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Multi-Stage Hydraulic Fracturing Completion Design Based on Ball-and-Sleeve Method

Kasi Njeudjang [a, *], Alain Amougou Zanga [b], Nasr Saeed [c], Théophile Ndougsa-Mbarga [d], and Philippe Njandjock Nouck [e]

a Department of Quality Industrial Safety and Environment. National Advanced School of Mines and Petroleum Industries. University of Maroua. PO. Box: 46, Maroua, Cameroon
b Fundamental Physics Laboratory, Department of Physics, Faculty of Science, University of Douala, P.O. Box 24 157 Douala, Cameroon
c Department of Physics, College of Education, Nyala University, P.O. Box: 155, Nyala, Sudan
d Department of Physics, Advanced Teacher's Training College, University of Yaoundé I, PO. Box 47, Yaoundé, Cameroon
e Department of Physics, Faculty of Science, University of Yaoundé I, PO. Box 47, Yaoundé, Cameroon

Abstract

This paper proposes a completion that can allow fracturing four zones in a single trip in the well called "Y" (for confidential reasons) of the field named "X" (for confidential reasons). The steps to design a well completion for multiple fracturing are first to select the best completion method then the required equipment and the materials that it is made of. After that, the completion schematic must be drawn by using Power Draw in this case, and the summary installation procedures explained. The data used to design the completion are the well trajectory, the reservoir data (including temperature, pressure and fluid properties), the production and injection strategy. The results suggest that multi-stage hydraulic fracturing can be done in a single trip by using the ball-and-sleeve method. Metallurgy and hydrogenated nitrile are sealing elementary constituent of chromium which are essential materials found in alloy with 13% of chromium.

Keywords: Hydraulic fracturing, well completion, Multi-stage fracturing, Ball-and-sleeve, Power Draw.

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1- Introduction

In the beginning, one of the most important motivations in drilling a well is to affirm the presence of hydrocarbons as highlighted in reference [1-4]. In the field X, 7 wells were dried out of 10 and so spending money on them is not required. Investigations on the practical petroleum geochemistry for exploration and production as well as the future of oil supply have been carried out to in [5, 6].

The authors of [7, 8] verified if the presence of hydrocarbons were commercially feasible, then production begin after careful installation of some special equipment in the well and this is known as well completion. The articulation between the surface facilities and the reservoir can equally be referred to as completion as stated in [9-11]. And this has made it possible to produce a more safely and efficiently well. To attain the production objectives, the completion string must be properly designed. In some cases, permeability is low, leading to low production rates. This requires hydraulic fracturing to create a conductive path for the fluid from the reservoir to the well [12-14]. This process can significantly increase well productivity and oil and gas reserves. This topic is well addressed in the literature [15-18]. However, it deals with only one reservoir. Sometimes several reservoir zones are to be produced with a single well as it is more economical. Fracturing multiple zones is challenging because one zone has to be isolated while treating another zone [19].

The multistage hydraulic fractured technique has been proven to be a key technique to attain economic production from several kinds of reservoirs [20-23]. Hydraulic fracturing is a technology used since 1950 to improve oil production from tight reservoir [24, 25]. It consists of pumping a special fluid at a pressure high enough to initiate cracks in the rock. This process can significantly improve well productivity in low permeability reservoirs. A single well can be frequently produced from many zones due to economic considerations which makes it difficult to fracture them all at once since one zone must be separated while the other is being treated [26, 27]. These costs comprises of completion costs, fluid and proppants costs, and pumping charges [28]. When the operating time of the Multi-stage hydraulic fracturing (MSHF) is longer, the costs equally increased [29]. Recently, several investigations have been carried out to know the most economical method of completion [30]. Following the investigation in [30], there's no existing method of completion that's the best, but it rather depends on the applications. The total cost of MSHF can be reduced by carrying out a single trip operation. To design a completion that can perform

*Corresponding Author: Name: Kasi Njeudjang, Email: kasinj2006@yahoo.fr

hydraulic fracturing of multiple zones in a single trip in the well Y of the field X, the aim of this paper is to evaluate the feasibility of this design and to improve the conductivity near the horizontal section of selected well (Horizontal well).

The MSHF operation can be made successful, by constructing a perfect planned ahead. This can be done by choosing the most suitable materials, completion techniques and equipment. For a completion map to be successful, we are require to accomplish the following tasks: (i) Select the most appropriate completion techniques and corresponding equipment; (ii) choose a suitable materials so that the equipment can be used during the entire life of the well and (iii) draw the completion schematic and write installation procedures.

