A Concept of 500 kWe Thermoelectric Power Conversion System to Make Use of Waste Heat of PWR Power Plant

Background

Conventional power plant adopts steam turbine generators. In case of light water reactors, the conversion efficiency is about 33%, therefore more than 60% of the reactor thermal power is disposed. An attention was focused on applying thermoelectric (TE) power conversion system to the PWR steam generator blowdown system in view of higher exhaust temperature and greater steam flowrate. Steam is continuously released from the PWR steam generator blowdown systems to keep the water purity in the steam generators. For example, steam of 220℃, 97 ton/h is released from an 1100 MWe (3200 MWt) PWR power plant. This waste heat is not used in most of the plants. This research was funded by the Institute of Applied Energy (IAE).

Objectives

Realize a design concept of TE power conversion system applied to PWR steam generator blowdown system, and to make cost estimation.

Principal results

1) Configuration of the TE system is shown in Fig. 1. TE modules are sandwiched between the hot ducts in which 220℃ steam flows and the cold ducts in which 20℃ water flows. TE modules are brazed only on the cold ducts using lead-free solder HITASOL[*1]. While TE modules are not brazed on the hot ducts but contacted with a carbon sheet inserted between the TE modules and hot ducts. Carbon sheet allows slide movement of the hot duct and TE modules due to thermal expansion. It also has a role of reducing the thermal contact resistance. The inflatable bags ensure uniform pressing force on the TE modules. This configuration enables thermal stress relaxation and reduction of thermal contact resistance, then 1.8 times greater temperature gradient on the TE cell as that of conventional TE system is achieved. In general, the energy conversion efficiency of the TE cell is roughly proportional to square of the temperature gradient exerted on it. Therefore 3 times (1.8 × 1.8) greater energy conversion efficiency could be available. The long life durability of the TE module would be achieved as well. Figure 2 shows a TE module with compliant pads[*2]. The TE module performance (i.e. electric resistance and seebeck coefficient) satisfied the required specification. Sufficient bonding strength of the HITASOL was also confirmed.
2) The thermal transfer analysis revealed that the TE system provides AC 500 kWe. The electric cost of 8.5 yen/kWh would be achieved in the future (refer to Table 1). This estimation was based on the literature issued by the United States manufacture in which 2 million modules/year was assumed.

A concept of TE power conversion system applicable to the PWR power plants has been confirmed. This system is also applicable to the waste heat of lower temperature available in other industries. In order to realize proposed system, subscale endurance tests demonstration is requested.

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Reference

M. Kambe et al.,"Development of High Energy Density Thermoelectric Energy Conversion Systems (2)," CRIEPI Report T02009, March 2003.

[*1] : HITASOL is lead-free solder developed by Hitachi Powdered Metals and CRIEPI.

[*2] : Compliant pad (patent pending) is made of sintered Cu, which play a role of thermal stress relaxation to protect fragile TE cell. It enables greater temperature gradient in the TE cell. In the vicinity of the compliant pad surface, there is a porous region in which braze filler material is infiltrated.

