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Evaluation and optimization of insulation status test for primary heating network

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Abstract

To accurately understand the insulation status of primary heating pipe network in the Chengyin District of Daqing City, its present insulation status has been tested through the enthalpy drop method. The field test results, with the data processing, are compared and analyzed, which reveals that there are weak links in the insulation structure of the primary heating pipe network in the Chengyin area. Before the insulation structure is optimized according to the field conditions, which provides a basis and reference for testing the insulation status of the heating pipe network, and has a guiding significance for evaluating and optimizing the insulation structure of pipe network.

Keywords: heating pipe network, insulation, testing, optimization

1 Introduction

With the development of production and economy, the situation of energy shortage in China is becoming more and more severe. Energy is the fundamental guarantee of economic development, and the missions of energy conservation and emission reduction have been highly paid attention by the country and all the aspects of trades and professions. In the heating industry, a large amount of heat energy is transmitted through the heating pipe network, in which the heat loss is comparatively large. Currently, the pipeline is being used in the heating industry on the external thermal insulation has the shortcoming, simple installation process, resulting in the actual heat preservation effect is not up to the theoretical requirements, tightness and airtightness are not up to the requirements of process piping insulation [1–3]. Many scholars have made a comprehensive analysis of the main problems. It is proposed that in-depth study should be carried out against the aspects of pipe insulation layer

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materials, structural and optimization algorithm of economic thickness to better work out practical problems about the design and replacement of pipe insulation layer [4–6]. With the test in the insulation status of the heating pipe network for operation, evaluation in its insulation effect and optimization for its insulation structure, it matters a great deal to great environmental, economic and social benefits to achieving the purposes that reduce smoke pollution, save energy and ensure the economic development and the safe production [7–9]. Yu analyzes the heat transfer characteristics of the direct buried hot water heating pipe. According to this characteristic, the economical thickness of the large pipe diameter of the long-distance direct-buried hot water pipe is calculated. It is of great significance to saving energy in the long-distance pipeline network, and also supports the engineers in the calculation of the thickness of the long-distance direct-buried hot water pipe insulation [10]. Gao summed up the common methods of heat loss measurement and made a comparative analysis [11].

There is a primary heating pipe network of about 90 km in Chengyin District of Daqing City, including 4.88 km overhead pipelines and 85.15 km pipelines in the underground. Since the laying foundation of the heating pipe network, these have not been tested or evaluated the current situation of insulation and have not mastered the weak links of insulation; many pipelines' insulation structure has been in disrepair for a long time and is seriously damaged. Over the years, due to the leakage of the pipe network, the leakage point and the nearby pipeline insulation layer were damaged, the surrounding insulation layer was seriously immersed, and the insulation was failed. As a result, there is a large amount of heat loss in the heat energy transportation process, which reduces the economic benefits of the enterprise and affects the heating quality and the thermal comfort of users. Test and evaluation of the insulation status in heating pipelines can identify the weak links of insulation and provide theoretical basis and technical support for the insulation reforming.

2 Research on testing and evaluation methods

According to the standard (GB/T8174-2008 Testing and Evaluation of Insulation Effect of Equipment and Pipelines), surface temperature test methods include thermocouple method, surface temperature method, infrared radiation thermometer method and infrared thermography, the test method of surface heat loss includes heat balance method, heat flux method, surface temperature method and temperature difference method, we usually use the following three methods for a detailed field test of pipeline loss: heat flux method, surface temperature method and enthalpy drop method [12].

2.1 Heat flux density method

Using thermal resistance heat flow meter, bury its sensor (probe) in the insulation structure or attached it to the outer surface of the insulation structure to measure the heat flow density and then calculate the heat loss value according to the measured outer surface area of the insulation structure.

2.2 Surface temperature method

There is convective heat transfer and radiation heat transfer occurs between the heat transfer pipeline and the surrounding environment. Measure the external surface temperature, the surface emissivity, ambient temperature and the ambient wind speed of pipeline insulation structure and then calculate the heat loss of pipeline surface according to the convection heat transfer and radiation heat transfer formula. There are usually thermocouple method, surface thermometer method, infrared radiation thermometer method, infrared thermography method and so on for the surface measuring.

2.3 Enthalpy drop method

For a long enough thermal pipeline without branches along the line, test the temperature of inlet and outlet heating medium, calculate the in and out enthalpy H of inlet and outlet hot water and then measure the flow

mass G of hot water, and then it will get its heat loss along the way:

$$Q = G \times (H_{in} - H_{out}) \quad (1)$$

To ensure the accuracy of the measurement results, it adopts the heat flux density method and the surface temperature method. It should select both representative cross-sections and representative test points in each isothermal area when determining test points. At present, most of the primary heating pipe networks in Chengyin District of Daqing City are buried pipes, which do not meet the above-mentioned conditions, so we chose enthalpy drop method as the main test and evaluation method.