2- Data, Methods and Results

The data used to design the completion is presented in Table 1.

Table 1. Completion Data Representation for Well Y

Reservoir Data	Temperature=115°C Pressure = 4200 psi Fluid API gravity =32 Fluid type = Naphthenic H_2S content= 5ppm; CO_2 content=2.5mole%
Well Data	MD at toe =3500 ft Inclination= 90° at 2600 mMD
Productions objectives	Production strategy= 4 zones commingled Zone 4: Top=3200 mMD; bottom= 3240 mMD Zone 3: Top=3300 mMD; bottom= 3315 mMD Zone 2: Top=3420 mMD; bottom= 3450 mMD Zone 1: Top=3420 mMD; bottom= 3450 mMD
Injections objectives	Operation constraints=fracture in single trip Injection prsessure=High (Above reservoir break down pressure)

Based on the data of Table 1, the aim of this paper is attain by applying the appropriate economic evaluation and by using the PowerDraw software. The PowerDraw software is the well and completion schematics drawing program for the oil and gas industry which is a plug-in for Microsoft Visio. There are shapes for well and completions in PowerDraw software. By using the reservoir and well data as the input data of PowerDraw software, we can drag and drop the shapes of well and completions found in PowerDraw software to build the well and completion schematics, customize them, assemble them, calculate their depths, and write their descriptions in a table. Fig. 1, depicts the primary well schematic.

In Fig. 1, the casing design for well Y is consisted of 2 casings (13-3/8” surface casing at 750mMD, 9-5/8” intermediate casing at 1900mMD, both grades are L80) and 2 liners (7” liner at 2600mMD and 4-1/2” liner at 3500mMD, both grades are L80). When the well is at 100 mMD, it is being control by the tubing retrievable security valve (TRSV) which constitute 4-1/2’’ of the upper completion, a chemical injection mandrel to allow chemical injection at 1600 mMD, temperature and pressure at 2350 mMD are measure using a gauge mandrel, a landing bust beyond the production crowd and a landing bust beneath the production crowd to set plugs. The nominal weight of tubing with a magnitude of 4-1/2” is 12 pounds per feet, with a division of L80. The tubing string ends with a polished bore receptacle (PBR) and a seal assembly to seal in it. The PBR is used as a tieback for the 4-1/2” liner so that the production string has a consistent diameter of 4-1/2”.

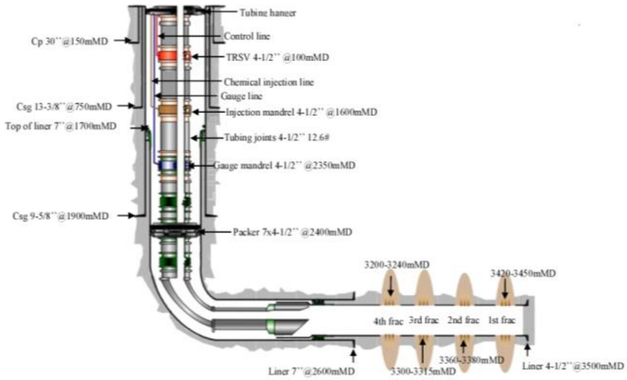

Fig. 1. Schematic of Primary Well

2.1. Metallurgy selection, seal selection and completion method selection

The results obtained in this subsection are based on the first-pass selection graph, the corrosion rates as a function of chromium content (Sumitomo Metals Industries, 2008) and the completion data of well Y. The qualified pressure of CO_2 and H_2S is 105 psi and 0.021 psi respectively. In assent, one of the most important metallurgy is alloy which constitutes 13% of Chromium (13Cr). In addition, the temperature of the reservoir is 115°C, which is 239°F. At this temperature, 13Cr has a lower corrosion rate than 9Cr. Fluids with H_2S content of 5 ppm, which is less than 10 ppm are kwon as Non-aromatic fluids. Furthermore, acid stimulation is not needed here, so there will be no presence of HCl. In addition, since there will be no injection of methanol (it is injected when there are hydrates in the well and hydrates form only in low temperatures, which is not the case here), nitrile should be the most appropriate elastomer for the sealing elements. Here, the temperature of operation is so close to the overlying maximum of nitrile temperatures. The best solution in this demonstration is done by using hydrogenated nitrile since HCl acid is not present. It has good physical properties and can resist higher temperatures.

