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Studies on energy consumption of crude oil pipeline transportation process based on the unavoidable exergy loss rate

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ABSTRACT

In order to ensure the crude oil pipeline process smoothly, the driving force has a certain exergy loss. Based on the exergy analysis method, according to the required minimum potential difference of pipeline transportation, the unavoidable exergy loss is defined in the process. In order to reflect the real effective utilization degree of energy consumption, the unavoidable exergy loss rate is put forward as the evaluation index. And it is calculated by the ratio of related the unavoidable exergy loss and the exergy loss. The crude oil pipeline exergy loss rate is calculated under different conditions. The orthogonal experiment analysis used to compare the influence degree of different operating parameters on the pipeline unavoidable exergy loss rate show that the influence degree on the unavoidable exergy loss rate in turn is: outbound temperature, flow and outbound pressure. It also provide the reference for the energy-saving transportation of crude oil pipeline.

The crude oil produced in our country is mostly easy condensable and high viscosity crude oil. The heating mode is used in the pipeline transportation, and the energy consumption is high. Especially the heat self oil consumption of pipeline with long transmission distance and low flow usually consumes 1–3% of the flow, or even higher [1]. Along with the rising demand of crude oil, the economic operation management are facing greater challenges.

At present, the energy consumption analysis in the hot oil pipeline transportation process is based on the analysis of "quantity". However, the energy efficiency of the main thermodynamic indexes can be used to determine the thermodynamic perfection of the equipment. Because of the different energy "quality" involved in energy analysis method, the efficiency can not be further improved. So the researchers have used exergy analysis method based on first and second law of thermodynamics [2,3] to analyze crude oil transportation energy consumption. Yonghui Yuan [4] established the energy balance model and balance equation to analyze the oil-gas gathering system, and carried out the exergy balance analysis of the system. Some evaluation indexes such as "energy consumption rate", "effective energy consumption rate" and "energy loss rate" were put forward, and the energy consumption evaluation criteria and analysis criteria of the gathering transportation system were given. In general, the ideal process without the driving force is the basis of conventional energy analysis method, but the actual thermodynamic process needs the certain driving force, including temperature difference, pressure difference and chemical potential difference. Meng Zhang [5] pointed out that the crude oil pipeline transportation must be accompanied by a process of driving exergy consumption. Based on the exergy analysis principle, the exergy analysis model was established, the driving exergy consumption formula was derived, and driving exergy consumption situation with changes of operating parameters were further analyzed, which laid a foundation for the transportation process of exergy flow classification. Based on external exergy loss and internal energy dissipation, from the essence of the pipeline process, Zhe Li [6] proposed to divide exergy flow into effective exergy consumption and ineffective exergy consumption, and derived the effective

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exergy consumption and the ineffective exergy consumption calculation methods.

The driving force including temperature difference, pressure difference certainly leads to the exergy loss which includes the pressure exergy loss and the thermal exergy loss. The faster of the process proceeding, the greater loss of the exergy. In order to proceed the thermodynamic processes and cycles, it is unavoidable to produce some exergy loss. At present, the international related areas introduce the concept of the unavoidable exergy loss to energy evaluation system. After understanding the relationship between the avoidable exergy loss and the unavoidable exergy loss, George Tsatsaronis et al. [7] calculated the avoidable investment cost according to the avoidable exergy loss, and took heat and power cogeneration as an example to discuss how to estimate the avoidable and unavoidable exergy loss. Based on related concepts about the exergy loss, Farid Bahiraei et al. [8] studied the impact of factors on the avoidable exergy loss with water serving as working medium, such as coil curvature ratio, inlet temperature difference, coil length and fluid properties. The results show that the thermal optimization of spiral coil has great potential. In addition to establishing the exergy balance equation, Kamran Taheri et al. [9] combined the exergy efficiency and energy loss together, which highlighted the low efficiency of the system energy. The obtained exergy analysis is usually suitable for a given purpose comparative process method.

