	0.08	2020	7.6416	12.3573	8.7845	gravel invaded by sand
0.079 x 0.132	6/10	0.106	2670	10.1251	16.3734	11.6395	gravel invaded by sand

Well A + B

Gravel Size	U.S.	Approximate Median Diameter		D50/d50			Remarks
(in.)	Mesh Size	(in.)	(µm.)	MAX	MIN	MED	Kg/Kr>6 -- Sand Invation
0.006 x 0.017	40/100	0.012	300	1.0981	1.9423	1.3531	No Sand Invation
0.008 x 0.017	40/70	0.013	330	1.1897	2.1042	1.4658	No Sand Invation
0.010 x 0.017	40/60	0.014	350	1.2812	2.2660	1.5786	No Sand Invation
0.017 x 0.033	20/40	0.025	630	2.2878	4.0465	2.8189	No Sand Invation
0.023 x 0.047	16/30	0.035	880	3.2029	5.6651	3.9465	No Sand Invation
0.033 x 0.066	12/20	0.05	1260	4.5756	8.0930	5.6379	gravel invaded by sand (Min)
0.039 x 0.066	12/18	0.053	1340	4.8501	8.5785	5.9761	gravel invaded by sand (Min)
0.033 x 0.079	10/20	0.056	1410	5.1247	9.0641	6.3144	gravel invaded by sand (Min & Med)
0.047 x 0.079	10/16	0.063	1590	5.7652	10.1971	7.1037	gravel invaded by sand (Min & Med)
0.066 x 0.094	8/12	0.08	2020	7.3209	12.9487	9.0206	gravel invaded by sand
0.079 x 0.132	6/10	0.106	2670	9.7002	17.1571	11.9523	gravel invaded by sand

Table 5. : D_{50}/d_{50} calculation for respective group of samples

Based on data calculation as above, the 16/30 and the next smaller of comercial gravel size indicated will not be invaded by formation sand (Kg/Kr ≤ 6) for all group of formation sand samples.

By using all constant parameters, hidrostatic pressure calculated by multiplying Specific gravity, gradien pressure and depth. From the calculation, resulted hidrostatic pressure is about 134.7153 psi, bottom hole pressure can be calculated by adding tubing pressure to hidrostatic

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pressure, resulted the bottom hole pressure is about 154.7153 psi. The original pressure drop (with out gravel) is the differences between reservoir pressure to bottom hole pressure, about 105.2846 psi. By using Darcy's law, produce fluid rate with out gravel and total pressure drop occurred around wellbore can be defined. The produce fluid rate without gravel is about 391.3146 BOPD (Barrel Oil Per Day). The total pressure drop, produce fluid rate and productivity that resulted by installing every comercial gravel are shown in **Table 6**

U.S. Mesh Size	Permeability [Darcy]	Pressure Drop Reservoir	Outside Pipe	Perfor Tunnel	Inside Pipe	Total [Psia]	K average [Darcy]	Qg [BOPD]	Qg/Q Productivity	Remark
-6 +10	2703	80.3161	0.0148	4.6023	0.0044	85	2.0970	454.92	1.3106	Indicated, gravel will be invaded by formation sand based on D50/d50 calculation data
-8 +12	1969	80.3161	0.0203	6.3180	0.0061	87	2.0969	454.89	1.3105	
-10 +16	1185	80.3161	0.0337	10.4980	0.0101	91	2.0965	454.81	1.3103	
-10 +20	881	80.3161	0.0453	14.1205	0.0136	94	2.0962	454.75	1.3101	
-12 +18	668	80.3161	0.0598	18.6230	0.0180	99	2.0958	454.66	1.3099	
-12 +20	640	80.3161	0.0624	19.4377	0.0188	100	2.0958	454.65	1.3099	
-16 +30	200	80.3161	0.1997	62.2007	0.2508	143	2.0922	453.87	1.3076	
-20 +40	171	80.3161	0.2336	72.7493	0.2934	154	2.0913	453.68	1.3071	
-40 +60	69	80.3161	0.5790	180.2918	0.1741	261	2.0824	451.75	1.3015	
-40 +70	59	80.3161	0.6771	210.8498	0.2036	292	2.0799	451.20	1.2999	
-40 +100	29	80.3161	1.3776	428.9702	0.4143	511	2.0620	447.33	1.2888	