It is well known that the two most commonly used techniques for a multi-stage hydraulic fracturing are the plug-and-perf technique and the ball-and-sleeve technique [31, 32]. In this case, the most appropriate method is ball-and-sleeve. The plug-and-perf method requires multiples wireline and coiled tubing runs to place the fracturing fluid. This improved the time and costs to carry out the fracture treatment. Moreover, the performance constraint of the fracture treatment in a single trip is clearly executed so that less rig time is required and high costs are saved. The cost of the apparatus to the rig cost is added to guess the cost of each technique. The pumping charges, fluid and proppants costs are the same for both plug-and-perf and ball-and-sleeve whereas the apparatus and equipment cost are different as shown in Table 2 and Table 3.

Table 2. Apparatus Cost for the "Ball-and-Sleeve" Technique

Item	Cost/unit ($)	Unit	Cost ($)
Fracking sleeve	9,000	3	27,000
Non-prep toe valve	4,000	1	4,000
Isolation valve	5,000	1	5,000
Isolation packer	3,500	5	17,500
Bullnose	1,000	1	1,000
Total cost ($)			54,500

Table 3. Equipment Cost for "Plug-and-Perf" Method

Item	Cost/unit ($)	Unit	Cost ($)
Bridge plug	8,000	3	24,000
Total cost ($)			24,000

The cost of the apparatus needed for plug-and-perf and ball-and-sleeve, can be compared when plug-and-perf completion appears to be more economical. But the plug-and-perf techniques need coiled-tubing interference for perforating and setting plug. It was approximated that the time to rig up (RU) and rig down (RD) between stages is 3 hours. It takes 1 hour to pump the treatment for each stage. The rig cost in shallow water offshore is predicted to be 400,000$ per day. So from calculation, the approximate cost for one hour is 16,667$. The costs of operation for both activities are presented Table 4 and Table 5.

Table 4. Operation Cost for "Ball-and-Sleeve" Method

Operation	Cost/Time($/hr)	Time (hr)	Cost ($)
Stage treatment	16 ,667	4	66,667
Total cost ($)			66,667

Table 5. Operation Cost for "Plug-and-perf" Method

Operation	Cost/Time ($/hr)	Time (hr)	Cost ($)
Stage treatment	16,667	4	66,667
RU/RD	16,667	12	200,000
Total cost ($)			266,667

Now for ball-and-sleeve completion, the costs are 54,500$ for equipment and 66,667$ for operation. The total cost is, therefore, 121,167$. For the plug-and-perf completion, the costs are 24,000$ for equipment and 266,667$ for effectiveness. The total expenditure in this demonstration is 290,667$. In this manifestation, ball-and-sleeve completion is more sparing. This paper discussed the completion design and its technical feasibility. In this demonstration, the reservoir pressure is 4,200 psi. By using a safety factor of 10%, the maximum working pressure is 4,620 psi. Therefore, equipment must be rated at 5,000 psi. Also, the working pressure of the equipment should be above 125°C.

2.2. Well completion design and running procedure

The proposed well Y completion design is depicted in Fig. 2.

