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Case Study: Successful Application of a Novel Gas Lift Valve in Low Pressure Wells in Fuling Shale Gas Field

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Abstract: The Fuling shale gas field is facing a rapid gas production decline due to heavy liquid loading issues. Given the condition that most wells are located at remote areas in the mountains, the traditional gas lift methods that require either fixed compressor or skid-mounted gas lift trucks do not seem feasible and occur high operation costs. A new type of gas lift valve that can be opened or closed at a low valve dome pressure indicates the high sensitivity to low production pressure. Thus, the piping line pressure can be utilized to activate the valve due to its new advantages. In addition, the specially designed structure of the gas lift valve can be activated via pressure increases in the tubing to create a channel between the tubing and annulus. The valve that previously functioned as a dummy valve was then switched to a gas lift valve. Field application results show that all wells were successfully restarted by only utilizing the low piping pressure, and loaded liquid was lifted with gas production at an incremental rate that reached up to 27.4 × 10 kscm/d per well. Fewer slickline operations were conducted to replace the dummy valve. The result of the application shows that the new type of gas lift system has a wide range of application prospect for low pressure wells, especially for shale gas wells.

Keywords: shale gas; low pressure; gas lift; piping line

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1. Introduction

The Fuling shale gas field, which is located in southwest China [1], announced the first gas production since 2013, and it is now the largest gas field in China (Figure 1) in which most wells are horizontal wells and completed with a hydraulic multi-fracturing method [2,3]. The annual gas production increased dramatically from 5 bcm to 10 bcm with an increased number of new tied-in wells and effective stimulation methods such as hydraulic fracturing. The gas reservoirs are widely distributed with a large variety of production characteristics [4–6]. For instance, wells in the Jiangdong block are produced with average water production of 25 scm/d and peak production of 200 scm/d. With average well depths of 3571 m, wells tend to load liquid due to hydraulic fracturing and well undulation. The statistics show that 85% of gas wells' production has started to decline, and the annual gap between real production and actual demand is around 0.35 bcm, (Figure 2) which imposes a big challenge to the field development.

Gas lift systems have proven to be an extremely flexible and economical means of lifting fluid from deep wells, particularly from those with high-flowing bottom-hole pressures [7]. Whereas the required high gas lift pressure on the surface of the traditional gas lift method may not only require a high gas compressor capacity but also the high CAPEX, studies also show that there might be flow assurance issues—e.g., salt precipitation—in wells produced under high pressure and high temperature [8]. This may cause a negative impact on the production layer because it may force the loaded liquid into the reservoir of wells with depths more than 3657 m. Since the average well depth in the Fuling gas field is more than 3657 m, most wells are loaded with a heavy water column that imposes high requirements of compressor capacity to lift water. The wellsite compressor with a capacity of 25 MPa can hardly meet the requirement and eventually a big portion of wells were shut in. A novel gas lift valve has been successfully applied in the Fuling shale gas field with more than 40 gas wells that produce a new solution to handle the liquid loading problem by running holes in multiple special gas lift valves with tubing to unload the liquid in the tubing by staged gas lifting methods. This new type of gas lift valve was designed under a low valve dome pressure, thus it is sensitive to low pressure which can be opened and closed by injecting the piping line pressure to activate the valve and create a channel between the tubing and annulus. With the staged gas lift operation process, the gas lift system restored the gas wells' production rapidly after hydraulic fracturing by fully utilizing the piping line pressure (Figure 3). This method in general reduces the operation pressure and operation time in field applications and promote the application efficiency in shale gas reservoirs.

