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Design of LPG burner for hot air puffing machine

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ABSTRACT : In puffing machines the hot air is produced either by burning liquefied petroleum gas (LPG) or electric heaters to develop puffed ready-to-eat (RTE) product. In puffing machine the product is puffed in LPG flue gas mixed hot air based on the whirling bed principle. Therefore, to produce hot air by burning LPG, three non-premixed diffusion type burner configurations were designed to produce a stable blue flame with minimum soot length. In Type I burner of 20 cm length two concentric galvanized iron pipes- inner gas pipe of 2.7 cm (OD) and outer air pipe of 5 cm (OD) were used. The gas was introduced in the inner pipe of burner through copper pipe of 1.3 cm (OD) from outside. It works and produces the flame with an obstruction plate of diameter equal to inner burner pipe which was positioned in front of inner pipe for stability of flame. In experimental tests it was observed that flame do not catches when blower was started and forms a single jet unstable luminous (soot) flame at high air velocity. In Type II burner two steam pipes of diameter 4.7 and 2.7 cm (OD) were used for fabrication. In order to protect the flame from high velocity air, a truncated conical metal (cast iron) shield of 4.7 cm diameter was welded to the rim of air pipe. The Type II burner produced characteristic long blue flame and less soot length but there was soot formation in flame at relatively low air flow rates. To overcome the problem of flame instability and soot formation a third burner configuration was used. Three concentric steam pipes were used for Type III burner. It was observed that the secondary air from central pipe results in proper combustion, complete blue flame formation at the burner tip and better flame stability under variable air flow rates. In Type II and Type III burner, the flue gases of temperature ranging from 90^o – 300^o can be produced at gas flow rates from 7 – 22 lpm.

KEY WORDS : Burner, Flame stability, Blue flame, Combustion

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Puffing is the expansion of food stuff because of sudden increase in the internal pressure of vaporized moisture due to intense heat. There are different types of puffing process like sand puffing, hot air puffing, oil puffing, gun puffing, etc. In puffing process the heat transfer is by either conduction or convection. In hot air puffing the convective heat transfer media is hot air. This hot air is produced by electric heating (Chandrasekhar and Chattopadhyay, 1989) or by mixing flue gases from LPG (Pardeshi and Chattopadhyay, 2010), natural or other types of gas burners in air. Liquefied petroleum gas (LPG) is widely used as a fuel in domestic heating appliances throughout the world because its combustion products are relatively clean.

Climate change and pollutant emission issues worldwide are related to the conversion of chemical energy to sensible energy (heat) via a combustion process in a turbulent flow environment. A burner is a fuel and air metering device. Its purpose is to provide an environment for the proper fuel and air mixture ratio to mix and react. Swirl flow (SB), radial flow (RB), swirl flow bluff body, inverse diffusion flame back-step burner, pre-mixed, non-premixed, diffusion type, non-diffusion type are some of the burners that can be used for producing hot air. The combustion process in such devices often is characterized by complex turbulence–chemistry interactions that span multiple combustion regimes (Haworth, 2009). Swirl flow, loading height, primary aeration, secondary aeration, gas flow rate (heat input), gas supply pressure and semi-confinement of combustion flame are the significant parameters that influence on thermal efficiency and CO_x, $NO_{x,}$ SO_x emissions from the gas burners. In burner performance complete burning of fuel with blue flame is the desired character but it produces high temperature which leads to NO_x formation whereas less intense flame may cause higher soot formation. Therefore, a balance between desired and non-desired character needs to be sought in burner design.

Ronald and Saad (1987) investigated the jet mixing in confined swirling flow, using carbon dioxide as the jet fluid, for burner design and found that density difference and swirl combined to give rise to an accelerated decay of the jet and increased mixing between jet and swirling air. Consequently, the second reversed flow region observed in the swirling flow was only slightly displaced downstream. Hou *et al.* (2007) found that the swirl flow burner (SB) yields higher thermal efficiency and emits only slightly higher CO concentration than those of the conventional radial flow burner (RB). The thermal efficiency of the SB with the semi-confinement of flame by metal shield yields a markedly higher thermal efficiency, by about 12 per cent, than that of the RB with open flame. Vortex interactions with flames play a key role in many practical combustion applications. Vortices of various types are often used to enhance mixing, organize the flame region, and improve the flame stabilization process (Renard *et al.*, 2000).