Table 6. : Total Pressure Drop, Average Permeability and Productivity Calculation Results

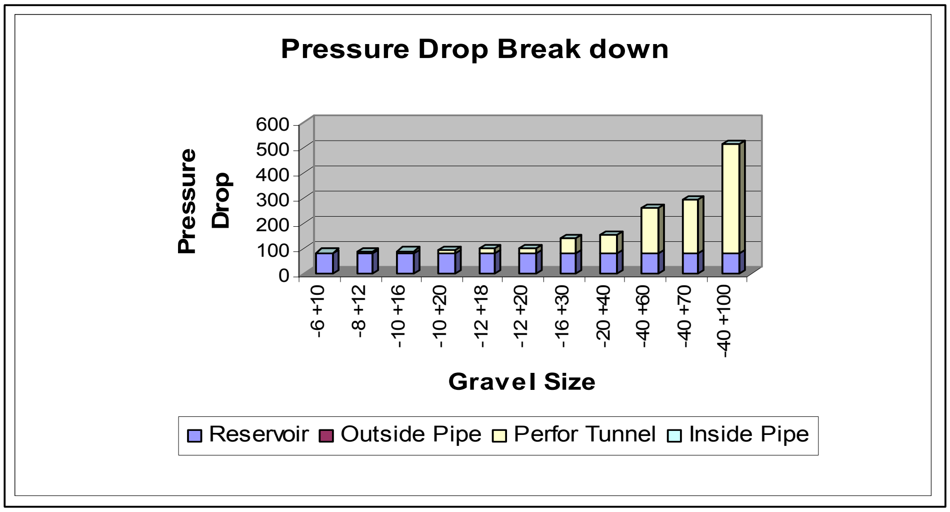

Figure 7 : Pressure Drop Break Down

In **Figure 7**, if gravel 40/60 or next smaller gravel being used to control production sand, it will generate high pressure drop in the perforation tunnel, more than presure drop that occurred in reservoir (80.3161 psi). Using too small gravel will increase pressure drop significantly, however, will restrict well productivity.

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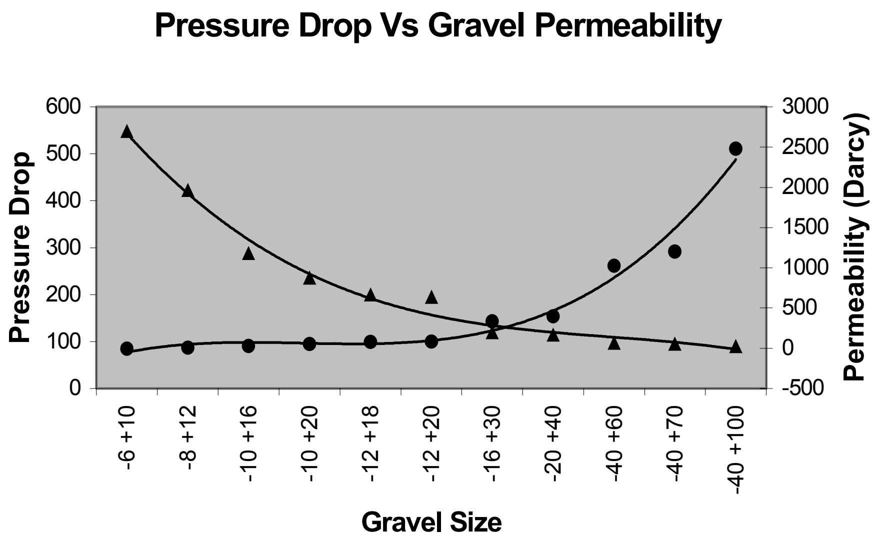

Figure 8 : Pressure Drop Vs Gravel Permeability

The **Figure 8** shows the relation between generated pressure drop with permeability for each of comercial gravel that available. From that figure the intersection between pressure drop and permeability curves are in 16/30 gravel pack size, and it is probably indicated as optimum gravel size that can minimize and/or stop formation sand movement.

