Adaptability Analysis And Structure Optimization Of The Medium-Pressure Gas Pipeline Network

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Abstract

In this paper, with the characteristics of complex gas source and complex pipeline structure, the medium-pressure gas pipeline network in Qingbaijiang district, China, is selected as an example. And the TGNET (3.2) software is used to establish the steady-state model of it. According to the calculation results of the software, the adaptability of this medium-pressure gas pipeline network is analyzed and the optimization scheme of it is also proposed. At the same time, this paper proposes a principle of choosing the equation of gas state equations and the friction coefficient equations when the TGNET software will be used.

Keywords

Medium-pressure gas pipeline network, steady-state model, adaptability, TGNET software.

1. Introduction

With the highly speed development of natural gas, the gas transmission and distribution system is in constant construction and expansion. In order to ensure the gas network safe and reliable, comprehensive monitoring should be carried out. Concretely, analyzing the situation of gas supplies and users according to the data collected and sample of actual data, and then carry out technical evaluation on gas pipeline network, analyze the distribution ability of existing gas pipeline network, assess the rationality of the structure, then propose the retrofit scheme, perfect the gas transmission and distribution system.

Steady-state simulation and dynamic simulation are the two methods for pipeline network simulation. The steady-state simulation for pipeline system is the case that the operation parameters of each node in the network system do not change with time or change a little with time. This paper is mainly aimed at the analysis of the existing operating conditions and the capacity of gas transmission and distribution of the medium-pressure pipeline network. Thus, the steady-state analysis is used to simulate the pipeline network of Qingbaijiang.

2. Establishment of the TGNET steady-state model

2.1 Mathematical model

The equations involved in the simulation of the steady-state flow of the pipeline network are as follows [1]:

Continuity equation:

$$\frac{v}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_P\frac{dT}{dx}+\frac{v}{\rho}\left(\frac{\partial\rho}{\partial P}\right)_T\frac{dP}{dx}+\frac{dv}{dx}=0 \tag{1}$$

Motion equation:

$$\frac{1}{\rho}\frac{dP}{dx}+v\frac{dv}{dx}=-\frac{\lambda}{D}\frac{v^2}{2}-g\sin\theta \tag{2}$$

Energy equation:

$$\left(\frac{\partial h}{\partial T}\right)_P \frac{dT}{dx} + \left(\frac{\partial h}{\partial P}\right)_T \frac{dP}{dx} + v\frac{dv}{dx} = -\frac{4K\left(T-T_0\right)}{\rho v D} - g\sin\theta \tag{3}$$

Enthalpy equation:

$$h = h\left(P,T\right) \tag{4}$$

where ρ is gas density (kg/m^3); v is gas flow velocity (m/s); P is absolute pressure (Pa); T is absolute temperature (K); h is gas enthalpy (J/kg); λ is hydraulic friction coefficient of pipe; D is the pipe diameter (m); T_0 is the soil temperature at the depth of pipe buried (K); K is the coefficient of heat transfer (W/m^2 K); θ is the included angle between pipe and horizontal plane (rad); g is gravitational acceleration (m/s^2); and x is the pipe length (m).

If the working condition is the steady-state, the basic flow of the horizontal pipe can be calculated according to the pressure at the both ends of the pipe, the formulation is as follows [2]:

$$Q = 0.03848\left[\frac{\left(P_Q^{\ 2} - P_Z^{\ 2}\right)D^5}{\lambda Z \Delta_* T x}\right]^{0.5} \tag{5}$$

where Q is the standard volume flow of pipe, (Nm^3/s); P_Q is the pipe starting pressure (Pa); P_Z is the pipe end pressure (Pa); D is the pipe diameter (m); x is the pipe length (m); T is the average temperature in pipe (K); Z is the average gas compressibility coefficient; Δ_* is the relative density of gas in the pipe under standard condition; and λ is hydraulic friction coefficient of pipes.

The flow of pipe and the pressure drop can be calculated by using Eq. (1) to (5). According to the calculation results, it can perform the analyses of the operation condition and the transmission and distribution capacity of the pipeline network.

