Development of stacking type thermoelectric power generation unit for potential waste heat recovery applications

A. Yamamoto¹ and H. Nishiate¹

¹ National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, 305-8568, Japan
e-mail : a.yamamoto@aist.go.jp

Abstract. A 10 W class thermoelectric power generation unit is designed and prototyped. The power unit is designed based on a concept of a compact heat exchanger integrated with thermoelectric module. The power unit specifically targeted hot water waste heat of which temperature is below 100 °C. The preliminary lab testing of the unit showed maximum power output of 10.6 W under conditions of $T_h = 95$ °C, $T_c = 10$ °C, the flow rate = 7 L/min. The size of unit is 5.4 x 11.2 x 14.4 cm and the calculated specific power of the unit is 12.1 W/L or 12 kW/m³ which is much higher than a value ever reported. We conducted long term stability tests in three different sites; 1) hot spring, 2) waste heat from inductive heating furnace and 3) boiler blowdown water in addition to one preliminary test at other hot spring site. All collected data in the demonstrations described above proved good stability of the performance of the power unit. On-site, self-powered remote sensing is also demonstrated at the hot spring site and successful data acquisition of temperatures and water flow rates at every seconds were confirmed.

1. Introduction

The Fukushima nuclear accident in 2011 in Japan recalled us the importance of deployment of renewable energy and energy saving technology. Energy saving is the most important measure for social sustainability and utilizing wasted thermal energy is potential target to realize energy saving in large scale. Along this context, thermoelectric power generation from wasted heat has been re-focused and increasing number of demonstrative experiments have been reported [1][2].

In this study we report the stacking type thermoelectric power generation module which can be utilized in low grade waste heat such as hot water from factory, hot spring etc. [3][4][5][6][7]. The units were recently tested in various fields and showed reliable performance in those experiments.

2. Stacking Type Power Generation Unit

2.1. Design Concept of the Unit

A cost of initial installation is one of the most important part of deployment of new energy technology for any purpose. A binary turbine power generation can be a potential candidate technology for low grade waste heat recovery, but the initial cost still much higher than 0.5 million yen/kW, [8][9] Thermoelectric power generation has great potential in cost reduction since the devices used in the system is in principle semiconducting product. In this study we designed the power generation unit with conventional thermoelectric module integrated with plastic heat exchanger instead of expensive...
metal based heat exchange. Ten 40 mm x 40mm thermoelectric modules were stacked with plastic water jacket and the piping was also made of plastics such as POM or PPS.

Figure 1. Pictures of prototype of the stacking type thermoelectric power generation unit.

2.2. Basic performance of the Unit
The power generation characteristics of the unit was examined in a laboratory test bench. Hot water and cold water were supplied by circulators and electrical power output was measured as a function of the hot water temperature and the flow rate. Figure 2 shows the basic properties of the unit. The maximum power output was 10.4W at 95°C and 7 L/min.

Figure 2. Basic power generation performance of the unit. (a) voltage - current relationship, (b) output power – current, (c) temperature difference – maximum output power.

3. Results of field test
The prototyped power generation units were then tested in three different sites to verify the durability in real use. The examined hot water are supplied from 1) cooling water of inductive heating furnace (SINTOKOGIO Ltd., Aichi) 2) secondary hot water in hot spring centre Yakushi-yu (Yumura hot spring, Hyogo) and 3) boiler blowdown water (The Japan Wool Textile Co., Ltd., Hyogo). The expected temperature of hot water are roughly 40 °C, 60 °C, and 80 °C, respectively

3.1. Inductive heating furnace
The cooling water of inductive furnace is designed to be cooled down by heat-exchanging with primary cooling water connected to a cooling tower. We modified the water pipings to bypass the fin and plate type heat exchanger so that the unit utilize hot water and cold water from existing system. Figure 3 shows result of contentious data acquisition for one month. The hot side temperature fluctuating since the furnace is often repeatedly operated during day and night. The flow rate of cooling water in figure 3 (b) showed gradual decrease and then completely clogged up at around three
week. This was caused by sludge accumulated in the strainer located before the inlet of the power generation unit. Despite the lack of cooling water supply, the unit kept producing electricity as seen in figure 3 (c) for week3 and week4.