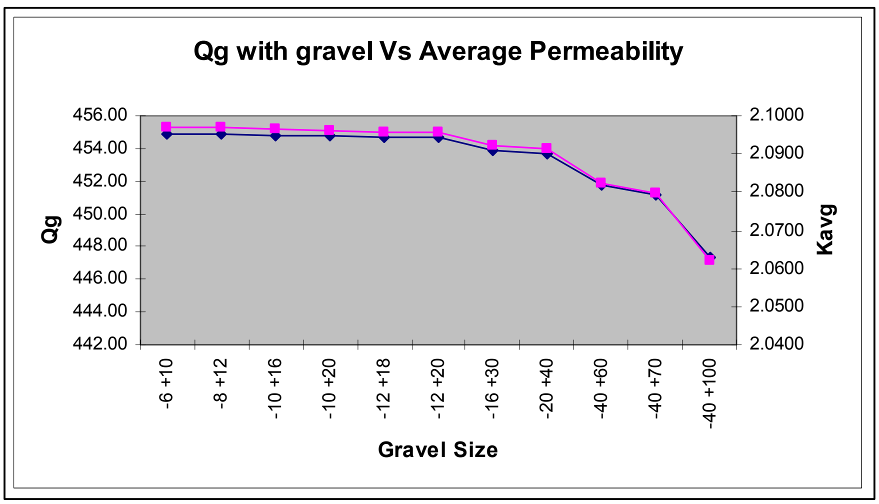

Figure 9 : Qg With Gravel Vs Average Permeability

The **Figure 9** shows that installing gravel pack creates a permeable down hole filter that will allow the production of the formation fluids, the permeability will increase about 2 darcy (K without gravel only 1.6 Darcy). Due to permeability at down hole increase, installing gravel pack also increase the production of formation fluid and productivity about 1.3 compared to fluid rate without gravel installed. Based on the relations between rate and average permeability as effect of gravel pack, 12/20 or larger comercial gravel have higher productivity. Using too large gravel will increase permeability significantly, however, will permit invasion of the formation sand into the gravel and then result in lower permeability (often to less than the native reservoir's permeability), restricted productivity, and increase draw dawn pressure /Pressure drops. Same as using too large gravel, too small gravel use will generate high pressure drop and significantly drop average premeability and well productivity. There is no significant differences between 16/30 and 20/40 gravel size in either production rate or average permeability. And by considering, any formation sand probably finest than 30 mesh, the next

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smaller gravel size (20/40 gravel) is recommended to minimize and/stop formation sand movements.

For screen selection that can hold the 20/40 gravel in place are based on the smallest of selected gravel size. The smallest gravel size is 40 mesh which about 0.017 inch. The spacing between the wires should be 0.5 to 0.9 (50% to 90%) times the diameter of the smallest pack sand grains. In this paper, the spacing between the wires is about 75% (0.75) of the smallest gravel sand. So the slot gauge of screen that recommended to hold 20/40 gravel in place is about 0.01275 inch or 12 gauge (a gauge = 0.001 Inch)

5. Conclusions

- The "minimum" distribution size is recommended to select proper gravel pack for controlling sand production.
- Most of population of formation sand samples relatively uniform, thats can be defined by their uniformity coefficient that are less than 5 ($Uc < 5$)
- By refer to Saucier's experimental results, if a gravel/sand ratio more than 6 invasion into the gravel caused the permeability ratio to decrease significantly. the 16/30 and the next smaller of comercial gravel size indicated will not be invaded by formation sand ($Kg/Kr \leq 6$) for all group of formation sand samples.
- if gravel 40/60 or next smaller gravel being used to control production sand, it will generate high pressure drop in the perforation tunnel, more than presure drop that occurred in reservoir (80.3161 psi). Using too small gravel will increase pressure drop significantly, however, will restrict well productivity.
- The production formation fluids rate before install gravel is about 391.3146 BOPD (Reservoir permeability=1.6 Darcy)
- Gravel pack placement creates a permeable down hole, the permeability increase to 2 darcy and increase well productivity about 1.3 compared to fluid rate without gravel installed.
- Using too large gravel (12/20 or larger comercial gravel) will increase permeability significantly, however, will permit invasion of the formation sand into the gravel and then result in lower permeability, restricted productivity, and increase draw dawn pressure /Pressure drops.
- Using too small gravel size (40/60 or next smaller comercial gravel) will increase pressure drop and significantly drop average permeability and well productivity.
- There is no significant differences between 16/30 and 20/40 gravel size in either production rate or average permeability.20/40 gravel size is recommended to control sand production as the next smaller comercial gravel size of 16/.30.
- The Screen gauge that can hold gravel in place is 12 gauge.