2.2 Hydraulic calculation of pipeline network

In this study, we use the TGNET 3.2 to perform the hydraulic calculation of the pipeline network of Qingbaijiang. The calculation results of the TGNET are proved to be reliable according to many years of use [3]. The pipeline network model of research object can be established by using TGNET 3.2. The calculation method of the model, boundary conditions and constraint conditions should be set up before the simulations. There is a need to perform the validity check for these models. In this study, the pipeline network model is simulated by steady-state.

2.2.1 Establishment of pipeline network models

The establishment of the network model is actually a new KEYWORD file in the TGNET. According to the compositions of the urban medium-pressure pipeline network, the pipeline network can be drawn in the software with the appropriate simplifications of pipe network. The urban medium-pressure pipeline network is mainly composed of distribution stations, pipelines, valves and users.

Generally, in the setting of the models, the distribution stations are set to Supply [2]. Due to the pipeline is the most basic structure unit of pipeline network, its parameters should be set in detail instead of simplifying. A valve is arranged on each pipeline in the pipe network. Under normal circumstances, they are all in open state. Only in emergency situations, they will be shut down so as to play a temporary role in cutting off the pipe network. Thus, in this study, we do not consider the effects of the valves. Finally, the users are the final service units of the urban medium pressure pipe network. According to the user's manual of TGNET, we set the users to Deliveries [2].

2.2.2 Basic parameters

The basic parameters mainly include pipeline parameters, gas source parameters and user parameters. The pipeline parameters consist of the length, diameter, wall thickness and wall roughness. The gas source parameters and user parameters include the outgoing station pressure, gas supply and gas pressure, gas consumption, respectively. The pipeline parameters can be obtained by the actual situation of target pipe network. However, due to the pipe wall roughness has great effects on the pressure drop of a pipe, it is necessary to conduct a thorough research. The gas source parameters can also be obtained according to the actual situation of target pipeline network. However, for user parameters, the user gas consumption is the most critical parameter.

(1) Determination of the gas consumption of users

Accurate calculations of gas consumption of gas pipeline network directly determine the accuracy of the simulations of the pipeline network. The users of the urban medium pressure gas pipeline network are usually divided into three categories: resident users, business users and industrial users.

1) Gas consumption of the resident users

The gas consumption of the resident users can be calculated according to the user scale, the user consumption index and the city gasification rate of the target city. Based on the fifteenth requirement of China, the value of the city gasification rate is 95% [4]. In order to simplify the model, in this study the community residents are set as centralized users. And we assume that there is a gas cooker and a gas water heater in a family. Because of the existence of the gas consumption is very strong, in this study the work coefficient method is used to determine the amount of gas consumption of the resident users. The work coefficient method is as shown in the formula (6).

$$Q_h = K_t \sum K_0 Q_n N \quad (6)$$

Where Q_h is the flow of the courtyard and indoor gas pipeline, m^3/h; K_t is the coincidence factor of the different types of users (K_t=1); K_0 is the coincidence factor of the same gas appliance; Q_n is the rated flow of a gas appliance (m^3/h); and N is the total number of the same appliance. The values of the K_0 and Q_n can be obtained according to the recommendations of the Gas Combustion and Application [4].

2) Gas consumption of the business users

Based on the business planning of the target city, the gas consumption of the business users can be obtained. Due to the Qingbaijiang district belongs to the southwest of China, the gas consumption of the business users is 40%-50% of the gas consumption of the resident users [5].

3) Gas consumption of the industrial users

According to the progress of the industrialization of the target city, the gas consumption of the industrial users can be obtained based on the statistics on the planned gas consumption in the industrial area.

(2) Determination of the absolute roughness of pipes

The pipeline roughness has effect on the friction coefficient of the pipeline. Thus, the pipe pressure drop and the pipeline transportation capacity are also affected by the pipeline's absolute equivalent roughness. The statistical results of the absolute equivalent roughness of the pipeline at home and abroad are shown in Table 1 and 2 [6, 7].

