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The influence of CO2 in biogas flammability limit and laminar burning velocity in spark ignited premix combustion at various pressures 2

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The Influence of CO2 in Biogas Flammability Limit and Laminar Burning 2

Velocity in Spark Ignited Premix Combustion at Various Pressures

W. Anggono1,a), I. N. G. Wardana2, M. Lawes3, K. J. Hughes4, S. Wahyudi5, N. Hamidi6 and A. Hayakawa7 1Mechanical Engineering Department, Petra Christian University, Surabaya, Indonesia 2,5,6Mechanical Engineering Department, Brawijaya University, Malang, Indonesia. 3School of Mechanical Engineering, The University of Leeds, Leeds, LS2 9JT, UK 4Department of Mechanical Engineering, The University of Sheffield, Sheffield, S1 3JD, UK. 7Institute of Fluid Science, Tohoku University, Sendai, Japan a) Corresponding author: willy@petra.ac.id Abstract.Biogas is an alternative energy source that is sustainable and renewable containing more than 50% CH_4 and its biggest impurity or inhibitor is CO_2. Demands for replacing fossil fuels require an improved fundamental understanding of its combustion processes. Flammability limits and laminar burning velocities are important characteristics in these processes. Thus, this research focused on the effects

of CO2 on **biogas flammability** limits **and laminar burning** velocities **in spark ignited** premixed **combustion.** 2

Biogas was burned in a spark ignited spherical combustion bomb. Spherically expanding laminar premixed flames, freely propagating from spark ignition in initial, were continuously recorded by a high-speed digital camera. The combustion bomb was filled with biogas-air mixtures at various pressures, CO_2 levels and equivalence ratios (ϕ) at ambient temperature. The results were also compared to those of the previous study into inhibitorless biogas (methane) at various pressures and equivalence ratios (ϕ). Either the flammable areas become narrower with increased percentages of carbon dioxide or the pressure become lower. In biogas with 50% CO_2 content, there was no biogas flame propagation for any equivalence ratio at reduced pressure (0.5 atm). The results show that the laminar burning velocity at the same equivalence ratio declined in respect with the increased level of CO_2. The laminar burning velocities were higher at the same equivalence ratio by reducing the initial pressure. INTRODUCTION Biogas is an alternative source of energy that is sustainable and renewable. The main sources of biogas are organic animal waste that when broken down by anaerobic bacteria forms biogas in digestion tanks, where the humidity and temperature are controlled, to optimize biogas production. Biogas contains over 50% methane, other impurities or inhibitors are carbon dioxide and nitrogen, as well as small amounts of H_2, O_2, H_2S and others. Inhibitors are defined as substances that reduce laminar burning velocity [1]. A previous study found that carbon dioxide effects biogas combustion by reducing its flame speed [2].However, the effects of carbon dioxide in biogasflammability limits and laminar burning velocities, as themost important fundamental combustioncharacteristics of the fuel, have notbeen studied yet. Thus, the aim of this paper is to investigate

the influence of CO2 in biogas flammability limits **and laminar burning** velocities **in spark ignited premix combustion at various pressures.** 2

