Compressor Station Optimization During Gas Injection into Underground Storage

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Summary

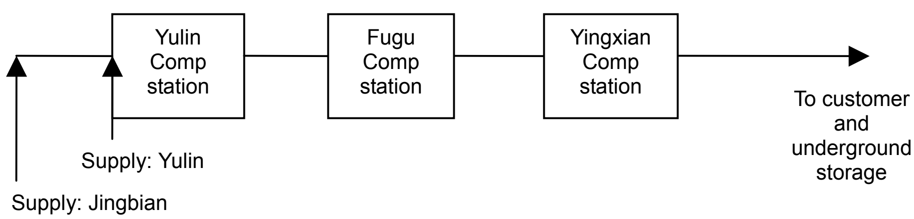
Beijing Huayou Gas Company Ltd (BHGC) has used Pipeline Studio (PLS) to optimize compression operations on the Shaan Jing pipeline during the summer months. BHGC's techniques illustrate the methodology used to analyze compressor station fuel usage and optimize operations for increased fuel efficiency.

Subject Headings: Gas pipeline Compressor station Analysis Optimization

Preface

BHGC owns and operates the Shaan Jing pipeline, which runs approximately 1100 km from Jingbian to Beijing and Tianjin. The pipeline includes three compressor stations and two underground storage facilities, with a third underground facility under construction (Figure 1).

Figure 1: Overview of Shaan Jing Pipeline



Gas is injected into the storage facilities during the summer months. During the winter months, gas is removed from the storage to meet customer demand. The pipeline can supply a maximum throughput of $377 \times 10^4 m^3/d$ with no compressors operating. The total demand during the summer months is $450 \sim 550 \times 10^4 m^3/d$ (including customer demand and injection into the underground storage).

Demand during the summer is high enough that at least one compressor must operate to fill it. Compressor fuel consumption is a significant part of the operating costs during the summer months. One of BHGC's objectives is to reduce fuel consumption during the summer to cut costs.

To reduce fuel consumption, BHGC had to answer the following questions:

- What is the maximum capacity of the pipeline with one compressor station operating?

- Which compressor station has the lowest fuel cost?
- What are the compressor setpoints for the lowest fuel cost?
- Can we develop a steady-state model of the pipeline that is accurate enough to make a useful analysis?

BHGC used Energy Solutions' Pipeline Studio to create and run an offline model of the Shaan Jing pipeline. BHGC then used this model to perform a fuel cost analysis for each compressor station, and generated setpoints for the least expensive compressor control based on the results of the analyses.

Ⅰ. Compressor Station Capacity Analysis

The details of the compressors are given in Figure 2.

Figure 2：Compressor stations on Shaan Jing Pipeline

	Yulin Compressor Station	**Fugu Compressor Station**	**Yingxian Compressor Station**
Compressor type	Reciprocating	Centrifugal	Centrifugal
Driver type	Natural gas engine	Gas turbine engine	Electric motor
Number of units	4	2	2
Compressor station arrangement	Parallel Connection	Parallel Connection	Parallel Connection
Distance from Jingbian（km）	101	281	489

BHGC set some fixed boundaries before performing its analysis:

- The maximum inlet pressure at Yulin was 4.20 MPa.
- The minimum inlet pressure at Dagang station (978 km from Jingbian) was 2.50MPa.

BHGC used the PLS model of the Shaan Jing pipeline to calculate pipeline capacity in three cases. In each case, only one of the three compressor stations was running. BHGC drew the following conclusions from the results:

- The Yulin compressor station drives the line at a capacity of 450~580$\times 10^4$ m^3/d with two compressors operating.
- The Fugu compressor station drives the line at a capacity of 450~490$\times 10^4$ m^3/d with one compressor operating. With a second compressor operating, the suction pressure is too low for stable pipeline operations.
- The Yingxian compressor station drives the line at a capacity of less than 450$\times 10^4$ m^3/d, the minimum demand for the summer months.

Operational results from the pipeline for 2001 concur with the results of the analysis performed with PLS.

The results show that the Yulin compressor station has the largest capacity range that can meet the changing demand for gas during the summer months. The Fugu compressor station could meet the minimum demand, but its capacity range was too small to meet the maximum demand. The Yingxian compressor station does not drive enough capacity to make it useful during the summer.

Ⅱ. Compressor Fuel Cost Analysis

BHGC used PLS to perform additional analysis on the Yulin and Fugu compressor stations to obtain fuel consumption data for individual compressors. Consumption was calculated with demand in the 450~480×10^4m^3/d range. Figure 3 shows the fuel consumption data.

Figure 3: Comparison of fuel consumption under different daily capacity

Capacity	$450×10^4m^3$/d		$480×10^4m^3$/d	
Station	Yulin compressor station	Fugu compressor station	Yulin compressor station	Fugu compressor station
Inlet pressure of Yulin station (MPa)	4.20	-	4.20	-
Suction pressure (MPa)	4.05	3.50	4.05	3.40
Discharge pressure (MPa)	5.08	4.52	5.32	4.69
Station total power (KW)	1718	2044	2156	2910
Fuel consumption ($×10^4m^3$/d)	1.374	1.808	1.724	2.574
Inlet pressure of Dagang station (MPa)	2.50	2.50	2.50	2.50

The simulations show that the Yulin compressor station has a lower fuel consumption than the Fugu compressor station at both 450×10^4m^3/d and 480×10^4m^3/d demand scenarios. In the former scenario, demand is 24% (4,340 m^3/d) less at Yulin than Fugu; in the latter, demand is 33% (8,500 m^3/d) less.