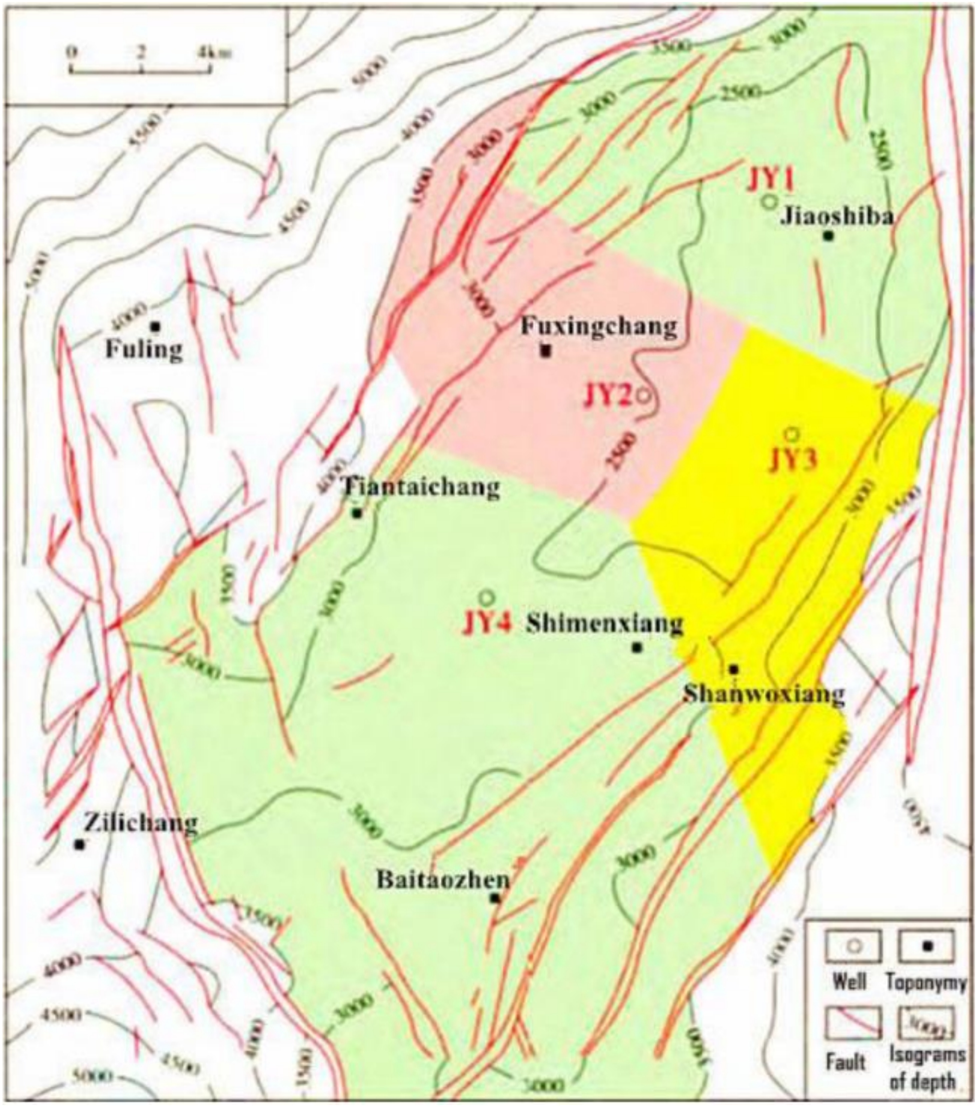

Figure 1. The main district of the Fuling shale gas field.

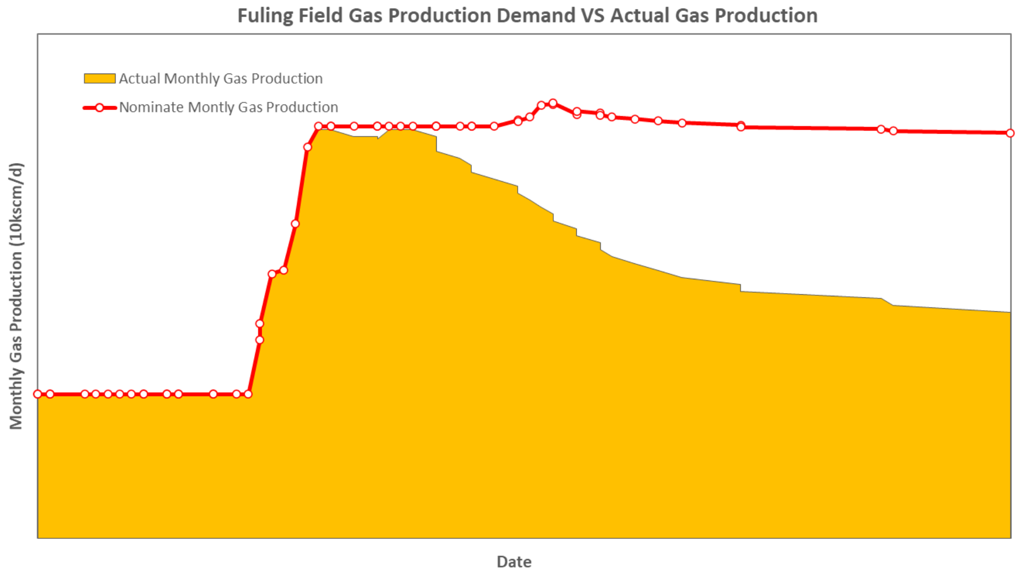

Figure 2. Fuling field gas production demand vs. actual gas production.

