DESIGN PARAMETERS OF A VORTICAL(SWIRLER), RADIAL AND AXIAL FLAME HOLDER

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Abstract. *This work deals with the main parameters of two types of aerodynamic flame holders, presently employed in industrial plants: swirler of axial and radial types. In the aerodynamics of combustion one of the fundamental problems is the holding and anchoring of flame. The increase in the efficiency of combustion points that the flames must be turbulent and the more the turbulence the better the efficiency since the turbulence promotes a better mixture of oxydizer and fuel. However on the other hand the increase at the level of turbulence of a flame might cause its lifting due to the excessive velocity and eventually its blow out of the burner causing consequently its extintion. In order to avoid this kind of undesirable phenomenon it is a common practice to use bluff bodies as flame holding devices which usually are conical or circular disk and frequently have holes and slots in its surface permitting by this way the direct flow of air for preventing overheating and the formation of scars on the front surface. By this way, in order to avoid overheating and surface scars and also due to the fact that the admission of air close to the base of the flame contributes to the increase in the efficiency of the combustion. All this aspects led to the development of aerodynamic flame anchoring device of vortical type (swirlers). These devices are usually employed in the design of modern burners.*

Keywords*. Combustion, Swirler, Flame holding, bluff body.*

1. Introduction

There are basically two kinds of aerodynamic flame holders: axial and radial swirlers. The axial one usually employs inclined vanes located at the extremity of the hub, attached to the fuel ejector and may have length smaller or equal to the distance between the ejector and the wall of the air out let duct.

The one of radial type normally has fixed and inclined blades and a moveable part responsible for the continued narrowing of the air entrance area that in its turn is responsible for the flame anchoring.

When constructed with the purpose of finding experimental data it has moveable blades that make it easy the variation of the swirl number, parameter very important for the performance of the device. The flame holder of the radial type frequently uses the decreasing of the air admitting area as a way of varying the swirl number. Such a device uses a set of fixed and inclined blades and a set of moveable blades which are responsible for the variation of the area of air entrance, varying by this way its velocity and blockage coefficient and at the same time maintaining the air mass flow, or in other words, varying the swirl number through the increase in the Reynolds number.

Swirlers nowadays have a great number of applications such as flame holders, in the modern industries plants, in turbines and in every burner in which flame anchoring is necessary. They are designed and constructed in substitution to the bluff bodies and screens devices since the employment of such swirlers does not result in great pressure losses as the imposed by the bluff bodies and neither suffer the imposition of elevated temperatures, and at same time show excellent performance to the stabilization of flame and proportionate fast transfer of energy (Syred, 1972 and Beér and Chigier, 1974). The utilization of swirlers in the industry is the result of three decades of intense research in the field of swirling flows since the very first work of Chigier and Béer (1964) who introduced the concept of number of swirl and created the base for future works (Lilley, 1977). More recently, Weber and Dugué (1992) proposed the so called effective swirl number for the well mixtured flames for taking into account the effect of combustion in turbulent fluxes. They also have shown how the inner recirculation zone can be correlated to the swirl number. In the article of Weber and Dugué it was proposed an easy control of the level of swirl by the division of the entrance air in lines of tangential and axial fluxes, varying then the ratio of the tangential flow with the entrance of air. A swirler with moveable blades was introduced and used for the same objective, that is, to perform a control of level of swirl (Weber and Dugué, 1992, Wall, 1987, Heap et all, 1973). Both the axial and radial swirler are broadly used in the industry for the control of flame (anchoring and size of flame). Here in this article it is described the performance of such systems, varying the angle of the blades in the axial type swirler and varying the entrance area of air in the radial type swirler.

2. Governing equations

2.1. Axial swirler

Figure (1) shows the scheme of construction of a swirler with blades in a tube of axial flow where D_h is the hub diameter, D_3 is the duct radius, D_s is the swirler radius and α is the vane angle. The characteristics of this swirler i.e., the swirl number, $S_s^{'}$, the alternative swirl number, S′, the permeability, μ and the blockage coefficient, C_b, given below, have been calculated elsewhere (Couto et all, 1995).

