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Micro gas turbine cogeneration system with latent heat storage at the University: Part III: Temperature control schedule

Osamu Kurata [a, *], Norihiko Iki [a], Takayuki Matsunuma [a], Tetsuhiko Maeda [b, 1], Satoshi Hirano [c], Katsuhiko Kadoguchi [d], Hiromi Takeuchi [d, 2], Hiro Yoshida [e]

[a] Turbomachinery Group, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8564, Japan

[b] Socio-economics and Policy Study Group, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8564, Japan

[c] Thermal and Fluid System Group, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8569, Japan

[d] Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305, Japan

[e] Department of Vehicle System Engineering, Kanagawa Institute of Technology, Atsugi, Kanagawa 243-0292, Japan

HIGHLIGHTS

- Proper use of latent heat storage system saves energy and reduces exhaust emissions.
- Cogeneration with latent heat storage was demonstrated under service conditions.
- Additional heat supply by the heat system improves the temperature rise.
- Larger latent heat storage makes temperature rise more comfortable with less energy.

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ABSTRACT

The latent heat storage system is a novel heat storage system. At the University under service conditions, it was demonstrated with a micro gas turbine (MGT) cogeneration system (CGS). Expanding the latent heat storage system into new applications is expected to save energy economically with high density energy storage and reduce exhaust emissions and reduce operational costs. This is the first demonstration of using a latent heat storage system with CGS under service condition and its characteristics are very important.

In Part I, a fixed operating schedule of the system was planned and demonstrated at the University. The charge/discharge cycles of the latent heat storage system were repeated for 407 times. The energy flow test of the system shows the importance of the heat release source and total system design. In Part II, an irregular charge case of the latent heat storage system was discussed when the prime mover of the system was operated at a part load and thermal priority mode. A highly sophisticated system design that solves these problems was necessary for extending the applications of the latent heat storage system.

In Part III, a temperature control schedule of the system was demonstrated during winter mornings using a new programmable logic controller (PLC). Using a fixed schedule, the MGT-CGS with latent heat storage reduced the CO_2 emission when the energy utilization factor was above 50%. The temperature control schedule was considered to be better than the fixed schedule, both in terms of the operational efficiency of the overall system and CO_2 reduction. The temperature control schedule was executed using an empirical formula for the temperature rise in a classroom. The restriction on the operation time by the contract with the gas supplier and the low heating capacity of the CGS affected the heating time and temperature rise. The temperature rise in the classroom was almost proportional to the integrated temperature difference across the hot water header of the heating system. On cold days, the rate of temperature rise produced by the CGS was very slow, therefore, additional heat supplied by the original

* Corresponding author. Turbomachinery Group, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), 1-2 Namiki, Tsukuba, Ibaraki 305-8564, Japan.

E-mail address: osamu.kurata@aist.go.jp (O. Kurata).

[1] Present address: Integrated Hydrogen System Group, Energy Technology Research Institute, AIST, Tsukuba, Ibaraki 305-8564, Japan.

[2] Present address: Chemical Materials Evaluation and Research Base, AIST Tsukuba Central 5-2, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan.

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boiler was used to increase the temperature rise. If larger latent heat storage systems will be developed in future, it will be expected that the temperature of the classrooms are kept more comfortable with less energy consumptions and lower CO_2 emission.

1. Introduction

A cogeneration system (CGS) is used for efficient supply of electric power and heat in a distributed energy system. Initially, CGSs were mostly used to compensate for imperfect grid power supply [1,2]. More recently, they have been widely used to prevent global climate change and reduce energy costs. The prime movers used for such systems are gas turbines [1–4], gas engines [5,6], Stirling engines [7–9], and fuel cells [10]. The gas turbine is preferable for larger distributed energy systems. Compared to reciprocating engines, gas turbines have higher specific power, are easy to soundproof and contain relatively few operational parts [3]. Micro gas turbine (MGT) CGSs have been widely used over the last decade [11,12]. Many studies have analyzed the energy [13,14], exergy [1] and economy [15,16] of MGT-CGSs. However, these analyses were based on nominal rated load specifications. Such limited field tests may obscure the actual efficiency and performance of such systems [5].