![Figure 3](image_url)

**Figure 3.** Time evolution of (a) hot and cold side temperature, (b) water flow output power – current, (c) temperature difference – maximum output power.

### 3.2. Hot spring

A demonstrative data acquisition and long distance transmission was performed using the power generation unit in hot spring center Yakushi-yu. The center provides Onsen bath service for public purpose and utilize the primal hot spring water (~ 98°C) for warming up the secondary clean water (~ 60°C) which is used for the bath service. We bypassed the piping to supply hot and cold water to the unit. The generated power was directly connected to a conventional battery charge controller that control 12V lead-acid battery. Data logger (Graphtec, GL-100-WL-4VT) monitored 5 channels (temperature and flow rate of hot water and cold water and output voltage) and transmitted the data via WiFi to rooter that is connected commercial 3G network. The data, updated every second was monitored by network PC which located in AIST in Tsukuba. All the electronics were operated by the generated power so that the system can be completely self-powered. Figure 4 shows one of example of remote sensing experiment. The flow rate of cold water is quite fluctuating, since we bypassed the cold water piping which is connected shower and toilet. The resulting power output also fluctuate depending on the cold water flow rate, however the hot water was relatively stable.

![Figure 4](image_url)

**Figure 4.** An example of the self-powered remote data acquisition results. Upper : water temperature and the difference, lower : water flow rates.
3.3. Boiler blowdown water

Innami factory of The Japan Wool Textile Co., Ltd. equips many through flow boiler to generate steam for factory operation and emits a lot of blowdown water. The water temperature is roughly 80°C and shows alkaline properties. We pumped up the blowdown water and directly used for the power generation. Two unit were connected in parallel and the data logger recorded the flow rate, the temperature and the output voltage of individual thermoelectric module every 10 sec. Total 50 million data was collected for the period from Oct. 2016 to June 2017. Figure 5 shows the time evolution plot of monitored data in the field test. The hot water clogged up repeatedly during the test as shown in figure 5 (b) and the reason is sludge accumulation at a strainer near the circulation pump for hot water. Frequent cleaning by an operator was needed to continue the experiment. We confirmed that the power generation unit itself was unchanged and quite stable after half year field test.

![Figure 5. Time evolution data of (a) temperature of hot and cold water, (b) water flow rates, (c) output voltage, (d) generated power.](image)

**Summary**

We designed and prototyped stacking type thermoelectric power generation unit and tested its performance in three field test. The unit produced electricity depending on the temperature and the flow rates of supplied hot water and cold water. The performance of the unit itself was unchanged and stable during the long term test. We need further verification of the life time of the unit through field demonstrations and need to find out some measures for the clogging at the strainer in the piping.

**Acknowledgments**

Authors would like to special thanks to S.Iijima of SINTOKOGIO Ltd., K.Taniguchi of Shin Onsen Town, and K.Togashi and Y.Konishi of The Japan Wool Textile Co., Ltd. for kind offers of field test sites and cooperation in the demonstrative experiments.

**References**

[1] K. Takahashi, et al, Scientific Reports 3, Article number: 1501 (2013)
[2] http://news.panasonic.com/jp/press/data/jn110620-2/jn110620-2.html, download on 2017/10/12
[3] H. Nishiate, et.al., Proc. 11\textsuperscript{th} Annual symposium of Thermoelectric Society of Japan (TSJ 2014), p64
[4] H. Nishiate, et.al., Proc. 12\textsuperscript{th} Annual symposium of Thermoelectric Society of Japan (TSJ 2015), p137
[5] H. Nishiate, et.al., Proc. 12\textsuperscript{th} Annual symposium of Thermoelectric Society of Japan (TSJ 2015), p138
[6] H. Nishiate, et.al., Proc. 13\textsuperscript{th} Annual symposium of Thermoelectric Society of Japan (TSJ 2016), p113
[7] Bertrand F.Tchanche, Gr.Lambrinos, A.Frangoudakis, G.Papadakis, Renew. Sust. Energ. Rev., Vol.15, 8, October (2011) pp.3963-3979
[8] http://geothermal.jogmec.go.jp/report/file/023.pdf, download on 2017/10/12