U.P.B. Sci. Bull., Series B, Vol. 69, No. 4, 2007 ISSN 1454-2331

OBTAINING AND CHARACTERIZATION OF RADIANT FLAMES IN GAS FUELS BURNING

Victor GEANTĂ[1], Vasilica DINA[2], Ionelia VOICULESCU[3], Radu ŞTEFĂNOIU[4], Ion CIOACĂ[5]

Lucrarea face o sinteza a rezultatelor, ca urmare a unor cercetari teoretice si practice, privind arderea combustibililor gazosi, cu autocarburarea flacarii. In acest scop s-a realizat un stand de incercari si un tip de arzator adecvat, in trei variante dimensionale, pentru stabilirea, prin experiment, a conditiilor optime de generare si control a autocarburarii flacarii, rezultata la arderea combustibililor gazosi, care contin compusi cu C. S-a efectuat un numar foarte mare de experimentari, in conditii variabile, privind debitul de gaz, raportul debit gaz/debit aer, excesul de aer.

The paper presents the results of a number of experimental researches to test a burner model in order to define the self-carburizing process at gas fuels combustion. A laboratory stand and several burners with ring-shaped flame holders were designed and a large number of experimental regimes have been tested, where the natural gas flow, combustion air flow and air excess are variable.

Keywords: gas fuel, burning, flame, self-carburizing, burner.

1. Introduction

The use of gas fuels as a thermal source in the thermal-technological processes is very developed due to the known advantages. So the constant concern for scientific researches to identify the optimum conditions for gas fuels burning process is justified. For this reason, it is necessary to expand the fields where the gas fuels (especially natural gas) are efficiently used. The design and construction of new combustion installations and the elaboration of new burning process conditions are the main research objectives [1, 4].

[1] Prof., Dept. of Engineering and Management of Metallic Materials Elaboration, University "Politehnica" of Bucharest, Romania
[2] Prof., Dept. of Materials Processing and Eco Metallurgy, University "Politehnica" of Bucharest, Romania
[3] Prof., Dept. of Materials Technology and Welding, University "Politehnica" of Bucharest, Romania
[4] Lecturer., Dept. of Engineering and Management of Metallic Materials Elaboration, University "Politehnica" of Bucharest, Romania
[5] Eng., Dept. of Design , S.C. ROMTOROIDAL S.A., Bucharest, Romania

The national and international studies and experimental researches focused on the combustion process and specific installations, include the self-carburizing combustion mechanism, the positive effects on the combustion efficiency and the decrease of gaseous emission (especially *NO* and NO_x). The selection of self-carburizing optimal method and the optimal burner type are the final aim of these researches [5,6].

2. Theoretical aspects

The self-carburizing process develops at a certain level for the gas fuels, since the gas fuels have the carbon tied on the various chemical forms (hydrocarbons). The carburizing process can be increased by burning in gas fuel, in special conditions, without external contribution in C or other solid particles. For both situations, the cracking phenomenon is specific.

By the use of self-carburizing technology, it is aimed to obtain other economic advantages, such as:

- increase of the thermal transfer intensity from the flames to the receiver surfaces of the furnaces, at sole combustion of natural gases; this contributes to diminishing the negative effect caused by the useful energy transfer reduction, when liquid fuel (oil fuel) is replaced by gaseous fuel (natural gases) in the energy installations;
- reducing the combustible elements content in the burned gases evacuated from the combustion chamber by using gas fuels with excess air equal or close to the stoechiometric one;
- reducing the energy necessary for supplying the combustion air at parameters characteristic for the rotational combustions in the classic burners;
- using less refractory materials for building up the combustion chambers of the furnaces with classic burners.

With the constructive solution proposed for the new burners, both the successive combustion of the gaseous and liquid fuels combustion and the simultaneous combustion, in any proportion, are possible. The chosen proportions are those the beneficiary desires or those imposed by technical deficiencies occurring at natural gases supply or at liquid gas (oil gas) stocking and combustion preparation. For the classic burners, the gas fuels combustion develops without a preliminary preparation to increase the total flame darkness coefficient, ε_t that would influence favorably the energy transfer through radiation. Therefore, the darkness degree of the flames is determined solely by the tri-atomic gases' presence in the flame (water vapors and carbon dioxide); these gases radiate and absorb the energy at specific bands of the radiation spectrum, more exactly in the invisible field, thus the flames are clear.

