Laboratory work No 3: Determination of the isobaric specific heat of air

1. Objective

Find the isobaric specific heat of air for certain temperature range by calorimetric method.

2. Necessary equipment

1. Pressurized air line
2. Through-flow calorimeter
3. U-tube water manometer
4. Gas flow meter
5. T-type differential thermocouple with tables
6. Millivoltmeter
7. Wattmeter
8. Thermometer
9. Variable transformer
10. Stopwatch

3. The experimental apparatus and basics

The air from the pressurized air supply system 1 flows through the calorimeter 5 made of glass. Electric heater 7 is located inside the tube. The power of the heater can be adjusted with variable transformer 11 and is measured with wattmeter 10. Glass tube is made of double walls and the space between the walls is filled with vacuum 6. The inner wall is covered with silver layer. The vacuum and the silver layer prevent the heat loss from inside the tube to surrounding environment almost entirely. Air flow through the calorimeter is measured with gas flow meter 2. Air pressure entering into calorimeter is measured with U-tube water manometer 3. The temperature of the air leaving the calorimeter is measured with thermometer 4. Temperature increase inside the calorimeter is measured with differential thermocouple 8 connected with millivoltmeter 9.

Heat in the isobaric process from temperature t_1 to t_2

$$Q = c'_{pm} V_0 \left(t_2 - t_1\right) \quad \text{J} \tag{3.1}$$

where c'_{pm} – average isobaric volumetric specific heat in range of temperature from t_1 to t_2, J/(m^3·K);

V_0 – volume of gas (air) at standard conditions (0°C and 101325 Pa) participating in process, m^3.

Isobaric volumetric specific heat

$$c'_{pm} = \frac{Q}{V_0\left(t_2 - t_1\right)} \qquad \frac{J}{m^3 K} \tag{3.2}$$

Amount of air V_0 flowing through calorimeter is measured during time period is measured along with the average power P_w of the electric heater. The average increase of the air temperature in calorimeter Δt and the temperature of air t_2 leaving the calorimeter are measured also.

The results of experiments can be compared with the results of isobaric volumetric specific heat from the literature in case of average specific heat

$$c'_{pm} = \frac{c'_{pm2}\, t_2 - c'_{pm1}\, t_1}{t_2 - t_1} \quad \frac{J}{m^3 K} \tag{3.3}$$

where c'_{pm2} ja c'_{pm1} – average isobaric volumetric specific heats in temperature interval from 0 °C – t_2 °C and 0 °C – t_1 °C. These values can be found from the tabels for specific gas.

