Application of low temperature transportation of 0# diesel oil in North China

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Abstract. Wax deposition in diesel transportation pipe at low temperatures is one of the harassing problems faced by the diesel transportation companies. In winter, the temperature is very low and the demand of diesel is increasing greatly in northern region of China. This work is focused on proposing a new method to transport diesel at low temperature, by analyzing the operating process of diesel transportation, studying the characteristics of the diesel wax deposition process in pipe by experimental measurements and ensuring the safety of diesel transportation at low temperature. The new diesel transportation method at low temperature built up some key parameters about the process of diesel entering to pipeline and achieved normal operation of the 0# diesel transportation system in winter. This achievement has been added into the operating regulations to promote the application of refined oil pipelines in the northern region.

1. Introduction

With the crisis of energy supply and global warming, the demand for 0# diesel oil with lower price in winter in northern China is increasing¹², because the 0# diesel oil has 29% higher fuel calorific value but 23.05% lower cost than -35 diesel oil with the same quality. From the perspective of marketing, the sales company has an anti-season storage plan of 0# diesel oil every winter to meet the urgent needs of the market. The wax precipitated from diesel oil in low temperature adheres to the pipe wall, and a large amount of wax is dissolved in gasoline, which results in the unqualified quality of gasoline and the large increase of oil mixture. A similar production accident has occurred in a domestic product oil pipeline, and the amount of oil mixture has increased nearly 50 times³. What’s more, the design of most product oil pipelines in the northern region does not take into account the transportation of 0# diesel in winter, which is lack of corresponding insulation and other supporting measures. Therefore, for pipeline operators, there is a certain risk to transport 0# diesel oil in winter, which poses a double-challenge to the safe operation of pipelines and the quality control of oil products. Cai et al. proposed measures such as adjusting the production plan of the refinery, adding pour point depressant and adjusting oil delivery batch in long-distance pipeline, dissolving diesel oil and pigging with ball to solve the problem of diesel wax precipitation³. The production plan of the refinery is based on the market demand for oil products. The addition of pour point depressant can reduce cold filter plugging point and prevent wax precipitation. However, for pipeline operators, this increases the operating cost,
and the addition has a certain safety risk, which is not the optimal solution for transporting 0# diesel oil in winter.

In order to solve the contradiction between supply and demand mentioned above, this paper starts with the analysis of pipeline operation technology, carries out the experimental research on the law of low-temperature wax precipitation of diesel oil, and discusses the method of transporting 0# diesel oil in the north.

2. Method of transporting 0# diesel oil at low temperature

2.1. Improvement of pipeline adaptability

It is necessary to improve the adaptability of product oil pipeline without insulation measures for the transportation of 0# diesel oil in winter. It mainly includes two parts: burying ground temperature monitor and adopting insulation measures for stations and valve boxes.

The ground temperature along the line is a key parameter to determine the index of line-in 0# diesel oil in winter. The ground temperature data must be accurate and reliable, which can truly reflect the change law of ground temperature along the pipeline. Firstly, the ground temperature instruments of each station and monitoring valve box of the pipeline should be calibrated regularly; secondly, the ground temperature monitoring devices should be deployed along the pipeline every 20-30 km on average to ensure the continuity of ground temperature data. The following principles should be followed when setting the temperature measurement points. (1) It is necessary to rely on the existing local and remote ground thermometers of the station and monitoring valve box. (2) The distance between adjacent measurement points should not be more than 30 km, and the measurement points should be deployed and controlled according to the distance between the valve box and the station without existing support. (3) The measurement points should be set in typical and special sections. (4) Considering the investment cost and construction period, the ground temperature monitoring adopts local instruments and is carried out regularly to realize long-term tracking and monitoring. Necessary insulation measures should be taken for the above-ground pipeline of station and valve box and the transition section between buried pipeline and above-ground pipeline.

2.2. Experimental study of wax precipitation characteristics of 0# diesel oil

At present, the research on the wax precipitation characteristics of oil products in the industry is mainly concentrated on crude oil, while the research on diesel oil is less, so we can only use the measurement method of wax precipitation characteristics of crude oil for reference. The research methods of wax precipitation characteristics of crude oil mainly include component analysis (SARA), gas chromatography, pulsed nuclear magnetic resonance, differential scanning calorimetry (DSC) [4]. Among them, DSC method is easy to operate, requires less samples and has high accuracy, and relevant standard SY/T 0545 "Determination of thermal characteristic parameters of wax precipitation of crude oil: DSC" has been issued. Numerous methods have been reported abroad for the determination of wax precipitation characteristics of diesel oil using DSC, but the determination methods are not uniform and the purpose of the research is mostly studying the melting conversion process of solid diesel oil [5-7]. The temperature range of the measurement of standard SY/T 0545 is -25 to 80 °C, and the cooling rate is 5 °C/min, which is obvious that the upper limit temperature is too high and the cooling rate is too fast for diesel wax precipitation, so this measuring method is not suitable for the research of diesel oil.

