Feasibility Assessment Study on Residual Pressure Power Generation in Xiangguosi Gas Storage Facility

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Abstract

Since its establishment, Xiangguosi Gas Storage has carried out dozens of gas production operations, with a cumulative gas production of 20 × 10^8m^3 during the gas production period. The gas source pressure of the storage has reached over 10MPa, and it has abundant natural gas pressure difference resources. However, in the transportation and production process of gas storage facilities, a large amount of natural gas pressure energy is wasted without being utilized, directly entering the station infrastructure, pressure regulating valves and other pipelines. Therefore, this article discusses the feasibility assessment of the construction of residual pressure power generation projects based on the pressure difference resources existing in the Xiangguosi gas storage facility. The results show that the residual pressure resources at the J-T valve dehydration device of the Xiangguosi gas storage facility are abundant and can meet the conditions for low-temperature natural gas reheating and export, making it feasible for residual pressure power generation; If a residual pressure power generation equipment with a total installed capacity of 1800kW is constructed in the J-T valve dehydration unit of Xiangguosi gas storage facility, based on the annual power generation hours of 2640h during the gas storage period, the residual pressure power generation capacity is 451.6kWh, saving 1361.09tce of standard coal annually and reducing 3583.84t of carbon dioxide annually. The estimated total investment for construction is 21.6 million yuan, with an average annual operating income of 3.14 million yuan, an internal rate of return on project investment of 9.16%, and a static investment payback period of 9.84 years.

Keywords

Xiangguosi Gas Storage; Residual Pressure Power Generation; Pressure Difference Resources; J-T Valve Dehydration Device; Gas Production.

1. Introduction

The Xiangguosi gas storage facility is located in Chongqing and was completed and put into operation in 2013. It is the first underground gas storage facility in the southwest region and has functions such as seasonal peak shaving and emergency response. It is the main facility for ensuring the safe supply of natural gas [1,2,3], as shown in Fig. 1. Its designed storage capacity is 42.6 × 10^8m^3, with a maximum gas injection capacity of 1600 × $10^4m^3/d$, a maximum gas production capacity of 3100 × $10^4m^3/d$, and an operating pressure of 13.2-28 MPa.

Fig. 1 Aerial view of Xiangguosi gas storage injection and production station

As of now, the gas storage facility has completed 11 injections and 10 extractions. The injection period for gas storage is generally from April to October, and the extraction period is generally from November to March of the following year. The interval between the injection and extraction periods is about 15-30 days. During the gas production period of the gas storage facility, the gas produced by the injection and production wells enters the injection station through the southern and northern gas production trunk lines, and is transported to the dehydration unit for dehydration treatment. After measurement, it is transported by the copper phase line to the Tongliang gas transmission station or by the phase drought line to the dry soil station after measurement and pressure regulation. During the entire production and transportation process, the J-T valve dehydration device of the gas storage and injection station, the J-T valve process, the inlet and outlet pressure regulating valves of the triethylene glycol dehydration device, the pressure regulating valves for the external transmission of the Xianghan line, the outlet pressure regulating valve of the Xiang-14 well, and the outlet pressure regulating valve of the Fuxing station have significant pressure difference resources. Residual pressure power generation technology involves introducing residual pressure natural gas into an expander to do work, driving the generator to rotate coaxially and generate electricity. This can effectively utilize pressure energy and recover this portion of residual pressure resources [4,5,6]. At present, natural gas residual pressure power generation technology has been researched and applied in several natural gas purification plants, pressure regulating stations, gas transmission stations, and other stations [7,8,9]. This article will focus on the feasibility assessment of residual pressure power generation for Xiangguosi gas storage, explore how to reasonably utilize the large amount of residual pressure resources in the storage, achieve residual pressure recovery, improve energy utilization efficiency, and bring certain social and economic benefits.

