Analysis of Proppant Hydraulic Fracturing in a Sand Oil Reservoir in Southwest of Iran

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Abstract- Hydraulic fracturing is one way to increase the productivity of oil and gas wells. One of the most fundamental successes of hydraulic fracturing operation is selecting the proper size and type of proppants which are used during the process.

The aim of this study is optimizing the type and size of used propant in hydraulic fracturing operation in a sand oil reservoir in southwest of Iran. In this study sand and ceramic (sintered bauxite) have been considered as proppant type. Also the various types of resin-coated sand and resin-coated ceramic have been considered. Then the various scenarios have been designed to optimize the size and type of proppant used in hydraulic fracturing in a sand oil reservoir in southwest of Iran.

Also in this study increasing the cumulative oil recovery in fractured and Non-fractured wells in a sand oil reservoir in southwest of Iran have been investigated.

Keywords- Hydraulic fracturing, Proppant, Sand, Ceramic, Resin

I. Introduction

Proppant is used to keep open the fracture channel and create a permeable path for passing the reservoir fluid through the fracture. Putting the appropriate type and concentration of proppant into fractures is the most basic in success of hydraulic fracturing treatment. Proppant must resist against the ground stresses and fracture closure pressure, so that can keep open the fracture channel after releasing the fracture fluid hydraulic pressure. So the strength of the proppant mass ingredients is extremely important. Proppant must be so hard that tolerate the closure stress, otherwise it will be crushed by these closure stresses and fracture conductivity will be significantly lower than planned. In addition to the proppant strength, other factors that should be considered for selection proppant include size, composition and density. [1]

Much work has focused on developing and evaluating various materials for use as proppants for hydraulic fracturing. Sand is used most often as a fracturing proppant in shallow wells. Deep wells with high closure stresses require a proppant, such as sintered bauxite, that will not crush under adverse conditions. Ceramic and zirconium oxide beads and resin-coated sand proppants also have been developed for deep hydraulic fracturing.

Underdown and Das (1985) developed a new fracturing proppant that exhibited the properties necessary for use in deep hydraulic fracturing. This proppant was produced by precuring a specially modified phenolformaldehyde resin onto sand. The new proppant maintained conductivity and resists crushing much better than did sand. The new proppant was compared to intermediate-density sintered bauxitic proppants and cured-in-place proppants and the tests were confirmed by an independent laboratory. [2]

McDaniel and Hoch (1988) presented comparisons of the old data and the more realistic values in their research. They also illustrated the significant effect that use of the new data could have on fracturing treatment design. In many applications the recommended proppant addition schedule was much more ambitious. Some well conditions might result in the need for a stronger propping agent than had been predicted using less realistic hydraulic conductivity data. [3]

Freeman and Allen (2009) introduced new patent-pending technology that enabled wellsite-proppant sampling and evaluation before the fracturing treatment. Having prefrac data gave one the opportunity to make any necessary changes in fracture design and implementation to get the most from available proppant. It also provided for a detailed inspection of the wellsite-delivered proppant supply. For instance, one could isolate and sample each pneumatic trailer and monitor associated pneumatic discharge pressures. Case histories, onshore and offshore, support qualifying proppant performance. [4]

One of the most important factors for selecting proppant is its permeability in addition to its strength, because the proppant permeability effects directly on the fracture conductivity. The fracture conductivity is defined as the following equation:

$$C_f = K_f.W_f \qquad (1)$$

Where C_f is fracture conductivity, K_f, fracture permeability or proppant mass permeability, W_f , fracture width. The fracture width directly depends on proppant porosity, proopant size and proppant size distribution into the fracture channels. The proppant permeability can be calculated by the following equation:

$$K_f = \frac{10^{12} d_p^2 \emptyset_p^2}{9.86923 \times 150 \left(1 - \emptyset_p\right)^2} \qquad (2)$$

Where K_f is proppant permeability (md),d_p, proppant diameter (cm), $\emptyset_p$, proppant porosity. [5]

Establishing the appropriate conductivity is one of the most important parameters in the selection of proppant. Therefore proppant granulation has become important. Generally in oil and gas industry proppant not be used in different sizes. What is the most common is choice proppants with the same size that are classified as follow based on their strength under specific stresses:

A) Sand: For closure stresses less than 6000 psi

B) Resin-Caoted proppant: For closure stresses less than 8000 psi

C) Intermediate strength proppant: For stresses between 5000 to 10000 psi

D) High strength proppant: For stresses more than 10000 psi

Proppant with big size leads to greater permeability, because according to Equation 2 proppant permeability is proportional to the square root diameter of proppant. On other hand using proppant with big size will not work in deep wells, because its strength is decreased by increasing the proppant size. Hence these types of proppants may soon be crushed under high stresses. The proppant sphericity also has significant effect on fracture conductivity. Sphericity and the same size of proppant cause uniform distribution of stress on it. While angular proppant will crush in less stresses and their crushed particles reduce the fracture conductivity. [6]

II. Investigating of Hydraulic Fracturing in Oil Reservoir "Z" in Southwest of Iran

A large number of Iran's hydrocarbon reservoir with oil production dating back of several years, are now in a declining period of their production. This has prompted the authorities and petroleum engineers to use effective methods for increasing production. In addition some reservoirs have the good initial oil inplace but they have not a desirable flow capacity. That is why the well stimulation operations seem to be necessary for increasing the permeability.

A. Studied field characteristics

Studied field is an asymmetric anticline with a length of 11 km and width of 3 km. This is a single-porosity sandstone field with 16 oil layers. Its oil is a relatively heavy with API grade of 25. Gas-Oil ratio in this reservoir has estimated at 700 scf/STB and oil formation volume factor (FVF) is about 1.4 Rbbl/STB. This is a newly explored oil field and now is in a stage of development.

