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Gas Well Performance Analysis for Different Velocity Strings' Diameter at Certain Surfactant Concentration: A Simulation Approach

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***Abstract* - Liquid loading in gas wells is a critical challenge that limits gas production and can lead to well abandonment if not effectively mitigated. Analyzing the performance of a gas well under different liquid loading mitigation methods is necessary to achieve optimal gas production. Mitigation techniques such as surfactant injection and velocity strings have shown varying degrees of success but are rarely studied in combination. This study aims to evaluate the combined effectiveness of surfactant injection and varying velocity string diameters in mitigating liquid loading to optimize gas production rates. A numerical simulation approach was employed using the PROSPER simulator. Four wellbore models were developed: a base model without mitigation, a model with surfactant injection, a model with velocity strings, and a combination model utilizing both techniques. Sensitivity analysis was performed for varying surfactant concentrations and velocity string diameters to determine optimal deliquification conditions. The results reveal that the gas production rate increased with surfactant concentration up to the critical micelle concentration (CMC). The highest production rate was achieved at a surfactant concentration of 0.4 mass percent, which was determined to be the optimal concentration for liquid unloading. A velocity string diameter of 0.2 inches yielded the highest gas production rate. However, velocity strings alone were insufficient to fully deliquify the well and achieve optimal production. The combination of surfactant injection and velocity strings proved to be a more effective approach to deliquification compared to individual methods. These findings provide valuable insights for enhancing gas well performance under liquid-loaded conditions.**
***Keywords:* Liquid Loading, Gas Production, Surfactant Injection, Velocity Strings, Deliquification**

I. INTRODUCTION

Gas wells with insufficient velocity due to pressure depletion are prone to liquid loading, which, if not mitigated, can lead to well failure. Liquid loading is a major production challenge in gas wells. It occurs when the gas velocity is lower than the critical velocity required to transport liquid to the surface [1]. The presence of liquid in the wellbore limits gas production by forming a fluid hydrostatic column, which generates significant backpressure that can prevent gas flow from the reservoir into the wellbore [2]-[4].

Liquid loading significantly impacts the productivity of gas wells. Liquid accumulation in the wellbore creates various problems that adversely affect gas output: the liquid column in the wellbore generates backpressure on the reservoir, increasing the hydrostatic pressure at the well's bottom. This backpressure reduces the driving force needed for gas to flow into the wellbore, further lowering gas production rates [5]. As liquid loading becomes more severe, the gas flow rate decreases because the gas can no longer effectively displace the liquids. In extreme cases, the well may need to be shut in, and gas flow may cease entirely. Liquid loading may also result in slugging - an unstable production process caused by the sudden and massive rise of liquid to the surface - which can lead to operational downtime. Wells experiencing liquid loading require remediation such as chemical treatments, artificial lifting, or adjustments to operating parameters. However, these measures are not always effective and can be costly.

In some cases, liquid loading can lead to well abandonment if remediation proves too expensive. Therefore, it is crucial to detect and address liquid loading promptly to ensure the economic viability of gas wells [6]. In such scenarios, deliquification becomes essential for sustaining gas productivity and enhancing the superficial gas velocity required for liquid lifting [7].

Various methods are employed to address the problem of liquid loading. These methods, commonly referred to as deliquification techniques, include mechanical approaches such as plunger lift and critical velocity reduction systems, as well as chemical techniques involving the use of surfactants or foaming agents [8]. The use of downhole surfactant (foamer) injection as a chemical method offers a highly adaptable, flexible, and cost-effective treatment approach [9]-[12].

Previous research has investigated the impact of surfactant injection and velocity strings on the gas well deliquification process. P. Oudeman highlighted that selecting the correct velocity string size is a critical step before installation [13]. A very small flow conduit increases pressure loss and reduces production, while an excessively large string results in production rates below the minimum critical rates, potentially shortening the well's production life. In their study on the effect of various surfactant concentrations on the gas well deliquification process, B. B. Kinate *et al.,* concluded that surfactants should not be injected at concentrations higher than the critical micelle concentration

(CMC). Exceeding this concentration significantly increases the frictional component of fluid pressure loss due to the foam's rheology [14]. The primary objective of surfactant injection is to remove a portion of the stored liquid and sustain gas production. Thus, surfactant injection alleviates, but does not entirely resolve, the liquid-loading issue.