2. Gas Storage Facilities Can Utilize Residual Pressure Resources

2.1 J-T Valve Dehydration Device

The Xiangguosi gas storage facility is equipped with four sets of J-T valve dehydration devices, with a single processing capacity of 700 × $10^4 m^3$/d and a maximum processing capacity of 2800 × $10^4 m^3$/d. According to the operational data of the tenth gas production period of the gas storage facility, the total natural gas processing capacity of the J-T valve device is (400~2800) × $10^4 m^3$/d, and the processing capacity of a single device is (200~700) × $10^4 m^3$/d. The pressure difference between the inlet and outlet of the J-T valve fluctuates between 1~3 MPa, as shown in Fig. 2.

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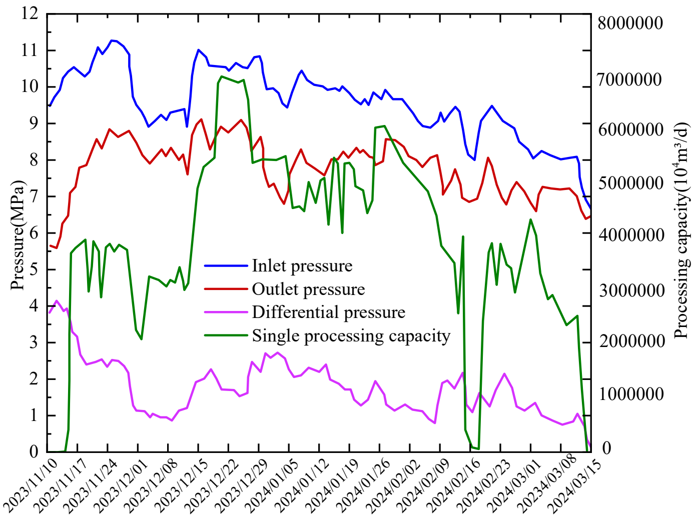

Fig. 2 Pressure and natural gas processing capacity of J-T valve device during gas production period

As the gas production process progresses, the temperature of the wellhead gas gradually increases, and the temperature of the natural gas entering and leaving the J-T valve also increases. The inlet temperature rises from 10 ℃ to about 20 ℃, and the outlet temperature rises from 5 ℃ to 15 ℃. Finally, based on the J-T valve inlet temperature of 10 ℃, inlet pressure of 11MPa, and average pressure difference of 2MPa between inlet and outlet, the pressure difference resource analysis data for a single J-T valve dehydration unit is shown in Table 1. As the natural gas flow rate processed by the J-T valve dehydration unit changes, the calculated pressure difference resources at the inlet and outlet of a single J-T valve fluctuate between 230 and 800 kW, indicating good potential for power generation.

Table 1. Calculation Table of Differential Pressure Resources at the Inlet and Outlet of a Single J-T Valve

Numble	Tnternet traffic ($10^4m^3/d$)	Inlet temperature (°C)	inlet pressure (MPa)	Outlet temperature (MPa)	Outlet pressure (°C)	Power (kW)	Outlet temperature of pre cooler after heat exchange(°C)
1	200	10	11	9	-11.7	234	-1.6
2	700	10	11	9	-11.7	818	-1.6

2.2 Triethylene Glycol Dehydration Unit

The construction scale of the triethylene glycol dehydration unit at the Xiangguosi gas storage and injection station is 1000 × $10^4m^3/d$. The average natural gas processing capacity during the tenth gas production period is 580 × $10^4m^3/d$, and the highest processing capacity is 815 × $10^4m^3/d$. The inlet and outlet of the triethylene glycol dehydration unit are equipped with pressure regulating valves. The inlet pressure regulating valve is used to stabilize the operating pressure and ensure the stable operation of the triethylene glycol dehydration unit. The outlet pressure regulating valve is used to adjust the outlet pressure of the dehydration unit to match the outlet pressure of the J-T valve dehydration unit. As shown in Figure 3, the pressure difference range of the inlet and outlet of the triethylene glycol dehydration unit is 1MPa~2.5MPa, the pressure difference range of the inlet pressure regulating equipment is 0.5~1.5MPa, and the pressure difference range of the outlet pressure regulating equipment is 0.5~1MPa.

