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Modeling of Heat Transfer Equations for Estimation of Temperature Variations Inside the Oil Transport Pipe Line

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원유 수송관 내부의 온도 변화 예측을 위한 열전달 방정식의 모델링

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Abstract

In the present study, the simple form of the heat transfer equation were suggested to estimate the temperature variation inside the oil pipe in order to determine the thickness of the insulating materials to retain the working oils below the critical temperature. The conservation of the thermal energy at arbitrary time were modeled to one dimensional unsteady equation with the empirical formula or data. The calculating results for non-insulation case showed that the temperature were very sensitive to the thermal convection by the velocity of the external wind. For insulation case, the insulation material which has higher density and specific heat, lower thermal conductivity should be chosen with more brighter coloring outside the pipe in order to retain the working oils below the critical temperature.

1. Introduction

The climatic conditions in the area of the dessert, Middle Asia are changed dramatically even in the one-day long. So, the oil in the transport pipe installed in that area lies under the danger of the boiling by the external thermal radiation if exposed to the sun without the insulation materials nor the color-painting. In addition, the temperature variation during the whole one day is so large that the thermal loading condition might be considered for the structural analysis.

In the present study, the simple form of the heat transfer equation were suggested to estimate the temperature variation inside the oil pipe in order to determine the thickness of the insulating materials to retain the working oils below the critical temperature. The calculations were performed for the two cases, i.e., one for the non-insulation, the other for the insulation

2. Derivation of heat transfer equations

For the thermal surroundings as shown in Fig. 1, the conservation of the thermal energy at arbitrary time were modeled to one dimensional unsteady equation as following equations.[1]

$$\dot{q}_{rad} - (\dot{q}_{ref} + \dot{q}_{c,\infty}) = \dot{q}_{c,f} + \left.\frac{\partial E}{\partial t}\right|_f + \left.\frac{\partial E}{\partial t}\right|_m + \left.\frac{\partial E}{\partial t}\right|_I \qquad (1)$$

As shown in Fig. 2(a), the oil pips were composed of three mediums, I.e., working fluids, pipe metals and insulation materials if applied. For the simplifications, the temperature profiles inside the oil pipe were assumed as shown in Fig. 2(b). Considering the temperature difference between the outside of the insulation and the averaged pipe-line temperature as shown in Fig. 2, the correction factor were defined as follows:

$$K_c = T_I(t) / T_m(t) \qquad (2)$$

Using the equations driven in the previous reports [2] with the above correction factor, the heat transfer equation has the following forms:

$$(1-\alpha)\dot{q}_{,A}(t) - h_\infty[K_C T_m(t) - T_\infty(t)] = \left(\frac{m_m C_m + m_f C_f + m_I C_I}{A_I}\right)\frac{dT_m}{dt} \qquad (3)$$

With the modeling of the effective thermal-radiation and the atmospheric temperature during whole one day as shown in Fig. 2, and Fig. 3, the eq.(3) could be simplified into the following forms for the metal temperature.[3]

$$\frac{dT_m}{dt} + \frac{K_C h_\infty}{K} T_m = \frac{h_\infty}{K} T_\infty + \frac{(1-\alpha)}{K}\dot{q}_{,A} \qquad (4)$$

where heat convection coefficient by the atmospheric air-cooling, h_∞ were computed by the empirical formula in reference[4] and the several material properties for eq.(4) were given in reference[5].