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ATTACHMENTS

Attachment 1 : Charateristics of Tyler Mesh and U.S Mesh

Tyler Mesh	U.S Mesh	D - mm	D - in.	ϕ	Fall Rate in Water - ft/min
2.5	2.5	8.0	0.315	-3	-
3	3	6.73	0.265	-2.75	-
3.5	3.5	5.66	0.223	-2.5	-
4	4	4.76	0.187	-2.25	-
5	5	4.0	0.157	-2.0	-
6	6	3.36	0.132	-1.75	-
7	7	2.83	0.111	-1.5	-
8	8	2.38	0.094	-1.25	-
9	10	2.0	0.079	-1.0	35.8-49.2
10	12	1.68	0.066	-0.75	32.7-44.5
12	14	1.41	0.056	-0.5	29.5-39.8
14	16	1.19	0.047	-0.25	26.4-35.0
16	18	1.0	0.039	0.00	23.2-30.7
20	20	0.841	0.033	0.25	20.5-26.4
24	25	0.707	0.028	0.50	17.7-22.0
28	30	0.595	0.023	0.75	15.2-18.7
32	35	0.500	0.02	1.0	12.6-15.5
35	40	0.420	0.017	1.25	10.4-12.8
42	45	0.354	0.014	1.5	8.7-10.4
48	50	0.297	0.012	1.75	7.1- 8.7
60	60	0.25	0.0098	2.0	5.7- 6.9
65	70	0.21	0.0083	2.25	4.4- 5.5
80	80	0.177	0.007	2.5	3.5- 4.3
100	100	0.149	0.0059	2.75	2.8- 3.3
115	120	0.125	0.0049	3.0	2.2- 2.4
150	140	0.105	0.0041	3.25	-
170	170	0.088	0.0035	3.5	-
200	200	0.074	0.0029	3.75	-
250	230	0.063	0.0025	4.00	-
270	270	0.053	0.0021	4.25	-
325	325	0.044	0.0017	4.5	-
400	400	0.037	0.0015	4.75	-

Ref: Carver, Robert E.: "Procedures in Sedimentary Petrology," Wiley-Interscience 1971