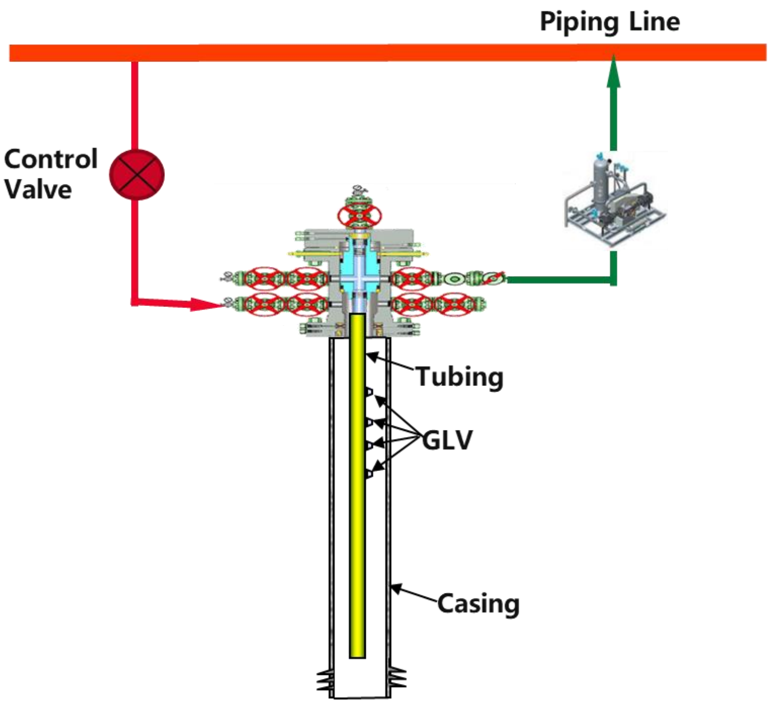

Figure 3. Low pressure wells' gas lift operation loop.

2. Gas Lift Valves

This fixed gas lift valve is a newly designed valve that contains 3 main parts (Figure 4): upper part 1, middle part 2 and low part 3; the parts are connected with thread. The first through hole 4 is located in the middle part, and the second through hole 5 is located in the hydraulic moving piston 6. On top of the valve is the fishing neck 7. The advantages of the valve compared with the traditional valve is list as follows.

1. The pressure control components are made of three layers of monel alloy and the test rack opening pressure is very sensitive to low pressure, thus it meets the accuracy of low-pressure well activation.
2. The new type of gas lift valve can connect/disconnect the first and second through-hole of the internal structure of the air lift valve by installing a hydraulic piston that can move axially inside the valve body. This technology connects the space of the

annulus and tubing by injecting liquid inside the tubing to activate the gas lift valve, thus it greatly reduces the operation frequency of replacing the dummy valve and as a result reduces the cost and risks and saves time.

3. The most import function of this new type of valve can greatly reduce the required gas lift pressure to the level of piping line pressure which is approximately around 5 MPa. By utilizing piping line pressure, the gas wells' production can be restored instantaneously after a hydraulic fracturing operation or being heavily water-loaded.

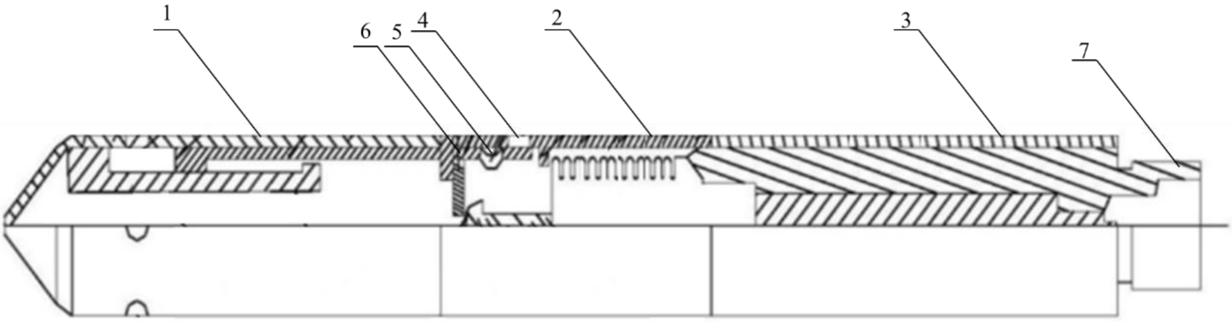

Figure 4. New type of fixed gas lift valve structure.

