International Journal of Heat and Mass Transfer 127 (2018) 89–101

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Heat flow coupling characteristics analysis and heating effect evaluation study of crude oil in the storage tank different structure coil heating processes

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ARTICLE INFO

Article history:
Received 9 March 2018
Received in revised form 31 July 2018
Accepted 10 August 2018

Keywords:
Coil heating
Heat flow coupling
Heating rate
Uniformity of temperature field

ABSTRACT

Considering the factors such as ambient temperature, solar radiation, heating steam pressure and physical properties of oil products, a theoretical model for heating process of large floating roof tank coil is established. The numerical solution technology of the crude oil temperature field and flow field is studied to reveal the coupling characteristics of crude oil heat transfer and flow during the storage tank heating process. Furthermore, the influence law of different coil structures on the temperature field and flow field during the crude oil heating process is discussed. On this basis, the evaluation indexes of the heating effect on the crude oil storage tank is set up, which are combined with heating rate and uniform degree of temperature field. The results show that according to variations of crude oil flow field in the tank, the tank steam coil heating process has been divided into four stages including natural convection formation, small vortex formation, large vortex formation and large vortex development. The coil structures have great influence on the temperature field and the flow field of the crude oil tank. The vertical structure and the stereoscopic structure coils will form a certain thickness low temperature zone at the tank bottom during heating process, but the serpentine structure coil will form a heated dead zone at vertex angle and base corner of the tank where area is relatively small. On this basis, comparing the heating effect of the three kinds of coils, it is found that the heating rate of serpentine structure coil is the fastest and more stable. The uniform degree of temperature field is affected by the oil liquid level. Environmental temperature and other factors have little effect and the best heating effect.

1. Introduction

When the crude oil temperature in the tank is lower than the wax precipitation point in production operation of the oil tank, the waxy crude oil will form condensate oil layer with certain strength and thickness in the inner edge of tank. In order to ensure the safe operation of the storage tank, the crude oil in the tank must be heated [1,2] in a timely manner. Each heating technology has its own advantages and disadvantages. According to the specific conditions, it should be applied in combination with the nature of oil, the nature of operation, the characteristics of regional and temperature, and the safety factors. Most of the crude oil produced in the main oil fields of our country are high waxy crude oil, and the wax content is as high as 15–37%. When a large amount of loading and unloading operation is carried out in a short period of time, a comprehensive heating technology is used in order to ensure safety [3–6]. At present, the most common heating mode is to install heating coil inside the oil storage tank, which has the advantages of simple structure, low cost and convenient operation. However, heating in this way will cause huge energy waste. Therefore, it is necessary to analyze the coupling characteristics of heat transfer and flow in the heating process of the existing storage tank coil, and put forward the evaluation method of heating effect, so as to achieve the goal of high-efficiency and energy saving [7–10].

In the aspect of crude oil heat transfer and flow coupling, the mathematical model of electric field, crude oil flow field and temperature field were established by using lattice Boltzmann method for Wang et al. [11]. The experimental results are in good agreement with the numerical simulation results. It is found that the effect of electric field on heat transfer is obvious under the action of gravity. And as the temperature increases, it increases. Kuznetsova and Maksimov [12,13] set up a mathematical model for the fuel oil tank where the internal storage is the incompressible viscous fluid and the tank bottom is considered as the heat source. Unsteady Navier Stokes equation, energy equation and heat conduction equation in a fixed initial and boundary conditions

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https://doi.org/10.1016/j.ijheatmasstransfer.2018.08.035
0017-9310/

Nomenclature

ρ	the density of crude oil, kg/m^3
λ	the heat conductivity coefficient, W/(m^2 °C)
μ	the viscosity of crude oil, Pa s
c	the specific heat of crude oil, J/ (kg °C)
t_{oil}	oil temperature, °C
q_0	heat flux of solar radiation absorbed, W/m^2
Q_{tf}	tank roof heat flux of solar radiation absorbed, W/m^2
Q_{tw}	tank roof heat flux of solar radiation absorbed, W/m^2
F_{tf}	the area of tank roof, m^2
F_{tw}	the area of tank wall, m^2
I	solar constant, W/m^2
φ	atmospheric transparency coefficient, nondimensional
θ	the zenith angle of the sun at noon, °
σ	coefficient related to day length, nondimensional
m	coefficient related to atmospheric quality, nondimensional
η	emissivity of tank float plate, nondimensional
t_{en}	environment temperature, °C
t_{soil}	soil temperature, °C
u	transverse flow velocity of oil, m/s
v	longitudinal flow velocity of oil, m/s
τ	heat transfer time of unsteady state, s
P	fluid pressure, Pa
G_k	turbulent kinetic energy generated by laminar velocity gradient, J
$C_\mu, C_{1\varepsilon}, C_{2\varepsilon}, C_{3\varepsilon}$	turbulence calculation constant, non-dimensional
α_k	the Prandt number corresponding to the turbulent kinetic energy k, non-dimensional
α_ε	the Prandt number corresponding to the dissipation rate ε, non-dimensional
R_ε	turbulence viscosity coefficient under low Reynolds number, non-dimensional

