Productivity Analysis of Frac-pack Completion in M Well with Sand Problem Indication and High Permeability Formation

Herianto, Prasandi Abdul Aziz, Wijoyo Niti Daton, Steven Chandra

Petroleum Engineering Program, Institut Teknologi Bandung, Jalan Ganesha No 10, Bandung, Indonesia

Keywords: Frac-pack, Completion, Sand Control, Skin, Productivity Index.

Abstract: Sand problem is one of the obstacles happening in oil and gas wells, especially in poorly consolidated formation. flowing fluid will generate friction force during flow in porous media and in a longer timeframe, it can erode the wall of formation and sand will be produced along with the hydrocarbon and become problem in the whole production system. The negative impacts of this sand start from eroding the tubing wall until entering the surface facilities, such as separator. Due to this problem, the damaged equipment needs to be fixed or maintained, which means additional cost. Frac-pack is one of completion methods which is quite popular nowadays in oil and gas industry due to its proven effectiveness of utilization in the field. Frac-pack is a combination between hydraulic fracturing and sand control. Utilization of gravel pack only will cause additional skin for wellbore, leading to decrement of well productivity index. In frac-pack, the hydraulic fracturing process will cover the losses and reduce the skin generated. Therefore, sand problem can be mitigated, and production also can be compensated. This study will observe frac-pack, starting from its history, mechanism and effectiveness to be applied in M Well. The gravel pack size will be calculated first and is used as fundamental of proppant size selection. Then, fracturing process simulation is done using commercial software generating fracture width and fracture half-length. The result will be used to calculate final well productivity by considering skin generated. This research has proven that productivity can be enhanced by using frac-pack until 5.23%. Therefore, frac-pack can be an effective choice of sand control completion method in M Well.

1 INTRODUCTION

Well completion is a process of preparing drilled well to become a ready-to-produce well. In other words, it is a bridge between drilling and production phase. Well completion itself consists of many sub-processes, i.e. perforation and surface facility installation. In designing a good well completion plan, there are many things that should be put into consideration. One of them is concern if the well produces sand or not.

Sand production has been an obstacle in oil and gas industry. Sand production is usually caused by poorly consolidated formation. The problem becomes a challenge for companies since it can bring harm to hydrocarbon production and the durability of equipment. These damages are finally leading to cost increment, which is avoided by company. Negative impacts of sand production can be: produced sand becomes waste at surface; eroded tubing or casing wall; maintenance cost of surface facilities to remove the produced sand.

Sand problem itself is not a new thing anymore in Indonesia. Many wells in Kalimantan Island has experienced severe sand problem (Angtony et al., 2018; Abass and Nasr-El-Din, ; Bellarby,). There have been some completion methods, which have been usually used to mitigate sand problem in unconsolidated reservoir, such as critical rate control, gravel pack, chemical consolidation and frac-pack. These proposed methods cause dilemma for companies due to the impacts they give. Critical rate control is a method of maintaining the producing rate below the limit of erosion rate. This can be useful but still it sets a limit to hydrocarbon production.

Second, gravel pack is quite popular, but it takes expensive cost for the installation and maintenance. Furthermore, the gravel pack can give additional skin to the reservoir. The third method is chemical consolidation, which can also cause permeability reduction, leads to decrement of hydrocarbon production (Chaudhri, 2003; Cinco-Ley and Samaniego,).

Nowadays, in oil and gas industry, frac-pack becomes a thing for becoming chosen completion

Herianto, ., Aziz, P., Daton, W. and Chandra, S.
Productivity Analysis of Frac-pack Completion in M Well with Sand Problem Indication and High Permeability Formation.
DOI: 10.5220/0009359902910298
In *Proceedings of the Second International Conference on Science, Engineering and Technology (ICoSET 2019)*, pages 291-298
ISBN: 978-989-758-463-3

method to mitigate sand control. This is not surprising since frac-pack combines two processes, fracturing and packing. Fracturing will create more paths for hydrocarbon to flow and gravel packing will resist sand to be produced. Thus, well productivity logically will increase but still sand problem can be mitigated. This thesis will mostly talk about frac-pack and its modelling in M Well in Indonesia.

