STUDY OF CHEMICAL INJECTION APPLICATION WITH CAPILLARY STRING TECHNIQUE TO OVERCOME LIQUID LOADING IN X1 WELL, WEST JAVA

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Abstract- Due to the increasing of natural gas demand, the continuity of natural gas production from gas well should be maintained. However, problem in gas well is common, especially liquid loading. This study aims to overcome liquid loading in X1 well with chemical injection using capillary string. Software simulation proves gas production increase up to 57.1% by reducing surface tension up to 47.8% and critical rate up to 15.6%. Injecting 19.4 bbls of water and chemical mixture requires 783.55 psi of pump discharge and 0.29 hp of power with pressure ratio of 56.64. Meanwhile, the payback period for the chemical injection cost is 20 days. Chemical injection with capillary string is effective to overcome liquid loading in X1 well.

Index Terms- Capillary string, chemical, gas, liquid loading.

I. INTRODUCTION

The demand of natural gas in Indonesia, especially in West Java Province increases every year. It is along with economic growth that boosts the gas user industries to increase their production. Other sectors also increase their demand on natural gas for some utilities, such as city gas, transportation, oil lifting, and power generation (electricity). Unfortunately, the increased demand of natural gas hasn't compensated with sufficient supplyin West Java which causes negative gas balance. The total demand of natural gas in West Java is 2,107 MMSCFD which consists of committed demand, uncommitted demand, and potential demand, while total supply is only 687 MMSCFD which consists of 447 MMSCFD of existing gas pipe supply, 149 MMSCFD of existing LNG supply, 82 MMSCFD of gas pipe project supply, and 9 MMSCFD of LNG project supply [1].

The shortage of natural gas supply in West Java is caused by some factors, especially the small gas reserve and the appearance of gas well technical problems. Guo *et al* (2007) mentioned that there are four main categories of gas well problems : low productivity, excessive water production, sand production, and liquid loading [2]. From those technical problems in gas well, liquid loading is a problem that often occurs, especially in West Java. Sajjad and Sukarno (2010) mentioned that liquid loading phenomena is caused by the accumulation of liquid in bottom hole that causes increased saturation of water or condensate around the bottom hole. It decreases effective gas permeability and gas production rate [3]. In the early of gas production while the reservoir pressure is high, annular – mist flow dominates the gas well.

In this condition, gas phase becomes the dominant phase and is able to lift liquid from bottom hole to surface. The continuity of gas production causes accumulation of liquid in bottom hole. In this condition, slug flow dominates the gas well. Gas phase does no more become the dominant phase and isn't able to lift liquid from bottom hole to surface. Higher accumulation of liquid in bottom hole decreases gas production rate, even it may shuts well off.

Few alternatives can be used to overcome liquid loading in gas well, such as liquid pumping from bottom hole to surface or installing gas heater in bottom hole to convert accumulated liquid becomes vapor phase. Unfortunately, those alternatives don't directly separate gas phase with liquid phase in bottom hole, so the alternative is remanent and must be applied frequently. The best alternative that can be applied to overcome liquid loading in gas well is chemical injection with capillary string that has smaller inner pipe diameter than that in production pipe.This string can be installed inside the production pipe or casing that maintain annular – mist flow inside the gas well. It causes gas phase become dominant and is able to lift liquid phase from bottom hole to surface. Beside that, the injected chemical will react with accumulated liquid in bottom hole to form foam, so it decreases fluid surface tension and fluid density. It will ease accumulated liquid to be lifted from bottom hole to surface. Ardianto and Mucharam (2013) mentioned that based on laboratory experiment, smaller pipe diameter can lift liquid easier from bottom hole to surface [4].

II. LIQUID LOADING PROCESS

Gas well produces natural gas with particular amount of liquid, whether formation water or condensate in annular mist flow. Due to gas rate decreases caused by reservoir pressure decline, the flowing capacity will also decline until critical level. In the critical condition, fluid from reservoir will start to accumulate in bottom hole and alter the annular – mist flow to slug flow.The accumulation of liquid in bottom hole

decreases gas production rate [2].Low gas rate causes decreased gas velocity and forms bubble flow, then may shut well off.

The occurrence of liquid loading in gas well can be indicated with some alerts, such as :

- liquid slug in surface,
- increase of pressure difference between tubing and casing,
- the excessive change of flow gradient,
- the excessive decline of gas production,
- unstable pressure measurement in orifice,
- the fluctuative gas production rate.