3. Geological Overview

The Fuling shale gas field is located in the Sichuan Basin of the south region of China (Figure 5) [8], which is the first major commercial discovery of shale gas outside North America in the world [3]. Most gas occurs in the lower Paleozoic Wufeng–Longmaxi marine shale play which consists of black shale and has a steady thickness of about 328 ft buried between 2150 mTVD and 3150 mTVD. This gas field was once screened out as shale gas potential due to its high complexity. Nevertheless, the structure of this field, the Jiaoshiba Structure, is a diamond faulted anticline with axial trending in a northeast direction, which is controlled by two main groups of faults trending northeast and near north, respectively.

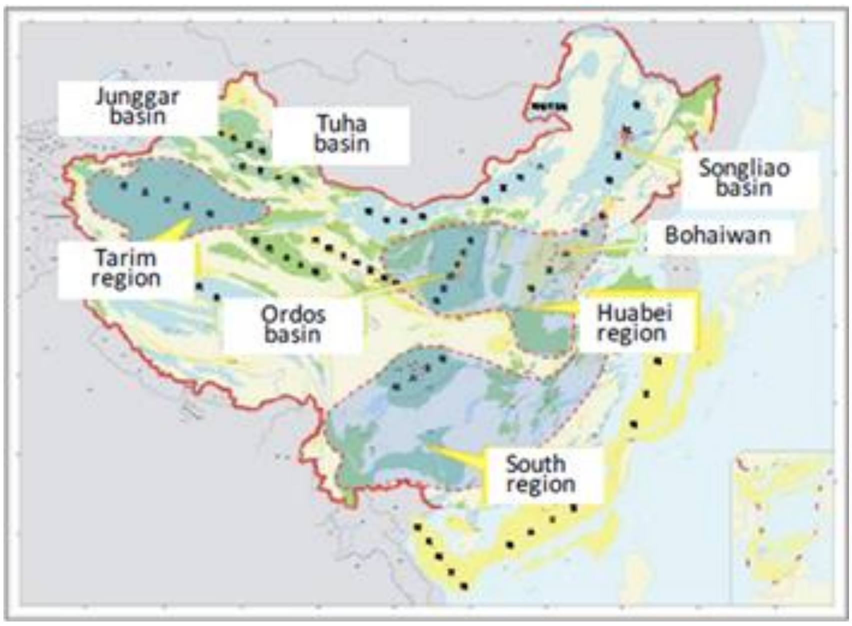

Figure 5. Distribution map of favorable exploration areas for shale gas in China.

Since the discovery of the Fuling field after a successful drilling of well Jiaoye 1, the production formation of Wufeng–Longmaxi was proven to be a prospective formation of an industrial gas flow at 0.2 bm/d. By the end of July 2014, the proven gas reserves climbed to 106 bcm [3]. The targeting Wufeng–Longmaxi Fm. is short for the Upper Ordovician Wufeng Formation and the first section of the Lower Silurian Longmaxi Formation (Figure 6). The formation is the main prospective formation of the lower Paleozoic marine shale of the Sichuan Basin. Based on the seismic date, Wufeng–Longmaxi Fm. is proven to consist of sandstone, whereas the Longmaxi formation mainly consists of limestone.

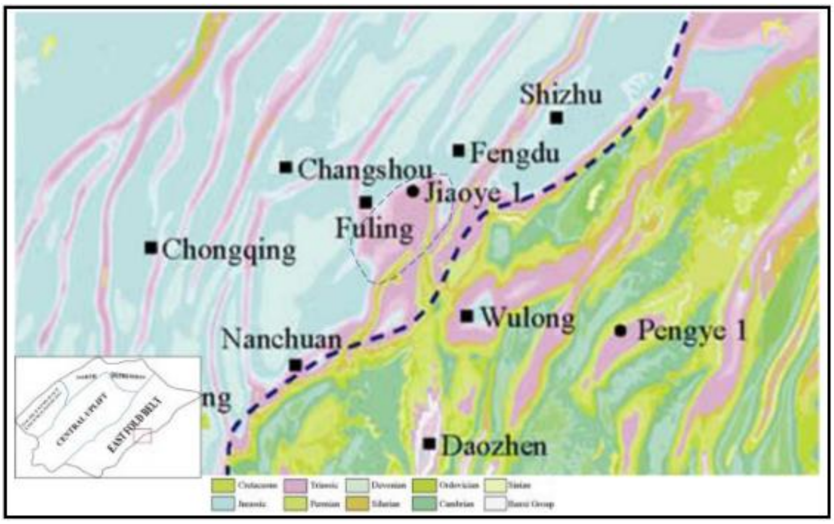

Figure 6. The location of the Fuling shale gas field.

