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Development of biogas combustion in combined heat and power generation

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A B S T R A C T

Based on the biogas feedstock and its generation cycle, a considerable part of biogas ingradients are noncombustible gases. Low calorific value (LCV) of biogas is one of the most important barriers of biogas development in the combined heat and power (CHP) generation. Biogas purification is usually performed in sensitive utilizations, however modification methods such as cryogenic and membrain are not economic. Therefore, new methods of biogas utilization should be experimented. In this study, characteristics of biogas are investigated under various combustion regimes such as biogas conventional combustion, hydrogen-enriched biogas traditional combustion, biogas flameless mode and hydrogen-enriched biogas flameless combustion. Since biogas conventional combustion is not well-sustained due to LCV of biogas, hydrogen addition to the biogas components could improve combustion stability however NO_x formation increases. Although flameless combustion of fosil fuel have been developed, few documents could be found about biogas flameless mode. Flameless combustion of biogas could be one of the best methods of pure biogas utilization in CHP generation. Combustion stability and low pollutant formation are the main advantages of biogas flameless combustion. The initial cost of flameless combustion instalation is high due to the cost of instrumentation and special equipments. In order to maintain the temperature inside the flameless chamber, some especial materials such as ceramic should be utilized. Biogas flameless combustion could be modified by hydrogen-enrichment strategy. The temperature distribution inside the flameless chamber is more uniform when small amounts of hydrogen added to the biogas components and the flameless regime is more sustained. In this circumstance the rate of pollutant formation is a little higher than pure biogas flameless combustion.

Contents

1. Introduction

Climate change and global warming as the most important greenhouse gases (GHG) effects have become the main concerns of humanity. The negative effects of GHG ingredients such as carbon dioxide (CO_2), methane (CH_4), water vapor (H_2O), nitrous oxide

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(N_2O) and ozone (O_3) on people health are unavoidable fact [1]. Beside these ecological constraints, the increasing rate of nitride oxide (NO_x) emissions should also be controlled in the combustion systems. Since thermal NO_x formation mechanism is responsible for the major part of NO_x formation in the CHP generation systems, flame temperature should be reduced [2]. In industrial point of view, boilers and gas turbines are the most commonly gaseous fuel consumers for CHP generation. Due to Kyoto protocol (KP) stringent standards, great progress has been made to reduce GHG in CHP generation systems by implementation of some strategies such as alternative fuel utilization or clean combustion of fossil fuels using dry low emission techniques, based on lean premixed combustion [3]. In order to approach to the clean environment, both clean fuel and clean combustion technology should be taken into consideration. Biogas generated from organic material can be utilized as an alternative fuel and a source of renewable and sustainable energy in transportation and industrial boilers. In addition to biogas, fertilizer and irrigation water are produced from anaerobic digestion (AD) of organic waste materials. Unlike fossil fuels and other renewable energy resources, biogas generation is not limited to the specific geography. Higher calorific values of biogas can be achieved when methane (CH_4) concentration increases by dioxide carbon (CO_2) elimination from biogas ingredients. Indeed, in the specific utilization such as vehicle fuel, hydrogen sulfide (H_2S) and water vapor should be removed from biogas components due to their corrosive characteristics. Just clean and upgraded biogas is eligible to be applied in sensitive applications such as injection to the gas grid or using as vehicle fuel.

1.1. Environmental panorama of biogas utilization

Energy and fossil fuel consumption are the basis of industrial and economic development. However, increasing rate of GHG generation, climate change and global warming (GW) are the main results of excessive fossil fuel utilization [4]. GHG play crucial roles in GW constitution by trapping heat radiation from the earth's surface [5]. CO_2 and CH_4 are the most important GHGs with 60% and 15% contribution in GW formation [6]. Fossil fuel utilization in transportation systems releases the considerable part of GHGs and biomass has emerged as a savior due to its environmentally sound characteristics [7]. Climate change is one of the most important reasons why governments have been convinced to invest in biomass production. Among different biomass resources, biogas characteristics have made it an acceptable source of renewable energy throughout the world [8]. Indeed, without appropriate strategies for biogas capturing from AD, huge amounts of CO_2 and CH_4 could be released to the environment. Hence, biogas collection from AD not only can provide an acceptable source of energy but also can save the environment from toxic gas emissions [9]. Although high quality of gaseous fuel is not required for CHP generation and biogas can be utilized directly, the corrosive characteristics of water vapor and H_2S as the ingredient of biogas highlights the necessity of biogas cleaning treatments [10]. The presence of H_2S in biogas components could damage CHP equipment in conventional biogas flames and during biogas combustion, it could form sulfur dioxide (SO_2) and sulfur trioxide (SO_3) which are toxic emissions [11].

