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# HYDRAULIC FRACTURING EVALUATION OF WELL ZAA-011 PANGKALAN SUSU FIELD, NORTH SUMATRA

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## ABSTRACT

Well ZAA-011 is a well located in the Pangkalan Susu field that has been depleted, where the reservoir has experienced a decrease in producing ability due to fair permeability. Well ZAA-011 produces with artificial lift in the form of a hydraulic pumping unit (HPU) and has a water cut value of 72%. The well is producing in sandstone Structure B, located at a depth of 3392 - 3412 ft MD, with a reservoir pressure of 606 psia. Well ZAA-011 has a permeability of 10 mD or fair and a productivity index of 1.084 bpd/psi. The method used to evaluate hydraulic fracturing stimulation in the ZAA-011 well is by using MFrac simulation which is an evaluation measurement in the previous hydraulic fracturing process. The fracture properties parameters are fracture half-length, fracture width, fracture height, fracture conductivity, dimensionless frac conductivity, and reservoir permeability. Production parameters are seen through pipesim simulation in the form of nodal analysis to see the optimal production rate. Economic parameters using profit indicators are calculated with the production sharing contract model cost recovery model including NPV, IRR, ROI and POT obtained. Based on the simulation using MFrac software, the hydraulic fracturing design values are fracture half-length 34.239 m, fracture width 0.37321 inch, fracture height 14.42 m, fracture conductivity 12984 mD-ft, dimensionless frac conductivity 6.4239. Permeability was found to be 37 mD and theoretically the average is about 36.7 mD and the productivity index also increased by 2.383 bpd/psi. Plus nodal analysis in the wellbore using pipesim software obtained a production rate of 238.8 BLPD (67.54 BOPD). Economic analysis using profit indicators obtained an NPV value of MUS$ $937, IRR with a value of 250.71%, ROI of 77.22% and POT obtained 0.354 years or about 4,248 months. This indicates that the redesign work on hydraulic fracturing in the ZAA-011 well is effective and optimal.

**Keywords:** hydraulic fracturing; fracture half-length; fracture height; conductivity fracture; dimensionless frac conductivity.

## I. INTRODUCTION

Hydraulic fracturing is an option in increasing the productivity index value and permeability price. Especially for the sandstone formation in the ZAA-011 well, the hydraulic fracturing method is appropriate for stimulation. The goal is to improve the fluid flow capacity in the formation and pave the way for hydrocarbons to flow more easily into the wellbore in order to obtain a large increase in production. Hydraulic fracturing is the most widely applied technique in oil and gas well stimulation, and has a significant effect on productivity. This method is superior compared to other stimulation techniques. Fractured formations are capable of increasing small to high permeability. The control system for the success parameters of this stimulation includes the permeability formed, fracture conductivity and parameters related to fracture geometry (fracture half-length, fracture width and fracture height).

Hydraulic fracturing includes two main parts: proppant and fract fluid. Proppant is the material used in hydraulic fracturing to keep the fractures open and thus aid extraction. Proppants are available in various materials and sizes, and each type has its own advantages. One of these is Resin-Coated Sand. The advantage of using Resin-Coated Sand technology is that individual proppant grains are allowed to bond to each other resulting in silica grains that will bond uniformly when the temperature and pressure reach the appropriate level. To perform hydraulic fracturing, frac fluid is injected at high speed and pressure into the wellbore. The volume of fluid pumped will affect the length of the fractures created. However, without pumping proppant into the fractures, the fractures created will close after the pumping operation stops. Fract fluid is needed to prevent particles from settling before reaching the end of the fracture. The best way to control the viscosity of fract fluid is by the addition of synthetic or natural polymers. Hydraulic fracturing operations must be carried out with sound environmental practices to reduce the risk of air, water, and soil contamination. All activities should adhere to the relevant environmental laws and regulations. Any hazardous material spills should be promptly addressed in line with an established spill response plan. Waste and surplus materials should be managed and disposed of safely for the environment.

Well candidate selection is an important factor that plays a role in the success and failure of hydraulic fracturing treatments. The main step of hydraulic fracturing stimulation selection is to select the target well and formation. Selection of well candidates that have great potential for implementation can increase the success rate. Well ZAA-011 is in a sandstone formation where cementation or bonding between grains in the formation is small. Hydraulic fracturing design has several success parameters: proppant characteristics, fract fluid characteristics, field considerations, and data set development. Improving the elements involved in hydraulic fracturing design can save time and money during the process. So in the economic calculation, it is necessary to see the amount of cost components incurred in the hydraulic fracturing design that must be profitable until the stimulation process is completed.