2 BASIC THEORY

History of Frac-pack

Frac-pack term is first popularized in the late of 1950 by Shell in Germany to define a completion method which conducts fracturing before installing gravel pack (Ellis, 1998). Another application of frac-pack is conducted by Amoco in Hackberry, Louisiana, in 1964, which involves fracturing method in the current sand control completion. At that time, the process is called "hack fracs" (Ellis, 1998; Economides et al.,).

Not until the successful result of Tip-Screenout (TSO) in North Sea Chalk formations. Prudhoe Bay and Kuparuk Field (Alaska) in 1987, frac-pack method is focusly developed. Over the years, frac-pack is now utilized by combining TSO hydraulic fracture, which creates short and high conductive fracture, and gravel pack, which resist the proppant from flowing back. The fracture created is meant to bypass near-wellbore damages, which can give negative impact to hydrocarbon production.

However, before frac-pack is highly recommended for sand problem mitigation nowadays, this method apparently is used to be highly debatable. This conflict is caused by concerns that frac-pack is prone to problems, such as adding the completion cost and contaminating the nearby water bearing sands. This concerns can be tackled by the effectiveness of frac-pack utilization in many fields in the world, starts from Gulf of Mexico, America, Africa, Europe until Asia Pacific, as stated by R.C. Ellis (Ellis, 1998; Febriani, 2003; Hashemi and Gringarten,). Until now, the number of frac-pack utilization keeps increasing all over the world and this shows a good prospect of frac-pack in the future.

Frac-pack Mechanism

Frac-pack is originally a combination between fracturing and gravel-pack. The standard to measure a successful frac-pack is the ability of this method to mitigate sand problem and at the same time create fracture to cover the skin made by the sand screens. This fracture created is held open by utilizing proppant pumped along with the fracturing fluid.

Tip-screen out fracturing is a method used to do fracturing in weak and high permeability reservoir. The goal is creating short and wide fracture with length of 25 to 50 ft and width of 1 to 2 in by forcing an early screen-out. Screen-out is a condition when treatment area cannot accept proppant anymore, causing the pump pressure increase to its limit and proppant cannot flow farther to the tip (Houchin and Dunlap, ; Odeh, 1980; Ott, 2003). This is occurred when the fluid leaks off to the formation faster than predicted, caused by the high permeability of the formation. Screen-out is usually undesirable because a fracturing process with early screen-out cannot achieve its designed fracture length and width. However, in frac-pack, the fracture geometry is not the main goal. Fracturing process is conducted by following these stages:

- Spearhead stage

Also known as acid stage, this stage is meant to clear debris which may still exist in the wellbore by using a mixture of water and diluted acid, i.e. hydrochloric acid. The result of this stage is a clear pathway for fracturing fluid to flow into the formation.

- Pad stage

In this stage, the fracturing fluid will be pumped into the well to frac the formation and initiate fracturing of target formation. Due to its purpose to make fractures only, proppant has not been mixed in the fracturing fluid. Proppant/slurry stage In this stage, proppant (sand) will be mixed with the fracturing fluid before being pumped into wellbore. Proppant is used to keep the fracture opened. Thus, it is meant to maintain the enhanced permeability created by the fracturing in the pad stage.

- Flush stage

In this stage, fresh water will be pumped into wellbore. It is meant to flush out any excess proppant, which may still exist in the wellbore. Tip Screen-out fracturing process in each stage can be seen in Figure 1.

Frac-pack Benefits

Frac-pack offers many benefits, which impacts to its popularity as sand control completion method, which are:

- Lower average skin value: skin generated from fracturing process can reduce the skin create by the gravel pack only, leading to a better productivity.
- Support high production rate of production
- Longer life span. As proppant is filling the fracture to the tip, the sand will be filtered from pack at the tip first. This can improve the life span of frac-pack because the sand pack around perforation is not affected too much.

