Influence of a Single Fracture and Its Aperture on Gas Production from a Tight Reservoir*

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Abstract

Tight gas exists in reservoirs with very low porosity and microdarcy range permeability, but has an enormous future potential for production. Usually production from tight gas wells is low compared to gas production from conventional reservoirs. Tight reservoirs cannot be produced economically without hydraulic fracturing. This paper presents an experimental study of enhancing gas recovery from low permeability reservoirs by the creation of a single fracture perpendicular to the flow direction. The considered porous medium sample is a slot-pore type tight sand from the Travis Peak Formation with permeability in the microdarcy range and a porosity of 7%. A series of single-phase experiments (gas and water) were conducted at different pressure drops ranging from 100 to 600 psig and at overburden pressures of 2000, 3000 and 4000 psig, respectively. The obtained results showed that the sample used is very sensitive to overburden pressure. Also, the experimental data showed that the presence of a fracture in a low permeability porous media is the key factor for enhancing the gas recovery from tight gas reservoirs. The presence of a fracture enhances the gas flow, not only due to the increase in overall permeability, but also due to the creation of different flow patterns which locally shifted the two phase flow away from capillary force domination region. Furthermore, the fracture aperture plays a significant role in enhancing flow due to both reconfiguration of connecting pores and joining of the non-connecting pores to the flow network.

The studied slot and solution tight sand porous medium core sample was taken from the Staged Field Experiment (SFE) of the Travis Peak Formation in East Texas at a depth of 8707 ft. Pakdel (1994) studied flow of gas, water and two phase flow of gas and water through a non-fractured sample. We cut this core sample into two equal parts of 3.81 cm in diameter and 4.35 cm in length. Then these two cylindrical parts were put on the top of each other in the core holder of the experimental setup described in Khlaifat (1998) to give a sample of a total length of 8.7 cm with a fracture. A fracture perpendicular to the flow direction at the middle of the sample was created. Several single phase gas and water flow runs were carried out at different pressure drops and overburden pressures. The overburden pressure, which represents

the pressure caused by the overlying rocks, was set by using water pressure. Before each experiment, the core sample was set under the desired overburden pressure for several days so we could get a uniform stress distribution and exceed the core sample relaxation time.

Single-Phase Gas Flow Experiments

Since the SFE2-8707-Plug No. 2 sample used from Travis Peak Formation belongs to the slot-pore solution type sandstone which is sensitive to stress change, we left the core sample in the core holder for several days at the desired overburden pressure before starting each experimental run. This ensured that the porous media structure variation during the experimental runs was minimal. In all the experimental runs that we conducted, the outlet gas pressure was set at atmospheric pressure. We performed the experimental runs at three different overburden pressures: 2000, 3000, and 4000 psig. The range of overburden pressure was chosen because the fluid may bypass the core sample at overburden pressures less than 2000 psig, and there is a possibility of destroying the sample at 5000 psig overburden pressure; Pakdel (1994). In all steady state runs, the inlet pressure was in the range of 100 to 600 psig, while the exit pressure was atmospheric for both the steady state and transient runs. For the steady state gas flow measurements at 2000 psig overburden pressure and with fracture aperture of 0.0 mm, we usually started by setting 100 psig inlet pressure to the core sample from the gas cylinder. After reaching the steady state condition, the inlet pressure was increased to 200 psig. This increase in pressure drop by 100 psig increments was continued until we reached the inlet pressure of 600 psig.

When the steady state gas flow rate at 600 psig pressure drop across the sample was reached, the transient gas flow measurement was taken at the same confining stress. The procedure for taking transient gas flow measurement is as follows. After doing steady state and transient experiments at overburden pressure of 2000 psig, the overburden pressure was increased to 3000 psig, and after waiting for several days the same procedure above was repeated. The same measurements were done at 4000 psig overburden pressure as well. When we finished doing all of the above-mentioned experimental runs, an aperture of 0.5 mm thickness was made in the fracture. Only the steady state gas flow runs were performed at 3000 psig overburden pressure.

Results and Discussion

Figure 1 shows the gas flow rate versus pressure drop at different overburden pressures (OBP). The figure shows an exponential increase in the gas flow rate as the gas inlet pressure increases. This phenomenon was due to an increase in gas velocity, and the fact that a higher pressure drop across the sample enabled the gas to move through smaller pores more efficiently. This in turn enlarges the pore network which is available for flow. From this figure, it is obvious that at low pressure, 100 psig, there is no difference in gas flow rate at different OBP for the same pressure drops. Also, at a higher pressure drop, the flow rate at 3000 psig OBP is 12% to 18% higher than that at 4000 psig, and at 2000 psig OBP the flow rate is 6% to 27% higher than that at 3000 psig. This can be explained by the fact that when the OBP is increased, some of the pores may be closed and a higher driving force is needed to overcome the pore entry pressure. Also, at the same pressure drop, less gas pore network will be available at the higher OBP. This confirms the sensitivity of our sample to overburden pressure. The higher overburden pressure results in a lower gas flow rate.