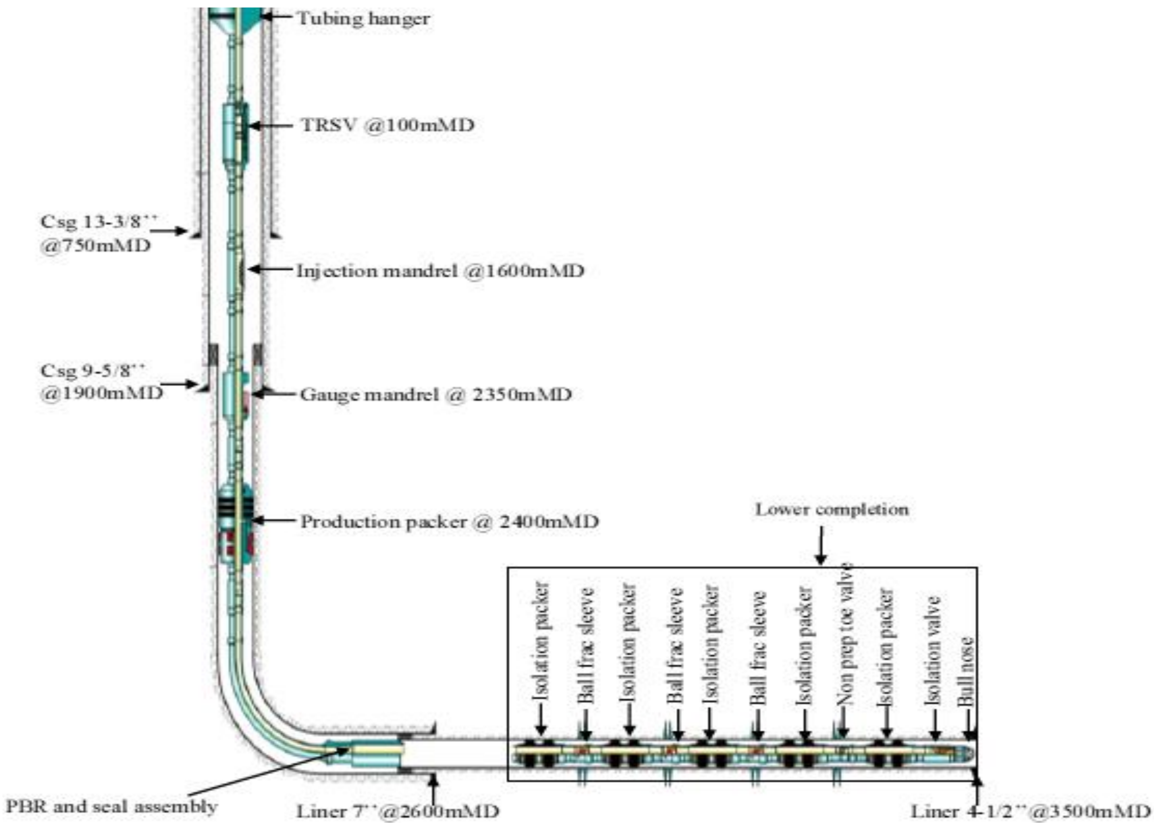

Fig. 2. Proposed Well Y Completion Design

In the lower completion, a ball and sleeve method is proposed. This consists of 5 isolation packers, 3 ball-activated fracking sleeves, 1 pressure-activated fracking sleeve or non-prep toe valve, 1 isolation valve and a bullnose as shown in Fig. 3.

The completion running process of the production section is done in ten steps. Initially, the well is perforated and filled with killing fluid then lower completion is run in the hole until total depth with a service tool as shown in Fig. 4.

The next step is to test all pumping lines to make sure they can deliver the required flow rates. Then a ball is dropped to land in the ball seat of the isolation valve, and when the pressure reaches the required pressure, the isolation valve closes. Now it is time to set the packers by applying perforated well filled with killing fluid internal pressure as shown in Fig. 5.

These packers will be set at a specified pressure. Of course, the uppermost packer is settled first, followed by the lower packers. The next step is to pump the first stage to fracture the first zone. The fracturing fluid is pumped from the surface, then through the lower completion. At this point, all the ball-activated fracking sleeves are closed. The non-prep toe valve will open at the required pressure and allow the fracturing fluid to enter the annulus between the casing and zone 1 as shown in Fig. 6.

