Optimal Injection Time and Parametric Study on Gas Condensate Recovery

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ABSTRACT: A study on optimal injection time and parametric evaluation on gas condensate recovery is presented. Gas-condensate wells experience a significant decrease in gas productivity once the flowing bottom-hole pressure drops below the dew-point pressure. Gas recycling is a known method of remedying this problem and improving recovery. However, there is still a lack of understanding on how the gas re-injection affects the deliverability because of the complex phase and flow behaviors. The difficulty of understanding the phase and flow behaviors lies in the variation of the composition due to the existence of two-phase flow and the relative permeability effect, which brings about a change in saturation and phase properties of the fluids. These effects will impact the mobility, in turn productivity and hence the viability of a gas recycling project. This work studied the impact of relative permeability and critical condensate saturation on the flow behavior of the gas-condensate system under a gas cycling scheme, through reservoir simulations and a series of optimization, using experimental designs.

Results from this study show that productivity improves significantly during gas recycling. Also from the numerical optimizations conducted, it was determined that the conditions under which the injection takes place significantly affect the result. Optimal time of gas injection enhances project economics. Arbitrary choice of injection time leads to waste of gas that could be monetized at the commencement of the project

Key word/ Index terms: injection time, gas injection, parametric study, gas condensate, enhanced recovery, permeability, optimal

1.0 INTRODUCTION

The global demand for natural gas has increased immensely because of its more environment-friendly characteristics compared to oil resources. Condensates in the form of very light oil are produced along with natural gas production depending on the production conditions and reservoir fluid characteristics. This explains the obvious rising interest in the exploration of gas condensate reserves.

Much attention has been paid to the study of in-situ liquid formation and fluid flow mechanisms in gas condensate systems in recent years (1) (2) (3). When gas condensate reservoirs are developed by pressure depletion, gas well deliverability is affected by the amount and the distribution of the condensate formed around the wellbore (4).

Understanding of the parameters that affect the distribution and the amount of condensate saturation in the near wellbore region and the effect of these parameters on gas and liquid flow are important in the development of the methods for increased gas deliverability, gas cycling is one of such methods and hence the motive for which this study was carried out.

In this study, condensate fluid data from a mature Niger Delta field, Nigeria was used, while reservoir parameters range used were based on values obtainable in Niger delta as well. Design Expert software was used in design of the experiments, screening of parameters and optimization whereas a compositional simulator was used to perform the simulation study.

The study will cover the following areas:

- Selection and screening of reservoir uncertainty parameters that affect recovery.
- Characterization of gas condensate reservoir fluid.
- Compositional simulation of the reservoir to study the gas injection.

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- Sensitivity analysis to determine the effects of relative permeability and critical condensate saturation.

Typical retrograde condensate reservoirs produce gas/liquid ratios of approximately 3-150 MCF/STB, or condensate surface yields ranging from 10 to 300 STB/MMSCF (5). The added economic value of produced condensate liquid, in addition to gas production, makes the recovery of condensate a key consideration in the development of gas-condensate reservoirs. As production progresses in the gas-condensate reservoirs, the flowing bottom-hole pressure normally declines down below the dew point pressure of the produced fluid. A condensate phase accumulates in the near wellbore region. This condensate drop out during gas production will impair the relative permeability to gas and cause a significant loss in gas productivity (6) (7) (8). Several techniques have been used to revitalize productivity in gas condensate reservoirs, such as wettability alteration (9), water injection/water flooding (10), miscible and immiscible gas injection (11) (12) and use of horizontal wells (13). Gas is cycled to maintain pressure high to keep the amount of retrograde condensation at minimum. In addition, dry gas is miscible with virtually all reservoir gas condensate systems that make it the primary choice for cycling. Gas cycling also has other two economically driven advantages; it provides an economically viable use for gas when the gas market is sluggish and the means to produce valuable liquid from gas condensate reservoirs. However, the attractiveness of gas cycling projects is controlled by many other factors such as product prices, the cost of processing and compression, liquid contents of reservoir gas, and the degree of reservoir heterogeneity where both vertical and lateral permeability variations can have marked impact on recoveries by cycling (14) (15). Injection of produced gas has been found successful (16) in resolving productivity decline in gas condensate reservoirs but the appropriate time to commence injection is lacking in the literatures. The suggestion has always been to inject above the dew point pressure. This work determines the optimal injection time for the case study