Studied field is in undersaturation conditions and there is no gas cap in studied reservoir. Its reservoir rock is oil wet. Studied field has 16 oil layers with thickness of totally 196 m or 643 feet. The average pressure of studied reservoir is about 240.5 atm (3535 psia). The datum depth of calculations is about 7100 feet in this reservoir. Oil-Water contact in this reservoir has estimated at 2164.7 m (7453.1 ft) and Gas-Oil contact is estimated about 526 m (1725 ft). The datum depth for aquifer calculations has estimated at 2286.6 m (7500 ft) in this reservoir. A summary of the geology and fluid properties of the studied field is presented in Table 1.

Table I. Fluid General Characteristics of the Studied Field

Properties	Value	Properties	Value
API	25	FVF , RbbL/STB Oil	1.4
Total thickness , ft	642	Oil Viscosity , cp	0.68
GOR , SCF/STB	700	Gas Viscosity , cp	0.021
Rock Compressibility,psi^{-1}	$2.8 * 10^{-6}$	Reservoir Temperature , °F	140
Average Porosity , %	12.5	Bubble Point Pressure , Psia	1995
Average Permeability@ Permx	154.55	Average Reservoir Pressure@ datum depth , Psia	5290
Average Permeability@ Permz	2.1	Oil in Place,STB	$3.2*10^8$
Initial Oil Saturation , %	79		

III. Scenarios of Determining the Type and Size of Proppant

In this study Bradley sand and ceramic (sintered bauxite) have been investigated as the proppant type used in hydraulic fracturing in oil reservoir "Z" in southwest of Iran. Also various types of resin-coated sand and resin-coated ceramic in hydraulic fracturing process have been evaluated in studied oil reservoir. Then various scenarios have been designed for optimizing the size and type of proppant used in hydraulic fracturing process in oil reservoir "Z".

A. Scenarios for the proppant types of sand and ceramic

In this section the types of proppant used in hydraulic fracturing have been considered for sand and ceramic. Then the hydraulic conductivity of fracture and cumulative oil recovery resulting from hydraulic fracturing treatment has been estimated. Also improving the flow performance in stimulated wells and Non-stimulated wells have been evaluated for each scenario of size and type of proppant used in hydraulic fracturing in oil reservoir "Z".

1) Scenario A-1: Proppant size equal to sand 8/12 and ceramic 8/12

In this scenario the proppant size of sand and ceramic has been intended to 8/12. Then improving cumulative oil recovery as a result of the hydraulic fracturing process has been estimated. The cumulative oil production versus time and fracture half length has provided in Figures 1 and 2, respectively, for the scenario of proppant size equal to sand 8/12. Also Figures 3 and 4 show cumulative oil production versus time and fracture half length, respectively for the scenario of proppant size equal to ceramic 8/12.
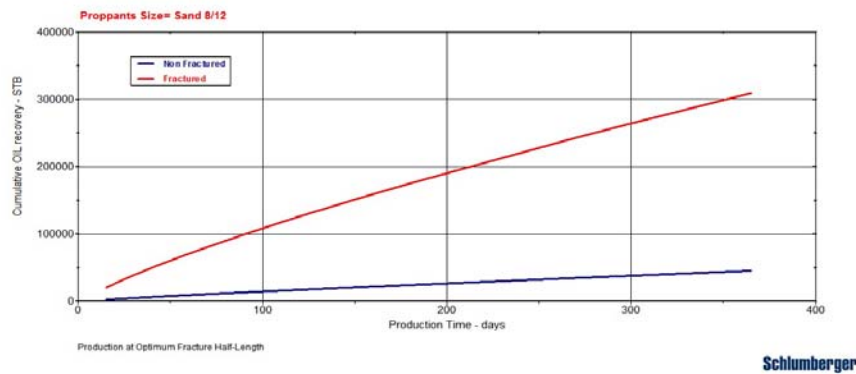
Fig. 1. Cumulative oil recovery versus time for proppant size equal to sand 8/12
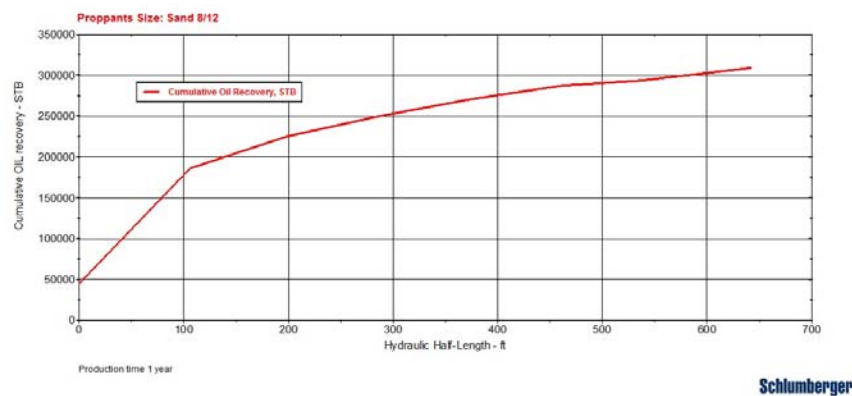

