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Simulation Analysis of Influence of Accident Conditions on Hydraulic Reliability of Gas Pipe Network

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Abstract: Taking reliability as the starting point, based on Pipeline Studio software and combined with the actual situation of medium-pressure gas pipe network in Weidu District, Xuchang City, the operation conditions of gas pipe network under design conditions and accident conditions were simulated, and the accident conditions were assumed to be the shutdown of important pipe segments for reasons or the failure of the pipe segment with the maximum flow rate. According to the simulated hydraulic calculation results, the overall gas supply capacity of the pipeline network is comprehensively evaluated and analyzed, and the conclusion is reached that the pipe network can meet the requirements of normal and accident conditions by properly enlarging the pipe diameter closer to the gas source point.

Keywords: Gas pipe network; Hydraulic calculation; Accident condition; Reliability analysis.

1. Introduction

The urban gas system is a vital infrastructure for the survival and development of modern cities and towns, playing a crucial role in enhancing people's quality of life as well as ensuring their safety in terms of life and property. Therefore, it is imperative to enhance the reliability of the pipe network and strengthen its resilience against potential risks[1].

If the topology of the natural gas pipeline network is not optimized, it can significantly reduce the gas supply capacity and lead to a substantial decrease in pressure at most or all nodes. In certain instances, transmission may even fail due to pipe segment failures or reduced gas supply pressure during operation[2]. Therefore, regular data collection and analysis are crucial for evaluating the current state of transmission and distribution capacity as well as assessing the rationality of the pipeline network. When working conditions do not meet gas supply requirements, timely adjustments should be made based on relevant parameters to ensure the safety and reliability of gas supply within the pipeline network [3].

2. Analysis of Pipe Network Status

2.1. City Overview

The design area serves as the cultural and tourism hub in Weidu District of Xuchang City, which is the most developed city among all districts and counties in Xuchang City. The gas infrastructure in this area is evenly distributed, with a small portion of planned industrial land. The total land area measures 59.19 square kilometers, accommodating a population size of 597,900 with a gas penetration rate of 95%. The gas source pipeline connected to this area is the Pingtai Line, which forms part of the second line of west-east gas transmission system and receives gas supply at Xuchangxi sub-transmission station. Situated at the intersection of Nongda Road and West Outer Ring Road Extension Line in the northwest region of Weidu District, Xuchang City, Xuchangxi Branch Station lies approximately 15.6 km away from Gate Station.

2.2. Pipe network Status

2.2.1. Pipeline Network planning Ideas and Requirements

(1) It should be carried out in combination with the overall urban planning and related professional planning, and the gas pipeline network should be arranged on the basis of investigating and understanding the status quo and planning of various underground facilities in the city;

(2) The planning and wiring of the pipe network should be combined with the near and far, with the near-term as the main policy, and the arrangement of phased construction should be proposed to facilitate the work in the design stage;

(3) The gate station should be as close to the user as possible to ensure that the shortest line length is used to achieve the same gas supply effect;

(4) Projects such as crossing rivers, waters and railways should be reduced to reduce investment;

(5) In order to ensure reliable gas supply, the general pipe network at all levels should be arranged along the road;

(6) The gas pipe network should avoid laying parallel to the high-voltage cable, otherwise, the induction electric field will cause serious corrosion to the pipeline [5].

2.2.2. Analysis of pipe network status

The pressure grade system is medium-pressure A first-level pipe network with an hourly peak flow of 30830.5m3/h. The gate station is located at the edge of the planning area from west to north of the design area. Natural gas is transported from Xuchang sub-transmission station to Weidu District gas Gate Station, after metering, filtration and separation, pressure regulation and re-metering into the city's medium pressure pipe network, through the city's medium pressure pipe network transportation, to all kinds of users. PE100 and SDR11 series polyethylene gas pipelines are used for medium pressure pipelines, and steel pipes are used for high pressure gas source pipelines. The design pressure of the air source pipeline is 3.5MPa, the outlet pressure of the gate station is 0.4MPa, and the design pressure of the end of the medium pressure pipe network is 0.25MPa. Medium pressure pipe network, a total of 26 rings, 121 pipe segments, the number of nodes 121. The pipe network scheme is shown in Figure 1.

Modeling and calculation of the current pipe network show that the lowest pressure appears at points 104 and 105, and the lowest pressure is 250.3kPa, which meets the hydraulic calculation requirement that the design pressure at the end of the medium pressure pipe network is not less than 250kPa. The hydraulic calculation parameters of some pipe sections are shown in Table 1.

