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VERIFICATION OF METHODOLOGY FOR DETERMINATION OF DEPOSIT THICKNESS ON HEAT TRANSFER SURFACE OF NATURAL GAS COOLERS

OVĚŘENÍ METODIKY PRO STANOVENÍ TLOUŠŤKY NÁNOSU NA TEPLOSMĚNNÝCH PLOCHÁCH CHLADIČŮ ZEMNÍHO PLYNU

Abstract

The paper describes briefly an original methodology for the determination of the deposit thickness on the inside heat transfer surface of natural gas cooler and a procedure of its verification at the cooler CH_R of the booster station KS01 in Velké Kapušany. The methodology is based on the measurement of the degree of the gas cooling. It has the universal validity and can be used to determine the thickness of the deposits of all types of coolers working on any booster station.

Abstrakt

V příspěvku je stručně uvedena původní metodika pro stanovení tloušťky nánosu na vnitřní teplosměnné ploše trubek chladiče zemního plynu a postup při jejím ověření na chladiči CH_R kompresorové stanice KS01 ve Velkých Kapušanech. Metodika je založena na měření stupně ochlazení plynu. Má univerzální platnost a lze ji využít ke stanovení tloušťky nánosu u všech typů chladičů pracujících na libovolné kompresorové stanici.

1 INTRODUCTION

The methodology for the determination of the thickness of the deposits in the pipes of the cooler developed by the authors of this contribution, details of which are described in [1], is based on the measurement of the degree of the gas cooling Δt (the difference between the temperature of the gas at the input of the cooler $t_{1,1}$, and at its output $t_{1,2}$). The degree of cooling directly depends on the current value of the coefficient of heat transmission from cooled gas into the ambient air which is significantly affected by the thickness of the deposit.

By using the original nondestructive methodology for the natural gas coolers which are installed on KS01 in Velké Kapušany, the diagrams for the determination of the current thickness of the deposit $h_{n,1}$ on the inside heat transfer surface have been set up. Shape, size and arrangement of the heat transfer surface are implicitly considered in the diagrams. In addition to the graphs for the determination of the thickness of the deposits also diagrams to determine coefficient of heat

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transmission were constructed, on which basis the cooling power of the cooler can be subsequently determined.

2 THE ESSENCE OF THE METHODOLOGY OF THE DEPOSIT THICKNESS CALCULATION

On a clean inside heat transfer surface, while volume flow rates of the gas $Q_{V,1}$ and the air $Q_{V,2}$ are constant, the degree of gas cooling between the entry and the exit of the cooler is greater than in the case of the surface with deposits. The thicker is the deposit thickness, the lower are the degree of gas cooling and coefficient of heat transmission, under the same operating conditions. The reason is the fact that the deposit has extremely high thermal resistance as its thermal conductivity, in comparison with the material of the pipe, is approximately 80-times lower.

Thermal conductivity of the deposit removed from the tube of the cooler CH_4, was experimentally determined at VŠB-TU Ostrava, the Department of thermal engineering. Its value is 0,746 W m^{-1} K^{-1}. Scheme of the measurement is in the figure 1 and the view on the experiment is in the figure 2. The methodology of the measurement and results of the experiment were published in [2].

For the purpose of determination of coefficient of heat transmission for the cooler with deposits on the inside surface, the authors derived a formula that respects the varying width of the deposit $h_{n,1}$ and the total size of the heat transfer surface. Applies

$$k = \frac{1}{\left(\frac{1}{\alpha_1} + \frac{h_{n,1}}{\lambda_{n,1}}\right) \cdot \frac{S_e}{\pi \cdot (d_1 - 2 \cdot h_{n,1}) \cdot L} + \frac{s_{ru}}{\lambda_{ru}} \cdot \frac{S_e}{S_1} + \frac{1}{\alpha_2}} \qquad (1)$$

where

$h_{n,1}$ is the deposit thickness on the inside heat transfer surface [m],

$\lambda_{n,1}$ – deposit thermal conductivity [W.m^{-1}.K^{-1}],

λ_{ru} – tube wall thermal conductivity [W.m^{-1}.K^{-1}],

S_e – total outer heat transfer surface of the ribbed tube [m^2],

S_1 – inside heat transfer surface [m^2],

d_1 – inside diameter of the tube [m],

s_{ru} – tube wall thickness [m],

L_1 – tube length [m].