The Wufeng–Longmaxi Fm. can be divided into three type of layers (Figure 7) which are: (1) section I, carbonaceous siliceous shale; (2) section II, gray black silty mudstones; (3) section III, gray argillaceous mudstones and gray black carbonaceous shale.

Sichuan Basin					
ERA	PERIOD	EPOCH	FORMATION		AGE(Ma)
PALEOZOIC	Permian	Lower	Maokou	TP_1m	230-270
			Qixia	TP_1q	
			Liangshan	TP_1l	
	Carboniferous	Middle	Huanglong	TC_2h	270-320
	Silurian	Middle	Hanjiadian	TS_2h	320-570
		Lower	Xiaoheba	TS_1x	
			Longmaxi -3	TS_1l^3	
	The Wufeng-longamxi Fm.		Longmaxi -2	TS_1l^2	
			Longmaxi -1	TS_1l^1	
	Ordovician	Upper	Wufeng	TO_3w	
			Jianchaogou	TO_3j	
		Middle	Baota	TO_2b	
		Lower	Meitan	TO_1m	
			Honghuayuan	TO_1h	
			Tongzhi	TO_1t	

Figure 7. Stratigraphy of the Paleozoic of the Sichuan Basin, highlighting the Wufeng-Longmaxi Formation.

4. Candidates Selection

The selection of an appropriate gas well de-liquification method depends on several factor [9,10], such as well and reservoir characteristics, field locations, operational conditions (power availability, temp, facility constraints, water production etc.), long term reservoir performance, change in production over the life of the well and economics. The table listed below (Table 1) shows the specifications needed for a well to conduct a gas lift operation [11].

Table 1. Candidate selection criteria for different gas well de-liquification methods.

Comparison	Selection Criteria	SRP	PCP	ESP	Jet Pump	GL
System Condition	System Complexity	Simple	Simple	Downhole Complex	Surface Complex	Surface Complex
	Initial Investment	Low	Low	High	High	Highest
	Operation Cost	Low	Low	High	Low	Low
Fluid Range,	Fluid Rate Range	1–100	10–200	80–700	10–500	30–3180
m^3/d	Maximum Range	300	250	1400	1590	–7945
Lifting Depth, m	Lifting Depth	<3000	<1500	<2000	<2000	<4000
	Maximum Depth	4421	1700	3084	3500	4500
Downhole Condition	Small Tubing Size	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
	Multiple Layer Production	Not Applicable	Not Applicable	Applicable	Applicable	Applicable
	Slanted Well	Normal Wear	Normal Wear	Applicable	Applicable	Applicable
	Degree of Hollowing Out	High	Very High	High	Very High	High
Surface Condition	Offshore	Not Applicable	Very Applicable	Applicable	Applicable	Very Applicable
	Remote Area	Normal	Normal	Applicable	Applicable	Applicable
Operation	High GOR	Very Applicable	Normal	Not Applicable	Applicable	Very Applicable
	Heavy Oil	Applicable	Applicable	Not Applicable	Very Applicable	Not Applicable
	Sand Production	Very Applicable	Applicable	Not Applicable	Applicable	Very Applicable
	Corrosion	Applicable	Applicable	Applicable	Applicable	Applicable
	Scale	Applicable	Not Applicable	Not Applicable	Applicable	Applicable
	Adjust Working System	Convenient	Convenient	Not Convenient	Convenient	Convenient
	Power Supply	Electricity, Oil, NG	Electricity, Oil, NG	Electricity	Electricity, Oil, NG	Electricity, Oil, NG
	Power Medium Requirements	None	None	None	Hydrodynamic Fluid	Anti-hydrate
Maintenance Management	Pump Inspection	Tubing WO	Tubing WO	Tubing WO	Slickline Ops	Slickline Ops
	Avg. WO Period, a	2	1	1.5	0.5	3
	Auto-control	Applicable	Applicable	Applicable	Applicable	Applicable

Based on the selection criteria above, a workflow has been created to screen most candidate wells in the Fuling gas field. The tubing sizes are 48.26 mm and 60.33 mm with an average well depth of 4738 m and surface piping pressure of 4.87 MPa. All wells are horizontal wells that are completed with hydraulic fracturing. Six wells are new tied-in wells that are not activated due to a heavy fracturing liquid column and the rest of the wells are heavily water-loaded (Table 2). To fit the slickline operation, the gas lift valves should be set within the inclination of 38° and the gas lift valves were assembled on tubing during tubing run in hole operations.