Transient run showed that both gas pressure and gas flow rate profiles show an exponential decrease as a function of time. This behavior is expected, because closing the inlet gas basically stopped the source of driving force. A comparison between transient and steady state gas flow rate at different pressure drops at the same overburden pressure of 3000 psig showed that the experimental data on gas flow rate for both cases are in good agreement. This means that the transient data may be used instead of the steady state measurement. Since the time and effort needed to obtain transient data is much lower than that needed to obtain similar steady state data, a significant cost saving is expected using transient measurements.

Figure 2 shows the comparison between Pakdel (1994) steady state gas flow rates using a non-fractured sample with our data using a fractured sample of the same porous medium at different OBP. The gas flow through the fractured sample was higher than the corresponding one. It is obvious that the gas production rate is higher in the case of the fractured sample than that for the flow rate through the non-fractured medium. This was dictated by the role of the fracture which is enhancing the flow rate as a result of increasing permeability of the gas.

Figure 3 shows a comparison between steady state gas flow rate experiments through three different media (non-fractured, fractured with 0.0 mm aperture, and fractured with an aperture of 0.5 mm). From this figure, we can see that the gas flow rate for the case of the fractured sample with an aperture of 0.5 mm is the highest. This could be explained partly by an increase in the overall permeability of the fractured porous media.

In the case of 0.0 mm aperture, despite the presence of a fracture, we expect some of the connected pores to the entering gas to the sample, which is originally connected to the exit, may become closed at the fracture, and some of the non-connected pores may become connected to the flow network. This random change in connected pore distribution, along with the presence of the fracture results in an increase in gas flow rate. In the case of 0.5 mm aperture, no closing of connected pores occurred. Only some of the non-connected pores became connected to the flow network via the fracture; therefore, a higher gas flow rate was obtained. In other words, by making an aperture of 0.5 mm, we have overcome the effect of blind capillaries in the sample.

Gas Permeability Calculations

The permeability of rocks in conventional reservoirs has been determined from Darcy's law (flow through porous medium is directly proportional to the differential pressure). Our experimental data showed that for the fractured tight sand porous medium that we examined, Darcy's law is no longer valid. The indicator line (plot of gas flow rate versus pressure drop) becomes more concave toward the pressure drop axis. This phenomenon usually happens in-situ for the following reasons: 1) Very wide pore size distribution of low permeability media, with large pores connected through very small pores, and 2) Rock permeability grows as a result of cleaning of the pore space at large velocities. When the fluid velocity deviated from Darcy's law, the following non-Darcy equation for pressure gradient was used. The non-Darcy equation for the incompressible, one-dimensional steady state flow can be expressed as:

$$\Delta P/L=(\mu/\kappa)\upsilon+\beta\rho\upsilon 2$$

or substituting for superficial velocity, $\upsilon=Q/A$ the non-Darcy equation may be written as:

$$\Delta P/L=(\mu Q/\kappa A)(1+Q(\beta\rho\kappa/\mu A))$$

The calculated permeability values showed that for the case of the non-fractured sample, we have a permeability decrease of 20.98 % when overburden pressure increased from 2000 to 3000 psig, and a decrease of 17.81% when the OBP increased from 3000 to 4000 psig. At the same time, the parameter increased 13.05% when OBP increased from 2000 to 3000 psig, and increased 4.8% for the increment in OBP from 3000 to 4000 psig. Analyzing the fractured case parameters we found a 16.96% decrease in the permeability and a 12.70% increase in parameter when we increased the OBP from 2000 to 3000 psig, and a 12.83% decrease in permeability and a 20.40% increase in parameter when the OBP increased from 3000 to 4000 psig. When we compared the values of k and parameters for both fractured and non-fractured cases from Table 1, we found that both k and values for the fractured case were higher than those for the non-fractured case.