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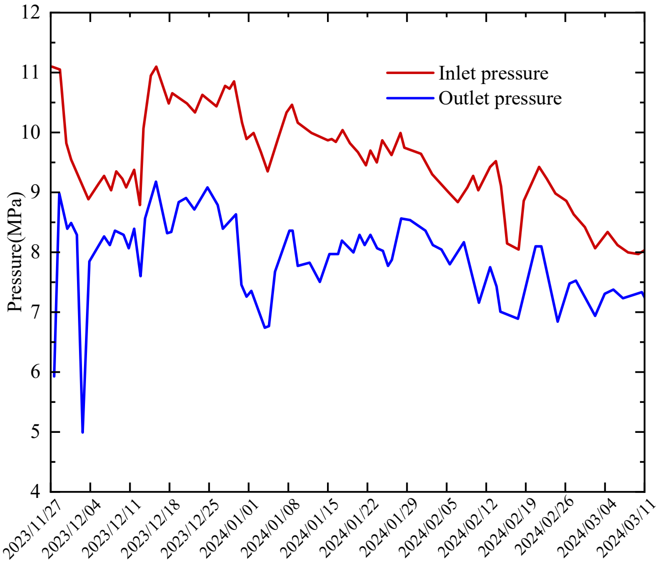

Fig. 3 Pressure diagram of inlet and outlet operation of glycerol dehydration unit during gas production period

Based on an average natural gas processing capacity of 580 × $10^4m^3/d$, the total pressure difference resources for the inlet and outlet of the triethylene glycol dehydration unit are calculated to be 960kW, as shown in Table 2.

Table 2. Calculation Table of Differential Pressure Resources for Triethylene Glycol Dehydration Unit

Numble	Differential pressure position	Tnternet traffic ($10^4m^3/d$)	Inlet temperature (℃)	inlet pressure (MPa)	Outlet temperature (MPa)	Outlet pressure (℃)	Power (kW)
1	Inlet pressure regulation	580	10	11	9.5	-0.8	537
2	Outlet pressure regulation	580	-0.8	9.5	8.5	-7.6	421

2.3 Xianghan Line, Xiang-14 Well, Fuxing Station Outbound Pressure Regulating Valve

The gas from Xiangguosi gas storage is not only transported to Tongliang compressor station via the Zhonggui pipeline, but can also be regulated and transported to Hantu station via the Xianghan line to enter the Sichuan Chongqing pipeline network or further regulated before being transported to Xiang-14 well and Fuxing station. The gas volume and pressure during the ninth and tenth gas production periods are shown in Table 3.

From the data in the table above, it can be seen that the pressure difference resources before and after the regulating valves of Xianghan Line, Xiang-14 Well, and Fuxing Station are relatively large, and the gas supply flow rates during different gas production periods also vary greatly. Among them, the pressure difference resources of the outgoing pipeline of Xianghan Line can reach up to 3000 kW, and the pressure difference resources of the outgoing pipeline of Xiang14 Well and Fuxing Station can reach 415 kW, as shown in Table 4. However, after the expansion of natural gas for power generation, the temperature drops significantly, and it is necessary to reheat the natural gas generated by residual pressure to above 0 ℃ to meet the needs of natural gas export. The natural gas reheating power after residual pressure power generation in the outgoing pipeline of Xianghan Line is 6500 kW, and the natural gas reheating power after residual pressure power generation in the outgoing pipeline of Xiang-14 Well and Fuxing Station is 634 kW, both of which are higher than the residual pressure power generation power.