Fig. 2. Cumulative oil recovery versus fracture half length for proppant size equal to sand 8/12
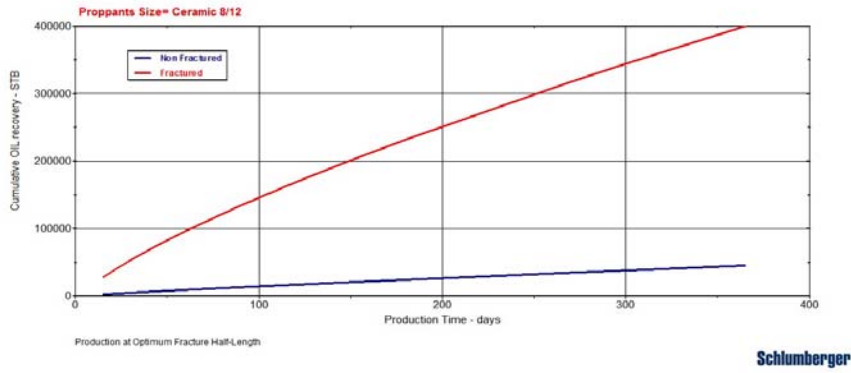
Fig. 3. Cumulative oil recovery versus time for proppant size equal to ceramic 8/12
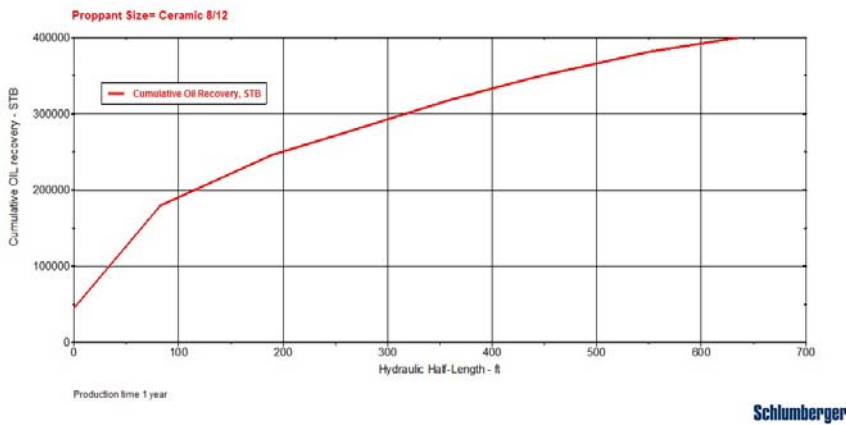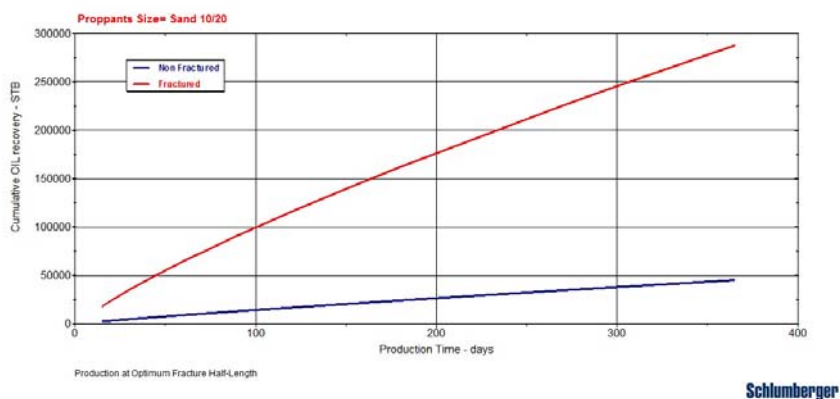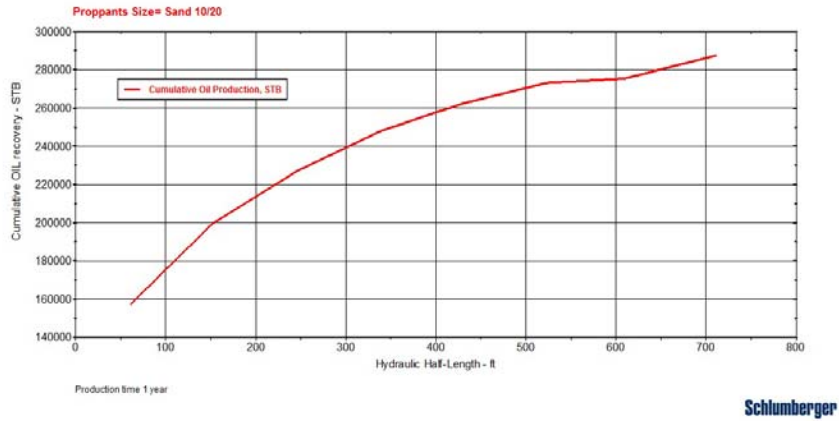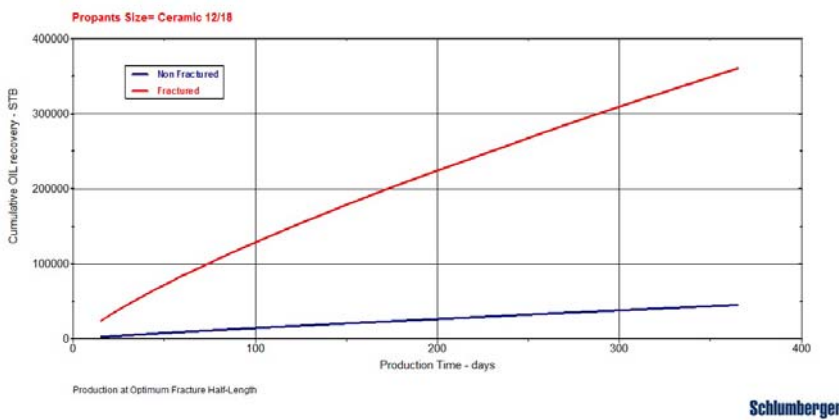

Fig. 4. Cumulative oil recovery versus fracture half length for proppant size equal to ceramic 8/12

2) Scenario A-2: Proppant size equal to sand 10/20 and ceramic 12/18

In this scenario the proppant has been intended to the size of sand 10/20 and ceramic 12/18. Then improving cumulative oil recovery as a result of the hydraulic fracturing process has been estimated. The cumulative oil production versus time and fracture half length has provided in Figures 5 and 6, respectively, for the scenario of proppant size equal to sand 10/20. Also Figures 7 and 8 show cumulative oil production versus time and fracture half length, respectively for the scenario of proppant size equal to ceramic 12/18.

