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MINIMIZE SAND PRODUCTION BY CONTROLLING WELLBORE GEOMETRY AND FLOW RATE

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Abstract

The production of sand particle has become serious problem to oil and gas well and was subject for study during the past years. Basically, sand production must be the results of a change in strength of the formation rock due to drilling, perforation and production operation and drag forces of the produced fluids. Therefore, during designing and developing stages, parameters related to sand production need to be examined carefully. This paper presents an experimental study of the effects of wellbore geometry and flow rate to sand production and total oil recovery; to minimize sand production as well as optimize production. The experimental works include of static and dynamic sand production tests, which were carried out on wellbore models with different wellbore angle, perforation shot density, and perforation pattern and flow rate using Servo Control Compression Testing Machine (SCCTM). The results show that oil production is reduced as sand production increases and most of produced sand are large size indicating the dominant effects of the breakage of cementing materials. Sand production increases significantly after effective stress reaches 35-60% of rock compressive strength and followed by the reduction of total oil recovery to 55-73%. In addition, sand production increases as wellbore angle, shot density, flow rate increase and as perforation pattern change from spiral to inplane and finally inline, especially for model with more than 10^o well bore angle, inline pattern and 1600cc/h flow rate. Therefore, in order to optimize production, sand production must be minimized by reducing wellbore angle ($<10^o$), shot density, flow rate ($<$1600cc/h), perforated with spiral pattern and pore pressure should be controlled so that effective stress around a wellbore is not more than 35% of rock compressive strength.

Introduction

Most of oil and gas wells produced through sandstone formation that was deposited in marine or detritus environments. Marine deposits are often cemented with calcareous or siliceous minerals and may be strongly consolidated. In contrast, miocene and younger sands are often unconsolidated or poorly consolidated with soft clay or silk. During the production of oil and gas from reservoir, the pore fluid pressure will generally decline and results in the increase of effective stress within the reservoir. The increase of effective stress acting on the contact between grain to grain in the unconsolidated or poorly consolidated sandstone will cause the rock easy to break and particle sand will be produced. These processes always have adverse effects to oil wells such as reduce well productivity, damage production equipment, wellbore and casing collapse, land subsidence and environment problems. Billion of dollars are spent each year on attempts to predict and control sand production and repair well equipment. But control sand in unnecessary case will result in increasing cost and reducing oil recovery. Inversely, if sanding occurs and no controlling method is implemented, considerable impact on oil and gas wells will occur. Therefore, during designing stage, engineer should consider all aspects related to sand production. This paper examined the effects of wellbore geometry and flow rate to sand production in order to control sand production as well as to optimize the oil production by controlling wellbore angle, perforation shot density, perforation pattern and production flow rate.

Experiment:

Sample preparation

Two types of sandstone core samples were used for this study. Low porosity and permeability sample was used for static sand production test and sample with high porosity and permeability was used for dynamic sand production test. These core samples were trimmed to cylindrical model of 6" x 6", with borehole of 2" diameter and casing of 1" diameter.

Sand production tests

Sand production tests were carried out in two condition, i.e., static and dynamic. Static test was performed on models with different wellbore angle of 0, 5, 10, 15 and 20°, perforation shot density of 4, 6, 8, and 16 SPF and perforation pattern of inline, inplane and spiral. Dynamic test was performed on models with different flow rate of 400, 800 and 1600 cc/h.

Static sand production tests

Considering gradient of overburden (1 psi/ft) and pore pressure (0.45 psi/ft), for the sample at depth 12000 feet, the 12000 psi of overburden and 5600 psi of confining pressure are modeled. The testing was designed to keep overburden load constant and reduce confining pressure until the model fail. Models with different wellbore angle, perforation shot density and pattern were put centrally under SCCTM. After overburden and confining pressure were increased to 1464 KN (12000 psi) and 36 MPa (5600 psi), respectively, the confining pressure was reduced at a constant rate of 100 KPa/s until the model fail. The produced sands were collected at 4 MPa of confining pressure reduction then were sieved to determine sand particle size distribution.