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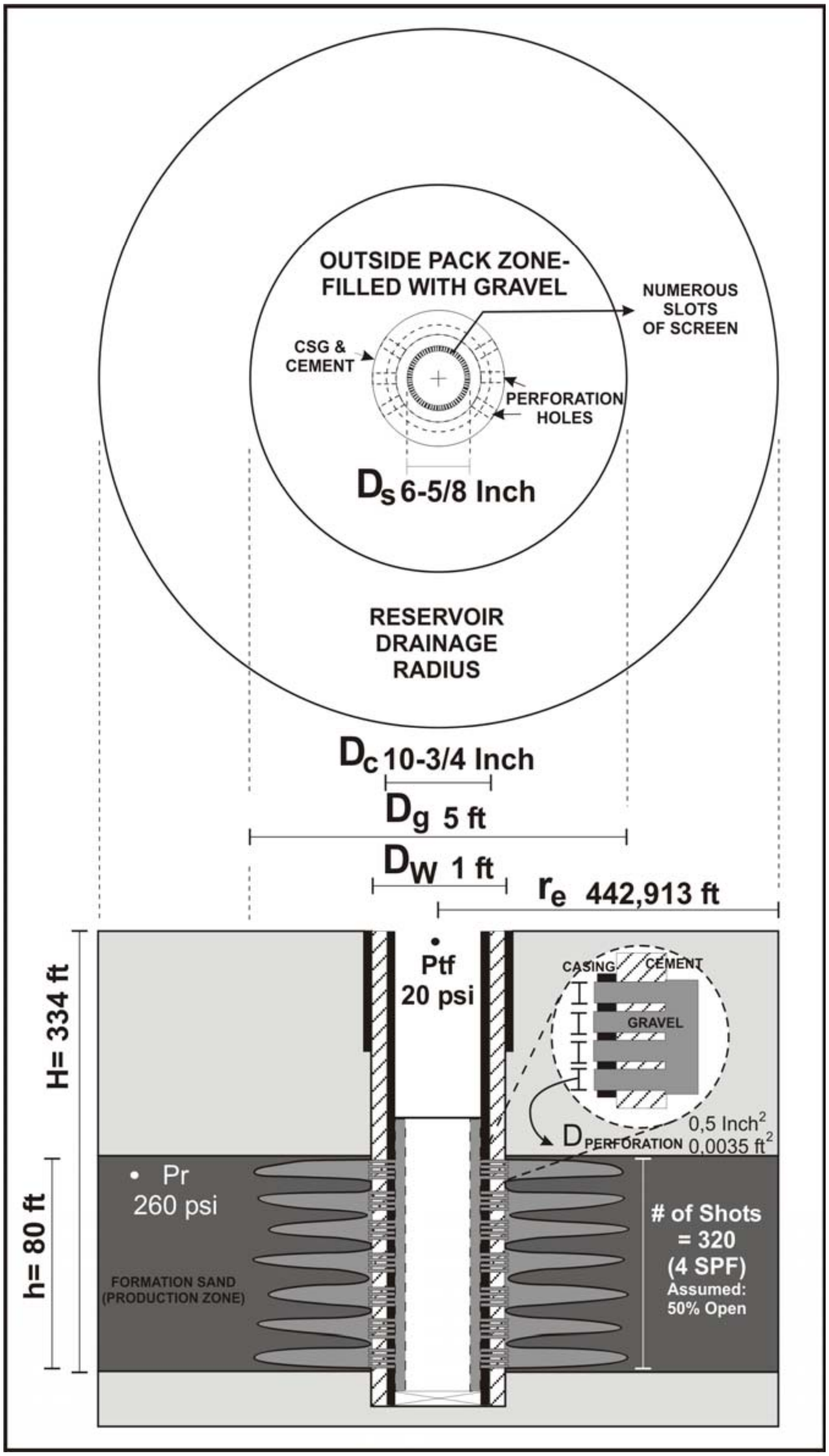
Attachment 2 : Wellbore Diagram and Constans Parameter Ilustration



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Attachment 3 : Abstract (BAHASA)

APLIKASI ANALISA PENGAYAKAN DI INDUSTRI PERMINYAKAN, MENENTUKAN UKURAN GRAVEL DAN SCREEN UNTUK MENGONTROL PRODUKSI PASIR

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Abstrak

Terproduksinya pasir formasi bersama dengan minyak dan/atau gas akan menimbulkan masalah yang berpotensial bahaya dan mahal (kehilangan produksi, kerusakan akibat erosi oleh pasir, pembuangan & penanganan pasir di permukaan, dan lain lain). Di industri perminyakan yang memproduksi minyak/gas, analisa pengayakan (Sieve Analysis) digunakan untuk menggambarkan populasi pasir formasi. Sieve analysis menjadi suatu metoda yang dapat diterima untuk mendeskripsikan pasir formasi dan pasir gravel yang kemudian digunakan sebagai media untuk mengontrol produksi pasir formasi. Gravel pack merupakan metoda yang paling sering digunakan dan paling sukses dalam mengontrol produksi pasir, sedangkan penyaring/Screen akan menjaga pasir gravel tetap di tempatnya. Adapun tujuan dari studi percobaan ini adalah, menggambarkan populasi pasir formasi, menentukan koefisien keseragaman masing masing sample pasir formasi, menentukan ukuran gravel yang dapat meminimalkan dan/atau menghentikan pergerakan pasir formasi dan ukuran screen yang dapat menahan gravel tetap di tempatnya.