3 Test scheme and measures

3.1 Temperature fluctuation

Sometimes, the temperature data collected at the same time are higher than the outlet water temperature of the heat source, which is caused by the long-distance of the whole line of the primary heating pipe network. The water supply from the heat source flows through multiple heat exchange stations and it takes >2 h to reach the end heat exchange station. Therefore, because the distance between the heat station and the heat source is different, the peak and trough positions of its temperature curve are different, and the specific time delay of each heat station can be judged through the curve.

3.2 Temperature measurement

The thermocouple is mainly used as the temperature sensor in the field temperature collection. The thermocouple is placed in the temperature measuring sleeve and injected with a certain amount of heat-conducting oil to measure the medium temperature in the pipeline. The temperature measurement accuracy of thermocouple, the depth and diameter of the casing and the oil quantity of heat transfer oil are the factors influencing the temperature measurement accuracy. Chengyin District has realized remote monitoring of the temperature of supply and returns the water in the whole thermal station of the primary heating pipe network. However, temperature sensors are not arranged in the inspection wells and valve wells, and the temperature of the medium cannot be collected. Therefore, the enthalpy drop under different flow conditions cannot be accurately calculated, and the heat preservation status of the corresponding pipelines cannot be determined. To collect the medium temperature at the three-way points of shunt and confluence, install a temperature sensor on the surface of the pipeline in the valve well and reverse the internal medium temperature by using the surface temperature.

3.3 Flow test

For the thermal power station with installed flowmeter, if the flow deviation is within 5%, which meets the basic requirements of engineering calculation, and the test data of flowmeter shall prevail; and for the heat station with larger fluctuation of flow data, it will be calibrated by the portable ultrasonic flowmeter; The heat stations or nodes without flowmeter will be tested by the portable ultrasonic flowmeter.

4 Test and evaluation of primary heating pipe network

4.1 The evaluation index

According to GB/T4272-2008 General Principles of Thermal Insulation Technology for Equipment and Pipes [13], the maximum heat dissipation loss on the outer surface of equipment, pipelines and their accessories in seasonal operation shall not exceed the provisions in Table 1.

If the insulation test value exceeds the allowable maximum heat loss value, it shall be deemed as unqualified

Table 1 Maximum allowable heat dissipation loss value under seasonal operating conditions

External surface temperature of equipment, pipes and accessories/K(°C)	323 (50)	373 (100)	423 (150)	473 (200)	523 (250)	573 (300)
Maximum allowable heat loss/(W/m ²)	104	147	183	220	251	272

and shall take technical measures such as insulation transformation. The temperature of supply and return water in the first-class heating pipe network of Chengyin District is 110/75°C, and the allowable values of heat dissipation loss on its outer surface are determined to be 154 W/m² and 126 W/m², respectively, through differential calculation.

By testing the inlet and outlet medium temperature of each pipe section, it can calculate the enthalpy values H_{in} and H_{out} of the inlet and outlet hot water. At the same time, according to the measured mass flow rate G of hot water, the heat loss can be obtained along the way. Combined with the pipe diameter and pipe length, the heat loss of the outer surface of the pipeline can be calculated:

$$q = \frac{G \times (H_{in} - H_{out})}{\pi dl} \quad (2)$$

4.2 Layout of temperature measuring points

At least three measuring points [14, 15] shall be arranged on the representative section of the isothermal area. For pipes with an outer diameter <500 mm, each test section is provided with three measuring points, namely, upper, middle and lower. For pipelines with an outer diameter >500 mm, arrange the four measuring points on the upper side, upper-middle part, lower-middle part and lower side, respectively, as shown in Figure 1. Five measuring points for each section of the pipeline with an outer diameter exceeding 1000 mm can be arranged.

Fig. 1 Schematic diagram of cross-section temperature measurement points.

4.3 Test data and evaluation results

After sorting out, screening and calculating the test data, the enthalpy difference method is used to evaluate the insulation status of the primary heating pipe network in the district of Chengyin. Part of the evaluation results of some pipe sections is shown in Table 2.

It can be seen from Table 2 that among the test results of the listed 10 pipe sections, the heat dissipation loss of the 4 and 5 pipe sections exceeds the allowable value of 154 W/m², and the over-standard rates are 37.55% and 27.84%, respectively. However, among all the 128 sections tested, there are 30 sections the heat loss exceeded the allowable value, the length of the main pipe was 19.1 km, the over-standard rate was 1.02%~49.61%. The heat loss in one heating season was about 20×10^3 GJ.