Although various studies have examined the effects of surfactant concentrations and velocity strings on liquid loading, no study has evaluated the combined use of surfactant injection and velocity strings. Therefore, it is essential to analyze the well performance, production rate, and lifting efficiency of a gas well by considering the simultaneous application of surfactant injection and velocity strings.

II. METHODOLOGY

A. Simulator and Input Data

The PROSPER simulator was utilized for wellbore model development and numerical simulation, incorporating data on fluid properties, well equipment (deviation survey, geothermal gradient, downhole equipment), surfactant concentration as a function of foam density and surface tension, velocity string diameters, and setting depth. The data are presented in Tables I-X.

TABLE I MODEL SETUP DATA

Property	Specification
Fluid type	Dry and Wet Gas
Separator	Single-Stage Separator
Water vapor	Calculate Condensed Water Vapor
Artificial lift	Foam lift (surfactant injection)

TABLE II FLUID PROPERTIES DATA [14]

Property	Specification
Gas gravity	0.58
Separator pressure	200 psig
Condensate gas ratio	1 STB/MMscf
Condensate gravity	50°API
Water gas ratio	100 STB/MMscf
Water salinity	100000 ppm
Mole % H_2S	0%
Mole % CO_2	0.50%
Mole % N_2	2%

TABLE III FLUID CALIBRATION DATA [14]

Pressure (psig)	Z Factor	Gas Viscosity (Cp)	Gas FVF (ft^3/scf)
5300	1.03183	0.024644	0.0034174
3020	0.9053	0.01869	0.005239
2140	0.89365	0.01648	0.06733
1000	0.9287	0.014213	0.016213

TABLE IV DEVIATION SURVEY [14]

Measured Depth (ft)	Total Vertical Depth (ft)
0	0
1500	1500
2000	1980
2500	2450
3000	2883
3500	3300
4000	3721
4500	4140
5000	4560
5400	4900

TABLE V DOWNHOLE EQUIPMENT DATA FOR THE BASE MODEL AND VELOCITY STRINGS

Type	Measured depth (ft)	Inside diameter (in)	Roughness (in)
Xmas Tree	0	-	-
Tubing	1000	2.375	0.0006
SSSV	-	2.375	-
Tubing	5000	2.375	0.0006
Casing	5400	4.778	0.0006

TABLE VI DOWNHOLE EQUIPMENT DATA FOR SURFACTANT INJECTION AND COMBO SYSTEM

Type	Measure depth (ft)	Tubing ID (in)	Roughness (in)	Tubing OD (in)	Casing ID (in)
Xmas Tree	0	-	-	-	-
Tubing	1000	0.95	0.0006	1.125	3.958
SSSV	-	0.95	-	-	-
Tubing	5000	0.95	0.0006	1.125	3.958
Casing	5400	-	0.0006	-	4.778

TABLE VII GEOTHERMAL GRADIENT [14]

Measure Depth (ft)	Formation Temperature (°F)
0	45
1500	75
5400	166

B. Simulation Procedure

Four wellbore models were developed in PROSPER: a base model without surfactant injection or velocity strings, a model with surfactant injection, a model with velocity strings, and a model with both surfactant injection and velocity strings. These models were created by configuring the system options for the various scenarios using the information provided in Table I.

The fluid properties data in Table II were entered into the fluid properties section. Laboratory test data in Table III were matched against the fluid properties correlations at 166°F and 1200 psig. The deviation survey data in Table IV were entered into the deviation survey section. The downhole equipment in Table V was installed for the base model and velocity strings. The geothermal gradient data presented in Table VII, along with an Overall Heat Transfer Coefficient (OHTC) of 3 Btu/h/ft²/°F, were entered into the temperature survey input section. Reservoir data in Table VIII were inserted into the reservoir section.

TABLE VIII RESERVOIR DATA [14]

Property	Specification
Reservoir pressure	1200 psig
Reservoir temperature	166 °F
CGR	1 STB/MMscf
WGR	100 STB/MMscf
Reservoir permeability	25 Md
Reservoir thickness	55ft
Drainage area	500acre
Dietz shape factor	31.6
Wellbore radius	0.354ft
Perforation interval	55ft
Time since production started	59days
Connate water saturation	0.25
Reservoir porosity	0.15
Skin	+2

TABLE IX SURFACTANT CONCENTRATION AND SURFACE TENSION [15]

Surfactant concentration (Mass Percent)	Surface tension dyne/cm
0.02	66
0.05	59
0.1	52
0.15	46
0.2	44
0.5	36

TABLE X SURFACTANT CONCENTRATION AND FOAM DENSITY [15]

Surfactant concentration (Mass Percent)	Foam density (Ib/ft^3)
0	68
0.05	53
0.1	45
0.25	33
0.5	30.5

Well performance calculations were conducted using the system analysis option. With the well proven to be liquid loaded, the surfactant injection, velocity strings, and combo (surfactant injection + velocity strings) wellbore models were constructed following the same procedure. The data presented in Table VI were used to redefine the downhole equipment section to include the annular space between the coil tubing and the main production tubing for surfactant injection. The data in Tables IX and X were entered for the surfactant injection.