Kenbar *et al.* (1995) studied the peripheral fuel injection system in a small-scale adiabatic furnace of 0.225 m inside diameter and 0.9 m length. The furnace was fired by natural gas through a variable-swirl burner with a quarl. This system resulted in a stable flame even without a central reverse-flow zone (CRZ). Compared to the central axial fuel injection, the peripheral injection produced flames of higher intensity with wider stability ranges. Authors also studied an alternative way of achieving the CRZ that is to create an aerodynamic blockage by introducing part of the combustion air radially outward through a central gun. The gun used had 16 holes, each 5 mm in diameter, spaced on its outer periphery. In this arrangement about 10 per cent of the combustion air was supplied through the central gun. In this case a stable flame was achieved even without swirl. Weber and Dugue (1992) studied the effect of combustion on properties of swirl induced internal recirculation zone (IRZ) formed in the vicinity of swirl stabilized burners. Authors demonstrated that the basic effect of combustion is to reduce both the size and the strength of the IRZ. Combustion reduces importance of the centrifugal forces with respect to flow inertia by increasing the latter substantially. Diffusion type II flames were generated with annular fuel injectors and demonstrated that in type II diffusion flames the bluff body effects are also very important.

Mahesh and Mishra (2008) reported the stability characteristics and emissions from turbulent LPG inverse diffusion flame (IDF) in a backstep burner. The blow-off velocity of turbulent LPG IDF is observed to increase monotonically with fuel jet velocity. Author used soot free length fraction (SFLF) for qualitative estimation of soot reduction in this IDF burner and found that SFLF increases with central air jet velocity indicating the occurrence of extended premixing zone in the vicinity of flame base. Mukherjee (1997) developed a pre-mixed air-LPG burner fitted into a plenum chamber. The plenum chamber was too large to ignite the gas initially. In this burner there was no special gas ignition system and the burner had to be started with external flame. This often resulted in explosive start of burner.

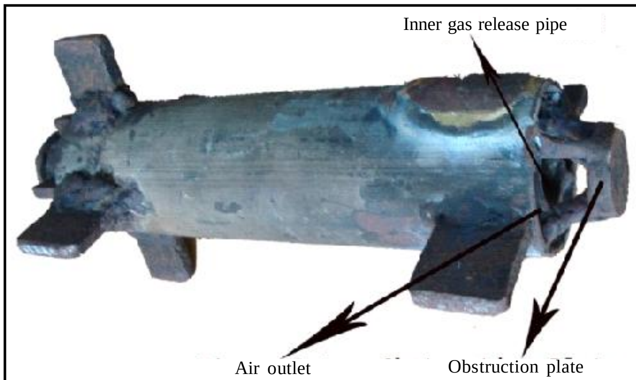
With this background of burner configurations, flame stability, thermal efficiency and soot free length fraction as quality parameter it was planned to configure a simple design of burner to suit to the requirements of hot air puffing machine to be operated by a single air blower. The objective was to produce LPG burnt flue gas mixed hot air with 50 – 270 °C temperature range. In the present work the hot air puffing machine was used to develop puffed product from millet based composite flour.