Fig. 5. Cumulative oil recovery versus time for proppant size equal to sand 10/20

Fig. 6. Cumulative oil recovery versus fracture half length for proppant size equal to sand 10/20

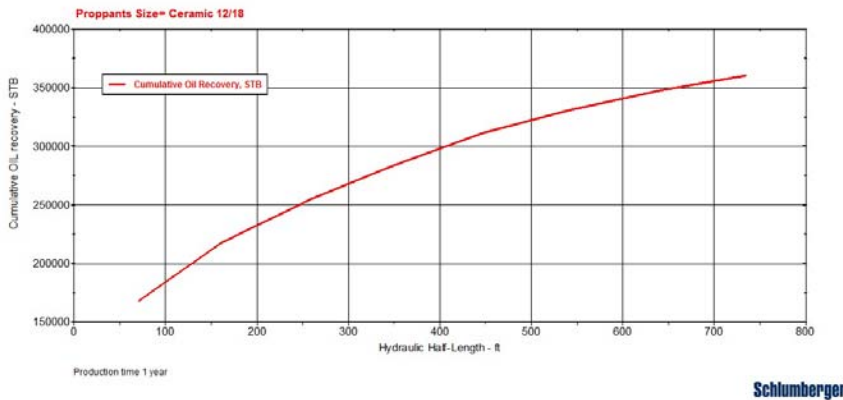Fig. 7. Cumulative oil recovery versus time for proppant size equal to ceramic 12/18

Fig. 8. Cumulative oil recovery versus fracture half length for proppant size equal to ceramic 12/18

3) Scenario A-3: Proppant size equal to sand 20/40 and ceramic 20/40

In this scenario the proppant size of sand and ceramic has been intended to 20/40. Then improving cumulative oil recovery as a result of the hydraulic fracturing process has been estimated. The cumulative oil production versus time and fracture half length has provided in Figures 9 and 10, respectively, for the scenario of proppant size equal to sand 20/40. Also Figures 11 and 12 show cumulative oil production versus time and fracture half length, respectively for the scenario of proppant size equal to ceramic 20/40.
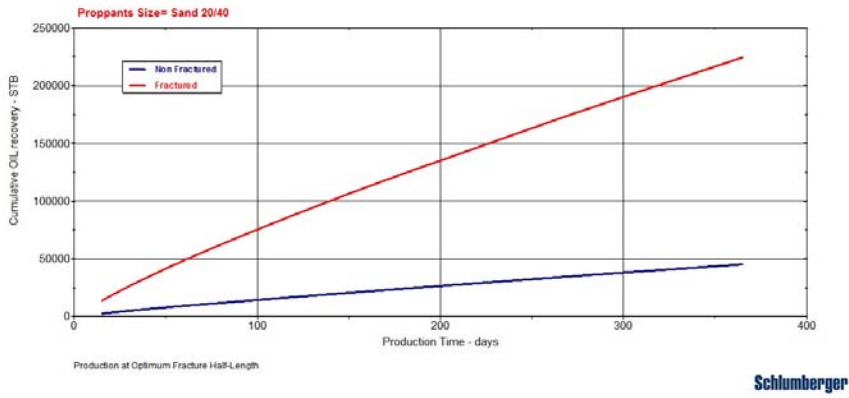
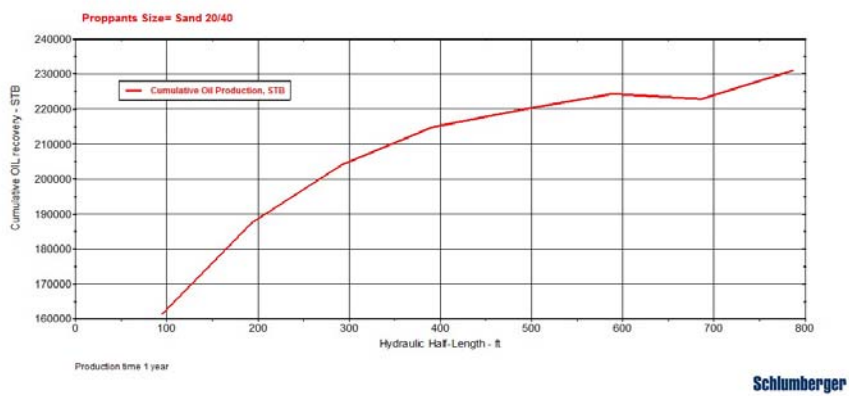Fig. 9. Cumulative oil recovery versus time for proppant size equal to sand 20/40

