Temperature of a gas flame

Introduction

Flame is a result of complex interactions between physical and chemical processes occurring simultaneously during combustion of fuel. It represents the reaction zone that can propagate through space at subsonic speed or can be stationary, if the burning velocity is the same as the speed of the fuel and oxidizer mixture (premixed flame) or is equilibrated with the mixing rate of fuel and oxidizer (non-premixed flame). In various combustion systems, flame is a source of heat and hot flue gas.

Temperature can be thought of as a state parameter defining system ability to transfer heat. Therefore, knowing the temperature in the combustion system is important from a heat transfer viewpoint. Due to its relation to chemical kinetics of combustion system, it reveals localization and structure of a reaction zone (flame).

Practical methods of temperature measurements can be divided into: probe thermometry, optical thermometry and specification of flame gases density [1]. The most easily available and frequently applied method is probe thermometry. Application of this method is based on introduction of probe into the flame. The probe size should be small compared to characteristic dimension of the flame. The probe should also be resistant to high temperatures. The most often used thermometer is a thermocouple. The thermocouple is a device which consists of two wires made out of two different metals. The wires are connected at one end (the measuring end) and the other ends are placed in a medium of lower temperature, for example in a thermostat. There is an electric potential difference between the two connected ends of wires whose value is proportional to the temperature difference between hot and cold ends. Moreover, the electric potential difference depends on the material used to build the thermocouple, however it does not depend on the way of making the connection (welding, torsion of wires), if the connection is done properly. There are certain advantages of thermocouple measurement technique over other methods. These include: high precision of electrical measurements; possibility of making very small thermocouples from high temperature resistant materials; data recording possibility, very low measurement error (in the range of 1-5% depending on class of device). The main disadvantages of this method are the heat losses caused by radiation of the thermocouple junction, which result in significant deviation of the measured value and the real temperature. The thermocouple placed in the flame disrupts the flow field, and possibly reaction kinetics by catalytic influence of thermocouple metals on chemical phenomena.

Aim of the exercise

The aim of this exercise is getting acquainted with a method of measurement of gas flame temperature and problems related to such measurements. During the exercise temperature distribution in the flame is measured and the influence of various factors on the temperature field in the flame are shown and discussed.

Experimental setup

The test rig used for examining the temperature of gas flame is presented in Fig. 1. In this experimental setup natural gas (or other gases like carbon monoxide or liquid natural gas) is burnt in an open, vertical flame. The air and fuel are supplied at the bottom part of the burner. Their flow rates are measured by means of two flow meters. The thermocouple joint (PtRh-Pt) is placed on a moveable handle, thereby the junction can be relocated vertically and horizontally within the flame. The electric potential difference between hot and cold ends of the thermocouple is displayed on a digital meter.

