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Development and performance evaluation of a biomass gasification system for ceramic firing process

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Abstract

Ceramic products are manufactured in many countries worldwide. Ceramic manufacturing industry is vital in terms of employment and economics. The industry is very energy intensive, consuming large amount of fuels. Liquefied petroleum gas (LPG) and natural gas are usually used, representing a significant portion of the total production cost. Switching to alternative gaseous fuel such as biomass derived producer gas may result in lower energy cost. Producer gas generated from biomass gasification process contains H_2, CO and CH_4 which are combustible. Under carefully controlled conditions, burning of producer gas can provide suitable firing atmospheres for manufacture of ceramic products. In this work, attempt has been made to develop a 600 kW_{th} biomass gasification system for ceramic firing. Woodchips were used as fuel. Product gas was generated and analyzed for its composition and energetic content. Firing of this fuel gas in place of LPG with modified gas burners in a firing chamber and preliminary testing at a local ceramic factory were carried out and demonstrated. It was found that required heat outputs and high temperature conditions were realized. Acceptable quality of the ceramic products was obtained. A simple economic analysis yielded an attractive return on investment. This proved to be a very promising energy option for substitution of fossil based gaseous fuels in ceramic industry.

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Keywords: Bioenergy; Energy conservation; Producer gas; Renewable energy; Thermochemical conversion

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1. Introduction

Ceramic product is referred to any pottery made from fired high quality clay, silica and feldspar. Manufacture of ceramic products takes place in different types of kilns, involving four basic steps; shaping, drying, firing and glazing. During firing step, accurate temperature evolution is necessary to ensure that the right heat treatment of the products is obtained. Controlled cooling is subsequently required for the products to gradually release heat and preserve their structure. Afterwards, they are packaged and stored for delivery.

Ceramic manufacturing industry is vital to the economy of many countries, including Thailand. It is a source of employment and occupation of the local people, generating income for Thailand's economy. Original ceramics industry was mainly distributed in Samutsakhon, Saraburi, Chiang Mai, and Lampang. Ministry of Industry revealed that the number of industrial ceramic operations across the country was about 530 ceramic factories [1]. Export of ceramic products generates large revenue from Japan, China, USA, Australia, Germany and Asian countries, totalling about 725 million USD in 2013. The products exported include wall tiles, floor tiles, sanitary ware, tableware and other ceramic products. Production and sales of ceramic products are likely to increase due to growth in domestic demand and global economic recovery [2].

For ceramic firing procedure, thermal energy is usually provided from combustion of liquefied petroleum gas (LPG) or natural gas. This process is energy-intensive, consuming large amount of gaseous fuels. Ceramic manufacturing industry requires LPG and natural gas as fuel, accounting for approximately 15-40% of production costs [3]. Energy conservation measures are urgently needed for the industry to remain competitive. One of the possible solutions is switching to alternative gaseous fuel such as biomass derived producer gas that may result in lower energy cost.

Producer gas is from conversion of solid biomass into fuel with the fuel synthesis process called gasification. Energetic content of the producer gas is in the range of 3-6 MJ/Nm^3 if air is used as gasifying agent. Composition of the producer gas is dependent on conditions, techniques, production methods, but it contains combustible gases, mainly CO, H_2, and CH_4, from the following reactions;

Gasification: $$\text{Biomass} \rightarrow \text{char} + \text{tar} + \text{gases } (H_2, CO, CO_2, CH_4) \quad (1)$$

Thermal decomposition: $$\text{tar} \rightarrow \text{gases } (H_2, CO, CO_2, CH_4) \quad (2)$$

Boudouard reaction: $$C + CO_2 + 162 \text{ kJ/mol} \leftrightarrow 2CO \quad (3)$$

Steam reforming reaction: $$CH_4 + H_2O(g) + 206 \text{ kJ/mol} \leftrightarrow CO + 3H_2 \quad (4)$$

Water gas reaction: $$C + H_2O(g) +131 \text{ kJ/mol} \leftrightarrow CO + H_2 \quad (5)$$

Water–gas shift reaction: $$CO + H_2O - 41 \text{ kJ/mol} \leftrightarrow CO_2 + H_2 \quad (6)$$

Oxidation: $$C + O_2 - 408.8 \text{ kJ/mol} \leftrightarrow CO_2 \quad (7)$$

Hydrogasification: $$C + 2H_2 + 75 \text{ kJ/mol} \leftrightarrow CH_4 \quad (8)$$

Methane steam reforming reaction: $$CO + 3H_2 - 206 \text{ kJ/mol} \leftrightarrow CH_4 + H_2O \quad (9)$$
$$CO_2 + 4H_2 - 165 \text{ kJ/mol} \leftrightarrow CH_4 + 2H_2O \quad (10)$$

Gasification offers optional conversion technology for the biomass residues available that has high thermal efficiency and environmental acceptability. The technology is well established and employed in many countries to generate electricity, synthetic fuels, and process heat [4-6]. It has been demonstrated to be relatively economical for use in small and medium enterprises and in rural areas [7-11]. For direct thermal application, many types of biomass gasifiers have been developed and demonstrated. Among the most popular designs of gasifier adopted was downdraft system from experimental reactors to commercially installed systems [7, 12, 13]. The technology may be adopted by ceramic manufacturing industry.