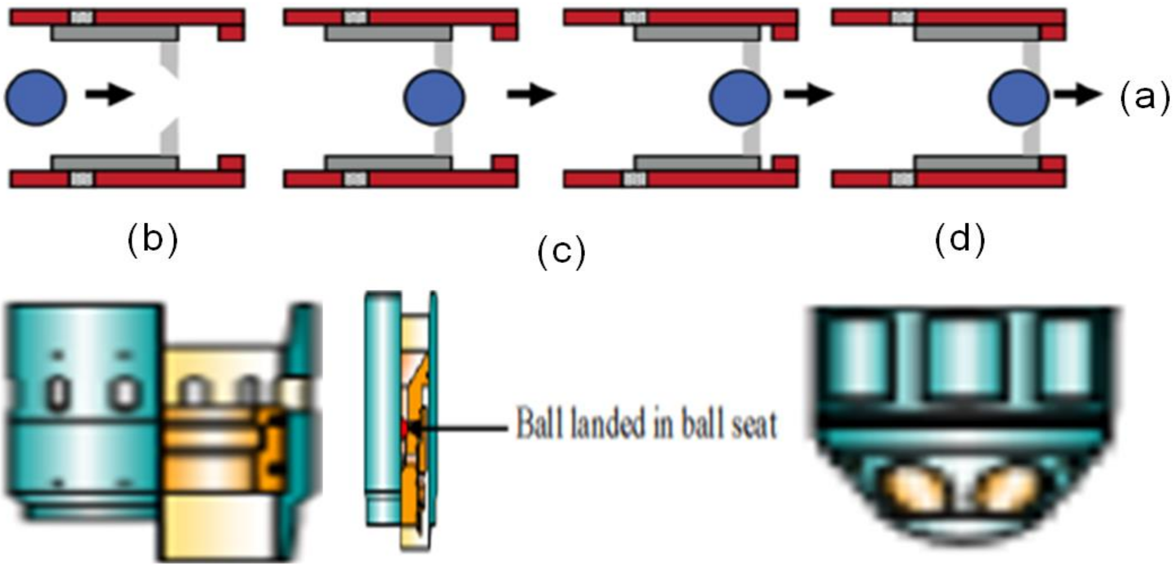

Fig. 3. (a) Activation Process of a Ball-Activated Fracking Sleeve, (b) Non-Prep Toe Valve, (c) Isolation Valve and (d) Bullnose

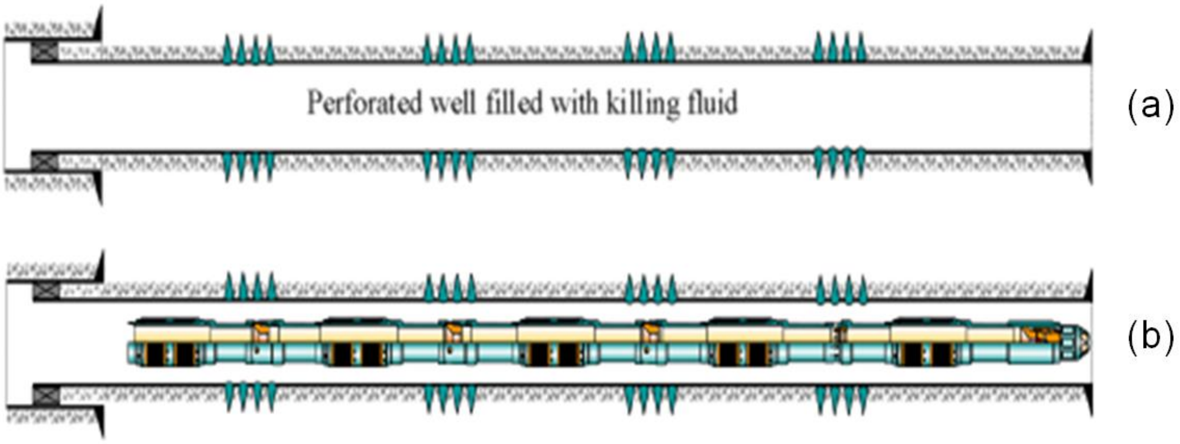

Fig. 4. (a) 4-1/2" Liner Initially and (b) Lower Completion Run in Hole

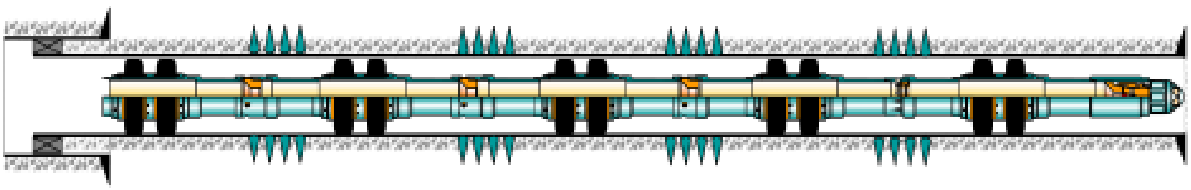

Fig. 5. Packers are Set, and the First Stage is Ready to be Pumped

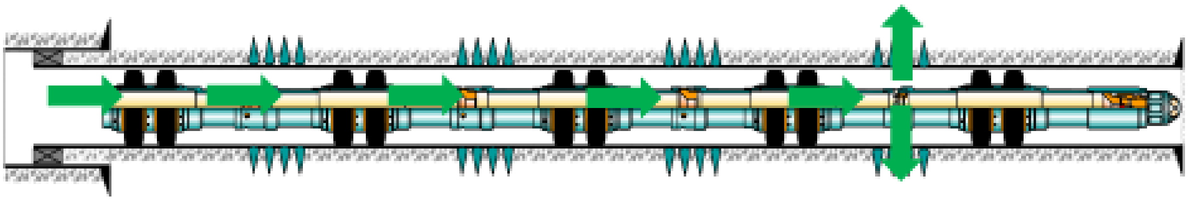

Fig. 6. Fluid Flow when Treating Zone 1

The second stage is to treat the zone 2 and isolate zone 1 at the same time. The smallest ball is dropped in the well and guided by the fluid to the lowest ball seat as shown in Fig. 7.