Dynamic sand production test

It was designed to keep confining pressure at a constant and increase overburden load until the model fails. Models were put centrally under SCCTM. Initially confining pressure was increased to 1.5 MPa with a constant rate of 100 KPa/s. Then pore pressure was increased to 1.35 MPa with a constant rate of 100 KPa/s for flow rate of 400 cc/h at drawdown of 1.25 MPa with 60 cp oil. After flow rate is stable, the axial load was increased with a constant rate of 0.7 MN/m2 until the model fails. The produced sands were collected at 100 KN of axial load increment then were sieved to determine sand particle size distribution.

Repeat the whole procedure with pore pressure of 3.5 MPa and 6 MPa to simulate flow rate of 800 and 1600cc/h with 60 cp oil.

RESULTS AND DISCUSSIONS

Generally, sand production is affected by borehole angle, perforation shot density, perforation pattern and flow rate. Sand production increases as borehole angle, shot density and flow rate increase and as perforation pattern changes from spiral to inplane and inline.

Effect of wellbore angle to sand production

Summarized results of sand production tests with different borehole angle are shown in Table 1. Figures 1 shows that for a 4 SPF and inline pattern, the sand production of the vertical borehole is 1.02g. While the sand production for 5°, 10°, 15° and 20° borehole angle model are 1.65g, 2.01g, 3.80g and 4.3g, respectively. Figure 1 also shows that sand production increases significantly (double) when wellbore angle larger than 10 degree. The vertical model failed after effective stress reaches 94.0% of compressive strength. While the 5°, 10°, 15° and 20° wellbore angle model failed at 93.5%, 90.5%, 88.2% and 85.9%, respectively. These results show that as the wellbore angle increases, the rock will easier to fail and result in more sand produced.

It is because, an inclined wellbore will create angular relationship between wellbore and the principal stress axes hence increasing the shear stress. Thus, it can be concluded that as the wellbore angle increases, there is a tendency to shear or slide along the wellbore inclination since the concentration of the shear stress is greatest. Therefore, sand production increases as the wellbore angle increases.

Effects of perforation shot density to sand production

Summarized results of sand production tests with different perforation shot density are shown in Table 2. Figure 2 shows that sand production also increases as shot density increases. The sand production of model with 4 SPF is 1.02g compare to 2.37g, 4.01g and 5.72g of model with 6, 8 and 16 SPF, respectively. The 4 SPF model fails at 94.0% of compressive strength, followed by 93.8%, 85.9% and 73.3% for 6, 8 and 16 SPF model, respectively. These results show that as shot density increases, the model will be easier to fail and results in more sand produced.

This phenomenon occurs due to the fact that as shot density increases, the critical drawdown for shear failure decreases due to stress relief, especially for very high density. In addition, as shot density increases, the rock mass has to carry more redistributed stress along the perforation system. As a result, the rock mass strength is reduced significantly as shot density increases. Since sand production increases as rock strength decreases, it will increase as shot density increases.

Effects of perforation pattern to sand production

Summarized results of sand production tests with different perforation pattern are shown in Table 3. As pore pressure depleted, sand production increases. However the increment is affected by perforation pattern of the model especially for inline pattern. The model with inline pattern produced 5.72g, 3 times of spiral pattern model (1.98g) and 1.7 times of inplane pattern model (3.45g) as shown in Figure 3. The 16 SPF and spiral model failed at 92.3% of compressive strength, while the inplane and inline model failed at 87.5% and 70.9%, respectively. These results show that as perforation pattern changes from spiral to inplane and finally inline, sand production and sand production increase.

The above phenomenon is understandable since the perforation tunnels in the inline pattern are in one vertical line, which is parallel to the applied load and provide a shortest distance between perforation hole. Thus resulting in lower rock mass stress than for inplane pattern where the perforation tunnels are in one horizontal line, which is perpendicular to the applied load. Therefore, rock mass stress in an inplane pattern is higher than in an inline pattern. As for the spiral pattern, the perforation tunnels are in a plane of higher rock mass stress than for two previous patterns. The spiral pattern also produces the greatest distance between each successive perforation and therefore a strongest perforated structure. Therefore sand production is highest for the inline pattern, followed by an inplane and finally spiral pattern, since sand production increases as the rock mass strength decreases, especially the inline pattern.

