Hydraulic Fracturing Designs For Low Permeability Gas Condensate Reservoirs Having Lean and Rich Condensate Compositions

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***Abstract*— Gas condensate reservoirs have been challenging many researchers in petroleum industry for decades because of their complexities in flow behavior. After dew point pressure is reached, gas condensate will drop liquid out and increase liquid saturation near wellbore vicinity called condensate banking or condensate blockage. Hydraulic fracturing in horizontal direction has been proved to be a reliable method to mitigate condensate blockage and increase productivity of gas condensate well by means of pressure redistribution in the near wellbore vicinity. In this paper the parameters of dimensionless fracture conductivity and Stimulated Reservoir Volume (SRV) designs of lean and rich condensate compositions are studied. Well productivity and saturation profile of each design had been observed. The results from this study indicate that the higher dimensionless fracture conductivity gives the higher well productivity in every studied parameter in lean condensate composition. However, in rich condensate composition shows different trend of results because it has higher heavy ends (C_{7+}) that drop into liquid easier once pressure falls below dew point pressure. The maximum number of fracture and fracture permeability can be recognized in the study of rich condensate. In the study of SRV indicates that number of fracture is superior to fracture width in both gas and condensate productivity. Moreover, performing hydraulic fracturing can decrease pressure drawdown, production time and liquid dropout which leads to the mitigation of condensate banking near wellbore that can be recognized in the study of condensate saturation profile.**

***Index Terms*—Hydraulic fracturing, Horizontal well, Low permeability gas condensate reservoir, Condensate blockage**

I. INTRODUCTION

A gas condensate reservoir originally has single fluid, gas phase, in the reservoir when pressure is higher than dew point pressure and composed mainly of methane, other light hydrocarbons dominate and small portion of heavy ends. As the production continues, pressure will eventually fall below the dew point pressure, then the composition that rich in heavy ends will drop the liquid out of the gas causing the change from single phase into two phase composed of gas phase and liquid phase as it is shown in Figure 1.

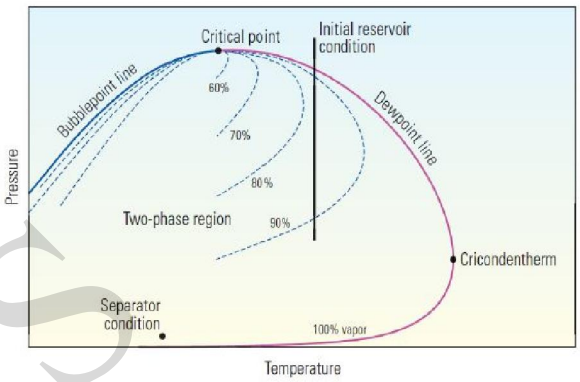


Fig. 1. Phase diagram of a gas condensate reservoir [1]

At the early time of liquid form out of condensate, the liquid is trapped in the pore because capillary force acts on the fluids, those liquid accumulations and normally mobility can be neglected when it is faraway except near wellbore this effect becomes significant. As it can be seen in Figure 2 that once liquid drops out and forms condensate banking around the wellbore, relative permeability of gas (k_{rg}) decreases when relative permeability of liquid (k_{ro}) increases.

This is because two fluids, gas and liquid, try to compete each other for flow path. Consequently, there are two drawbacks from this effect. Firstly, gas and condensate production decrease because of near wellbore condensate. Secondly, produced gas contains fewer valuable heavy ends because they have been lost while flowing toward the well during production. The amount of liquid that drop out of the gas is not only depending on pressure and temperature but also depending on compositions of the fluid itself.