The ball reaches the first ball seat, and when enough pressure is applied to it, the sleeve shifts and opens the ports as shown in Fig. 8.

The third stage is pumped from the surface through the lower completion. The ball-activated fracking sleeves in front of zone 3 and zone 4 are still closed. The fluid enters the annular between the casing and zone 2. The ball prevents the fluid from going to zone 1. After treating zone 2, the next size ball is dropped from the surface and reaches the seat of the ball-activated fracking sleeve in front of zone 3. When enough pressure is applied, the ball-activated fracking sleeve is opened and zone 3 is treated as shown in Fig. 9.

After treating zone 3, the fourth stage is started where the largest ball is dropped from the surface and guided until it reaches the seat of the uppermost ball fracking sleeve. When enough pressure is applied above the ball, the sleeve shifts and the ports are open. Zone 4 is treated while the other zones are isolated as shown in Fig. 10.

Now that all the 4 zones are treated, the service tool can be pulled out of the hole. The balls are dissolved after a few hours, and the treated zone can be produced at the same time.

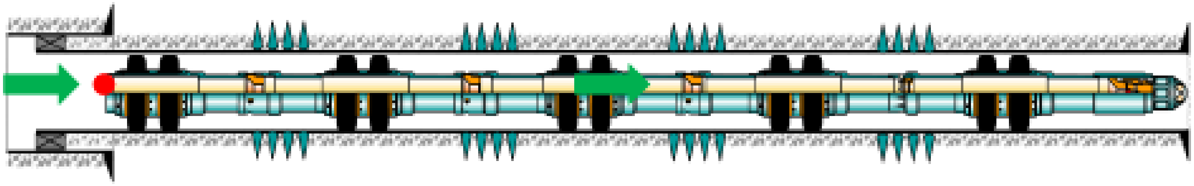

Fig. 7. First Ball is Dropped in the Well and Guided

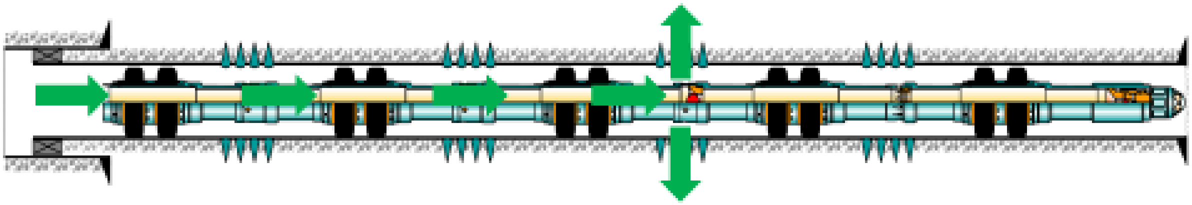

Fig. 8. First Ball Fracking Sleeve is Opened, and Zone 2 is Ready for Treatment

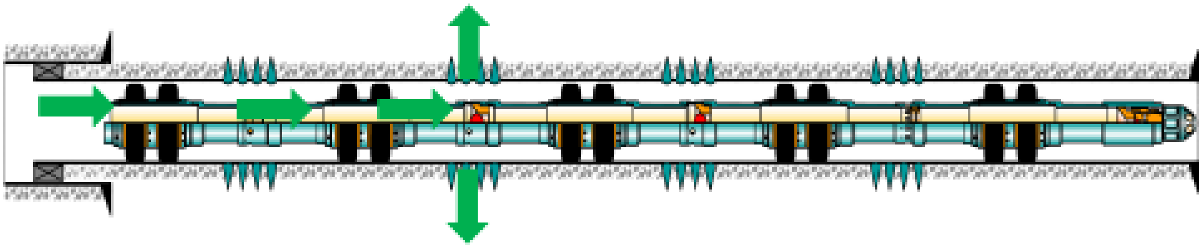

Fig. 9. Treatment of Zone 3

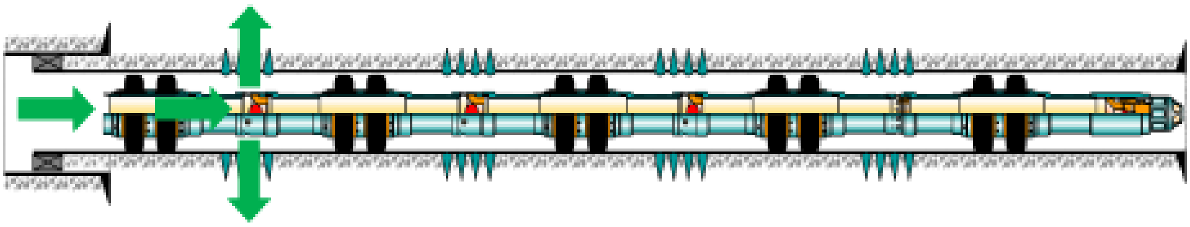

Fig. 10. Treatment of Zone 4

3- Conclusion

This paper present a completion outline to fracture 4 zones in a solitary trip needed in well Y of the field X. We found out that Metallurgy and hydrogenated nitrile are sealing elementary constituent of chromium which are essential materials found in alloy with 13% of chromium. In addition, it was found that in a corrosive environment, the resistance of steel at a temperature of 239°F is increase by adding 13% of chromium to produce better results than when 9% chromium is added. In the presence of fluids such as fabricated fluid, completion fluid, and fracturing fluid, both Metallurgy and hydrogenated nitrile could be used. But the operating temperature of the borehole was very close to the overlying maximum of nitrile applications, and hydrogenated nitrile was finally justified. The best completion technique, in this case, was the ball and sleeve method because it is the only one that can be performed in a single trip, and it is economical. To fracture