Liquid loading occurs when gas production rate is smaller than critical rate. Critical rate is defined as the minimum gas rate to lift liquid droplet from bottom hole to surface. If gas production rate is smaller than critical rate, liquid from water formation or condensate will be accumulated in bottom hole and can't be lifted by gas to surface [5]. Critical rate is a function of gravity such as shown in Fig.1.

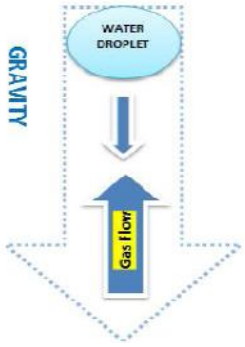


Fig.1. Gas and Liquid Flow

Gas flow from bottom hole to surface is always followed by liquid.Gravity affects gas flow from bottom hole to surface. Therefore, gas rate must higher than critical rate as function of gravity.Lower gas rate than critical rate causes water droplet drops to bottom hole and forms liquid accumulation that causes liquid loading.

Some methods had been used to predict liquid loading in gas well and are classified into two categories, correlation method and mechanical method [6]. Correlation method that is common in predicting liquid loading in gas well is *Turner* correlation that analyzesforce balance in liquid droplet for vertical flow and calculates critical rate in gas well. The critical rate can be obtained by calculating velocity using *Turner* correlationas in (1) and convert it into critical rate as in (2).

$$v_t = 17.6 \frac{\sigma_L^{1/4}(\rho_L - \rho_G)^{1/4}}{\rho_G^{1/2}} \qquad (1)$$

$$q_{cr} = \frac{3.067\, P\, v_{cr}\, A}{(T+460)z} \qquad (2)$$

A is the production pipe surface area that can be calculated by using (3).

$$A = 1/4 \frac{\pi\, ID_{pipe}^2}{144} \qquad (3)$$

The calculated critical rate then compared with existing gas production rate that can be obtained from production data report. If existing gas rate is lower than critical rate, liquid loading may occurs in the well.

Lea (2003) mentioned the process of liquid loading in gas well such as shown in Fig. 2 [7].

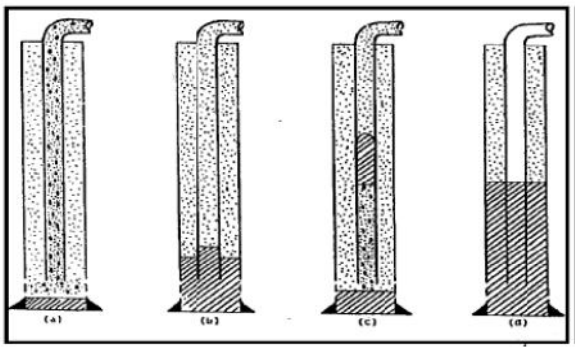


Fig.2. Liquid Loading Process

Based on Fig.2, liquid loading doesn't occur directly in gas well, but through some processes that occurs sequently.

a) *Process (a)* shows an early production condition when gas can produce effectively because the reservoir pressure is still high and sufficient to lift gas and liquid phase from bottom hole to surface. In this condition, gas rate is higher than critical rate, so gas phase can flow effectively, while liquid phase as droplet is inorderly suspended at high gas rate, that it can also flow from bottom hole to surface.
b) *Process (b)* shows the condition when reservoir pressure is start to decline, so it decreases gas rate. Gas rate slowly decreases until it is lower than critical rate.Therefore, liquid droplet that is in orderly suspended at gas phase starts to drop to bottom hole due to gravity and forms accumulation. This process allows liquid to block gas phase effective flow area that interfere gas production from bottom hole to surface.
c) *Process (c)* shows the liquid accumulation in bottom hole that decreases gas phase effective flow area. Gas rate that is inversely proportional with flow area causes increased gas rate for a while. In this condition, liquid in slug flow can be lifted from bottom hole to surface.
d) *Process (d)* shows that with continuous production, duration that is needed by reservoir to lift slug liquid from bottom hole to surface will increase due to pressure decline.

Meanwhile, hydrostatic pressure in well increases due to accumulated liquid and it gives back pressure impact from bottom hole to reservoir. Back pressure increases with time and drives flow into reservoir to avoid gas flow from reservoir into well. This condition causes complete liquid accumulation in bottom hole with no more gas production, that is liquid loading. It occurs continuously until reservoir pressure can't totally flow gas phase from reservoir into bottom hole and then shut well off.

