Freely propagating jet

Introduction

Gaseous reactants are frequently introduced into combustion chambers as jets. Chemical, thermal and flow processes that are taking place in the jets are so complex that analytical description of the jet propagation is very difficult to solve. Only the simplest cases of jets can be described by analytical and empirical relationships. Examples of such jets are free stream isothermal and non-isothermal jets. The jet has higher momentum than the surrounding fluid and it propagates in such a way that the surrounding fluid is entrained by the jet. Scheme of a freely propagating jet is presented in Figure 1.

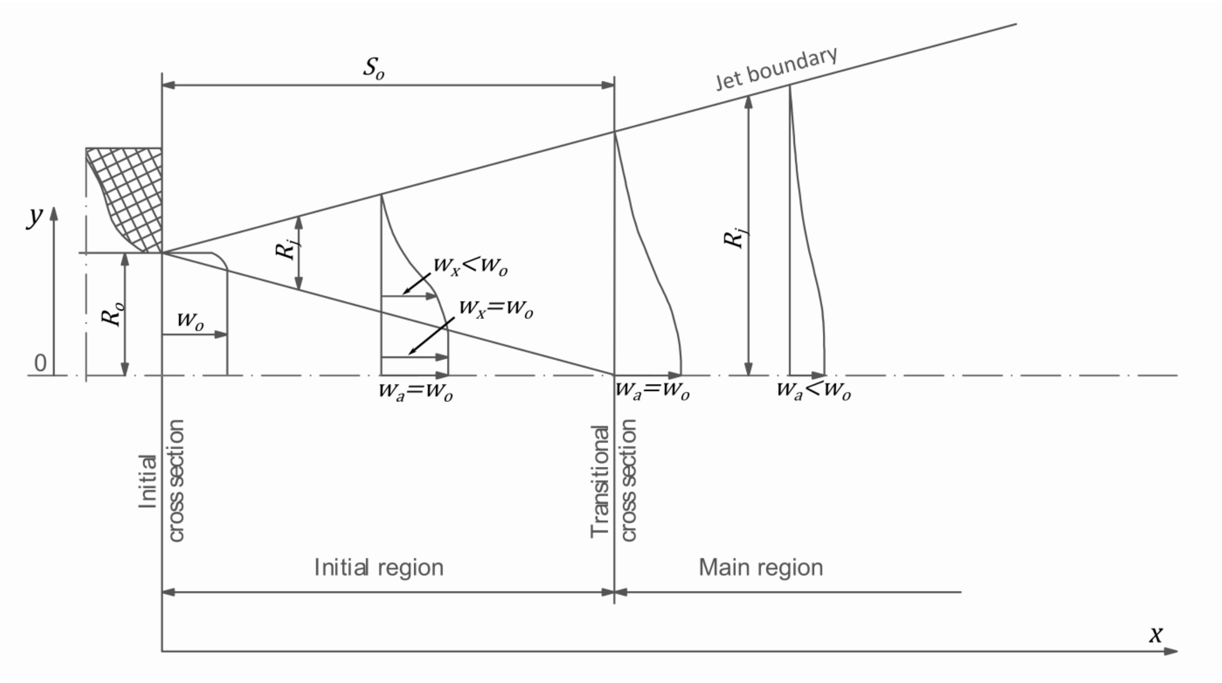

Fig. 1. Isothermal freely propagating jet

Velocity distribution in an isothermal jet is described by empirical equations [1, 2]:

$$\frac{w}{w_a} = \left[1 - \left(\frac{y}{R_j}\right)^{\frac{3}{2}}\right]^2 \tag{1}$$

$$\frac{w_a}{w_o} = \frac{0.96}{\frac{ax}{R_o} + 0.29} \tag{2}$$

where: x – the distance from the injection nozzle outlet, y – the distance from the axis of the jet for the primary section and distance from the border of the constant speed cone for the initial section, R_o – the radius of the outlet nozzle, R_j – the half width of a jet for the primary section or the width of the boundary layer for the initial section, w_a – axial velocity (at the axis), w_o – the injection nozzle outlet velocity, a – the number of the structure of a jet (0.066-0.08).