Table 2. Well candidates for low pressure gas lift operation.

Series No.	Well Name	Tubing Size, mm	Casing Size, mm	Well Depth (MD), m	Piping Line Pressure, MPa	Tubing Setting Depth, m	New Tied in Well
1	FL-1HF	48.26	139.70	4576	5.5	3067	N
2	FL-2HF	48.26	139.70	4157	6.5	2620	Y
3	FL-3HF	48.26	139.70	5176	6.0	3564	Y
4	FL-4HF	48.26	139.70	4840	6.1	3277	N
5	FL-5HF	48.26	139.70	4840	6.3	3212	N
6	FL-6HF	48.26	139.70	5335	5.9	3527	N
7	FL-7HF	48.26	139.70	4471	5.7	2977	N
8	FL-8HF	48.26	139.70	4640	5.9	2506	Y
9	FL-9HF	48.26	139.70	4545	6.7	2976	N
10	FL-10HF	60.33	139.70	4324	6.2	2568	N
11	FL-11HF	48.26	139.70	4341	6.1	2717	Y
12	FL-12HF	48.26	139.70	4966	6.5	3452	Y
13	FL-13HF	48.26	139.70	5030	6.1	3248	Y

5. Project Validation

5.1. Unloading

As described in Section 4, the new gas lift valves were installed on tubing to restart heavily water-loaded wells. The gas lift valves that have been used are specially designed for low pressure wells due to its high sensitivity to low pressure. The setting depth was designed by PIPESIM by considering well completion, reservoir pressure and compressor capacity. The assumption is to determine the gas injection point depth under constant wellhead pressure. The curve below shows the basic principles of how to calculate the injecting point (Figure 8).

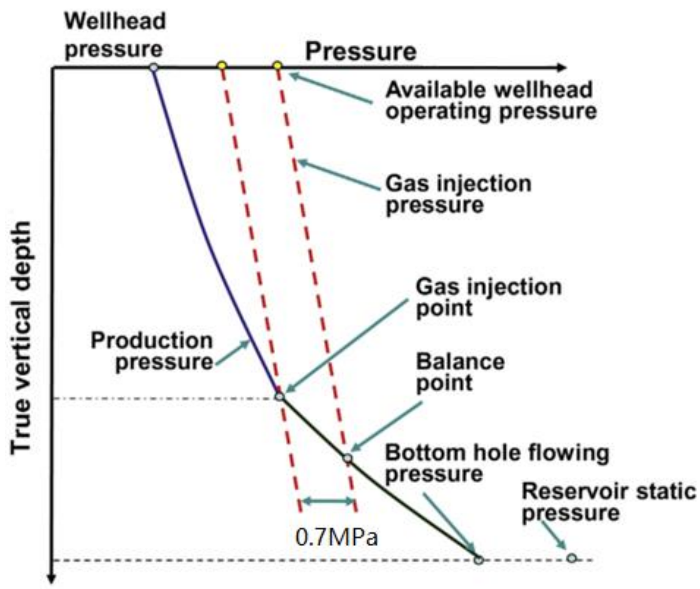

Figure 8. Depth of the operating gas injection point.

With variable sensitive data of GLR, the lifting liquid rate can be obtained at a different pressure gradient curve (Figure 9).

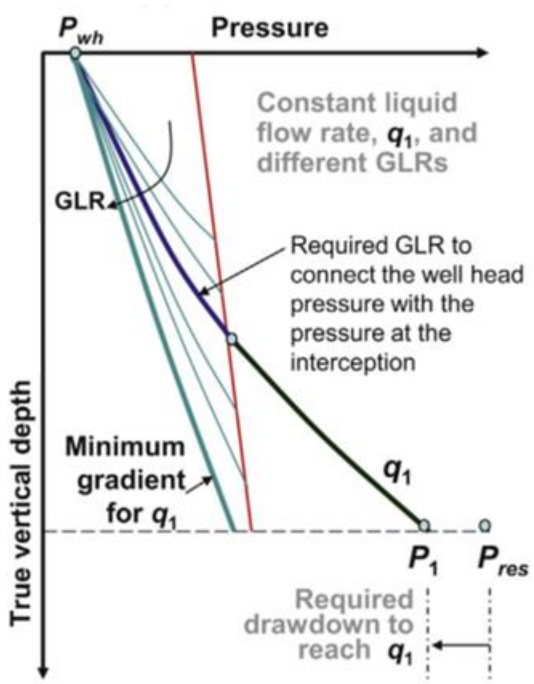

Figure 9. Procedure to find the liquid production at different pressure gradients.

