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Experimental study on the flame propagation and laminar combustion characteristics of landfill gas

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A B S T R A C T

Biogas is the least expensive renewable energy source with an almost neutral balance of CO_2 emissions. As a type of biogas, landfill gas could potentially be used in the internal combustion engines, gas turbines, and industrial furnaces. However, the combustion characteristics of landfill gas, which are the foundations of further use of the landfill gas, are not clear. In this paper, the flame propagation characteristics of landfill gas were measured in a constant volume combustion chamber using a schlieren system. The experiments were conducted over the equivalence ratio range of 0.7–1.4, the pressure range of 0.1–0.5 MPa, the temperature range of 290–380 K, and the methane contents of 47%, 55.5% and 59%. The main influencing factors of the combustion stability and laminar combustion velocity of landfill gas in laminar combustion were also investigated. The results showed that the preferential diffusion or buoyancy instability appeared during the flame propagation process, and flame front exhibited irregular cellular structure and protuberances or the flame core moved upward under the condition that the Markstein number was small or the laminar burning velocity was lower than 0.15 m/s. At the same time, the Markstein number and the stability of the flame front decreased with a lower equivalence ratio and methane content or higher initial pressure. However, the effect of the initial temperature on the Markstein number was not obvious. The unstretched flame velocity and the laminar combustion velocity initially increased and then gradually decreased with the increase of the equivalence ratio, and the maximum values were measured under the condition that the equivalence ratio was 1.1. Furthermore, the laminar combustion velocity of landfill gas decreased with a higher initial pressure or lower initial temperature and methane content.

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1. Introduction

For the purposes of reducing CO_2 emissions during combustion of fossil fuels and removing wastes due to environmental and health concerns, biomass derived gas (biogas), which is an attractive and potentially renewable energy source from living such as wood, waste, landfill, and alcohol fuels via gasification, pyrolysis or fermentation processes, has been widely studied to replace fossil fuels [1]. At the same time, financial incentives for the production and utilization of biogas were introduced in many countries. In Italy for example, as discussed by Patrizio et al. [2], almost 800 biogas power plants were operating at the end of 2012 with a total capacity of 650 MW. China has committed itself to further promotion of small- and large-scale biogas projects to become less reliant on fossil fuels [3]. In 2000, the Chinese Ministry of Agriculture proposed the 'Prosperous eco-farmyards' plan, which aims to improve rural living standard and reduce the environmental pollution caused by rural energy use at the same time. Following this, a national rural biogas construction plan for the period from 2003 to 2010 was issued to further promote household-based biogas digester project across the whole country. In 2007, the national rural biogas construction plan was updated with targets of 40 million household-based digesters in 2010 and 80 million units maintained in 2020, and a new development plan for the agricultural bio-energy industry was carried out regarding household-based biogas construction as the most important instrument in the development of rural renewable energy [4].

With economic developing, urban-population growing, and living standards improving, the municipal solid wastes are rapidly increased. In the next 10–15 years, municipal solid waste is

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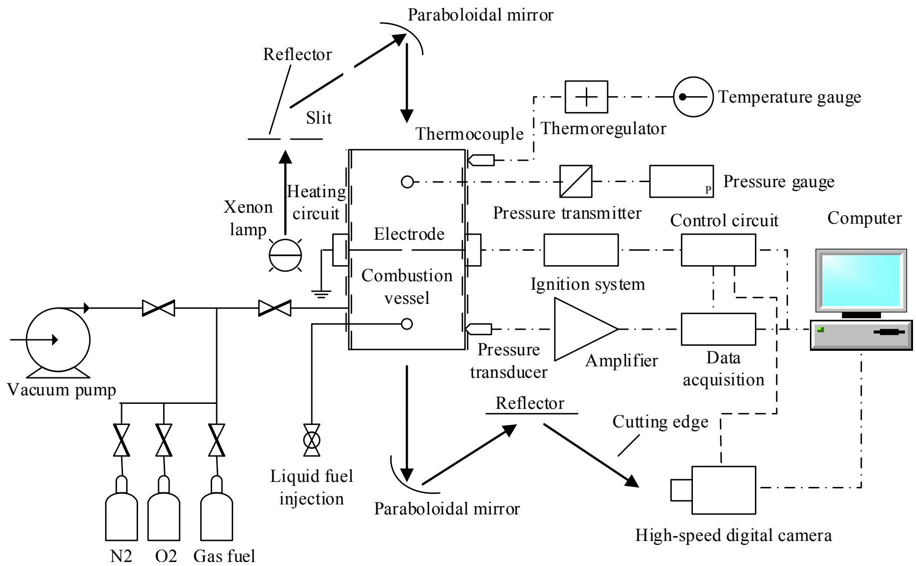

Fig. 1. Schematic diagram of the experimental facility.