III. CHEMICAL INJECTION WITH CAPILLARY STRING

Chemical injection by using capillary string is a simple method to overcome liquid loading in gas well. The operation expenditure of this technique is also cheaper than other method [8]. The main principal of chemical injection is lowering gas critical rate by decreasing surface tension of the liquid. The reaction between injected chemical and accumulated liquid also decreases liquid's density, so it can flow easier from bottom hole to surface. There are some advantages of applying chemical injection method with capillary string :

- surfactant that is used in this technique is simple and cheap, especially for gas well with low gas rate,
- the using of capillary string for chemical injection doesn't need complex downhole equipment, and
- this method is effective to be applied even in gas well with very low gas rate.

Chemical injection, which is surfactant, alters liquid into bubble film that decreases density and surface tension due to significant decrease of critical velocity. Surfactant is reactive to polar molecule. Since that, surfactant can reacts effectively with accumulated liquid (especially water) to form foam.

Capillary string that is used to inject chemical to bottom hole consists of some components which is shown in Fig.3 [9]. The system consists of chemical tank, chemical pump, capillary hanger, chemical injection manifold, capillary injection string, and chemical injection valve.

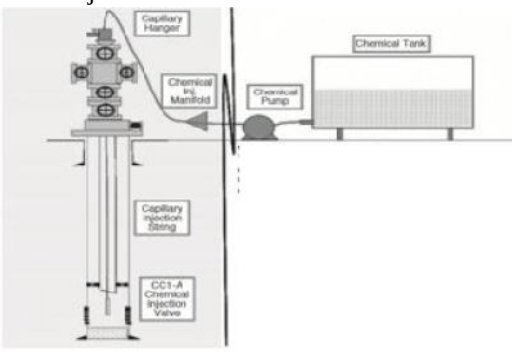


Fig.3. Conventional Component of Capillary String

Surfactant is used as the injected chemical due to its reactivity with accumulated water in bottom hole that comes from formation (reservoir). In designing surfactant to be injected, there four main parameters that must be considered and calculated : type, specific gravity, concentration, and volume.

The chemical is a compound of water with some components, mainly *ethoxy sulphate*, *alkane sulphonate*, and *petroleum sulphonate.* This is because it fulfills these criterias :

- reacts well with accumulated water in bottom hole,
- doesn't produce impurities in well temperature,
- doesn't form gel when react with liquid,
- foam as result of reaction between chemical and liquid can flow well from bottom hole to surface or doesn't cause foam locked in bottom hole,
- has proved in similar well in other location.

The chemical concentration needs to be considered to get perfect reaction between it and accumulated liquid. Compatibility test using dynamic foam test in laboratory is used to get proper concentration. Itis performedby mixing reservoir liquid sample (water) with chemical which is set in reservoir temperature (140^oF to 180^oF).The test principal is to analyze reaction flow of this mixture in particular chemical concentration with no gel found or foam locked in the experimental tube. In this case, chemical concentration range that doesn't produce gel is between 0% to 40%. The result is as shown in Fig.4.

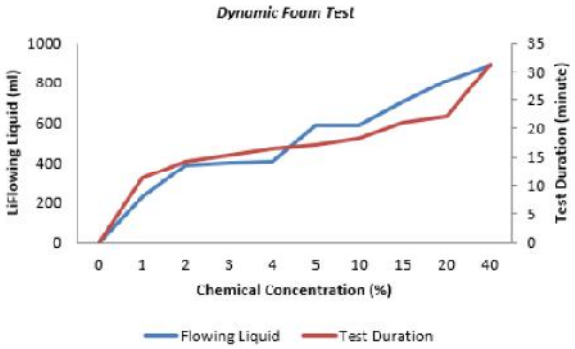


Fig.4. Dynamic Foam Test Result

Based on Fig.4, fluid can flow properly in concentration range between 1% to 40%. With 0% of chemical concentration, liquid that is accumulated in the tube bottom can't flow to surface. Liquid is significantly flow to surface when the chemical concentration is between 1% to 2%. Higher than 2% of chemical concentration, the liquid volume that flows to surface is no more significant. Thus, 2% of chemical concentration is used in this study.

Obtaining chemical concentration, chemical volume that will be injected is then calculated using (4).

$$V_{chem} = C_{chem} \, x \, V_{liq} \qquad (4)$$

V_{liq} refers to accumulated liquid volume in bottom hole to be overcome. It can be calculated using (5) which is obtained geometrically from well scheme.

$$V_{liq} = 0.0492\pi[ID^2_{casing}(D - EOP) - OD^2_{tubing}(EOT - EOP) + ID^2_{tubing}(EOT + h - D)] \quad (5)$$

By obtaining chemical concentration and accumulated liquid volume, then chemical volume that should be injected into liquid loaded well can be obtained.