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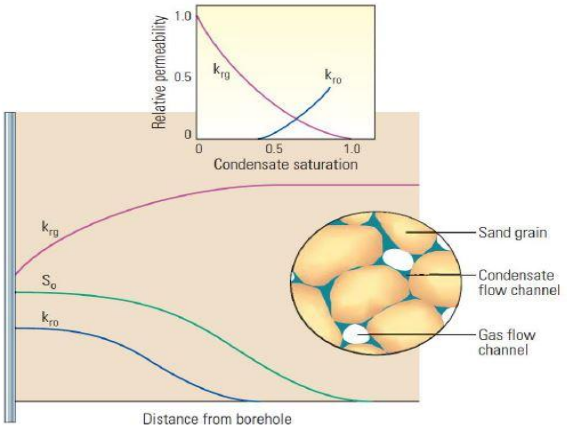


Fig. 2. The effect of condensate banking on relative permeability to gas and liquid [1]

Hydraulic fracturing in horizontal direction has been proved to be a reliable method to mitigate condensate blockage and increase productivity of gas condensate well by means of pressure redistribution in the near wellbore vicinity [1]. However, the complexities of gas condensate behavior have not been fully understood yet, especially in low permeability reservoir. This problem can be more severe if the permeability of the reservoir is low [2,3].

The objectives of this study are 1) To study the effect of parameters of dimensionless fracture conductivity with different fluid compositions on well productivity and hydrocarbon recovery and 2) To investigate condensate saturation profile in unfractured and hydraulically fractured wells. The compositional reservoir simulator ECLIPSE®300 was used to simulate flow behavior and assist the understanding of flow behavior. Moreover, it can provide accurate calculation by allowing the non-Darcy flow and capillary number effect to be included [4,5].

II. METHODOLOGY

The reservoir model is a single homogeneous layer in rectangular shape with Cartesian grid and block center condition as it is shown in Figure 3. The top of the reservoir is at 8,000 ft. Reservoir dimension are 3,100 ft.×1,550 ft.×110 ft. with 31×31×11 cells in the x, y and z direction respectively. To capture the changes of saturation in both gas and condensate near wellbore and to enhance the accuracy of near wellbore region and fracture calculation [6], therefore, the local grid refinement (LGR) was applied in this study.

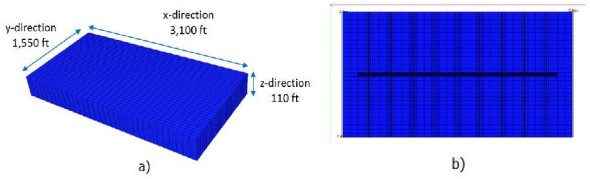


Fig. 3. (a) Dimension of reservoir model (b) Aerial view of the reservoir model at the middle layer showing wellbore grid structure.

The horizontal well is located at the depth of 8,055 ft. with wellbore diameter of 6-1/2 in. and tubing diameter of 2-7/8 in. Well length is 2,700 ft. and placed along x-direction of the reservoir. The gas condensate reservoir is a low permeability reservoir with the value of 0.2 mD and reservoir temperatures are 228 °F for lean condensate and 330 °F for rich condensate.

A compositional PVT equation of state based program, PVTi, was used for characterization between lean and rich condensate compositions [7]. Lean condensate has dew point pressure at 3,499 psia and the condensate to gas ratio (CGR) is at 18 STB/MMSCF. While rich condensate has dew point pressure at 3,423 psia and the CGR is 125 STB/MMSCF. Phase behavior of lean and rich condensate compositions are shown in Figure 4 and Figure 5 respectively.