Pipe section	1	2	3	4	5	6	7	8	9	10
Survey point	Heat source Well	Well 7-Well 9	Well 9-Well 11	Well 11-Number 11 Station	Number 11 Station Well 87	Well 87-Well 21	Well 21-Number 1 Station	Well 21-Well 23	Well 23-Number 16 Station	Well 125-Number 8 Station
Pipe length/m	2803	913	642	800	675	1500	312	300	1912	249
Pipe diameter/mm	1000	1000	1000	1000	1000	1000	200	900	200	250
Entrance temperature/°C	80.60	80.31	80.22	80.15	80.00	79.89	79.63	79.63	79.57	79.53
Exit temperature/°C	80.31	80.22	80.15	80.00	79.89	79.63	79.3	79.57	67.2	78.9
Entrance enthalpy/J	337.97	336.75	336.37	336.08	335.45	334.99	333.9	333.86	333.61	333.61
Exit enthalpy/J	336.75	336.37	336.08	335.45	334.99	333.90	332.52	333.65	281.27	330.84
Flow/m ³ /h	3893.70	3893.70	3893.70	3893.70	3893.70	2453.88	97.8	2356.08	14.08	46.94
Density of the heat flow/W/m ²	136.29	130.33	141.45	246.60	213.40	143.40	147.18	145.9	131.14	139.99
Excessive rate of the heat dissipation loss/%	-12.99	-18.16	-8.87	37.55	27.84	-7.39	-4.63	300	-17.43	-10.01

Table 2 The test data and evaluation results of insulation status of the primary heating pipe network (for water supply)

Evaluation and optimization of insulation status test

5 Optimization of the insulation structure

The main problems existing in the present heat preservation structure of heating pipelines include the following aspects:

(1) Settlement of insulation structure.

After the insulation structure is used for a period of time, due to its own gravity or external force, the insulation layer sinks, resulting in the insulation thickness of the upper half of the horizontal pipe thinning or even becoming falling off, while the insulation thickness of the lower half is thicker or falling off, too. Once the pipeline insulation structure subsides, the heat flux distribution on the outer surface will be uneven and the resulting heat dissipation loss will become larger.

(2) Local damage to insulation structure.

Due to the limited strength and construction level of thermal insulation materials, combined with the influence of external factors and man-made damage, the thermal insulation structure will be partially damaged or fall off, resulting in the pipe in bare points or even whole bare pipes occur in the pipeline, making the pipeline excessive heat of dissipation loss.

(3) There are many gaps in thermal insulation construction.

During construction, due to the limitation of thermal insulation material specifications or the shrinkage of thermal insulation material itself, it will be a large number of gaps after thermal insulation construction, which are the weak links of thermal insulation and that will increase the heat loss of pipelines.

(4) The outer protective layer damaged.

The damage of the outer protective layer is very common. Once the protective layer is damaged, it will affect the strength and thermal insulation performance of the whole insulation structure, shorten the service life of the insulation structure or even accelerate the corrosion rate of pipelines.

(5) The pipeline is corroded to a certain extent.

There are two main reasons causing pipeline corrosion, one is that the pipeline anti-corrosion work is not done well properly and the second is that the performance of the insulation materials is unqualified. Once the insulation materials present acidic, they will have a great effect on the pipeline corrosion, so it is required that the pH value of insulation materials should be kept between 9 and 11.

Comprehensive considering many factors such as pipeline anti-corrosion, crack treatment, structural stability, outer protective layer, construction conditions and service life finally select two kinds of thermal insulation structures suitable for the heating pipelines: they are diatom shell and diatom coating composite thermal insulation structure and polyurethane thermal insulation structure. The schematic diagrams of the two thermal insulation structures are shown in Figures 2 and 3.

Fig. 2 Schematic diagram of the composite insulation structure made of diatom shell and diatom coating.

Fig. 3 Schematic diagram of polyurethane made insulation structure.

The construction procedures of diatom shell and diatom coating composite insulation structure:

- (1) St2 rust removal on the surface of the light pipe.
- (2) Coated the surface of steel pipe with LD-SH acid-alkali resistant epoxy anticorrosive paint for twice, and the paint film will reach 100 microns.
- (3) Construction on the composite diatom fibre hard shell.

During construction, apply 2 mm thick paste on the interface of the four walls of the pipe shell and the inner wall of the pipe shell, then buckle the pipe shell on the pipeline, and level and fill the joint with thermal insulation coating.