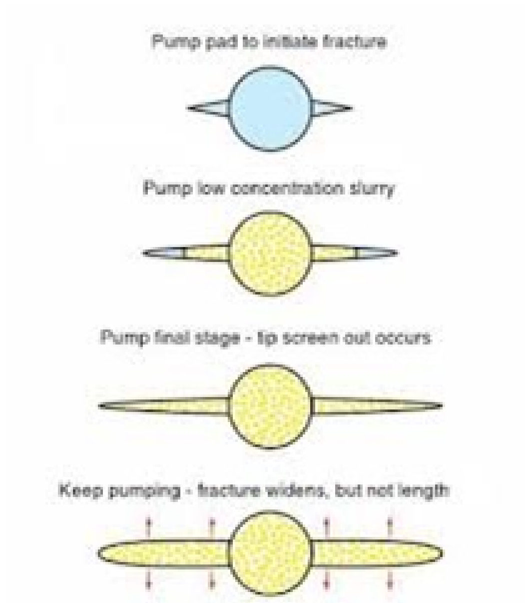

Figure 1: Tip Screen-out Process (Well Completion Design (Bellarby,2009))

- Has small failure percentage, shown in Figure 2 than other sand control completion method.

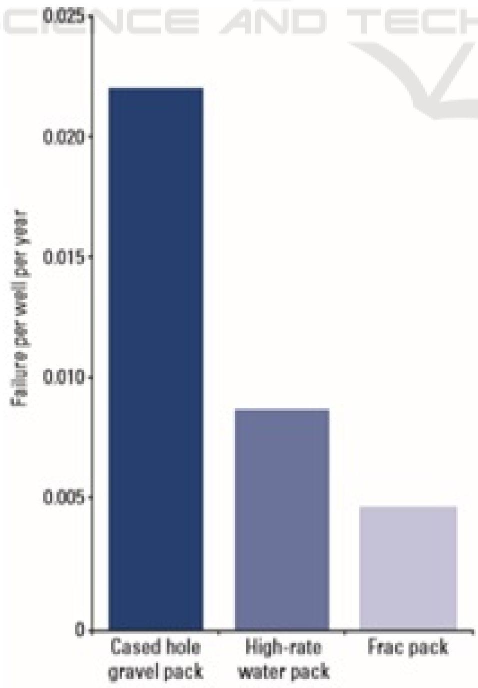

Figure 2: Comparison on Failures of Sand Control Method (Ellis, 1998)

Frac-pack Limitation

Despite of its effectiveness, frac-pack also has some limitations, namely

- Inappropriate for wells with gas cap
- Inappropriate for wells with poor cement quality
- Inappropriate if there is no effective barrier between aquifer and reservoir zone. However, thin shale barrier (about 1 m) is enough to ensure safe operation

3 METHODOLOGY

Sand Pack Sizing

In frac-pack method, this sand sizing is used later to determine the size of proppant used in fracturing process. Proppant will take role to keep the fracture open and become screen for sand. In determining which size of proppant to use, sieve analysis is one common method to use. In this thesis, sizing will be based on Schwartz correlation (1969)(Pucknell and Clifford, ; Renpu, ; Saucier, 1974), which considers the uniformity of formation and velocity to pass the screen. The sieve analysis result will be used to calculate the gravel size. For non-uniform sand condition, Schwartz suggested a correlation to determine the effective gravel size.

$$D_(40(gravel)) = 6 * D_(40(formation)) \quad (1)$$

D40(gravel) is the recommended gravel size and D40(formation) is formation grain size where 40% of the grain is grain from the biggest diameter. In addition, uniformity coefficient term is introduced to analyze the distribution of gravel size, formulated as follows.

$$UC = D_g 40 / D_g 90 \quad (2)$$

Then, a minimum and maximum size of gravel diameter is calculated using these formulas.

$$D_(40(gravel)) = 0.615 * D_g 40 \quad (3)$$

$$D_(40(gravel)) = 1.383 * D_g 40 \quad (4)$$

The minimum and maximum values of gravel diameter will be suited to the availability of sand pack size, shown in Figure 3.