The successful evaluation of hydraulic fracturing in Well ZAA-011 can be seen from the measurement results of the use of proppant which is able to increase the value of fracture half-length, fracture width, fracture height, fracture conductivity, and fracture permeability. In the production aspect, it can increase the productivity index (PI) and production rate. In the economic aspect, the optimization values of NPV, IRR, ROI and POT were obtained.

## II. METHODS

In this study, an evaluation of the hydraulic fracturing process at the ZAA-011 well will be carried out. The data required are reservoir data, production data, well completion, post-job report and economic data. The initial stage carried out is the evaluation of fracture geometry by manual calculation with the 2D PKN method, then calculating the average formation permeability with the Howard and fast method. Calculating formation productivity (J/Jo) with the prats method, and determining the nodal analysis graph before fracturing and after fracturing. then calculating economic parameters using profit indicators calculated with the production sharing contract model cost recovery model including NPV, IRR, ROI and POT obtained.

## III. RESULTS AND DISCUSSION

Well ZAA-011 is producing with an artificial lift hydraulic pumping unit (HPU) and has a water cut rate of 72%. The well is producing in sandstone Structure B, located at a depth of 3392 - 3412 ft MD, with a reservoir pressure of 606 psia. The decision to conduct hydraulic fracturing on well ZAA-011. The decision to conduct hydraulic fracturing in the ZAA-011 well is based on the reason that the ZAA-011 well has a small permeability of 10 mD, and with a low fluid production rate of 167 BLPD (46.76 BOPD) through nodal analysis calculations using pipesim software. Hydraulic fracturing stimulation is expected to form conductive channels in the form of fractures, which will increase the price of oil production rates, so as to increase well productivity and achieve the desired production target. This part consists of the research results and how they are discussed. The results obtained from the research have to be supported by sufficient data. This section must be around 50% of the total article text.

### Determination of Proppant and Fracturing Fluid Concentration

The implementation of hydraulic fracturing design is carried out with the help of MFrac software, but before the hydraulic fracturing design stage is carried out, it is necessary to conduct a series of tests to obtain data that will later be used to design hydraulic fracturing. The implementation of the hydraulic fracturing design of the ZAA-011 well itself is divided into several stages. After several preparations for data collection and several tests, the next stage is the main fracturing. so that the following results are obtained.

**Table III-1**
**Hydraulic Fracturing Surface Treatment Schedule Design Data**

| *Stage No.* | *Avg Slurry Rate (bpm)* | *Liquid Vol. (bbl)* | *Slurry Vol. (bbl)* | *Total Slurry Volume (bbl)* | *Total Time (min)* | *Fluid Type* | *Prop Type* | *Cone. From (lbm/gal)* | *Cone. To (lbm/gal)* | *Prop. Stage Mass (lbm)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 54.007 | 16.173 | 16.173 | 16.173 | 32.444 | FG30 7% | 0000 | 0 | 0 | 0 |
| 2 | 11.381 | 13.093 | 13.093 | 1.471 | 14.748 | FG30 7% | 0000 | 0 | 0.00099113 | 27.251 |
| 3 | 10.697 | 8.595 | 88.047 | 23.515 | 22.979 | FG30 7% | 0000 | 053.914 | 053.914 | 19.462 |
| 4 | 12.518 | 64.641 | 67.225 | 30.238 | 2.835 | FG30 7% | C003 | 056.821 | 12.397 | 24.542 |
| 5 | 13.228 | 36.675 | 3.965 | 34.202 | 31.347 | FG30 7% | C003 | 13.128 | 23.555 | 28.253 |
| 6 | 12.791 | 30.947 | 35.182 | 37.721 | 34.098 | FG30 7% | C003 | 24.534 | 37.353 | 4022 |
| 7 | 11.158 | 34.466 | 40.721 | 41.793 | 37.747 | FG30 7% | RC1630 | 38.102 | 43.985 | 59.413 |
| 8 | 11.252 | 29 | 34.786 | 45.271 | 40.838 | FG30 7% | RC1630 | 44.285 | 45.959 | 54.959 |
| 9 | 11.671 | 37.589 | 46.643 | 49.936 | 44.835 | FG30 7% | RC1630 | 46.708 | 62.247 | 86.006 |
| 10 | 11.693 | 31.197 | 4.089 | 54.025 | 48.332 | FG30 7% | RC1630 | 63.464 | 77.082 | 92.075 |
| 11 | 11.927 | 46.612 | 62.562 | 60.281 | 53.577 | FG30 7% | RC1630 | 77.613 | 77.167 | 15151 |
| 12 | 11.076 | 1.059 | 1.059 | 6.134 | 54.533 | FG30 7% | RC1630 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 6.134 | 82.267 | FG30 7% | 0000 | 0 | 0 | 0 |

