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STATIONARY GAS FLOW FROM A TANK

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Abstract: *The term combustion includes a list of phenomena that have a fundamental common characteristic: it is a chemical reaction between a fuel and an oxidant. Speaking of burning gases, characteristics of physical and chemical phenomena are strongly affected by how fuel (gas) and oxidant (air) are mixed. Fixed Flames are usually divided into three classes depending on how the fuel and oxidant are combined: non-aerated, partially aerated, and fully aerated. In a diffusion flame or non-aerated, the diffusion combustion is performed by injecting into the combustion chamber unburned fuel. Alternatively, the flow of unburned fuel can be supplied with air (known as primary air), before combustion occurs. If all the air required for complete combustion is supplied as primary air, then the flame is said to be fully aired or fully premixed. If only a part of the total air required is provided in the primary air, then the flame is said to be partially aerated and the remaining air (known as secondary air) diffuses into the hot combustion gases downstream of the front flame. Moreover, in this paper we will refer to the premixed and diffused flames. These flames will be reviewed taking into account only the laminar regime, where the speed is ideally parallel to the axis of the wall with a parabolic distribution, as a function of the distance from the wall, while the pressure is a function of distance in downstream direction.*

Keywords: *composite material, liner, mechanical characteristics, canal tube.*

1. INTRODUCTION

Designers of burners for gas cookers intend to create better performing devices. However, less than complete understanding of physical phenomena has limited the innovation of burner. This section covers the main phenomena of fluid dynamics that occur during operation of domestic gas burner.

Domestic gas burner is a device partially remixed where development and homogenization of reactive mixture are due to the driving force of fuel jet exiting the injector and geometric characteristics of the burner. This flow of unburned fuel is supplied with air before combustion takes place.

However, only part of the air required for complete combustion is initially provided inside the burner: therefore the first objective of a designer of aerated burner is to provide a correct mixture of air and gas. This mixing process leads to performance of the domestic cooking device and is a key factor in the development of the burner. Therefore, a brief review of phenomena of fluid dynamics involved in the formation and homogenization of reactive process is presented in the next part.

2. NOTIONS OF GAS DYNAMICS

Notions of gas dynamics refer to the flow characterized by the following simplifying assumptions:

- Gas movement is unidirectional (along a single axis, longitudinal axis);
- Stationary (does not depend on time);
- The values of flow parameters can be considered of average value on the cross-section of the gas flow;
- Gas is perfect.

Gas flow is influenced by the compressibility thereof. Unlike liquids, where the density remains constant in the stationary movement, the gas density varies according to the section and the speed. Mach criteria reflect the influence of gas compressibility on the flow. Mach number, M, is defined as:

$$M = \frac{w}{a} \quad (1)$$

where w is - local speed of gas, $[m/s]$; a - local speed of conveyance of sound, $[m/s]$[1].

3. GAS FLOW FROM A TANK

3.1. Flow through an orifice with thin walls

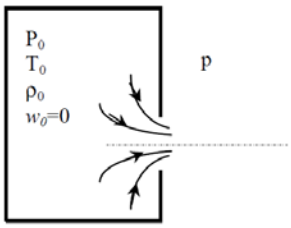


Fig.1 Gas flow from a tank through a thin-walled orifice

Features of gas in the reservoir are: pressure p_o, temperature T_0, density ρ_0, corresponding to gas in repose (speed w_0). These parameters are called parameters of stagnation. Pressure of exterior environment is denoted by p. Outdoor gas flow is considered isentropic evolution.