Hydraulic Fracturing Simulation

After determining the suitable proppant size, the next step is making simulation of fracturing. This simulation is held in a commercial fracturing software. In this software, fracture analysis is conducted. The procedures, as shown in Figure 4, are: entering the well parameters, selecting proppant, selecting fracturing fluid, designing treatment schedule and

Sieve size	Opening		Standard Mesh
(mm)	(in)	(10^{-6} m)	US
11.2	0.438	11200	7/16"
6.35	0.250	6350	1/4"
5.6	0.223		3.5
4.75	0.187		4
4.0	0.157		5
3.35	0.132		6
2.80	0.110		7
2.36	0.0937		8
2.0	0.0787		10
1.7	0.0661		12
1.4	0.0555		14
1.18	0.0469		16
1.0	0.0394		18
0.841	0.0331	841	20
0.71	0.0278		25
0.595	0.0232	595	30
0.50	0.0197		35
0.400	0.0165	400	40
0.355	0.0139		45
0.30	0.0117		50
0.250	0.0098	250	60
0.210	0.0083	210	70
0.177	0.0070	177	80
0.149	0.0059	149	100
0.125	0.0049	125	120
0.105	0.0041	105	140
0.088	0.0035	88	170
0.074	0.0029	74	200
0.063	0.0024	63	230
0.053	0.0021	53	270
0.044	0.0017	44	325
0.037	0.0015	37	400
0.025	0.0010		500
0.020	0.0008		632

Figure 3: Availability of Gravel Pack Size (Reproduced from Febriani, 2003)

running the simulation. The simulation result will show the fracture profile, from the proppant concentration until the fracture conductivity distribution. The result will be used in the next step, which is determining whether frac-pack is effective to be applied in M well or not.

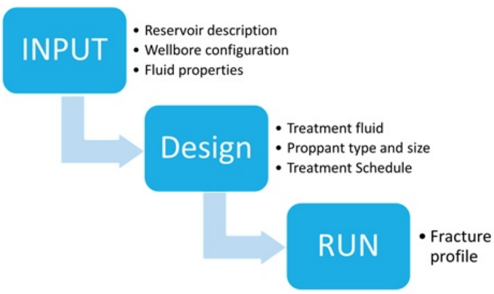

Figure 4: Flowchart of fracturing simulation

Skin Calculation

Frac-pack will be called effective if it can mitigate sand problem by applying the sand screen and increase the production. This can be known by calculating the skin that may be caused by frac-pack process. Based on the book written by Chaudhri (Chaudhri, 2003), there are some causes that can create skin. In this thesis, there are only three relevant skin causes, which are: partial penetration, perforation and fracturing.

Skin Due to Partial Penetration

Partial penetration is commonly happened in gas well. The wells are usually produced in only certain parts of pay zone, creating limited entry for the fluid. Partial penetration scheme can be seen in Figure 5. The formula to calculate skin factor due to partial penetration, Sp, is presented by Yeh and Reynolds (Yeh and Reynolds,), as follows.

$$S_p = (\frac{1-b\prime}{b\prime})ln(h_{wd}) \tag{5}$$

Where :

$$h_wd = \frac{c'b'(1-b')h_d}{exp(c_1)} \tag{6}$$

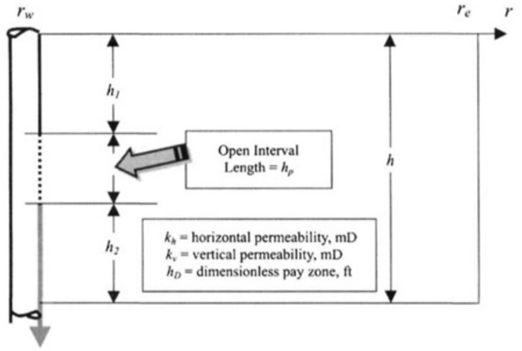

Figure 5: Partial Penetration Scheme (Gas Well Testing Handbook (Chaudhri,2003))

$$b' = \frac{h_p}{h} \tag{7}$$

$$h_D = \frac{h}{rw\sqrt{\frac{kh}{kv}}} \tag{8}$$

$$c_1 = 0.481 + 1.01(b') - 0.838(b')^2 \tag{9}$$

$$\Delta Z_D = \begin{bmatrix} h_1 & h_2 \\ h & h_1 \end{bmatrix} \tag{10}$$

While c' can be estimated using the graph in Figure 6.