THE METHOD USED

The primary aim of this study is to determine effects of relative permeability and critical condensate saturation on gas condensate recovery, under a gas cycling scheme. Design-Expert® software was used in design of experiments and screening of parameters, while Eclipse was used in the simulation studies. Some parameters which affect recovery were selected and assigned limits based on values obtainable in Niger Delta, these values were used in the Design of Experiment using a two-level factorial screening design (Plackett-Burman) in Design-Expert which yielded sets of simulation runs, further study was conducted to show their influence on gas and condensate recovery. The reservoir parameters screening were done with Pareto chart to select influential parameters. Eclipse was now used to simulate (under varied conditions to study) the effects of relative permeability and critical condensate saturation on gas and condensate recovery.

An economic analysis was conducted using a formula to evaluate Net present Value (NPV), for each injection condition. The formula which took into consideration the total revenue from gas and condensate less the approximated injection cost was used to evaluate the recovery in each simulation case, compare in relative monetary terms, in US dollars. The cost of Oil (condensate), gas and injection used in the formula were current prices

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gotten from US Energy Information Administration (EIA) as posted on indexmundi.com

$$NPV = (FOPT * Co) + (FGPT * Cg) - (FGIPT * Cinj) \qquad (1)$$

Where,

FOPT = Produced oil total (Condensate), bbls

C_o = Cost of condensate (dollars per bbl)

FGPT = Produced gas total, Mscf

C_g = Cost of gas (dollars per Mscf)

FGIT = Injected gas total

C_{inj} = Injection cost (Approximated compression cost + cost of injected gas)

Using the above formula, calculations of NPVs against production time was made, for depletion and injection, a sensitivity analysis was also conducted.

RESULTS

The NPV relationship for Depletion and Injection with respect to production time is represented graphically in the figure1 below. Based on this figure the optimal time to commence injection in the reservoir with this scenario is 2.1 years after the reservoir is put on production. Injection between the period of 0 to 2 years would have deferred the revenue obtained from gas sales during the period.