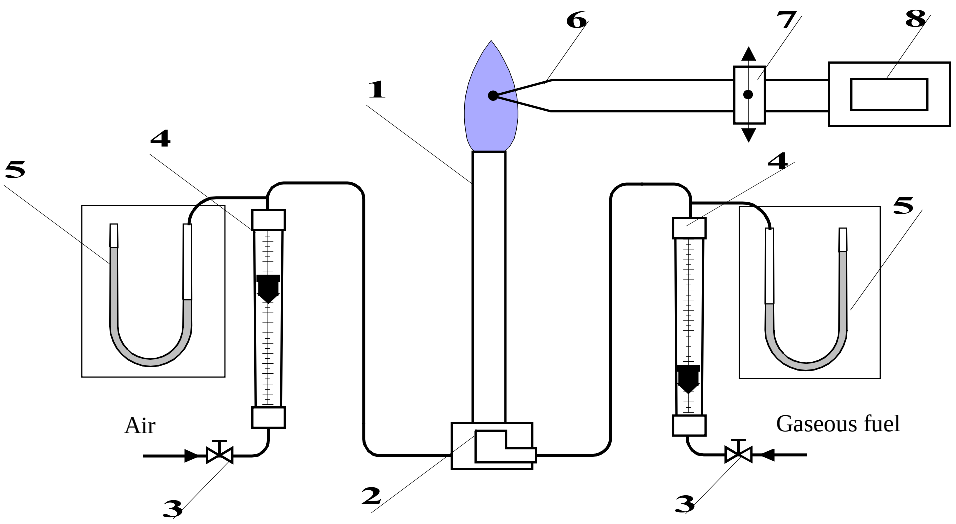

Fig.1. Scheme of the gas flame temperature measurement facility 1. gas burner; 2. mixing chamber; 3. regulating valves; 4. flow meters; 5. differential manometers; 6. thermocouple; 7. moveable handle; 8. thermocouple meter

Methodology of measurements

The aim of the exercise is to measure the temperature distribution in chosen flames along the burner axis and to examine the influence of various factors (gas and air flow, type of burners) on the measured values. Measurements should be carried out in the following order:

1). Prepare the program of measurements, that is a set of parameters for examining the flames; criterion for comparison of flames should be chosen (it can be the same thermal power or flow rate of fuel, etc.).

2). For the chosen set of flames, flow rates of air and fuel should be determined. The flow meters are calibrated for air, thus corrections for fuel flow should be made.

3). Check whether the junction of the thermocouple is located in the axis of the burner.

4). Ignite the flame and set up gas and air flow rates desired for the first measurements series. Adjust the movable handle to place the thermocouple junction at the first measurement point.

5). Note down the temperature in each point located along the flame axis. During the measurements the temperature readings should be taken only when the thermocouple joint is located inside the flame (wait out the waving of a flame caused by random movements of air).

6). Choose another variant of the measurements by adjusting the flow rates and repeat steps 3-5.

7). Measure the diameter of the thermocouple joint as well as the ambient air temperature in the laboratory.

Tip

Control stability of gas and air flow rates during the measurement. Keep a safe distance from the flame and hot parts of the experimental setup.

Analysis of the results

The temperature measured during the exercise, is in fact the temperature of the thermocouple joint located in the flame rather than the gas temperature. Deviation of measurement is a result of conduction and radiation heat transfer between flame gases and the hot junction of a thermocouple, as well as between the junction and objects surrounding the flame (walls of combustion chamber, room walls). It should be determined for all measured temperatures. Deviation of measurement can be calculated using for instance equation formulated by Kaskan. However, knowledge of additional parameters such as composition of flame gases or velocity of these gases in measurement point is required in this approximation. Estimated value of deviation of measurement can be calculated using the following formula [1]:

$$\Delta T = a \cdot \varepsilon_j \cdot \sigma \cdot d_j \cdot \left(T_j^4 - T_w^4\right) \qquad (1)$$

Where: $a = 5\ \mathrm{mK/W}$ – experimental constant for gaseous flames [2]

ε_j – emissivity of thermocouple junction. For PtRh-Pt $\varepsilon_j = 0.000106 \cdot t_j + 0.0383$

d_j – diameter of junction of thermocouple, m

$\sigma = 5.67 \cdot 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$ – Stefan-Boltzmann constant

T_j, T_w – temperature of the junction of the thermocouple and surrounding walls.

Using the Eq. (1) determine temperature in each measurement point in the flame axis and list the results in Table 1. Based on this data, plot the temperature distributions along axial distance $t_j = t_f(x)$ for examined flames. Draw conclusions from the obtained results.

Table 1. Temperature in the axis of the gas flame

Burnt gas: natural gas Flow rate of gas: m_n^3/h, Flow rate of air: m_n^3/h,		Power of burner: kW λ: $t_{ambient}$: °C		
Distance from the burner x, cm	Milivoltmeter reading U, mV	Thermocouple junction temperature T_j, K	Deviation of temperature measurement ΔT, K	Temperature in the flame T_f, K

Literature

[1] Paliwa i ich spalanie. Część V Laboratorium (R. Petela - editor), Skrypt Politechniki Śląskiej Nr 1191, Gliwice, 1989

[2] Spalanie i paliwa (W. Kordylewski - editor.), issue II, Oficyna Wydawnicza Politechniki Wrocławskiej, 1999