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Design of a partially aerated naturally aspirated burner for producer gas

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ABSTRACT

This article presents a detailed methodology for the design of a partially aerated naturally aspirated burner used for combustion of the producer gas generated in a downdraft gasifier cookstove. The main difference between an LPG burner and producer gas burner is that the former uses a high velocity jet of gas at ambient temperature whereas the latter uses a low velocity, high mass flow rate, buoyant jet of gas at 100–300 °C. Due to the elevated temperatures, buoyancy force plays an important role in entraining combustion air into the burner for producer gas. This has been accounted for in the new methodology, developed based on the design procedure available in the literature for hydrocarbon fuels. A mathematical model for fluid flow and heat transfer through the burner has been developed to predict percentage of primary aeration in the burner at different producer gas flow rates. The pressure drops predicted by the model have been validated using experimental measurements. The predictions of the model have been used to corroborate the assumptions and heuristics used in the design methodology. The predictions have also been used to demonstrate the importance of considering buoyancy in burner design, by comparing with a burner designed ignoring buoyancy. With the use of the newly designed burner, the thermal efficiency of the gasifier cookstove was found to improve substantially. Carbon monoxide (CO) emissions from the cookstove using this burner were also found to be within the limits (<5 g/MJ_d) recommended in the Indian Standards for cookstoves.

1. Introduction

Partially aerated naturally aspirated burners are commonly used with gaseous hydrocarbon fuels. These burners entrain part of the combustion air, called primary air, and hence the name. Jones [1] presented a design methodology to calculate the important dimensions of such a burner. The relations developed by him have been used by other researchers for more detailed analysis [2,3]. Some researchers have focused on improving the performance of these burners by a variety of means such as bimetallic material for regulation of primary air [4]; a swirling flame [5]; porous burner materials [6–8] and flat flame burner [9]. Experimental and CFD analysis of gas burners has also been reported [10]. All the above literature pertains to hydrocarbon fuels, while literature on burners for renewable fuels such as producer gas is quite limited. Industrial size (about 150 kW_{th} capacity) fully premixed burners for efficient combustion of producer gas were developed by Bhoi and Channiwala [11] and Panwar et al. [12]. On partially aerated naturally aspirated burners for producer gas, no work has been found in the literature. The design methodology presented by Jones [1] neglects the buoyancy of the fuel gas, while the producer gas emanating from a gasifier is hot and hence is essentially buoyant. Thus there is a need to develop a methodology for burner design that takes buoyancy in fuel jets into account.

The present work aims at bridging this gap by first modifying the methodology of Jones [1] for a buoyant fuel gas. This methodology is then used to design a working prototype burner for producer gas. The prototype burner has been fabricated and tested experimentally. In addition, this burner has been analysed for its performance using a mathematical model of heat transfer and fluid flow through the burner. The model predictions are validated with the experimental measurement of pressure values at different locations in the burner. This model also predicts the primary aeration at different producer gas flow rates for a given burner geometry and hence also helps in identifying the limiting values of producer gas flow rates for which a given burner can be used. This article presents the design methodology; the results of burner testing; the

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Nomenclature

A	area (m^2)
B	width (m)
C_p	specific heat at constant pressure (kJ/kg k)
C_v	specific heat at constant volume (kJ/kg k)
D, d	diameter (m)
f	buoyancy flux (kg-m/s^3)
g	acceleration due to gravity (m/s^2)
h	heat transfer coefficient (W/m^{2}K)
H	Head loss (m)
k	thermal conductivity (W/mK)
l, L	length (m)
$\dot{m}$	mass flow rate (kg/s)
M	molecular weight (kg/kmol)
MO	momentum flux (kg-m/s^2)
Nu	Nusselt number
P	pressure (N/m^2)
p	perimeter (m)
Pr	Prandtl number
$\dot{q}$	rate of heat transfer (W)
R	gas constant (J/kgK)
Re	Reynolds Number
R_u	universal gas constant (J/molK)
$\bar{S}$	average dilution ratio
T	temperature °C or K
t	time (s)
v	velocity (m/s)
$\dot{V}$	volume flow rate (m^3/s)
X	Mole fraction
Z	Height (m)

Subscripts

0	initial or stagnation
∞	ambient
a	air
annu	annular
avg	average
B	base of fin
C	cross-sectional, critical
conv	convection
conver	converging
div	diverging
fin	Fin
i	injector
mix	mixture
p	port
pa	primary air
pg	producer gas
stoic	stoichiometric
t	throat

Greek symbols

ε	accuracy (kg/s)
ρ	density (kg/m^3)
f	friction factor
ξ	Graetz-type variable
μ	dynamic viscosity (Ns/m^2)
θ	angle (°)

details of the mathematical model and its predictions-all applied to the producer gas burner coupled to a domestic downdraft biomass gasifier cookstove. It also brings out the importance of accounting for buoyancy in the design of a burner through results of simulation. The design methodology presented here can be applied to any gaseous fuel at a temperature higher than ambient and hence having significant buoyancy.

2. Partially aerated gas burners

In a partially aerated naturally aspirated LPG burner, the flow of primary air is driven by the momentum of fuel gas. The basic configuration of the burner is same as that shown in Fig. 1. Pressurized LPG from a bottle flows through a pressure regulator, and is injected at a high velocity (~30 m/s) through an injector nozzle of small diameter (generally less than 1 mm in the case of domestic LPG burners), into the throat of a venturi. As the fuel jet and the air entrained by viscous shear move through the converging part of the venturi, the pressure decreases owing to acceleration of flow and becomes minimum at throat. This helps in drawing in more primary air. Typically, 60% of stoichiometric air is drawn as primary air. The air and fuel are mixed in a mixing chamber which forms the divergent part of the venturi burner. Pressure of the mixture gradually increases while moving from throat through the diverging part (the mixing chamber). The pressure of air-fuel mixture again drops to ambient as the flow passes through the burner ports.

Calorific value of LPG is around 90 MJ/Nm^3[13], while that of producer gas is much lower (4–5 MJ/Nm^3). Thus, for the same power as that of an LPG burner, the volumetric flow rate of

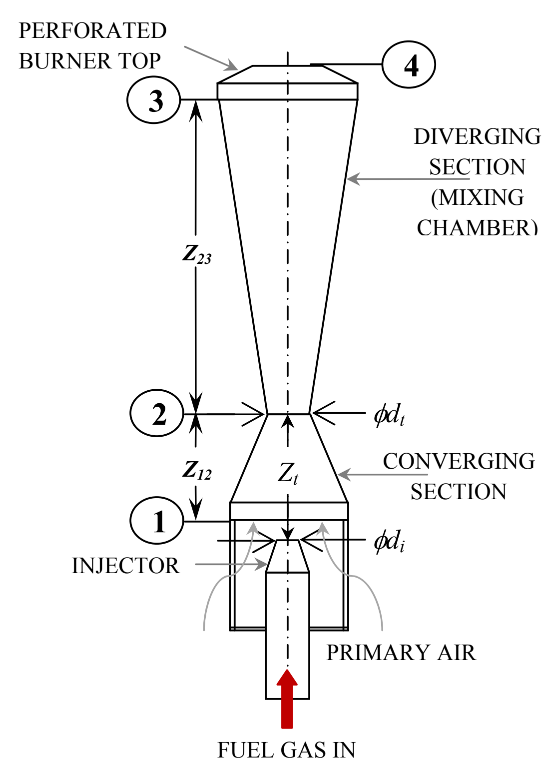

Fig. 1. Schematic of a partially aerated naturally aspirated burner.