Gas debit, $\dot{m}$, is given by the *continuity equation*:

$$\dot{m} = \rho w A \quad (2)$$

where ρ is - gas density
w - local speed of gas, $[m/s]$
A - aria of the orifice

The (2) is the equation expressing conservation of mass of a gas in stationary movement. Pressure equation written for a point in the reservoir, where the gas is in repose, and a point outdoor of the orifice, where the speed of the gas is w, has the form:

$$\frac{k}{k-1}\frac{p_0}{\rho_0} = \frac{1}{2}w^2 + \frac{k}{k-1}\frac{p}{\rho} \quad (3)$$

where k is - thermal conductivity coefficient

This equation expresses the conservation of energy per kilogram of ideal gas moving without friction. [2]

Thus, the potential energy of the gas pressure in repose in the tank (in the left-hand expression of equality) is found in the kinetic energy (the first term of the sum of the right member of equality) and potential energy of the gas pressure (the second term of the sum of the right member) out of the tank. The equation shows that along a gas flow in the section where the pressure increases, the speed decreases, and vice versa.

Law of isentropic transformation:

$$\frac{p}{\rho^k} = \frac{p_0}{\rho_0} \quad (4)$$

The above equations lead to Saint Venant equation for mass flow rate of gas of the tank:

$$\dot{m} = \alpha A\sqrt{\frac{2k}{k-1}\left(\frac{p}{p_0}\right)^{\frac{2}{k}}\left[1-\left(\frac{p}{p_0}\right)^{\frac{k-1}{k}}\right]} \quad (5)$$

Where α is - flow coefficient that takes into account the losses α < 1; A - Orifice area.

Studying the above relation, regarded as a function of a single variable [3]

$$\dot{m} = f(p) \quad (6)$$

It may reveal the character of the gas flow through the orifice: subsonic or sonic.

We assume that initially, the external pressure is equal to the inner pressure:

$$p = p_o \quad (7)$$

Obviously, in this case no gas is coming out, so the flow is null $\dot{m}=0$.

In the event the external pressure decreases, gas flows from the tank, being accelerated from speed $w=0$, in recipient, to a certain speed, $w<a$, in minimum section of gas flow. Minimum section, A_{min} is not the orifice. It is located immediately downstream of the orifice, since, due to inertia, the gas stream continues to contract even after it came out through the orifice, as suggested by lines shown in Figure 1.

The flow is subsonic, characterized by the Mach number, $M<1$. Mass flow rate depends on internal pressure and external as well.

Continuing to diminish the external pressure, while the parameters of the gas in the container do not changes the flow rate increases.

Setting aside the first derivative of this function is obtained a value of external pressure, called critical pressure, p_{cr}:

$$\frac{p_{cr}}{p_0} = \left(\frac{2}{k+1}\right)^{k/k-1} \qquad (8)$$

where the maximum debit is reached, m_{max}.

Therefore, when external pressure reaches critical value, mass flow rate is maximum and flow in the minimum section (called critical section) becomes critical (sonic).

In the minimum section of gas flow, A_{cr}, speed, pressure, density and temperature take critical values, denoted by index "$_{cr}$", while $M=1$. Critical speed, w_{cr} is:

$$w^2_{cr} = kRT_{cr} \qquad (9)$$

where R is gas constant [J/kg.K].

Maximum debit is given by:

$$m_{max} = \alpha\left(\frac{2}{k+1}\right)^{\frac{1}{2}\cdot\frac{k+1}{k-1}}\sqrt{k}\,\frac{A\cdot p_0}{\sqrt{RT_0}} \qquad (10)$$

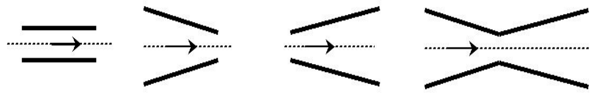
Resulting that, *the maximum flow rate does not depend on the value of external pressure, but only on the parameters of the flow upstream of the orifice (p_o ,T_o).* [4]

Further lowering the external pressure, mass flow rate remains constant, at the maximum value, regardless of the value of this pressure. Flow is called blocked. Flow parameters remain at critical values in the minimum section.