The world energy council has stated that energy demand will increase along with economic growth. BP similarly projected that by 2035 global energy consumption would increase by 37%. Consequently, energy supply and source have become increasingly important. Energy can be divided into two different types, conventional energy and unconventional energy (renewable energy). Renewable energy demand is growing fast at 6.3% annually [3]. Sustainable Energy and Advanced Materials AIP Conf. Proc. 1717, 030001-1–030001-7; doi: 10.1063/1.4943425 © 2016 AIP Publishing LLC 978-0-7354-1365-8/$30.00 As a fuel, the methane component of biogas has both technical and environmental advantages and it can reach high temperatures similar to those of hydrocarbon fuels but generates fewer emissions [4-6]. Biofuels as both liquids and gases have become the subject of much interest and research throughout the world. As fossil fuel costs have risen ever higher, it has become an important potential form of fuel, particularly to developing countries with high fossil fuel import costs. In addition, biofuels have the potential to fulfill demands for replacing fossil fuels in order to reduce emissions but requires an improved fundamental understanding of its combustion processes. Flammability limits and laminar burning velocities are the most important characteristics in the combustion process. Thus, this research was conducted to uncover the flame characteristics in biogas spark ignited premixed combustion. The spark ignited premixed combustion characteristics (flammability limits and laminar burning velocities) are important to several biogas combustion applications especially for internal combustion engines. In addition to biogas use in its internal combustion engines, there has been research into combustion and emissions characteristics for use in dual fuel engines. These dual fuel engines consume two types of fuel, gaseous fuel known as primary fuel and liquid fuel known as pilot fuel and methane, the main component in biogas, produces far lower emissions of NOx when burnt than other hydrocarbon fuels [1,2,5,7,8]. Combustion can be defined as an exothermic chemical reaction between fuel, oxidizer and igniter. In this experiment, biogas was employed as the fuel, oxygen as the oxidizer and a spark as the igniter. The experiment was conducted at both ambient temperatures and atmospheric pressures using the stoichiometric standard. The equivalence ratio (ϕ) is commonly used to determine whether the fuel-oxidizer mixture is stoichiometric ($\phi=1$), lean ($\phi<1$), or rich ($\phi>1$). Stoichiometric condition is useful for some applications. This application can also reduce the exhaust emissions and improve thermal efficiency. For most kinds of fuel, the lean mixtures have slower flame speed than rich mixtures [9]. Flame diffusion or propagation plays a vital role in the success of combustion ignition. For instance, the flame speed data is used to specify the internal combustion chamber material and other parts that are directly connected to the chamber. During a methane explosion, theoretically, the biogas combustion compresses the medium in front of the flame front surface and creates a compression wave. Due to the chemical reaction, the flame propagates very fast. As a result, the pressure, density, and temperature rise sharply to establish a detonation wave [10-11]. EXPERIMENT METHODS A Spherical spark ignited premixed combustion bomb was used for the biogas combustion research as mentioned in the previous studies [1-2,5,12-17], the combustion bomb is filled with fuel-air mixtures with the various carbon dioxide compositions (25% and 50%) in biogas. All the experiments were conducted at various pressures (atmospheric pressure (1 atm) and reduced pressure (0.5 atm)), various equivalence ratios (from lower flammability limits to upper flammability limits) and ambient temperatures. The experimental results were also compared to those of the previous study on methane (inhibitorless biogas) at various pressures and various equivalence ratios. The schematic diagram of the combustion bomb system is shown in Fig. 1. The laminar burning velocity of a spherically expanding flame was deduced from the high speed camera images, the procedures to find the laminar burning velocities can be found in the previous studies[1-2,5,12-17]. FIGURE 1.Schematic diagram of the combustion bomb system RESULTS AND DISCUSSION The fuel (biogas with 25%CO_2)-air mixtures produced propagating flames at atmospheric pressure for the equivalence ratios of 0.6, 0.8, 1.0, 1.2 and 1.3. The mixtures were centrally ignited and the resulting flame propagation was recorded at 2500 frames/second by a high speed camera. The images of the spherical flame flaring within the combustion chamber with 150 mm diameter windows are lain out in Fig. 2. At ambient temperatures and atmospheric pressure, no flames were propagated from the rich ($\phi=1.4$) and lean fuel-air mixtures ($\phi=0.50$). As seen from the prior