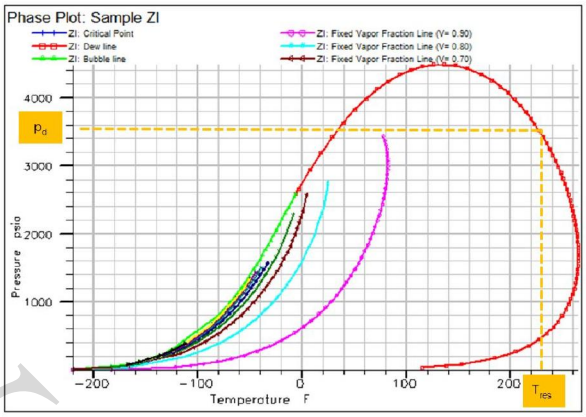


Fig. 4. Phase behavior of lean condensate composition

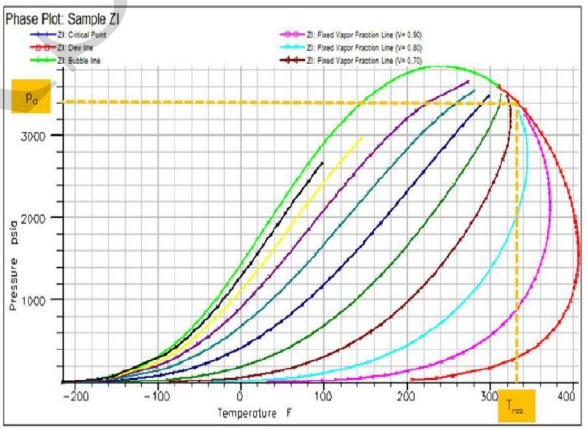


Fig. 5. Phase behavior of rich condensate composition

Figure 6 illustrates the workflow where dimensionless fracture conductivity parameters such as fracture width and number of fractures are varied into 3 values to observe the effects of each parameter on hydrocarbon production in low permeability gas condensate reservoirs which have lean and rich condensate compositions. Then the effect of the same stimulated reservoir volume (SRV) at different designs are studied based on previous values of fracture width and number of fractures.

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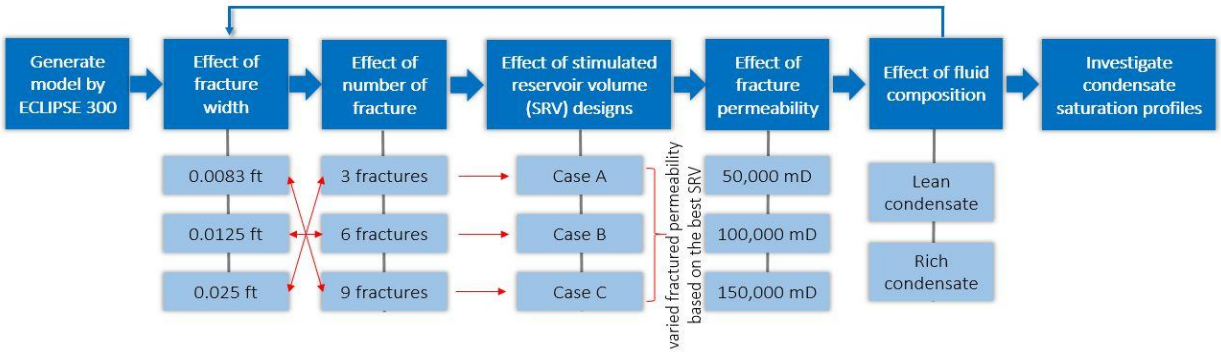


Fig. 6. An illustration of simplified work flow, three values of each studied parameter in dimensionless fracture conductivity were studied. While two fluid samples (lean and rich condensate) were investigated.

Additionally, the study of condensate saturation near wellbore versus time is defined by the nearest block next to the wellbore. Then the region of condensate banking around the wellbore at the highest condensate saturation is evaluated to non-fractured case to determine the effect of hydraulic fracturing near wellbore. According to the previous study on condensate region [8], conceptual area around the wellbore can be separated into 3 regions successively away from the wellbore which are; first region, where condensate and gas are mobile, this is the major cause of well productivity loss due to the competition between gas and liquid flow.

The second region is where condensate is immobile and gas is mobile. In this zone, fluid saturation keeps increasing and it reduces relative permeability to gas. The third region is the farthest distance from wellbore, it is a single-phase region with constant fluid composition equal to the original fluid reservoir because reservoir pressure is still above dew point pressure in this region.

III. EFFECT OF PARAMETERS OF DIMENSIONLESS FRACTURE CONDUCTIVITY AND HYDRAULIC FRACTURING DESIGNS

Figure 7 and Figure 8 depict gas and condensate production for lean and rich condensate respectively. Obvious improvement on condensate production can be observed in both lean and rich condensate compositions. Condensate production in lean condensate increased to the range of 63.28-65.78 Mstb and in rich condensate increased to 372.41-373.98 Mstb compared to non-fractured case. This is because fracture width has impact on controlling inertial effect. Increasing fracture width is consequently decrease non-Darcy flow, hence, condensate relative permeability and condensate production increased. Therefore, smaller condensate occupies in the reservoir when fracture width is increased.

