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RESEARCH ARTICLE

A Comparative Study of Drillstring Gas Injection Method and Parasite Casing String Gas Injection Method for Aerated Liquid Drilling

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ABSTRACT

Conventional drilling operations often encounter many drilling problems such as low penetration rate, high formation damage, differential pipe sticking, loss of circulation, and short bit life. Underbalanced Drilling (UBD) technique is one of unconventional drilling techniques, which offers effective solution to the previous conventional drilling problems. In UBD technique, the wellbore pressure exerted by drilling fluid is intentionally less than the pore pressure in any part of the exposed formations. Low density fluids, such as air, mist, foam, or aerated mud are used to create the appropriate underbalanced condition, there are two main methods for gasification the drilling fluid: injection the gas into the drillstring through the standpipe at the surface, and injection the gas downhole into the annulus through parasite casing string, parasite tubing string or completion. In this paper, a detailed comparison including benefits, limitations, and hydraulic performance between the standpipe gas injection method and parasite casing string as injection method is presented.

1. INTRODUCTION

Gasified or aerated liquid drilling is the predominant underbalanced drilling technique used all over the world (McLennan et al., 1997). The liquid phase is normally crude oil, diesel or water gasified with nitrogen to reduce the hydrostatic pressure exerted by the liquid phase. The created equivalent circulating densities usually range from 4 to 7 ppg which considered an appropriate range to achieve the designed underbalanced condition in most cases of depleted reservoirs. Figure 1 shows the different gasification techniques used for UBD as mentioned previously.

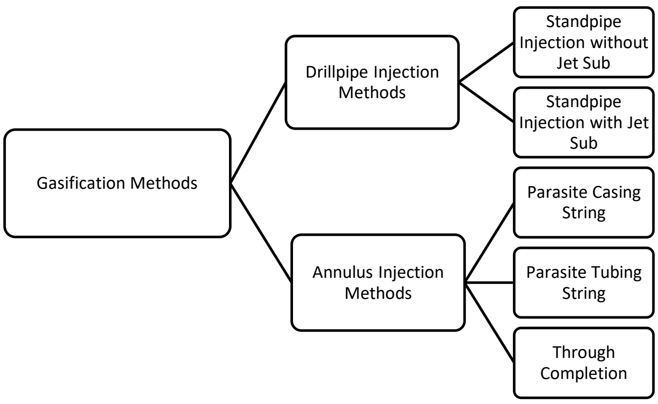


Figure 1: The different gasification techniques

Much of studies and research present the evaluation of many case studies of oil and gas wells drilled underbalanced using gasified liquid. discussion of the objectives, designing, problems encountered, and lessons learned during the first application of UBD wells in Libya (Ben Shatwan et al., 2011), regardless of showing the differences in bottomhole circulating pressure (BHCP), standpipe pressure (SPP), minimum annular vertical velocity and cutting transport ratio between the well drilled using drillstring gas injection and the well drilled using concentric casing gas injection. The oil wells drilled only with parasite tubing string injection method in the Piceance basin in northwestern Colorado in the United States were evaluated (Gala et al., 2009).

Development of a computer simulator for aerated liquid drilling using drillstring gas injection method was advantageous in UBD operation, results found differences between the predicted and measured standpipe pressure about 10 % when drilling at depths from 3000 ft to 7000 ft for drillstring gas injection method (Guo et al., 1996) but without any results of pressure prediction in case of using parasite tubing string for gas injection. Many case studies of gasified liquid drilling using coiled tubing in Western Canada and Egypt have been discussed and analyzed to determine the feasibility of coiled tubing utilization during UBD operation (Smith et al., 2000; Kamel et al., 2024). A numerical simulation developed based on two case studies of underbalanced wells to study the effect of hydraulic diameter, cross-sectional area, liquid density, and liquid viscosity on BHCP and hole cleaning (Ghobadpouri et al., 2021). The previous literature review shows that there is no research or case studies focused on a comparison implementation between the two methods of gas injection in the UBD operation. In this paper, a horizontal underbalanced well in Egypt is simulated using WellPlan ™ software, results of well data simulated in case of using standpipe gas injection method is compared with results of well data simulated in case of using parasite string gas injection method. This comparison provides the differences in UBD operating envelope, created bottomhole pressure, predicted SPP, minimum annular vertical velocity and cutting transport ratio between the two methods.