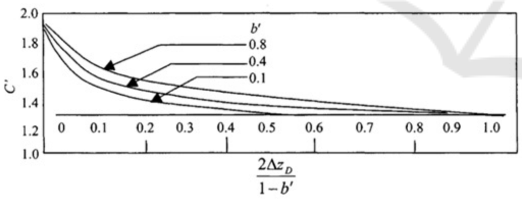

Figure 6: C' Determination on Yeh and Reynolds Method (Gas Well Testing Handbook (Chaudhri,2003))

Skin Due to Perforation

Skin due to perforation can be calculated using a semi-analytical solution presented by Karakas and Tariq (Karakas and Tariq, 8247). This perforation skin is sum of plane flow effect (S_H), vertical skin effect (S_V) and wellbore effects (S_{wb}).

Plane Flow Effects

$$S_H = ln\left(\frac{rw}{r'w(\theta)}\right) \tag{11}$$

$$r'_{\mathrm{w}}(\theta) = \{a_\theta(r_{\mathrm{w}} + L_{\mathrm{perf}})\} for \theta \neq 0 \tag{12}$$

$$r'_{\mathrm{w}}(\theta) = \{a_\theta(r_{\mathrm{w}} + \frac{L_{\mathrm{perf}}}{4})\} for \theta = 0 \tag{13}$$

Vertical Skin Effect

$$S_v = 10^a h^{\frac{b-1}{d}} r^{\frac{b}{d}} \tag{14}$$

$$h_d = \frac{hp}{lp}\sqrt{\frac{kv}{kH}} \tag{15}$$

$$r_d = \frac{r_{\mathrm{p}}}{2h_{\mathrm{p}}}\left(1 + \sqrt{\frac{kv}{kH}}\right) \tag{16}$$

$$a = a_1 log r_D + a_2 \tag{17}$$

$$b = b_1 r_D + b_2 \tag{18}$$

Wellbore Effects

$$S_w b = c_1 e^{c2rWD} \tag{19}$$

$$r_W D = \frac{r_w}{L_P + r_w} \tag{20}$$

a_1,a_2,b_1,b_2,c_1, c_2 are functions of perforation phasing and can be seen in Figure 7.

Perforation phasing	a	a_1	a_2	b_1	b_2	c_1	c_2
0° (360°)	0.250	−2.091	0.0453	5.1313	1.8672	1.6E-01	2.675
180°	0.500	−2.025	0.0943	3.0373	1.8115	2.6E-02	4.532
120°	0.648	−2.018	0.0634	1.6136	1.7770	6.6E-03	5.320
90°	0.726	−1.905	0.1038	1.5674	1.6935	1.9E-03	6.155
60°	0.813	−1.898	0.1023	1.3654	1.6490	3.0E-04	7.509
45°	0.860	−1.788	0.2398	1.1915	1.6392	4.6E-05	8.791

Figure 7: Constants for Perforation Skin Effects Calculation (Gas Well Testing Handbook (Chaudhri,2003))

After calculating all those elements, skin due to perforation can be calculated using this formula:

$$S_P f = S_H + S_V + S_w b \tag{21}$$

Skin Due to Fracturing Fracture performance is a function of dimensionless fracture conductivity (CfD) as shown in Figure 8. Dimensionless fracture conductivity can be calculated using this formula.

$$C_{fd} = \frac{kfw}{kx_f} \tag{22}$$

This relationship is presented by Cinco-Ley and Samaniego (1981). Equivalent wellbore radius is calculated for the fracture by assuming that the fracture is not adjacent to ant boundaries that may cover interval of its reservoir. Using blue line in Figure 8, skin due to fracturing can be determined using this relationship S_f+ln(x_f/r_w). In 2005, the relationship