Conclusions

Single-phase gas flow experiments through low permeability fractured porous media of tight sand formation of Travis Peak Formation were conducted at different operating conditions. The following conclusions can be drawn from our study:

1. Single-phase flow experiments through fractured tight formation showed non-Darcy behavior for the gas phase.

2. Our experimental data showed very good agreement between steady state single-phase gas through fractured tight sand porous media and the similar transient experiments. This means replacement of transient data with steady state data is a feasible task and, therefore, could result in significant savings of time, effort, and expense in core analysis.

3. The permeability of slot and solution pore type of tight sand medium decreased with an increase in the overburden pressure. The flat narrow slots provide a bottleneck for movement of pore fluids and make the rock tight.

4. Evidence that the fracture enhanced the flow of gas through low permeability porous media. Moreover, having an aperture in the fracture resulted in higher flow rate than in the case of a fracture with no opening. This occurred due to an increase in the overall permeability of the fractured porous media and a reduction in the effect of blind capillaries in the porous medium.

References

Khlaifat, A., 1998, Two Phase Flow through Low Permeability Fractured Tight Sand Porous Media: PhD Thesis, Illinois Institute of Technology, Chicago, Illinois, 204 p.

Pakdel, P., 1994, Analysis of Two Phase Flow through Low Permeability Tight Sand Porous Media: PhD Thesis, Illinois Institute of Technology, Chicago, Illinois, 193 p.