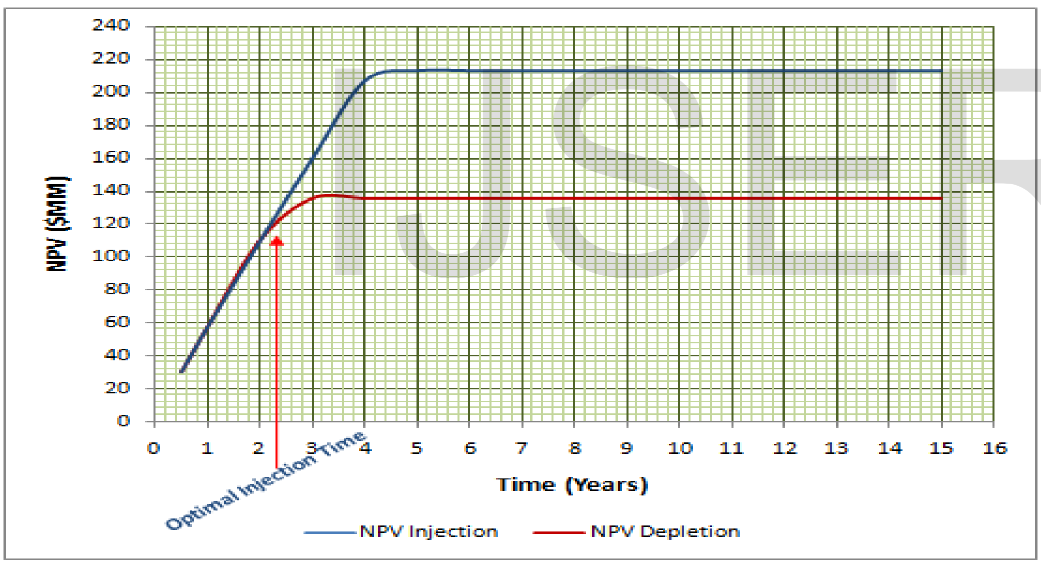

Figure 1: Comparative analysis of the Injection and Depletion cases

Effect of Relative Permeability

Effect of Relative permeability was studied by observing the changes in recovery at varied relative permeability values, effect of relative permeability on condensate and gas production are represented graphically in figures 2 and 3 respectively.

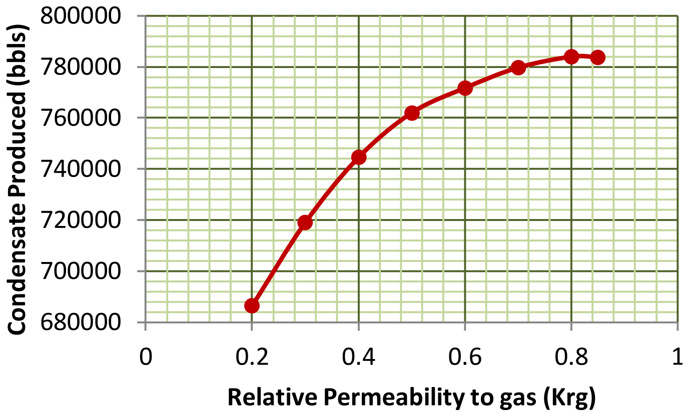

Figure 2: Effect of Relative Permeability (Krg) on Condensate production

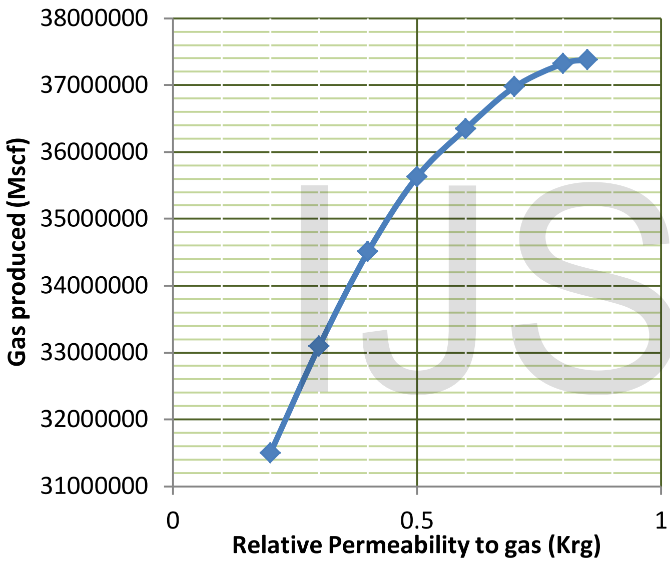

Figure 3: Effect of Relative Permeability (Krg) on Gas production

Effect of Critical Condensate Saturation

Effect of Critical Condensate Saturation was also studied by observing the changes in recovery at varied critical condensate saturation values, effect of critical condensate saturation on condensate and gas production are represented graphically in figures 4 and 5.