The darkness coefficient of the clear flames for which the radiation is given only by the tri-atomic gases can be analytically calculated using the Buger – Bähr relations [1, 2]. The combustion technology at the classic burners using natural gas determines a clear, low radiant flame, with a total darkness coefficient $\boldsymbol{\varepsilon_t = 0.4}$. This value is inferior to the one obtained at oil fuel combustion, that has a value of $\boldsymbol{\varepsilon_t = 0.8}$. Following the reduction of the flame darkness coefficient, at the transition from the oil fuel combustion to the natural gas combustion, there is a decrease in the radiation heat transfer towards the boiling pipes in the combustion chamber furnace, thus reducing its power.

By the new burning technology and new burners respectively, the total flame darkness, $\boldsymbol{\varepsilon_t}$ can be increased by the self-carburizing of the flame.

The self-carburizing process requires a two-stage combustion:

- during the first stage, in the ring-shaped jet, approximately 50 ÷ 60 % of the gas fuel which flows through the burner is being combusted completely and rapidly (for a given capacity in the burner's control range). This phenomenon is due to a high air excess ($\boldsymbol{\lambda_a \approx 1,8 \div 2}$) (highly oxidizing flame) and to the rapid and uniform mixture of the fuel in the combustion air. From this first combustion stage, a short, clear and medium – temperature flame (high excess air) emerges, able to heat up both the burner's ceramic part (up to 1000 ^{0}C) and the fuel in the central jet , that has not been involved in the combustion process yet. The same type of combustion also occurs in the recirculation currents that appear downstream the flame holder;

- during the second stage, the dissociation products in the remaining gas fuel (40 ÷ 50 %) are being combusted completely; the gas fuel is introduced in the combustion chamber under the form of an axial jet.

By the self-carburizing process, the high quantities of free carbon solid particles are produced in the flame, as a result of the hydrocarbons' thermal decomposition in carbon and hydrogen. This process depends on the following factors [1]:

♦ the physical-chemical properties of the gas fuels, determined in the first instance, by the C/H ratio in the fuel;

♦ the excess air coefficient value, $\boldsymbol{\lambda_a}$;

♦ the mixture conditions between gas fuel and combustion air;

♦ the flame temperature (the increase of temperature determines a more intense cracking process);

The heat quantity released by the flame radiation, $\boldsymbol{Q_f}$ is given by relation:

$$Q = \varepsilon_t \cdot C_o \cdot S \cdot [(T_f/100)^4 - (T/100)^4],\ W \qquad (1)$$

where: ε_t – is the total flame darkness degree (it depends on the fuel quality and varies between 0.2 ÷ 0.85);
C_o – the emission coefficient of the completely black body, in W/m^2K^4;
S – the equivalent radiation surface, in m^2;
T_f – the flame average temperature, in K;
T – the average temperature of the heated surface, in K.

The adiabatic temperature and the average flame temperature, T_f are controlled by the fuel quality. The ***C/H*** ratio provides preliminary information on the flame's radiating capacity and the adiabatic temperature. By additional constructive and functional measures, adopted at the design and construction of gas fuel burners (especially natural gas), the flame darkness coefficient, ε_n and total flame darkness coefficient, ε_t can be enhanced through self-carburizing.

3. Results and discussion

In order to analyze the self-carburizing processes of flames resulting from natural gas combustion, a laboratory stand was designed; its configuration is showed in Fig. 1. On the laboratory stand, three types of devices generating radiant flames by self-carburizing (laboratory burners) have been investigated; their angle of beam spread was of 10^o, 20^o and 30^o.