After chemical design is obtained, pump design is also important to be prepared. It consists of three main parameters that are designedusing software simulation : pump discharge, pump power, and pump pressure ratio.These parameters are simulated by considering some assumptions as follows :

- temperature in chemical tank and string is constant at ambient temperature (60°F),
- pressure in chemical tank and string before wellhead is 14.7 psi,
- pump mechanical efficiency is 85%,
- chemical mixing in tank is running well,
- no pressure drop between chemical tank to pump due to its close distance (164 ft),
- injection point pressure is equal to reservoir pressure (730 psi),
- water cut of injection fluid is 100%,
- chemical mixture volume is equal to accumulated liquid in bottom hole.

The decrease of surface tension in accumulated liquid and gas critical rate can be obtained after injection process.As explained, determination of gas critical rate is calculated by determining surface tension and liquid density using (6).

$$\sigma = [P\sum_i^n \frac{\rho_i}{Mw_i}]^4 \quad (6)$$

P is parachor constant for gas component mixture. It is an emphirical constant that is related to molecular volume as the comparison of molecular volume when liquid has equal surface tension to determine partial structure of the mixture. Produced gas composition is obtained from chromatograph test, while molecular weight and parachor constant of each component is obtained from software simulation. Hydrocarbon and non-hydrocarbon component is mixed with chemical component (stated as pseudo component) after injection process.

IV. CASE STUDY

A. Well Description

X1 well is a vertical well with 615 m (2,017 ft) depth and perforated at X1 layer at 551 to 554.5 m (1.808 to 1.817) depth. It is a gas production well with reservoir pressure of 730 psi and 176°F of reservoir temperature. X1 well is produced at 580 psi of tubing pressure and 340 psi of line pressure. The temperature at wellhead is 110°F. The average gas production is 1.19 MMSCFD with 1 BOPD of oil production and 90 BWPD of water production. Oil and water production at X1 well indicates potential problem of liquid loading when gas rate is lower than critical rate. From gas chromatograph test to determine gas composition, there is no H_2S content and CO_2 component is only 0.4% mole. The low content of thus impurities shows that produced gas from X1 well is sweet and can be monetized with proper quality. Complete gas composition is as shown in Table 1.

Table 1. Gas Composition

Component	Unit	Content
CO2	%mole	0.40
N2	%mole	3.94
C1	%mole	90.88
C2	%mole	2.37
C3	%mole	0.95
nC4	%mole	0.21
iC4	%mole	0.44
nC5	%mole	0.02
iC5	%mole	0.26
C6	%mole	0.52
Z Factor	*dimensionless*	0.9977
GHV	BTU/SCF	1043.80
H2S	ppm	0.00

Based on Table 1, C_1 and C_2 content is high, respectively 90.88% mole and 2.37 %mol. It shows that produced gas from X1 well is dry gas. It is also supported with z factor value which is close to 1 (ideal condition), that is 0.9977. Due to this, dry gas is applied in software simulation.

The phase envelope is as shown in Fig.5.The cricondenterm and cricondenbar is respectively at 48.8016 °F and 1,534.66 psig. In surface condition, with 14.7 psi of pressure and 60° of temperature, produced gas is remain in gas phase.

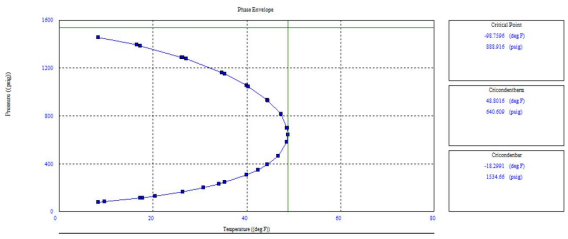


Fig. 5. Phase Envelope

Average gas production is 1.19 MMSCFD, close to software simulation result to determine gas production, that is 1.22 MMSCFD. Fig. 6 shows detail gas production data from X1 well since it was started to produce at May 30th 1992.

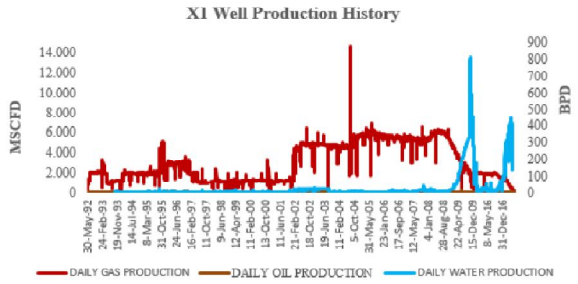


Fig. 6. Production Data History of X1 Well

Beside showing gas production data of X1 well in common, Fig. 6 also shows the relationship between gas production and water production to analyze liquid loading. In normal condition when there is no liquid loading in X1 well, the decline of gas production followed by increased water production. It is shown in period between the middle of 2008 and the end of 2009. In this period, gas production decreased significantly which was followed by excessive water production. The indication of liquid loading in X1 well can be seen in the end of 2016 when gas production decline was followed by water production decline. In this condition, produced gas can't flow well from bottom hole to surface because of lower flow area due to water accumulation in bottom hole. Reservoir pressure can't lift water properly to surface and water is accumulated in bottom hole due to gravity impact. Consequently, both gas and water production decrease.

