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Burner rim geometry effect on flame stability

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Abstract. We studied a swirl burner in atmospheric pressure combustion system with different burner lengths to burner rim diameter ratios (L/D). Three ratios, of L/D 1, 2 and 3, were used to investigate the effect of the burner's geometry on the stability window. The results show that the position of the flame front stabilization changes with L/D ratio. The flame front stabilizes closer to the burner rim as the length of the burner is increased. The equivalence ratio of the mixture was taken as constant for the comparison's sake. The flame stabilizes closer to the rim with an increase of the rim length.

Introduction

The world's growing population is demanding more and more power. This puts huge pressure on the power generation sector to provide that power and meanwhile, growing power consumption has serious climatic effects. So the search is on to find a quick solution for emission reduction around the world.

The use of gas or biofuels could be part of a future solution for lowering gas emissions. However, switching to use cleaner gases or biofuels will mean altering the classic combustion system, to meet the safety requirements that are needed to operate power plants safely.

Flame stability issues, such as blow-off and flashback, are major obstacles to the use of novel fuels in main power plants. Blow-off occurs when the flame leaves the burner rim and is extinguished in the downstream region, and it is affected by the fuel type, flow velocity and mixing ratio [1]. Flashback is a penetration of the flame upstream, into the fuel system. The flashback can potentially cause disastrous damage in the combustion system. The flashback mechanisms are more complicated compared than those of the blow-off. The flashback has been linked to the following mechanisms: CIVB (core induced vortex breakdown), BLF (boundary layer flashback), TCF (turbulent core flashback) and combustion instabilities flashback [2]. Furthermore, the fuel type, equivalence ratio, and flow type can all have an effect on the flashback mechanism. For example, the TCF, combustion instabilities and BLF occur on diffusion flow systems, while CIVB is the mark of swirl flow beside the BLF.

However, swirl flow is preferable in the combustion system due to the large reduction in NOx emission [3]. On the other hand, the swirl flame structure is complicated, and parameters that influence the swirling flame are not completely understood. The CIVB is a dominant flashback mechanism in swirl burners, where a flame bubble is developed at the center of the flow and propagates upstream. Many techniques have been studied to avoid CIVB[4]. The bluff body can be used to stabilize the flame downstream through increased turbulence of the flow in the recirculation zone, which helps to reduce the tendency of a system to flashback[5]. Although the bluff body is solid (usually a pipe, nozzle or a piece of metal) if geometry is impeded in the central area of the flow, the bluff body could be used to produce a central fuel or airflow [6, 7]. However, any central injection of air or fuel in the combustion field, as well as the presence of the bluff body, will increase the probability of boundary layer flashback [8]. In boundary layer flashback the flame propagates upstream in the low-velocity region near burner walls or bluff body walls[9]. The techniques that are used to avoid boundary layer flashback focus on ensuring that the critical velocity gradient is pushed towards the wall, where the heat transfers to surroundings, extinguishes the flame and prevents the flame from propagating near the wall [10]. Also, injecting air from a side wall helps to push the flame to the high-velocity field and hence avoid the BLF[11].

In recent work, using stainless steel wire screen as a liner at the inner wall of burner rim to alter the boundary layer [6], and the combination of the central injector and wire mesh have produced, more balanced effects between CIVB and BLF[12]. However, the aerodynamic characteristics of the burner rim and their effects on the burner's stability are still not clarified.

Thus, we have studied the effect of the burner length to diameter ratio (L/D) on the flame stability. Three L/D ratios 1, 2 and 3 were studied and the results are discussed.

Experimental work

The experimental rig is a swirl burner, shown in Figure 1. The air is delivered tangentially from a three- phase blower attached to the burner body . The maximum airflow rate delivered by the blower is around 11.5m^3/min or 190 l/s. The amount of air supplied to the system can be controlled electronically using three single-phase variacs or mechanically by using a slide window that partially blinds the intake opening of the blower. The LPG is supplied from a pressurized cylinder through a high-pressure plastic hose, connected to a bank of rotameters. The delivered air is mixed with LPG in the bottom of the burner, then the mixture goes through a swirler plate to swirl the mixture and thus produce a premixed fuel.

The rest of the burner geometry is of a divergent shape, which slows the flow to give the mixture time to mix fully, then the premixed fuel is accelerated through a convergent part and goes through the burner rim. The burner rim's diameter is 5cm and the length of the rim is variable (5cm, 10cm and 15cm) to ensure L/D ratios 1, 2 and 3. A pilot flame is produced by a secondary ignition system coming from a central nozzle with an adjustable length, where it is ensured that the top of the pilot ignition system nozzle lies at the same level as the burner rim's top edge.

In this study, the flame stability was captured using a 1000 fps camera. In each experiment, the amount of air and the amount of LPG were fixed, to ensure the same equivalence ratio. Also, the experiments were carried out at separate times to ensure the same initial conditions, such as lab temperature and burner rim temperature.