The non-isothermal jet (jet temperature different from the temperature of the surrounding medium), in addition to the velocity distribution, is also characterized by temperature distribution. Based on the analogy of turbulent heat and momentum transfer phenomena, in the non-isothermal jets the temperature surplus distribution is similar to the velocity distribution:

$$\frac{\Delta T}{\Delta T_a} \sim \sqrt{\frac{w}{w_a}} = C_1 \sqrt{\frac{w}{w_a}} \tag{3}$$

$$\frac{\Delta T_a}{\Delta T_o} \sim \sqrt{\frac{w_a}{w_o}} = C_2 \sqrt{\frac{w_a}{w_o}} \tag{4}$$

In equations (3) and (4) the indices a and o concern the parameters on the axis and in the initial cross section of the nozzle outlet, respectively, and the symbol Δ stands for the difference between the temperature at the certain location within the jet and the temperature of the surrounding medium.

The aim of the exercise

The aim of the exercise is to study the structure, size and parameters of the real jets and to verify these parameters distributions obtained from the measurements with empirical relationships outlined above.

Description of the test rig

Figure 2 shows the test stand which can be used to measure the parameters of freely propagating isothermal and non-isothermal jets. The air from the compressed air network is delivered through a reducing valve, flow meter, heater and a short metal tube into the surrounding air, where it forms a jet. Electric heater, powered by an autotransformer, heats the air flow and therefore a non-isothermal jet is formed. Moveable measurement sensor comprised of thermocouple and a Pitot tube allows measuring the temperature and dynamic pressure, and thus the velocity of gas, within the jet at selected points situated in a horizontal plane passing through the axis of the jet. The measured flow parameters can be read form the temperature gauge and micromanometer [1].

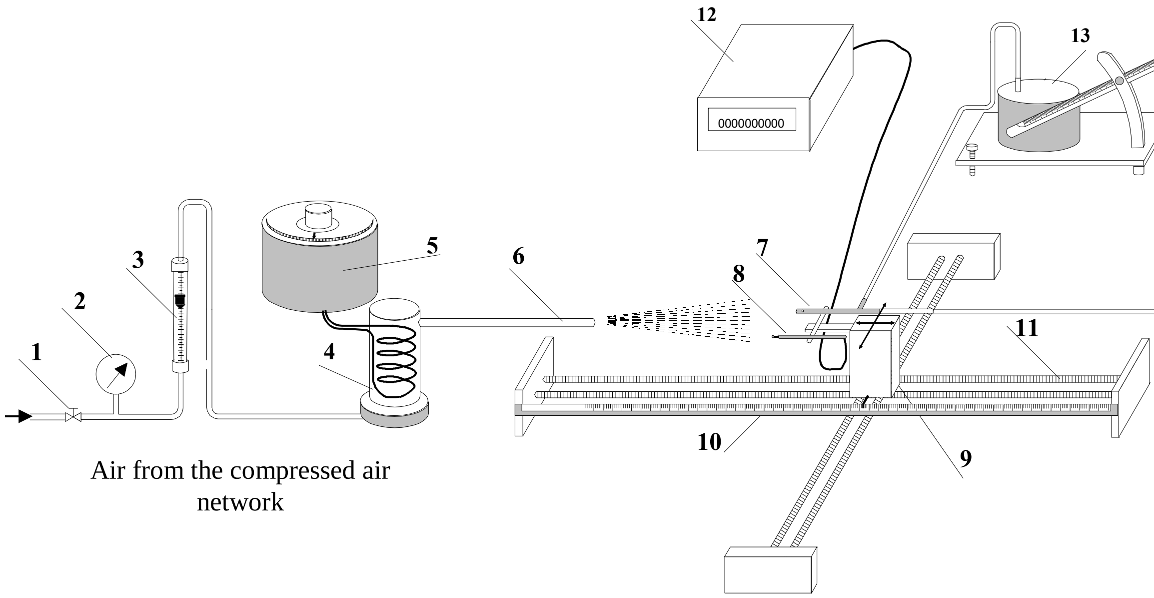

Fig. 2. Test stand for measurements of the jet parameters. 1. control valve; 2. manometer; 3. rotameter; 4. electric heater; 5. autotransformer; 6. nozzle; 7. Pitot tube; 8. thermocouple; 9. moveable base; 10. ruler; 11. rail system; 12. temperature gauge; 13. micromanometer