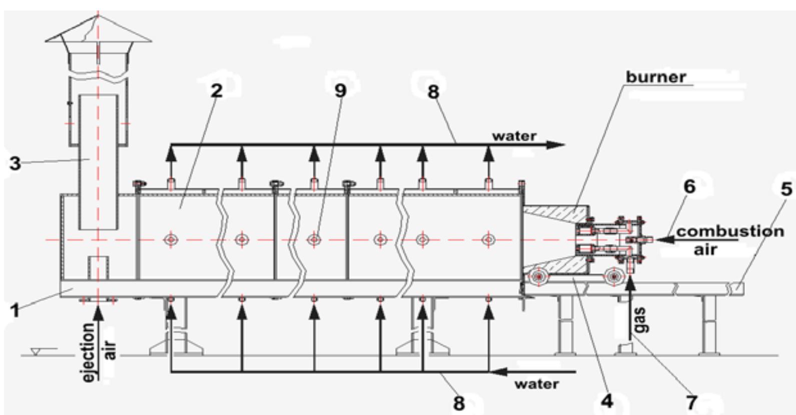


Fig. 1. Laboratory experimental installation (constructive design):
1 - carcass; 2 – flame cooling sector; 3 –burned gases ejection area;
4 – burner support wagon; 5 – wagon support; 6 – air combustion installation;
7 – natural gas installation; 8 – cooling water installation;
9 –work orifices (for measuring the flame parameters).

The flame stability was achieved with the help of a ring-shaped holder, in three constructive forms of the following characteristic dimensions: Φ_{ext} / Φ_{int} = **Φ120/Φ40; Φ110/Φ50** and **Φ104/Φ56.** On the flame holders, one can install sets of nozzles with various outlets for the axial flow of the natural gas.

Throughout the experiments, the three holders are introduced consecutively inside the burner, in order to obtain various flow sections of the combustion air through the ring-shaped spaces in the burner's end zone. By combining the component parts of these three flame holders (for each having the possibility to adjust the dimensions of the natural gases flow sections in seven versions) and three combustion chambers, more working regimes were obtained.

The experimental study consisted in running 140 experimental regimes for which the natural gas consumption ranged between ***4.1÷16.7 Nm³/h***, the injected airflow between ***50 ÷169 Nm³/h***, the excess air, λ_a between ***0.4 ÷ 3.42.***

The proportion of natural gas, injected through the axial nozzles of the three flame holders, subjected to cracking was ***13 ÷ 40 %*** of the total gas volume. The natural gas speed in the flame holders' nozzles ranged between ***6.05 ÷ 46.85 m/s***, and the combustion air speed between ***1.95 m/s ÷ 13.63 m/s.***

Table 1 presents a summary of the 16 versions of experimental researches, where:

- V_{gaz}, V_{aer} is the gas and combustion air flows, in Nm^3/h;
- w_{gaz}, w_{aer} - gas and combustion air speed, in m/s;
- S_r – the gas flow radial surface, in m^2;
- $S_{g.\,t}$ – the gas flow total surface, in m^2;
- λ_a – excess air coefficient;
- α – burner's angle of beam spread,
- d_e – the holder's exterior diameter, in mm;
- d_i – the holder's interior diameter, in mm.

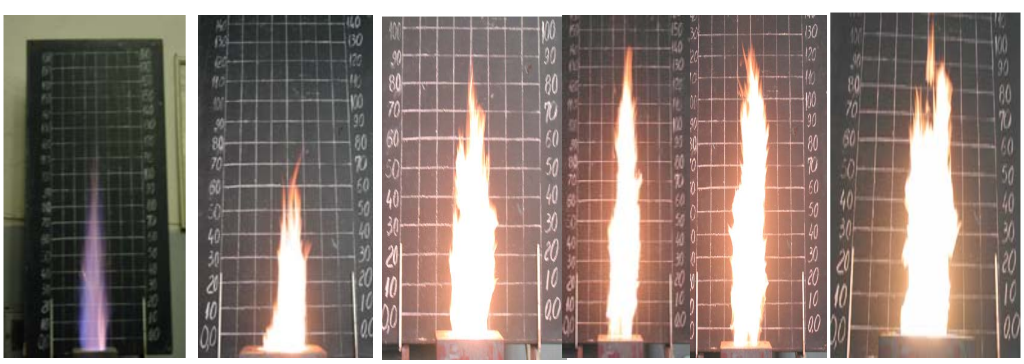
In the first experimental stage (free flame regions) the visual characteristics of the visible self-carburizing flames (shape, length and radiation), for all 140 experiments presented in Table 1, were photographed. For this purpose, over 550 photographs were taken. Out of these images, 414 were considered representative for the experimental program. Fig. 2 presents a few types of thoroidal, ring-shaped radiant flames.