Table 3. Operation Data Sheet for Xianghan Line, Xiang-14 Well, and Fuxing Station

Time		Xianghan Line			Xiang-14 Well and Fuxing Station		
Gas production period	Gas supply days(day)	Pressure(MPa)		Tnternet traffic ($10^4m^3/d$)	Pressure(MPa)		Tnternet traffic ($10^4m^3/d$)
		Before adjusting the pressure	After adjusting the pressure		Before adjusting the pressure	After adjusting the pressure	
The ninth gas production period	90	6.5-8.5	4.5-5	200-800	4.5-5	2	50-80
The tenth gas production period	8	8.7-8.0	4.4-4.7	300-320	4.4-4.7	2	90-95

Table 4. Calculation Table for Differential Pressure Resources of Outbound Pipelines of Xianghan Line, Xiang-14 Well, and Fuxing Station

Numble	Working condition	Tnternet traffic ($10^4m^3/d$)	Inlet temperature (℃)	inlet pressure (MPa)	Outlet temperature (MPa)	Outlet pressure (℃)	Power (kW)
1	Xianghan Line	200	3	8.5	4.5	-33	750
2		800	3	8.5	4.5	-33	3000
3	Xiang-14 Well and Fuxing Station	80	3	4.5	2	-37	415

2.4 Feasibility Analysis of Residual Pressure Resources

According to the analysis of pressure difference resources in the Xiangguosi gas storage facility, the residual pressure resources at the J-T valve dehydration unit are relatively abundant. At the same time, during the residual pressure power generation process, the internal energy of natural gas is converted into mechanical energy and output for power generation through an expansion machine, so that the natural gas temperature after expansion and pressure reduction is lower than the natural gas temperature after throttling by the J-T valve dehydration unit by -7.5 ℃. After separation, the outlet water dew point will be lower than the water dew point after J-T dehydration, which can effectively improve the depth of natural gas dehydration.

After the residual pressure power generation at the triethylene glycol dehydration unit, there is a fluctuation in pressure, and the pressure control and regulation of the expansion machine are complex, which is not conducive to the stable operation of the triethylene glycol dehydration unit. Therefore, it is not recommended to consider residual pressure power generation in the pressure regulation process of the triethylene glycol dehydration unit. The natural gas after dehydration in the triethylene glycol unit should be mixed with the natural gas after residual pressure power generation in the J-T

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valve dehydration unit to increase the temperature of the exported natural gas after residual pressure power generation.

The Xianghan Line, Xiang-14 Well, and Fuxing Station have abundant pressure difference resources before and after the pressure regulating valve. However, the gas supply volume is affected by the operation and scheduling of the gas storage and pipeline network, and the pressure difference resources fluctuate greatly. At the same time, in order to meet the high natural gas reheating power required for natural gas export temperature, it is not recommended to carry out residual pressure power generation.

Finally, considering that the pressure difference resource expansion power generation of the J-T valve dehydration unit at the injection station results in a relatively small decrease in natural gas temperature, and the natural gas temperature can reach above 0 ℃ after mixing with the natural gas processed by the triethylene glycol dehydration unit (about 10-20 ℃), it is selected to install residual pressure power generation equipment at the J-T valve dehydration unit, with the J-T valve as a backup pressure regulating facility.

3. Design of Residual Pressure Power Generation Process for Gas Storage Facility

3.1 Residual Voltage Power Generation Process Flow

According to the on-site process flow of the dehydration device of the J-T valve in the Xiangguosi gas storage facility, a pipeline and an electric regulating valve are added at the front and rear ends of the J-T valve to connect the residual pressure power generation device in parallel with the J-T valve. The existing equipment is used for the raw gas separator, pre cooler, and high-efficiency separator. The J-T valve, as a bypass or backup pressure regulating facility for the residual pressure power generation device, can ensure the normal operation of dehydration production when the gas production is large or the residual pressure power generation device cannot operate due to maintenance or malfunction, as shown in Fig. 4.

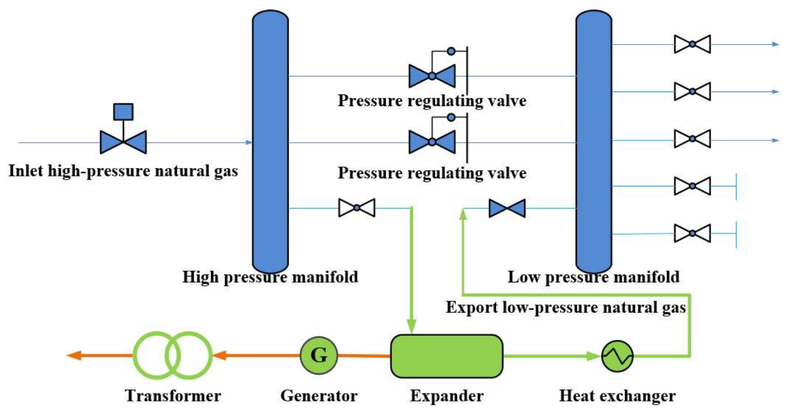

Fig. 4 Schematic diagram of natural gas residual pressure power generation process block