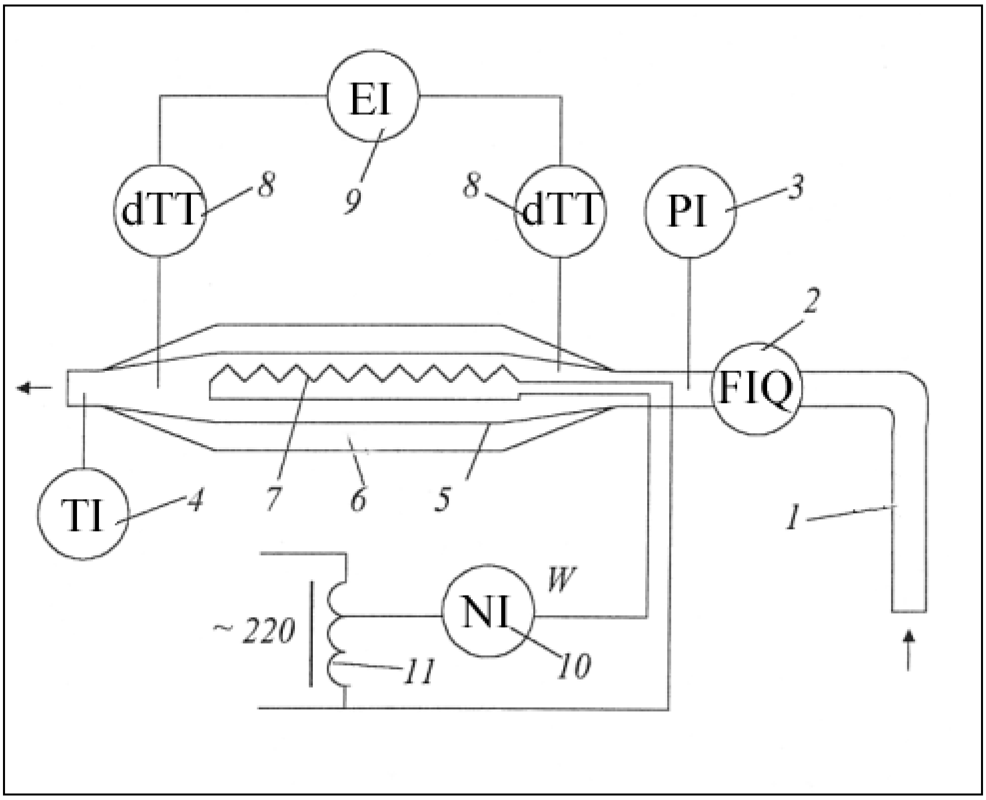

Figure 3.1. Scheme of device to measure isobaric specific heat of air: 1 – pressurized air supply; 2 – gas flow meter; 3 – U-tube water manometer; 4 – thermometer, 5 – calorimeter; 6 – vacuum inside the glass tube; 7 - electric heater; 8 – differential thermocouple; 9 – millivoltmeter; 10 – wattmeter; 11 – variable transformer.

Average isobaric mass specific heat can be calculated

$$c_{pm} = \frac{c'_{pm}}{\rho_0} \quad \frac{J}{kg \cdot K} \tag{3.4}$$

where ρ_0 – air density at normal condidtions kg/m^3, $\rho_0 = \mu/22{,}4$ kg/m^3, μ – molar mass of air μ = 28,93 kg/kmol.

Relation between isochoric and isobaric specific heat (Mayer formula)

$$c_{vm} = c_{pm} - R \quad \frac{J}{kg \cdot K} \tag{3.5}$$

where R - gas constant kJ/(kg·K).

$$c'_{vm} = c'_{pm} - R \quad \frac{J}{m^3 \cdot K} \tag{3.6}$$

where R - gas constant kJ/(m^3·K).

4. Procedure of experiment

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

5. Processing of the Experimental Data

Averages from table 4.1 are used to calculate the specific heat with formula 3.2.

Energy given to air in isobaric heating process

$$Q = Q_{electric} = P_W \tau \cdot 10^{-3} \quad kJ \tag{3.7}$$

where P_w – output of the electric heater, W;

τ - duration of the measuremet, s.

Remark: It is not entiraly correct to take the energy transferred to air equal to heat generated by heater (3.7). Actually

$$Q_{el} = Q + Q_k + Q_n \qquad \text{kJ} \tag{3.8}$$

where Q_k – energy going to increase the temperature of the parts of the calorimeter, kJ;

Q_n – loss of energy through the walls of the calorimeter into surrounding air, kJ.

Q_k and Q_n are very small and it's almost impossible to evaluate those correctly and therefore the equation 3.7 can be taken as valid. It should be taken into account only for uncertainty analysis

Volume of air at standard conditions flowing through the calorimeter during measurement

$$V_0 = \frac{273{,}15 \cdot P_1 V_1}{101325 \cdot T_1} \varepsilon = 0{,}270 \cdot 10^{-2} \frac{P_1 V_1}{T_1} \varepsilon \qquad \text{m}^3 \tag{3.9}$$

where V_t - volume of air flowing through the calorimeter during measurement measured with flowmeter, m^3;

P_1 – absolute pressure of air at the entrance into calorimeter , Pa;

T_1 – absolute temperature of air at the entrance into calorimeter , K;

ε - correction factor acquired from calibration of the gas flow meter, ε = 1,19.

$$P_1 = B + p_1 \quad \text{Pa} \tag{3.10}$$

where B - barometric pressure, Pa.

p_1 – pressure measured with U-tube water manometer, Pa.

Table 3.1 Table for experimental data

No of run	Reading	P_w	p_1	B	P_1	Δt	$\Delta t = t_2 - t_1$	t_2	Reading of the gas flow meter
	No	W	mmH_2O	mmHg	Pa	mV	°C	°C	m^3
1	1 2 3 4 5 6								At the beginning ………………… At the end ………………… Duration τ ……………….s
	Averages								Difference V_t: …………
2	1 2 3 4 5 6								At the beginning ………………… At the end ………………… Duration τ ……………….s
	Averages								Difference V_t: …………

Calculate c'_{pm} (3.2), c_{pm} (3.4), c_{vm} (3.5), c'_{vm} (3.6) and $k = c_{pm}/c_{vm}$.

Compare the results from the experiment with the values from literature.