Note that the liquid production here is the liquid that should be lifted to restart the loaded gas well.

5.2. Field Trail Result and Data Validation

The gas lift valves' specifications are listed as follows. Total length of the valve is 300 mm with OD of 18.8 mm (Table 3), which was assembled with a fixed mandrel that aligned with the tubing size. For example, with FL-2HF, the well was vented to the atmosphere after hydraulic fracturing, though no production was observed, and the tubing head pressure dropped to zero right after the opening of the well. With the proper design of the gas lift, six stages of gas lift valves were installed on tubing (Table 4) to lift the loaded water. The loaded liquid was gradually lifted to the surface, and gas production reached 33.8 × 10 kscm/d at the peak production rate. Although the well was shut in after the operation, the gas rate was restored to a higher number, mostly due to the pressure build up effect (Figure 10).

Table 3. Parameters of gas lift valve.

Type	SKY-GLV-18.8
OD, mm	18.8
Length, mm	300
Effective area of bellows, sq. mm	110
Connection Thread	1/4 NPT
Pressure Rating, MPa	50
Valve hole size, mm	3.17, 4.76

Table 4. Setting depth of gas lift valve—FL-2HF.

Kick off Pressure: 15 MPa Operating Pressure: 5.5 MPa Injecting Gas Rate: 0.8 10 kscm/d								
Stages	**Setting Depth (MD), m**	**Setting Depth (TVD), m**	**Inclination Angle, °**	**Valve Hole Size, mm**	**Pro, MPa**	**Pv-Open, MPa**	**Pv-Close, MPa**	**Mandrel Type**
1	470.18	470.13	0.6	3.2	5.032	5.098	4.954	SKY-FGLM-90
2	907.39	907.29	0.8	3.2	4.602	4.975	4.851	SKY-FGLM-90
3	1294	1293.9	0.7	3.2	4.382	4.852	4.747	SKY-FGLM-90
4	1629.6	1629.4	0.4	3.2	4.193	4.73	4.644	SKY-FGLM-90
5	1913.3	1913.1	6	3.2	4.037	4.61	4.541	SKY-FGLM-90
6	2157	2146.7	32.2	3.2	3.913	4.492	4.437	SKY-FGLM-90