3.2 Process Simulation Calculation

The processing capacity of a single J-T valve dehydration device in Xiangguosi gas storage fluctuates between 200~700 × 10^4m^3/d, with an average processing capacity fluctuating between 300~400 × 10^4m^3/d. The design scale of the simulated residual pressure power generation device is considered to be 400 × 10^4m^3/d. The input power of the expander is calculated to be 670 kW, and the expansion shaft power is 467 kW. Considering factors such as transmission efficiency and motor efficiency, the generator power value is 450 kW. The calculation table and process flow simulation of the residual pressure power generation of the J-T valve dehydration device are shown in Table 5 and Fig. 5.

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Table 5. J-T valve device residual pressure power generation calculation table

Differential pressure position	Tnternet traffic ($10^4m^3/d$)	Inlet temperature (°C)	inlet pressure (MPa)	Outlet temperature (MPa)	Outlet pressure (°C)	Power (kW)
J-T valve dehydration device	400	10	11	9	-11.7	467

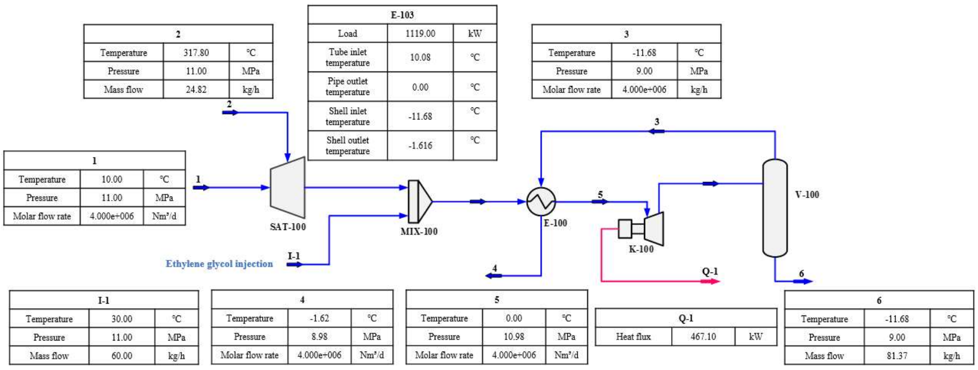

Fig. 5 Simulation diagram of J-T valve residual pressure power generation process flow

3.3 Selection of Key Equipment

The core equipment for natural gas residual pressure power generation is the expander, which can be divided into reciprocating, turbine, screw, and double rotor types according to structural principles. Among them, the main ones suitable for natural gas residual pressure power generation are turbine, screw, and double rotor [10,11]. The specific selection of expansion equipment needs to consider pressure, flow rate, residual pressure, and sealing effects [12]. The performance of the expansion machine is shown in Table 6.

Table 6. Performance Comparison Table of Expansion Machines

	Turbo-expander	Screw expander	Double rotor expander
Equipment features	Speed: 10000-40000 r/min, isentropic efficiency can reach over 80%, complex structure, many vulnerable parts, high noise, requiring supporting deceleration structure and sealing system.	Speed: 1500~3000r/min, isentropic efficiency can reach over 65%, compact equipment, simple structure, high noise, requiring a sealing system.	Speed: 1500~3000r/min, isentropic efficiency can reach over 70%, simple structure, few vulnerable parts, high noise, high equipment price, using magnetic coupling, no need for sealing system.
Scope of application	Suitable for pressures of 10.0MPa and below, full flow conditions, with a variable operating capacity of 30% to 100%, and high requirements for the working fluid.	Suitable for working conditions with a pressure of 3.0MPa and below and a flow rate of 12000m3/h and below, with a variable operating capacity of 25% to 120%, and strong adaptability to working fluids.	Suitable for working conditions with a pressure of 6.3 MPa or below and a flow rate of 100000 m3/h or below, with a variable operating capacity of 70% to 100%, and strong tolerance for working fluids.