Effects of flow rate to sand production

Summarized results of sand production tests with different flow rate are shown in Table 4. Figure 4 shows the effects of flow rate to sand production. For the 400 and 800 cc/h sand production are not much different (8.57 and 10.56g), however for 1600 cc/h model sand production increase to more than double (19.35g). The first sight of sand production occurred when effective stress reached 38.2% of compressive strength for model with flow rate of 400 cc/h and 17.6% and 5.1% of compressive strength for model with flow rate of 800 cc/h and 1600 cc/h, respectively. This result strengthens the view that effective stress cause damage in the rock around the perforation and flow cause sanding by removing and transporting the damaged material into the wellbore. Further more, higher flow rate contribute to sand production by moving and transporting more sand due to higher fluid drag forces.

The 400 cc/h flow rate model failed at 70.6% of compressive strength, followed by 61.0% and 58.1% for 800 cc/h and 1600 cc/h model, respectively. These results show that as flow rate and viscosity increase, the sandstone model easier to fail and results in more produced sand.

These results can be explained by considering that when fluid are produced from sandstone reservoir, the stress due to the pressure differences between wellbore and reservoir and frictional forces will act on sand grain causing the stress state change in the sand formation. Such stress state change unstabilizes the formation and perforation hole. As the flow rate increases, the drag forces increase and encourage sand production by tensile failure.

Effects of sand production to produced oil

Effect of sand production on produced oil is shown in Figure 5. It can be seen that as sand production increases, oil produced decreases. Initially, sand production increases slowly with stable oil recovery. After sand production increases to 3.5 g (35-60% of rock compressive strength), the produced oil starts to decrease. After sample yield completely and failed, produced oil decreases to only 55-73% of expected oil recovery. It can be explained by the fact that sand production is the process that causes the reduction of porosity and permeability (Morita et. al. 1984, Fjaer et. al.1992), therefore production flow rate is reduced since production flow rate is affected mainly by porosity and permeability of the reservoir rock.

Sand particle size distribution

Total amount of produced sand collected after tests were used for sieve analysis. The trend of sand particle size distribution for static tests are presented in Figure 6. This figure shows that most of the fragments produced are over size (> 500 μm), it is varying from 59.47% to 85.29%. The sand grain size distribution from 250 to 500 μm varying from 9.09 to 30.6%. While the smaller size of 125-250 μm and less than 125 μm present in small amount (0 to 15.46%). These results indicate that most of the produced sand are intact grains and large burst of sand. This can be explained as under the increasing of axial effective stress, the models were compacted due to the slip and slide of sand grains. These processes cause breaking of cementing materials, therefore release sand grains. The small size grain (< 250 μm) presents with small amount (< 20%) due to the breaking of sand grain play minor role during sand production.

Conclusions

From these experiments, it can be concluded that:

1. Sand production increases significantly after effective stress reaches 35-60% of rock compressive strength and followed by the reduction of total oil recovery to 55-73%.
2. Sand production increases as wellbore angle, shot density, flow rate increase and as perforation pattern change from spiral to inplane and finally inline, especially for model with more than 10° wellbore angle, inline pattern and 1600 cc/h flow rate.
3. Most of produced sands are large in size indicating the dominant effects of the breakage of cementing materials.

Therefore, in order to optimize production, sand production must be minimized by reducing wellbore angle (< 10°), shot density, flow rate (< 1600 cc/h), perforated with spiral pattern and pore pressure should be controlled so that effective stress around the wellbore not more than 35% of rock compressive strength since produced oil from the reservoir is affected by sand production, which is related to wellbore angle, perforation shot density, perforation pattern and flow rate.