**Table III-2**
**Fluid and Proppant Type Design Specification Data**

| Parameter | Nilai | Satuan |
|---|---|---|
| *Fluid Type*: FG35 7% - COSL PA-FG35 w/ 7% KCl + 2 gpt PA-BF, 18 gpt XT-9, 4.0 pp | 574 | (bbl) |
| *Proppant Type*: C003 - 20/40 CARBO-Lite | 9288,8 | (lbm) |
| *Proppant Type*: S100 - 100 Mesh | 1946,2 | (lbm) |
| *Proppant Type*: RC1630 - RCS SuperLC 16/30 SanTrol | 44418 | (lbm) |

After some preparation of data collection and some tests, the next stage is the main fracturing. This stage is the main stage, namely applying the design that has been prepared as **Table III-1** and **Table III-2**. Furthermore, in the main fracturing process, several pressure parameter values are also obtained which serve as a comparison and matching with the previous production and Borehole Hydraulic data in **Table III-3.**

**Table III-3**
**Borehole Hydraulic Well ZAA-011 Data**

| Parameter | Nilai | Satuan |
|---|---|---|
| ***Hydraulic Power Required*** | 1502,3 | hhp |
| ***Surface Pressure, Min.*** | 297,25 | psi |
| ***Surface Pressure, Max.*** | 5278,7 | psi |
| ***BHTP Pressure, Min.*** | 2166,9 | psi |
| ***BHTP Pressure, Max.*** | 3276,2 | psi |
| ***Gravitational Head, Min.*** | 1544,1 | psi |
| ***Gravitational Head, Max.*** | 2174,6 | psi |
| ***Frictional Pressure Loss, Min.*** | 530,06 | psi |
| ***Frictional Pressure Loss, Max.*** | 3816,8 | psi |

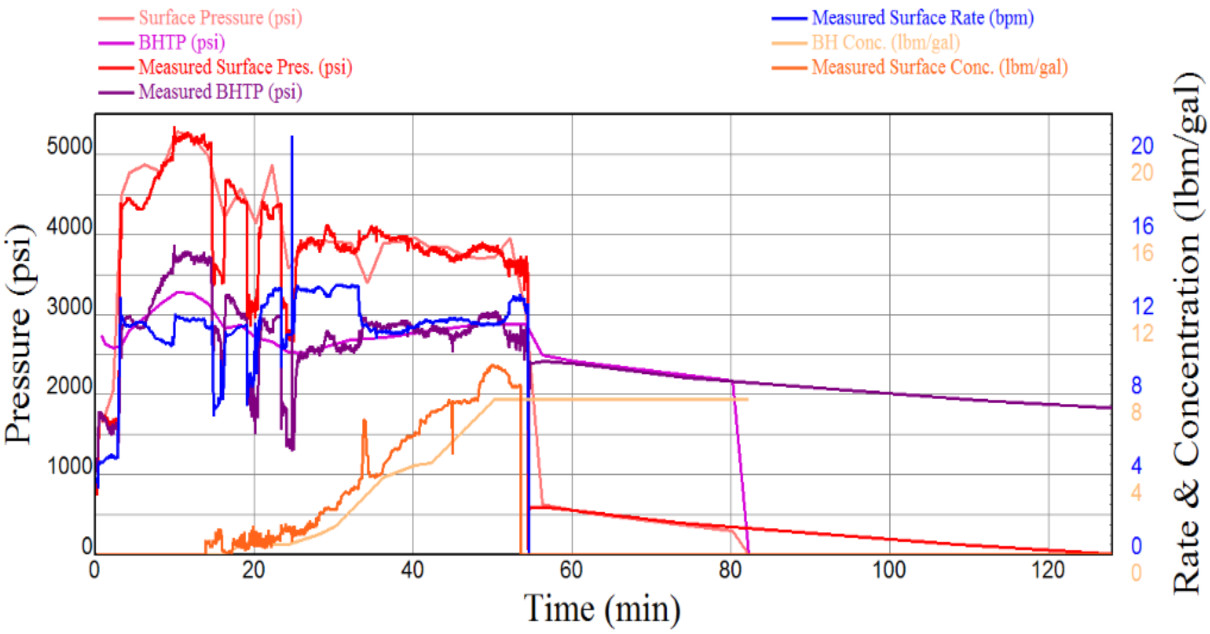


**Figure I. Design of Main Fracturing Pressure Matching Well ZAA-011**

**Determination of Design Value of Fracture Properties**

Based on the simulation design using MFrac software, it is estimated that the geometry model that will be formed is shown in **Figure 2**. Described in the figure displays the distribution of fracture width and length obtained in the hydraulic fracturing process. In addition to fracture properties, it also displays the value of stress distribution at that depth.