Fig. 10. Cumulative oil recovery versus fracture half length for proppant size equal to sand 20/40
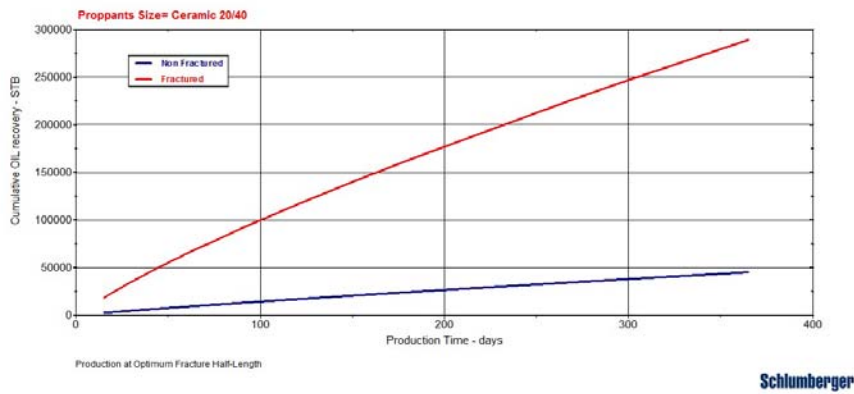

Fig. 11. Cumulative oil recovery versus time for proppant size equal to ceramic 20/40
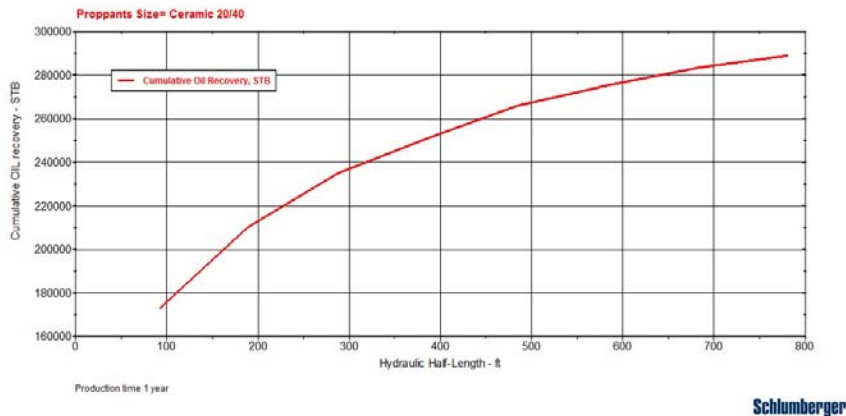
Fig. 12. Cumulative oil recovery versus fracture half length for proppant size equal to ceramic 20/40

As it is cleared from Figures 1 and 3, proppant size of 8/12 has made greater cumulative oil recovery than pther sizes for both proppant sand 8/12 and ceramic 8/12. Further increasing in fracture hydraulic conductivity by proopant size of 8/12 than other sizes is the main reason of further increasing in cumulative oil recovery in studied sand oil reservoir in southwest of Iran. Increasing in fracture hydraulic conductivity has increased the fracturing operation efficiency and consequently has improved well flow performance. Also carefully at the results of scenarios it can be concluded that ceramic proppant has the better performance than sand proppant in oil reservoir "Z". The reason for this is the high strength of ceramic proppant against fracture closure stresses. Ceramic grains used in hydraulic fracturing have faced under sintering process. Sintering is a thermal process in which metal powder is converted to metal mass. Sintering of ceramic causes that even in case of overcoming the fracture closure stresses on proppant strength, the ceramic grains not be completely crushed but also be converted to larger particles than powder. [7] So fracture hydraulic conductivity is maintained to a high level. There for using ceramic proppant has been caused further cumulative oil recovery than sand proppant in sand oil reservoir "Z" in southwest of Iran.

B) Scenarios for the proppant types of resin-coated sand and resin-coated ceramic

In this section the types of proppant used in hydraulic fracturing have been considered for resin-coated sand and resin-coated ceramic. Then the fracture hydraulic conductivity and cumulative oil recovery resulting from hydraulic fracturing treatment has been estimated. Also improving the flow performance in stimulated wells and Non-stimulated wells have been evaluated for each scenario of size and type of proppant used in hydraulic fracturing in oil reservoir "Z".

1) Scenario B-1: Proppant size equal to resin-coated sand 12/20, 16/30 and 20/40

In this scenario the type of proppant used in hydraulic fracturing have been considered for resin-coated sand. The proppant size of resin-coated sand has been intended to 12/20, 16/30 and 20/40. Then improving cumulative oil recovery as a result of the hydraulic fracturing process has been estimated. The cumulative oil production versus time and fracture half length has provided in Figures 13 and 14, respectively, for the scenario of proppant size equal to resin-coated sand 12/20. Also Figures 15 and 16 show cumulative oil production versus time and fracture half length, respectively for the scenario of proppant size equal to resin-coated sand 16/30. The results related to prediction of cumulative oil recovery versus time and fracture half length for scenario proppant size equal to resin-coated sand 20/40 have provided in Figures 17 and 18 respectively.
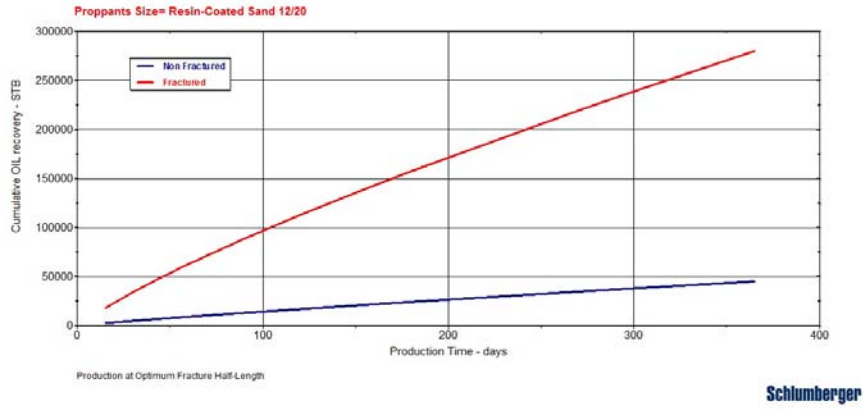
Fig. 13. Cumulative oil recovery versus time for proppant size equal to resin-coated sand 12/20
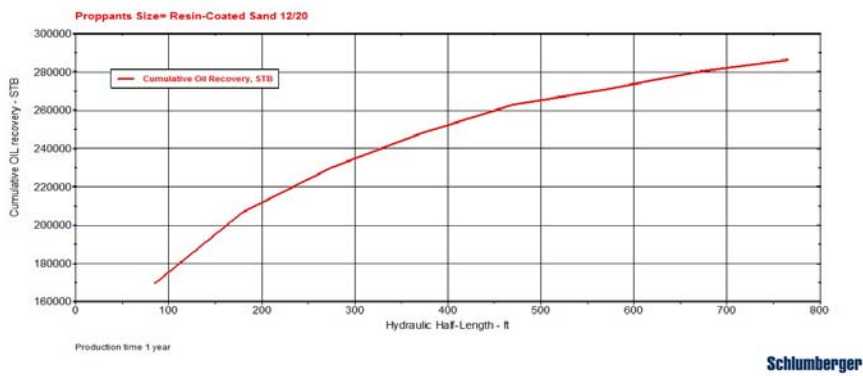