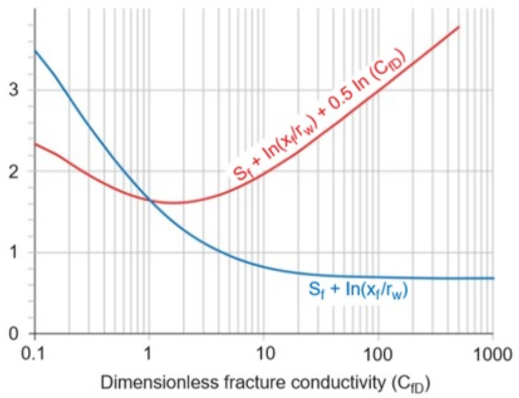

Figure 8: Fracture Performancen Under Pseudo Radial Flow (Well Completion Design (Bellarby,2009))

between skin and dimensionless fracture conductivity (CfD) is generalized and validated by Meyer and Jacot (Meyer and Jacot,).

Productivity Analysis

Determination on whether the productivity is increasing or not can be concluded by its Fold of Increase (FOI), which is represented below:

$$FOI = \frac{ln\left[\frac{re}{rw}\right] - 0.75 + S_{pre}}{ln\left[\frac{re}{rw}\right] - 0.75 + S_{post}} \quad (23)$$

4 CASE STUDY

This thesis uses data from M well, an offshore gas well in Indonesia which has been indicated to produce sand. The reservoir pore pressure is measured to be 5,812 psi. This well's formation has medium to high permeability for about 259 mD and porosity for about 19.4%. The fluid viscosity is about 0.0299 cp. Water saturation in this well is big enough, for about 41%. This reservoir is sandstone in the interval of 10,335 – 10,839 ft TVDSS. There is no gas cap indication that means frac-pack can be conducted in this well. In addition, the water depth is 4,255 ft and has been observed that the temperature in depth of 10,312 ft is 182°F.

Based on DST data which conducted in M Well, the drainage radius of this well is 4000 ft. The design of M well consists of 4 casing string: conductor casing, surface casing, intermediate casing and production liner with OD of 36", 20", 13-5/8" and 9-5/8" in order. This well is perforated in the interval of 10,405 – 10,479 ft TVDSS. The perforation scheme is: shot density: 4 SPF; perforation radius (rp): 0.25 inches; perforation penetration depth (L_{perf}): 8 inches and phasing angle: 120°.

A study has been conducted to analyze the rock strength of M reservoir and the result states that the formation is medium in strength, means that this well needs sand control method so that it can produce fluid until depletion phase. Furthermore, the reservoir is not well distributed so that a completion type with larger gravel/sand interface is required to prevent plugging. Frac-pack is the sand control method chosen to mitigate sand problem in this well. To determine the effective gravel size, sieve analysis is conducted with the result in Table 1.

5 RESULT AND DISCUSSION

The sieve analysis result shows that the uniformity coefficient is 6.18. From Table 2, C value shows that the sand grain in this M formation is poorly sorted. In order to use Schwartz correlation, D40 value is required. From the calculation, it is obtained that D40 value is 0.01793 in. The gravel design, based on Schwartz concept, results in minimum gravel diameter (D_{min}) of 0.01103 in and maximum gravel diameter (D_{min}) of 0.02480 in. According to the availability of gravel size shown in Figure 3, the gravel size chosen is 20/40 US Mesh. This result will be used to choose proppant selection in Fracpro simulation.

Proppant used in the simulation is Brady 20/40 because of some reasons. First, Brady 20/40 is a natural-source sand, make it easy to obtain. The sand will be shifted to the size of 20/40 US Mesh. Due to its availability, this sand will cost cheaper than another type of proppant.