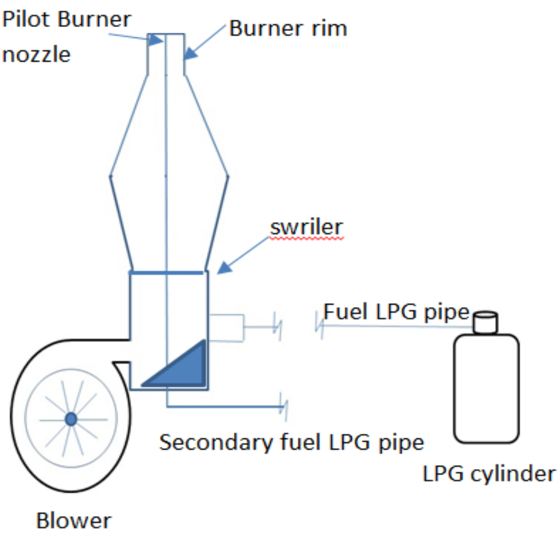

Figure 1 Sketch of the experimental rig.

3- Results and Discussion

The experimental tests focused on the effect of the rim length (L) to the diameter (D) on the stabilization of the flame. The equivalence ratio (ϕ) of the mixture was taken to be 0.9 where the system is stable and far away from blow-off and flashback. The results show that for a stable flame, the position of stabilization downstream is affected significantly by the L/D ratio. For the burner with L/D equal to 1 and the flame stabilized far away from the larger burner (X/D), any increase in L/D will stabilize the flame closer to the burner rim. The increase in L/D ratio causes the flame front to move towards the upstream and stabilize closer to the rim (Figure 3). The increase of burner length will force the swirl mixture to move for longer to reach the burner exit, which causes increasing swirl decay and reduces the flow turbulence. The turbulence in the combustion zone is important, since the increase of turbulence in the downstream flow will increase the residual time, which gives more time to complete the combustion. A completed combustion will increase the economic advantage and reduce the amount of emissions. Also, the decay in swirl strength will influence the of the flow[13]. Coherence of the flow will improve the combustion**.**

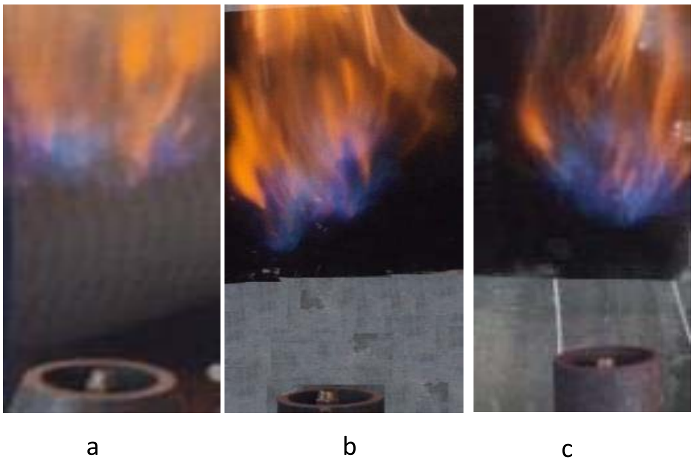

Fig. 2 The flame front height at different rim lengths (L) a) 5cm b) 10cm c) 15cm.

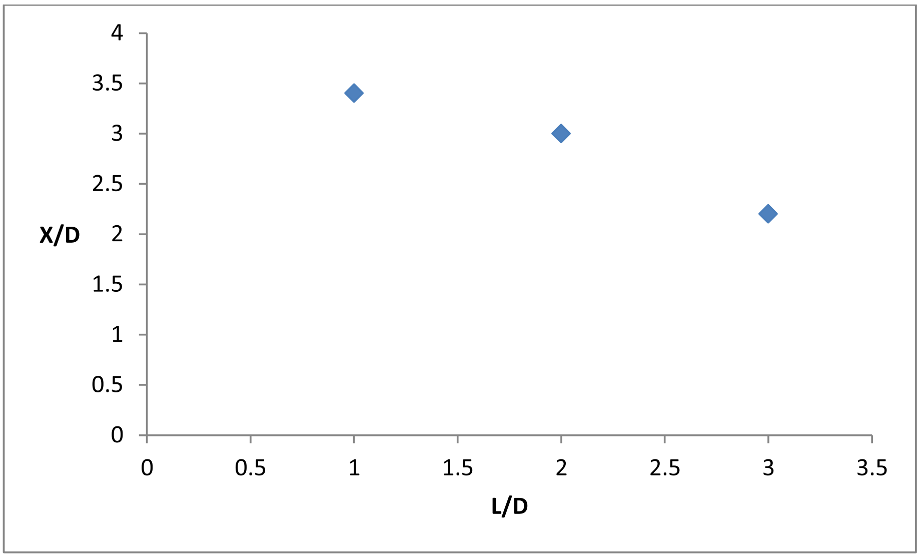

Figure 3. Flame stabilization position in downstream (X)

Conclusion

The main conclusion that can be drawn from these experiments is that increase in the length of the burner rim causes more decay in swirl strength. That reduces the coherence of the flow downstream and the momentum of the mixture: such weakness in flow structure will move the flame front closer to the rim and make the system more vulnerable to flashback issues.

Nomenclature

L	Burner rim length.
D	Burner rim diameter
ϕ	Equivalence ratio
X	Downstream distance (distance from burner rim towards combustion zone)

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