Fig. 14. Cumulative oil recovery versus fracture half length for proppant size equal to resin-coated sand 12/20
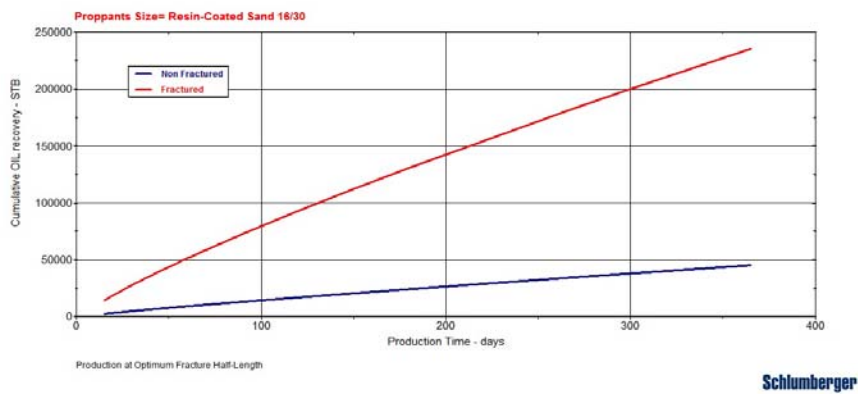

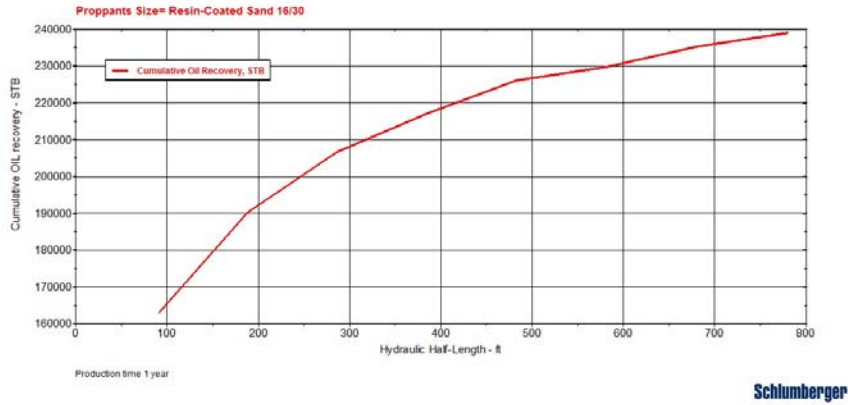Fig. 15. Cumulative oil recovery versus time for proppant size equal to resin-coated sand 16/30

Fig. 16. Cumulative oil recovery versus fracture half length for proppant size equal to resin-coated sand 16/30
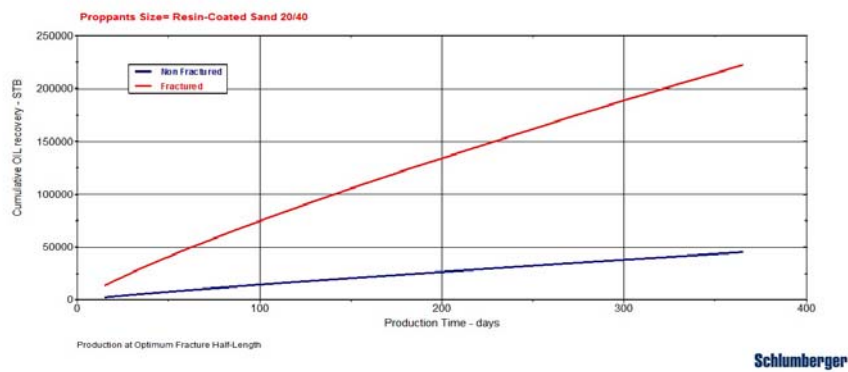