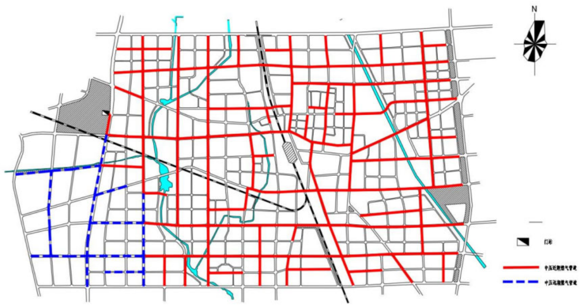

Figure 1. Pipe network plan

Table 1. Pipe section parameter

Section number	Inside diameter(mm)	Section flow(m^3/h)	Pipe section pressure drop(kPa^2)
Air source near the pipe section			
0-1	327.2	30830.5	14.3
1-2	327.2	21081.7	12.0
1-3	327.2	9509.1	2.2
2-4	163.6	572.9	0.4
2-5	163.6	2766.9	8.6
2-7	327.2	17234.7	7.8
Other sections with large pressure drops			
Section number	Inside diameter(mm)	Section flow(m^3/h)	Pipe section pressure drop(kPa^2)
7-16	163.6	3041.8	23.8
7-19	204.6	10302.4	28.2
52-56	114.6	1443.1	22.2
62-81	114.6	1777.5	22.4
64-92	114.6	1818.9	23.1
67-74	114.6	1768.5	24.8
68-72	114.6	1781.8	25.2
81-89	114.6	1070.2	25.4

2.3. Existing problem

The calculated data of node flow and node pressure show that the network flow distribution is uniform, the lowest pressure point of the network is normal, and the pressure reduction from the air source point to the lowest pressure point is smooth and uniform. The data in Table 1 show that there are some problems in the hydraulic calculation results of some pipe sections. The pipe section near the air source point has a large flow rate and a large diameter, and the pressure drop in the pipe section is normal. The pressure drop in the pipe sections 7-19, 81-89, 67-74 and so on is large, because the pipe diameter of these pipe sections does not match the flow rate, and the pipe diameter is relatively small. In general, the current pipe network can meet the needs of normal working conditions.

3. Accident Condition Analysis

Special conditions such as partial pipe section failure and gas supply pressure reduction occur in urban gas pipe network during operation, which are called accident conditions. In the event of accident conditions, the pressure and flow distribution of the pipe network will change greatly, and some users may not reach the required pressure and flow. Accident condition analysis is to ensure that all users can still reach a certain flow and pressure when an accident occurs in the pipe network. For accident condition analysis, more typical conditions need to be selected for analysis. The pipe network is a medium-pressure pipe network with single air source, and the typical working conditions are the failure of structural important pipe segments or large flow pipe segments, that is, the failure of 1-2, 1-3 pipe segments. The accident condition analysis requirements are that the maximum pressure drop does not exceed 0.2MPa, that is, the minimum pressure is controlled at 0.2MPa.

3.1. Hydraulic calculation results of accident conditions

3.1.1. Failure of pipe section 1 (1-2) in accident condition

Accident condition 1 Simulates the failure accident of pipe section 1-2, assuming that the pipeline is disconnected in the middle, as shown in Figure 2. The main hydraulic calculation parameters of some pipe sections are shown in Table 2.

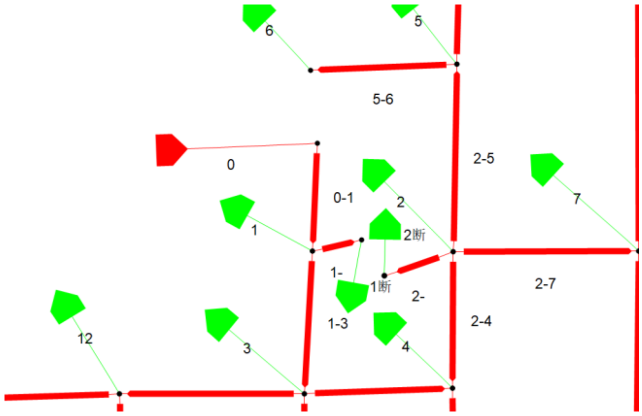

Figure 2. Schematic diagram of accident condition 1

Table 2. Hydraulic calculation results of part 1 pipe section under accident condition

Section number	Pipe diameter(mm)	Flow rate(m^3/h)	Pressure drop(kPa^2)
2-4	163.6		128.6
3-4	163.6		167.5
14-15	114.6		106.1
15-16	114.6		120.0

The hydraulic calculation results of accident condition 1 show that the pressure drop of most pipe sections increases, and the pressure drop of some pipe sections exceeds 100kPa2. The pressure of all nodes decreases significantly, and the pressure of 43.8% nodes is negative. It indicates that the pipeline network cannot complete gas transmission normally under the condition of accident condition 1.

3.1.2. Failure of pipe section 2 (1-3) in accident condition

Accident condition 1 Simulates the failure accident of pipe section 1-3, assuming that the pipeline is disconnected in the middle, as shown in Figure 3. The main hydraulic calculation parameters of some pipe sections are shown in Table 3.