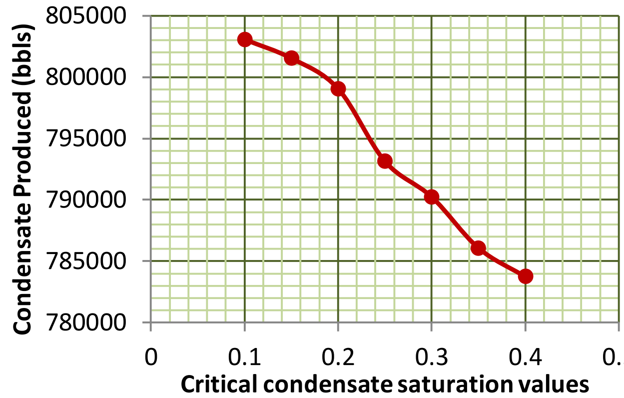

Figure 4: Effect of Critical condensate saturation on Condensate production

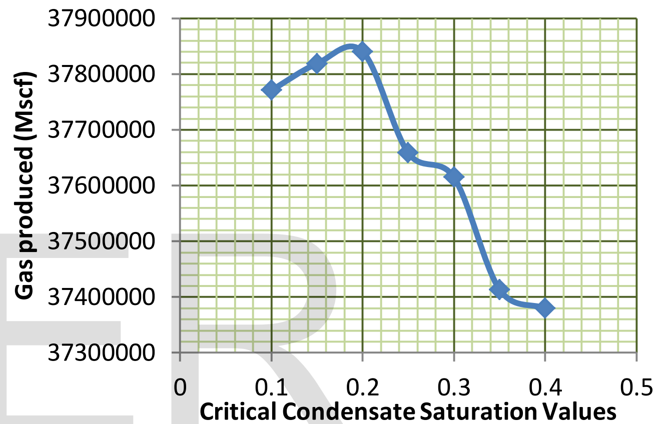

Figure 5: Effect of Critical condensate saturation on Gas production

RESULT DISCUSSIONS

From the Design Expert screening it was obtained that the Relative permeability and Critical condensate saturation contributed 8.44% and 9.10% respectively, to the recovery of gas and condensate, thus proving that the two parameters affect recovery. Improvement in recovery was observed during injection as opposed to depletion. There was 40% increase in the cumulative gas production as well as up to 33% increase in condensate production. The

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economic analysis take into consideration the injection costs, to determine if the process was a viable one.

Economic Analysis

Figure 1 shows the relationship between the net revenue for the depletion and injection scheme with time. This clearly shows that the optimal time to start injection is after the first two years of production, as revenue for the depletion and injection remained closely the same before this period. From the second year up to the fourth year recorded rapid increase in revenue for the injection scheme before recording stable revenue for the rest of the production years. This clearly shows that the injection scheme was viable.

Effect of Relative Permeability

Figure 2 show the relationship between varying relative permeability values and gas production. Gas production increases with increasing relative permeability up to a point where production is almost constant. This is same for condensate production as can be seen in figure 3.

Therefore, it can be concluded that increase in values of relative permeability, would result in corresponding increase in cumulative recovery during a gas cycling scheme, thus higher values of relative permeability would result in higher yield and consequently higher revenues.

Effect of Critical Condensate Saturation

The effect of critical condensate saturation (Scc) on recovery shows that high values of critical condensate saturation results in decreasing recovery. The relationship between the changes in critical condensate saturation and the gas and condensate recovery can be seen graphically in figures 4 and 5 respectively. This means that the higher the critical condensate saturation values for a particular reservoir, the lower the condensate yield during depletion process. At lower critical condensate saturations few of the reservoir pore spaces are blocked with condensed hydrocarbon liquid. Effects of critical condensate saturation on recovery were investigated in a gas cycling project. The results are shown in figures 6 to 15. The effects are evaluated at different injection pressures. At high injection rates (Fig.6 - 9) more gas was recovered from the reservoir with critical condensate saturation of 0.2 up to injection pressure of 4600psia but below this pressure more gas was recovered from critical condensate saturation of 0.3. This trend was observed for injection rates of 12400mscf/d and 9920mscf/d except for injection pressure of 5500psia at injection rate of 2400mscf/D where more gas production was encountered at Scc value of 0.3. In condensate production (figures 12 – 15) for all the injection rates studied more condensate were recovered from reservoir with higher critical condensate saturation. For all the cases considered during gas cycling, reduction in injection pressure led to decrease in production of both gas and condensate. Therefore, at higher critical condensate saturations gas cycling is very effective for removal of condensate lost in the pore spaces.