B. Critical Rate Calculation

Using combination of (1), (2), (3), and (6), gas critical rate in X1 well before chemical injection can be determined. Based on gas composition as shown in Table 1 which is simulated in software simulation, gas molecular weight is obtained, 18.0169 lb/mole as shown in Fig.7.

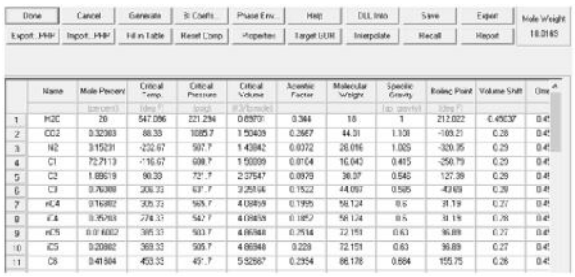


Fig. 7. Gas Molecular Weight

The accumulated water density is 67 lb/mole with surface tension of 60 dyne/cm. The critical rate calculation is shown in Table 2.

Based on Table 2, gas critical rate in X1 well is 1.28 MMSCFD, higher than the existing gas production rate. This condition causes gas can't flow properly from bottom hole to surface since it doesn't have sufficient minimum rate to lift againts gravity influence.

Table 2. Critical Rate Calculation

Parameter	Value	Unit
Critical Velocity Calculation		
Surface tension	60	dyne/cm
Liquid density	67	lb/ft^3
Gas density	0.35	lb/ft^3
Gas critical velocity	21.41	ft/s
X1 Well Coverage Area		
Well inner diameter	2.441	in
Well inner surface area	0.03	ft^2
Critical Rate Calculation		
Line pressure	340	psia
Line temperature	110	^oF
Gas compresibility factor	0.9978	-
Gas critical rate	1.28	MMSCFD

C. Chemical Volume

Surfactant that is injected into X1 well consists of ethoxy sulphate, alkane sulphonate, and petroleum sulphonate with volume comparison of 75% : 6.2% : 18.8% respectively. Accumulated liquid volume can be determined by using (5). Height column is determined by considering fluid density and hydrostatic pressure. The result is as shown in Table 3 and Table 4.

Table 3. Height Column

Parameter	Value	Unit
Hydrostatic pressure	646	Psi
Liquid density	67	lb/ft3
Height column	185	ft

Table 4. Accumulated Liquid Calculation

Parameter	Value	Unit
Casing inner diameter	9.625	in
Well depth	2017	ft
End of Packer	1,672.8	ft
Tubing outer diameter	2.469	in
End of Tubing	1,705.6	ft
Height column	185	ft
Accumulated liquid volume	3,089	liter
	19.4	bbl

Based on Table 4, volume of accumulated liquid in X1 well is 19.4 bbls. Using (4) with 2% of chemical concentration, chemical volume that is needed to overcome liquid loading is 0.388 bbls (61.69 liter). Convert it into mass unit by using density of each component, chemical component mass can be determined as shown in Table 5.

Table 5. Chemical Component Mass

Component	Density (g/ml)	Mass (g)
ethoxy sulphate	1.5	92,535
alkane sulphonate	0.124	7,650
petroleum sulphonayte	0.376	23,195

D. Pump Design

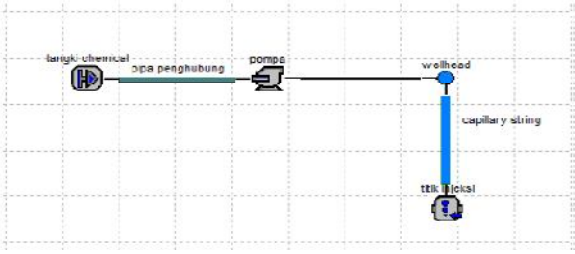


Fig. 8. Capillary String Configuration

Fig.8 shows the configuration of capillary system to inject chemical from surface into well. The system consists of chemical tank, connector pipe, pump, wellhead, capillary string, and injection point (valve). Three pump parameters will be determined using software simulation by considering physical properties in each point of the system. These parameters include pump discharge, pump power, and and pump pressure ratio. Five scenarios are run to indicate the influence of accumulated fluid volume to the need of pump discharge and pump power.