Studi percobaan ini dimulai dengan aktifitas Coring. Sampel core/ pasir formasi diambil pada kedalaman yang berbeda dari 2 sumur baru, Sumur A dan Sumur B yang terletak di Utara lapangan minyak Duri. Sampel pasir formasi dari Sumur A diambil di kedalaman 521', 547', 601' dan 608' (ft). Sedangkan sampel pasir formasi dari Sumur B diambil di kedalaman 623', 637', 650', 664', 690' dan 710' (ft). Sebelum dilakukan analisa ayak, setiap sampel pasir formasi harus dibersihkan dari zat pengotor menggunakan Ekstraksi Soxhlet dan Toluen digunakan sebagai pelarutnya. Kemudian sampel pasir dikeringkan, ikatan antara partikel pasir di pisahkan menggunakan Mortar, tujuannya bukan untuk memecahkan tapi hanya memisahkan ikatan antar partikelnya. Selanjutnya, sampel pasir formasi yang sudah diketahui beratnya, dilewatkan pada set ayakan yang ukuran bukaannya (mesh) diketahui.

Berdasarkan pada interpretasi dan data perhitungan, diperoleh beberapa kesimpulan antara lain: semua populasi sampel pasir formasi relative seragam, ditandai dengan koefisien keseragaman di bawah 3, ukuran gravel pack yang sesuai untuk menghentikan dan/atau mengurangi produksi adalah +20-40 (membandingkan total kehilangan tekanan masing masing ukuran gravel – persamaan Darcy), sedangkan bukaan/lubang penyaring yang digunakan untuk menahan gravel adalah 12 gauge (0,012 Inch)

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Kata Kunci: Sieve Analysis, Sand Control, Coring, (Soxhlet) Extraction, Uniformity Coefficient, Screen gauge, Particle size distribution.

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Attachment 4 : Well A Experimental Data

Sieve Analysis		Sample #A1 (521 ft)			Sample #A2 (547,7 ft)			Sample #A3 (601,9 ft)			Sample #A4 (608,8 ft)		
[U.S. Sieve]	[inches]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]
16	0.0460	4.79	4.80	4.80	6.81	6.80	6.80	0.61	0.61	0.61	3.53	3.56	3.56
20	0.0328	3.68	3.69	8.48	1.78	1.78	8.58	2.71	2.72	3.33	3.40	3.43	6.99
25	0.0276	2.85	2.86	11.34	1.18	1.18	9.77	1.53	1.54	4.86	3.57	3.60	10.59
30	0.0232	2.54	2.54	13.88	2.21	2.21	11.98	0.22	0.22	5.08	2.50	2.52	13.11
35	0.0195	4.84	4.84	18.72	4.98	4.98	16.96	0.76	0.77	5.85	3.50	3.53	16.63
40	0.0164	4.85	4.86	23.58	6.53	6.53	23.49	0.86	0.87	6.71	4.37	4.41	21.04
45	0.0138	8.45	8.46	32.04	8.41	8.41	31.89	1.86	1.87	8.58	8.52	8.59	29.63
50	0.0116	10.77	10.79	42.82	10.11	10.10	41.99	3.33	3.34	11.92	11.55	11.66	41.29
60	0.0098	15.47	15.50	58.32	20.05	20.04	62.03	7.51	7.54	19.45	14.71	14.84	56.13
70	0.0083	12.21	12.23	70.55	16.65	16.64	78.68	13.13	13.17	32.63	10.19	10.28	66.41
100	0.0058	13.03	13.05	83.60	12.26	12.26	90.93	42.77	42.92	75.55	15.34	15.47	81.88
140	0.0041	6.36	6.37	89.97	4.09	4.09	95.02	15.92	15.97	91.52	8.99	9.06	90.94
200	0.0029	4.10	4.10	94.07	2.23	2.23	97.25	3.09	3.10	94.62	3.49	3.52	94.47
270	0.0021	2.28	2.28	96.36	1.24	1.24	98.49	1.54	1.54	96.17	2.04	2.06	96.52
325	0.0017	0.82	0.82	97.18	0.71	0.71	99.20	0.94	0.94	97.11	0.79	0.80	97.32
PAN	0.0015	2.82	2.82	100.00	0.80	0.80	100.00	2.88	2.89	100.00	2.66	2.68	100.00
Total		**99.86**			**100.07**			**99.65**			**99.13**		