experimental investigations to find the laminar burning velocities [1-2,5,12-17], the laminar burning velocities of biogas-air mixtures premixed combustion has been found for biogas with 25% CO_2 at atmospheric pressure, ambient temperature and various equivalence ratiosas shown in Table 1. FIGURE 2.The biogas with 25%CO_2 flame propagation at atmospheric pressure TABLE 1. Laminar burning velocities of biogas with 25% CO_2 at atmospheric pressure Equivalence Ratio Laminar Burning Velocity (m/s) 0.5 No Propagation 0.6 0.080 0.8 0.229 1.0 0.289 1.2 0.236 1.3 0.144 1.4 No Propagation The fuel (biogas with 50%CO_2)-air mixtures produced propagating flame at atmospheric pressure for the equivalence ratios of 0.6, 0.8, 1.0 and 1.2. At ambient temperatures and atmospheric pressure, no flames were propagated from the rich (ϕ=1.3 and ϕ=1.4) and lean (ϕ=0.5) fuel-air mixtures. The images of the spherical flame flaring within the combustion chamber with 150 mm diameter windows are lain out in Fig. 3. As seen from the prior experimental investigations to find the laminar burning velocities [1-2,5,12-17], the laminar burning velocities of biogas-air mixtures premixed combustion has been found for biogas with 50% CO_2 at atmospheric pressure, ambient temperature and various equivalence ratios as shown in Table 2. FIGURE 3.The biogas with 50%CO_2 flame propagation at atmospheric pressure TABLE 2. Laminar burning velocities of biogas with 50% CO_2 at atmospheric pressure Equivalence Ratio Laminar Burning Velocity (m/s) 0.5 No Propagation 0.6 0.061 0.8 0.154 1.0 0.189 1.2 0.117 1.3 No Propagation 1.4 No Propagation The fuel (biogas with 25%CO_2)-air mixtures produced propagating flame at reduced pressure (0.5 atm) for the equivalence ratios of 0.7, 0.8 and 0.9. At ambient temperatures and reduced pressure, no flames were propagated from the rich (ϕ=1.2, ϕ=1.3 and ϕ=1.4), stoichiometric (ϕ=1.0) and lean (ϕ=0.5 and ϕ=0.6). The images of the spherical flame flaring within the combustion chamber with 150 mm windows are lain out in Fig. 4. As seen from the prior experimental investigations to find the laminar burning velocities [1-2, 5, 12-17], the laminar burning velocities of biogas-air mixtures premixed combustion has been found for biogas with 25% CO_2 at reduced pressure, ambient temperature and various equivalence ratios as shown in Table 3. FIGURE 4.The biogas with 25%CO_2 flame propagation at reduced pressure TABLE 3. Laminar burning velocities of biogas with 25% CO_2 at reduced pressure Equivalence Ratio Laminar Burning Velocity (m/s) 0.5 No Propagation 0.6 No Propagation 0.7 0.187 0.8 0.252 0.9 0.292 1.0 No Propagation 1.2 No Propagation 1.4 No Propagation The fuel (biogas with 50%CO_2)-air mixtures at reduced pressure (0.5 atm) were shown no propagating flame for all various equivalence ratio and there are no flammable area for this fuelas shown in Table 4. For better understanding, the flammability limits and laminar burning velocities of various levels of CO_2 in biogas both at reduced pressure and atmospheric pressure are presented in Fig. 5. TABLE 4. Laminar burning velocities of biogas with 50% CO_2 at reduced pressure Equivalence Ratio Laminar Burning Velocity (m/s) 0.5 No Propagation 0.6 No Propagation 0.7 No propagation 0.8 No Propagation 0.9 No Propagation 1.0 No Propagation 1.2 No Propagation 1.4 No Propagation FIGURE 5.The Biogas Flammability limits and laminar burning velocities of various levels CO_2 Carbon dioxide inhibits laminar burning velocity by diluting the concentration of reactive species in the biogas- air mixtures for a given equivalence ratio, and also by absorbing some of the heat thus reducing both the flame temperature and chemical reaction rates. The effect of CO_2 is more pronounced due to the relatively higher proportion of this inhibitor. At lower pressures, laminar burning velocities are higher, as lower pressures cut back diffusion times, raise residence times and thermal diffusivity which lowers reaction times and thus increases laminar burning velocities. In biogas with a 25% content of CO_2 at lower pressures, the flame propagates within a very narrow range of equivalence ratios, whereas, biogas with 50% CO_2 at reduced pressures has no propagating flame for all the equivalence ratios. For at this level, the inhibition of CO_2 is enhanced to such an extent that the extremely low reaction heat energy is only enough for burning the mixtures within a very limited range of equivalence ratios. CONCLUSION The flammable areas become narrower with increasing percentages of carbon dioxide or lowering pressure, there was no flame propagation of biogas with 50%CO_2 content at reduced pressure (0.5 atm) and various equivalence ratios. The results show that the laminar burning velocity at the same equivalence ratio declined in respect with the increased level of carbon dioxide. The laminar burning

velocities were higher at the same equivalence ratio by reducing the initial pressure.
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