The Greenhouse Gas Technology Center [11] reported using a Capstone 60 kW MGT-CGS at a supermarket. Chikahisa et al. [17] compared the CO_2 reductions and the energy costs of CGSs in various buildings such as houses, offices, stores, and hotels and analyzed the ratios of the heat to power demand, the installed capacities, and the proper operation of the system. Guiterman et al. [18] analyzed the energy costs of the pumps and hot water supply of the CGS in the University of Colorado recreation center.

Between 2006 and 2010, the National Institute of Advanced Industrial Science and Technology (AIST) in Japan demonstrated an MGT-CGS with latent heat storage at the University. The latent heat storage system was an original design of AIST [19] and utilized a phase-change material (PCM) [20]. Latent heat storage systems can store heat for a long period with little heat loss. They utilize waste heat produced by spatial and temporal mismatch when there is a time gap between the generation of electric power and heat utilization. Overcoming this spatiotemporal mismatch in the utilization of heat and electricity is the major challenge in distributed energy systems.

The latent heat storage system is a novel heat storage system, and it was demonstrated with an MGT-CGS at the University under service conditions. Expanding the latent heat storage system into new applications is greatly expected to save energy, as well as reduce the initial and operational costs and reduce exhaust emissions.

In Part I [21], the plan and energy flow test of the system were described. An operation schedule of the CGS with latent heat storage was planned, and then the system was demonstrated at the University under service conditions. The latent heat storage system was charged during the daytime and discharged during the evening and the following morning. A total of 407 charge/discharge cycles of the latent heat storage system were repeated. Although the latent heat storage system saved energy, the total system efficiency was not very high. The energy flow test of the CGS revealed the importance of the heat exchanger and operational time for heat storage.

In Part II [22], a part load and thermal priority mode of the CGS were described. An irregular charge case of the latent heat storage system was discussed. Under normal situations, the latent heat storage system was expected to save energy and reduce exhaust emissions. Surplus heat of the cogeneration system made a gas turbine operate at part load and in the thermal priority mode. In the specific system, when the flow of heat to CGS heat exchanger was controlled, the latent heat storage system failed because of the low charging temperature of the PCM. Moreover, maintaining a high charging temperature of the PCM may cause mechanical damage to the gas turbine due to the switchable combustor design. These problems were not solved in this specific system; they will be solved in later latent heat storage system with sophisticated design.

In Part III, a temperature control schedule of the system is described. Apart from a fixed operating schedule, the temperature control schedule during a winter morning was demonstrated, because it was expected to save energy and reduce CO_2 emissions and operational costs. Although this latent heat storage system was designed for heating small locker rooms, the larger heat storage capacity should help heat larger classrooms. In this concept, the temperature control schedule for heating a large lecture hall was performed. The charge/discharge sequences of the latent heat storage system were linked with the operation of the MGT, and the sequences were repeated using a new programmable logic controller (PLC) [21]. The temperature rise of the large lecture hall was controlled, and it was proportional to the heat supply to the header system of the building. The temperature rise will improve if the start times of the air-heater and heat output of the original boiler are controlled. An advanced system design with a larger latent heat storage system will be used to heat the large lecture hall in winter mornings and it is expected to greatly improve the temperature of the classrooms with less energy consumption and less CO_2 emission.

2. MGT-CGS with latent heat storage [21]

The University is located in the suburbs of Sapporo city, where there is more snowfall than in the city center. On the campus, there are a main building, Building A, Building B, a gymnasium, a library, and other buildings. Building C has three floors above the ground and one in the basement; it contains 13 classrooms, one big lecture hall, two shower rooms, one locker room, and six lavatories.

A Takuma TCP30LH model with a 30 kW class Capstone MGT was used as the CGS. Its nominal specifications are as follows:

- Hot water package with a vacuum-type hot water heater (Vacotin heater)
- Natural gas: 13 A
- Electricity generation capacity: 27 kW
- Hot water production capacity: 59 kW (under heat exchanger inlet/outlet temperatures of 50/60 °C)
- Fuel consumption rate: 120 kW

Thus, the rated nominal efficiencies of the electricity and heat generation and the overall efficiency of the system were 22.5%, 49.2%, and 71.7%, respectively.

Fig. 1 shows the details of the MGT-CGS with latent heat storage. The system was set up in a new energy machinery room in the basement of Building C. A Vacotin heater (VH) and an economizer (ECM, 10 kW) were arranged in parallel downstream of a bypass dumper of the MGT exhaust gas. In winter, the hot water from the