1.1 Benefits of drilling underbalanced

UBD has been used with increasing frequency to minimize or eliminate problems associated with overbalanced drilling (OBD). The benefits of UBD generally fall into two categories:

Cost reduction: including mitigation of OBD problems as low rate of penetration, high formation damage, loss of circulation, differential pipe sticking, short bit life.

Value adding: including productivity improvement due to the lower formation damage, production while drilling, higher ultimate recovery, and real-time formation evaluation and reservoir characterization while drilling.

1.2 Drillpipe injection method

It is the most common and simplest method for gasification a system, the gas is injected into the drillpipe in conjunction with the liquid phase of the drilling fluid being pumped through the standpipe. Ultimately the gas-liquid mixture passes through the bottom-hole assembly (BHA) and the drill bit, then flow from the drill bit into the annulus formed by the drillstring and the open hole.

Advantages of drillpipe injection method:

1. It is simple and the well design requires minimal modifications.
2. The total volume of gas-liquid mixture is available at the mud motor and drill bit which provides good bit hydraulics and hole cleaning.

Disadvantages of drillpipe injection method:

1. The volume of injected gas is constrained by the mud motor and conventional measurement while drilling tool (MWD).
2. The calculation of the pressure loss across the BHA is complicated which affects the prediction of BHCP and SPP.
3. Making a connection takes longer time because it is necessary to bleed down the pressure of compressed gas in the drillstring by the standpipe bypass before breaking open the joint. UBD

contractors recommend for the drilling crew to take 5 to 15 minutes before breaking open the joint during making connections.
4. Pressure fluctuations particularly during making connections and tripping.
5. The entire drillstring exposes to higher corrosion rate.

1.3 Parasite casing string injection method

It is also called concentric casing string or dual casing string. A temporary casing string is hung off inside the previous cemented casing string to form a false or micro annulus used to inject the gas down through the milled injection ports in the temporary casing. The size of the cemented casing inside which a temporary casing is installed may have to be increased to accommodate a temporary casing string with sufficient drift diameter for hole section drilling. (Deis et al., 1995) presented a case study of horizontal well drilled with annulus gas injection using 5½ inch temporary casing inside 7⅝ inch intermediate casing, and the bit size used to drill the hole section is 4¾ inch. Without annular gas injection, the intermediate casing was 7 inch and the bit size to drill the hole section below was 6⅛ inch.

Advantages of parasite casing string injection method:

1. Making connection does not require long time because there is no compressed gas inside the drillstring.
2. Conventional mud pulse MWD can be used.
3. The temporary casing string can be installed as a tie-back liner and retrieved to remove the slotted sub or removed for reuse.
4. Provide continuous gas injection during making connections or tipping which minimizes the pressure fluctuations problems and enhances bottomhole pressure control during making connections or tripping.
5. Facilitate the use of downhole deployment valve by incorporating it with the temporary casing to accelerate tripping process.

Disadvantages of parasite casing string injection method:

1. The hole size and hence the casing size in which the temporary casing is installed should be increased to accommodate the temporary casing inside with an adequate clearance or annulus for injected gas.
2. Wellhead modification is required to hang off the temporary casing string.
3. Accumulator effect due to the large storage capacity of the micro-annulus causes the circulation system to be unstable.

2. OVERVIEW OF GASIFIED LIQUID DRILLING OPERATIONS

In gasified drilling technique, the target underbalanced pressure must be at least 500 psi lower than the formation pressure to minimize the effect of pressure fluctuation during tripping or making connections (McLennan et al., 1997). For safety considerations, UBD contractors recommended for the drilling crew to take 5 to 15 minutes before breaking open the joint during making connections to bleed down the pressure in the drillstring through the standpipe bypass line, if the drillstring gas injection method is utilized. Two float valves have been utilized within the drillstring, sometimes a third float is set near to the surface to reduce the bleed down time of the string and accelerate the operation.