Once all the models were built, well performance calculations were carried out to determine the flow rate for each model. Sensitivity analysis was performed on surfactant concentration and velocity string diameter for a water-gas ratio (WGR) of 100 STB/MMScf.

III. RESULTS

A. Well Inflow Performance Relationship and Production Rate for the Base Case

Figure 1 illustrates the well inflow performance relationship (IPR) curve for the base case without surfactant injection or velocity strings. The results demonstrate that the well has an Absolute Open Flow Potential (AOFP) of 13.3861 MMscf/day, indicating that the reservoir delivered 13.3861 MMscf/day of gas when the flowing bottomhole pressure was at atmospheric conditions. The production rate decreases with increasing flowing bottomhole pressure, as shown in Figure 2.

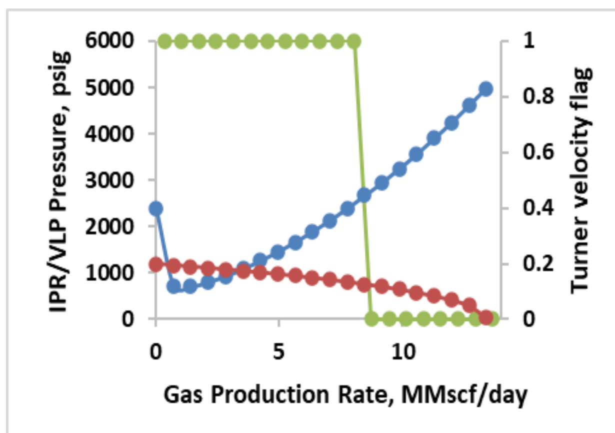

Fig. 1 Inflow and outflow curves

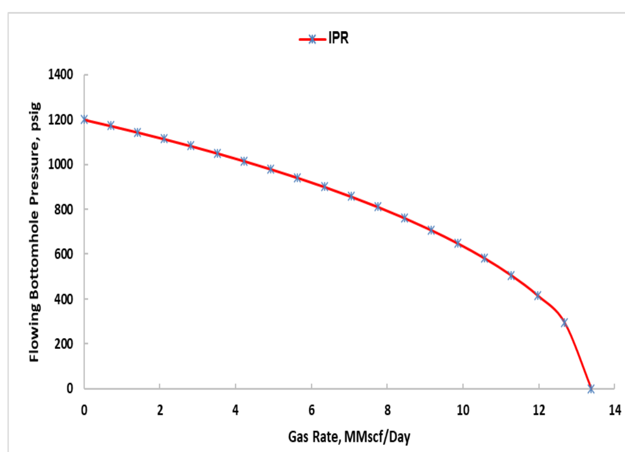

Fig. 2 Well inflow performance curve

B. Well Performance Curves for Different Surfactant Concentration

The relationship between flowing bottomhole pressure and gas production rate for different surfactant concentrations, including the inflow performance relationship and vertical lift performance (VLP), is presented in Figure 3. The vertical lift performance curves shifted downward as the surfactant concentration increased. The results reveal a gas production rate of 7.80343 MMscf/day when surfactant was injected, compared to 3.25868 MMscf/day for the base model. Additionally, the critical gas production rate for liquid loading decreased from 4.2329 MMscf/day to 3.5297 MMscf/day due to surfactant injection.