the 4 zones in a single trip, 5 isolations packers, 3 ball-activated fracking sleeves, 1 non-prep toe valve, 1 isolation valve and 1 bullnose were needed. The packers isolated the annulus between the completion string and the casing, leaving this annulus as the only way to fracture and produce a target zone. The ball activated fracking sleeves isolated the lower zone while treating the upper zone, and later dissolution of the ball permitted commingled production. The non-prep toe valve has the same role as the fracking sleeve, but it is more economical to use it for the first stage. Finally, the isolation valve allowed setting packers. Here, the temperature of operation is so close to the overlying maximum of nitrile temperatures.

References

[1] Total, Formation of hydrocarbon deposits Planet energies, 20, 10-12 (2014).

[2] M. Economides, Petroleum production systems. Prentice-Hall (1994).

[3] M. Alain, Geology and Geodynamics of Hydrocarbons, Encyclopedia of Energy 5, 11-15 (2014).

[4] N. Arzhang, Best Method for Enhanced Oil Recovery from Saravak Reservoir abd Analyse Sensitive Parameters. Thesis. Iran, 105 (2016).

[5] Harry, Jr., Practical Petroleum Geochemistry for Exploration and Production, Elsevier, USA (2017).

[6] R. G. Miller and S. R. Sorrell, The future of oil supply, Phil. Trans. R. Soc. A 372, 20130179-20130205 (2014), https://doi.org/10.1098/rsta.2013.0179.

[7] Desorcy G. J., Estimation methods for proved recoverable reserves of oil and gas. 10th petoleum congress, 58 (1979).

[8] W. Oswald, K. Harper, P. Barickman, using growth and decline factors to project VOC emissions from oil and gas production, Journal of the Air & Waste Management Association 65, 64-73 (2015), https://doi.org/10.1080/10962247.2014.960104.

[9] R. John and L. Richard, Introduction to petroleum engineering. Wiley, New Jersey (2017).

[10] A. Hernandez, Fundamentals of Gas Lift Engineering: Well design and Troubleshooting. Elsevier Inc. (2016).

[11] B. Guo, W. C. Lyons and A. Ghalambor, Petroleum Production engineering a computer Assisted Approch. (E. S. Books, Éd.) (2007).

[12] A. Dheyauldeen, et al., Effect of well scheduling and pattern on project development management in unconventional tight gas reservoirs, Arabian Journal of Geosciences 15.14, 1-22 (2022), https://doi.org/10.1007/s12517-022-10500-z.

[13] Q. Lei, W. Xiong, J. Yuan, S. Gao & Y. S. Wu, Behavior of flow through low-permeability reservoirs, In Europec/EAGE Conference and Exhibition. OnePetro (2008), https://doi.org/10.2118/113144-MS.