2. Biogas composition

The process of fossil fuel formation is very slow, taking many years, and current fossil fuel utilization is rapidly depleting the natural reserves. Therefore, many studies have been undertaken to find a variety of renewable fuels to replace these transient fossil fuels [12]. Biogas, which is formed in the AD of biomass, is a renewable and flammable gas with relatively short formation time. The type of AD feedstock plays crucial role in the biogas ingredients [13]. LCV biogas consists of combustible CH_4, noncombustible CO_2 as the basic components and low amounts of nitrogen (N_2), hydrogen sulfide (H_2S), carbon monoxide (CO), ammonia (NH_3), hydrogen (H_2), oxygen (O_2), water vapor (H_2O), dust and occasionally siloxanes [14]. Agricultural products, rice paddies [15], municipal solid waste (MSW) [16], domestic garbage landfills and old waste deposits [17], palm oil mill effluent [7], sewage sludge [18], manure fermentation and cattle ranching [19], coal mining [20] are the most important biogas resources in the world. The digestion process takes place in digestion tanks which allow the possibility of controlling humidity and temperature to optimize biogas generation. Most of the energy content of organic material is transformed to biogas in the AD system and less heat is released. AD process works well when heat is added to the system [21]. Compare to the calorific value of natural gas (36 MJ/m^3), the average calorific value of biogas is very low (around 21.5 MJ/m^3). Due to the various AD feedstock, CH_4 forms around 40–80% of the biogas ingradiants. Therefore, invoking to the lower heating value of CH_4 at the standard temperature and pressure (around 34,300 kj/m^3), the lower heating value of biogas should be around 13,720–27,440 kJ/m^3. Since more than 98% of biogas is a combination of CH_4 and CO_2, the physical properties of biogas are usually modeled by these two gases. Table 1 depicts biogas ingredients based on various feedstock [22].

2.1. Biogas upgrading

In order to remove noncombustible gases from biogas ingredients and increase calorific value of biogas, some upgrading methods such as water scrubbing, cryogenic, chemical absorption technique and membrane have been proposed. Water scrubbing system as a physical biogas purification method is applied to neutralize corrosive gases such as H_2S and to eliminate interfering gases like CO_2 and particulate matter from biogas components due to their higher

Table1
Biogas composition based on different feedstock.

Component	Unit	[a]POME biogas	Sewage plant	Landfill
CH_4	Vol%	60–70	55–65	45–55
CO_2	Vol%	30–40	35–45	30–40
N_2	Vol%	<1	<1	5–15
H_2S	ppm	10–2000	10–40	50–300

[a] POME biogas: Biogas released from palm oil mill effluent.

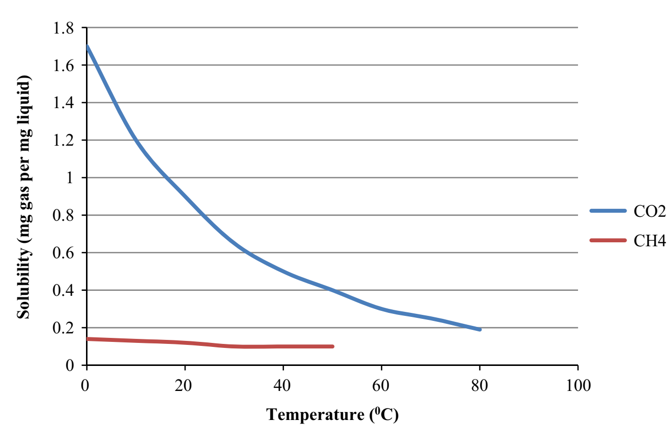

Fig. 1. Solubility of CH_4 and CO_2 in water.