Fuel 119 (2014) 153–156

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Short communication

Improvement of domestic cooking flames by utilizing swirling flows

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ARTICLE INFO

Article history:
Received 11 September 2013
Received in revised form 9 November 2013
Accepted 11 November 2013
Available online 25 November 2013

Keywords:
Swirling flow
Heating efficiency enhancement
Pollutant emission

ABSTRACT

Premixed flames are widely used in domestic cookers. However, full utilization of premixed flame is usually restricted by its narrow operation range. Redesigning the burner cap is the focus of the present study. Two swirl burners, where the swirling flow is induced by two different methods, are proposed. It is found that compared to the Benchmarking cooker, both swirl burners are able to yield a higher heating efficiency under most of the operation conditions tested. Swirl Burner II shows lower CO emission than the Benchmarking cooker. Besides, Swirl Burner II has wider operation range. However, there is no evidence that Swirl Burner I can reduce the pollutant emission, or enlarge the operation range.

1. Introduction

Nowadays, domestic cookers utilizing premixed flames are widely used in many parts of the world. The usage is so enormous that just a little improvement on combustion behaviors of premixed flames can significantly reduce energy consumption and pollutant emission. Swirling flow has been induced successfully in many large-scale industrial applications [1,2]. However, studies on introduction of swirling flow to small-scale, low pressure and laminar premixed flames have rarely been reported.

Huang et al. [3] studied the thermal characteristics of an laminar flame with induced swirl and observed that a more uniform heat flux received by the impingement plate. Zhao et al. [4] assessed an impinging flame system and found a more widespread flame layer along the impingement plate from the flame with induced swirl. Hou et al. [5] investigated the influence of swirl on the thermal efficiency of a domestic burner, showing that the swirl burner yields higher thermal efficiency than the burner without swirl. Jugjai et al. [6] proposed swirl as an effective method to enhance the thermal efficiency of a gas cooker. Luo et al. [7] found that the swirling flow in the premixed flame strengthens the entrainment of ambient air and induces a larger contact area.

The literature review indicates that swirling flow is possible to improve the heating efficiency of a domestic cooker. However, the technique for swirl generation, though very important as it affects of the thermal and emission characteristics of the swirling flame, has been less investigated. Hence, the objective of this study is to compare swirling burners or flames utilizing two different techniques to generate swirling motion.

2. Conceptual designs

Most cookers in the market are based on a single ring of slot or round jets along the burner circumference. A Benchmarking cooker is shown in Fig. 1(a). Radial channels direct the flame jets to flow radically and slightly upward with an angle of 18° towards the horizontal plane. Two new designs utilizing swirling flow are proposed in this study, which allow two different methods to incorporate swirling flow. The swirl burners are designed to have the same total exit area as the Benchmarking cooker, and the three cookers have the same hydraulic diameter of $d = 21.2$ mm. For the Benchmarking cooker, the non-dimensional jet-to-jet spacing is $S/d = 0.18$.

The flame from Swirl Burner I is produced by continuous swirling flow, namely, curved flow. Ten guided vanes are fabricated, as shown in Fig. 1(b), and the air/fuel mixture flowing through the curvy channels is guided to form ten separate swirling flame jets. The curvy channel has an inclination angle of $\alpha = 60°$ and a radius of 3 mm, whereas the non-dimensional jet-to-jet spacing, S/d, is 0.8. Bilen et al. [8] suggested that for guided vanes swirl generator, the geometric swirl number can be calculated as:

$$S_n = \frac{2}{3}\frac{(1-\alpha^3)}{(1-\alpha^2)}\tan\theta \quad (1)$$

where θ is angle between swirl vane and vane axis and a is hub ratio. For Swirl Burner I, the swirl number is calculated to be 0.45.

Fig. 1(c) shows that Swirl Burner II incorporates both swirling motion and inward motion. The concave surface of the burner cap has an inclined angle of $\alpha = 30°$ towards the horizontal plane, and the slots are fabricated with an angle of $\beta = 10°$ off the normal direction of the surface, such that a skewed channel, similar to that of guided vane, is formed inside each slot. The non-dimensional

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http://dx.doi.org/10.1016/j.fuel.2013.11.025

Nomenclature

H	burner-to-pot distance (m)	LHV_{fuel}	lower heating value of the fuel (kJ kg^{-1})
d	hydrodynamic diameter of the burner, $d = \sqrt{4A_t/\pi}$ (m)	m_{fuel}	mass of fuel consumed (kg)
S	jet-to-jet spacing (m)	m_{water}	mass of water heated by the impinging flame (kg)
Re	reynolds number of the air/fuel mixture flow	T	temperature (K)
Φ	equivalence ratio of the air/fuel mixture	C_{water}	specific heat of water (kJ kg^{-1} K^{-1})
η	heating efficiency of the impinging flame		