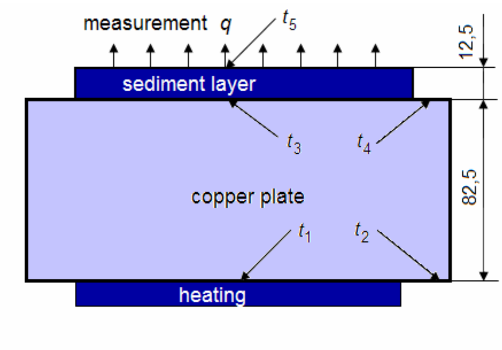

Fig. 1 Measurement schematic diagram

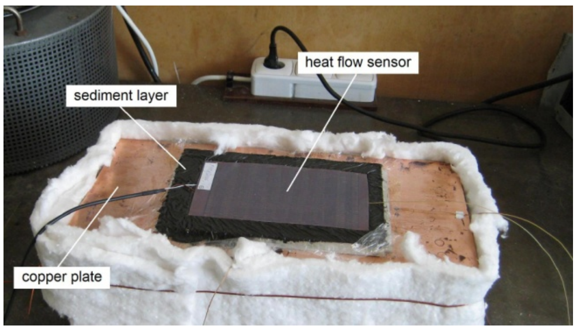

Fig. 2 Experiment

In the formula (1), the influence of the gas temperature on the value of coefficient of heat transmission k is not explicitly taken into account even if just this temperature preferably affects the coefficient. Influence of temperature reflects in the formula mainly through the heat transfer coefficient from the gas into the deposit α_1 and partly also through the heat transfer coefficient from the surface into the cooling air α_2.

The change of the transported gas temperature is an important contributor to its physical properties. For the various operating pressures p the basic physical properties of the gas in the range of temperatures from 10 to 80 °C were described by functional dependencies. On the basis of the regression curves can be, for the requested range of temperatures of the gas, determined the specific values of physical properties and those subsequently taken into a solution of the deposit thickness on the internal heat transfer surface.

3 THE CONDITIONS OF APPLICATION OF THE PROPOSED METHODOLOGY

The methodology is based on the assumption that the thickness of the deposit will be expressed as a function of the gas temperature decrease for all coolers on KS01 under the following conditions [3]:

- temperature of the ambient air will be around 15 °C at the time of the gas cooling degree measurement,
- the outer heat transfer surface of the cooler will be clean,
- pressure of gas during the measurement will be around p = 6.53 MPa,
- specified number of fans must be turned on during the experiment at each cooler,
- specified flow rate of gas will be set during the experiment.

For each type of cooler the last two conditions for the experiment were defined individually.

For cooler CH_E the conditions are the following:

- volumetric gas flow rate to be at the moment of measurement approx. $3{,}15.10^6\ m^3 \cdot h^{-1}$ (at normal conditions),
- flowing of air will be provided by 16 fans.

For the cooler CH_R:

- volumetric gas flow rate to be at the moment of measurement approx. $3{,}15.10^6\ m^3 \cdot h^{-1}$,
- flowing of air is provided by 11 fans.

For the coolers CH_5, 6, 7:

- volumetric gas flow rate to be at the moment of measurement approx. 1.05.106 $m^3.h^{-1}$,
- flowing of is provided by 7 fans.

From the proposed methodology followed dependencies of the deposit thickness and coefficient of heat transmission on the current degree of gas cooling. Dependencies are universal solutions for a range of input temperatures of the gas from 45 °C to 60 °C.