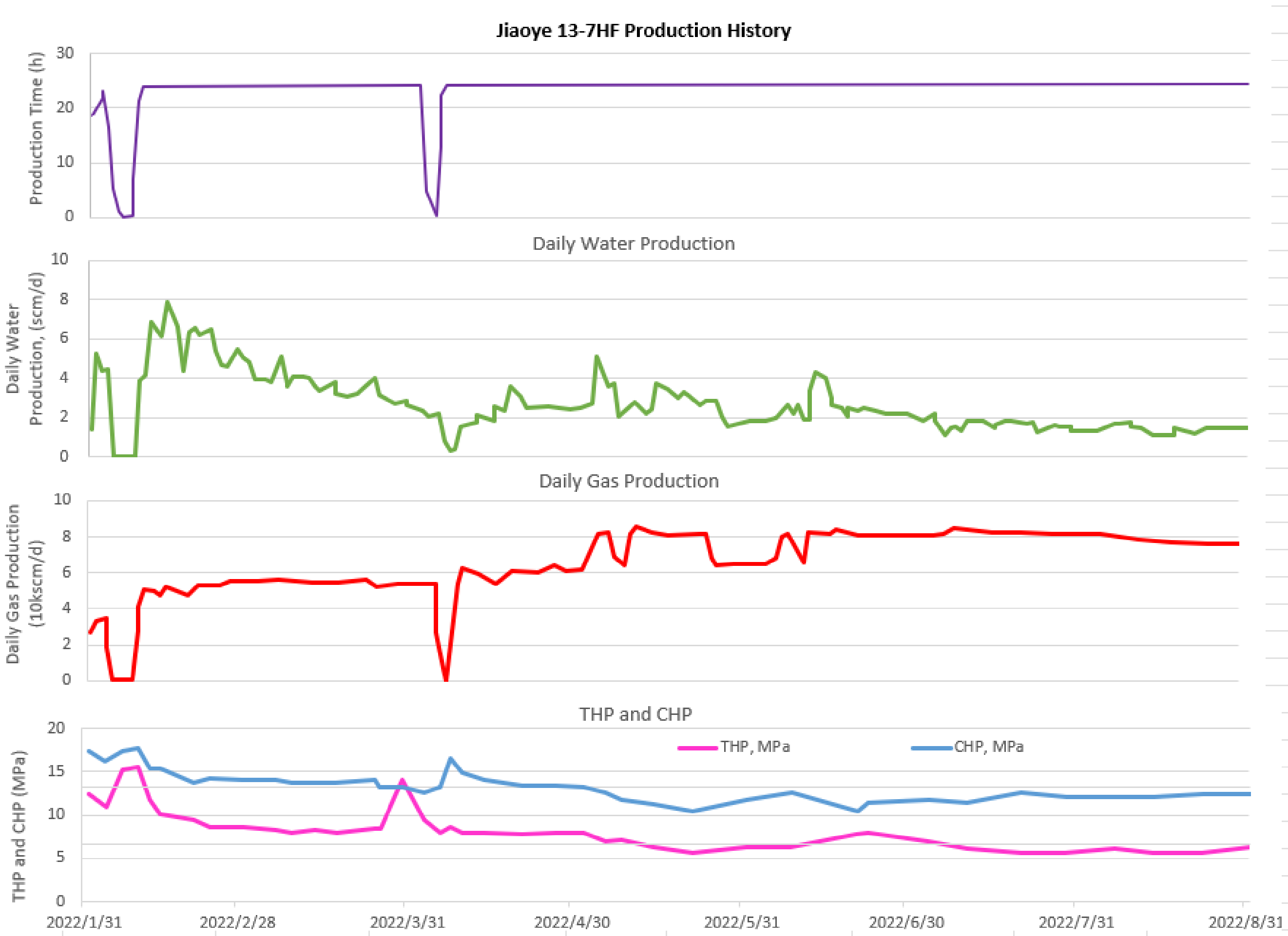

Figure 10. FL-2HF's production history.

A total of 13 wells were assembled with gas lift valves and 8 of them were operated successfully; the total incremental of gas rate is 219 × 10 kscm/d with a total lifted liquid volume of 104.7 scm (Table 5). The rest of the wells were waiting to operate once the equipment was ready. The field operation showed the great potential of the new gas lift valves in the Fuling gas field.

Table 5. Gas lift result with the new gas lift valves.

Well Name	Lifted Liquid Volume, scm	Gas Rate before GL Operation, 10 kscm /d	Gas Rate after GL Operation, 10 kscm/d	Incremental of Gas Rate, 10 kscm /d	Remarks
FL-1HF	52	0.3	1.83	1.53	Wells loaded with liquid
FL-2HF	4.6	0.1	3.48	3.38	New tied-in well shut in due to loaded liquid
FL-3HF	2	0.3	1.4	1.1	Wells loaded with liquid
FL-4HF	/	/	/	/	Waiting to be operated
FL-5HF	/	/	/	/	Waiting to be operated
FL-6HF	/	/	/	/	Waiting to be operated
FL-7HF	6	1.7	2.1	0.4	Wells loaded with liquid
FL-8HF	5.5	0.1	5.8	5.7	New tied-in well shut in due to loaded liquid
FL-9HF	23	0.05	2.4	2.35	Wells loaded with liquid
FL-10HF	6	0.1	4.3	4.2	Wells loaded with liquid
FL-11HF	5.6	0.1	3.2	3.1	New tied-in well shut in due to loaded liquid
FL-12HF	/	/	/	/	Waiting to be operated
FL-13HF	/	/	/	/	Waiting to be operated
Total	104.7			21.76	

6. Conclusions

A new type of gas lift valve that was specially designed for shale gas reservoir low-pressure wells has been introduced in this paper. On the basis of field operation, we derived conclusions as follows.

The new type of gas lift valve is very sensitive to low piping pressure due to its low valve dome pressure, and as a result it was used as an effective tool to re-activate the heavy water-loaded wells by staged gas lift operations. Field operation results show that the piping line pressure that is required for the gas lift operation can be as low as 5.5 MPa, which shows a prospective application for the shale gas field in the future. The low pressure gas wells gas lift operation process was created by the candidates selection criteria, and eight wells were selected to conduct the operation using the noval gas lift valves. Eight wells in the Fuling gas field was successfully restarted by this new type of well in tandem with the staged gas lift operation to unload water in wells. The total lifted water for the eight wells of one operation is 13 scm, and the total of gas production incremental is 218×10 kscm/d. The field operation cost can be greatly reduced due to its special function in which the dummy valve can be swtiched to the gas lift valve via pressure changes in the tubing. As a result, the operation risks can also be reduced to a low level.

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