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Attachment 5 : Well B Experimental Data

Sieve Analysis		Sample #B1 (623,5 ft)			Sample #B2 (637,6 ft)			Sample #B3 (650 ft)			Sample #B4 (664,3 ft)			Sample #B5 (697 ft)			Sample #B6 (710 ft)		
[U.S. Sieve]	[inches]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]	Weight [gr]	Weight [%]	Cum Weight (d) [%]
16	0.0460	0.19	0.19	0.19	2.04	2.06	2.06	3.93	3.95	3.95	8.50	8.54	8.54	1.59	1.72	1.72	3.50	3.69	3.69
20	0.0328	0.39	0.39	0.58	2.97	2.99	5.05	6.13	6.17	10.12	3.25	3.27	11.81	10.42	11.31	13.03	1.71	1.81	5.50
25	0.0276	0.34	0.34	0.92	3.21	3.23	8.28	4.08	4.11	14.22	1.95	1.96	13.77	4.74	5.14	18.17	1.43	1.51	7.01
30	0.0232	0.35	0.35	1.27	3.03	3.05	11.33	2.16	2.18	16.40	1.36	1.37	15.14	3.60	3.91	22.08	1.19	1.25	8.26
35	0.0195	1.09	1.10	2.37	5.54	5.57	16.90	3.42	3.44	19.84	2.81	2.82	17.96	4.08	4.42	26.51	3.02	3.19	11.45
40	0.0164	2.10	2.12	4.48	5.43	5.46	22.36	3.37	3.39	23.24	2.49	2.51	20.47	3.68	3.99	30.50	4.13	4.35	15.80
45	0.0138	6.91	6.95	11.44	7.87	7.92	30.28	5.11	5.15	28.38	4.73	4.76	25.23	5.02	5.45	35.95	8.68	9.15	24.95
50	0.0116	11.78	11.86	23.29	7.00	7.05	37.33	5.27	5.30	33.68	5.16	5.19	30.42	5.92	6.42	42.36	11.74	12.37	37.32
60	0.0098	18.95	19.08	42.37	7.59	7.64	44.97	8.57	8.62	42.30	6.13	6.17	36.59	9.23	10.01	52.38	16.32	17.20	54.52
70	0.0083	17.39	17.51	59.89	6.28	6.32	51.29	9.45	9.51	51.81	4.98	5.01	41.60	9.01	9.78	62.16	13.50	14.23	68.75
100	0.0058	22.34	22.50	82.39	14.08	14.17	65.46	12.46	12.54	64.36	11.44	11.50	53.10	11.28	12.24	74.40	16.79	17.70	86.45
140	0.0041	9.48	9.54	91.93	17.29	17.40	82.86	6.81	6.85	71.21	16.09	16.18	69.27	5.96	6.47	80.87	6.68	7.05	93.50
200	0.0029	2.90	2.92	94.85	7.55	7.60	90.47	8.88	8.93	80.14	8.88	8.93	78.21	4.75	5.15	86.02	3.13	3.29	96.79
270	0.0021	1.44	1.45	96.30	3.18	3.21	93.67	9.15	9.21	89.35	4.88	4.91	83.12	3.29	3.57	89.59	1.00	1.06	97.85
325	0.0017	0.41	0.41	96.72	1.29	1.30	94.97	2.84	2.86	92.21	2.72	2.74	85.85	1.56	1.69	91.28	0.31	0.33	98.18
PAN	0.0015	3.26	3.28	100.00	4.99	5.03	100.00	7.74	7.79	100.00	14.07	14.15	100.00	8.03	8.72	100	1.73	1.82	100
Total		**99.30**			**99.35**			**99.38**			**99.45**			**92.16**			**94.86**		