4 EXPERIMENTAL VERIFICATION OF THE METHODOLOGY FOR DEPOSIT THICKNESS CALCULATION

Any condition listed in chapter 3 plays a very important role during an experimental way of determining the thickness of the internal deposit. It cannot be unambiguously determined the condition, failure to comply with which has the most pronounced effect on its results. For example, in case of deposits on the outer heat transfer surface, even in compliance with all other conditions, the influence will be very important, because the dust coating significantly affects heat exchange with the ambient. This results in a very small decrease in the temperature of the gas during flowing through the cooler.

Clean inside heat transfer surfaces had all coolers only at the time of the entry into service. Such state matches their maximum cooling power P and the maximum value of coefficient of heat transmission k from the gas into the cooling air. After the start of operation, a slow and gradual fouling of coolers begins, which manifests itself mainly by reducing the cooling performance.

Determining the current thickness of the deposit $h_{n,1}$ for all coolers was preceded by the calculation of the cooling power P, based on the mechanism of the heat transport and the balance method. It was followed by the calculation of coefficient of heat transmission for clean inside and outer heat transfer surfaces, i.e. the maximum against which the value of k found in the operated coolers is then compared. The specific value of coefficient of heat transmission in the case of the cooler in operation is the starting point for determining the current thickness of the deposit. The thickness of the deposit is determined for each cooler by iteration procedure on the basis of the measured values of the input and output gas temperature.

Tab. 1 The parameters of the new and operated coolers

Cooler	new	operating status		
	k ($W.m^{-2}.K^{-1}$)	k ($W.m^{-2}.K^{-1}$)	$h_{n,1}$ (mm)	$h_{n,2}$ (mm)
CH_R	31,16	4,86	1,5	0,00
CH_E	25,39	6,54	0,0	0,14
CH_5,6,7	27,87	9,22	0,0	0,13

For all analyzed coolers on KS01 the calculated values of coefficient of heat transmission k and the thicknesses of deposits $h_{n,1}$, $h_{n,2}$ are shown in the table 1 For **new** coolers clean internal and external surfaces are assumed, the thicknesses of deposits are zero. In the experimental validation of the methodology in accordance with the above conditions results were obtained, shown in the table 1 in a column entitled **operating status**.

The procedure for determining the current thickness of the deposit is described in more detail in the figure 3 (for the cooler CH_R). The experiment took place under the operating pressure p = 7,177 MPa, the air temperature t_{ok} = 14,22 °C, four ventilation fans on and clean outer heat transfer surface. Standard quantity of gas was Q_V = 1 990 846 $m^3 h^{-1}$, the degree of gas cooling Δt = 8,62 K. The chart shows that the average thickness of the deposit inside of the tube was 1,5 mm.