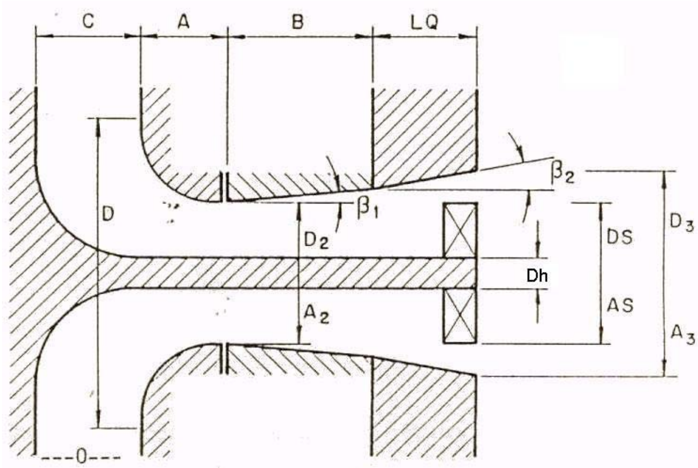

Figure 1. Schematic of the axial swirler construction (Muniz, 1993).

The swirl number for a flow in a mechanical device as shown in the Fig. (1) is calculated as following:

$$S_s^{'} = \frac{2C_b(r_s^3 - r_h^3)\tan\alpha}{3(r_3 - r_h)(r_3^2 - r_h^2)} \tag{1}$$

where :

$$r_s = \frac{D_s}{2}, \quad r_h = \frac{D_h}{2}, \quad r_3 = \frac{D_3}{2} \tag{2}$$

$$S^{'} = \frac{1}{1+M_R} S_s^{'} \tag{3}$$

$$M_R = \frac{\dot{m}_p U_p}{\dot{m}_s U_s} \tag{4}$$

where M_R is the momentum ratio, $\dot{m}_{p,s}$ and $U_{p,s}$ are the mass flow rates and axial velocities of the primary and secondary flows, respectively

$$C_b = \left(\frac{1}{1-\sigma}\right) \tag{5}$$

where the blockage factor is:

$$\sigma = \frac{A_s - A_{ef}}{A_3 + A_s} \tag{6}$$

$$A_s = \pi\left(r_s^2 - r_h^2\right) \tag{7}$$

and

$$A_{ef} = A_{ss} - A_f + A_b \tag{8}$$

with

$$A_{ss} = \pi(r_s^2 - r_h^2)\cos\alpha \tag{9}$$

$$A_f = zs(r_s - r_h)\cos\alpha \tag{10}$$

and

$$A_b = z\left(\tan\frac{\pi}{z} - \frac{\pi}{z}\right)r_h^2 sin\alpha \tag{11}$$

2.2. Radial swirler

The swirl number for a vortical generator of radial swirler as shown in the figs. (2-4) is given as:

$$S_s' = \sigma\frac{R}{2B}\left[1 + \left(\frac{R_h}{R}\right)^2\right] \tag{12}$$

where σ is given by:

$$\sigma = \frac{1}{1-\psi}\frac{\tan\alpha}{1 + \tan\alpha\tan(\pi/z)} \tag{13}$$

and ψ is given by:

$$\psi = \frac{zs_h}{2\pi R_1} \quad \text{e} \quad \mathrm{S_h} = \left(h\,\mathrm{sen}\,\alpha + s_t\right) \tag{14}$$

