

Simulation of ice formation on the gas transfer tube surrounded by a water medium

Marinyuk Boris*, Leontev Andrey and Zabugina Anna

Department of Low Temperatures Engineering named by P.L.Kapitsa, Moscow Politechnic University, Russia

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*Corresponding author:

Marinyuk Boris

Department of Low Temperatures
Engineering
Moscow Politechnic University
Russia
E-mail: marinyukb@yandex.ru

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Abstract

The growth rate of ice layer on a surface of the long tube immersed within water medium and containing cold gas flow is considered.

It was determined the layer thickness of ice forming along the tube surface as function of gas follow rate and its initial temperature. The temperature of water medium is above zero.

Keywords: Water ice, heat transfer coefficient, mass gas flow rate, ice thickness, ready made solution, water medium.

Introduction

The math model of heat and mass transfer process under formation water ice on the surface of the tube wall is suggested.

The task is actual for under water works, connected with natural gas, transferred within tube crossing water barriers in winter.

Theory

Let it consider the tube being cooled inside by natural gas, having low temperature $t_s = -45^\circ\text{C}$, water temperature T_w °C has positive level of temperature, its flow velocity don't exceed 1 m/s, heat transfer from the side of natural gas is known $\alpha_s = 300\text{W}/\text{m}^2$. The tube has no insulation protection, the tube radius is given 0,5m, mass flow rate of the gas G_s is $7,7 \cdot 10^5$ kg/s.

The heat balance differential equation can be expressed in the form

$$G_s C_{ps} d(T_s^{in} - T_s) = \frac{(T_w - T_s) \pi (D + 2\delta) l \cdot dl}{\frac{1}{\alpha_w} + \left(\frac{\delta}{\lambda}\right)_{ice} + \frac{1}{\alpha_s}} \quad (1)$$

C_{ps} – specific heat accumulation of gas, Dj/kgK

T_s^{in} , T_s – initial and current temperatures of natural gas glow, K, $T_s^{in} = 228\text{K}$

dl – elementary tube length, m

α_w – heat transfer from the side of water, $\alpha_w = 150\text{W}/\text{m}^2$ s

G_s – mass rate of natural gas, pumping inside the tube, kg/s

δ – ice thickness, m

λ – heat conductivity of ice, W/mK [1]

D – the tube diameter, m

The aim of this model is to find temperature of gas and ice layer thickness as function of the tube length. To get the result, it is necessary to draw ready made solution, which was made earlier for a case when ice thickness was determined for a flat plate put in to water medium [2]

$$\delta = -\frac{\alpha_w(T_w - T_f)\tau}{\rho L} + \frac{\lambda}{\rho L} \sqrt{\left[\frac{\alpha_w(T_w - T_f)\tau}{\lambda}\right]^2 - \frac{2\rho L(T_w - T_s)\tau}{\lambda}} \quad (2)$$

where T_f – temperature of phase changed $T_f = 273K$
 L – heat of phase changes (freezing of water into ice),
 $L=334 \cdot 10^3J/kg$

ρ – ice density, kg/m^3

If ice thickness is small enough in compare with tube radius, the use of equation (2) justified.

The joint solution of two equations gives the values of the required parameters T_s and δ .

For a long term exploitation of the tube it is of a an interest to estimate maximum ice layer thickness for a certain conditions, this can be described by a stationary – type equation.

$$q_l = \frac{T_w - T_f}{\frac{1}{\alpha_w D_i}} = \frac{T_w - T_s}{\frac{1}{\alpha_w D_i} + \frac{1}{2\lambda} \ln \frac{D_i}{D}} \quad (3)$$

Where T_w – water temperature, $T_w = 277K$

T_s – temperature of gas, $T_s = 228K$

q_l – density of the heat flux perm, W/m

$\alpha_s = 300W/m^2K$; $\alpha_w = 150 W/m^2K$

D_i – the diameter of the tube-ice composition, m

The calculation results are presented on the Figure 1. The dotted line demonstrate the character of the ice layer formation for a short period of the process. The solid line gives maximum ice thickness, m

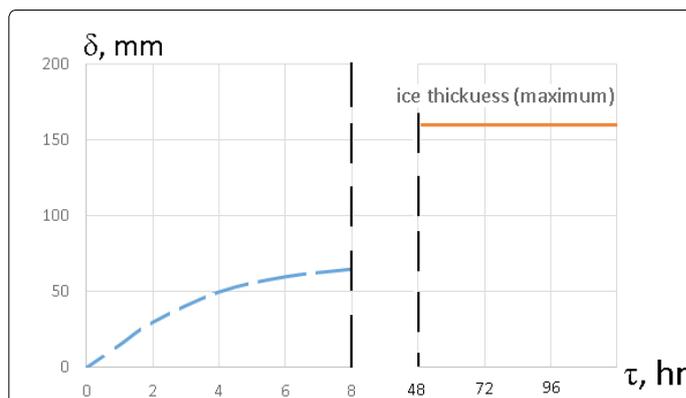


Figure 1. Maximum ice thickness on the tube surface.

Conclusion

1. Math model was composed to predict ice layer thickness and gas temperature along the length of the tube being cold from inside by a low temperature gas.
2. The estimation of maximum ice layer thickness, on the tube surface was made.
3. In winter conditions and a long term expluataion of the tube line the thickness of ice layer forming on it may reach the size compared with the tube radius.

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