CONCLUSIONS

In this work, study on the productivity of gas-condensate reservoirs was addressed. Firstly, an experimental design was used to study the influence of selected parameters on recovery. Then a compositional simulation model was used to study the recovery process, which reaffirmed the positive effect of gas cycling on the recovery of gas-condensate fluids, by valuating the process using a derived

Net present value formula. In addition, the effects of Relative permeability and Critical condensate saturation on the overall recovery of the fluids in place were examined.

The major conclusions drawn from the work are the following.

- ✓ Efficiency of the recovery of Gas and Condensate from a gas condensate reservoir is affected by various reservoir and production parameters.
- ✓ Gas cycling is a viable method of enhancing recovery from gas condensate reservoirs, especially when the initial reservoir pressure is slightly above the dew point pressure.
- ✓ The optimal time to begin injection is shortly after production begins, at the time when pressure drawdown is approaching the dewpoint.
- ✓ NPV has been used in this work to ascertain when to effective start gas injection. For the case considered it is appropriate to start at 2.2 years after production begins. That means gas produced within this period would give substantial revenue of $120.0MM.

Relative permeability and Critical condensate saturation are key parameters to be considered in the evaluation of possible recovery strategies and determining flow capacity.

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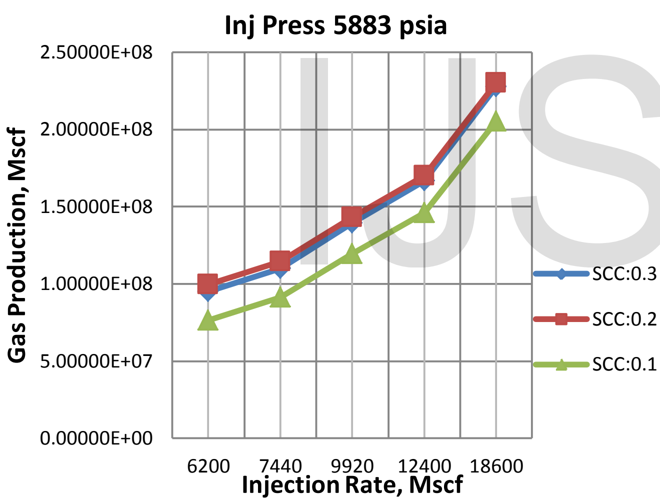

Figure 6: Variation of gas production with injection rate at different critical condensate saturations and injection pressure.

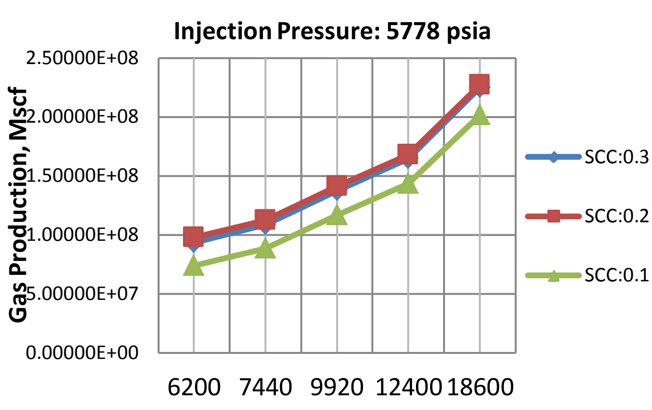

Figure 7: Variation of gas production with injection rate at different critical condensate saturations and injection pressure 5778 psia.