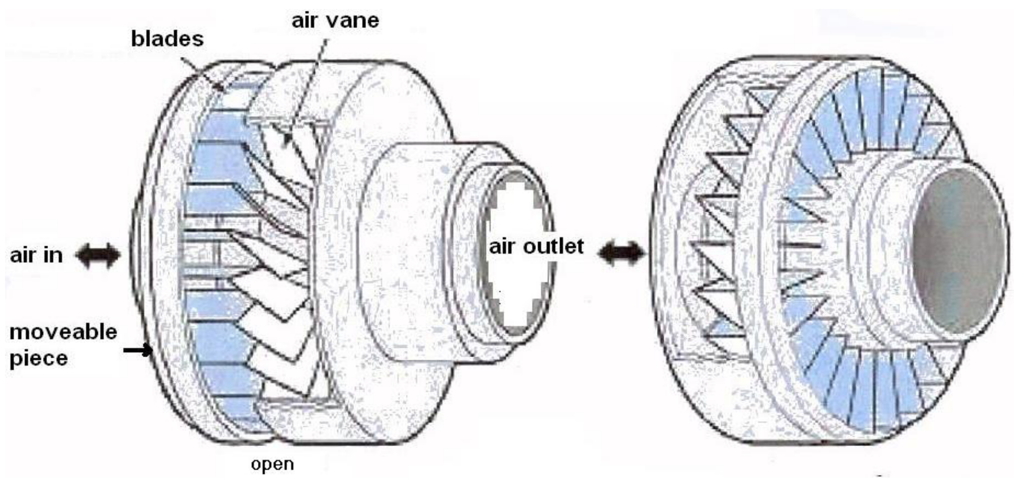

Figure 2 – Schematic diagram of a generator device of radial swirler (Lewis, 2003).

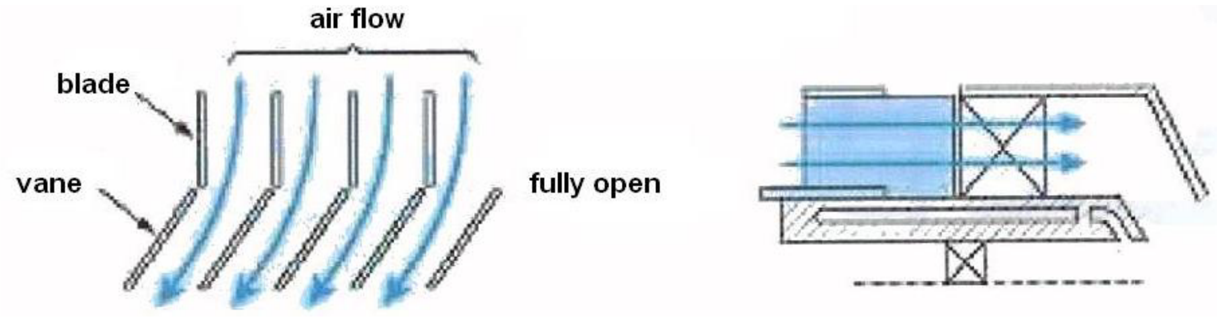

Figure 3 . Vanes of the radial swirler construction (Lewis, 2003).

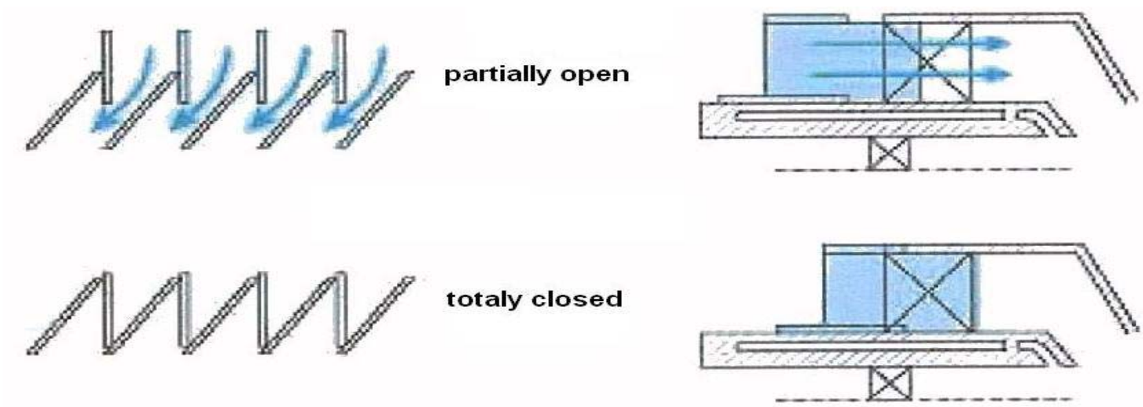

Figure 4 . Vanes of the radial swirler construction(Lewis, 2003).

$$B = \frac{2\pi R_1}{z} - s_h \tag{15}$$

where:
A_s swirler circular crown area;
A_{ef} swirler effective flow area;
α is the vane angle;
z is the number of vanes;
s_t is the thickness of the vanes;
s_h is the apparent thickness of the vanes ;
h = is the length of penetration of the moveable blade;
R_1 = inner radius of the swirler;
B = channel width ;
R = out let radius of the swirler;
R_h = radius of the fuel ejector;

Knowing that only the secondary air flows inside the duct of the swirler, (being the primary flow is the fuel which does not have angular momentum) we may then write that:

$$S' = S'_s / (1 + M_R) \tag{16}$$

where M_R is given by:

$$M_R = \left(\frac{\rho}{\dot{m}^2}\right)_s \left(\frac{\dot{m}^2}{\rho}\right)_p \frac{\left(R^2 - R_h^2\right)}{R_i^2} \tag{17}$$

where the subscripts are: s = secondary, p = primary and i = injector.

