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## Protective materials thermal conductivity research for heat exchanger tubes of a networking heater

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Abstract. In network heaters the tubes are exposed to negative impact of the working medium leading to their corrosion, abrasive attrition and destruction. Nowadays to cut their repair costs and to increase the efficiency of heaters in energy objects, a priority task is to recover and protect heat exchange tubes without full substitution of tube bundle, by application special protective materials on an internal surface. For repairing the tubes several protective coatings were formed, they are based on epoxide and phenol-formaldehyde resin. Same of the main characteristics of these materials are their thermal conductivity and thermal resistance. In this work the results of the got coating thermal resistance and thermal conductivity research that investigated by balance method on experimental installation are given.

#### 1. Introduction

Stainless steel tubes of heat exchanger during work are subjected to destruction. The damaged tubes reduce heat transfer in the tubes, increase the temperature drop and deficiency of the turbine work with an increase in fuel consumption.



Figure 1. Distribution of the "muffled" tubes in the sector of HNH.

When the normative number of "muffled tubes" is achieved, the whole tube bundle of the heater must be replaced, that makes the equipment repair expensive.

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The partial repair of the damaged tubes without full substitution of a tube bundle will significantly decrease the repair cost and increase the heater efficiency.

#### 2. Research objects

The partial repairing of the damaged tubes by application special protective materials is a research object and the work on materials formation was conducted in horizontal network heater (HNH).

#### 2.1. Description of HNH

HNH is intended to heating the network water for the centralized heat supply. Heating of network water to a certain temperature is due to heat of steam condensation. The tube system of HNH has radial configuration and contains 7208 9-m-long tubes. The steam is supplied into a tube streamlining its external surface, and the heated network water start moving in tubes.

HNH chosen for experiment were in work since 1986. In the explored heater 1009 damaged tubes (figure 1) from steel AISI 321 [1] were muffled.

To determine the reasons of heating surface destruction, the complex tests on the damaged tubes were conducted. Among them were the chemical analysis of the tube metal and corrosion products, a metallographic research of corrosion damage and determining the strength characteristics of metal.

As a result it has been established that the corrosion damage and the destruction of the heater tube metal happen on the mechanism of intergranular cracking (figure 2). Intergranular corrosion of stainless steels is connected with depleting the grains boundaries of chrome or forming the impurity – chrome carbides. The cause of intensive corrosion is the content of sulfur in water, which being connected with oxygen, dissolved in water, formed sulfur-containing acids, the action of which was enhanced by high temperature.



Figure 2. The cutting tube with a zone of partial cleaning and a microstructure of tube metal.

#### 2.2. The description of the developed materials

Nowadays the most effective and protective materials are based on polymer compositions [2].

In pure form, polymer coatings cannot be used for a repair of HNH tubes, because of high temperature of liquid and their low thermal conductivity. To increase thermal stability and thermal conductivity, metals, their oxides or metal alloys in a disperse form, for example, iron powder, zinc powder or aluminum powder are used as fillers.

For protection and repair of internal surfaces of HNH heat exchange tubes, including filling of corrosion ulcers, cavities and defects through tubes protective materials, resins on the basis of epoxy (coating N $^{0}1$ ) and phenol-formaldehyde (coating N $^{0}2$ ) were created. Therefore the importance of thermal stability and their thermal conductivity of a coating layer was devote.

#### 3. Measuring thermal conductivity of protective materials

Four sample of HNH tubes were used as research objects: the cleaned tube, the tube with deposit, the tube with a coating  $N_{2}$ . All tubes had outer diameters of 25 mm. The wall

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thickness ( $\delta_{wall}$ ) was determined with microscope and the specimens of tubes in various cross-sections are shown on figure 3.



**Figure 3.** Images of tube specimen : a – tube with deposit, b – tube with covering No. 1, and c – tube with covering No. 2.

#### 3.1. Research of thermal stability

During the research, various methods of thermal conductivity determination were considered [3].

When choosing a method it is necessary to consider certain propriety of the sample. The form and characteristics of the created protective materials impose certain limitation. In the work balance method of thermal stability and thermal conductivity determination on experimental stand was used.