The final form of the eq.(4) is the first order of ordinary differential equation $T_m(t)$, so the solution could be obtained in the followings:

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$$T_m(t) = e^{-\int \frac{K_C h_\infty}{K} dt} \left[\int e^{\int \frac{K_C h_\infty}{K} dt} \{ \frac{K_C h_\infty}{K} T_\infty(t) + \frac{(1-\alpha)}{K} \dot{q}_{,A} \} dt + C \right] \quad (5)$$

3. Calculation results

In order to predict the temperature inside the oil transport pipe line, the calculations based on the eq.(5) were performed for the two cases, i.e., one for the non-insulation, the other for the insulation. The criteria were given as 80[℃] for crude oil and 60[℃] for fuel oil [2]

Fig. 5 shows the typical results computed with eq.(5) to estimate the temperature variations inside the oil pipe under the conditions that DN100, Crude oil with Grey coloring without insulating materials. If the atmospheric conditions as thermal-radiation, air temperature were constant as given in Fig.3 and Fig. 4, the temperature inside the oil pipe might be varied periodically about 7-10 days as shown in Fig. 5.

Fig. 6 shows the effects of air velocity in the conditions of nominal diameter of pipe, 100 mm without the insulation materials. The calculating results for non-insulation case showed that the temperature were very sensitive to the thermal convection by the velocity of the external wind. So, the proper choice of the air velocity v_∞ might be very important to get the valuable information on the temperature inside the oil transport pipe line.

Fig. 7 shows the influence of insulation thickness to see whether the working oils could be retained below the critical temperature. In the present simulation, the air velocity v_∞ were fixed as 0.01 m/s, the simulations were performed in the following three cases for two parameters, I.e., insulation materials, k_I and color-paintings, α .

[Table1] Given condition from Siemens:

$k_I = 0.044$, $\alpha = 0.78$

[Table2] Change of thermal conductivity of insulation:

$k_I = 0.0044$, $\alpha = 0.78$

[Tavle3] Change of color:

$k_I = 0.044$, $\alpha = 0.84$

The conclusive comments for insulation case were drawn that insulation material which has higher density and specific heat, lower thermal conductivity should be chosen with more brighter coloring outside the pipe in order to retain the working oils below the critical temperature.

4. Concluding remarks

The heat transfer equations were simplified to estimate the temperature variation inside the oil pipe in order. The applications were done for the two cases, I.e., one for the non-insulation, the other for the insulation. The computed results were sensitive to the air velocity. To keep the oil temperature below the given criteria, the proper choice of insulating material and color-painting would be necessary.

Reference

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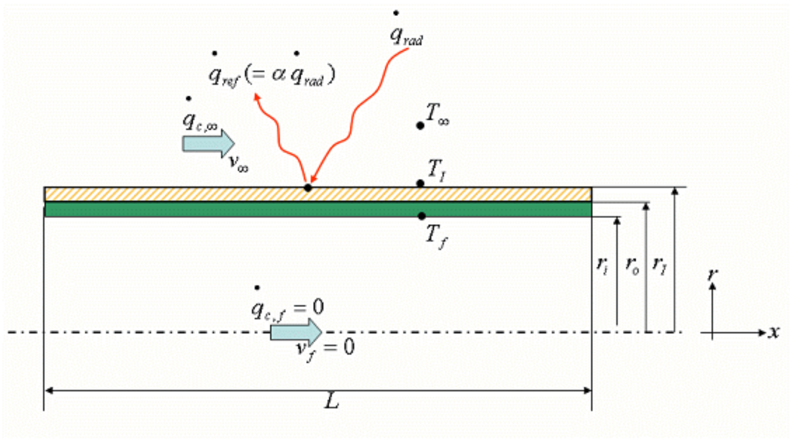