- Scenario I : accumulated volume is 19.4 bbl (V_o).
- Scenario II : accumulated volume is 24.25 bbl ($1.25V_o$).
- Scenario III : accumulated volume is 29.1 bbl ($1.5V_o$).
- Scenario IV : accumulated volume is 33.95 bbl ($1.75V_o$).
- Scenario V : accumulated volume is 38.8 bbl ($2V_o$).

As a sample calculation, scenario I is calculated using software simulation. The need of pump discharge and pump power is shown in Fig. 9 and Fig. 10 respectively.

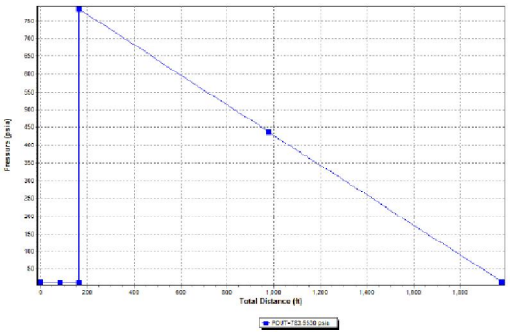


Fig. 9. Pump Discharge for Scenario I

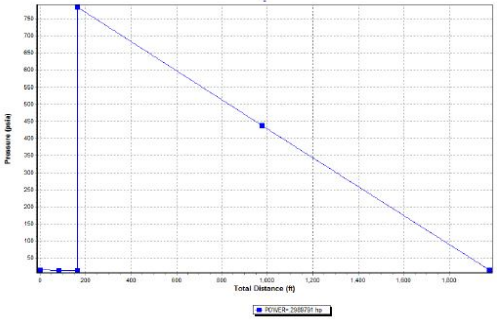


Fig. 10. Pump Power for Scenario I

Based on Fig. 9, the need of minimum pump discharge to inject chemical into X1 well for scenario I is 783.55 psi. While based on Fig. 10, pump power that requiered is 0.29 hp. Pressure ratio profile is also obtained as shown in Fig. 11., that is 56.64.

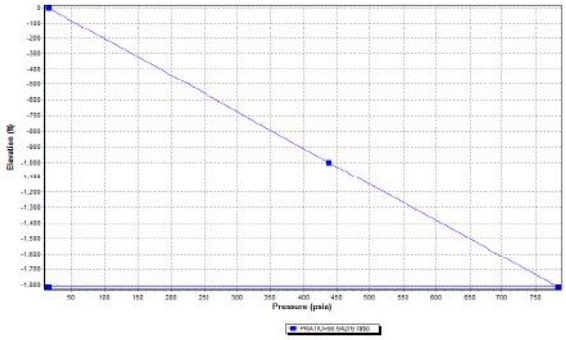


Fig. 11. Pressure Ratio for Scenario I

With similar calculation and simulation, the need of pump discharge, pump power, and pressure ratio for each scenario is shown in Table 6.

Table 6. Pump Profile for Each Scenario

Scenario	Accumulated Volume (bbl)	(Vo)	Pump Discharge (psi)	Pump Power (hp)	*Pressure Ratio*
I	19.4	Vo	783.55	0.29	56.64
II	24.25	1.25 Vo	784.01	0.37	59.28
III	29.1	1.50 Vo	784.46	0.45	61.89
IV	33.95	1.75 Vo	784.91	0.52	65.16
V	38.8	2 Vo	785.36	0.6	69.25

Based on Table 6, higher accumulated liquid volume requires higher pump discharge, pump power, and pressure ratio. Consequently, more accumulated liquid requires higher operational cost.

E. After Chemical Injection

Chemical injection into X1 well decreases surface tension of the accumulated liquid. Decreasing surface tension allows gas to have lower critical rate. The condition at which critical rate is lower that gas rate allows gas to flow effectively from bottom hole to surface. After chemical injection process is done, surface tension can be calculated using (6). Parachor of each component is obtained through software simulation as shown in Fig. 12.

	Component	Parachor
1	N2	60.4000015
2	CO2	78
3	H2O	78
4	C1	70
5	C2	115
6	C3	155
7	iC4	181.5
8	nC4	200
9	iC5	225
10	nC5	245
11	C6	282.5
12	PS-1	418.209442
13	PS-2	467.597321
14	PS-3	1130.70508

Fig.12. Parachor of Each Component

By inputing parachor and molecular weight of each component into (6), surface tension of accumulated liquid after chemical injection is obtained to be 31.3 dyne/cm. It is lower than that before chemical injection, that is 60 dyne/cm. It shows that chemical injection effectively decreases surface tension of accumulated liquid in bottom hole. After obtaining new surface tension, new gas critical rate after chemical injection can be obtained by using (1), (2), and (3). The result is shown in Table 7.