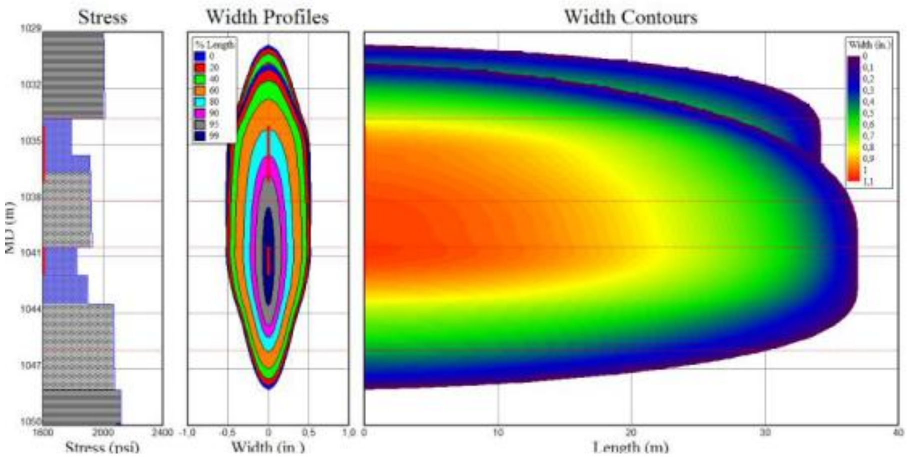


**Figure 2. Well ZAA-011 Fracture Geometry Design Model**

Based on simulations using MFrac software, Determination of fracture half-length, fracture width, fracture height, fracture conductivity and dimensionless frac conductivity. estimated fracture geometry formed as in **Table III-4.**

**Table III-4**
**Fracture Properties Design Results Well ZAA-011**

| Parameter | Nilai | Satuan |
|---|---|---|
| *Frac Fluid Efficiency* | 0,34943 | |
| *Net Frac Pressure* | 629,55 | (psi) |
| *Frac Length - Created* | 34,239 | (m) |
| *Frac Length - Propped* | 34,226 | (m) |
| *Frac Height - Avg.* | 14,42 | (m) |
| *Propped Height (Pay Zone) - Avg.* | 4,3974 | (m) |
| *Max Width at Perfs - EOJ* | 1,0335 | (in.) |
| *Propped Width (Well) - Avg.* | 0,37321 | (in.) |
| *Propped Width (Pay Zone) - Avg.* | 0,3637 | (in.) |
| *Conc./Area (Frac) - Avg. at EOJ* | 2,3908 | (lbm/ft²) |
| *Conc./Area (Pay Zone) - Avg. at Closure* | 3,0052 | (lbm/ft²) |
| *Frac Conductivity (Pay Zone) - Avg. at Closure* | 12.984 | (mD-ft) |
| *Dimensionless Frac Conductivity (Pay Zone)* | 6,4239 | |
| *Avg. Fracture Permeability* | 430,84 | (darcy) |
| *Res. Permeability* | 37 | mD |

**Determination of Production Data**

The success or failure of hydraulic fracturing is based on the production and productivity produced after hydraulic fracturing. In this case, production evaluation is carried out by certain methods which include evaluation of the average permeability of the formation, evaluation of the productivity index ratio. Well ZAA-011 produces hydrocarbon fluid from a formation with a small permeability of 10 md. After simulation, a permeability value of 37 mD was obtained. Theoretically, hydraulic fracturing of a rock formation will increase the permeability price of the rock followed by an increase in fluid flow rate. The following is the calculation of the permeability price after fracturing (Kf) and the average permeability distribution price (Kavg) as a result of hydraulic fracturing at well ZAA-011.