Screening experiments are carried out with six solvents at different ratio and concentration to determine that wax crystal can be obtained from diesel oil by solvent de waxing of butanone and methyl isobutyl ketone in certain ratio. Gas chromatographic (Agilent 7890-5975c) analysis of the pure diesel wax crystals extracted reveals that the distribution of carbon number of wax crystal of diesel oil is generally in the range of C12-C30, concentrated in the range of C17-C27, which is quite concentrated and shows Gaussian distribution, with the peak near C21 and a wax content of 18%. It can be seen that wax crystal of diesel oil is obviously different from wax crystal of crude oil. The
carbon number of wax crystal of Daqing crude oil ranges from C20 to C56, with the peak near C39 and a wax content of 6.9%. The wax crystal of crude oil has a broader carbon number distribution with a large proportion of high carbon numbers. The experimental temperature range of -25~25 °C is determined based on the melting point of paraffin and the percentages of n-alkanes under different carbon number.

The physical properties and wax precipitation characteristics of 0# diesel oil transported by different pipelines such as Lan-Zhen-Chang, Hu-Bao-E and Ji-Chang are tested. The results are shown in Table 1, Figure 1 and Figure 2.

| Experiment No. | Diesel brand | Condensation point | Cold filter plugging point | Wax precipitation point/°C | Peak point of wax precipitation/°C | Enthalpy of wax precipitation/(J/g) |
|---------------|--------------|--------------------|---------------------------|---------------------------|-----------------------------------|-----------------------------------|
| (a) Sample 1  | -2           | 1                  | 0.74                      | 1.14                      | 2.231                             |
| (b) Sample 2  | -3           | -2                 | -1.36                     | -1.85                     | 2.810                             |
| (c) Sample 3  | -4           | -2                 | -0.91                     | -1.26                     | 2.408                             |

It can be seen from Table 1 that the cold filter plugging point of sample 1 is 1°C, and the wax precipitation point is 0.74°C; the cold filter plugging point of sample 2 is -2°C, and the wax precipitation point is -1.36°C, which are similar; the cold filter plugging point of sample 3 is slightly different from its wax precipitation point. The physical properties of different batches of diesel oil produced by different refineries are different, but we can be told from the overall experimental results that the wax precipitation process of diesel oil is obviously different from that of crude oil. The process of wax precipitation from the beginning to the peak is quick, with concentrated wax crystal precipitation, which is also reflected in the DSC wax precipitation characteristic curve, as shown in Figure 1 and Figure 2. The curve shows a narrow peak, which is consistent with the distribution law of carbon number of diesel wax crystal.

2.3. Technical index of line-in diesel oil in winter
The key issue of transporting 0# diesel oil at low temperature is to avoid the wax precipitation and to ensure that the temperature during transportation is higher than the cold filter plugging point of diesel oil. The normal temperature transportation process is generally adopted for the product oil pipeline. After the oil is transported from the initial station for a certain distance, the temperature of oil in the pipeline is equivalent to the ground temperature at the buried depth of the pipeline. Although the
ground temperature of the long-distance pipeline cannot be changed, the cold filter plugging point of diesel can be adjusted by the refinery. Therefore, the process indexes with the idea of regulating the cold filter plugging point of line-in diesel are proposed to meet the operational requirements of the pipeline. Meanwhile, the pipeline is adapted to reduce the risk of pipeline operation and enable successful transportation of diesel oil at low temperature. Based on the ground temperature with the premise that the ground temperature along the line is true and accurate, taking into account the natural environment, production and operation and other unforeseen factors, it is necessary to leave an appropriate safety margin and ensure that there is no wax crystal precipitation above 3℃ of 0# diesel oil. The technical index of transporting 0# diesel oil at low temperature is determined as follows: the cold filtering plugging point of line-in 0# diesel oil is 3℃ lower than the lowest ground temperature at the buried depth of the pipeline in the month; the ground temperature is subject to the historical ground temperature data in the past three years; at the same time, it is necessary to ensure the continuous operation of the pipeline during the transportation of diesel oil and avoid unplanned shutdown; it is recommended to communicate with the downstream sales company to promote the oil-receiving unit to carry out insulation, heat tracing and other corresponding modifications of the tank-in pipeline to ensure the successful transportation of the downstream pipeline.

3. Case analysis

3.1. Pipeline situation
A product oil pipeline in the northern region has a total length of 168km, with two stations at the two ends, without intermediate stations and distribution points, and it adopts the airtight batch transportation at normal temperature. There are eight valve boxes along the line, including two monitoring valve boxes. The transmission medium is mainly gasoline and diesel oil. According to the requirements of a sales company, it is necessary to transport 0# diesel oil from February to March to meet the market demand. The cold filter plugging point of 0# diesel oil is 1-3℃, and the lowest ground temperature of the coldest month of the year is 0℃, which is lower than the cold filter plugging point of diesel oil. Therefore, the operation has certain risks from the perspective of pipeline operators.