The second experimental stage consisted in the combustion on the system *tunnel-burner* – presented in Fig. 3 – flame characteristic parameters were measured. The following: *the flame temperature in axis and at the interface flame – wall tunnel, on the length of flame, temperature and chemical composition of exhausted burned gases.* The flame total darkness degree value, ε_t, depending on the medium mixture temperature, T_m, (between natural gas and burned gases from tunnel) was established.

Table 1.

The experimental research on the laboratory stand

No. crt.	No. exp.	V_{gaz}, Nm^3/h	V_{aer}, Nm^3/h	w_{gaz}, m/s	w_{aer}, m/s	$S_r / S_{g\,t}$	λ_a	α, ^{0}	Holder' radial width, $(d_e-d_i)/2$, mm
1	6	7÷12	75–169	26.85÷46.1	2.88÷9.59	0	1.13÷1.48	10	24
2	3	4.1÷12.9	110÷162	10.2÷32.1	4.22÷6.2	0.35	1.32÷2.82	10	24
3	12	2.5÷13.4	50÷161	6.05÷32.45	1.95÷6.41	0.37	1.18÷4.9	10	24
4	6	5.2÷12.1	85÷161	19.95÷46.42	3.26÷6.17	0	1.17÷1.72	10	24
5	10	6.2÷14.5	102÷161	12.9÷36.1	3.91÷6.17	0.13	1.14÷3.23	10	24
6	7	11.7÷14.2	54÷160	35.64÷43.25	2.07÷6.14	0.21	0.4÷1.4	10	24
7	10	9.3÷14	111÷158	22.9÷33.87	4.26÷6.06	0.37	0.95÷1.73	10	24
8	10	7.5÷13.6	69÷159	20.1÷36.43	5.95÷13.7	0.38	0.77÷2.21	10	40
9	9	6.1÷14	71÷158	20.41÷46.85	4.14÷13.6	0.27	0.78÷1.76	10	40
10	12	4.8÷14.8	77÷159	12.47÷38.46	6.6÷13.7	0.40	0.74÷2.37	10	40
11	12	5.9÷15	48÷158	8.97÷22.82	4.14÷13.6	0.31	0.84÷2.77	10	40
12	12	6.1÷14.8	74÷158	9.29÷22.7	6.38÷13.6	0.32	0.72÷2.73	30	40
13	9	7.7÷16.7	94÷162	12.82÷27.79	5.42÷8.95	0.25	0.59÷2.2	30	30
14	10	6.4÷15.8	72÷162	10.65÷26.3	4.26÷8.95	0.25	0.7÷2.58	20	30
15	10	6.4÷15.9	81÷163	10.65÷6.13	4.48÷9.9	0.25	0.54÷.68	20	30
16	10	5.5÷16.1	53÷163	8.32÷26.8	2.93÷9.9	0.25	0.63÷3.42	20	30



(a) **(b)** **(c)**

Fig. 2 – Few examples of experimental radiant flames:
a – transparency (without free C); b – normal self-carburizing;
c – intensive self-carburizing.

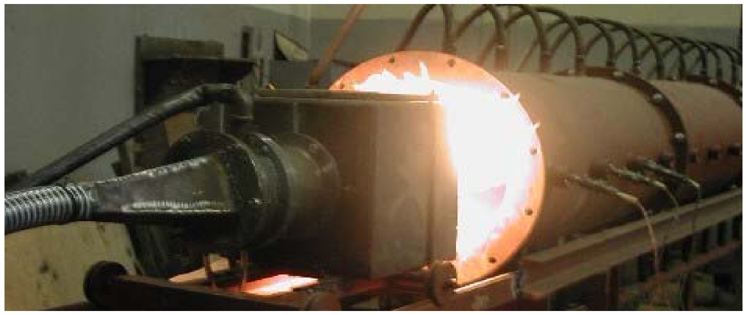


Fig. 3 - The experiments on the system: *tunnel – burner*
(the flame properties: axial temperature, brightness temperature etc. are tested).