Table 1 Absolute equivalent roughness of the commonly used tubes

Tubing	Absolut equivalent roughness (mm)
Glass tube, cold drawn seamless steel tube, lead tube	0.0015
Steel tube, wrought iron tube	0.0457
Plating iron tube	0.15
Cast iron tube	0.26
Cement tube	0.30-3.6
Used for several years tube	0.20
New, clean tube	0.05
Lightly corroded tube	0.15
Medium degree of corrosion tube	0.50
Corroded tube	1.0
Heavily corroded tube	3.0

Table 2 Estimated value of the absolute equivalent roughness of tubes in the USA

Tube conditions	Absolut equivalent roughness (μm)
New clean bare tube	12.7-19
After six months of exposure in the atmosphere	25.4-31.8
After twelve months of exposure in the atmosphere	31.8
After twenty-four months of exposure in the atmosphere	44.4-50.8
Sand blasted steel tube	7.6-12.7
Cleaned tube with pipeline pig	5.1-7.6
Steel tube with epoxy or acrylic acid	7.6-12.7

According to the data shown in Table 1and 2, the absolute equivalent roughnesses of new cold drawn seamless steel tube and new welded steel tube are equal to 0.014mm and 0.05mm, respectively. In China, the absolute equivalent roughnesses of new steel tubes without coating and new steel tubes with internal coating are equal to 0.04mm and 0.008mm, respectively. Due to the inner surfaces of the PE tubes are smooth; the range of absolute equivalent roughness of PE tube is from 0.01-0.015mm.

2.2.3 Selections of the gas equation of state

The gas state equations mainly include the Sarem equation, the Peng-Robinson equation and the BWRS equation [8]. The computational accuracy of the Sarem equation is very high, when it is used in the normal pressure natural gas system. In the process of using the Sarem equation, the few gas parameters are required to describe. Only the relative density, the calorific value and the content of carbon dioxide are needed to set. However, the Sarem equation is not suitable for the low pressure conditions, and the calculation results which are obtained by using this equation in the areas near the phase transition region are not accurate enough.

The Peng-Robinson equation is quite close to the real gas in a certain range, but it cannot be used to the system for the treatment of hydrogen. The computational accuracy for the situation whose treatment is mixed gas with more non-hydrocarbons is relatively low. However, the BWRS is the equation which is obtained by modifying the above mentioned equations. The calculation results of this equation for higher pressure temperature conditions are very accurate. At the same time, it can be used to the situation whose treatment is mixed gas with more non-hydrocarbons. But, the calculation process of the equation is complex, and the calculation speed is slow.

2.2.4 Selections of the calculation formula of frictional coefficient

Generally, the fluid flow regimes in trunk pipelines are in the region of quadratic resistance-law. When the flow in the pipe cannot meet the load, the flow regimes of these pipelines are in the mixed friction region. However, the flow regimes in the city and the resident distribution pipeline are more in the hydraulically smooth region. In the TGNET software, they are recommended to use the formula for the calculation of the friction coefficient are mainly Weymouth formula, Colebrook White formula, Panhandle A formula and Panhandle B formula [9]. The Weymouth formula was the first proposed. Because the absolute roughness in this formula is large, it is mainly applicable to the gas pipeline with small diameter, small transport volume and poor purification degree. Due to the Colebrook White formula has good simulation accuracy, this formula is commonly used. In addition, the formula also considers the roughness of the inner walls of different pipes, so it can be applied to three zones of turbulent flow. Panhandle a formula is applied to the case of Reynolds number equal to 5×10^6-14×10^6. In this formula, the roughness of the inner wall of the steel pipe is considered to be a constant, so the friction coefficient is only related to the Reynolds number. Panhandle B formula is suitable for long distance natural gas pipeline with pipe diameter greater than 600mm. And it is mainly used for the calculations of gas transmission trunk lines. In this formula, the roughness of the inner wall is also considered to be a constant.

The city gas pipeline network is more seamless steel pipe with the use of longer time. And the roughness of inner wall of pipes cannot be considered as a constant. According to the comparison results of the above four formulas, and combined with the characteristics of the city gas pipeline network, the Colebrook White formula is chosen to calculate the module coefficient.