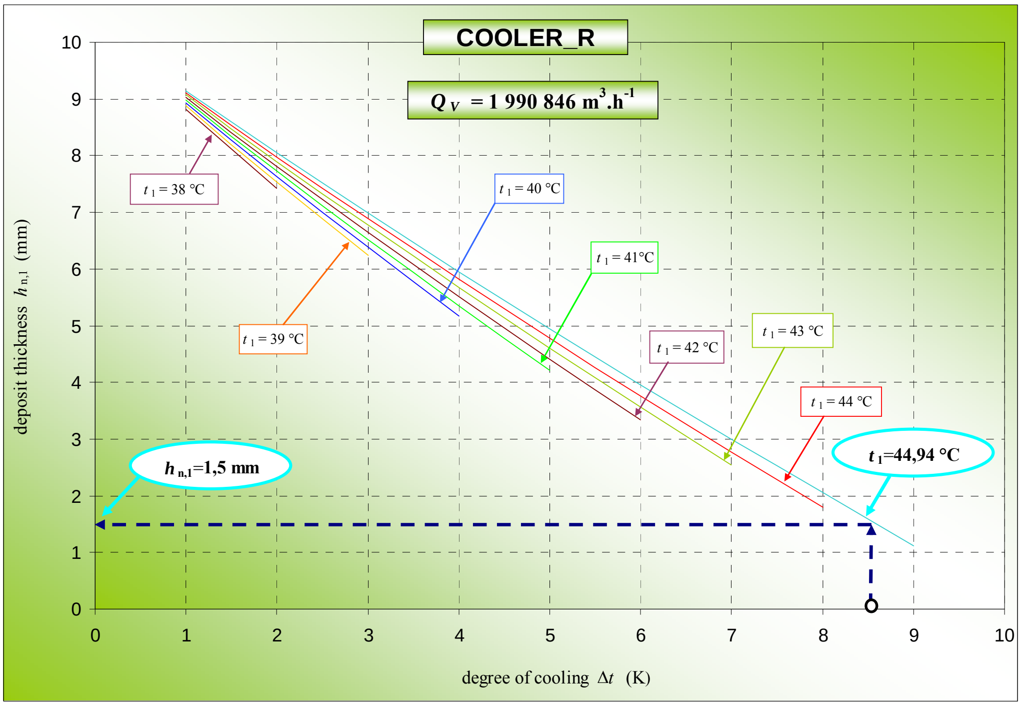

Fig. 3 Diagram for determination of inside deposit thickness

The experiment has proved that not all the conditions described in paragraph 3 can be met at normal operation for various reasons. There are e.g. unsuitable weather conditions, the request of the customer to a specific volume flow rate of the gas, low gas temperature at the outlet of the compressors etc. Therefore, the conditions were corrected in situ and for real operation are simplified to the maximum possible level.

For the determination of the thickness of the deposit in terms of universality, the conditions were then modified as follows:

- the experiment must be carried out with constant gas flow rate, which value is close to the project parameters,
- the pressure of the gas during the experiment must be constant,
- the gas will be cooled by all installed fans at a given cooler,
- the ambient temperature should not change,
- the outer heat transfer surface of the pipes and the ribs must be clean.

5 CONCLUSIONS

The methodology for the determination of the deposit thickness described in this contribution is original and applies universally for all types of coolers, working at any compressor station. For the individual cooler it is, however, necessary to plot a diagram for deduction of the deposit thickness and coefficient of heat transmission, individually, because each of them has its specific heat transfer surface and shape. The system of flowing of the media in coolers are either crossed streams or double crossed streams, which must be taken into account in the calculation of the deposit thickness through the correction factor ψ and the total heat transfer surface S_{Σ}.

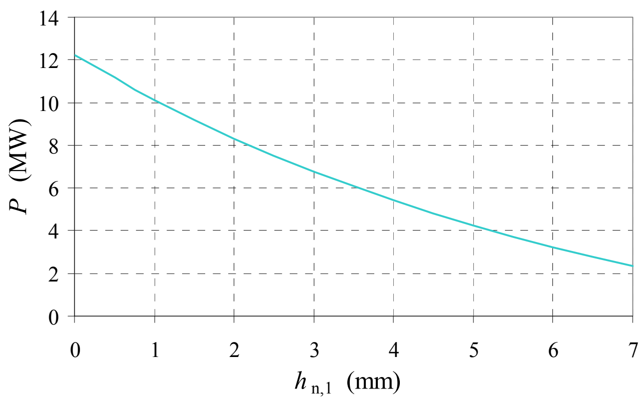

Fig. 4 Dependence of the cooling power on the thickness of the deposit

The coolers CH_5, 6, 7 at the KS01 in Velké Kapušany represent double crossed streams and the condenser CH_R has crossed streams. The other coolers CH_1, 2, 3, 4 and the cooler CH_E has double crossed streams. For each of these types of coolers the diagrams were drawn that allow easy determining the current degree of inside surface obstruction without the need for opening the coolers.

Under the operating conditions, for which the diagram in the figure 3 was drawn, coating thickness of 1,5 mm on the inside surface of the tube reduces the cooling power of CH_R by about 24,7%. The dependence of the cooling power on the increasing thickness of the deposit is in the figure 4.

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