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Performance evaluation of premixed burner fueled with biomass derived producer gas

P. Punnarapong, T. Sucharitakul, N. Tippayawong*

Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200 Thailand

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ABSTRACT

Energy consumption of liquefied petroleum gas (LPG) in ceramic firing process accounts for about 15–40% of production cost. Biomass derived producer gas may be used to replace LPG. In this work, a premixed burner originally designed for LPG was modified for producer gas. Its thermal performance in terms of axial and radial flame temperature distribution, thermal efficiency and emissions was investigated. The experiment was conducted at various gas production rates with equivalence ratios between 0.8 and 1.2. Flame temperatures of over 1200 °C can be achieved, with maximum value of 1260 °C. It was also shown that the burner can be operated at 30.5–39.4 kW_{th} with thermal efficiency in the range of 84 – 91%. The maximum efficiency of this burner was obtained at producer gas flow rate of 24.3 Nm^3/h and equivalence ratio of 0.84.

1. Introduction

With more than 550 factories across the country, ceramic making is one of the economically important industries in Thailand. In 2015, the overall ceramic industry earned over US$800 million in export value, accounting for 0.2% of Thailand's GDP [1,2]. The main ceramic products included kitchenware, floor tile, wall tiles, sanitary ware, souvenirs, ornaments, and insulators [3]. Manufacture of ceramic products involves four fundamental steps; shaping, drying, firing, and glazing. Ceramic firing is usually conducted under high temperature atmosphere in a kiln. To achieve proper thermal treatment of the ceramic products in the final two steps, accurate control of change in process temperatures is needed. Ceramic manufacturing industry utilizes LPG and natural gas as fuel. The manufacturing process is highly energy intensive. Specific energy consumption is estimated at about 5–60 GJ per ton of product [4]. For affected entrepreneurs, this high energy cost can make up to about 40% of the original cost impact on production. One of the solutions is to adopt alternative and less costly source of energy. However, important features of the substituted fuel to LPG are that it must be clean with combustion temperatures above 1200 °C [5].

Biomass is a strong candidate to replace LPG. A process of conversion of solid carbonaceous fuel into combustible gas by partial combustion is known as gasification. Gasification technology offers high thermal efficiency, good process controllability, economic viability and environmental acceptability while using agro and forestry residues available in rural areas. The resulting gas, known as producer gas, is more versatile in its use than the original solid biomass [6–9]. The producer gas can be used for thermal applications in boilers, drying units, chemical heating, cooking, ceramic kilns etc. through combustion of the gas in a burner [10–16].

The producer gas powered burner must be modified to produce high temperature heat to meet requirement of ceramic production. The present paper is concerned with the performance evaluation of developed premixed type gas burner for industrial applications.

* Corresponding author.
E-mail address: n.tippayawong@yahoo.com (N. Tippayawong).

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Nomenclature

A	Surface area of test rig (m^2)	Pr	Prandtl number (dimensionless)
D	Diameter of test rig (m)	Q_{loss}	Total heat loss (W/m^2)
E_{in}	Energy input rate (kW)	r	Radius of test rig (m)
g	Gravitational acceleration (m/s^2)	R	Thermal resistance (K/W)
h	Heat transfer coefficient (W/m^2 K)	Ra_L	Rayleigh number (dimensionless)
k	Thermal conductivity of material (W/m K)	T	Temperature (K)
l	Height of test rig (m)	β	1/ Film temperature (K^{-1})
LHV	Lower heating value (MJ/kg)	ε	Emissivity of material (W/m^2)
$\dot{m}$	Mass flow rate (kg/s)	η	Efficiency (dimensionless)
Nu	Nusselt number (dimensionless)	σ	Stefan–Boltzmann constant (W/m^2 K^4)
		υ	Kinematic viscosity of air (m^2/s)

2. Material and methods

2.1. Modified gas burner

An existing LPG burner of 50 kW_{th} was modified into a premixed burner for producer gas. The cross sectional view and components of the burner are shown in Figs. 1 and 2. The producer gas is supplied through a main tube with air in at a joining tube. The fuel and air are mixed in a mixing tube. The combustible mixture then goes through the burner stem with a swirl vane installed immediately before the gas exit for flame stabilization.

2.2. Experimental setup and procedure

Fig. 3 illustrates experimental setup for fuel gas generation and burning. Producer gas was generated from a gasifier designed and developed by Chiang Mai University. Charcoal was used as feedstock. Initially, 30–40 kg of charcoal was loaded into the gasifier and ignited with a torch. The blower was started and air was drawn through the top of the reactor. After 10–15 min, stable combustion zone was established and producer gas obtained was combustible. Subsequently, the gas burner inside a burner test rig is started.

The gas burner test rig (also shown in Fig. 3) was designed and developed to evaluate thermal performance of the burner. The rig was insulated with 150 mm thick ceramic fiber and covered with 3 mm steel sheet to maintain adiabatic condition. The flame was enclosed in the test rig in order to isolate it from the atmospheric conditions. There was circular toughened glass having size of 500×15×4 mm installed on the rig wall. The test rig had a number of vertically fixed and radially moveable temperature probes to measure the axial and radial flame temperature. Locations of temperature probe could be adjusted on vertical scale with 10 cm increment and on radial scale with 5 cm increment.

The premixed burner was operated at equivalence ratio between 0.8 and 1.2. The gas flow rate was varied from 21, 24 and 27 Nm^3/h. The observation data were taken after the stable operation of the system, i.e. constant raw gas temperature. Pt-Rh thermocouples and digital multi-channel temperature indicator were used to measure temperatures. Inclinometer manometers were used to measure the pressure drop at the orifice meter. Producer gas sample was collected by liquid displacement method and it was analyzed using gas chromatography (Shimadzu model GC-8A) to determine molar faction of H_2, O_2, N_2, CH_4, CO and CO_2. The orifice plates were used to determine the flow rates of producer gas and air. Excess O_2 were measured using combustion analyzer (Testo model 350X-L). NOx emissions were measured using nitrogen oxides test tube (Gastec tube No. 10). CO was measured using gas chromatography. Performance parameters like physical and thermal properties of fuel, axial and radial temperature distributions of flame, producer gas temperature at gasifier exit, pressure drop at orifice plate, and calorific value of producer gas were constantly monitored. Each test run was repeated for at least three times.

2.3. Heat transfer analysis

The thermal efficiency of the burner was defined as

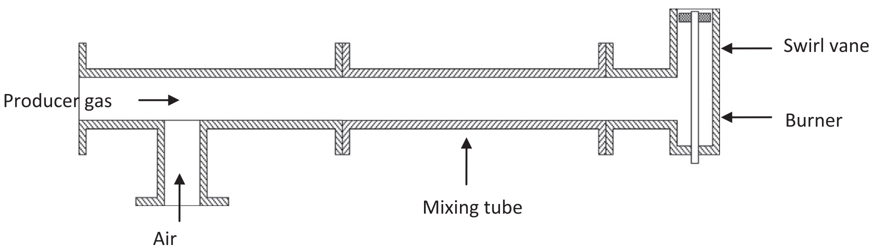

Fig. 1. Cross sectional view of producer gas premixed burner.