3.2 Flow through a nozzle

Nozzles are pipes of reduced length. The most common are:

- Straight nozzles, which have a constant cross-section;
- Converging nozzles, which have a cross section decreasing in the flow direction;
- Divergent nozzle, where the cross-section is increasing in the direction of flow;
- Convergent - divergent nozzle, consisting of a convergent nozzle continued with a divergent one.



a) b)
c) d)

Fig.2 Common type of nozzles:
a)straight; b)convergent; c)divergent; d)convergent-divergent (Laval)

A gas at rest can be accelerated to a speed equal to the local speed of sound, $M=1$, when gas passes through a convergent nozzle, if the external pressure is lower than the critical one and the minimum section is of critical value. [5]

When passing through the Laval nozzle, a gas started from rest can be accelerated up to M=1 in a minimum section, when the section has the minimum critical value. Furthermore, the nature of the gas flow through the diverging section of Laval nozzle depends on outside pressure:

- if the external pressure is greater than the critical one, the flow is subsonic, in which case the rate decreases and the pressure increases;

- if the external pressure is lower than the critical one, flow develops supersonically, in which case the gas rate further increases and the pressure decreases.

A gas at rest at the entrance of a straight or a divergent nozzle cannot be accelerated to critical values. Subsonic flow is maintained.

4. THE EJECTOR

The ejector is a device that uses the energy of a high pressure fluid, *working fluid,* to drive through the mixing, another lower fluid pressure, *fluid ejected*. The ejectors are subsonic, if the working fluid is accelerated through a convergent nozzle (Figure 3) or supersonic, if accelerated through a Laval-type nozzle (convergent-divergent).

Be the working fluid pressure, p1 and ejected fluid pressure, p_2. Accelerating the working fluid when passing through convergent nozzle decreases its pressure to the value p_3 in the mixing chamber (3):

$$p_3 < p_2 \qquad (11)$$

Following the pressure difference (p_2-p_3), fluid 2 is drawn into the mixing chamber (3). The two components, if they do not react chemically, come to form a mixture that is emptied through the distributor (4).

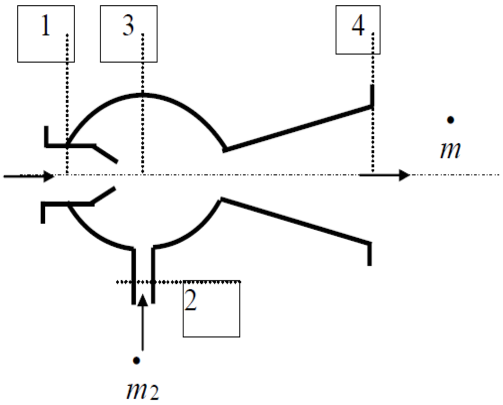


Fig.3 Sketch of a subsonic ejector: 1. convergent nozzle; 2.suction pipe of ejected fluid; 3. mixing chamber; 4.divergent nozzle for mixture discharge

The final state of the mixture out of the distributor is characterized by specific enthalpy and entropy given by the system:

$$\begin{cases} \dot{m} \cdot h = \dot{m}_1 \cdot h_1 + \dot{m}_2 \cdot h_2 \\ \dot{m} \cdot s = \dot{m}_1 \cdot s_1 + \dot{m}_2 \cdot s_2 \\ \dot{m} = \dot{m}_1 + \dot{m}_2 \end{cases} \qquad (12)$$

Where $m_{1,2}$ is mass flow rate of the working fluid, respectively of ejected fluid; $h_{1,2}$ - Specific enthalpy of the working fluid, respectively of ejected fluid; $s_{1,2}$ - Specific entropy of the working fluid, respectively of ejected fluid; m - Mixture debit.

In diagram h-s in figure 4, theory point of mixture A is on the right 1-2 splits it into segments proportional to the mass participation, g_i:

$$g_1 = \frac{h_1 - h_A}{h_2 - h_1} = \frac{s_1 - s_A}{s_2 - s_1} \qquad (13)$$
$$g_2 = \frac{h_A - h_2}{h_2 - h_1} = \frac{s_A - s_2}{s_2 - s_1}$$