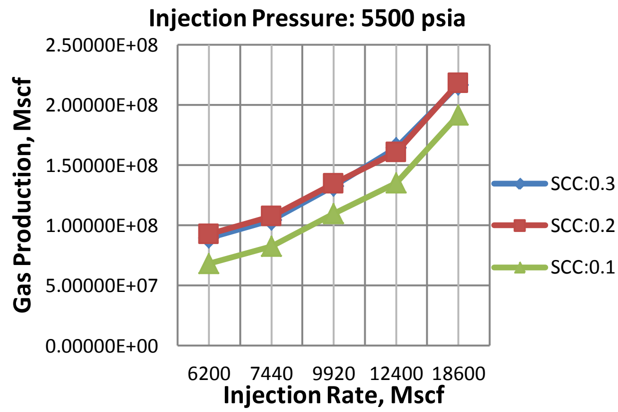

Figure 8: Variation of gas production with injection rate at different critical condensate saturations and injection pressure of 5500 psia.

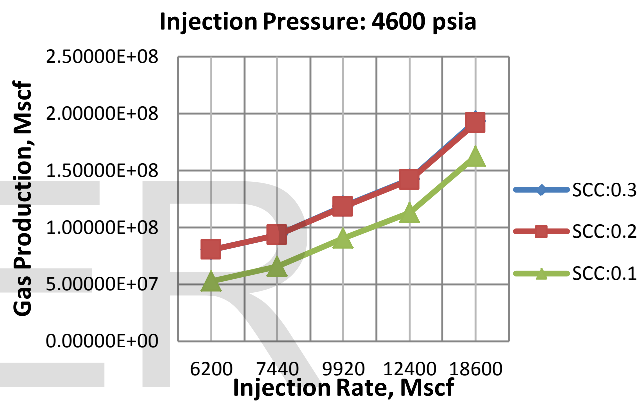

Figure 9: Variation of gas production with injection rate at different critical condensate saturations and injection pressure 4600 psia.

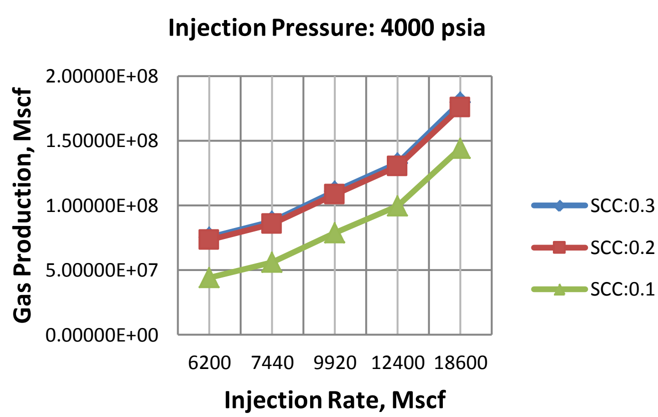

Figure 10: Variation of gas production with injection rate at different critical condensate saturations and injection pressure 4000 psia.

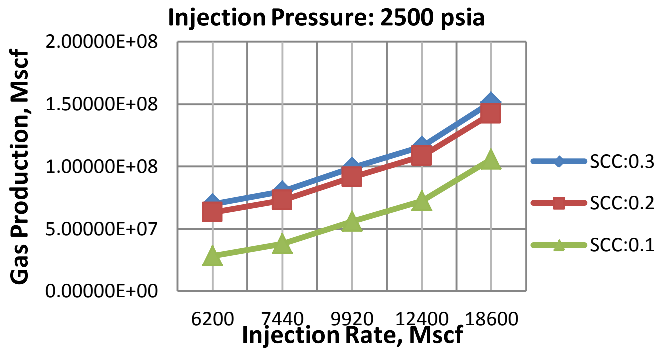

Figure 11: Variation of gas production with injection rate at different critical condensate saturations and injection pressure 2500 psia.