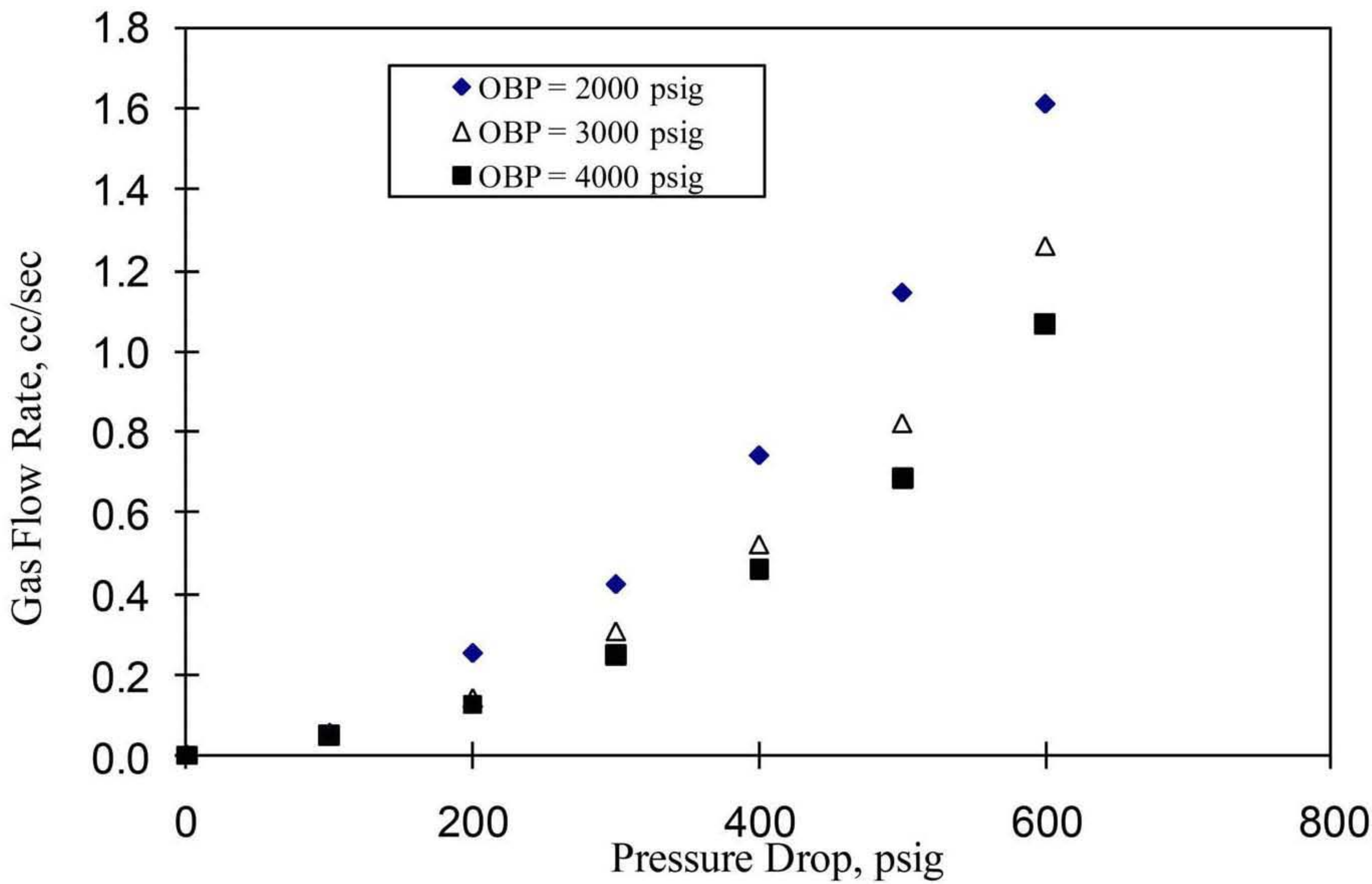

Figure 1. Experimental data of steady state gas flow through fractured SFE2-8707-Plug No. 2 sample with an aperture of 0.0 mm.

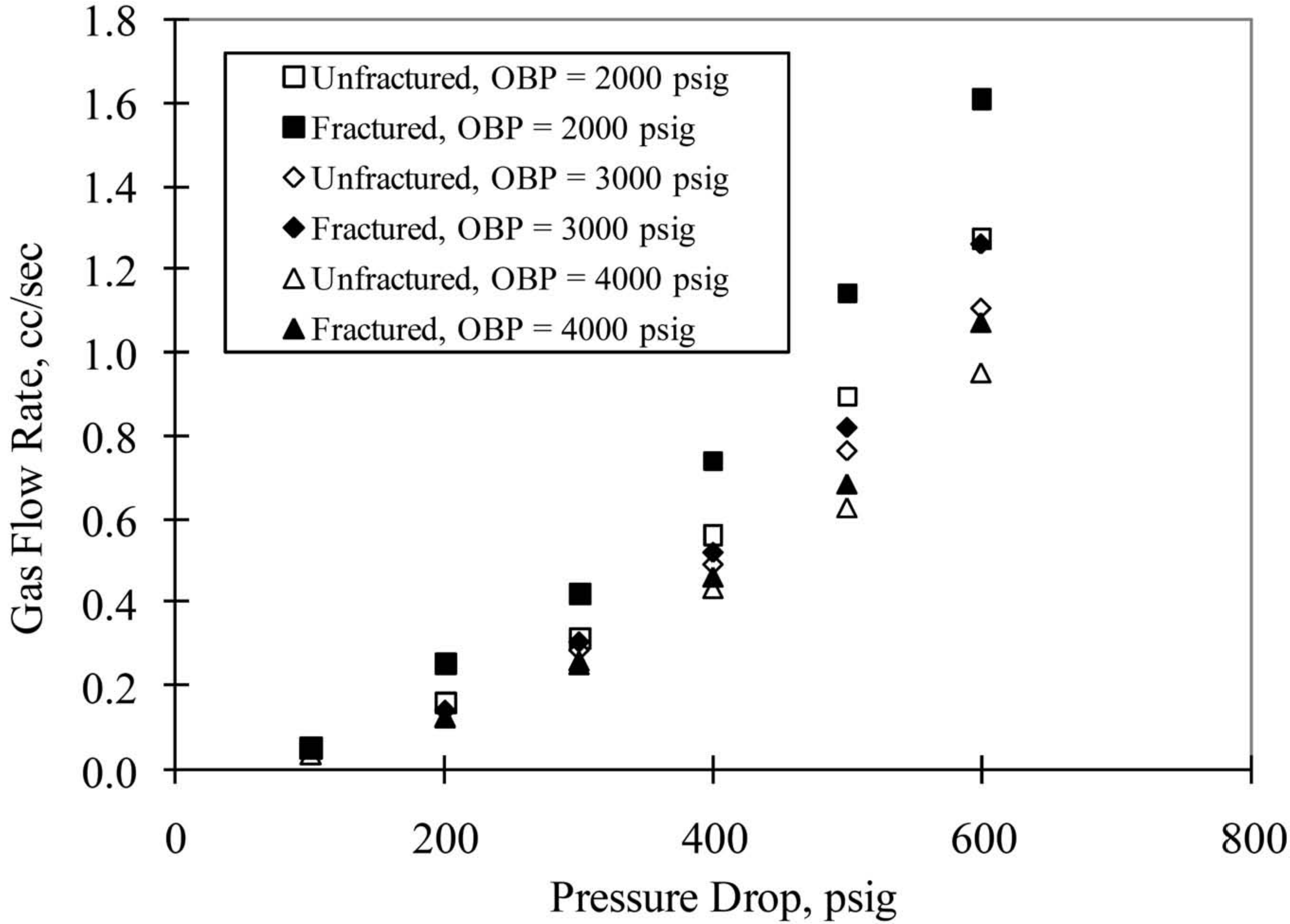

Figure 2. Comparison between experimental steady state gas flow through fractured SFE2-8707-Plug No.2 Sample with steady-state gas flow through non-fractured media.