In addition to the standard drilling equipment, additional equipment required to be used for gasified liquid drilling operations:

- Rotating control head
- 4-Phase horizontal separator
- Drillstring floats
- Rotating control head
- Dedicated underbalanced drilling choke manifold
- Nitrogen pumping unit
- Fluid management equipment
- Tank system to store produced fluids

The rotating control head and choke manifold system provide primary well control during underbalanced drilling operations. In case of flowing well, the drillpipe part of the drillstring is stripped through the rotating head or rotating blowout preventer while the bottomhole assembly part should be stripped through the annular preventer. The drill string floats are used to prevent flow up the drillstring during tripping and connections. The 4-phase separator separates the returns from the well into solid, gas, water, and hydrocarbon liquid phases. In addition to the active drilling fluid system, a tank system is required to store produced fluids. The fluid management equipment, such as transfer pumps, piping, and valving, control the shipping of the fluids between the separator, the active mud systems, and the storage tanks. The separated gas phase is typically sent to flare, but depending on the production rate, it may also be economical to recompress the gas and inject it into a near-by gas pipeline.

3. STUDY METHODOLOGY

The appropriate multiphase flow model is selected to be used in well data simulation. WellPlan ™ software provide five multiphase flow models in underbalanced hydraulic module, the selected multiphase flow model in the discussed case study is the Duns and Ros model because it predicts BHCP, SPP, and annular liquid velocity in this case with high accuracy. BHCP, SPP, and annular liquid velocity are predicted and the UBD operating envelope is constructed using the selected multiphase flow model in case of utilizing the drillstring gas injection method, then the previous hydraulic parameters are predicted at the same operating conditions using the same multiphase flow model in case of installation of a temporary casing inside the surface casing. A comparison is performed using the hydraulic parameters to show the effect of the selected gasification method on the hydraulic behavior of the gasified liquid drilling.

The following criteria should be considered during the design of UBD operations to ensure safe and cost-effective operation (Reham et al., 2012).

- Selecting compatible drilling fluids based on drilling and reservoir considerations.
- Maintaining the wellbore pressure low enough to create a sufficient drawdown but it must be high enough to prevent any open hole collapse.
- Maintaining an annular velocity higher than or at least equal to the minimum annular velocity required for hole cleaning.
- The equivalent liquid rate (ELR) at any operating point of liquid and gas injection rates must be within the operating range of mud motor.
- Controlling the reservoir fluid influx to ensure that the surface separating equipment capacities and pressure rating can accommodate the production while drilling and pressure at the surface.

4. UBD OPERATING ENVELOPE

To avoid the problems of breaking the target drawdown pressure, the downhole conditions response to the changes in liquid injection rate, gas injection rate, choke back pressure, hole cleaning, drillstring washout, drill bit nozzles plugging, etc. should be predicted before beginning the UBD operation. UBD operating envelope is a closed area by four constraints:

1. Target wellbore pressure
2. The maximum and the minimum mud motor equivalent liquid rate (ELR)
3. Minimum annular velocity for hole cleaning
4. The maximum allowable drawdown according to wellbore stability and surface equipment capacity and pressure rating or the minimum injected liquid rate.

These constraints are constructed on the pressure performance curves resulting from the plot of BHCP vs. gas injection rate. Any operating condition of UBD well must selected to be inside the operating envelope of this well.

5. RESULTS AND DISCUSSION

5.1 Comparison of bottomhole circulating pressure

Underbalanced hydraulics module in WellPlan ™ software from provides prediction of BHCP in aerated liquid drilling using various multiphase flow models. Table 1 shows the different operating conditions during drilling 6" lateral section from 8793 ft MD to 8986 ft MD in sandstone formation and the corresponding BHCP in case of using drillstring gas injection and in case of using a temporary casing inside the surface casing set at 3940 ft. The liquid phase is diesel oil with density of 7.25 ppg (specific gravity = 0.87), and nitrogen is selected as the gas phase. The predicted BHCP is illustrated in figure 1.

