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# Numerical simulation for the heat transfer behavior of oil pipeline during the shutdown and restart process

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ABSTRACT

Mathematical models for the heat transfer behavior of the oil pipeline during shutdown and restart are established. And the finite difference and finite volume method are used to disperse the mathematical models to investigate the heat transfer characteristics of the thermal system. Five simulation cases are executed to obtain some findings. During restart, the pipeline can be divided into three regions with each region has a certain temperature changing trait. And the increasing of temperature on certain position has two stages and each stage has a different temperature evolution due to the movement of remain cold oil and entering of hot oil. The surrounding soil has the analogical temperature evolution in contrast to the crude oil except some thermal hysteresis exists. And a thermal influence region is also found around the pipeline. The influence of restart flow and temperature on the oil pipeline is also investigated. There is a worthy of note that in case that the restart flow is lower than a certain value, there may be appears a period of time that the oil temperature continues to decrease although the pipeline has been restarted. This condition increases the risk of oil gelatinization.

## 1. Introduction

In the past ten years, the production of waxy crude oil around the world has increased rapidly, which nearly accounts for 20% of the world's crude oil reserves and pipeline throughput. However, due to the property of high pour point and poor mobility at normal atmospheric temperature, the transportation of waxy crude oil through the pipeline is much more difficult than that of the normal light crude oil. In China, most of the crude oil is waxy crude oil, and the heating process is generally used to reduce the viscosity of waxy crude oil so as to increase the safety during the transportation of waxy crude oil through pipeline. During the transportation, as suffering from the artificial or natural disasters, the oil pipeline is inevitably to be shutdown sometimes. During the shutdown process, the waxy crude oil is still stored in the pipeline, as driving by the large temperature difference between the oil and surroundings, the temperature of crude oil continues to decrease together with the deterioration of mobility of oil. Once the temperature approaches to some extremely low value which coursed the gelatinization of waxy crude oil, the pipeline condensation accident may be happened thus the restart of oil pipeline may be failure. This undoubtedly seriously affects the safe operation of oil pipeline and may causes huge economic loss. Therefore, in order to ensure the safe and efficient operation of waxy crude oil pipeline, the heat transfer characteristics of oil pipeline during the shutdown and restart process is vital important that is the basis to determine the safety shutdown time and propose the restart scheme.

At this point, many scholars had carried out extensive investigation dealing with the problem referring the process of shutdown

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**Nomenclature**

| | | | |
|---|---|---|---|
| $\eta$ | Viscosity, mPa·s | $h$ | Specific enthalpy of crude oil, J/kg |
| $T$ | Temperature, °C | $\beta$ | Crude oil expansion coefficient, °C $^{-1}$ |
| $c$ | Heat capacity, J/(kg °C) | $r$ | Radial position, m |
| $\rho$ | Density of crude oil, kg/m$^3$ | $\theta$ | Round curvature |
| $A$ | Cross section area, m$^2$ | $k$ | Thermal conductivity, W/(m °C) |
| $t$ | Time, s | $x$ | Horizontal position perpendicular to the axial direction, m |
| $w$ | Average oil flow rate, m/s | $y$ | Depth, m |
| $z$ | Axial position of oil pipeline, m | $T_n$ | Temperature of the thermostat, °C |
| $\alpha$ | Angle between axial and horizontal, ° | *Subscripts* | |
| $P$ | The average pressure of oil flow section, Pa | p | Pipeline wall |
| $f$ | Darcy friction factor | i | Insulation layer |
| $D$ | The inner pipe diameter, m | s | Soil |
| $q$ | The amount of heat dissipation of crude oil in the unit wall area per unit of time, W/m$^2$ | o | Inner wall of oil pipeline |
| $u$ | Specific internal energy of crude oil, J/kg | a | Atmosphere |
| $s$ | Elevation, m | | |

and restart. Against the heat transfer characteristic during the shutdown and restart process, some scholars adopted the numerical simulation method to analyze the heat transfer characteristics of crude oil, and some others focused on the temperature distribution around the soil and the effect of different physical properties of crude oil on the shutdown process was also discussed. Yu [1,2] divided the phase change of waxy crude oil during the shutdown process into four stages. Based on this division, a general phase-change heat transfer model was proposed for the thermal calculation of waxy crude oil during shutdown. Zhao [3] investigated the heat transfer characteristic of waxy crude oil after pipeline shutdown [4–7] by the numerical simulation, and the additional specific heat capacity and momentum source term methods were introduced in his research. Liu [8] simulated the temperature drop process of the buried hot oil pipeline which showed that the oil detemperature rate [9] was slow down obviously for buried pipelines. Cheng [10] established a partition method mathematical model for the shutdown process of an overhead pipe, and the effects of crude oil's variable physical properties on the heat transfer performance were analyzed. Comparing to the extensive research on the shutdown process, due to the complex coupling characteristic between the hydraulic and thermal process, the research on heat transfer characteristic during the restart process was relatively rare. Based on the Houska rheological model, Ali Ahmadpour [11] investigated the separate effects of structure and shear-dependent viscosity. Liu [12] carried out simulation testing on shut-down and restart-up in an overhead pipeline in Daqing Testing Base, and the variation law of parameters such as temperature and pressure was well obtained during shutdown and restart of hot oil pipelines. Liu et al. [13] established a transient simulation model of heated oil pipelines. Method of characteristic and finite difference method was applied to solve this model. Finally simulation software was developed to simulate the shutdown and restart process. Yu [14] investigated the restart process of this transportation process after its shutdown. A finite volume scheme combined with a finite difference method was used to discretize the governing equation. In Kang's [15] study, an unsteady-state computation module of oil temperature in excavation segment during the periods of shut down and restart was established. Qiu [16] successfully conducted an industrial field test in West Oil Pipeline, based on the study of rheological properties of the mixed oil and the digital simulation of the shutdown and restart processes.

Relatively speaking, many studies focused on the pressure and rheological properties of oil during the restart process. And these achievements also provided some insights to the investigation of heat transfer characteristic during shutdown and restart. In Lalit Kumar's paper [17], a finite volume method was implemented on a staggered grid. An iterative predictor-corrector algorithm was provided to the combined parabolic-hyperbolic set of governing equations. Finally a new shear-history dependent thixotropic rheology model was proposed for pressure wave propagation computations. Miao [18] studied on the safety of the restart of a long-term unpigged crude pipeline, and some significant conclusions were drawn.

Since the previous reports were mainly aimed at the heat transfer characteristic during the shutdown process or the pressure and rheological properties of oil during the restart process. And there are rare studies on the heat transfer characteristics during the restart process which is vital important for the analysis of the restart process. Therefore, in this paper, the method of numerical simulation is adopted to investigate the distribution and variation rule of temperature field of crude oil together with the surrounding soil during the restart process, which can provide reference for the production management and the safe and efficient operation of hot oil pipeline.

## 2. Problem definition

### 2.1. Computational domain

As there are many factors affecting the heat transfer process of the crude oil pipeline, it is simplified or assumed as follows:

a) As the soil temperature field near the hot oil pipeline is greatly influenced by the hot oil in the pipe, according to the practical