have been solved. Liu et al. [14] established two dimensional model of floating roof tank. The oil flow field in the tank and the oil temperature distribution near the tank wall are simulated with the tank bottom as the heat source, and the influence of the oil storage height and the steam heated amount on the tank bottom are also analyzed. Rejane [15] has done the stratified analysis of the hot oil in the insulated and small volume storage tank at the top and bottom. The finite volume method is used for numerical calculation. The temperature field and flow field of the crude oil in the storage tank are obtained. In evaluation of the crude oil heating effect, the finite volume method and standard k-epsilon turbulence model were used to study the heat flow characteristics of crude oil in the storage tank during the hot oil spraying heating process of by Zhao et al. [16]. Through the change of the heating rate for oil products, the improvement measures for the position of sprinkler were put forward. On the basis of simulating the heating process for the 10×10^4 m^3 crude oil storage tank, Lu et al. [17,18] analyzed the changing rule of temperature field. From the point of view of energy saving and safety, the location structure of heater were studied and analyzed, and the optimal outer diameter of coil heater was obtained. Zhang et al. [19] test the heating process of water and diesel respectively under the action of magnetic field. The heating effect of water and diesel oil under different magnetization and magnetization time was analyzed with the heating rate as the criterion.

To sum up, in the current numerical simulation of the coupling characteristics between crude oil heat transfer and flow in the coil heating process, the tank bottom is usually regarded as the heat source, and the influence of the coil structure on the temperature field and the flow field is always ignored [20–23]. On the other hand, the heating rate is used as the sole criterion for judging the heating effect of crude oil in the past, but it can only reflect the variation rule of temperature field with time, and can not reflect the spatial distribution of temperature field. Therefore, considering the cyclical variation of the environment and the physical properties of crude oil, the theoretical model of the heating process on the large floating roof tank steam coil is established including mass equation, momentum equation, energy equation and turbulence equation. The flow coupling characteristics of heat transfer and flow for crude oil coil during heating are revealed. By arranging the different coil layout methods such as vertical, stereoscopic, and serpentine, etc. The effect of coil structure on the temperature field and flow field of crude oil heating process can be reflected more clearly and intuitively. On this basis, the evaluation indexes of tank heating process heating effect are put forward. At the same time, we consider the factors of time and space, that is, heating rate and temperature field uniform degree. It can truly reflect the influence of factors such as tank oil level, heating steam temperature, external environmental conditions and other factors on the heating effect. The results can provide guidance for the design of heating coil.

2. A theoretical model for the tank coil heating process

During the heating process, the crude oil can exchange heat with the ambient temperature, solar radiation and other external environment by the heat conduction, thermal convection and thermal radiation way through the floating roof, tank wall and tank bottom. At the same time, the high temperature steam passes the heat to the oil in the tank through the coil, which causes the oil temperature rise near the coil, and the density decreases gradually. The temperature of other parts of the storage tank is relatively low, which causes the natural convection of crude oil, and the flow and heat transfer affect each other at the same time. Its physical model is shown in Fig. 1.

In order to facilitate the study of the heat transfer and flow coupling characteristics in the tank, the following reasonable simplification and hypothesis are made: After the scene investigation of oil depots, considering the smaller thermal conductivity of the oil in the tank, heat flow in the inner region of the tank changes slowly, and the simulation can assume that the initial temperature is uniform. Furthermore, the tank and coil are axisymmetric geometry and the variation of the circumferential temperature and velocity varies slightly. Neglecting its influence the storage tank and coil can be simplified as a two-dimensional model, and a mathematical model for the heating process of a crude oil storage tank coil can be established. On the physical properties of crude oil, variable physical model is adopted. Parameters all change with the temperature change, such as density, thermal conductivity, viscosity and specific heat capacity of crude oil. Compared with the crude oil constant model, the heat transfer and flow state can be more accurately reflected in the crude oil heating process. On the boundary condition, the periodic model is adopted, and the calculation formula of solar radiation heat flux at different times of tank top and tank wall are put forward, which includes the functional relationship between external environment and time such as air, soil. Compared with the fixed boundary conditions used in the past, it can