However, for different pipeline process requirements and different operating conditions, the exergy consumption and loss in the pipeline process are different. If the pipeline process energy consumption only evaluates from the energy consumption numerical size, there are some errors on the energy consumption evaluation results. It is difficult to reflect the comprehensive and scientific energy consumption level. So based on correctly distinguishing the avoidable exergy loss and the unavoidable exergy loss in the pipeline process, it is necessary to further introduce the dimensionless quantity——the unavoidable exergy loss rate. It is used to evaluate the exergy consumption status of the crude oil pipeline process, and it can truly reflect the exergy energy effective utilization degree. Changes of the thermal exergy utilization rate varying with the operation parameters are analyzed, which provided theoretical basis for energy-saving transportation of crude oil pipeline.

1. The unavoidable exergy loss during the pipeline transportation

The technical or economic minimum exergy loss is defined as the unavoidable exergy loss. So for the crude oil pipeline transportation process, there must be a theoretical temperature drop and theoretical pressure drop required to ensure the safe and economical crude oil transportation. The corresponding exergy loss is unavoidable exergy loss. In the actual transmission process, the part exceeding the theoretical value is the avoidable exergy loss. The exergy loss of routine exergy analysis method is divided into two parts: the avoidable exergy loss and the unavoidable exergy loss, thus:

$$E_x = E_{x,U} + E_{x,A} \tag{1}$$

Where, E_x——The total exergy loss; kJ/s; $E_{x,U}$——The unavoidable exergy loss, kJ/s; $E_{x,A}$——The avoidable exergy loss, kJ/s;

Considering the radiation loss and friction loss in the pipeline process, the thermal exergy loss and the pressure exergy loss correspondingly are existed in the pipeline transportation. Therefore, in order to ensure safe and economical operation of crude oil pipeline the theoretical temperature drop and theoretical pressure drop are obtained, so there exists the corresponding theoretical minimum $E_x(T)_{\min}$ and $E_x(p)_{\min}$ of the thermal exergy loss and the pressure exergy loss. The sum of them is the unavoidable exergy loss in the crude oil transportation process [10], thus:

$$E_{x,U} = E_x(T)_{\min} + E_x(p)_{\min} \tag{2}$$

Where, $E_{x,U}$——The unavoidable exergy loss, kJ/s; $E_x(T)_{\min}$——The unavoidable thermal exergy loss, kJ/s; $E_x(p)_{\min}$——The unavoidable pressure exergy loss, kJ/s;

According to the definition of the unavoidable exergy loss, there will unavoidably exist theoretical minimum temperature difference ΔT in technical and economic aspects during the crude oil pipeline transportation. The corresponding thermal exergy loss due to temperature difference is minimum thermal exergy loss in the process [11]. It can also be defined as the unavoidable thermal exergy loss $E_{x,U}(T)$, namely:

$$E_{x,U}(T) = E_x(T)_{\min} \tag{3}$$

$$\text{Andmeet: } E_x(T) = E_{x,U}(T) + E_{x,A}(T) \tag{4}$$

Where, $E_{x,U}(T)$——The unavoidable thermal exergy loss, kJ/s; $E_{x,A}(T)$——The avoidable thermal exergy loss, kJ/s;

In the oil transportation process, viscous friction which must be consumed to overcome the oil flow and the impetus which ensure the crude oil driving from the start point to terminal point smoothly are the minimum pressure drop value Δp. Accordingly the generated pressure exergy loss in the process is defined as the oil pipeline unavoidable pressure exergy loss $E_{x,U}(p)$. The pressure exergy loss beyond the unavoidable part is due to many factors especially the uneven pipe wall owing to corrosion, or reduction of effective through area owing to wax deposition in waxy crude oil. This part of the pressure exergy loss is called the avoidable pressure exergy loss $E_{x,A}(p)$, namely:

$$E_{x,U}(p) = E_x(p)_{\min} \tag{5}$$

$$\text{And meet: } E_x(p) = E_{x,U}(p) + E_{x,A}(p) \tag{6}$$

Where, $E_{x,U}(p)$——The unavoidable pressure exergy loss, kJ/s; $E_{x,A}(p)$——The avoidable pressure exergy loss, kJ/s;

After the exergy loss is divided into the avoidable exergy loss and the unavoidable exergy loss, the improvement of crude oil