Increasing number of fractures shows good improvement in condensate recovery, in lean condensate the increment is in the range between 60.72-65.78 Mstb and in rich condensate increased to 357.38-372.41 Mstb compared to non-fractured case, this is because higher number of fractures allows larger contact area between fractures and reservoir. Therefore, hydrocarbon can flow from low permeability reservoir to fractures and wellbore easier. However, an interesting result can be observed in rich condensate between 6 fractures and 9 fractures only gives small increment on their condensate productions. This is because the heavy ends in rich condensate compositions that condense and occupy in the pore space decrease the effectiveness of number of fractures.

At the same stimulated reservoir volume or SRV, it shows slightly different results on gas and condensate production. In lean condensate, gas production increased in the range of 6.74-6.77 Bcf while condensate production increased in the range of 60.72-63.28 Mstb. For rich condensate, the increment of gas production is between 5.62-5.68 Bcf and condensate production is in the range of 357.38-372.79 Mstb. However, it can be observed that number of fractures is superior to fracture width on condensate recovery in both lean and rich condensate compositions. Especially, case A which has the design of 9 fracture planes with minimum fracture width of 0.0083 ft. Even though, fracture width can control inertial effect near fracture but number of fractures allows larger contact area for hydrocarbon to flow from the reservoir.

The last parameter is fracture permeability which varied based on the best SRV design, i.e. case A. Fracture permeability shows small difference of gas and condensate production between each value in both fluid compositions. Lean condensate has small benefit from increasing fracture permeability, especially in gas production that increased to the range of 5.60-5.72 Bcf, while condensate production increased in the range of 368.85-374.15 Mstb compared to non-fractured case.

In rich condensate, fracture permeability gives better improvement on both gas and condensate productions, gas production increased to the range of 5.60-5.72 Bcf and condensate production had the increment between 368.85-374.15 Mstb compared to non-fractured case. However, small improvement after 50,000 mD can be observed. This is because fracture permeability at 50,000 mD is already high enough and causes a large difference between reservoir permeability and fracture permeability. Therefore, it did not show a significant improvement even fracture permeability was increased to 100,000 mD and 150,000 mD.

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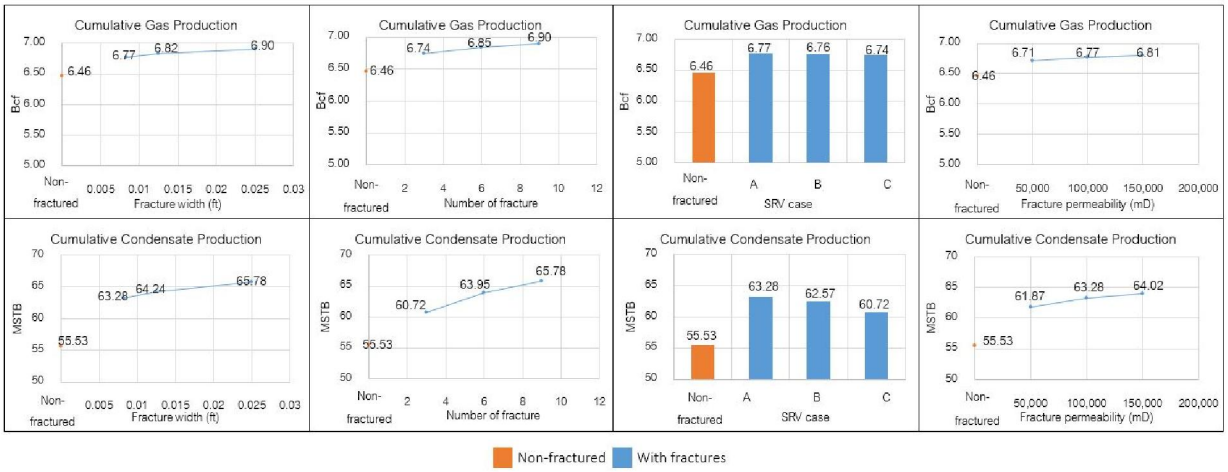


Fig. 7. Illustrations of gas and condensate production in lean condensate for each parameter.