[14] A. Dheyauldeen et al., Performance evaluation of analytical methods in linear flow data for hydraulically-fractured gas wells, Journal of Petroleum Science and Engineering 208, 109467 (2022), https://doi.org/10.1016/j.petrol.2021.109467.

[15] A. Z. Abidina, T. Puspasari and W. A. Nugroho, Polymers for Enhanced Oil Recovery Technology (Vol. 4). Bandung: Elsevier (2012), https://doi.org/10.1016/j.proche.2012.06.002.

[16] J. Bellarby, Well completion design, first edition, Elsevier, Amsterdam, Nertherlands 304-367 (2009).

[17] D. Matanovic, M. Cikes and B. Moslavac, Sand control in well construction and operation, Springer, Environmental Science and Engineering (2012).

[18] B. Bailey, M. Crabtree, J. Tyrie, J. Elphick, Kuchuk F, C. Romano, L. Roodhart, Water Control, Oilfield Review 12, 30-51 (2000).

[19] M. Economides & K. Nolte, Reservoir Stimulation. 3rd ed. Chichester: John Wiley & Sons (2000).

[20] M. Abdul Ameer & S. Hamed Allah, Experimental Work to Study the Behavior of Proppant Inside the Hydraulic Fractures and the Plugging Time, Iraqi Journal of Chemical and Petroleum Engineering, 17, 57–69 (2016).

[21] M. M. Rahman, M. M. Hossain, D. G. Crosby, M. K. Rahman & S. S. Rahman, Analytical, numerical and experimental investigations of transverse fracture propagation from horizontal wells, Journal of petroleum science and engineering 35, 127–150 (2002), https://doi.org/10.1016/S0920-4105(02)00236-X.

[22] O. Al-Fatlawi, M. Hossain, N. Patel & A. Kabir, Evaluation of the potentials for adapting the multistage hydraulic fracturing technology in tight carbonate reservoir, In SPE Middle East Oil and Gas Show and Conference. OnePetro (2019, March), https://doi.org/10.2118/194733-MS.

[23] Al-Sudani, J. A., & Husain, K. M. (2017). Evaluation of Acid and Hydraulic Fracturing Treatment in Halfaya Oil Field-Sadi Formation. Iraqi Journal of Chemical and Petroleum Engineering, 18(4), 25–33.

[24] F. Aminzadeh, Hydraulic fracturing and well stimulation. 1st ed. Hoboken: Jon Wiley & Sons (2009).
[25] J. Speight, Handbook of hydraulic fracturing. Hoboken: Jon Wiley & Sons (2016).
[26] R. Kleinberg, S. Paltsev, T. Boersma & D. Hobbs, Tight oil market dynamics: Benchmarks, breakeven points, and inelasticities. Energy Economics 70, 70-83 (2018), https://doi.org/10.1016/j.eneco.2017.11.018.
[27] A. Singh, L. Soriano & M. Lal, Comparison of multi-stage fracture placement methods for economic learning and unconventional completion optimization: A case history. Texas, Society of petroleum engineers, 20 (2017), https://doi.org/10.2118/184839-MS.
[28] H. Jabbari & S. Benson, Hydraulic fracturing design optimization - Bakken case study. San Francisco, American Rock Mechanics Association, pp. 1-6 (2013).
[29] O. Al-Fatlawi, M. Hossain, & A. Essa, Optimization of fracture parameters for hydraulic fractured horizontal well in a heterogeneous tight reservoir: an equivalent homogeneous modelling approach, In SPE Kuwait Oil & Gas Show and Conference, OnePetro. (2019), https://doi.org/10.2118/198185-MS.
[30] P. Mathur & N. Kumar, Contrast between plug-and-perf method and ball and sleeve method for horizontal well stimulation, at SPE Sub-Regional Meet held at UPES, Dehradun (2016).
[31] J. H. Lee, M. H. Lee and G. H. Jang, Effect of an Hourglass-Shape Tapered Sleeve on the Performance of the Fluid Dynamic Bearings of a HDD Spindle Motor, ASME 2013 Conference on Information Storage and Processing Systems (2013), https://doi.org/10.1115/ISPS2013-2870.
[32] E. A. Alali, M. A. Bataweel, R. Ernesto Arias Urbina and A. Bulekbay, Critical Review of Multistage Fracturing Completions and Stimulation Methods, Abu Dhabi International Petroleum Exhibition & Conference, SPE-203284-MS (2020), https://doi.org/10.2118/203284-MS.