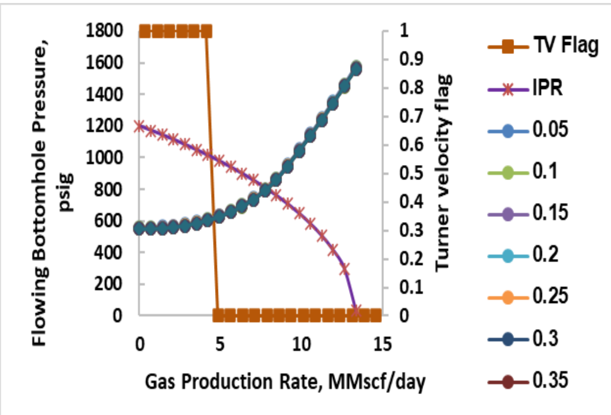

Fig. 3 Inflow and outflow curves for different surfactant concentration

C. Gas Production Rate for Different Surfactant Concentration

The gas production rate for different surfactant concentrations is shown in Figure 4. The results show an increase in the gas production rate with surfactant concentration up to the critical micelle concentration (CMC). The highest production rate (plateau) was obtained at a surfactant concentration of 0.4 mass percent, after which it declined. This indicates that a surfactant concentration of 0.4 mass percent was the optimal concentration for unloading liquids and maximizing gas production. This agrees with the work of Kinate *et al.,* [14].

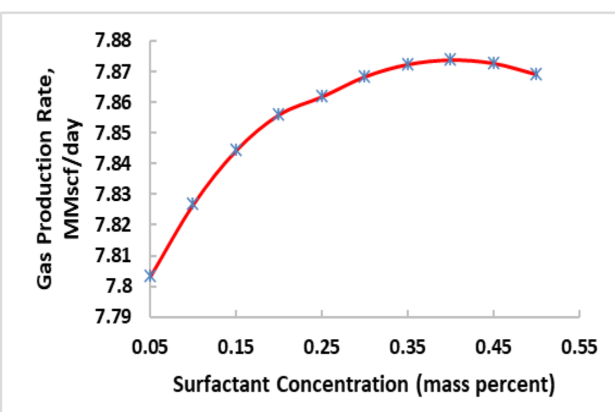

Fig. 4 Gas production rate against surfactant concentration

E. Well Performance Curves for Different Velocity Strings Diameter

Figure 5 shows the well performance curves for different velocity string diameters. The results show a downward shift in the outflow curves as the velocity string diameter increases. The critical gas rate for liquid loading decreased with an increase in tubing size. The increase in tubing size delayed the onset of liquid loading.

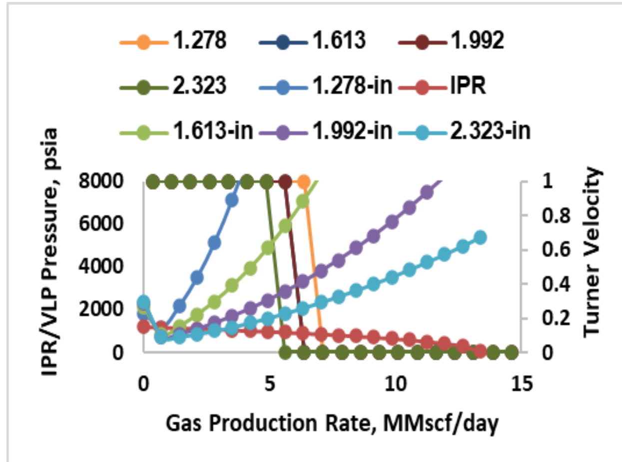

Fig. 5 Well performance curves for different velocity string's diameter

F. Gas Production Rate for Different Velocity Strings Diameter

The production rate for different velocity string diameters is presented in Figure 6. The results show that the production rate increases as the velocity string diameter increases. The production rate was lower than the critical rate predicted by the Turner model. The velocity string deployment was unable to lift the well outside the liquid loading region.

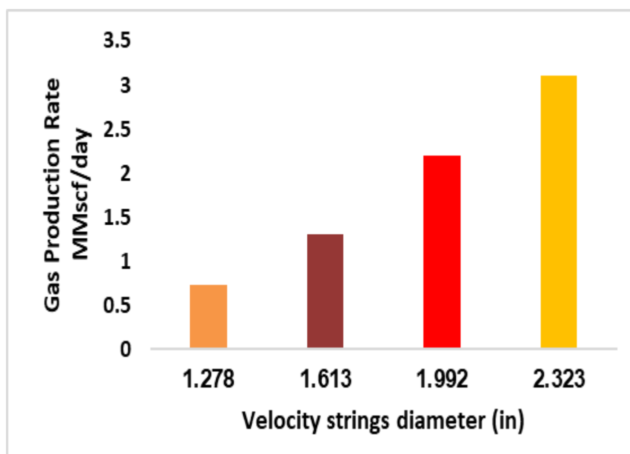

Fig. 6 Gas production rate against velocity string's diameter

G. Gas Production Rate at 0.1 Mass Percent Surfactant Concentration for Different Velocity String's Diameter

The variations in gas production rate with velocity string diameter at 0.1 mass percent surfactant concentration are presented in Figure 7. A decrease in production rate was observed as the velocity string diameter increased. The highest gas production rate was obtained with a 0.2-inch velocity string, while the lowest production rate was obtained with a 0.95-inch velocity string.