#### 3.2. Technique of thermal stability research

The research was conducted on experimental stand (figure 4) [4]. Temperature of the external wall of the tube (1) was measured in two points over the input perimeter and in four points over the output perimeter. Temperature of the water was measured before the input and behind the output of the heated sector. Changes in temperature of liquid in the tube as a result of heating were measured by means of the differential-thermocouple, the cold junction of which located at the input, and the hot junction – at the output. The tube temperature was measured with copper-constantan thermocouples. Thermocouples were welded to the wall by spot welding through holes in the heater.



Figure 4. Scheme and general view of experimental installation:
1 – working section; 2 – condenser; 3 – regulation valve; 4 – circulating pump; 5 – flowmeter;
6 – dc power supply; 7 – thermocouple; 8, 13 – digital multimeter Fluke 8045A; 9, 10 – platinum resistivity thermometer PT-100; 11 – heat-exchange facility; 12 – multi spike chromel-alumel differential thermocouple.

To obtain data on thermal resistance of the investigated tubes the displacer with a diameter of 20 mm was installed in each tube and the liquid flow with a necessary velocity in an ring slit. The electric heater had the form of a flexible tape and reeled up on an external surface of a tube. Junctions of the differential thermocouple and the platinum resistance thermometer were setting. The signal of the differential thermocouple was measured by a digital multimeter Fluke 8045A.

During the experiment the coolant temperature was measured at the input and the output from the working section. Before experiment the thermocouples were calibrated by means of the platinum resistance thermometer. For each thermocouple installed on a wall the calibration of thermal losses was realized to determine the wall temperature of the tube.

The electrical heater input changed in range (600-650 W). The water flow was heating during passage the test section. Mass flow rate varied in range (16-55 g/s). The average flow temperature was obtained in range (2-7.5  $^{\circ}$ C) between input and output of test section.

The main dependences used for determination of thermal resistance and thermal conductivity of the investigated materials are given below.

Velocity of the liquid movement:

$$\omega = \frac{G}{S},\tag{1}$$

where G is the liquid flow rate,  $m^3/s$ , S is the section area of ring slit,  $m^2$ .

Differential temperatures between the external surface of the tube and the liquid:

$$\Delta T = T_{wall} - T_{water} = q \left( \frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} \right), \tag{2}$$

where  $T_{wall}$  is the average temperature of the external surface of the tube, °C,  $T_{water} = (T_{ex} - T_{en})/2$  is the average temperature of liquid between the input and the output from the working section, °C, and  $\alpha_1$  is the heat transfer coefficient, W/m<sup>2</sup>\*K.

When comparing a logarithmic and arithmetic mean temperature differences it was found that the difference is not more than 0.15 %. That is why, to simplify the calculations, the arithmetic mean temperature difference was applied.

Heat flux density on the tube surface:

$$q = \frac{Q}{S_{tube}},\tag{3}$$

where Q is the heat power input, W, and  $S_{tube}$  is the surface area with heat transfer, m<sup>2</sup> (calculated by the internal diameter of a tube).

$$Q = \rho G c_p dT_{water.en-ex}, \qquad (4)$$

where  $\rho$  is the liquid density, kg/m<sup>3</sup>,  $c_p$  is the liquid heat capacity, J/kg\*K,  $dT_{water.en-ex}$  is the temperature difference of the liquid at the input and the output of the working section, K.

The measured overall heat transfer coefficient from the heater to the liquid is as follows:

$$K = \frac{Q}{\Delta TS_{tube}} \tag{5}$$

Heat transfer to the liquid in a ring slit with considering initial thermal station [5]:

$$Nu = Nu_{stab} \left(\frac{\mu_{wall}}{\mu_{water}}\right) \tag{6}$$

where  $Nu_{stab} = 5.38$  is the Nusselt number at the stabilized laminar flow in a ring slit,  $\mu_{wall}$  is the dynamic viscosity coefficient of water at wall temperature, Pa\*s,  $\mu_{water}$  is the dynamic viscosity coefficient of water at liquid temperature, Pa\*s.

Heat transfer coefficient:

$$\alpha = \frac{Nu\lambda_{water}}{d_{ea}} \tag{7}$$

where  $\lambda_{water}$  is the thermal conduction of water, W/m\*K, and  $d_{eq} = d_{internal.tube} - d_{displacer}$  is the equivalent diameter of ring slit, m.