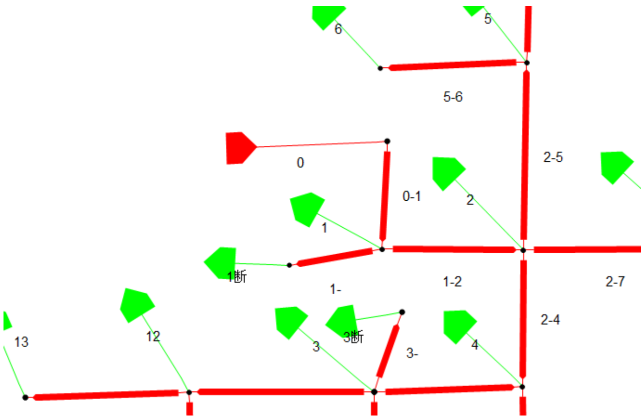

Figure 3. Schematic diagram of accident condition 2

Table 3. Hydraulic calculation results of part 2 pipe section under accident condition

Section number	Pipe diameter(mm)	Flow rate(m^3/h)	Pressure drop(kPa^2)
2-4	163.6	7156.6	44.4
7-14	163.6	4344.6	50.1
7-19	204.6	11511.5	36.6
67-74	114.6	1884.3	30.4

The hydraulic calculation results of accident condition 2 show that the lowest pressure occurs at 104 and 105, and the lowest pressure is 210.2kPa, which meets the requirements of accident condition no less than 200kPa. The pressure drop of pipe section does not increase significantly compared with the normal condition. Therefore, the pipe network can meet the requirements under accident condition 2.

3.2. Improvement measure

According to the analysis in 3.2.1, accident condition 1 cannot meet the gas supply requirements, while accident condition 2 can. Therefore, the pipe network adjustment is carried out based on the parameters of accident condition 1. If accident condition 1 meets the conditions, accident condition 2 will naturally meet them. When an accident occurred, the structure of the pipe network was still intact, so it could be judged that the failure of accident condition 1 to meet the gas supply demand was caused by the small diameter of some pipe sections, and these small pipe diameters were found and appropriately enlarged, that is, the improvement measures suitable for accident condition 1.

When adjusting the pipe diameter, the pipe diameter optimization sequence should be selected according to the importance of the structure and the pressure drop size, and the adjustment should be made in turn, and the hydraulic calculation should be performed again after each adjustment. First, the pipe diameter of section 3-4 is enlarged, because the pipe section is close to the air source point and the pressure drop is very large under the accident condition. After this adjustment, it is found that the requirements are still not met, but the working condition has been significantly improved. Then enlarge the pipe diameter of section 2-4, which is the pipe near the air source after 3-4, and its flow rate is large and the pressure drop is also large under the accident condition 1. After the completion of the two adjustments, the working conditions of the pipe network are improved, the lowest points are 104, 105, the lowest pressure is 201.6kPa, and the pressure drop of each pipe section is small. The data of pipe diameter adjustment are shown in Table 4. After the adjustment of the pipe diameter, the accident condition 1 meets the corresponding requirements. On this basis, the hydraulic calculation of normal condition is carried out again to observe the change of hydraulic calculation of normal condition. The lowest pressure is 105 and the lowest pressure is 254.8kPa, which meet the corresponding pressure requirements. The pressure drop of other pipelines is suitable except that the pressure drop of some pipelines exceeds 20kPa. The hydraulic calculation results show that the pipe network condition after the pipe diameter adjustment meets the requirements of normal and accident conditions, and this pipe diameter can be used as the final pipe diameter.

Table 4. Accident condition 1 Pipe diameter adjustment table

Section number	Pipe diameter(mm)	Pipe diameter(mm)
3-4	163.6	327.2
2-4	163.6	327.2

4. Conclusions

(1) Under normal working conditions, the pipe network in Weidu District, Xuchang City, although the pipe diameter of some pipe sections is relatively small and does not match the flow, in general, the current pipe network can meet the needs of normal working conditions.

(2) Under the condition that the pipe network can meet the needs of normal working conditions, the failure of a large flow or important pipe section may have a serious impact on the gas supply of the pipe network. The accident working conditions should be simulated and analyzed and adjusted in time to reduce the impact range of the accident and reduce the destructive power of the accident conditions.

(3) Under the conditions of the accident, the pipe section close to the gas source point is greatly affected. According to its structural importance and pressure drop, the appropriate pipe section is selected for the reasonable expansion and optimization of the pipe diameter, which effectively improves the hydraulic reliability of the pipe network under accident conditions.

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Southwest Petroleum University Students' Innovation and Entrepreneurship Training Project "Study on application of sulfur-free odorant in gas pipeline network "

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