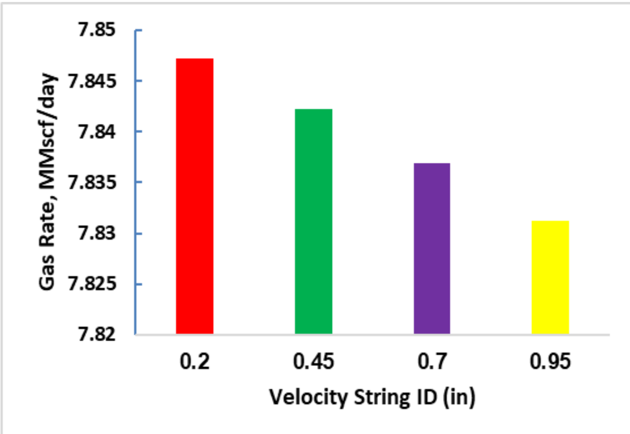

Fig. 7 Gas production rate for different strings diameter at 0.1 mass percent surfactant concentration

H. Gas Production Rate at 0.2 Mass Percent Surfactant Concentrations for Different Velocity String's Diameter

The gas production rate for different velocity string diameters at a 0.2 mass percent surfactant concentration is shown in Figure 8. An increase in velocity string diameter resulted in a decrease in production rate. The 0.2-inch velocity string produced the highest gas rate, with the 0.95-inch string yielding the lowest rate.

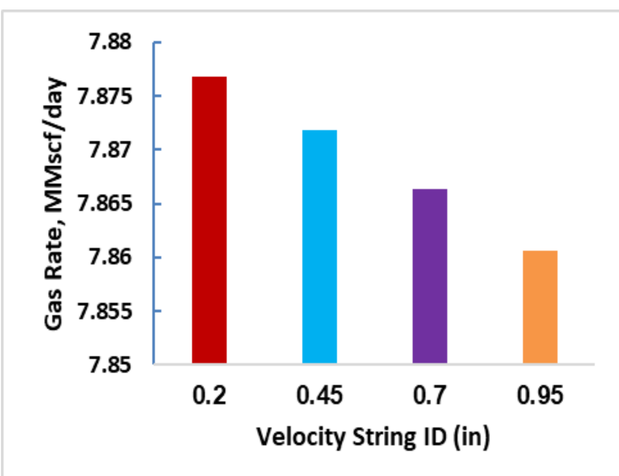

Fig. 8. Gas Production rate for different strings diameter at 0.2 mass percent surfactant concentration

I. Gas Production Rate at 0.3 Mass Percent Surfactant Concentration for Different Velocity String's Diameter

The gas production rate for different velocity string diameters at a surfactant concentration of 0.3 mass percent is presented in Figure 9. An increase in velocity string diameter decreases the gas production rate. There was little difference between the gas production rate for the smallest and largest velocity strings.

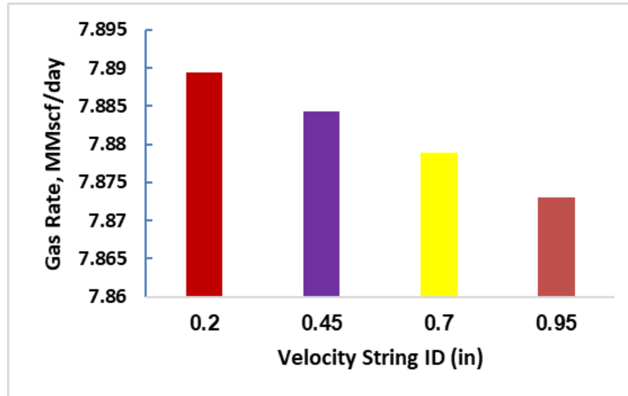

Fig. 9 Gas production rate for different strings diameter at 0.3 mass percent surfactant concentration

J. Gas Production Rate at 0.4 Mass Percent Surfactant Concentration for Different Velocity String's Diameter

Figure 10 shows the gas production rate at a surfactant concentration of 0.4 mass percent for different velocity string diameters. A decrease in gas production rate was observed as the velocity string diameter increased. The percentage decrease in gas production rates for each velocity string diameter was not significant, as they all remained within the same range.