Table 1: Comparison of predicted BHCP of drillstring and parasite casing string gas injection

BHCP, psi			
q_L, gpm	qg, scfm	Drillstring Gas Injection Method	Parasite Casing String Gas Injection Method
150	100	2865	2879
160	200	2776	2805
170	300	2703	2747
180	400	2641	2698
190	500	2575	2646
200	600	2516	2602
210	700	2460	2560
220	800	2411	2524
230	900	2363	2490
240	1000	2318	2459
250	1100	2280	2433
260	1200	2241	2407
270	1300	2206	2384
280	1400	2173	2363
290	1500	2143	2346
300	1600	2115	2329

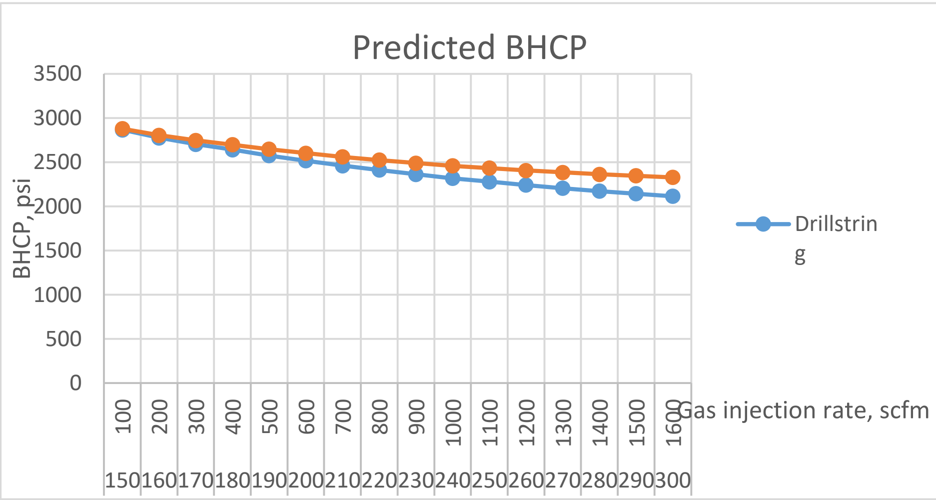


Figure 2: Comparison of predicted BHCP using drillstring gas injection method and parasite casing string gas injection method

The previous results show that the predicted BHCP created in case of using drillstring gas injection method is lower than that created in case of using parasite casing string ported at 3940 ft for the same operating conditions.

5.2 Comparison of standpipe pressure

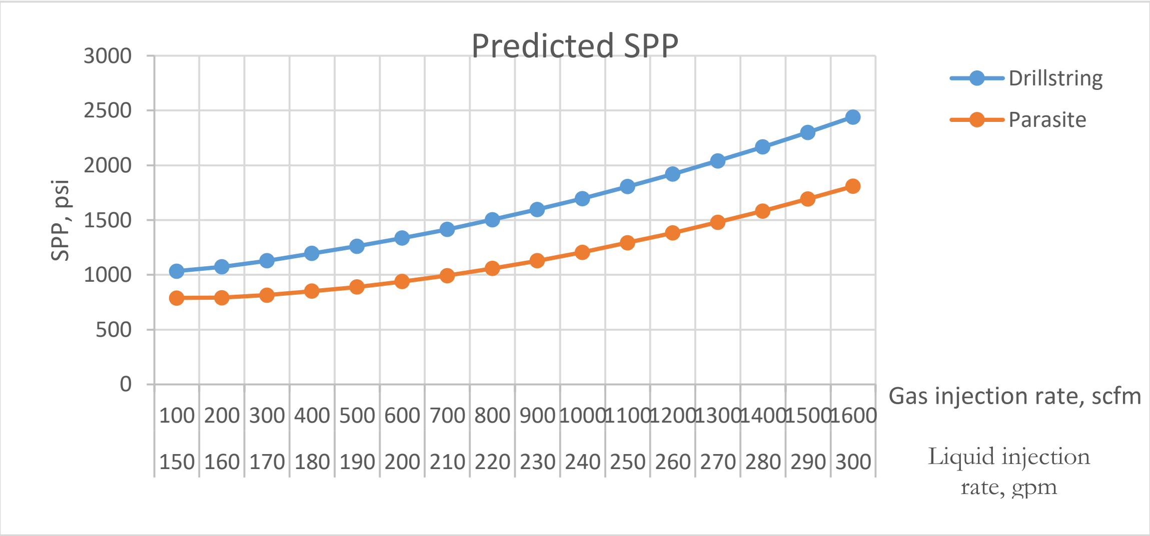
SPP is defined as the total frictional pressure loss in the drilling fluid circulating system, it is an important drilling parameter that must be monitored during drilling operation with an adequate accuracy because the continuous monitoring of SPP helps to identify downhole problems such as drillstring washout, broken drill string, plugged bit nozzles, inadequate hole cleaning, lost returns due to formation fracture, and an increase in mud density or viscosity. The prediction of SPP in aerated liquid drilling is more complicated than that in conventional drilling.