3.2. Implementation of operation plan for transportation of 0# diesel oil at low temperature
In order to improve the safety of anti-season transportation of 0# diesel oil, the ground temperature monitoring and the insulation measures for above-ground pipeline such as valve box are adopted. According to the survey along the line, the distance between stations and valve boxes is within 30km, and the block valve boxes are set before and after the crossing of large and medium-sized rivers. The whole line passes through two prefecture level administrative regions, and the temperature range at the tundra along the line does not change much, and the shallowest laying depth of the pipe is below the tundra. Considering the above factors, relying on each valve box, we choose to add six ground temperature detection points in the enclosure of the valve box and bury the thermometer in the primitive soil to prevent collapse and sedimentation, so as to ensure the accuracy of data. The monitoring results are shown in Figure 3.
According to the analysis of ground temperature monitoring data, the lowest ground temperature of the whole line appears in 5# valve box, with the lowest temperature 0.1℃ of the whole year, and the lowest ground temperature from February to March is 0.1-0.2℃, which is consistent with the initial data provided by a design institute. To determine whether it is feasible to transport 0# diesel oil in February and March, it is also required to investigate the oil temperature in the terminal station. According to the production and operation report in 2016, the oil temperature of the terminal station is calculated, as shown in Table 2.

Table 2. Oil temperature of pipeline inlet and outlet from December 2015 to April 2016 (unit: ℃).

| Date      | Product          | Initial station | # valve box       | Terminal station |
|-----------|------------------|-----------------|-------------------|-----------------|
|           | Outlet oil       | Ground          | Inlet oil         | Ground          | Inlet oil | Ground          |
|           | temperature     | temperature     | temperature       | temperature     | temperature | temperature     |
| 2015.12   | Gasoline         | 11.5-13.5       | 9.6               | 11.5            | 9.3        | 9.0     | 8.2-9.5         |
| 2016.1    | Gasoline         | 17.8-18.5       | 4.9-6.8           | 8-10.9          | 2.8-5.2    | 4-6     | 3.5-6           |
| 2016.2    | Gasoline/0# diesel oil | 11.8-15.5       | 3.1               | 10.5            | 1.5        | 2.4     | 1.9-2.5         |
|           | 36.5-39.6        | 3.1             | 10.5              | 1.5             | 2-4        | 1.9-2.5 |
| 2016.3    | Gasoline/0# diesel oil | 17.1-20.4       | 2.4               | 10.5            | 1.3        | 2       | 1.5             |
|           | 36.3-44.2        | 2.4             | 10.5              | 1.3             | 2          | 1.5     |

It can be seen from Table 2 that the ground temperature along the pipeline changes greatly during the above four months, and the oil temperature in the terminal station is basically the same as the ground temperature, and has little relationship with the outlet temperature. The pipeline runs at normal temperature and transports oil intermittently. When the pipeline is shut down, there is gasoline in the pipeline. The transportation is shut down for a long time, and the oil temperature is basically the same as the ground temperature. Therefore, when it starts transporting, the hot oil enters the pipeline, with a large temperature difference between the oil temperature and the ground temperature, so the cold pipeline absorbs a lot of heat from the hot oil, resulting the sharply decrease of the oil temperature. Therefore, the oil temperature is equivalent to the ground temperature when it reaches the terminal station. According to the transportation plan of the sales company, the demand for 0# diesel oil is mainly concentrated in February and March, with the lowest ground temperature 0.1-0.2℃ of the months, and the cold filter plugging point of the line-in diesel needs to be lower than -3℃. According to the requirements of this technical index, the pipeline will successfully realize the transportation of 0# diesel oil in winter.

Statistical analysis is made on the data of oil mixture volume during the period of 0# diesel oil transportation, and the results are shown in Table 3. Compared with the normal transportation, there is
no sharp increase in the amount of oil mixture in the transportation of 0# diesel oil in winter, which proves that the scheme is feasible.

Table 3. Statistics of oil mixture volume of a product oil pipeline

| Date    | Cutting interface | Cold filter plugging point of 0# diesel oil | Oil mixture volume (m³) |
|---------|-------------------|---------------------------------------------|------------------------|
|         | 97# and 35#       | -                                          | 50 66 - -               |
| 2016.1  | -35# and 97       | 78                                         | 102 - -                 |
|         | 97# and 0#        | -3°C                                       | 40 - - -                |
| 2016.2  | 0# and 93#        | 123                                        | - - - -                 |
|         | 97# and 0#        | -.4°C                                       | 47 52 52 33            |
| 2016.3  | 0# and 93#        | 113                                        | 120 94 87              |
|         | 97# and 0#        | 1°C                                        | 44 33 53 45            |
| 2016.4  | 0# and 93#        | 86                                         | 86 108 79              |

4. Conclusion
For the product oil pipeline in the northern region, it is necessary to fully consider the transportation of 0# diesel oil in winter in the design stage, and adopt supporting measures such as ground temperature monitoring and insulation. For the operating enterprises, the key technical indexes of 0# diesel oil transportation in winter are: the cold filtering plugging point of line-in 0# diesel oil is 3°C lower than the lowest ground temperature at the buried depth of the pipeline in the month; it is necessary to ensure the continuous operation of the pipeline during the transportation of diesel oil and the normal transportation of the downstream pipeline. After the trial application of several pipelines, the transportation of 0# diesel oil in winter has been realized successfully. At present, it has been popularized and applied in the product oil pipeline in the north area, and has been written into the operation regulations to guide the production.

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