1. Calculate formation permeability from wellbore to fracture tip/fracture permeability ($k_f$):

$$K_f = \frac{(Ki \times h) + WKf}{h}$$

$$K_f = \frac{(10 \times 20) + 12984}{20} = 650{,}7 \text{ mD}$$

2. Fracture formation causes permeability in the area around the well. Thus, the average formation permeability ($k_{avg}$)

$$K_{avg} = \frac{\log\left(\frac{820}{rw}\right)}{\left[\frac{1}{kf}\log\left(\frac{xf}{rw}\right)\right] + \left[\frac{1}{k}\log\left(\frac{re}{xf}\right)\right]}$$

$$K_{avg} = \frac{\log\left(\frac{820}{0{,}264}\right)}{\left[\frac{1}{650{,}7}\log\left(\frac{112{,}332}{0{,}264}\right)\right] + \left[\frac{1}{10}\log\left(\frac{820}{650{,}7}\right)\right]} = 36{,}7 \text{ mD}$$

After evaluating the average permeability of the formation, the next step is to analyse the productivity index ratio after hydraulic fracturing. The productivity index is an index that shows the ability of a well to produce. The calculation of the productivity index uses the prats method because the parameters used are fulfilled in the calculation. The following is the calculation.

$$\frac{J}{Jo} = \frac{\ln(\frac{re}{rw})}{\ln\ (\frac{re}{0.5\ Xf})} = \frac{\ln(\frac{820}{0,264})}{\ln\ (\frac{820}{0.5\ x\ 56,16634})} = 2,383$$

Based on the acquisition of data that has been obtained, then calculate based on nodal analysis in the wellbore. This calculation uses pipesim software in calculating each design parameter that has previously been obtained from both reservoir and production. So that the amount (**Figure 3**) of production rate is obtained both before and after the hydraulic fracturing evaluation. Before the evaluation was 167 BLPD (46.76 BOPD) and after the evaluation 238.8 BLPD (67.54 BOPD).

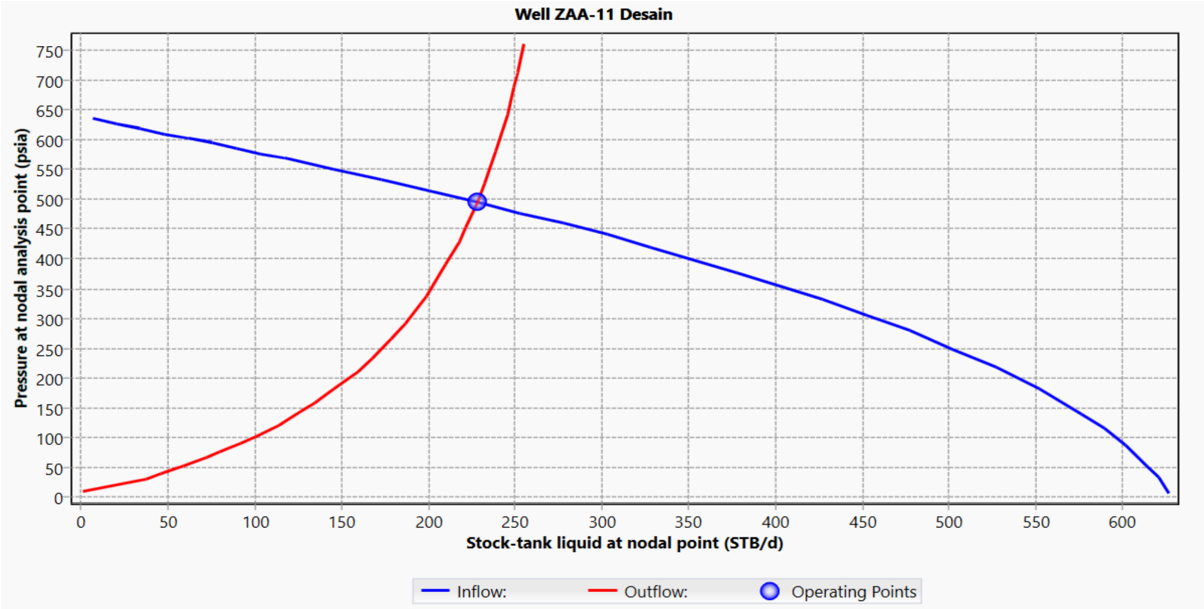


**Figure 3. Nodal Analysis Curve After Well ZAA-011**

### Economic Analysis

In this study, the profit indicators based on the production sharing model contract cost recovery used in the oil and gas industry will be discussed: NPV (Net Present Value), IRR (Internal Rate of Return), POT (Pay Out Time) and Return of Investment (ROI). The cost components arising from this project for the hydraulic fracturing process are as follows