■ METHODOLOGY

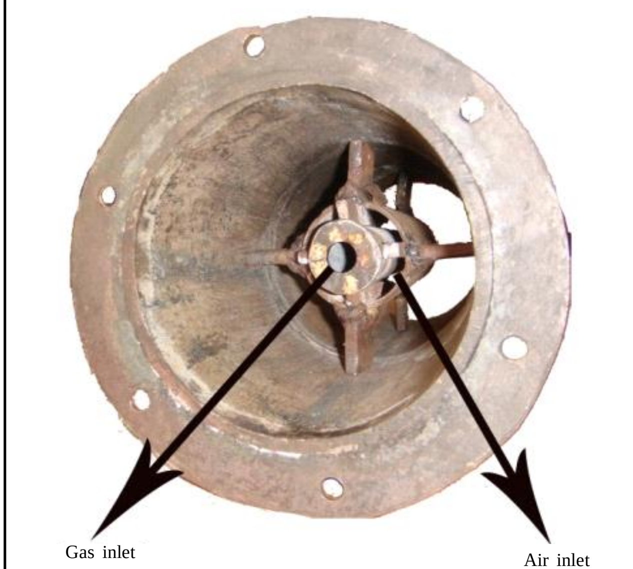
General burner design and operating considerations:

Gas tip and riser design must be resistant against coking, scaling, and corrosion. Inside the plenum chamber there is high temperature, reducing and oxidizing environment. Therefore, while selecting the material for burner tip fabrication, steam pipes and cast iron was used. Stainless steel tubes were used for hot air risers in plenum chamber (Darin, 2004). The cracking reaction is temperature and residence time dependent. Since gas tips can reach gas cracking temperatures it is important to control the residence time in the burner tips. In order to reduce the residence time and overheating of burner parts the burner was fitted in air blower pipe so that fresh air can flow surrounding the burner and parallel to the flame. The burner specifications must match the plenum and puffing chamber specifications and requirements to supply hot air of desired temperature and quantum. This ensures that the burner will operate in a range where the excess air is controllable. Controlling tramp air leakage by sealing the plenum chamber and closing dampers of burners is important. Additionally, controlling heat losses to conduction by having adequate furnace insulation are also of paramount importance in energy efficient operation. These parameters are the basic elements of burner and ultimately puffing machine efficiency.

In the present work it was planned to develop a compact puffing machine with minimum height. It was also decided to design a burner which can be operated by a single blower. Preliminary trials were conducted with a simple burner fabricated using two concentric galvanized iron pipes with 4.5 and 2.7 cm OD, respectively (Bloom and Hovis, 1961). The inner pipe was positioned at the center and its back end facing the blower was closed by MS plate with a hole for fitting the gas pipe Fig. A(a). Thus, the air could pass through the annular space between the two pipes. The length of burner was kept 30 cm and enclosed in a 10.5 cm inner diameter thick GI pipe. This GI pipe was fitted to the air blower duct with nut bolts and flange. The position of burner in the GI pipe Fig. A(b) was kept such that the excess turbulent air flowing between air duct and burner would create swirl around burner tip as well as flame and help in proper combustion of gas which will increase burner performance (John and Samuelsen, 1994). The turbulent air with swirling motion increases the combustion rate remarkably (Wang *et al*., 2008).



(a) Burner configuration



(b) Arrangement of burner in GI pipe

Fig. A : Type I burner

Preliminary work :

In trial versions the burner was designed such that a part of air should flow through the central pipe of burner and could be used for combustion of gas and the excess part of air from blower would pass over the burner through the space between burner and outer GI pipe. This air passing through the annular space would carry the flue gases from burner flame to the plenum chamber, prevent heating of blower duct and prevent overheating of burner components. The front end of pipe was tangentially inserted in the insulated plenum chamber of 57 cm inner diameter. It was also thought that the air flowing through annular space would take heat from the flame and cool it so that less NO_x (oxides of nitrogen) would be formed (Ballester *et al.,* 1997). The gas was introduced into the central pipe of burner from outside through a copper pipe. To start the burner by ignition of gas, a spark plug was introduced in the outer GI pipe just in front of burner from outside. The spark in the plug was created by electronic circuit which can create about 500 cycles per second. Thus, this arrangement of burner in blower duct facilitated the smooth running of burner as well as blowing of air with a single blower for producing hot air for further use in puffing of the product. The velocity of air was measured by digital anemometer and the temperature of hot air was measured with a digital thermometer. The gas flow rate was measured by LPG flow meter fitted in the LPG supply pipe. Three replications were taken in all measurements. The images of flames were taken with digital camera Konica, Japan. The camera was kept at fixed position on table such that images can be sighted clearly. The lengths of flame images were measured using Adobe Photoshop CS2 9.0 software. The curved lengths of the flame were measured by joining points on curvature with straight lines and all sub-sections added together. The flame characteristics study was carried out constant air velocity of 4 ms^{-1} through puffing machine as this was the operational terminal velocity of product to be puffed in the machine.