Gas velocity at a point, where the dynamic pressure is measured, is calculated from

$$w = \sqrt{\frac{2p_d}{\rho}} \tag{5}$$

where ρ is the density of gas at the measuring point.

Measurement procedure

After a general inspection of the test facility, the circuits and connections of measuring instruments, perform the following steps:

1) open the air control valve and (by using the reduction valve) set the air flow in such a way that the gas velocity at the outlet of the nozzle is approximately equal to $w_o \approx 15\ \mathrm{m/s}$ (it corresponds to the value of $h_d \approx 17\ \mathrm{mm}$ of liquid displacement in the manometer),
2) take measurements of the velocity values w_a on the axis at four points according to the program given in Table 1
3) Repeat the above steps for the two other speeds: $w_o \approx 20\ \mathrm{m/s}$ ($h_d \approx 30\ \mathrm{mm}$ column of liquid) and $w_o \approx 25\ \mathrm{m/s}$ ($h_d \approx 45\ \mathrm{mm}$),
4) set the air flow at a similar level to set the measurements for $w_o \approx 20\ \mathrm{m/s}$ and switch the air flow heater on (using autotransformer). The power should be set such that after determining an equilibrium thermal state, the temperature at the outlet of the nozzle will be slightly above 150°C. This can be achieved when powered heating element voltage will be approximately 90 V. Be aware that too high voltage may destroy the heating element,

5) after reaching a steady state take measurements of velocity and temperature at the outlet of the nozzle, the width of the stream R_j, velocity and temperature at the points at horizontal half-plane passing through the axis of the stream according to the program given in Table 2.

Tab. 1. The measurement results for isothermal jets.

The jet data	w_a = m/s R_j = mm Re =			w_a = m/s R_j = mm Re =			w_a = m/s R_j = mm Re =		
The distance from the nozzle outlet x, mm	h_d mm	w_a m/s	a	h_d mm	w_a m/s	a	h_d mm	w_a m/s	a
30									
60									
90									
120									

Tab. 2. The measurements results for non-isothermal jets

The jet data	$\Delta T = T_o - T_{atm}$ = K w_o= m/s				t_{atm}= °C R_o= mm			
location of measurement	R_j mm	ΔT K	h_d mm	ρ kg/m^3	w m/s	a	C_1	C_2
x_1= y = 0 y = 0,25·R_j y = 0,50·R_j y = 0,75·R_j								
x_2= y = 0 y = 0,25·R_j y = 0,50·R_j y = 0,75·R_j								

Hints

- Stability of velocity w_o during the velocity and temperature measurements inside the jet has to be ensured by maintaining stability of the float of the rotameter

- When measuring velocity at the outlet of the nozzle, make sure that the tip of the probe has not been inserted into the nozzle. This will reduce the cross-section of the outlet and cause falsification of reading. The tip of the sensor should be offset about 2 mm from the nozzle outlet.

Analysis and evaluation of the results

Based on the measurements, perform appropriate calculations according to formulae 2-4 and use the above-mentioned formulas to calculate the results by filling in Tables 1 and 2. For a given measurement point calculate the error of determining the *a* constant.

On the basis of the values of constants a, C_1 and C_2, check the degree of similarity of the velocity and temperature distributions of the examined jet. Determine the effect of Reynolds number on the obtained *a* constant.

References

[1] Spalanie i paliwa (W. Kordylewski - editor), Oficyna Wydawnicza Politechniki Wrocławskiej, Issue II, Wrocław, 1999

[2] Teoria turbulentnych strug (G.N. Abramowicz - editor), Nauka, Moskwa, 1984