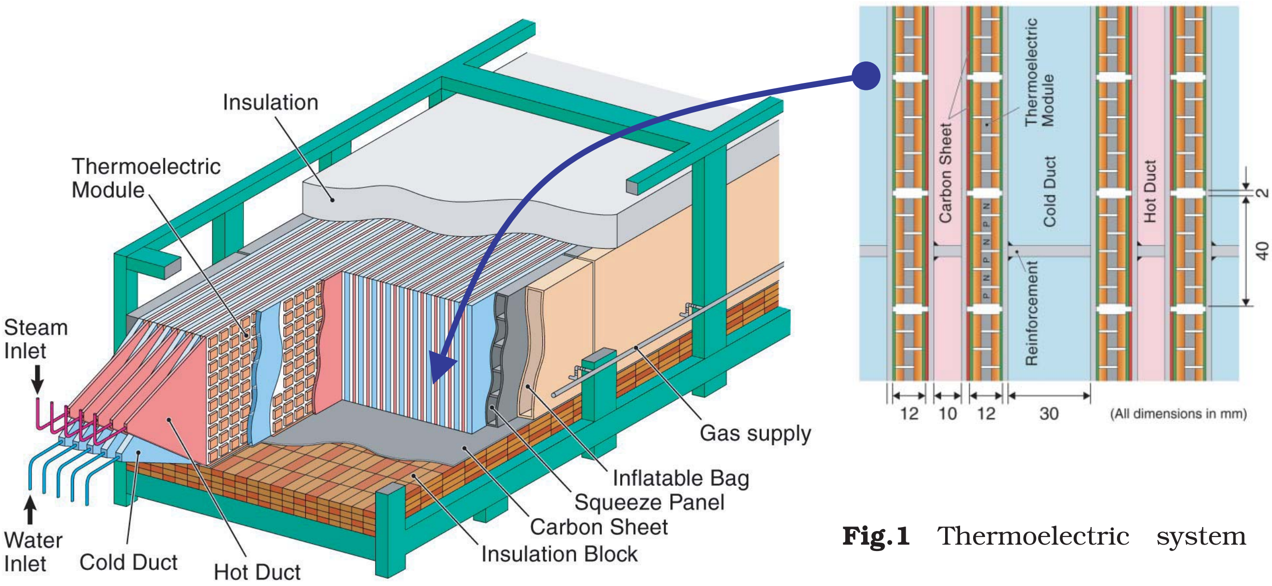


Fig.1 Thermoelectric system

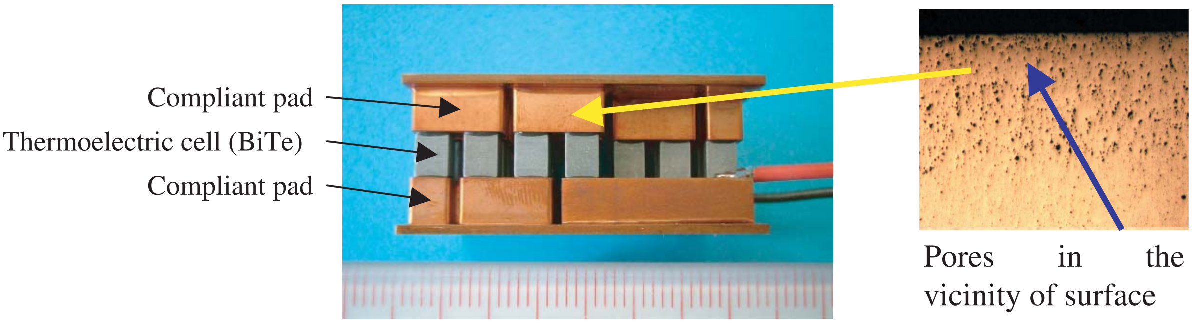
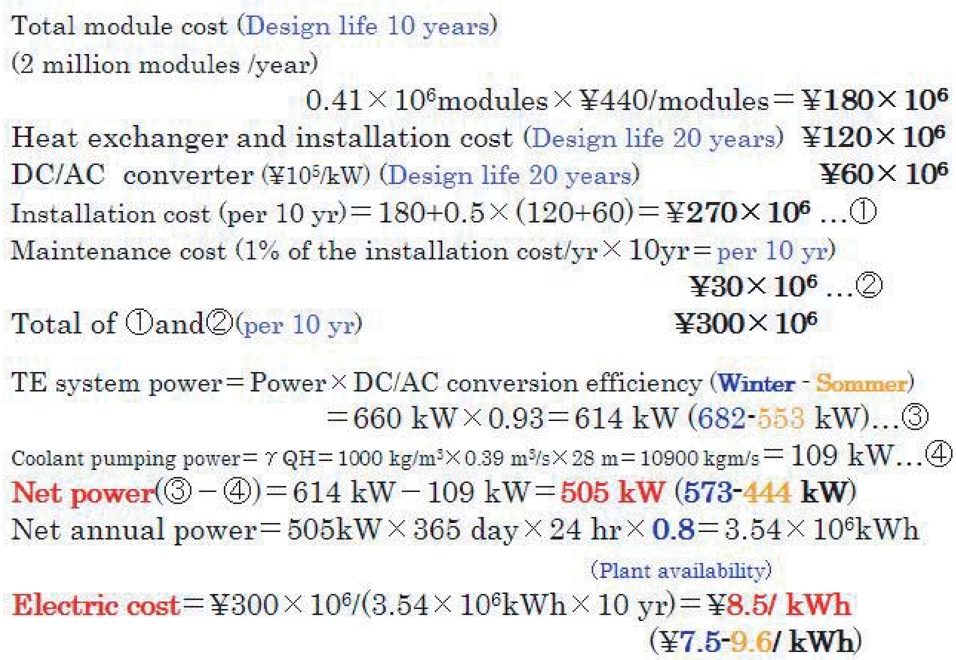


Fig.2 Thermoelectric module with FGM compliant pads (18 couples)

Table 1 Cost estimation of the 500 kWe thermoelectric system



Total module cost (Design life 10 years)
(2 million modules /year)
0.41×10^6modules × ¥440/modules = ¥180×10^6
Heat exchanger and installation cost (Design life 20 years) ¥120×10^6
DC/AC converter (¥10^5/kW) (Design life 20 years) ¥60×10^6
Installation cost (per 10 yr) = 180+0.5×(120+60) = ¥270×10^6 …①
Maintenance cost (1% of the installation cost/yr × 10yr = per 10 yr)
¥30×10^6 …②
Total of ①and②(per 10 yr) ¥300×10^6

TE system power = Power × DC/AC conversion efficiency (Winter - Sommer)
= 660 kW × 0.93 = 614 kW (682-553 kW)…③
Coolant pumping power = γ QH = 1000 kg/m^3 × 0.39 m^3/s × 28 m = 10900 kgm/s = 109 kW…④
Net power(③ − ④) = 614 kW − 109 kW = **505 kW** (**573-444 kW**)
Net annual power = 505kW × 365 day × 24 hr × **0.8** = 3.54×10^6kWh
(Plant availability)
Electric cost = ¥300×10^6/(3.54×10^6kWh × 10 yr) = **¥8.5/ kWh**
(**¥7.5-9.6/ kWh**)