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Fuel and emissions properties of Stirling engine operated with wood powder

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Abstract

From viewpoints of the environment and fuel cost reduction, small-scale biomass combined heat and power (CHP) plants are in demand, especially wood-waste fueled system, which are simple to operate and maintenance-free with high thermal efficiency similar to oil fired units. These are requested by wood and other industries located in mountainous region. To meet these requirements, a Stirling engine CHP system combined with simplified biomass combustion process with pulverized wood powder was developed.

In an R&D project started in 2004 considering wood powder properties as a fuel, combustion performance and emissions in combustion flue gas were tested using combustion test apparatus with commercial size units. The wood powder combustion system was modified and optimized during the combustion test results, and the design of the demonstration plant combined with 55 kW_e Stirling engine power unit was considered. The demonstration plant was finally completed in March of 2006, and test operation has been progressed for the future commercial CHP system.

In the wood powder combustion test, wood powder of less than 500 μm is mainly used, and a combustion chamber length of 3 m is applied. In these conditions, the air ratio can be reduced to 1.1 without increasing CO emission of less than 10 ppm and combustion efficiency of 99.9%. In the same conditions, NO_x emission is estimated to be less than 120 ppm (6% O_2 basis). Wood powder was confirmed to have excellent properties as a fuel for Stirling engine CHP system. This paper summarizes the wood powder combustion test, and presents the evaluation of the burner design parameters for the biomass Stirling engine system.
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Keywords: Biomass; Wood powder; Direct combustion burner; Stirling engine; CHP system

1. Introduction

From the environmental point of view, the use of biomass will help establish a sustainable society, because biomass has the advantages of being a renewable energy source and is neutral on carbon dioxide production. Development and commercial installation with the new power technologies utilizing biofuel have aggressively progressed in Japan [1]. The use of biomass in a large scaled power plant has also begun. The Japanese RPS (Renewable Portfolio Standard) program changed the electric power companies and the Independent Power Producers, and they positively promote the application of biofuel. Wood biomass co-firing with coal in a large scaled pulverized coal (PC) fired power plant is one of the most promising processes and many demonstration projects are under way

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[2]. This process can use much of the equipment of the existing power plant and it can expect to have quite high thermal efficiency utilizing biomass [3]. If the costs of biomass collection and its transportation can be made lower than the cost of coal, this process can be expected to spread greatly [4]. Biomass co-firing with oil fuel is also under development, and this technology is expected to not only result in CO_2 reduction but also result in oil fuel cost saving given the current oil cost situation [5].

In mountainous regions, there is a large amount of wood waste from the forestry and wood industries. However, Japanese forestry has atrophied and domestic forest devastation is spreading [6]. Because of this situation, much of wood-waste discharging in mountainous regions is left in the forests of Japan [7]. Furthermore, the rapid rise of oil prices has impacted the wood and other industries, and has initiated the shift from oil as the primary energy resource to woody waste biomass. Therefore, a distributed power system and small-scaled CHP (combined heat and power) plant with biofuel is applicable for the market of Japanese mountainous regions. Many suppliers are developing small-scale biomass gasification CHP systems to meet these requirements in Japan, and many types of biomass gasifiers are proposed and developed aggressively [8]. We also studied a usable gasification process of small scale, and as a result, we would assure that these systems are simple to operate and are maintenance free with high thermal efficiency similar to oil fired units [9].

To satisfy these requirements, an external combustion engine such as the Stirling engine is expected for the small-scaled power generation system with high thermal efficiency, and it can operate with high temperature fuel gas. This means that the biomass energy conversion process applied to the Stirling engine is more flexible and simpler than conventional biomass gasification with a gas engine [10]. On the other hand, wood powder burner could also be used in a simple combustion system, because wood powder has many advantages as burner fuel such as high heating value, high bulk density, small fuel size, good flow ability and others [10]. We started to develop a Stirling engine CHP system applying a simplified biomass combustion process with a pulverized wood powder burner instead of a gasifier CHP system with gas engine in 2004.

A package unit of 55 kW_e Stirling engine unit using clean gas fuel started the commercial selling in 2005. We selected this power unit for our CHP system development [11]. In addition to this Stirling engine, development of the biofuel Stirling engine has progressed aggressively in Europe and other countries. A wood gas fuelled Stirling engine with 9 kW_e power generation has been successfully run in Denmark [12]. 35 kW_e Stirling engine CHP system assembled with wood chip fired boiler has been operation since 2002 in Austria [13], and a 75 kW_e Stirling engine pilot plant with eight-cylinders designed based on the above experiences has been in operation since 2003 [14]. A wood powder combustion project with the same 35 kW_e Stirling engine has also started in Sweden [15]. Furthermore, new technologies of solar power Stirling engine [16] and low temperature Stirling engine [17] with further small units of 10 kW_e are also advanced. Stirling engines can be expected as a promising technology for the renewable energy utilization.

Many experiences on the wood powder burning technology of co-firing with coal or oil are demonstrated as mentioned above. And fuel properties, combustion and emissions performances and risks of bio-fuel are also reported [18,19]. However, the development of the wood powder burner was the key issue when this process was established because of the wood powder burner of 100% biofuel. Therefore, combustion tests of wood powder were carried out from the beginning of 2005 (STEP-I). In the next stage (STEP-II), the dummy heater test rig used to simulate the actual Stirling engine was installed at the exit of the combustion chamber, because we have been feeling the risk of ash deposits in heater tubes as reported [20,21]. As a result of STEP-II test, since the ash deposits in heater tubes and fins were clearly found, the trial tests for solving or reducing the ash deposits are being carried out with actual heater tubes and fins of 55 kW_e Stirling engine. These results will be reported in the future. System demonstration tests will be carried out through March 2007 (STEP-III). This paper presents combustion test results in STEP-I, which is a key technology of this system. Also discussed are the combustion parameters for the Stirling engine power system design.

2. Experiment and methodology

2.1. Test apparatus

The general specification of the test apparatus is shown in Table 1. A Stirling engine unit of 55 kW_e power output is applied in STEP-III. A Stirling engine of clean gas fuel type is used for the test, and some Stirling engine parts were modified for wood powder combustion. The biomass burning capacity of the test apparatus is sufficient to operate this engine. The maximum burning capacity of the burner is 0.03 kg/s of wood powder, which is a thermal capacity of 400 kW. In case of the 55 kW_e CHP system, fuel consumption in normal operation is approximately 0.02 kg/s.

The test apparatus for wood powder combustion is shown in Fig. 1. Wood powder fuel is transported by air from the fuel hopper, and the fuel feed rate is controlled

Table 1
General specification of test apparatus

Item	Specification
(1) Wood powder feed rate	Max. 0.03 kg/s
(2) Burner thermal capacity	400 kW
(3) Burner type	Diffusion mixing, dual fuel coaxial burner
(4) Combustion chamber type	Horizontal furnace, refractory lining
(5) Combustion chamber size	1.0 m ID × 6 m L
(6) Draft control	Balanced draft
(7) Main fuel	Pulverized wood powder
(8) Start-up fuel	LP gas

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