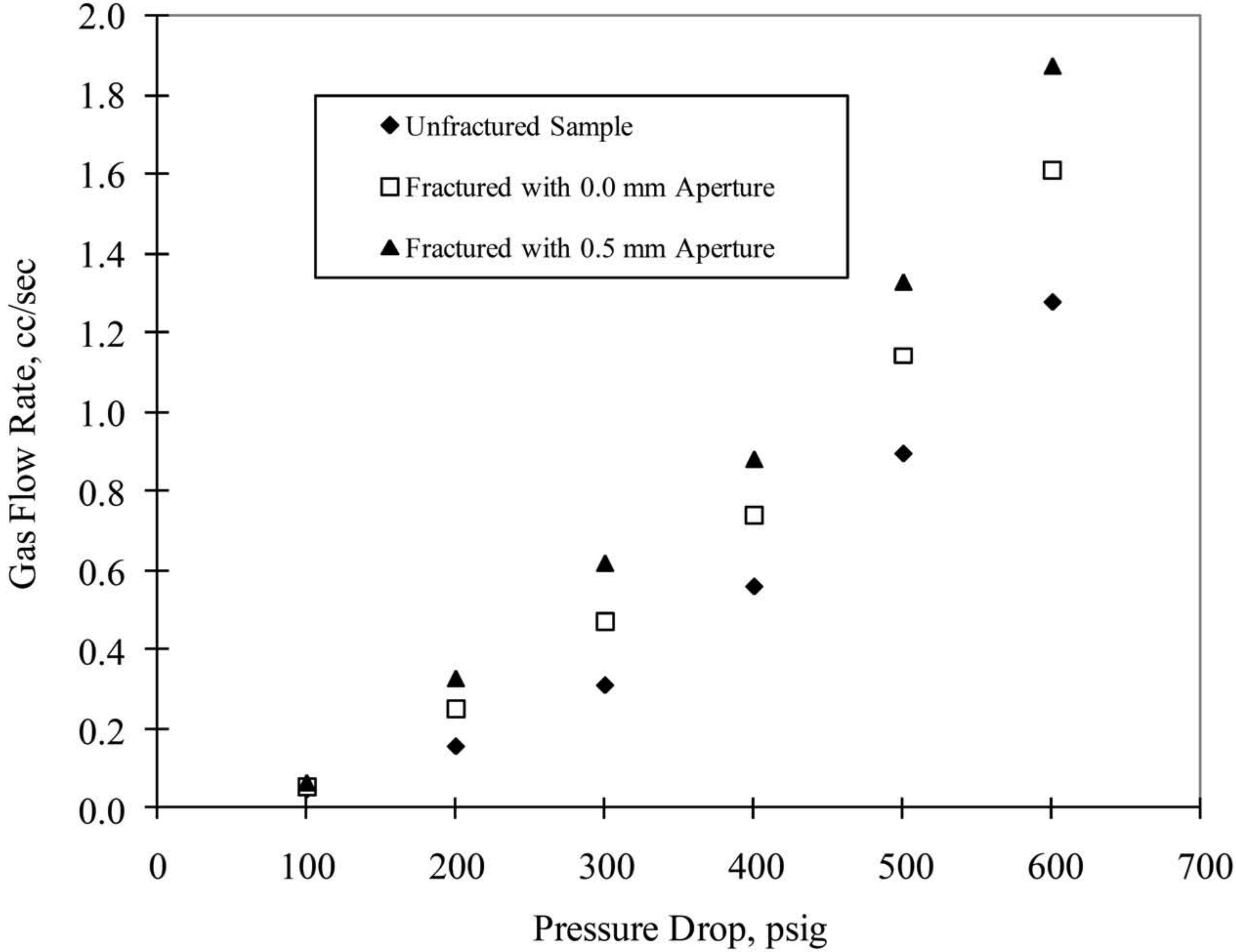

Figure 3. Comparison between experimental data of steady-state gas flow through SFE2-8707-Plug No.2 Sample at 3000 psig overburden pressure.

OBP, psig	k, %	β, %
2000	3.160	64.080
3000	8.503	76.000
4000	15.080	101.740

Table 1. The percentage increase of k and parameters for fractured case over the non- fractured case at different OBP. The information in this table demonstrates that the fracture has a greater effect in the case of higher overburden pressure.