Second, the screen will have a certain life span. In a time, the screen will be run out because it will be plugged by fine sand. That makes refracturing will be required. Using this type of proppant will make the refracturing easier. This refracturing is conducted after re-perforating the formation by using deep penetrating perforation. If resin-coated proppant or ceramic proppant is used, the process will be more difficult because those proppants will create a harder layer. Furthermore, Brady 20/40 is enough for this formation since the formation is not a tight formation or basement.

Fracturing fluid used in this simulation is Dynafrac HT 30, provided by Weatherford. Fracturing fluid will be used to bring proppant along, thus need a gel strength. Dynafrac HT 30 with viscosity of 270.9 cp is suitable to provide a good gel strength. In addition, this fluid is common so it will be easy to obtain.

In this case with high permeability involved, a slow fluid rate will be inappropriate. High permeability means that there will be more hole or pores in the

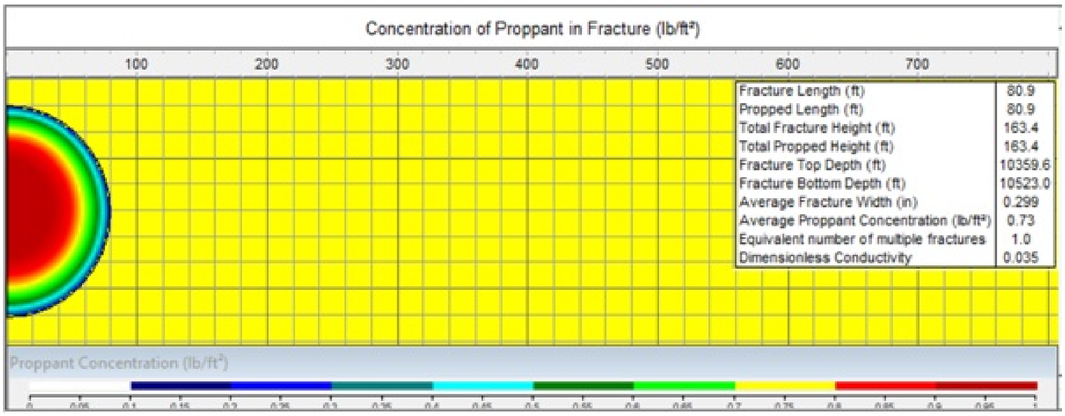

Figure 9: Fracture Profile as result from Fracpro simulation

Table 1: Sieve Analysis Result of M Well Formation

			MEASUREMENT I		MEASUREMENT II	
NO.	MESH	IN	% WEIGHT	% CUMM. WEIGHT	% WEIGHT	% CUMM. WEIGHT
1	20	0.0331	9.837	9.837	12.791	12.791
2	30	0.0232	2.350	12.187	2.581	15.372
3	35	0.0197	1.843	14.030	1.723	17.095
4	50	0.0117	7.591	21.621	7.661	24.755
5	60	0.0098	3.679	25.301	3.469	28.225
6	80	0.0070	9.496	34.797	6.786	35.011
7	100	0.0059	5.688	40.485	7.591	42.602
8	200	0.0029	32.005	72.490	26.691	69.293
9	pan	0	27.510	100	30.707	100

Table 2: C value Description

C<3	well sorted, highly uniform sand
3<C<5	uniform sand
5<C<10	moderate/poorly sorted sand
C>10	poorly sorted highly non-uniform sand

formation, commonly called sink hole. Thus, the fracturing fluid pumped to reservoir can enter the hole. If the rate is slow, the fluid can easily flow to the macro pores, leaving the proppant and then leading to early screen-out. This will create a very short fracture and fail to make a good frac-pack. However, in frac-pack method, a long fracture is unneeded because the focus is to mitigate the sand problem but here the treatment designed should be used effectively. That is why, in this case, a rate of 50 bpm is used. Meanwhile, the slurry treatment is conducted in 6 stages, whose proppant concentration are 2, 2, 3, 4, 5 and 6 ppg respectively. This is done so that the proppant will be well spread in the fracture until the tip.