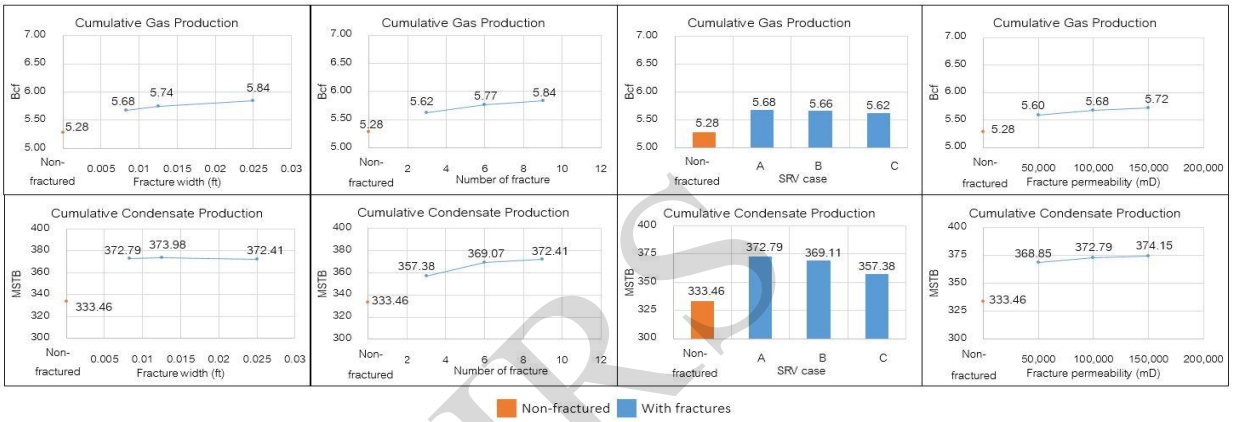


Fig. 8. Illustrations of gas and condensate production in rich condensate for each parameter.

IV. CONDENSATE SATURATION PROFILES NEAR WELLBORE

The investigation of condensate saturation took place at the nearest block to the wellbore. Figure 9 is the example from the study of number of fractures. Diagrams on the left shows the change of condensate saturation at near wellbore location with time. It can be observed that hydraulic fracturing in horizontal well is effective in reducing condensate banking near wellbore when number of fracture increased and this advantage also reveals itself in other studied parameters which are larger fracture width and higher fracture permeability gives smaller condensate saturation in both lean and rich condensate.

Pictures on the right in Figure 9 depict the cross-section of the reservoir to observe condensate saturation region around wellbore at the highest condensate saturation of each case. In lean condensate, the condensate saturation was increasing but did not reach the critical condensate saturation at 0.20 yet. Therefore, it could be identified as the second region where condensate saturation kept increasing which means condensate relative permeability was increased while gas relative permeability was decreased.

While in rich condensate, an interesting behavior can be observed where condensate saturation increased to its highest value in each case before decreased until the end of production. For example, 9 fractures case in rich condensate, condensate saturation increased to 0.22 within 0.5 year before decreased to 0.16 at the end of production. This is because revaporization was occurred. This effect can be observed clearer in the form of movement of condensate banking regions. At the early stage of production at day 7, third region and second region can be observed. When production continued to day 42, the first region where condensate saturation was higher than critical condensate saturation at 0.20 could be identified with the distance about 50 ft around wellbore before increased to the distance about 150 ft. at day 77 when condensate saturation reached its highest value. And at the end of production, condensate banking or the first region was absent because of the effect of condensate revaporization.