- (4) Bundle 14 iron wire on the outer side of the pipe shell, bind it once every 200 mm on the pipeline.
- (5) Coat diatom fibre with a thickness of 10~ 15 mm on the outside of the pipe shell in two layers.
- (6) Brush with the hydrophobic agent for once.
- (7) Wrap the glass fibre cloth twice, and brush with LD-XH thick paste anticorrosive primer on the outside. The first glass fibre cloth is painted once, and the second glass fibre cloth is painted twice.

Construction procedures of the polyurethane insulation structure:

- (1) St2 rust removal on the surface of bare pipe.
- (2) Apply two coats of LD-XH acid and alkali resistant epoxy anticorrosive coatings to the surface of steel pipe, and the paint film reached 100 microns.
- (3) Construction on polyurethane insulation tile shell.

During construction, the pipe shell shall be locked on the pipeline at the bayonet position, and the joint shall be levelled and filled with polyurethane foam.

- (4) The polyurethane tile shell shall be covered with a layer of PE film.
- (5) Wrap glass fibre cloth and brush glass fibre reinforced plastic resin outside, so as to achieve the three cloths and four oils.

6 Conclusion

1. According to the characteristics of the first-class heating pipe network in Chengyin District of Daqing City, select the enthalpy drop method to test the insulation condition of the pipe network. The results show that among the 128 sections, 30 of which the heat loss tested exceeds the allowable value, the length of the main pipe is 19.1 km, the over-standard rate is 1.02% ~ 49.61%, resulting the heat loss in one heating season is about 20×10^3 GJ.

2. Analyze the main problems existing in the insulation structure of the heating pipeline. Comprehensive considering many factors such as pipeline anti-corrosion, crack treatment, structural stability, outer protective

layer, construction conditions and service life, select two insulation structures suitable for heating pipeline, namely diatom shell and diatom coating composite insulation structure and polyurethane insulation structure.

This article provides the basis and reference for the heat supply network insulation status test and has a guiding significance for the evaluation and optimization of the pipe network insulation structure.

References

- [1] Sun Qingtao. Discussion on Insulation Technology of Buried Pipeline. *Total corrosion control*, 2019(5), pp.49-51.
- [2] Li Runchang. Design of a New Combined pipeline system. *Chemical Engineering Design Communications*, 2017, 43(011), pp.31-32.
- [3] Jiang Zhaoqiang, Gong Aimin, Zhang Xinqi. Study on Heat Loss of Insulation Structure of Long Distance Hot Water Pipeline. *Energy conservation technology*, 2020, 220 (38), pp.113-117.
- [4] Zhu Lijun. Optimization Analysis on insulation structure and material selection of large diameter steam pipeline. *China Equipment Engineering*, 2017, 000(023), pp.77-79.
- [5] Deng Zhiqiang, Shi Wen, Wang Qi, et al. Research Progress in Design Optimization of High-temperature Pipe Insulation Layer. *Pipeline Technique and Equipment*, 2016(6), pp.14-16.
- [6] Zhaohui, Zhupeng. Thermal Insulation Transformation Scheme and Economic Benefit Analysis of High Temperature Steam Pipelines. *Mechanical Engineer*, 2020, 000(003), pp.123-124.
- [7] Feng Hui-hui, Liu Guanglei, Villi Xing, et al. Detection method and application analysis of heat preservation and energy saving in heating pipe network. *Journal of shenyang jianzhu university (Natural Science Edition)*, 2012,28 (2), pp.303-310.
- [8] Paul W, Barbara B. Utility energy efficiency schemes: savings obligations and trading. *Energy Efficiency*, 2008(1), pp.297-311.
- [9] Marietta L, Sicurella F. Environmental and energy costs of a district heating network. *Environmental Studies*, 2002(6), pp.71-79.
- [10] YU Yaze. Study on the economic insulation Thickness of long-distance heating pipe system. CGS2019.
- [11] Gao Xue. Study on the Detection Method of Heat Loss in Urban Heating Network. Diss. 2016.
- [12] GB/T 8174-2008. Test and evaluation of insulation effect of equipment and pipelines. China Standards Press, 2009.
- [13] GB/T4272-2008. General Principles of Thermal Insulation Technology for Equipment and Pipes. China Standards Press, 2009.
- [14] Liu Lijun, Zhao Haiqian, Liu Ligang. Evaluation of insulation condition of high temperature steam pipeline. *Pipeline Technology and Equipment*, 2004, (6), pp. 14 ~ 19.
- [15] Guo Shuai. Study on Influencing Factors of Thermal Insulation Effect of Thermal Pipeline. Northeast Petroleum University, 2012.