Laboratory work No 5: Determination of heat transfer coefficient and overall heat transfer coefficient of central heating radiator using steam

1. Objective

Find the overall heat transfer coefficient U and the heat transfer coefficient h from surface to surrounding air of the central heating radiator using steam.

2. Necessary equipment

1. Radiator
2. 2 condensate containers
3. Scales
4. Manometer
5. Thermocouples
6. Stopwatch
7. Millivoltmeter
8. Thermometers
9. Barometer
10. . T-type thermocouple tables
11. Steam properties tables

3. The experimental apparatus and basics

Heat transfer from radiator heated with steam condensation to surrounding air is complicated process, where radiation, conductive and convective heat transfer exist side by side. Intensity of the process is described with overall heat transfer coefficient

$$U = \frac{1}{\frac{1}{h_1} + \frac{\delta}{k} + \frac{1}{h_2}} \quad W/(m^2\ K) \tag{5.1}$$

where h_1 – is heat transfer coefficient from steam to radiator wall, W/(m^2·K);

δ - thickness of the radiator wall, m;

k – thermal conductivity of the radiator wall material, W/(m·K);

h_2 – is heat transfer coefficient from radiator wall to surrounding air, W/(m^2·K).

Steam condenses inside the radiator and the heat released (heat of condensation) is transferred very intensely to inner surface of the radiation wall ($h_1 \approx 7000$ W/(m^2·K)). Thermal energy travels through the radiator wall with conduction ($\delta = 5$ mm; $k = 60$ W/(m·K)). Heat is transferred from radiator wall outer surface to surrounding air via convective and radiation heat transfer ant the heat transfer coefficient h_2 ($h_2 \approx 10$-12 W/(m^2·K)) that takes account both kind of heat transfer. Convective heat transfer in case of radiator outer wall is pure free convection. Radiation and convective heat transfer in the radiator case is roughly equal.

Remark! Steam is not used for heating living and working spaces nowadays anymore. It is technically more complicated and more expensive than heating with water. Steam is used in this laboratory work to enable to measure heat transfer coefficient h_2 more accurately, because of the chance to neglect the using of the value of h_1 in calculations due its large value. It's possible to measure the flow rate of the steam through the radiator through the radiator more accurately than in case of water.

The scheme of experimental setup is on figure 5.1. Radiator 1 receives steam from laboratory steam generator. Pressure inside the radiator is measured with manometer 8 connected to radiator and the pressure (flow rate) is adjusted with manometer 10 on steam inlet line. Five T-type thermocouples 9 are mounted on the outer surface of the radiator to measure the average surface temperature. Thermocouples are connected with meter 5 through rotary switch 2 witch is mounted into box. Thermometer 4 measures the cold junction temperature of those thermocouples. Switch is connected with meter with copper wires 3. Condensate is exiting from radiator via hose with glass tube in the middle. The hose connected to the bottom of the radiator. One K-type connected with meter 11 thermocouple is inside the tube to measure condensate temperature. The hose has clamp 7 to adjust the level (flow rate) of the condensate inside the glass pipe. A bowl 6 half filled with water is used to collect the condensate entering the radiator. The bowl is weighted before and after the measurements to find out how much steam condensate inside the radiator. The hose exit should be under the water level inside the bowl to avoid evaporation of hot condensate. The room air temperature is measured with several thermometers 12.