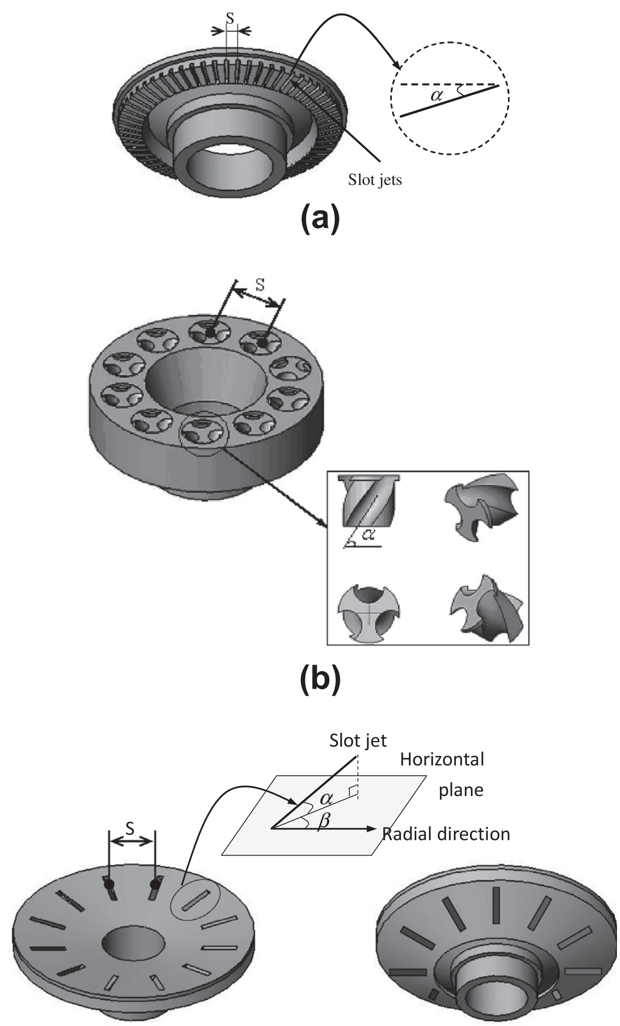

Fig. 1. (a) Benchmarking cooker. (b) Swirling Burner I. (c) Swirl Burner II.

jet-to-jet spacing (S/d) is 0.8. Note that in Fig. 1(c), the slots can not be seen through due to the skewed channels fabricated. So, Swirl Burner II creates both a tangential motion of the jets to generate a swirling motion and an inward motion. By referring to Eq. (1), the swirl number for Swirl Burner II is estimated as 0.35, smaller than that of Swirl Burner I.

3. Experimental investigation

The experimental setup is shown in Fig. 2. Commercial LPG and compressed air were metered and then premixed in an aluminum cylinder before entering the burners. At the inlet of the burners, the suction throat for natural aeration was sealed. The heating efficiency of the flames was measured according to National Standard of the People's Republic of China [9]. A pot filled with 750 ml of water was placed above the burners. A stopwatch was used to record the time required by the water to achieve a temperature rise of 60 °C. The water temperature was monitored with a T-type thermocouple with an accuracy of ±0.1 K. The heating efficiency can be determined by:

$$\eta = \frac{m_{water} C_{water} \Delta T}{m_{fuel} LHV_{fuel}} \quad (2)$$

Pollutant emissions of the flames were measured according to the standard in Ref. [9]. A sampling tube ring, connected to the Anapol EU-5000E exhaust gas analyzer for measuring the emission of CO, was set around the periphery of the pot and 4 cm above the bottom of the pot. The exhaust gases were only sampled after 15 min since ignition of the flame, and the averaged concentrations were reported. With the method suggested by Kline and McClintock [10], an error of 0.83% for heating efficiency and 8.8% for CO emission were estimated.

4. Results and discussions

4.1. Operation range

By measuring flame stability limits in terms of Reynolds number and equivalence ratio, the operation range of each burner

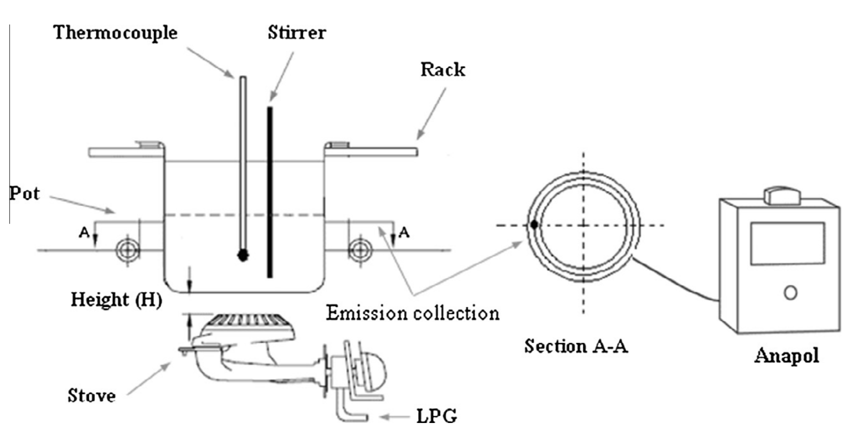

Fig. 2. Experimental setup.