Fig. 1 Definition of the present heat-transfer system

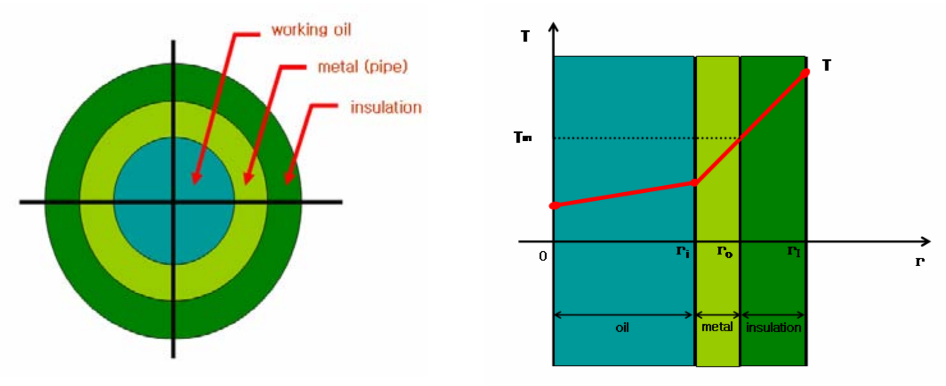

Fig. 2 Definition of the present oil pipe with internal temperature profiles

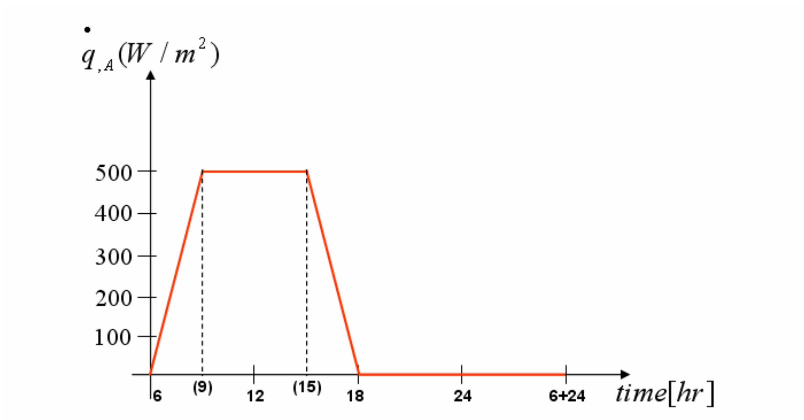

Fig. 3 Modeling of the effective thermal-radiation during whole one day

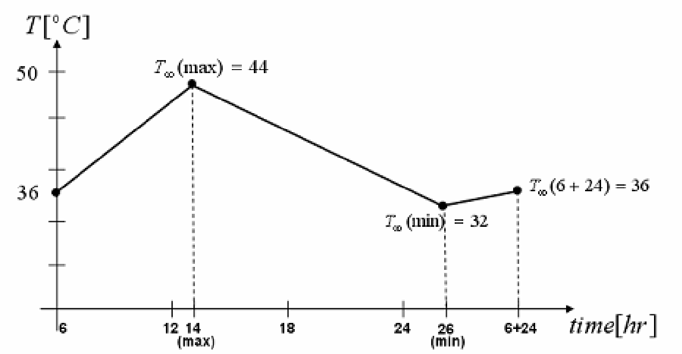

Fig. 4 Modeling of atmospheric temperature during whole one day