2.2.5 Steady state simulation and adaptability analysis of the pipe network

According to the setting conditions, the pipelines are divided into very small calculation sections. Then the TGNET steady-state simulations of the model can be carried out. In most cases, in order to get the convergent calculation results, the models will change. After the calculation, the pressure and flow rate of each pipe section, the pressure and flow rate of the users and the total gas transport volume and outgoing pressure of the gas source all can be obtained. The adaptability of the pipeline network can be obtained with the comparison between the calculated results with the actual design values. According to the result of adaptability analysis, the reconstruction scheme of the unreasonable situation in the pipe network can be obtained.

3. Case analysis

Based on the method proposed before, the adaptability analysis of the medium-pressure gas pipeline network of Qingbaijiang, China can be performed. And the reconstruction schemes are also can be proposed. According to the urban gas pipeline network evaluation data of Qingbaijiang in 2015, the pipeline network model can be established and simulated using TGNET software.

3.1 Basic pipeline network parameters of Qingbaijiang

Based on the urban gas pipeline network evaluation data of Qingbaijiang in 2015, the total length of the medium-pressure main pipe in the city is 50km. The PE pipe is about 20km; the steel pipe is about 30km. The diameters mainly include DN110, DN150, DN160, DN200, DN250 five kinds. The city has five gas sources. The users of this city are mainly residential gas, business gas and industrial gas.

Table 3 Partial pipeline parameters

Pipe name	Length (m)	Nominal diameter (mm)	Nominal wall thickness (mm)	Tubing	Location in the model
1st Huajin Avenue	102.96	150	4.0	Steel tube	Pipe A-1
2nd Huajin Avenue	256.04	150	4.0	Steel tube	Pipe 1-2
Passenger station road	97.37	110	10.0	PE tube	Pipe 3-4
Kailailijing residential quarters	705.80	110	10.0	PE tube	Pipe 3-5
Tonghua Avenue	130.15	200	4.8	Steel tube	Pipe 5-6
Industrial zone pipeline	273.12	200	18.2	PE tube	Pipe 8-9
Mimou gas station pipeline	536.21	250	4.8	Steel tube	Pipe 10-11

Table 4 Gas components of gas source

Components	Mole fraction (%)	Components	Mole fraction (%)
He	0.02	IC4	0.08
H2	0.08	NC4	0.08
CO2	0.03	IC5	0.03
C2H6	2.47	NC5	0.02
C3H8	0.46	N2	0.67
C1	96.06		

Table 5 Gas supply and outlet pressure of each gas source

Gas source	Flow (m3/h)	Operating pressure (MPa)	Location in the model
A Huayan 1	1000-9000	0.17-0.2	Supply Huayan
B Dawan	7000-11000	0.17-0.5	Supply Dawan
C Mimou	1500-4000	0.32-0.5	Supply Mimou
D external gas source	1000-2000	0.2-0.4	Supply external gas source
A Huayan 2	1000-3000	0.3-0.4	Supply 0023

(1) Pipeline parameters

The total length of the medium-pressure main pipe in the city is 50km. The diameter, the wall thickness and the serial number of each tubulation are shown in Table 3. According to the data shown in Table 1 and 2, the absolute equivalent roughnesses of steel pipe and PE are 0.01mm and 0.015mm, respectively.

(2) Gas source parameters

There are five gas sources in Qingbaijiang. The gas components of each gas source are the same, as Table 4 shows. However, the gas supply and gas pressure of each gas source are not the same, as shown in Table 5.

(3) User parameters

After statistics, there are 51379 residents in this city. According to the method in 2.2.2 Section, the parameters of each resident user can be calculated, as shown in Table 6. And there is an industrial zone in Qingbaijiang. Its hourly gas consumption in 2015 was 2000-14000 m^3/h.