Nomenclature

SPF = shot per foot
SCCTM = Servo Controlled Testing Machine

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SI Metric Conversion Factors

cp	x 1.0*	E-03=Pa's
ft	x 3.048*	E-01=m
ft^2	x 9.290 304*	E-02=m^2
ft^3	x 2.831 685	E-02=m^3
in.	x 2.54*	E+00=cm
lbf	x 4.448 222	E+00=N
md	x 9.869 233	E-04=μm^2
psi	x 6.894 757	E+00=kPa

TABLE 1-SUMMARIZED RESULT OF SAND PRODUCTION TESTS WITH DIFFERENT WELLBORE ANGLE.

Pore pressure Depletion (MPa)	Sand production, g				
	0°	5°	10°	15°	20°
0	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.07	0.00	0.08
26	0.07	0.00	0.15	0.12	0.12
29	0.18	0.09	0.23	0.30	0.45
31	0.30	0.24	0.33	0.78	0.87
32	0.42	0.57	0.67	1.23	1.60
33	0.55	0.66	0.80	2.00	2.97
34	0.70	0.98	1.24	2.70	4.30
35	1.02	1.65	2.01	3.80	

TABLE 2-SUMMARIZED RESULT OF SAND PRODUCTION TEST WITH DIFFERENT SHOT DENSITY.

Pore Pressure Depletion (MPa)	Sand Production, g			
	4 SPF	6 SPF	8 SPF	16 SPF
0	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.05
23	0.00	0.00	0.03	0.20
26	0.07	0.00	0.42	0.71
29	0.18	0.03	0.50	2.12
31	0.30	0.21	0.70	3.80
32	0.42	0.45	1.40	5.72
33	0.55	1.00	2.01	
34	0.70	1.80	4.01	
35	1.02	2.37		

TABLE 3-SUMMARIZED RESULT OF SAND PRODUCTION TESTS WITH DIFFERENT PERFORATION PATTERN.

Pore Pressure Depletion (MPa)	Sand Production, g		
	Inline	Inplane	Spiral
0	0.00	0.00	0.00
14	0.00	0.00	0.00
17	0.00	0.00	0.00
20	0.05	0.00	0.00
23	0.20	0.00	0.00
26	0.71	0.00	0.00
29	2.12	0.00	0.06
31	3.80	0.12	0.10
32	5.72	0.34	0.26
33		1.08	0.87
34		2.20	1.24
35		3.45	1.98

TABLE 4-SUMMARIZED RESULT OF SAND PRODUCTION TESTS WITH DIFFERENT FLOW RATE.

400 cc/h		800 cc/h		1600 cc/h	
Axial stress, MPa	Produced sand, g	Axial stress, MPa	Produced sand, g	Axial stress, MPa	Produced sand, g
0.00	0.00	0.00	0.00	0.00	0.00
1.57	0.00	1.00	0.00	0.00	0.00
4.40	0.00	3.15	0.00	0.70	0.00
7.22	0.00	5.97	0.00	3.47	0.17
10.05	0.00	8.80	0.02	6.30	0.32
12.87	0.00	11.62	0.10	9.12	0.50
15.70	0.07	14.45	0.56	11.95	0.78
18.52	0.21	17.27	0.87	14.77	1.00
21.35	0.75	20.10	1.31	17.60	1.41
24.17	1.18	22.92	1.87	20.42	2.00
27.00	2.81	25.75	2.55	23.25	2.70
29.26	6.27	28.57	3.87	26.07	3.50
		31.19	10.56	28.90	3.70
				31.72	4.20
				34.55	4.89
				37.37	5.66
				39.35	19.35

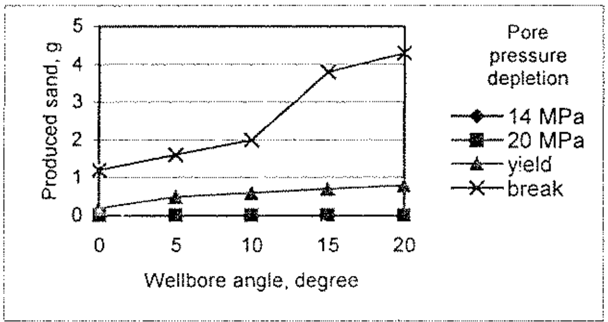

Fig.1-Effects of wellbore angle to sand production.