**Table III-5**
**Cost Components Arising Hydraulic Fracturing Process Well ZAA-011**

| MATERIALS | COST | |
|---|---|---|
| Acid DeRuster | Rp | 8.678.663 |
| Breakdown Test dan SRT Test | Rp | 104.556.382 |
| Mini Fracturing | Rp | 175.294.725 |
| Main Fracturing | Rp | 864.515.306 |
| Proppant | Rp | 724.840.080 |
| Services | Rp | 986.000.000 |
| **Totals** | **Rp** | **2.863.885.156** |
| **Dollar** | **$** | **191.000** |

Meanwhile, the revenue component is obtained from the oil produced (oil gain). In this case, an example case is taken for the ZAA-011 well with an oil gain of 67.54 BOPD, assuming an oil price of US$ 74.59 and a decline rate of 10% per year and monitoring for 2 years. The following is the calculation and tabulation of the NPV of ZAA-011 using ROR or an interest rate of 12% per year. The following is an economic calculation adjusted to the production sharing model contract cost recovery.

**Table III-6**
**Economic Calculation Result in Well ZAA-011**

| No | Parameter | Unit | Value |
|---|---|---|---|
| 1 | **PRODUCTION** | | |
| | - Oil Production | Bopd | 67,54 |
| | - Gas Production | Mmscfd | - |
| | - Condensate Production | Bcpd | - |
| | - LPG Production | Tpd | - |
| 2 | **PRICE** | | |
| | - Oil Price | USD/bbls | 74,6 |
| | - Gas Price | USD/mscf | - |
| | - Condensate Price | USD/bbls | 74,6 |
| | - LPG Price | USD/ton | - |
| 3 | **PRODUCTION COST** | | |
| | - Oil Production Cost | USD/bbls | 20,0 |
| | - Gas Production Cost | USD/mscf | - |
| | - Condensate Production Cost | USD/bbls | 20,0 |
| | - Other Production Cost | USD | - |
| 4 | **GROSS REVENUE** | **MUS$** | **3.493** |
| | - Oil Gross Revenue | MUS$ | 3.493 |
| | - Gas Gross Revenue | MUS$ | - |
| | - Condensate Gross Revenue | MUS$ | - |
| | - LPG Gross Revenue | MUS$ | - |
| | **FTP** | **MUS$** | **175** |
| | **Gross Revenue - FTP** | **MUS$** | **3.318** |
| 5 | **EXPENDITURE** | **MUS$** | **1.147** |
| | - Investment Cost | MUS$ | 191 |
| | - Investment Capital Cost | MUS$ | 191 |
| | - Investment Non Capital Cost | MUS$ | - |
| | - Abandonment & Site Restoration | MUS$ | 19 |
| | - Operating Cost | MUS$ | 937 |
| | - Depreciation | MUS$ | 210 |
| 6 | **Cost Recovery** | **MUS$** | **1.058** |
| 7 | **Equity To Be Split** | **MUS$** | **2.260** |
| 8 | **Government Take** | **MUS$** | **1.461** |
| 9 | **Contractor Take** | **MUS$** | **974** |
| **NPV** | | **MUS$** | **$937** |
| **IRR** | | **%** | **250,71%** |
| **POT** | | **Years** | **0,354** |
| **Net Profit** | | **MUS$** | **$885** |
| **ROI/Net Profit Margin** | | **%** | **77,22%** |
| **Profitability Index** | | | **5,91** |

Based on **Table III-6** above, it can be concluded that:

- The NPV value obtained is MUS$ 937 in the hydraulic fracturing design of Well ZAA-011.
- The ROR value is obtained at 250.71% which means that the hydraulic fracturing design of Well ZAA-011 is feasible.
- POT is obtained 0.354 years or about 4.248 months which means the time a project will return its initial investment.
- ROI is a comparison between net income and investment costs. The greater the ROI the better the project is to run and the acquisition of 77.22%.

## IV. CONCLUSION

1. The decrease in oil production from well ZAA-011 is due to the small reservoir permeability of 10 mD which is fair, resulting in the potential of the productive well ZAA-011 decreasing from before.
2. The hydraulic fracturing design values obtained are fracture half-length 34.239 m, fracture width 0.37321 inch, fracture height 14.42 m, fracture conductivity 12984 mD-ft, dimensionless frac conductivity 6.4239. Permeability

was found to be 37 mD and theoretically the average was found to be about 36.7 mD and the productivity index also increased by 2.383 bpd/psi. Plus nodal analysis obtained a production rate of 238.8 BLPD (67.54 BOPD).
3. Economic analysis using profit indicators obtained NPV value of MUS$ $937, IRR with a value of 250.71%, ROI of 77.22% and POT obtained 0.354 years or about 4,248 months.