Table 6 Gas consumption of some residents and business users

User name	User number	Rated gas consumption (m3/h)	Simultaneous working coefficient	Total gas consumption (m3/h)	Location in the model
Tongfu residential quarters	130	2.7	0.176	61.776	Delivery 15
Qifengju residential quarters	234	2.7	0.153	96.665	Delivery 18
Qilixixiang residential quarters	2164	2.7	0.118	689.540	Delivery 21
Wenhui residential quarters	828	2.7	0.133	297.335	Delivery 28
Maowen company	654	2.7	0.137	241.915	Delivery 31

3.2 Setting of the constraints

According to the above constraint conditions and setting value setting method, the constraints and setting values of each gas source all can be determined, as shown in Table 7. Each user is set in TGNET software. The constraint of the user is maximum flow, and the initial value of the user is hourly gas consumption.

Table 7 Constraint conditions and parameters of each gas source

Gas source	Mode	Operating pressure (MPa)	Constraint condition
Supply Huanyan	Minimum Pressure	0.17	Max Pressure
Supply Dawan	Minimum Pressure	0.17	Max Pressure
Supply Mimou	Minimum Pressure	0.32	Max Pressure

Supply external gas source 1	Minimum Pressure	0.2	Max Pressure
Supply external gas source 2	Minimum Pressure	0.3	Max Pressure

3.3 Analyses of the simualtion results

3.3.1 Verification of the pipeline network model

The reliability of the model is verified according to the amount of gas of distribution station obtained by simulation. In this study, the amount of gas of distribution station is 31007.56 m^3/h obtained by simulation, and the actual amount of gas of distribution station is 29000 m^3/h. As the result of the calculation and the actual engineering quantity error is 6.9%, the model can basically be judged to be reliable.

3.3.2 Analyses of the results

The medium-pressure gas pipeline network of Qingbaijiang is basic into a ring. And it has many gas supply points and large gas supply radius. The gas transmission capacity of this pipeline network is 31007.56 m^3/h, and it has relatively high gas supply reliability.

As shown in the simulation results, if the simulations are performed with the minimum outgoing pressure 0.17MPa of the distribution station, the pressure of the medium-pressure main pipe, which is far from the gas source, will be less than 0.15MPa. The medium-pressures of main pipes of Dushilanting, Guoshuisushe and Huiming residential quarters are less than 0.15MPa, as shown in Figure 1. When the supply point source is sufficient, improving the outgoing pressure of Huayan station and Dawan station to 0.2MPa can significantly improve the end pressure of pipeline network. However, this method does not solve the problem in essence.

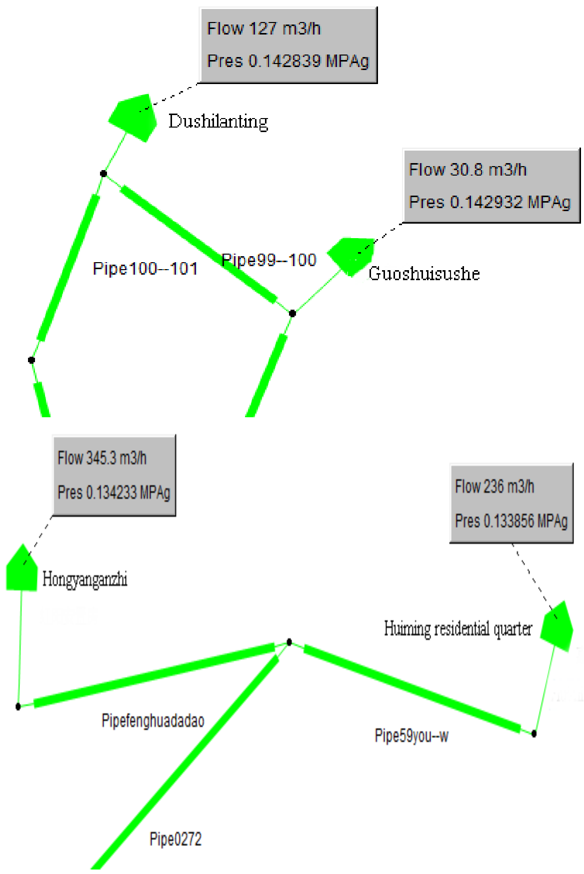

Fig. 1 Pressure distribution of medium-pressure main pipe

The Huayan station and the Supply external gas source 1 are the gas sources of these residential quarters whose end pressures are relatively low. The reason for the lower end pressure of the pipeline network is the sudden change of the pipe diameter of the gas pipeline of Supply external gas source 1.

