§ 5. Possibility of Gas-Turbine Energy Conversion System for FFHR's Liquid Blanket

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1. Gas-turbine systems for liquid blanket of FFHR

In spite of its long research history and its possibility of realizing high energy conversion efficiency, the gas-turbine system has not yet beem realized in the field of nuclear energy. In the fission field, the gas-cooling has disadvantages to the light water cooling in that its poor heat transfer performance limits the volumetric power generation rate and the coolant outlet temperature itself is restricted to a relatively low level due to the requirement of forming a perfect fission product barrier to the environment.

On the other hand, a liquid blanket concept is now being examined in the design study of FFHR, wherein molten salt FLIBE is assumed to be a coolant that serves as tritium breeding material as well. Combination of the FLIBE coolant and some advanced structural materials such as ferritic steel or vanadium alloy has a latent possibility of constructing safe and economical system with less pumping power. In this concept, the thermal energy output transported by the FLIBE should be transferred to a certain power cycle via. a heat exchanger. Of several candidate cycles, that of helium gas-turbine is attractive from its inherent safety and also from the possibility of tritium handling in dry conditions. When usual light water Rankine cycle is adopted, recovery of permeated tritium from the power cycle circuit will be very difficult.

2. Multi-stage compression/expansion gas-turbine

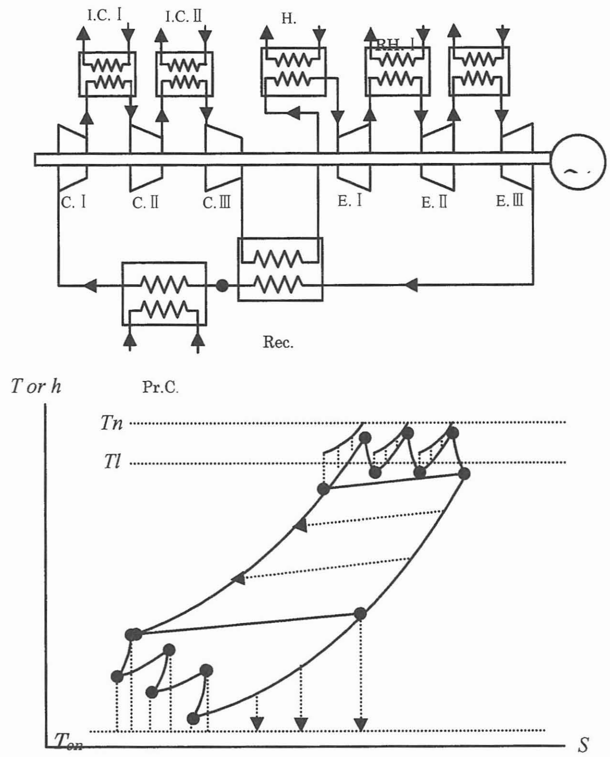
Meanwhile, the operating temperature region of FLIBE is extremely restricted due to its corrosive character as well as due to the high temperature creap of the structural materials, the upper and lower temperature limits being 550°C and 450°C, respectively. In order to realize an efficient gas turbine cycle that uses such low and limited heat receiving temperature, an adoption of multi-stage compression and expansion cycle that changes the cycle pattern from a slender shape to the Carnot one on *TS* or *HS* diagram is inevitable.

3. Energy conversion efficiency

With this background, the energy conversion efficiency of a closed helium gas turbine cycle was estimated, the attention being fixed on three-stage compression/expansion gas-turbine cycle. It consists of one pre-cooler, two inter-coolers, one regenerative heat exchanger, one main heat exchanger, two reheaters as well as three compressors and expanders. Heat rejecting temperature was fixed at 30°C and the compression and expansion ratio for each three stages was assumed to be of equal value.

According to the estimation, the maximum cycle efficiency of 37% was found to be realized when the stage compression ratio was 1.5, which can be favorably compared with standard thermal efficiency of conventional nuclear power plants.

4. Problems to be overcome



However, the problems related to the concept became also clear through the examination. Although the relative pressure drop through the cycle path was fixed at 0.1 which was the typical value in conventional gas turbine cycles, the present cycle contains total 7 heat exchangers in the operating flow path so that it cannot be applied as it is and the pressure drop reduction in heat exchangers is the key. Overcoming the leakage of tritium containing helium gas through shaft bearings is also important.

5. Perspective

Many problems are remained to be solved before realizing the gas-turbine systems in nuclear energy application both in fission and fusion fields. However, several important activities are now being performed. For instance, the R&D activity is being made to realize highly efficient heat exchangers by combined team of JAERI and Mitsubishi Heavy Industry Co. for HTGR power cycles, in which a plate-type ultra-fine fin heat exchanger is reported to be able to achieve over 95% heat exchange efficiency. Moreover, the new concept of ultra-high temperature gas-cooled fission reactor is now examined in which SiC-SiC composit is considered to be the main structural material, which will contribute much for the breakthrough of upper temperature limit. These activities will accelerate the solution of the problems related to the closed helium gas-turbine cycles.

Reference

The Design of High Efficiency Turbomachinery and Gas Turbines;D.G.Wilson & T. Korakianitis, Prentice Hall, 1998.