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GTHTR300 cost reduction through design upgrade and cogeneration

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ABSTRACT

Japan Atomic Energy Agency began design and development of the Gas Turbine High Temperature Reactor of 300MWe nominal output (GTHTR300) in 2001. The reactor baseline design completed three years later was based on 850 °C core outlet temperature and a direct cycle gas turbine balance of plant. It attained 45.6% net power generation efficiency and 3.5 US¢/kW h cost of electricity. The cost was estimated 20% lower than LWR. The latest design upgrade has incorporated several major technological advances made in the past ten years to both reactor and balance of plant. As described in this paper, these advances have enabled raising the design basis reactor core outlet temperature to 950 °C and increasing power generating efficiency by nearly 5% point. Further implementation of seawater desalination cogeneration is made through employing a newly-proposed multi-stage flash process. Through efficient waste heat recovery of the reactor gas turbine power conversion cycle, a large cost credit is obtained against the conventionally produced water prices. Together, the design upgrade and the cogeneration are shown to reduce the GTHTR300 cost of electricity to under 2.7 US¢/kW h.

1. Introduction

GTHTR300 is a multi-purpose, inherently-safe and site-flexible commercial reactor design under development in Japan Atomic Energy Agency. The baseline design concluded during 2001–2003 combined a 600 MWt prismatic HTGR having core outlet temperature of 850 °C and a direct-cycle gas turbine power generation system. It attained a net power generation efficiency of 45.6% based on then available technologies (Yan et al., 2003). The cost of electricity estimated assuming 40 year plant life, 80% load factor and 3% discount rate is 3.45 US¢/kW h or about 20% less than light water reactor (LWR) on comparable cost basis (Takei et al., 2006).

The past decade has seen major advances in several enabling technologies in both reactor and balance of plant areas. By incorporating these advances, the latest design upgrade of the GTHTR300 has increased the reactor power generating efficiency to 50.4%. Furthermore, several studies in JAEA have examined the potential of the design for cogeneration. Large-scale seawater desalination cogeneration has been found to be particularly attractive in that it can be performed efficiently by utilizing only the waste heat of the reactor plant, making sizable revenue return from energy saving at the water plant. Together, the design upgrade detailed in Section 3 and the desalination cogeneration in Section 4 are shown to yield a significantly reduced power generation cost for the GTHTR300.

2. Baseline design

2.1. Design description

Since the detail of the baseline design has been reported elsewhere (Yan et al., 2003; Kunitomi et al., 2004), only a summary is given here. The reactor primary system consists of three pressure vessel units, each housing the reactor core, gas turbine generator, and heat exchangers including a recuperator and a precooler, as shown in Fig. 1. The multi-vessel system is intended to facilitate modular construction and ease maintenance access to the functionally-oriented components contained in the vessels.

Fig. 2 shows the reactor power generation cycle and process parameters. With the reactor rated at 600 MWt, the gross power generation is 280 MWe. Minus house loads, the net plant power generation is 274 MWe. The average fuel burn-up is 120 GWd/t with a refueling interval of two years. A half core of fuel bocks are replaced during each refueling.

GTHTR300 delivers fully inherent reactor safety due mainly to three design features:

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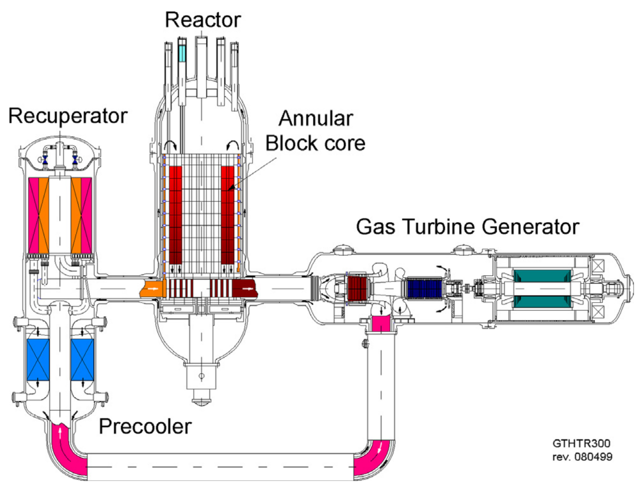

Fig. 1. Plant layout of GTHTR300.