The pipe diameter from DN150 mutation to DN100 leads to the reduction of the pipeline transport capacity and the end pressure of pipeline. Therefore, in this paper, we proposed to transform the pipe with the pipe diameter change, to improve the pipeline transportation capacity, and increase the end pressure of the pipe. The specific transformation scheme and results are shown in Table 8.

Table 8 Contrast of the parameters of the pipeline network before and after transformation

Pipeline name	Street name	Pipe diameter (mm)		End pressure of pipe (MPa)	
		Before reconstruction	After reconstruction	Before reconstruction	After reconstruction
Pipe 2-53	Jinghua road	100	150	0.149	0.155
Pipe54-55	Shijiazhan east road	100	150	0.135	0.154
Pipe55-56	Shijiazhan east road	100	150	0.131	0.153
Pipe56-57	Anju road	100	150	0.124	0.152
Pipe Shijiazhan middle road	Shijiazhan middle road	100	150	0.124	0.152

In order to study the influence of the absolute equivalent roughness on the pressure drop of the pipeline, this paper selects the 2nd Huajin Avenue as an example to carry out the experimental analysis. In TGNET software, the model of pipeline network is established by using different roughnesses of pipe inner walls, and the rule of pressure drop is obtained as shown in Figure 2.

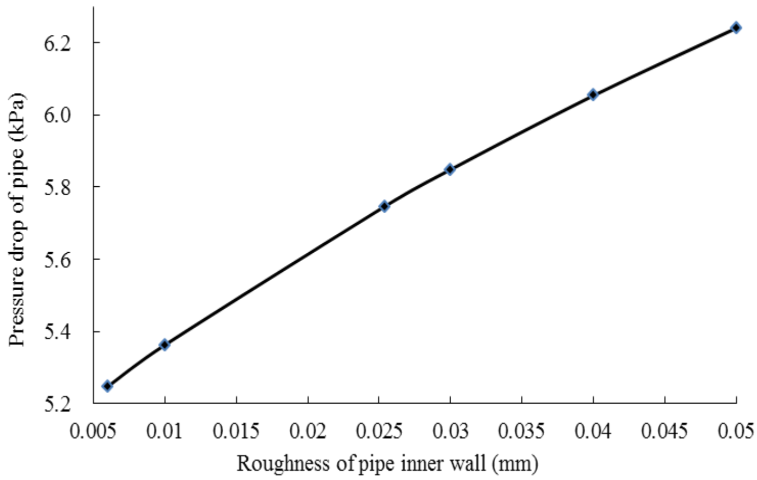

Fig. 2 Rule of the pressure drop with the roughness of pipe inner wall

The trend of the curve shows that the lower the roughness, the lower the pressure drops of the pipeline. And it also can be seen from Figure 2, that the sensibility of the roughness to the pipe pressure drop is gradually reduced with the increase of roughness.

4. Conclusion

(1) With the complexity of medium-pressure gas pipeline structure, this paper use the professional hydraulic calculation software TGNET (3.2) to establish a steady-state simulation model of pipeline network. The model can be used to analyze the adaptability and the transport capacity of the pipeline network. This paper provides a reliable method to analyze the adaptability of the medium-pressure gas pipeline network, and to optimize the structure of the medium-pressure gas pipeline network.

(2) In this paper, we use the method of working coefficient to calculate the gas consumption of the residents. At the same time, this paper sorted out the range of the absolute equivalent roughness of the inner wall of pipes at home and abroad, and recommended the applicable value of roughness.

(3) A lot of gas state equations are compared from the applicable range and the accuracy of the calculation. Finally, it is proved that the BWRS equation has a higher accuracy and range of use. At the same time, this paper also makes a comparison of the formulas for the calculation of the coefficient of friction resistance.

(4) The proposed method is used to analyze the adaptability of the medium-pressure gas pipeline network of Qingbaijiang district, China. And the transformation shceme has been put forward to the unreasonable pipeline network of this city. Finally, this paper also studied the influence of the rougness of inner wall of pipe on the pressure drop.

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