During trials it was found that the gas flame do not catches up when the blower was started and even if it fires, the flame was very unstable with luminous colour and with entire soot length. This flame was also characterized by a very high pinging sound due to shear between the flame and secondary air flow. Considering the experimental observations, three burner configurations were designed and tested for their suitability. The changes in the design of three types of burners were effected based on the results and problems faced in subsequent versions. In order to have free and uniform flow of air from blower to burner the length of burner was reduced from 30 to 20 cm without affecting the performance.

Type I burner :

In this design the inner small pipe was fitted in outer larger pipe with the help of mild steel (MS) pieces of 2-3 cm length on both the ends Fig. A(b). The lengths of inner and outer pipe were kept 19 and 16 cm, respectively. The inner pipe was fitted such that its excess length would protrude out of larger pipe on back side so that there would be lesser obstruction to air flow into burner in axial direction. The gas was introduced in the inner pipe of burner through a copper pipe of 1.3 cm (OD) form outside and connected to LPG cylinder through a needle valve regulator. Two large holes in series on four sides and diametrically opposite were drilled on front end of gas pipe. In order to stabilize the flame an obstruction plate (cast iron) of 0.6 cm thickness and diameter equal to that of inner pipe was welded to outer pipe with three iron rods like a tripod keeping the plate at center (Fig. A). This plate would make the gas to flow at an angle to axial direction and mix with air.

Type II burner :

In this design it was tried to provide holes on gas pipe so as to partially premix the gas and air before diffusion type flame forms. In this type two steam pipes of diameter 4.7 and 2.7 cm (OD) were used for burner fabrication. The inner pipe was kept protruding out by 3 cm through air pipe on blower side and 1.3 cm short of rim level of air pipe on front side. For partial premixing of gas in air, three holes in each of the four rows were drilled on diametrically opposite sides of inner gas pipe so that gas under high pressure would come out through holes and mix with air (Anonymous, 2010). The obstruction plate was positioned in front of the gas pipe leaving 0.7 cm gap and was welded to the outer air pipe at rim level. This obstruction plate acts as gas flow divider, improves distribution and retards flashback or back pressure in the event of variations in gas or air flow (Ogden, 1987) when blower is started and protects flame from blow off from burner tip. In order to protect the flame from high velocity air flowing through outer GI pipe, a truncated conical metal (cast iron) shield of 4.7 cm diverged diameter on front side was welded to the rim of air pipe (Fig. B).