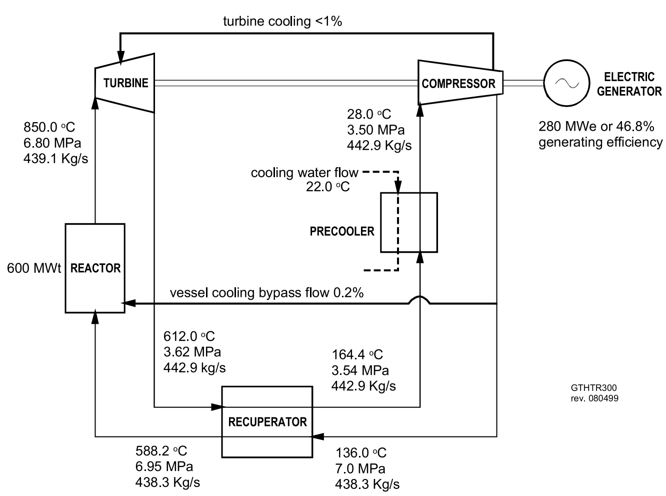

Fig. 2. GTHTR300 850 °C baseline cycle parameters.

(1) The ceramic coated particle fuel maintains its integrity of fission product containment up to a design temperature limit as high as 1600 °C.
(2) The reactor helium coolant is chemically inert and thus absent of explosive gas generation or phase change.
(3) The graphite-moderated reactor core is designed with negative reactivity coefficient, low-power density and high thermal conductivity.

As a result of these features, the reactor core can be shutdown and removed of decay heat, by natural draft air cooling from outside of the reactor vessel, without reliance on any equipment or operator action even in such accident cases as loss of coolant or station blackout, where the fuel temperature will remain below the fuel design limit.

2.2. Baseline system cost

Only a summary of the cost estimation formerly made for the baseline design for siting in Japan is given. Details can be found elsewhere (Takei et al., 2006). For the purpose of cost estimation, the plant construction assumes the following:

- *N*th of the kind plant (i.e., excluding R&D & design certification associated with a first-of-the kind plant)

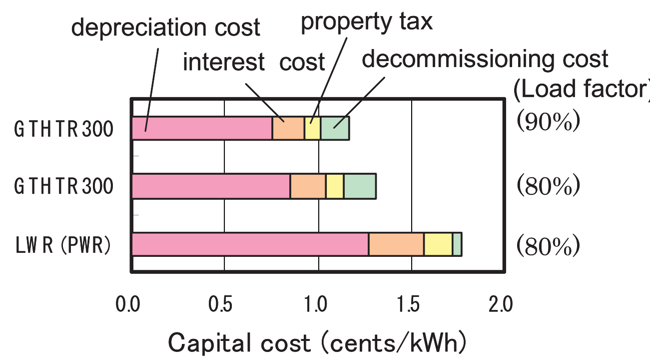

Fig. 3. Capital cost.

- Replacement of LWR on existing site
- Modular method of construction
- Equipment shipped to exclusive port on site
- Reactor building and structures similar to the HTTR's
- Seismic design conditions same as that of the HTTR
- Cost accounts for design, fabrication of facilities, plant construction, and commission operations

The capital cost estimation assumes a plant life of 40 years and a depreciation period equal to the plant life. The discount rate of 3% typically used for assessing utility nuclear plant cost in Japan is assumed. Residual book value is 5% at the last year of the plant operation.

2.2.1. Capital cost

Fig. 3 shows the capital cost of a plant with 4 reactor units (4 × 274 MWe) comparing with the LWR. The cost for the reference LWR of 1300 MWe was estimated by FEPC (FEPC, 2004). The cost of decommissioning GTHTR300 is higher because the number of systems and structures, such as pressure vessels and primary biological shielding, that become radioactive in operation and must be disposed of during decommission are larger in GTHTR300. However, the total capital cost of GTHTR300 (1.31 US¢/kW h) is about 25% lower than the LWR (1.77 US¢/kW h) because of the greater power generating efficiency of GTHTR300.

2.2.2. Operating cost

Fig. 4 shows the operating cost in comparison with the LWR. The operating cost of the GTHTR300 (0.92 US¢/kW h) is about 35% lower than the LWR (1.42 US¢/kW h) since the plant generating efficiency is higher and because the maintenance cost is lower owing to less number and material of systems to be regularly serviced.

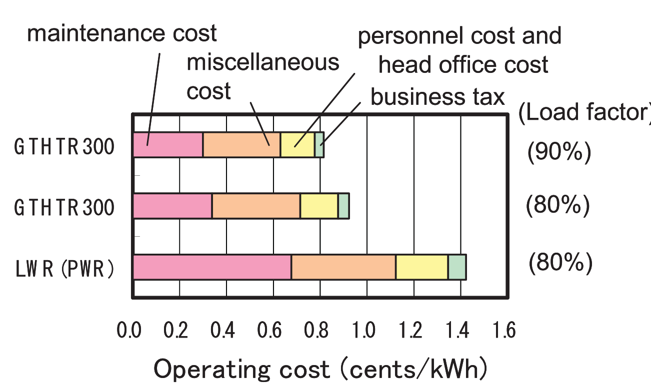

Fig. 4. Operating cost.

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