**REFERENCES**

Alderete, I. D., Sosa-Massaro, A., & D'Hers, S. (2017). *A Fluid Structure Interaction Model for Hydraulic Fracture Simulation on Vaca Muerta Argentina Shale Formation*. SPE Latin America and Caribbean Petroleum Engineering. SPE-185563-MS, 1-12. https://doi.org/10.2118/185563-MS

Bahtiar, Y. (2010). *Relevansi model psc modifikasi revenue to cost index(r/c) pada kerjasama migas di indonesia*. Institut Teknologi Bandung, 9.

Belyadi, H., Fathi, E., & Belyadi, F. (2019*). Hydraulic fracturing in unconventional reservoirs: theories, operations, and economic analysis*. Gulf Professional Publishing, 6.

Bhore, N. (2017). *An Investigation on Qualitative Analysis of Hydraulic Fracture Simulation for Field Development Planning*. SPE Annual Technical Conference and Exhibition. SPE-189281-STU. 1-8. https://doi.org/10.2118/189281-STU

Craft, B. C., Hawkins M. F., (1962). *Applied Petroleum Reservoir Engineering Second Edition.* Prentice-Hall Inc., Englewood Chiffs, New Jersey, 246-248.

Economides, M. J., & Hill, A. (1994). *Petroleum Production Systems*. Prentice Hall PTR. Upper Saddel River. New Jersey, 421-452.

Economides, M. J., & Kenneth. G, N. (2013). *Reservior Stimulation Third Edition*. Wiley New York, 1-28, 3-30, 6-4, 10-1.

Economides, M. J., & Martin, Tony. (2007). *Modern Fracturing: Enhancing Natural Gas Production*. BJ Services Company. Houston, 103–150.

Floriantina, E. (2021). *Perbandingan antara production sharing contract cost recovery dan gross split dalam usaha hulu minyak dan gas bumi di indonesia*. Jurnal Privat Law, 9-16.

Galawidya, D. A. (2008). *Analisis perbandingan termin fiskal production sharing contract di indonesia, production sharing contract non cost recovery dan production contract di Malaysia*. Unpublished Master Thesis. Universitas Indonesia, Depok, Indonesia, 15-18.

Gharibi, A., & Zoveidavianpoor, M. (2015). *Hydraulic Fracturing For Improved Oil Recovery*. Journal Of Advanced Research In Fluid Mechanics And Thermal Sciences Issn, 9(1), 1–18.

Kamal, H., Noke Fajar, P., Geraldus, Y., Luciana, S., Ricki Daniel, M., Reza, V., Apollinaris Stefanus Leo, A. (2018). *Successful Hydraulic Fracturing Optimisation in KS Field through Fracture Height.* SPE Asia Oil & Gas Conference in Exhibition Brisbane, Australia. SPE-191990-MS, 1-12. https://doi.org/10.2118/191990-MS

Kolawole, O., Esmaeilpour, S., Hunky, R., Saleh, L., Ali-Alhaj, H. K., & Marghani, M. (2019). *Optimization Of Hydraulic Fracturing Design In Unconventional Formations: Impact Of Treatment Parameters.* Society Of Petroleum Engineers - SPE Kuwait Oil and Gas Show and Conference, 2-3. https://doi.org/10.2118/198031-MS

Koplos, J., Tuccillo, M. E., & Ranalli, B. (2014). *Hydraulic Fracturing Overview: How, Where, And Its Role In Oil And Gas*. Journal - American Water Works Association, 106(11), 38–46. http://dx.doi.org/10.5942/jawwa.2014.106.0153

Kristanto, D., & Saputra, J. 2021. *An Integrated Analysis for Post Hydraulic Fracturing Production Forecast in Conventional Oil Sand Reservoir*. Journal Earth Energy Engineering, 6-10. https://doi.org/10.25299/jeee.2021.5024

Koesoemadinata, R. P. (1980). Geologi Minyak dan Gas Bumi, Jilid 1 dan 2. Institut Teknologi Bandung: Bandung, 79-83.

Limbong, H. (2008). *Optimasi Produksi Lapisan Conglomerate di Struktur Cemara dengan Hydraulic Fracturing*. IATMI 08-010. IATMI Simposium Nasional dan Kongres X, 2-6.

Lubiantara, Benny. (2012). *Ekonomi Migas: Tinjauan Aspek Komersial Kontrak Migas*. Jakarta: PT. Gramedia Widiasarana Indonesia, 77-87.

Lubis, Muhammad Arif Z., (2018) *Karakterisasi Litologi Serpih Formasi Baong Bagian Bawah Sebagai Reservoar Hidrokarbon Serpih di Daerah Tangkahan – Peunaron, Provinsi Sumatera Utara dan Aceh.* Universitas Trisakti, 16.