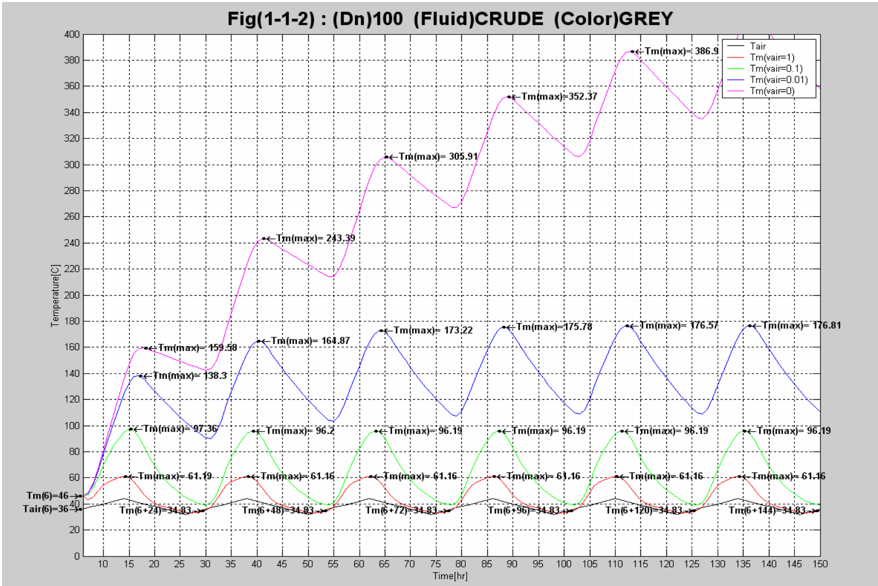

Fig. 5 History of temperature variations inside oil pipe during six(6) days
(DN100, crude oil with grey coloring, without insulation)

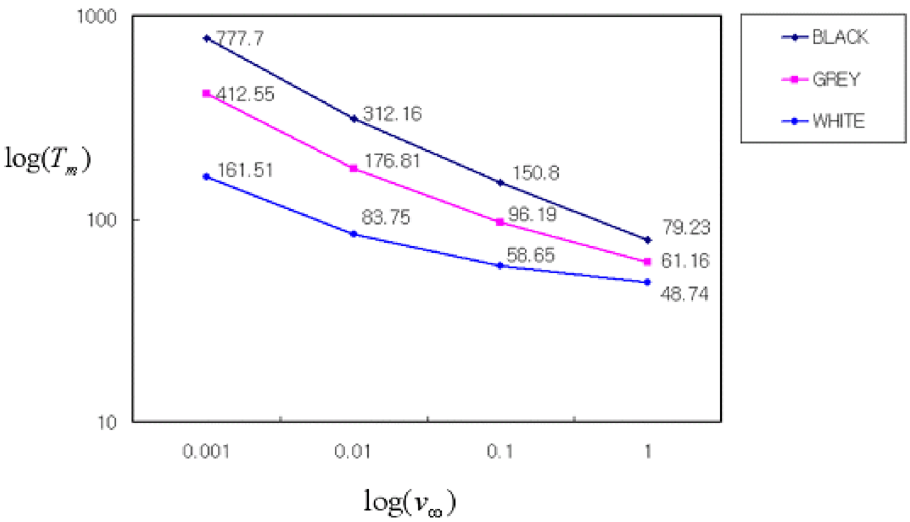

Fig. 6 Effects of air velocity on metal temperature (case#(1-1), non-insulation case)

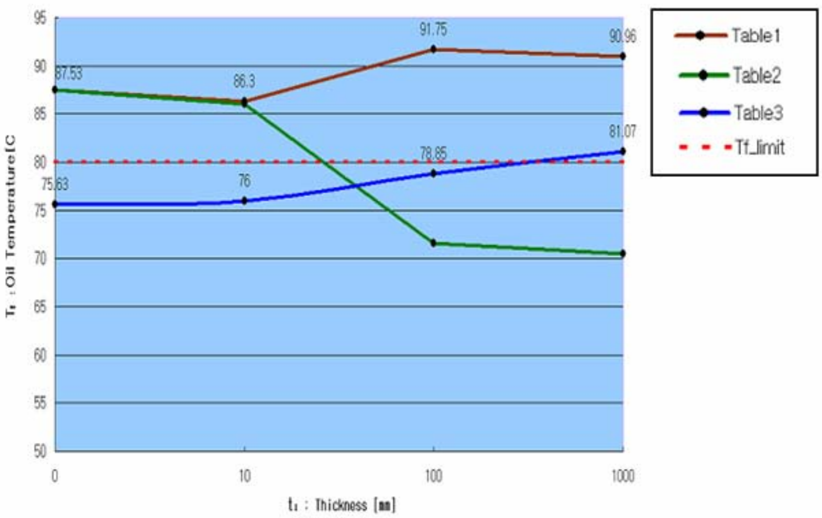

Fig. 7 Effects of insulation thickness on metal temperature (DN1000, insulation case)