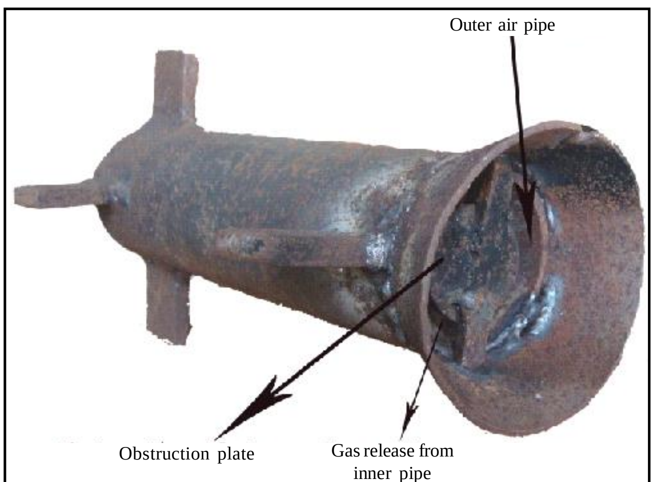
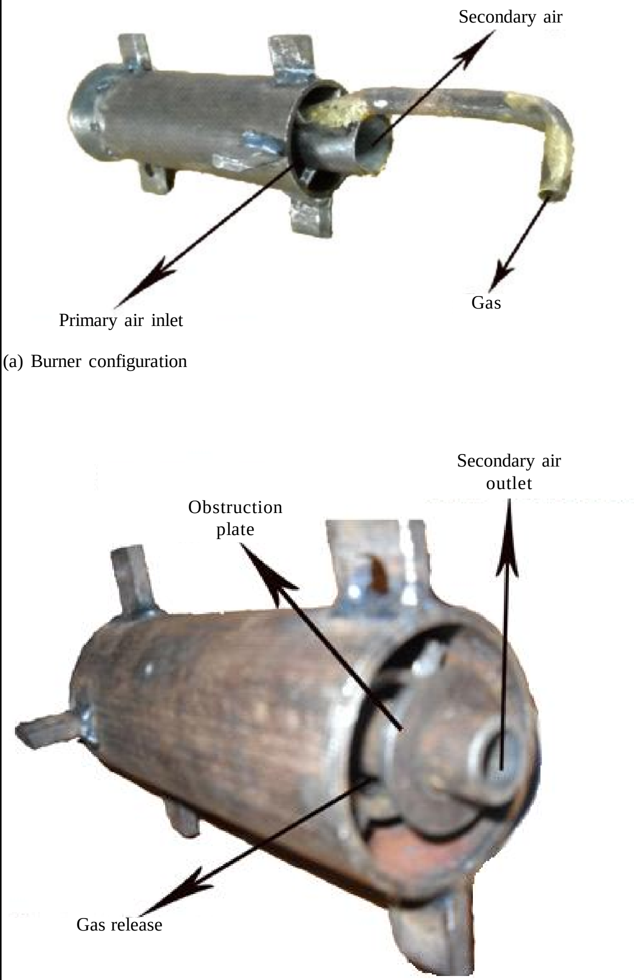


Fig. B : Type II burner



(a) Burner configuration

(b) Arrangement of obstruction plate and Secondary air outlet

Fig. C : Type III burner

Type III burner :

To overcome the problem of flame instability and soot formation in above burner types a third configuration was fabricated. In this design three concentric pipes and two types of air flows- primary and secondary flow were introduced in burner (Baukal, 2000). The outer air pipe and inner gas pipe had outer diameter of 6 and 3.4 cm, respectively. The third steel pipe of 1.7 cm (OD) was introduced through the inner gas pipe projecting out from the front end. A converging section of 3 cm length was fabricated and on blower side its diverged end was welded to the inner gas pipe Fig. C (a) and its converged end was fitted in the smaller central air pipe. Air accumulated in this section passes through central air pipe and gets released as secondary air flow in reaction zone at burner tip. A truncated conical metal (cast iron) shield of 7.3 cm diameter was welded to outermost air pipe of burner to protect flame.

The performance of burners during testing was measured in terms of soot length and blue flame length and the temperature of flue gas mixed hot air coming through plenum chamber. Flame stability under variable air flow rates was also observed. As in Type I burner flame was unstable it was not considered for temperature measurement.

■ RESULTS AND DISCUSSION

The preliminary trials revealed that the non-premixed diffusion type burner can be made from locally available steam pipes with satisfactory performance. All the three burner configurations were tested for different air flow, gas flow and temperature requirements of the puffing machine.

Burner performance and flame characteristics :

Type I burner :

During testing of it was observed that it was difficult to the catch the flame on burner at start and got extinguished when blower was started. Even if the flame hangs on, it was very unstable at relatively high air flow rates. The flame quality was not good as the combustion produced only soot with luminous colour Fig. 1(a). As obstruction plate was small in diameter than the inner diameter of burner outlet pipe and welded at some distance from outlet, gas was released in a jet divided into four sub-streams which merges in a single stream in front of the burner tip. The flame formed .resembles to a jet diffusion flame Fig. 1(a) which maintains itself at constant air flow. This local flame stabilization mechanism fails under high air velocities (Broadwell *et al.*, 1985) which is required in puffing machine to remove the puffed product out of puffing chamber. This operation needs extra air to be introduced through burner which would affect flame stability and burner performance. Therefore, Type I burner configuration was rejected.