For the same operating conditions at which BHCP was predicted, SPP is predicted for the two injection methods. Results are tabulated in table 2 and illustrated in figure 3.

Table 2: Comparison of predicted SPP of drillstring and parasite casing string gas injection

SPP, psi			
q_L, gpm	qg, scfm	Drillstring Gas Injection Method	Parasite Casing String Gas Injection Method
150	100	1033	788
160	200	1073	792
170	300	1129	815
180	400	1196	851
190	500	1261	889
200	600	1336	938
210	700	1415	993
220	800	1503	1058
230	900	1597	1128
240	1000	1697	1206
250	1100	1806	1293
260	1200	1920	1383
270	1300	2041	1480
280	1400	2168	1583
290	1500	2301	1693
300	1600	2441	1808

Figure 3. Comparison of predicted SPP using drillstring gas injection method and parasite casing string gas injection method



Drillstring gas injection method exhibits higher values of SPP than casing string gas injection method. The turbulent flow of gas-liquid mixture through the drillstring increases the pressure losses which result in higher SPP values. This gives a preference to the casing string gas injection method over the drillstring gas injection method.

5.3 Comparison of minimum annulus liquid velocity

Annular liquid velocity is an important parameter in hydraulic design to ensure efficient hole cleaning. In gasified liquid, the gas injection rate enhances the cutting carrying capacity of the drilling fluid because the existence of turbulent flow. Table 3 shows the minimum annular vertical liquid velocity in the two gasification methods. Results is illustrated in figure 4.

Table 3: Comparison of predicted minimum annular vertical liquid velocity in the two gasification methods

Min. Annular vertical liquid velocity, ft/min			
q_L, gpm	qg, scfm	Drillstring Gas Injection Method	Parasite Casing String Gas Injection Method
150	100	20.8	20.9
160	200	34.8	34.8
170	300	38.3	38.3
180	400	41.9	42
190	500	45.8	45.9
200	600	49.8	49.9
210	700	54	54.1
220	800	58.3	58.5
230	900	62.9	63.1
240	1000	67.6	67.8
250	1100	72.4	72.7
260	1200	77.4	77.7
270	1300	82.5	82.9
280	1400	87.8	88.2
290	1500	93.2	93.6
300	1600	98.7	99.2

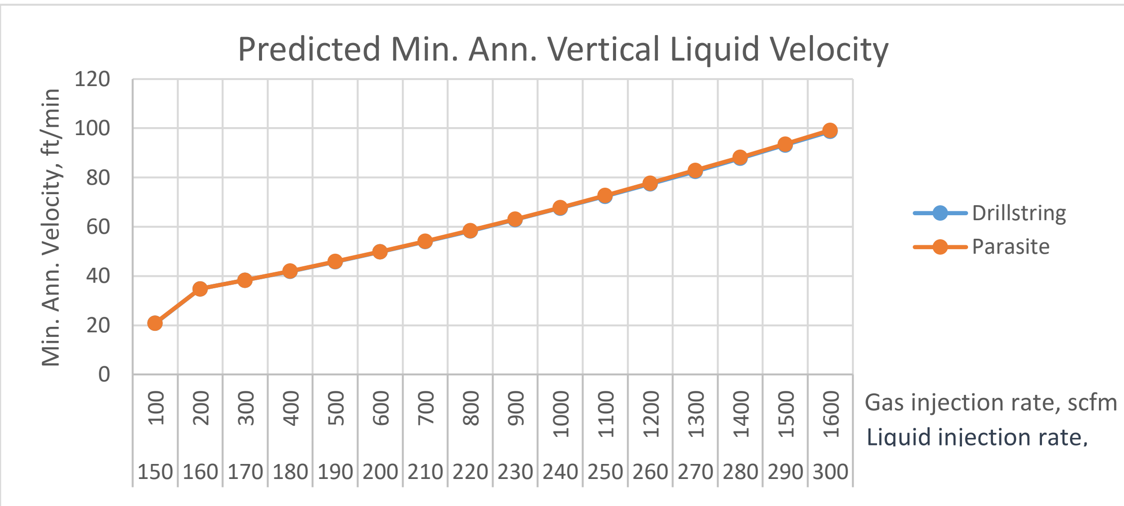


Figure 4: Comparison of predicted minimum annular vertical liquid velocity using drillstring gas injection method and parasite casing string gas injection method

The predicted minimum annular liquid velocity exhibits a negligible difference between the results of the two methods, particularly at low liquid and gas injection rates. As the liquid and gas injection rates increase, the minimum annular vertical liquid velocities of parasite casing string gas injection method exhibit higher values than that of drillstring gas injection method because the minimum annular liquid velocity in the horizontal section occurs near the surface at which the injection ports of temporary casing are located.