Table 7. Critical Rate After Chemical Injection

Parameter	Value	Unit
Critical Velocity Calculation		
New surface tension	31.3	dyne/cm
Liquid density	67	lb/ft^3
Gas density	0.35	lb/ft^3
Critical velocity	18.20	ft/s
X1 Well Coverage Area		
Well inner diameter	2.441	in
Well inner surface area	0.03	ft^2
Critical Rate Calculation		
Line pressure	340	psia
Line temperature	110	^oF
Gas compresibility factor	0.9978	-
New gas critical rate	1.08	MMSCFD

Comparing condition before chemical injection as shown in Table 2 with condition after chemical injection as shown in Table 7, the surface tension decreases from 60 dyne/cm to 31.3 dyne/cm (47.8%), while gas critical rate decreases from 1.28 MMSCFD to 1.08 MMSCFD (15.6%).

Injected chemical decreases surface tension by separating hydrocarbon bond in the fluid surface. It is obtained by locating hydrophilic heads of the injected chemical in the fluid surface, while hydrophobic aways from the liquid.

Decreasing surface tension and gas critical rate increases gas production from X1 well. Production test is applied in 14 days (2 weeks) to get gas production profile after chemical injection into X1 well.

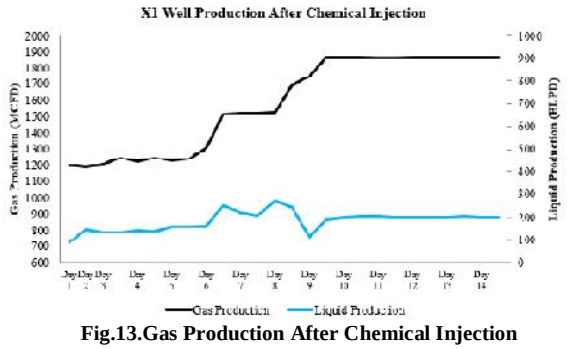


Fig.13.Gas Production After Chemical Injection

Table 8. Production Data After Chemical Injection

Day	Time	Pressure (Psi)		Gross Liquid	Gas Production	Pressure (Psi)
		Well Head	Flowline	BLPD	MCFD	Separator
Day 1	12:00 -24:00	580	340	90	1199	310
Day 2	12:00 -24:00	620	360	146	1189	310
Day 3	00:00 - 12:00	630	360	134	1209	309
	12:00 - 24:00	630	360	134	1247	308
Day 4	00:00 12:00	630	360	142	1224	310
	12:00 - 24:00	640	370	138	1248	309
Day 5	00:00 12:00	640	360	158	1231	316
	12:00 24:00	630	360	160	1240	310
Day 6	00:00 12:00	630	370	164	1310	307
	12:00 24:00	600	380	252	1513	301
Day 7	00:00 - 12:00	590	380	219	1523	303
	12:00 - 24:00	590	380	210	1523	300
Day 8	00:00 - 12:00	590	370	274	1525	309
	12:00 - 24:00	590	370	245	1691	311
Day 9	00:00 - 12:00	580	370	116	1750	313
	12:00 - 24:00	520	380	194	1872	315
Day 10	00:00 - 12:00	580	370	200	1871	313
	12:00 - 24:00	520	380	205	1870	315
Day 11	00:00 - 12:00	580	370	203	1865	313
	12:00 - 24:00	520	380	200	1866	315
Day 12	00:00 - 12:00	580	370	201	1870	313
	12:00 - 24:00	520	380	200	1869	315
Day 13	00:00 - 12:00	580	370	199	1872	313
	12:00 - 24:00	520	380	203	1870	315
Day 14	00:00 - 12:00	580	370	200	1869	313
	12:00 - 24:00	520	380	201	1872	315

As shown in Fig. 13 and Table 8, gas production from X1 well increases after chemical injection from 1.19 MMSCFD to 1.87 MMSCFD (57.1%). Liquid production also increases. In the early of production test, which is day-1 to day-8 after chemical injection, gas production increases slowly and stable at day-9 to day-14. It shows that injected chemical needs particular time to react effectively with accumulated liquid in bottom hole. After the reaction is complete, gas increased production is stable.