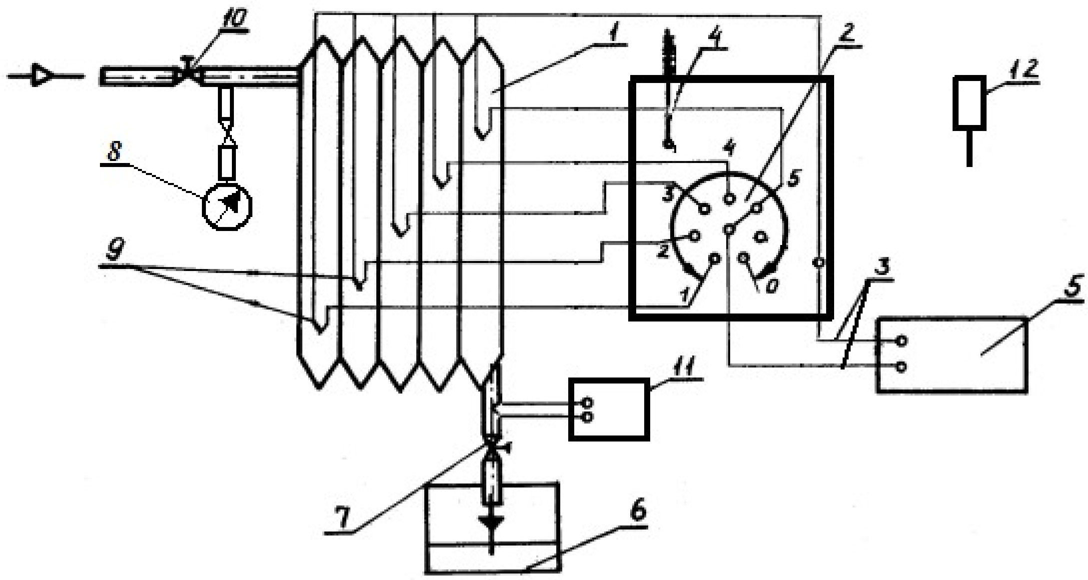

Figure 5.1. Radiator testing apparatus scheme 1 – radiator; 2 – thermocouple switch; 3 – extension cords for thermocouple; 4 – thermometer to measure cold junction temperature; 5 – millivoltmeter; 6 – bowl for condensate; 7 – condensate valve at the end of class pipe; 8 – manometer; 9 –thermocouples; 10 - steam valve; 11 – thermometer to measure condensate temperature; 12 – thermometer to measure air temperature.

4. Procedure of experiment

Procedure of experiment will be given by supervisor prior the experiment.

5. Processing of the Experimental Data

The temperature readings taken during the experiment are inserted into table 5.1. Other data under the table 5.1

Table 5.1 Table for experimental data

Time	Surface temperatures					Condensate temperature	Cold junction temperature	Room air temperature		
	1	2	3	4	5			1	2	3
min	mV	mV	mV	mV	mV	°C	°C	°C	°C	°C
0										
5										
10										
15										
20										
25										
30										
35										
40										
45										
AVG										

Duration of the experiment………………….s

Mass of the condensate bowl before the experiment……………………….kg

Mass of the condensate bowl after the experiment……………………….kg

Barometric pressure in the lab……………..mmHg

Gauge pressure inside the radiator……………..kg/cm^2

Calculate the average surface temperature of the radiator from readings of the five thermocouples and their cold junction temperature using the procedure described in Appendix A and the T-type thermocouple table in Appendix D.

Calculate the average condensate temperature and average room temperature.

Calculate the absolute pressure of the steam inside the radiator from measured gauge pressure inside the radiator and barometric pressure.

Thermal power of the radiator can be found

$$Q = \frac{m}{\tau}\left[x\Delta h_{vap} + (t_{steam} - t_{condensate})c_p\right]10^3 = \frac{m}{\tau}\left[h'' - (1-x)\Delta h_{vap} - h_{condensate}\right]10^3 \quad W \tag{5.2}$$

where m – mass of water that condensate during experiment, kg;

τ - duration of experiment, s,

χ - steam quality;

Δh_{vap} – latent heat of vaporization, kJ/kg;

t_{steam} – steam temperature inside the radiator, °C

$t_{condensate}$ – measured average condensate temperature exiting the radiator, °C

c_p – specific heat of condensate, kJ/(kg·K).

h'' - specific enthalpy of saturated steam, kJ/kg;

$h_{condensate}$ - specific enthalpy of condensate, kJ/kg.

Steam quality can be taken χ =0.9 based on experience. Latent heat of vaporization can be taken from saturated water and steam table in Appendix E based on absolute pressure of steam inside the radiator during experiment. Temperature of steam and specific enthalpy of saturated steam can be found from Appendix E based on steam pressure. Values of specific heat of condensate should be acquired from table of thermodynamic properties of water in Appendix F.

Calculate overall heat transfer coefficient from steam to air for the radiator

$$U = \frac{Q}{A(t_{steam} - t_{air})} \quad W/(m^2 \cdot K) \tag{5.3}$$

where A – surface area of radiator, m^2;

t_{air} – measured average room temperature, °C.

Surface area of the radiator is 1,15m^2.

Heat transfer coefficient from radiator outer surface to surrounding air

$$h = \frac{Q}{A(t_{radiator} - t_{air})} \quad W/(m^2 \cdot K) \tag{5.4}$$

where $t_{radiator}$ – measured average surface temperature of the radiator, °C.

Compare the result of heat transfer coefficient calculated from measurement data with theoretical value of this kind of situation found in literature.