Type II burner :

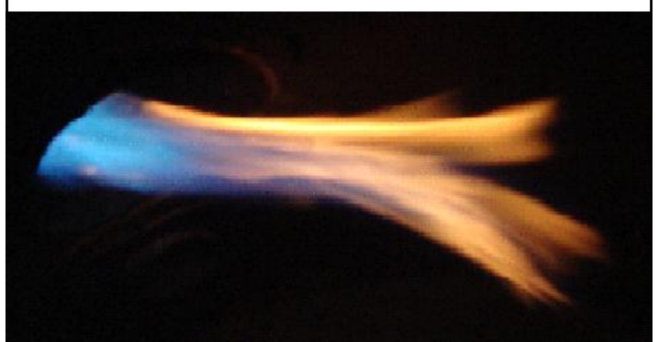
In this burner the aerodynamic blockage of gas was brought inside the burner pipe as against outside in Type I burner. During testing of Type II burner it was observed that the obstruction plate diverts the gas flow away from the center in radial direction in different smaller streams.

These small streams of gas mix more thoroughly with air in outer air pipe and forms long blue flame. It was due to the reason that the obstruction plate form a partial central reverse-flow zone (CRZ) in front burner tip (Kenbar *et al.*, 1995) which increases retention time of air-gas mixture in reaction zone and thus, helps better flame formation Fig. 1(b). The diverging shield around burner tip reduces effect air velocity from outside and protects flame under high air velocity. Also it has been demonstrated by Weber and Dugue (1992) that the low oxygen environment of CRZ can be utilized to reduce NO_x emissions. Thus, the fuel load or thermal input gets distributed (Ballester *et al.*, 1997) in Type II burner as compared to a jet of fuel released from Type I burner tip in which there was high thermal input across less cross section of burner and a single jet luminous (soot) flame was formed. The characteristics of flame were high blue flame length and less soot length and also the total flame length reduces with medium increase in air flow at constant gas flow. Flame in Fig. 1(b) is corresponding to a steady burning flame (Prade and Lenze, 1992). The temperature distribution of the same flame is good resulting in complete burning of fuel and in blue flame formation.

The blue flame length increases from 4.9 to 5.3 cm at gas flow rate upto 11 lpm and reduces considerably at high gas flow rates. The total flame length ranged from 5.5 to 16.6 cm under test conditions. Overall the flame characteristics in Type II were better than Type III burner (Table 1). This was true with medium air velocity of about 8 – 10 ms^{-1} through the burner or 4 ms^{-1} through the puffing machine but the flame gets wavered and flame buoyancy increased at very high or low air velocities.

(a) Type I burner

(b) Type II burner



(c) Type III burner

Fig. 1 : Typical flames of three types of burners

Table 1 : Comparative study of burner performance and flame characteristics at constant air flow rate of 4 ms^{-1} through the puffing machine

Sr. No.	Fuel flow, lpm	Burner type II				Burner type III			
		Flame lengths (cm)			Flue gas temp, °C	Flame lengths (cm)			Flue gas temp, °C
		Blue length	Soot length	Total		Blue length	Soot length	Total	
1.	7.5	4.9	0.6	5.5	116	7	0.1	7.1	101
2.	9	5	0.8	5.8	123	7.2	0.3	7.5	112
3.	10	5.2	1	6.2	137	7.3	0.6	7.9	117
4.	11	5.3	1.2	6.5	149	7.5	0.7	8.2	120
5.	12	4.5	2.3	6.8	153	7.3	1.5	8.8	137
6.	13	4	3.1	7.1	159	3.6	6.4	10.2	152
7.	14	3.2	4.4	7.6	169	4.9	6	10.9	181
8.	15	2.5	6.3	8.8	189	5	7	12	184
9.	18	2.3	11.7	14	230	4.9	9	13.9	236
10.	22	1.9	14.7	16.6	289	6.1	10.3	16.4	296

Variations in flame length= ±0.5 cm

Also there was soot formation in flame at relatively low air flow rates because at low air flow rates, the gas thermal input increases as a result the thermal efficiency reduces and the CO emission increases (Hou *et al*., 2007).