The fracture profile is shown in Figure 9. The proppant concentration profile shows that the proppant has been well spread in the fracture. It is less and less to the fracture tip. The fracture width (W_f) and half-length (X_f) created are 0.025 ft (0.3 in) and 80.9 ft respectively. The dimensionless fracture conductivity is 0.03511.

Then, skin calculation is done based on formula in Subchapter 3. It is assumed that M formation is isotropic. The result is shown in Table 3. From the result, the fracture skin is negative, means that frac-pack is successful because it can reduce the damage created by the partial penetration and perforation.

Fold of Increase is calculated to be 1.0523, means that frac-pack has increased the well productivity of 5.23%. This is good result because the goal of frac-pack, which are mitigating sand problem and increasing productivity index, is achieved.

Table 3: Skin Calculation

Skin due to Partial Penetration	Sp	27.80013
Skin Due to Perforation	Spf	0.120039
Fracture Skin Factor	Sf	-1.80814
Skin before frac-pack	Spre	27.92017
Skin after frac-pack	Spost	26.11203

6 CONCLUSION

In designing frac pack completion for well M, the proppant used is Brady 20/40, where the gravel size is selected based on sieve analysis. The fluid used is Dynafrac HT 30, whose vendor is Weatherford, based on its suitable characteristic for this case. The designed treatment has created fracture width of 0.3 in and fracture half-length of 80.9 ft. This thesis proves that frac-pack completion method is an effective method to be applied in sand problem indicated well, in this case, M well. The productivity enhancement is about 5.23%. This enhancement is happened due to fracturing process.

REFERENCES

Abass, H. H. and Nasr-El-Din, H. A. 2002. *Sand Control: Sand Characterization, Failure Mechanisms and Completion Method. SPE*, page 77686.

Angtony, W., Winarto, H., Chandra, S., Herianto, H., Nugroho, Y. A., and Marhaendrajana, T. (2018). *Application of Novel Doped Nanomaterial Resin to Increase Sand Consolidation in A Loose Sandstone Reservoir*. Proceedings Indonesian Petroleum Association, Forty Second Annual Conference and Exhibition.

Bellarby, J. *2009*. Well Completion Design.

Chaudhri, A. U. (2003). *Gas Well Testing Handbook*.

Cinco-Ley, H. and Samaniego, F. 1981. *Transient Pressure Analysis for Fractured Wells. SPE*, 7490.

Economides, M. J. et al. *1994*. Petroleum Production Systems.

Ellis, R. C. (1998). *An Overview of Frac-Packs: A Technical Revolution (Evolution) Process*.

Febriani, S. (2003). Penanggulangan masalah produksi. *Thesis in Islamic University of Riau No. TP.06. 01*, 01.(01).

Hashemi, A. and Gringarten, A. C. *2005*. Comparison of Well Productivity between Vertical, Horizontal and Hydraulically Fractured Wells in Gas-Condensate Reservoirs.

Houchin, L. R. and Dunlap, D. D. 1988. *Formation Damage during Gravel-Pack Completions. SPE*, page 17166.

Karakas, M. and Tariq, S. (18247). *1988*. Semi Analytical Production Model for Perforated Completion.

Meyer, B. R. and Jacot, R. H. 2005. *Pseudosteady-State Analysis of Finite-Conductivity Vertical Fractures. SPE*, page 95941.

Odeh, A. S. (1980). *An Equation for Calculating Skin Factor Due to Restricted-Entry*. JPT, Journal of Petroleum Technology,(June).

Ott, W. K. (2003). *World Oil: Modern Sandface Completion Practices Handbook First Edition*.

Pucknell, J. K. and Clifford, P. J. 1991. *Calculation on Total Skin Factors. SPE*, page 23100.

Renpu, W. *2011*. Advanced Well Completion Engineering.

Saucier, R. J. (1974). *Considerations in Gravel Pack Design*.

Yeh, N. S. and Reynolds, A. C. *1989*. Computation of the Pseudo-Skin Caused by a Restricted-Entry Well Completed in a Multilayer Reservoir.