Fig. 17. Cumulative oil recovery versus time for proppant size equal to resin-coated sand 20/40
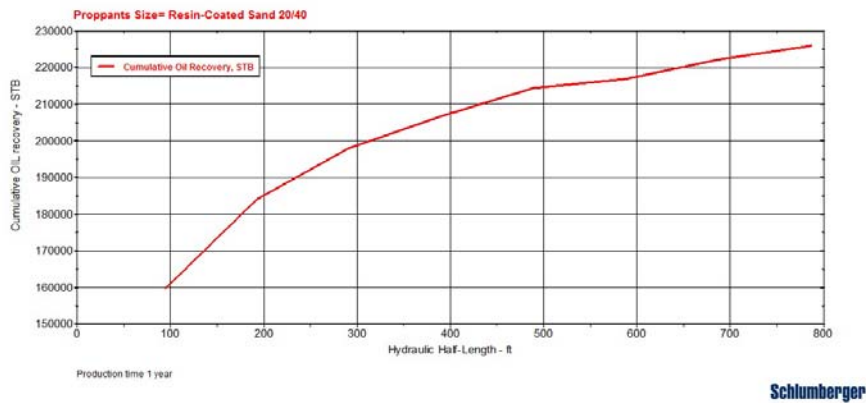

Fig. 18. Cumulative oil recovery versus fracture half length for proppant size equal to resin-coated sand 20/40

2) Scenario B-2: Proppant size equal to resin-coated ceramic 16/20, 16/30 and 20/40

In this scenario the type of proppant used in hydraulic fracturing has been considered for resin-coated ceramic. The proppant sizes of resin-coated ceramic have been intended to 16/20, 16/30 and 20/40. Then improving cumulative oil recovery as a result of the hydraulic fracturing process has been estimated. The cumulative oil production versus time and fracture half length has provided in Figures 19 and 20, respectively, for the scenario of proppant size equal to resin-coated ceramic 16/20. Also Figures 21 and 22 show cumulative oil production versus time and fracture half length, respectively for the scenario of proppant size equal to resin-coated ceramic 16/30. The results related to prediction of cumulative oil recovery versus time and fracture half length for scenario proppant size equal to resin-coated ceramic 20/40 have provided in Figures 23 and 24 respectively.
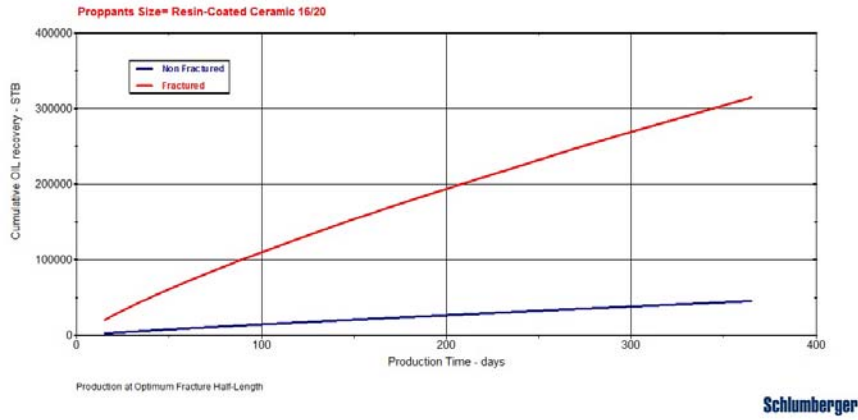
Fig. 19. Cumulative oil recovery versus time for proppant size equal to resin-coated ceramic 16/20
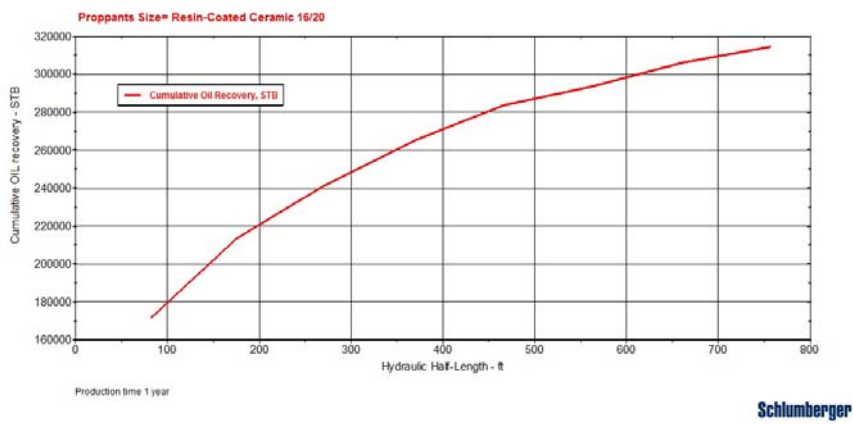

Fig. 20. Cumulative oil recovery versus fracture half length for proppant size equal to resin-coated ceramic 16/20

Fig. 21. Cumulative oil recovery versus time for proppant size equal to resin-coated ceramic 16/30