In the system (13) the notations are: mass participation is defined as the ratio of the mass of component *i* of the mixture, m_i, and the total mass of the mixture, m:

$$g_i = \frac{m_i}{m} \qquad (14)$$

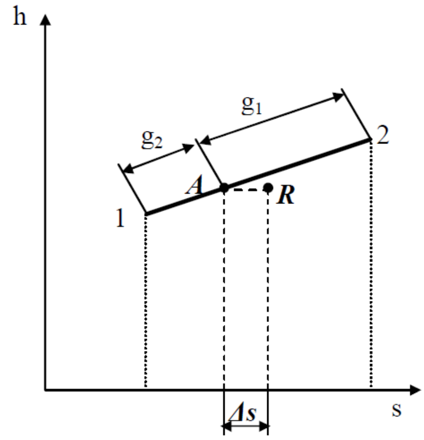


Fig.4 Diagram h-s to determine the theory point of mixture, A

The actual point of the mixture, R, takes into account the fact that during the mixing of the gaseous components, the entropy increase by Δ, and the enthalpy remains constant [6].

In figure 5 are presented the processes taking place into the ejectors. Working fluid pressure decreases from value p_1 to p_3 by real transformation 1-1'$_r$ (theory transformation is denoted 1-1').

Ejected fluid pressure p_2 lowers to p_3 through real transformation 2-2'$_r$ (theory transformation is 2-2'). Status 3, characterised by pressure p_3, is the status where the mixture is created.

Created mixture flows through the ejector distributor which undergoes a compression.

So, the pressure increases and speed decreases. It means that the kinetic energy of the gas stream is converted into potential pressure energy.

The compression process occurs theoretically after the reversible adiabatic 3-4 and in real, after polytrophic 3-4$_r$. [7].

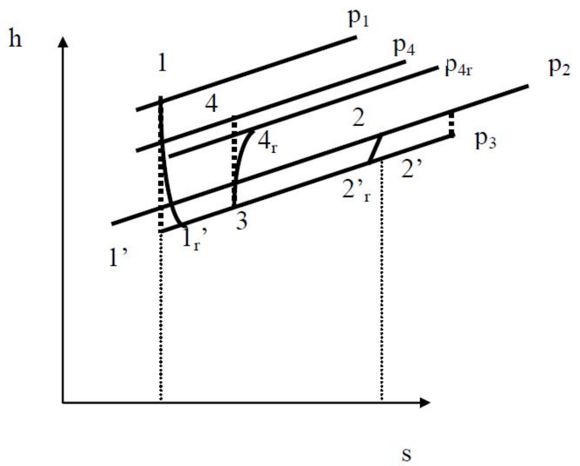


Fig.5 Diagram h-s for processes taking place into the ejector (index r for real status)

The size of the ejector is characteristic of a coefficient of ejection, which is defined as the ratio between the flow rate of the ejected fluid and the flow of the working fluid:

$$s = \dot{m}_2 / \dot{m}_1 \quad (15)$$

Ejection ratio is the amount of entrained low pressure gas per kilogram of working gas [***].

5 CONCLUSIONS

The flow of gas is considered to be turbulent, in this case we are in the quadratic flow regime (Moody chart) so that the coefficient of linear load loss of Darcy is constant: $\lambda = ct$.

In the divergent nozzle side the pressure falls below the critical pressure depending on the section of that point, so that, for the pressure in the exit section to be equal to the pressure outside, the section in that point must have a deducted value of the output equation.

Moreover, there is no need to refer to external pressure, but to a certain one of the divergent section, which is under critical pressure and is imposing the value of section in that point.

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CURGEREA STAȚIONARĂ A GAZELOR DINTR-UN REZERVOR

Rezumat: *Curgerea gazului este considerată turbulentă şi în acest caz ne găsim în regimul pătratic de curgere (din diagrama lui Moody), astfel încât coeficientul de pierdere liniară de sarcină a lui Darcy este constant: λ = ct. În partea divergentă a ajutajului, presiunea coboară sub presiunea critică în funcție de secțiunea din punctul respectiv, astfel încât, pentru ca presiunea în secțiunea de la ieşire să fie egală cu presiunea din exterior, trebuie ca secțiunea în acelaşi punct să aibă o anumită valoare dedusă din ecuația debitului.*

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