F. Cost Analysis

In applying chemical injection with capillary string technique to overcome liquid loading in X1 well, the cost scheme that is used is a service and equipment rental scheme. There is only operation expenditure without any capital expenditure. The cost components include service cost, chemical cost, and capillary string cost. The income is from gas monetization of increamental rate after chemical injection. The assumption of gas price in West Java is US$ 6/MMBTU.Based on cost component as shown in Table 9, the total cost to inject 19.4 bbls of chemical into X1 well is 53.632 US$. The biggest portion of the cost component is service cost, that is 58.9% of the total cost.

The cost component that consists of four main components (equipment, material, mobilization, and demobilization) depends on the chemical volume and concentration that designed to be injected into well. Beside that, pump profile such as pump discharge and pump power also affect the total cost. More injected chemical requires higher total cost. Higher pump discharge and pump power also requires more.

To balance total cost, income is considered to determine the payback period (PBP) of capillary string technique.

Table 9. Cost Component

No	Component	Cost (US$)
1	**Equipment**	
	- Capillary Unit Run	7,235
	- Capillary Installation / Retrieval	4,096
	- Capillary Crew	17,383
	- Crane	2,864
	Subtotal	**31,579**
2	***Material***	
	- Chemical Injection Skid	709
	- Hanger - Pack Off	1,260
	- Downhole Chemical Injection Valve	736
	- Tubing @ 1817 ft	336
	- Chemical @3085 liter	17,137
	Subtotal	**20,178**
3	***Mobilization***	**938**
4	***Demobilization***	**938**
	TOTAL	**53,632**

Table 10. Cashflow

	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Production (MMSCF)	1.19	1.20	1.19	1.23	1.24	1.24	1.21	1.22	1.21	1.21	1.17
Production Gas (MMSCF)		0.02	0.00	0.01	0.05	0.05	0.22	0.23	0.12	0.02	0.05
Cumulative Production Gas (MMSCF)		0.02	0.01	0.05	0.09	0.14	0.36	0.59	1.71	1.73	1.41
GHV (BTU/SCF)		1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8
Cumulative Production Gas (MMBTU)		9.39	8.39	48.01	96.02	144.02	376.72	722.93	1.158.02	1.806.02	2.537.22
Gas Price (US$/MMBTU)		6	6	6	6	6	6	6	6	6	6
Revenue Gas (US$)	0	56	50	288	576	961	2.348	4.334	6.952	10.841	15.103
Item Cost (US$)	53.632	0	0	0	0	0	0	0	0	0	0
Cummulative Cost (US$)	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632
Cashflow (US$)	-53.632	-53.576	-53.582	-53.344	-53.056	-52.778	-51.384	-49.298	-46.680	-42.791	-38.529

	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20
Production (MMSCF)	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
Production Gas (MMSCF)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Cummulative Production Gas (MMSCF)	5.89	5.17	4.43	3.15	2.81	8.49	7.17	1.83	8.51	9.21
GHV (BTU/SCF)	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8	1.045.8
Cummulative Production Gas (MMBTU)	3.222.21	3.911.47	4.643.20	5.352.61	6.062.10	6.772.17	7.482.34	8.192.71	8.901.53	9.611.31
Gas Price (US$/MMBTU)	6	6	6	6	6	6	6	6	6	6
Revenue Gas (US$)	19.333	23.480	27.854	32.116	36.374	40.631	44.890	49.150	53.409	57.668
Item Cost (US$)	0	0	0	0	0	0	0	0	0	0
Cummulative Cost (US$)	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632	53.632
Cashflow (US$)	-34.299	-30.043	-25.778	-21.516	-17.258	-13.000	-8.740	-4.482	-223	4.036

Based on Table 10, PBP is obtained in day-20 after chemical injection is done. It is shown with positive cashflow, indicating total cost has been covered with revenue. The PBP which is only 20 days is very short (attractive). Therefore, chemical injection using capillary string technique to overcome liquid loading in X1 well is economically very efficient.

CONCLUSION

Liquid loading, a condition where liquid is accumulated in bottom hole and blocks gas production, iscommon in gas well. Chemical injection with capillary string into X1 well is effective to overcome liquid loading.With particular volume of chemical and water mixture that is adjusted with accumulated liquid volume, chemical injection with capillary string can decrease surface tension and gas critical rate. Injected chemical disconnects hydrocarbon bond of the liquid in the surface of liquid molecule. New critical rate is lower than gas rate, that gas can effectively flow from bottom hole to surface. Pump design that consists of pump discharge, pump power, and pressure ratio is obtained from software simulation by considering chemical volume. Service and equipment rental scheme is used to habilitate the project. With US$ 6/MMBTU gas price, pay back period can be obtained in 20 days. Chemical injection with capillary string to overcome liquid loading isn't only effective, but also economical.

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