The analysis clearly demonstrates that BHGC can minimize fuel consumption by running the Yulin compression station during the summer months.

Ⅲ. Determination of Compressor Control Mode and Setpoint

Having selected the Yulin compressor station as the best option for running the pipeline during the summer months, BHGC needed to optimize compressor operations. BHGC used Pipeline Studio to select the control mode and setpoint with the lowest fuel cost.

The following equation calculates the power usage for the Yulin compressor station:

$$N = G \frac{\kappa}{\kappa - 1} zRT \left(\varepsilon^{\frac{\kappa - 1}{\kappa}} - 1 \right) \cdot \frac{1}{\eta}, \quad \text{kW} \qquad \text{/Ref 1/}$$

G——Mass flow, kg/s;

κ——Ratio of specific heat, determined by BWRS equation and gas component;

z——Natural gas press factor at compressor inlet;

R——Gas constant, kg•m / (kg•K) ;

T——Suction temperature, K;

ε——Pressure ratio, ε=suction pressure / discharge pressure;

η——Efficiency.

The equation shows that fixing the flow rate for the station fixes the discharge pressure. Therefore, the suction pressure controls the power usage and ultimately, the fuel consumption.

Figure 4: Fuel consumption under different suction pressure

Suction pressure, MPa	Discharge pressure, MPa	Pressure ratio	Consumed power of single compressor, kW	Single compressor fuel consumption, m^3/h	Station fuel consumption, m^3/d
3.80	5.44	1.421	1,431	477	22,883
3.90	5.44	1.385	1,327	442	21,233
4.00	5.44	1.351	1,228	409	19,643
4.10	5.44	1.319	1,132	377	18,109

Figure 4 demonstrates that the fuel consumption depends directly on the suction pressure for a flow rate of $500\times10^4 m^3/d$ at suction temperature of $16^{O}C$. It further shows that maintaining a higher suction pressure reduces fuel consumption. For instance, if demand is $500\times10^4 m^3/d$ and the suction pressure is set to 4.10 MPa, the fuel consumption is 20.86% less than when the suction pressure is set to 3.80 MPa, 17.25% less than when it is set to 3.90 MPa and 8.4% less than when it is set to 4.00 MPa.

Before 2002, the compressor stations on the Shaan Jing pipeline were controlled by flow rate. This control mode presented several related problems:

- The suction pressure varied widely, from 3.75MPa to 4.10MPa.
- The variance kept the compressors from running at their optimal setpoints.
- The operators needed to change the compressor setpoints frequently to compensate for variations in suction pressure.

Based on its analysis, in 2002 BHGC changed the control mode of the compressor stations to suction pressure control and reduced suction pressure to 4.05~4.15MPa. These steps reduced both the operators' workload and fuel consumption. Figures 5 and 6 show fuel consumption in

2001 and 2002 at similar demand rates.

Figure 5: Fuel Consumption in July 6-20,2001

July 6-20,2001	Transfer capacity $10^4 m^3/d$	Fuel Consumption $10^4 m^3/d$
7/06	521	2.210
7/07	519	2.382
7/08	501	2.244
7/09	509	2.300
7/10	507	2.249
7/11	487	2.075
7/12	491	2.028
7/13	492	1.998
7/14	492	1.997
7/15	486	2.010
7/16	473	1.868
7/17	469	1.761
7/18	467	1.698
7/19	472	1.633
7/20	471	1.634
Averaged	490	2.006

Figure 6: Fuel Consumption in June 1-15,2002

June 1-15,2002	Transfer capacity $10^4 m^3/d$	Fuel Consumption $10^4 m^3/d$
6/01	494	1.913
6/02	478	1.920
6/03	470	1.923
6/04	490	1.854
6/05	498	1.878
6/06	491	1.896
6/07	502	1.779
6/08	508	1.862
6/09	512	1.935
6/10	497	1.910
6/11	500	1.792
6/12	506	1.912
6/13	478	1.685
6/14	479	1.665
6/15	481	1.643
Averaged	492	1.838

The change to suction pressure control at the Yulin compressor station reduced fuel usage on the Shaan Jing pipeline for periods of similar demand by 1680 m^3/d between 2001 and 2002. Overall, fuel consumption decreased by 8.37% for the summer months.

Conclusion

BHGC used Pipeline Studio to model the Shaan Jing pipeline and perform offline simulations with different assumptions and conditions. The company's analysis of model results determined the following operational constraints.

- The pipeline's capacity with only one compressor station operating.
- The fuel cost for each compressor setpoint.
- The optimal setpoint and control mode for the Yulin compressor station.

Using the results of the analysis, BHGC was able to improve its operating procedures, with the following results:

- The pipeline runs with only one compressor station in operation during the summer months.

- Changing from flow rate control mode to suction pressure control mode reduced operator workload.
- Fuel costs have been reduced during the summer by more than 8%, for an annual savings of approximately 220,000 RMB (US$27,000).

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