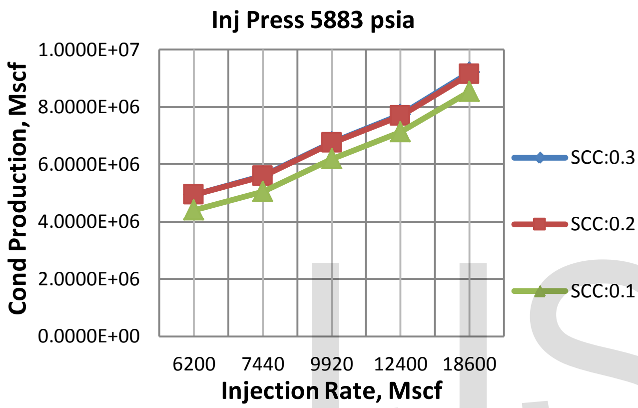

Figure 12: Variation of condensate production with injection rate at different critical condensate saturations and injection pressure 5883 psia.

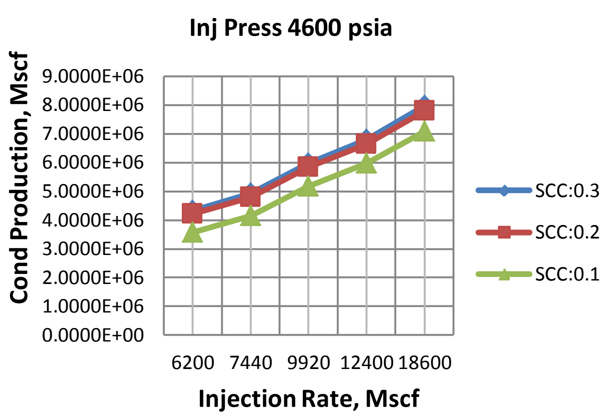

Figure 13: Variation of condensate production with injection rate at different critical condensate saturations and injection pressure 4600 psia.

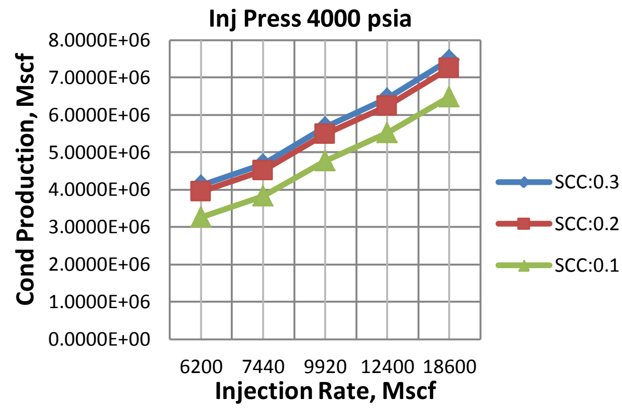

Figure 14: Variation of condensate production with injection rate at different critical condensate saturations and injection pressure 4000 psia.

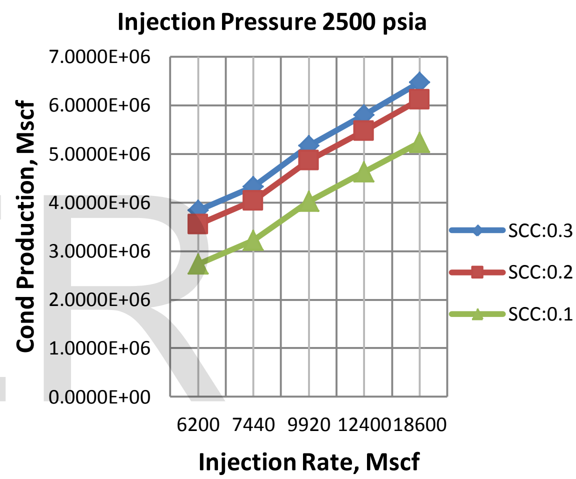

Figure 15: Variation of condensate production with injection rate at different critical condensate saturations and injection pressure 2500 psia.