5.4 Comparison of UBD operating envelope

The operating envelope is constructed using WellPlan ™ software. Figure 5 shows the operating envelope and its parameters in case of drillstring gas injection method. The minimum vertical annulus liquid velocity required for efficient hole cleaning that can be selected in case of drillstring gas injection method is 70 ft / min, this value is the maximum vertical annulus liquid velocity that could be selected according to the mud motor operational specifications.

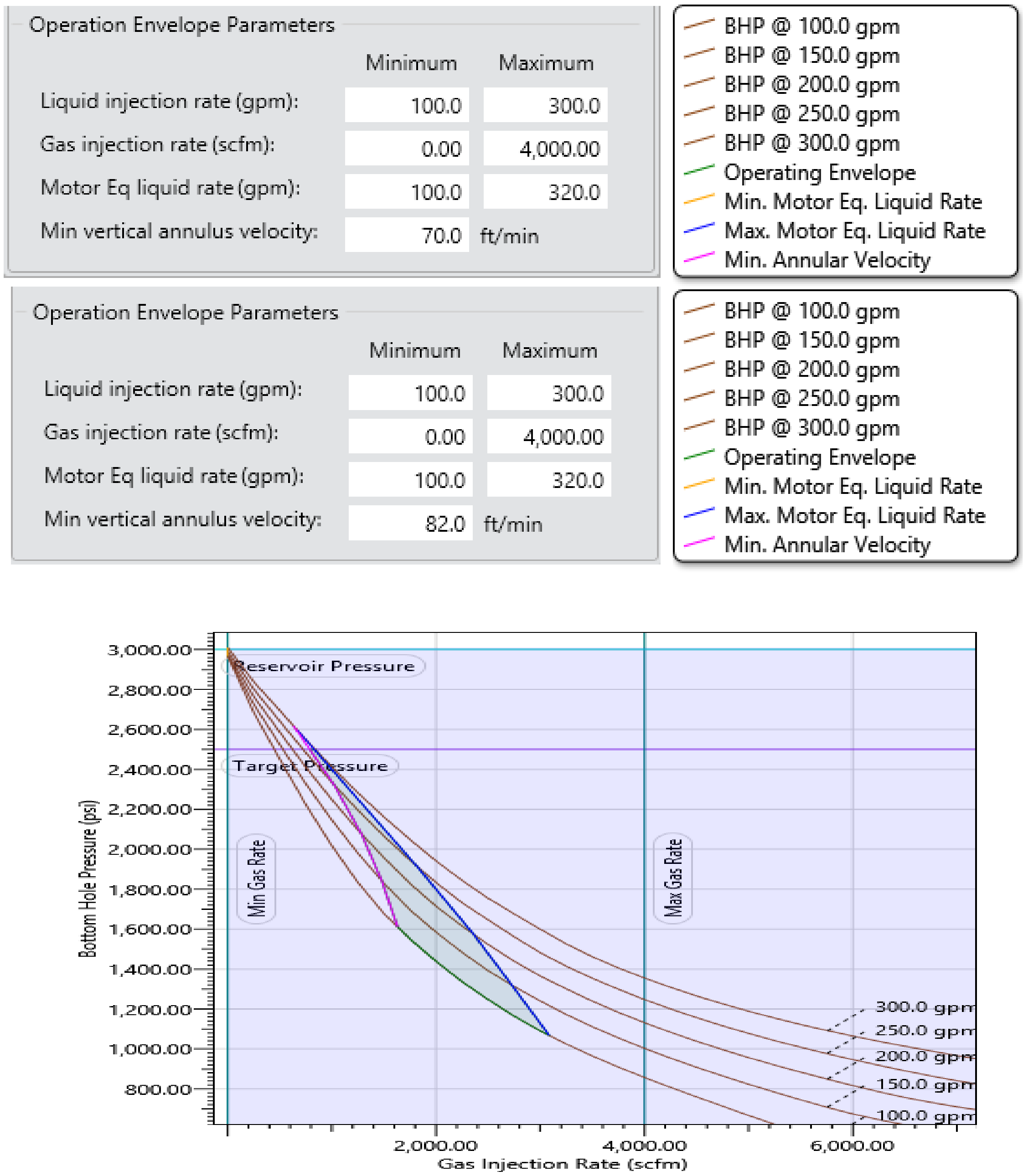


Figure 5: UBD operating envelope and its parameters using drillstring gas injection method

Figure 6 shows the operating envelope and its parameters in case of parasite casing string gas injection method. The minimum vertical annulus liquid velocity required for efficient hole cleaning that can be selected in case of parasite casing string gas injection method is increased to 82 ft / min. The explanation of that is the liquid phase only passes through the mud motor which creates annular liquid velocity higher than that created in case of gas-liquid mixture passes through the mud motor for the same ELR.

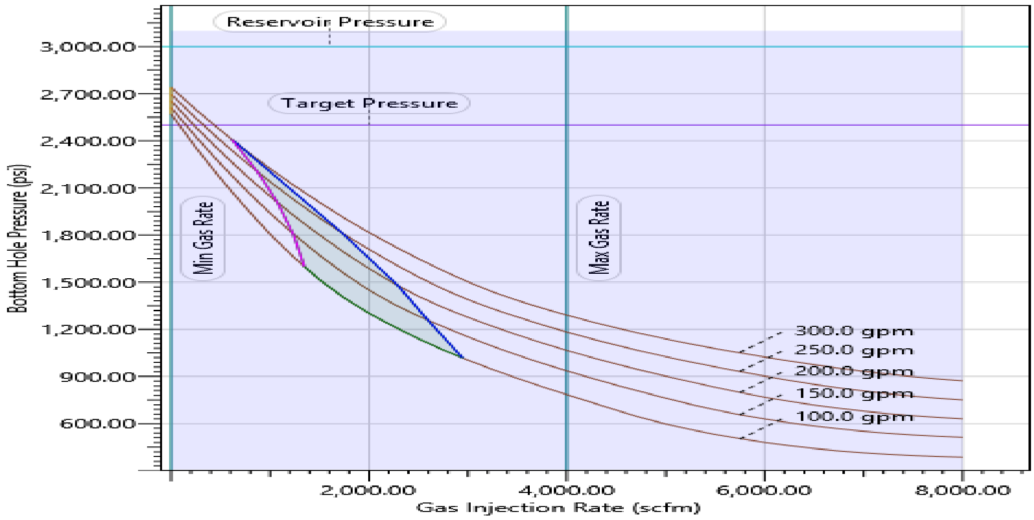


Figure 6: UBD operating envelope and its parameters using parasite casing string gas injection method

6. CONCLUSIONS

The comparison of drillstring gas injection method and parasite casing string gas injection method is provided based on actual field data of underbalanced well drilled using gasified liquid simulated on WellPlan ™ software. The effects of the two gasification methods on the hydraulic parameters such as: BHCP, SPP, minimum annular vertical liquid velocity and UBD operating envelope are investigated. The following conclusions may be drawn:

- For the same operating conditions of liquid and gas injection rates, drillstring gas injection method creates lower BHCP than that created in case of parasite casing string gas injection method.
- Contrary to BHCP, the drillstring gas injection method results in higher SPP than that resulted in case of using parasite casing string gas injection method.
- Gas injection method through parasite casing string exhibits a negligible increase of the minimum annular vertical liquid velocity.
- The operating envelope of drillstring gas injection method is more restricted than that of parasite casing string gas injection method because the maximum annular liquid velocity that can be created in the first case is lower than that can be created in the second case, hence it is recommended to use parasite casing method in case of drilling large hole size with mud motor.

6.1 Nomenclature

UBD	Underbalanced drilling
BHCP	Bottomhole circulating pressure
SPP	Standpipe pressure
OBD	Overbalanced drilling
BHA	Bottomhole assembly
MWD	Measurement while drilling
ELR	Equivalent liquid rate

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