Pica, N. E., Terry, C., & Carlson, K. (2017). *Optimization Of Apparent Peak Viscosity In Carboxymethyl Cellulose Fracturing Fluid: Interactions Of High Total Dissolved Solids, Ph Value, And Crosslinker Concentration*. SPE Journal, 22(02), 615–621.

Priyantoro, T. A., Prakoso, N. F., & Kahfie, R. M. (2012). *Journey of Hydraulic Fracturing Improvement to Increase Oil Recovery from Sandstone Formation in Rimau Block*. SPE International Production and Operations Conference, 6-7.

PT. Pertamina EP. (2019). *Program Pemboran Eksploitasi.* PT. Pertamina EP Asset 1 Pangkalan Susu Field.

Rachmat, Sudjati., & Berman, Danyel (2016). *Komputasi untuk Optimisasi Keekonomian Hydraulic fracturing Vertikal Di Sumur Minyak*. JTMGB Volume 10 No.1, 7.

Rachmat, S., & Nugroho, S. E. (2010). *Pengaruh Ukuran Butir dan Penempatan Proppant Terhadap Optimasi Perekahan Hidraulik Sumur Minyak*. JTM Vol.XVII No.2, 107-116.

Rahman, K., He, W., & Gui, F. (2014). *Reservoir Simulation With Hydraulic Fractures: Does It Really Matter How We Model Fractures*? *Society Of Petroleum Engineers* - SPE Asia Pacific Oil And Gas Conference And Exhibition, Apogce, 32–45.

Ramadhani, Ahmad Diyo. (2020). *Evaluasi Petroleum System Berdasarkan Metode Seismik dan Wireline Log Area 'D', Cekungan Sumatra Utara.* Universitas Trisakti, 3-11.

Ramones, M., Gutierrez, L., & Moran, M. (2015). *Unlocking A Mature Field Reservoir Potential Through Optimized Fit-For-Purpose Hydraulic Fracturing*. SPE-177219-MS, 6. https://doi.org/10.2118/177219-MS

Romadhon, T. M. (2009). *Pengaturan Production Sharing Contract Dalam Undang-Undang Minyak Dan Gas*. Jurnal Hukum Ius Quia Iustum, 16(1), 90.

Ryan Hadi Pratama, I., & Kartoadmodjo, Trijana. (2017). *Perencanaan Dan Evaluasi Stimulasi Perekahan Hidraulik Metoda Pilar Proppant Pada Sumur R Lapangan Y*. Seminar Nasional Cendikiawan, 111.

Santoso, R.R. (2017). *Evaluasi Keberhasilan Hydraulic fracturing Pada Sumur R Lapangan X*. Seminar Nasional Cendikiawan ke 3, 252.

Schechter, R. S. (1992). *Oil Well Stimulation*, Prentice Hall Englewood Cliffs, New Jersey 07632, 246.

Saputra, Asruddin. (2020). *Analisis Penerapan Corporate Social Responsibility (CSR) Pada PT. Pertamina EP Asset 1 Pangkalan Susu Field.* Universitas Islam Negeri Sumatera Utara, 34-37.

Shuai, L., Bo, C., Yunhong, D., Yongjun, L., & Chunming, H. (2016). *Damage of Fracture Face Skin in Massive Hydraulic Fracture Stimulation*. IADC, 1-9.

Sukarno, Pudjo. & Tobing, E. L., (1995). *Inflow Performance Relationship For Perforated Wells Producing From Solution Gas Drive Reservoir*. Asia Pacific Oil & Gas Conference and Exhibition Kuala Lumpur. SPE-29312-MS. 3-4. https://doi.org/10.2118/29312-MS

Sulistyarso, H. B. (2019*). Effect of Pump Rate Penetration Sensitivity on Hydraulic Fracturing in Low Resistivity Reservoir*. Petroleum and Science Engineering. Science Publishing Group, 10-11. https://doi.org/10.11648/j.pse.20190301.13

Speight, James G., (2016). *Handbook of hydraulic fracturing.* John Wiley & Sons. New Jersey. Canada, 174-200.

Usman, M. D., and Soelistijono, M. (2010) *Study on Productivity Improvement of Low Permeability Gas Reservoir by Hydraulic Fracturing.* Lemigas Scientific Contributions Vol. 33 No. 2, 120.

Valko, P. and Economides, M. J. (1995): "*Hydraulic Fracture Mechanics*", John Wiley and Sons, Chichester, England, 97-197.