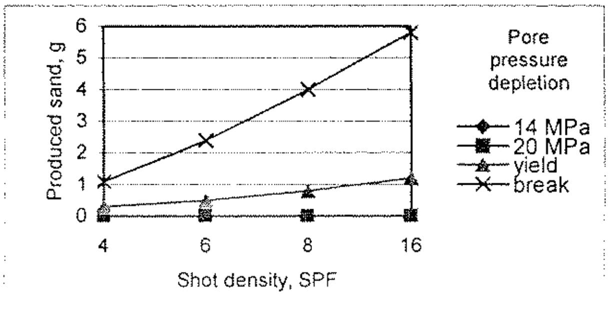

Fig. 2- Effects of perforation shot density to sand production.

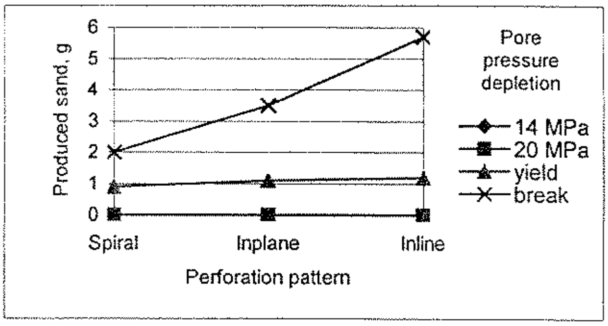

Fig. 3- Effects of perforation pattern to sand production.

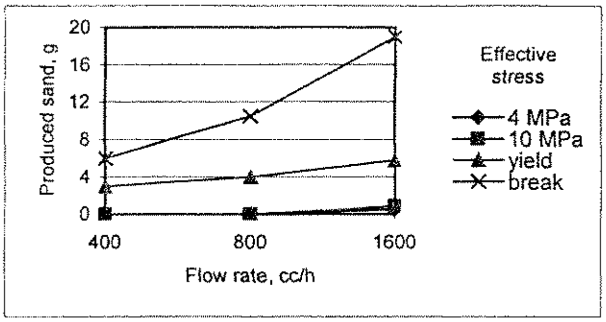

Fig. 4- Effects of flow rate to sand production.

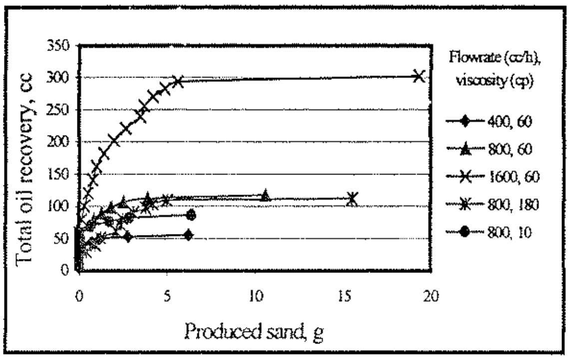

Fig. 5- Effects of sand production to total oil recovery.

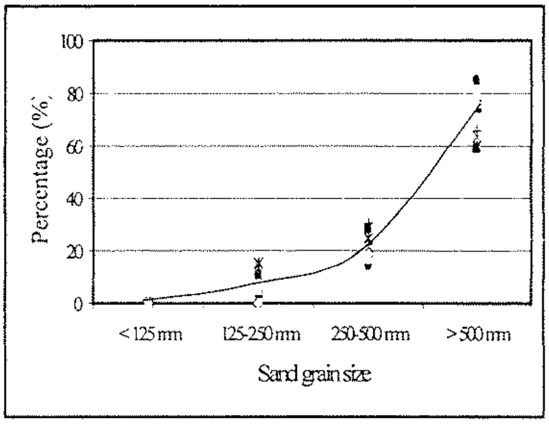

Fig. 6- Sand size distribution.