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Combustion characteristics of premixed propane flame with added H_2 and CO on a V-shaped impinging burner

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ABSTRACT

The combustion characteristics of H_2/C_3H_8/air and CO/C_3H_8/air premixed flames on a V-shaped burner have been investigated experimentally for future blended fuels with flow visualization, chemiluminescence and analysis of exhaust gases. The lean flammability of H_2/C_3H_8/air is expanded to 0.38 and that of CO/C_3H_8/air is expanded to 0.50 on the V-shaped burner. The flame configurations, flow structures, distributions of chemiluminescence intensity of CH* and OH*, flame temperatures and CO emissions under varied mixture conditions were recorded during the combustion. Two flame configurations were observed – of types M and hill. The addition of H_2 and CO to the fuel altered the flame pattern from hill-type to M-type (shorter flame) because the burning velocity, temperature and flame intensity increased with the addition of H_2 and CO in the fuel. Analysis of flow visualization and chemiluminescence revealed the impinging effect, in which the collision of mixture jets decreases the main flow velocity and increases the residence time. It results in a greatly decreased leakage of the unburned mixture with accumulated heat acting as a well stirred combustible mixture for improved flame stabilization. At $\phi = 0.6$, the flame temperature of H_2/C_3H_8/air with M-type flame is 1.37 times that of CO/C_3H_8/air with hill-type flame, while the C_3H_8/air flame is extinguished. The combustion of CO that occurs in the impinging region resulted in decreased CO emissions when the addition of CO to the fuel surpassed 73.7%. These findings about the combustion characteristics, mechanisms and effects of fuel variability provide industries with an effective concept of burning blended fuels, and are applicable to syngas combustion.
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Introduction

As climate change and environmental protection are currently major concerns in the world, the improved use of energy and decreased pollution become critical issues. To decrease the consumption of hydrocarbon fuel while maintaining energy security at the same level, the concept of combustion under lean conditions with added syngas or blended fuels is regarded as a feasible and further attractive way to fulfill these two requirements. Syngas is a mixture of many substances, primarily hydrogen and carbon oxide; other

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combustible gas including methane and higher hydrocarbons are present in trace proportions. The catalysis of biomass, such as wood and corn, under specific conditions might produce syngas without adding carbon to the entire carbon cycle, but both the quality of biomass and the condition of the catalysis might affect the components and composition of the produced syngas. Because of the varied components in the syngas, the detailed characteristics, including flame-flow interaction, physical and chemical effects, and the feasibility as a blended fuel, for syngas combustion remain unclear [1] and increase the difficulty in practical applications. For the design of the industrial burners with high efficiency and low emission, these substantial variations in composition and heating value might be the largest obstacle [2]. Investigation of the phenomena of syngas combustion hence plays an important role in the development of an effective and clean combustion of syngas. Much research has been done on the fundamental combustion characteristics [3,4]; some fundamental issues, such as the effects of dilution with inert gas [5] and the effects of Lewis number (*Le*) [4,6] on syngas combustion, have been addressed. The characteristics of a H_2/CO/air flame such as the flame structure, chemical reaction and fluid dynamics have been extensively investigated [7,8] and summarized [1].

A fuel composition varied through addition of hydrogen and carbon monoxide affects the chemical and physical processes in flames, such as the flame stability, flame-flow interactions, pollutants and efficiency. Hydrogen is considered to be a clean fuel with increased energy content and a low level of emissions, but its small volumetric density and ignition energy in nature restrict its use. The burning velocity and temperature of a flame were found to increase on addition of hydrogen to a premixed flow [9–11]. The effects of temperature on the combustion of hydrogen are investigated because of the varied sensitivity and chain propagation reactions [12]. To improve the safety of use of hydrogen, the effect of hydrocarbon added in small proportions on the kinetics of hydrogen-containing mixtures was investigated [13]. The combustion characteristics of CO, which is a leading intermediate during the reaction, differ from those of a commonly used fuel such as hydrogen and alkanes; the triple bond between C and O raises the activation energy of CO [14], causing difficulty in burning CO; the emission of unburned CO after the combustion of syngas constitutes pollution. The chemical kinetics [15–18] of syngas combustion indicate that adding a hydrogen-containing species in a small proportion can significantly accelerate the oxidation of CO through the reaction $CO + OH = CO_2 + H$, which is critical to the combustion of both fossil fuel and syngas. To understand further the characteristics of combustion with added CO, hydrocarbon flames that have been widely investigated, with addition of CO, were examined [19–21]. The effect of added hydrocarbon on the chemical kinetics of the CO flame was investigated [22]. Wu et al. [19] showed that the effect of added CO on the burning velocity of stoichiometric flames is dominated by some chemical kinetic steps.

The varied flow field causes also a varied combustion performance; many studies have been conducted to understand the characteristics of combustion in various flow fields. In this work we employed a V-shaped burner to form an impinging flow field. Such a flow field, covering varied fluid phenomena, heat transfer, boundary layers and strong curvature effects [23], has been investigated to improve the combustion efficiency and to decrease the pollutants [24–26] for two major reasons – the diverse applications of impinging flows and the simple geometry. In preceding work [27], a V-shaped burner in which a premixed flame of propane, a major fuel for both domestic and industrial use, interacted with an intersecting flow was demonstrated to achieve an excellent performance. The rich combustion of propane on a V-shaped burner clearly shows the benefits of extended residence time and accumulation of heat in the impinging region, and hence contributed to a superior performance. The main aim of our work was to investigate the flame characteristics of the lean combustion of propane with varied addition of H_2 and CO to the fuel on a V-shaped burner. The operating range of the lean propane flame with varied addition of H_2 and CO to the fuel on flat burner and V-shaped burner was obtained. The transition of flame configurations, enhanced flame stability, and tip-opening phenomena were observed and were investigated on analyzing visualized flow fields, chemiluminescence intensity of CH* and OH*, flame temperatures and CO emissions.

Experiments

Burner

For the comparison of the operating range and to study the influence of H_2 and CO added to a lean propane flame, the flat-type burner and V-shaped impinging burner were made of stainless steel (#310); Fig. 1a shows a photograph of the two burners and Fig. 1b shows sections including two honeycombs with varied aperture and the burner structure. Fig. 1c shows the exit comprising two planes inclined at angles 45° on a V-shaped impinging burner, with 16 rectangular slots (length 5 mm, width 2 mm) on each plane. The flow from the exit was

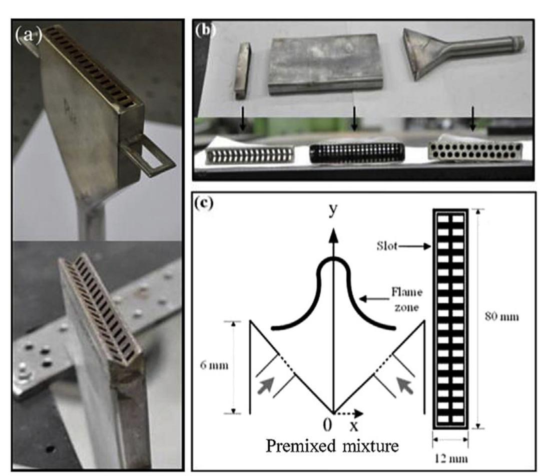

Fig. 1 – (a) Photographs of a flat-type burner (upper) and V-shaped burner (lower), (b) position of a honeycomb plate made of stainless steel, and (c) schematic diagram of the V-shaped burner.

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