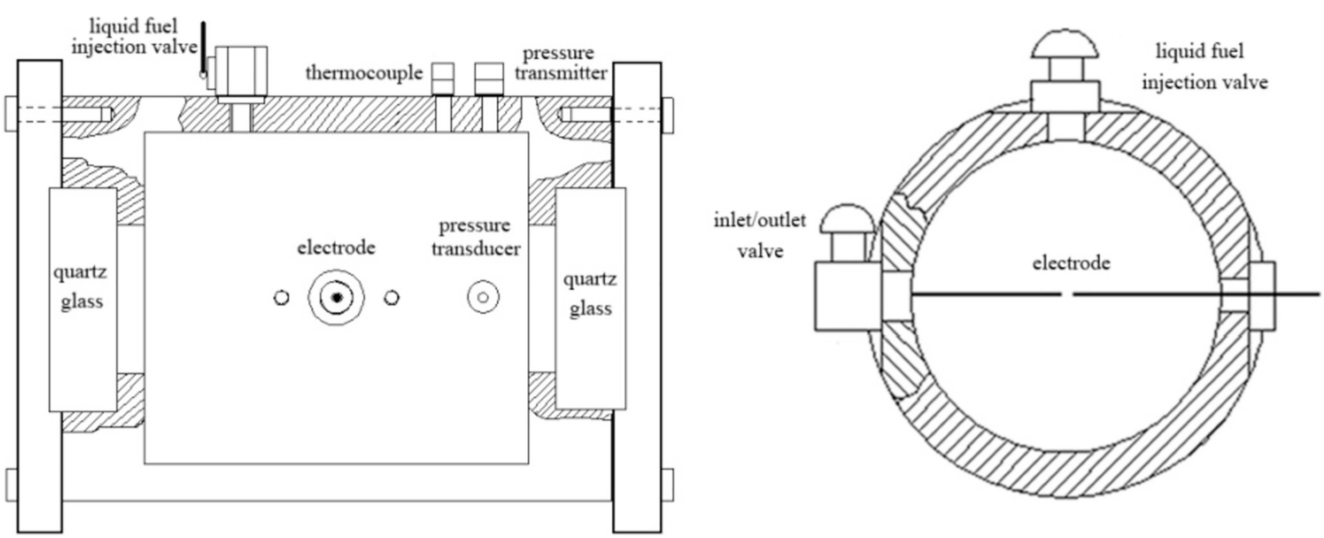

Fig. 2. Schematic diagram of the constant volume bomb.

Table 1
Compositions of landfill gas (volume fraction, **%**).

Composition ratio	CH_4	CO_2	O_2	N_2	H_2S	NH_3	H_2	CO	others
Reference ratio	47–59	35–41	<1	1–17	0–1	0.1–1	0–0.2	0–0.2	0.01–0.6
Distribution ratio (No.1)	47	35.5	0.5	17	0	0	0	0	0
Distribution ratio (No.2)	55.5	27	0.5	17	0	0	0	0	0
Distribution ratio (No.3)	59	23.5	0.5	17	0	0	0	0	0

estimated to increase at the rate of 2.3%–3.3% per year in China. Municipal solid-waste pollution has become a very serious social and environmental problem. The general treatment of municipal solid waste is through landfill. Given the high perishability and moisture content, these municipal solid wastes will be rapidly degraded, and generate a lot of landfill gases, resulting in high resource potential of the landfill. As a type of biogas, landfill gas is a combustible mixture containing gaseous combustible components, such as CH_4, H_2, and CO, with a calorific value of 4600 kcal/m^3. When landfill gas is used as fuel to generate electricity, it can not only recycle the resources, but also reduce the emission of polluted gas, resulting in significant economic and social benefits [5].

At present, the design fuel of the gas turbine for power generation is basically natural gas or light diesel. For the gas turbine using natural gas as fuel, when the fuel is changed from natural gas to landfill gas, the fuel composition changes, and the calorific value decreases (the calorific value of methane is 8580 kcal/m^3, and the calorific value of diesel is 9500 kcal/m^3). Moreover, the requirements of environmental protection, as well as the reliability and economy of the gas turbine have to be met. At the same time,

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