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The screw expander is not suitable for high-pressure applications with J-T valve devices due to its low equipment design pressure. At present, there is no relevant application performance of high pressure level for the dual rotor expansion machine manufacturer. At the same time, due to the complex operation and adjustment of the gas storage during the gas production period, and the large range of changes in the flow rate and pressure of the working medium, the J-T valve dehydration device residual pressure power generation expansion machine equipment adopts a turbine type expansion machine.

4. Benefit of Residual Voltage Power Generation

The total installed capacity of residual pressure power generation at the Xiangguosi gas storage and injection station is 4 × 450 kW, with an estimated total investment of 21.6 million yuan. The production period of gas storage facilities is generally from November 10th to March 10th of the following year, with a total of 110 days of gas production. Therefore, the annual operating time of residual pressure power generation is 2640 hours, and the expected annual power generation is 4.75×10^6 kWh. The main benefit indicators are shown in Table 7.

Table 7. Benefit Table of Residual Pressure Power Generation at Xiangguosi Gas Storage and Injection Station

Device name	Installed power (kW)	Annual power generation hours	Annual energy output (ten thousand kWh)	Electricity price (CNY)	Total Investment in construction (Ten thousand CNY)	Annual average operating income (Ten thousand CNY)	Internal Rate of Return	Static investment payback period (years)
Differential pressure power generation	1800	2640	451.6	0.696	2160	314	9.16%	9.84

(1) Economic benefits: After considering the self use power loss of the generator set, the estimated annual power supply of residual pressure power generation is 4.51×10^6 kWh. The average annual electricity price of the gas storage is 0.696 CNY/kWh, and the calculated annual operating income is 3.14 million yuan. The financial internal rate of return after investment income tax of the project is 9.16 %, and the static investment payback period of the project is 9.84 years.

(2) Social benefits: According to the residual pressure power generation project, the annual power generation is 4.51×10^6 kWh, saving 1361.09 tce of standard coal annually and reducing carbon dioxide emissions by 3583.84t annually.

5. Summary

(1) The Xiangguosi gas storage facility has abundant pressure difference resources at the J-T valve dehydration unit, triethylene glycol dehydration unit, Xianghan line, Xiang-14 well, and Fuxing station outlet pressure valves of the injection station. However, the installation of residual pressure power generation equipment at the triethylene glycol dehydration unit is not conducive to the stable operation of the dehydration process. The outlet pressure regulating valves of Xianghan line, Xiang-14 well, and Fuxing station are regulated by the upstream gas storage capacity, and the gas source distribution conditions are variable. Moreover, the reheating power is too high, which is not conducive to the development of residual pressure power generation.

(2) The J-T valve dehydration unit at the injection station has abundant residual pressure resources, and the gas storage tank has reheating conditions. It is feasible to carry out residual pressure power

generation here. According to the actual layout of the Xiangguosi gas storage facility, the residual pressure power generation renovation will add pipelines at the front and rear ends of the original J-T valve dehydration device to connect the residual pressure power generation device in parallel with the J-T valve, which will serve as a bypass or backup pressure regulating facility.

(3) Residual pressure power generation is carried out at the J-T valve dehydration unit of the injection station, with a total installed capacity of 4 × 450 kW, annual power generation hours of 2640h, and annual power generation of 451.6 kWh. The estimated total investment for the project construction is 21.6 million yuan, with an average annual electricity price of 0.696 CNY/kWh for the gas storage facility and an average annual income of 3.14 million yuan. The internal rate of return on project investment is 9.16%, and the static investment payback period is 9.84 years. The project saves 1361.09 tce of standard coal annually and reduces carbon dioxide emissions by 3583.84t annually.

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