For each cooling chamber, the brightness temperature values, T_1, T_2, T_3 (the tunnel having four cooling chambers) in all experimental situations (after every modification of working parameters) were measured. The scalar value of flame darkness degree, ε_n and total darkness, ε_t, with known relations from the thermal radiation theory were calculated, for each cooling chamber:

$$\varepsilon_n = 1 - e^{-\frac{C_2}{\lambda}\left(\frac{1}{T_3}-\frac{1}{T_1}\right)} + e^{-\frac{C_2}{\lambda}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)}; \quad (2)$$

$$\varepsilon_t = k_f \cdot \varepsilon_n + (1-x) \cdot \varepsilon_g \quad (3)$$

where: k_f defines the flame brightness, that equals $0.5 \div 0.6$ /2/;

ε_g - the darkness degree of burned gases from flame;

C_2 – the constant, equals $1.44 \cdot 10^{-2}$, in m·K;

λ – wave length of radiation pyrometer, for red filter: $\lambda = 0.65\ \mu$.

The values obtained on the basis of practical measured parameters (as a mean of all partially values), are placed in the limits: $\varepsilon_t = 0.53 \div 0.55$, similar with other results presented in the literature [4,6]. In normal conditions (burning without self-carburizing), this value is ***0.40***, for natural gas.

4. Conclusions

- to develop the experimental researches regarding the flames self-carburizing processes at gas fuels combustion, a laboratory stand was created. For this stand, three laboratory burners with three ring-shaped flame holders were designed. Three types of burners' geometry were tested, in multiple technological work versions.

- in all experiments using natural gas injected through the axial nozzles (136 functional regimes), multi-jet self-carburizing flames were obtained. The resulting flames were stable, silent and clear (self-carburizing radiant). The maximum clarity was achieved for the flames where the excess air, λ_a, ranged between ***0.9 ÷1.4*** and the natural gas percentage at cracking ranged between ***37 ÷ 40 %.***

- moreover, self-carburizing flames were obtained for various excess air coefficients by varying the work conditions. The self-carburizing flames' length depends on the process technological parameters (flows, pressures, flow speeds), increasing with the work speeds and air and gas flows.

- the results demonstrate that the self-carburizing of flame at gas fuel combustion is a very good method for intensive use of heat potential of gas fuels. The burner model proposed, that generates the self-carburizing, can be implemented in the industrial thermal installations, where the radiant flames are required.

R E F E R E N C E S

[1] *Dina, V., Geanta, V., s.a*. Arderea difuzivă în condiții de autocarburare controlată – soluție de valorificare intensive a potențialului energetic al gazului natural, vol. II, Cercetare de excelență – premiză favorabilă pentru dezvoltarea spațiului românesc de cercetare, Braşov, 2006. chap. L3-13, pg. 1- 8.

[2] *Dina, V.* Transfer de căldură şi instalații termice metalurgice. Editura Didactică şi Pedagogică, Bucureşti, 1996.

[3] *Mihăescu, L., Cristea, E.D., Pănoiu, N., Ganea, I., Totolo*, *Cr.* Arzătoare turbionare, Editura Tehnica, Bucureşti, 1986.

[4] *Delichatsios, M.A., Orloff, L., Delichatsios, M.M.* The Effect of Fuel Sooting Tendency an the Flow on Flame Radiation in Luminous Turbulent Jet Flames. Combustion Sci. Technologies, radiation pyrometer , for red filter with, $\lambda_o = 0,65\ \mu$ **84**, 1999. pp. 199-215

[5] *Kounalakis, M.E..* Structure and Radiation Properties of Turbulent Diffusion Flames, Ph. D. Thesis, Univ. of Michigan, Ann Arbor, 1990.

[6] *Cioacă, I.* Utilizarea arzătoarelor de tip toroidal cu flacără radiantă la cuptoarele de încălzire. Cercetări metalurgice, **15**, 1974, pp. 5 – 12.

[7] *Geanta, V., s.a*. Experimental Researches on the Auto-Carburant Processes at Gaseous Fuels Combustion. 3-rd European Combustion Meeting ECM 2007, Mediteranean Agronomic Institute of Chania, Crete, Greece, 11 – 13 April 2007, Session 20, p. 14-1 – 14-5.