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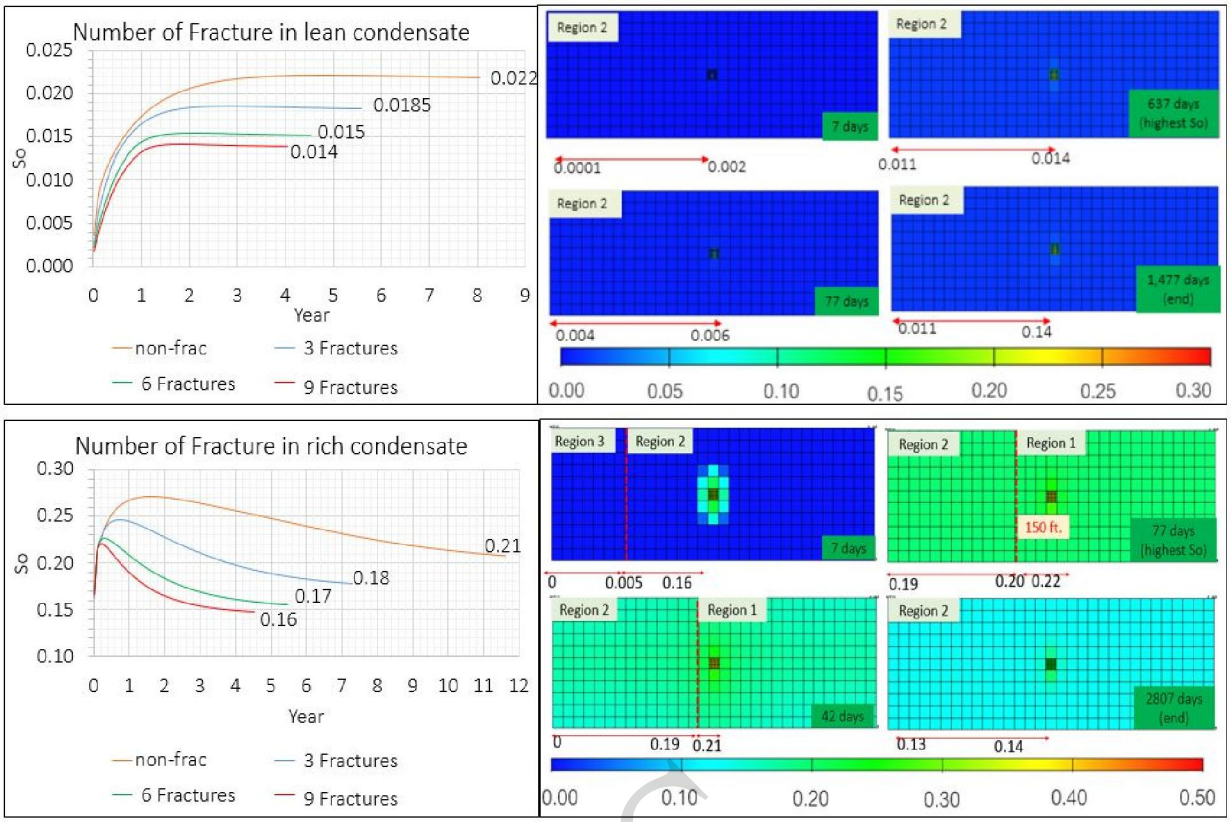


Fig. 9. Condensate saturation vs. time (left) and condensate saturation region at the highest condensate saturation (right) for lean and rich condensate.

Therefore, condensate revaporization in rich condensate helped decreasing condensate banking near wellbore and with the couple effect of hydraulic fracturing, condensate saturation can be decreased lower than the effect of revaporization alone.

V. CONCLUSIONS

Hydraulic fracturing is effective in reducing condensate banking near wellbore. Higher value of dimensionless fracture conductivity, i.e. larger fracture width, higher number of fractures and higher fracture permeability are suggested, especially number of fractures. However, it is not recommended to apply hydraulic fracturing in the reservoir with lean condensate composition in this study because only small benefit on gas and condensate productions can be obtained compared to rich condensate that gave significant improvements in both gas and condensate productions.

In addition, compositional study, especially in rich condensate, is suggested to comprehend more on their complexities in flow behavior. This can be assisted in economic evaluation for hydraulic fracturing designs which will eventually reduce risks and uncertainties for producers to achieve the best investment opportunity.

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