Fig. 22. Cumulative oil recovery versus fracture half length for proppant size equal to resin-coated ceramic 16/30
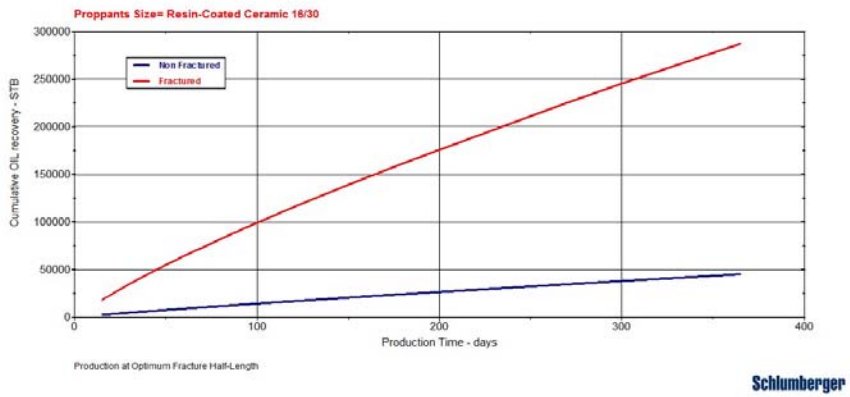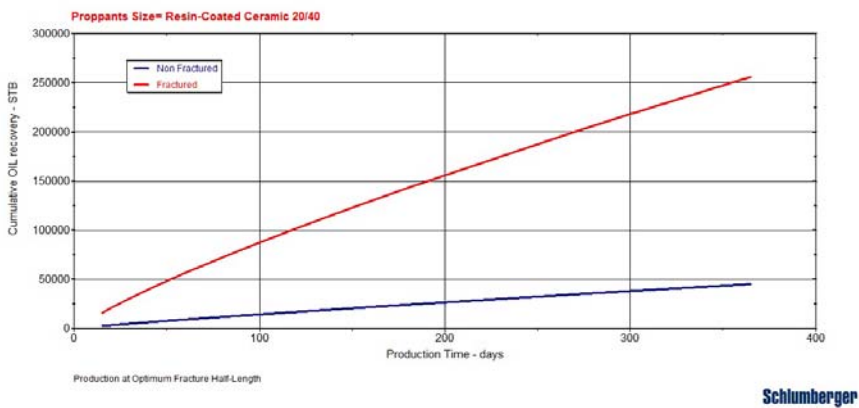

Fig. 23. Cumulative oil recovery versus time for proppant size equal to resin-coated ceramic 20/40
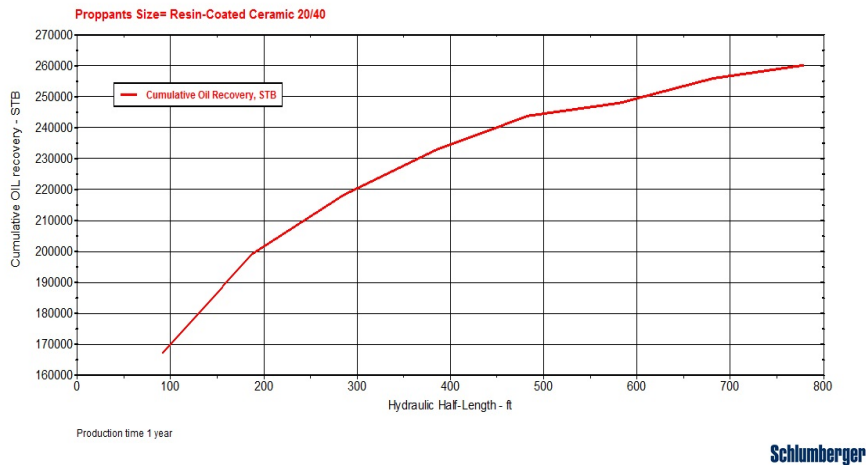

Fig. 24. Cumulative oil recovery versus fracture half length for proppant size equal to resin-coated ceramic 20/40

As it is cleared from Figures 13 to 18, the scenario proppant size of resin-coated sand 12/20 has made greater cumulative oil recovery than other sizes of resin-coated sand proppant. Also according to Figures 19 to 24 this can be concluded that the scenario proppant size of resin-coated ceramic 16/20 has made greater cumulative oil recovery than other sizes of resin-coated ceramic proppant. Further increasing in fracture hydraulic conductivity by proopant size of resin-coated sand 12/20 and resin-coated ceramic 16/20 than other sizes is the main reason of further increasing in cumulative oil recovery in studied sand oil reservoir in southwest of Iran. Increasing in fracture hydraulic conductivity has increased the fracturing operation efficiency and consequently has improved well flow performance. Also carefully at the results of scenarios it can be concluded that resin-coated ceramic proppant has the better performance than resin-coated sand proppant in oil reservoir "Z". The reason for this is the high strength of ceramic proppant against fracture closure stresses. Ceramic grains used in hydraulic

fracturing have faced under sintering process. Sintering is a thermal process in which metal powder is converted to metal mass. Sintering of ceramic causes that even in case of overcoming the fracture closure stresses on proppant strength, the ceramic grains not be completely crushed but also be converted to larger particles than powder. [7] So fracture hydraulic conductivity is maintained to a high level. There for using ceramic proppant has been caused further cumulative oil recovery than sand proppant in sand oil reservoir "Z" in southwest of Iran.

VI. CONCLUSION

1. In this study hydraulic fracturing process has been caused significant increase in cumulative oil recovery in oil reservoir "Z" in southwest of Iran.

2. Scenario of proppant size of 8/12 for both sand and ceramic proppants has had higher production efficiency than other sizes of proppant in studied reservoir.

3. Ceramic (sintered bauxite) has been had better performance than sand proppant in oil reservoir "Z".

4. Scenario of resin-coated sand 12/20 has made higher production efficiency than other sizes of resin-coated sand in studied reservoir.

5. Scenario of resin-coated ceramic 16/20 has been had better performance than other sizes of resin-coated ceramic proppants in oil reservoir "Z".

RECOMMENDATIONS

According to this important issue that scenario of ceramic (sintered bauxite) proppant has made higher cumulative oil recovery in hydraulic fracturing process in oil reservoir "Z", therefore it is recommended that priorities for selection of proppant type must be ceramic proppant in hydraulic fracturing process in studied reservoir.

Also proppant ceramic 8/12 has higher priority than other sizes of ceramic proppant for hydraulic fracturing in oil reservoir "Z" in southwest of Iran.

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