In Type III the secondary air flow through third central small pipe and radial gas flow over the obstruction plate is similar to peripheral or radial fuel injection system which produces high rates of mixing, leading to better combustion efficiency, heat transfer and flames of high intensity and wider stability (Kenbar *et al.,* 1995; Ballester *et al.,* 1997). In testing of the burner it was found that the secondary air provided the extra air for gas combustion and resulted in complete blue flame formation at the burner tip as well as better flame stability under medium air flow rates. Additionally, the provision of a shield on burner tip protects the flame (named semi-confined combustion flame) and achieves a great increase in thermal efficiency (Hou *et al*., 2007).

In Type III burner, when the gas was injected at high flow rate under fuel-rich conditions the flame lifts off the burner tip and in the lift-off condition the secondary air is mixed with the flame before the primary combustion stage has been completed. Thus, the secondary air flow also reduces air-gas species entrainment, moderates flame temperature and minimizes NO_x formation (Kenbar *et al.,* 1995, Ballester *et al.,* 1997). The cold air entraining in the flame from blower air duct mixes with reacting gas and air species (Ogden, 1987). This cold air helps in decreasing the flame temperature and the residence time in burner due to the stretched flames which results in reduced NO_x emission (Chen and Driscoll, 1990). The molecular diffusion of species and heat, accompanied by chemical reactions, occurs across the strained interface between the cold entrained air and the mixture of hot products and fuel. Then molecular diffusion homogenizes the remaining cold air and the mixture of hot products and fuel. Early in the flame, combustion occurs primarily in the strained flame sheets (curved flame edges as in Fig. 1c) due to homogenization. Near the flame end, combustion occurs both in the strained flame sheets and in the homogenized mixture (Dahm and Dibber, 1988). The flame ends when this homogeneous mixture is completely combustible.

The blue flame length increases from 7 to 7.5 cm at 7.5 to 11 lpm gas flow rate but reduces later at high gas flow rates (Table 1). The total flame length increased from 7.1 to 16.4 cm. Though the length of blue flame was considerable, the soot length was still higher than blue portion. In the presence of shorter reaction zone due to excess of cool air, it was observed that such temperature drops favours soot emission in diffusion flames (Cozzi and Coghe, 2006). The soot and total length reduces considerably at very high air flow rates. In Type III burner thermal performance and flame stability under sudden air flow changes was far better than Type II (Table 1). Temperature of hot air as high as 296 ^oC was achieved at 22 lpm gas flow rate with air velocity of 4 ms^{-1} through plenum chamber exit using Type III burner configuration. At this high gas flow rate and high temperatures the soot length increases to considerable extent (Fig. 1) and flame becomes unstable due to high heat input (Hwang *et al*., 2009). This could be due to substantial reduction in the internal recirculation zone (IRZ) size and strength when the gas load increases (Weber and Dugue, 1992). The authors studied the effect of combustion on properties of swirl induced IRZ formed in the vicinity of swirl stabilized burners. The reverse flow measured at (traverse 3) downstream of the gas injection, reduces from 15 to 8 per cent and then to 4 per cent with the gas load increasing from 200 kW to 300 kW and then to 400 kW. The reverse flow measured at (traverse 2) little upstream position, reduces from 8 to 5 per cent and 3 per cent. The reduction in the IRZ size and strength with gas load, which is observed downstream of the gas injection position, is through a reduction in the ratio of tangential over axial momentum.

Conclusion :

After test trials of three burners it was concluded that both Type II and Type III burners are good in efficient fuel combustion and hot air production. Flame stability is relatively higher in Type III burner than Type II burner and stable flames of moderate temperature with less pollutant can be achieved. The application of Type III burner in puffing machine was suitable for producing hot air of uniform temperatures from 90 to 300 ^oC at variable air flow rates and gas flow rates.

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