Thermal resistance of the wall of the studied tube:

$$\frac{\delta_{wall}}{\lambda_{wall}} = \frac{1}{K} - \frac{1}{\alpha}$$
(8)

where K is the measured overall heat transfer coefficient at Reynolds numbers 550, 680, 800,  $W/m^{2}*K$ , and  $\alpha$  is the measured heat transfer coefficient to the liquid, which was determined by the results of experiments on the test section.

The required value of thermal resistance of the tube was founding as an average three thermal modes with the lowest error value (the modes with the greatest temperature difference between the input and the output for water).

The measurement error was assessed on the following formula:

$$\delta \left( \frac{\delta}{l} \right)^2 = \delta K^2 + \delta K_{test}^2, \tag{9}$$

where  $\delta K^2 = \delta T_{wall}^2 + \delta T_{waler}^2 + \delta T_{in-out}^2 + \delta G^2 + \delta S^2 = (10 - 27 \%)$  is the total relative uncertainty of thermal resistance,  $\delta K_{test}^2 = (10 - 27 \%)$  is the total relative uncertainty of thermal resistance of the tube without coating,  $\delta T_{wall} = (5 - 7 \%)$  is the relative uncertainty of the external wall tube temperature measurement,  $\delta T_{waler} = (1.5 - 1.7 \%)$  is the relative uncertainty of water temperature measurement by the platinum resistance thermometer,  $\delta T_{in-out}^2 = (5 - 19 \%)$  is the relative uncertainty of the temperature difference at the input and output measured by the differential thermocouple,  $\delta G = (2.7 - 4 \%)$  is the relative uncertainty of the mass flow rate measurement,  $\delta S = (4.6 - 7.5 \%)$  is the relative uncertainty of sectional area in the ring slit measurement.

The total relative uncertainty of a thermal conductivity is ~50%. The one of the main culprits is the measurement of low temperature difference between input and output of water flow (2-7  $^{\circ}$ C).

#### 3.3. Results of research

During experiments, the data on thermal resistance of the tubes with coating at various Reynolds numbers were obtained (figure 5). Measurements were taking in areas of laminar and transient flow in a ring slit. This area was chosen because owing to the small tube length of  $\Box$  0.5 m, at large Reynolds numbers the stream ca not be heated to the temperature that can be measured by the differential thermocouple with a sufficient accuracy.



**Figure 5.** Overall heat transfer coefficient and line of approximation: 1– the cleaned tube ( $\delta_{wall} = 1.20 \text{ mm}$ ); 2 – tube with deposit ( $\delta_{wall} = 1.28 \text{ mm}$ ); 3 – tube with covering No1 ( $\delta_{wall} = 1.49 \text{ mm}$ ); 4 – tube with covering No.2 ( $\delta_{wall} = 1.28 \text{ mm}$ ).

The thermal resistance of the investigated tubes was found as an average three thermal regimes and thermal conductivity of investigated coatings was determined.

#### Conclusion

The research method was developed, the experimental setup was created and the thermal resistance of the studied tubes with coating and without coating were measured. According to results the thermal conductivity coefficient of coating No. 1 amounted to 0.91 W/m\*K, and that for coating No. 2 – to 0.93 W/m\*K. Thus, protective materials with creating thickness will not lead to essential thermal resistance and can be applied to effective repair of heat exchange tubes of various network heaters in comparison with "muffled" technology of the destroyed tubes.

#### References

- [1] State Standart 5632-2014 *The alloyed stainless steels and alloys corrosion-resistant, heatresistant and heat resisting* (Moscow: Standartinform Publ) p 16
- [2] V A Golovin, A B Ilin and et al 2003 Anticorrosive protection and repairing of the heatexchangers equipment with polymer coatings of ROKOR *Corrosion: materials, protection* vol. 7 pp 2 – 10
- [3] V A Osipova 1979 Experimental research of processes of heat exchange (Moscow: Energy) pp 30 74
- [4] V B Dzyubenko, Yu A Kuzma-Kichta and et al 2008 Intensification of heat- and mass exchange on macro-, micro- and nanoscales (Moscow: FGUP TsNIIATOMINFORM) pp 321 – 333
- [5] M A Mikheev and I M Mikheev 1973 Heat transfer bases (Moscow: Energy) pp 78 81