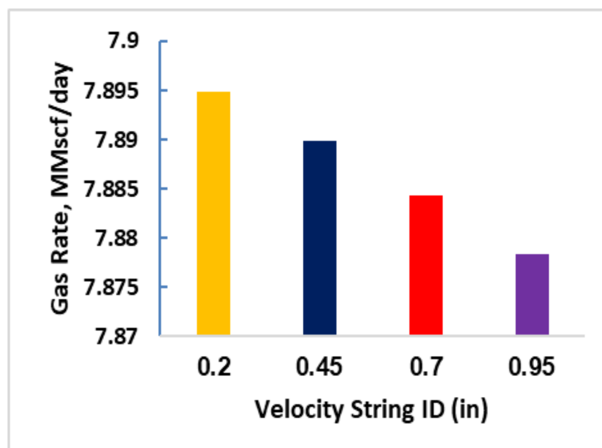

Fig. 10 Gas Production rate different strings diameter at 0.40 mass percent surfactant concentration

K. Gas Production Rate at 0.5 Mass Percent Surfactant Concentration for Different Velocity String's Diameter

The gas production rate for different velocity string diameters at a surfactant concentration of 0.5 mass percent is presented in Figure 11. The production rate decreased with an increase in the velocity string diameter. Additionally, there was an increase in gas production when comparing the 0.5 mass percent surfactant concentration to the 0.4 mass percent concentration.

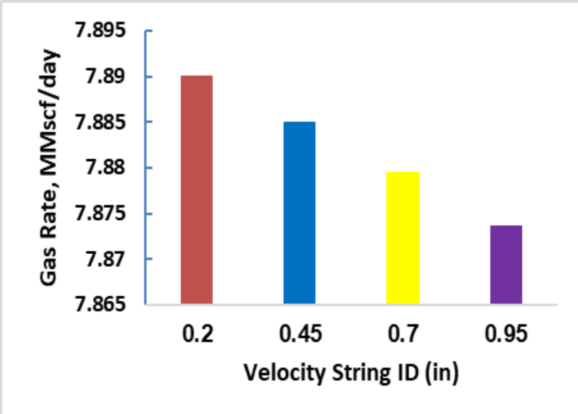

Fig. 11 Gas production rate different strings diameter at 0.5 mass percent surfactant concentration

L. Optimum Gas Production Rate for Different Techniques

Figure 12 shows the optimum gas production rate for the different deliquification techniques. A velocity string with a diameter of 2.323 inches gave an optimum gas production rate of 3.1052 MMscf/day. An optimum gas production rate of 7.87391 MMscf/day was obtained with surfactant injection at 0.4 mass percent, while 7.8768 MMscf/day of gas was the optimum rate obtained with a surfactant concentration of 0.2 mass percent and a velocity string diameter of 0.2 inches.

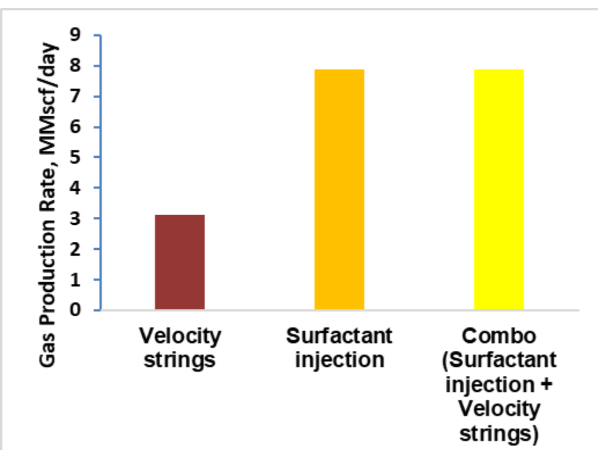

Fig. 12 Optimum gas production rate for different deliquification techniques

IV. CONCLUSION

This work investigates the application of surfactant injection and velocity strings in the deliquification of gas wells for optimal production. A numerical simulation approach was adopted to analyze well performance and gas production rates by injecting surfactants at different concentrations and installing velocity strings of various diameters. The study found that when combined with surfactant injection, an increase in the diameter of the velocity string leads to a decrease in the gas production rate. The optimum gas production rate was achieved at the highest surfactant concentration. Additionally, gas production increased with surfactant concentration up to the critical micelle concentration, after which it declined. Finally, gas production rate decreased with the flowing bottomhole pressure, causing a downward shift in the vertical lift performance.

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