Finally we may write the swirl number as:

$$S' = \frac{\sigma R}{2B(1+M_R)}\left[1+\left(\frac{R_h}{R}\right)^2\right] \quad (18)$$

3. Results and discussion

The simulation for the generator device of the radial swirl is presented in the fig. (5) below. It can be observed that the results show good fitting to the case of free flame. In the literature it is known that the limit of the strong swirl is S'≥ 0.5. However this limit is only verified experimentally for confined flames, while for semi confined flames the experimental limit is around 0.6.

Figure (6) shows the experimental data obtained for axial swirlers, where as can be seen the limit for strong swirler is around S' = 0.78 which is not too far from the obtained in the present simulation.

As for both the radial and axial generators the swirl number is calculated in the outlet of the duct, it is not expected great modification in the limits of the swirl number, that is, the results of the simulation for the radial swirler is equivalent to that one of the axial swirler.

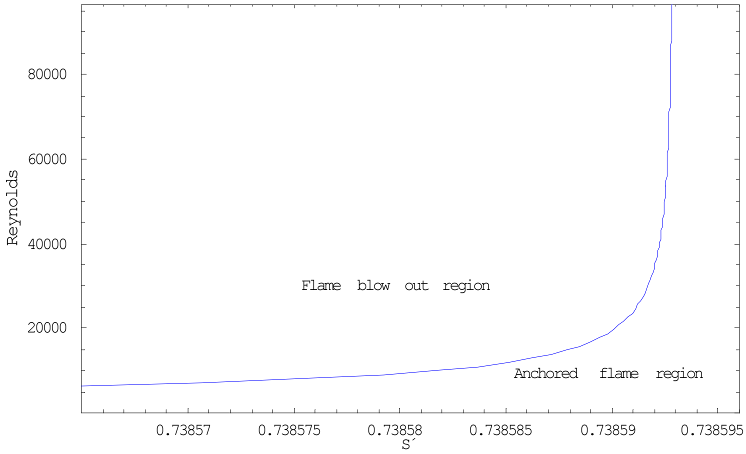

Figure 5. Numerical results for a axial swirler.

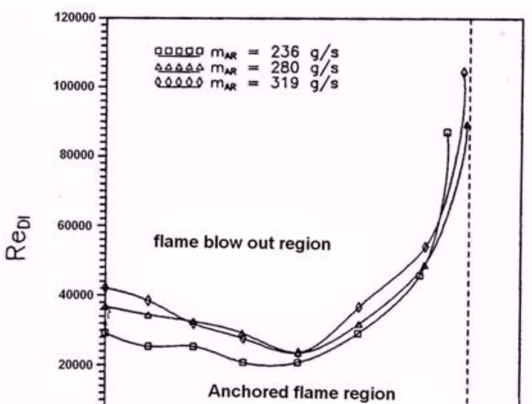

Figure 6. Experimental results for a axial swirler (Muniz, 1993).

4. Conclusion

It were obtained equations and design parameters for the generator of radial swirl as well as its simulation. It was verified that the simulation agrees with values of strong swirl for the generator of axial type. Experimental results for the radial generator herewith simulated will be implemented in the near future.

Obs.: The weak swirl number is the one which is below the value S’ = 0.5, according to the literature. In this level of swirl, there is no formation of the inner recirculation zone (IRZ) and consequently the flame may blow out of the nozzle according to the attained value of the momentum ratio.

The strong swirl number is the one whose level is higher than S’ = 0.5, according to the literature. Higher than that value of swirl number, no matter is the value of the momentum ratio, the flame will not blow out of the nozzle due to the formation of a inner recirculation zone. In the IRZ there exist adverse gradients of velocities which guarantee the anchoring of the flame.

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