Analysis of Nuclear Waste Heat Transport Using STA System

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1. Introduction

The necessity of the load following operation in nuclear power plants seems to be suggested because of the increased portion in total electricity supplied by nuclear power. However, in the case of load following operation, there is a shortage in the aspect to utilize uranium resources because the fuel once loaded cannot be saved. As a solution, we had presented the concept of the nuclear waste heat transport method which is to connect a secondary system with an absorptive cycle [1]. At that moment, we developed a simple simulation model using PEPSE to check the feasibility of the proposed concept. In this paper, we developed an elaborated simulation model using PEPSE (Performance Evaluation of Power System Efficiencies) which is for a secondary system and EES (Engineering Equation Solver) which is for an absorptive system, and attempted to determine the design parameters and ultimately optimize the entire system.

2. Methods and Results

2.1 Principles of Solution Transportation Absorption (STA) System

In this section, we briefly describe the concept of nuclear waste heat transport using an absorption cycle.

The STA system, which is our interest, is a kind of the absorptive refrigerator cycles. Different from conventional refrigerators, an absorptive refrigerator does not use a compressor so it is of great use in the place where electricity is not available. Especially it can have high efficiency when waste heat is accessible. Absorptive refrigerators make use of steam and hot water as heat source. An absorptive refrigerator consists of absorber, generator, condenser, evaporator, and Solution Heat eXchanger(SHX), solution pump. Figure 1 shows the schematic diagram of a single effect absorptive refrigerator [2].

An absorptive refrigerator works as follows: The refrigerant steam generated in an evaporator flows to an absorber. The refrigerant steam is absorbed to absorbent in the absorber and is changed strong solution. Strong solution in the absorber flows to a generator by a solution pump. While it flows to the generator, heat is transferred to weak solution in an SHX. The strong solution is separated by the difference of boiling points of an absorbent and a refrigerant by waste heat. After the absorbent and the refrigerant steam are separated, the refrigerant steam flows to a condenser. Also, the absorbent of weak solution returns back after cooling down in the SHX. After condensed, the absorbent steam absorbs the heat in the evaporator.

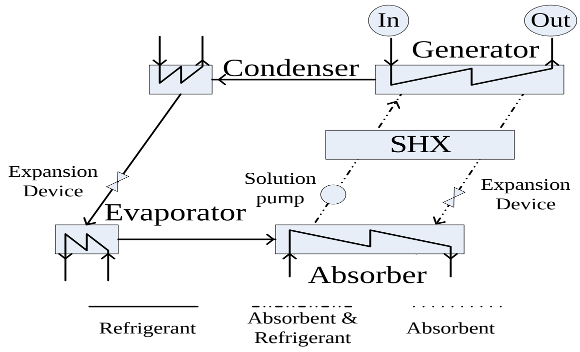

Figure 1. Schematic diagram of a single effect absorptive refrigerator

The STA system, which is a special configuration of the absorptive refrigerator, has a generator and a condenser at the waste heat supply side, and a absorber and an evaporator at the demand side, so that we can use the available energy of waste heat in a long distance away. The STA system has the following main advantage: (1) Insulation of the pipelines is not required, (2) The size of pipelines can be significantly reduced, and (3) Manufacturing and operating costs can be reduced. On the other hand, it has some disadvantages which is cost, toxic, safety or corrosive according to the choice of working fluids [6].

2.2 Combined System Simulation

Figure 2 illustrates the schematic diagram of the STA system with nuclear turbine cycle. In this system, a power plant, a generator, and a condenser are located at the supply side, while an evaporator and an absorber are located at the demand side. In this system, the heat source utilizes the waste heat from a nuclear power plant.

In Figure 2, all designations from 1 to 4 (total 9 cases) indicate the available waste heat and they can be supplied to the generator. The waste heat losing its energy flows to the condenser in the turbine cycle, which is designated as ‘out’ in Figure 2. Also in the schematic diagram of Figure 4, all designations from 1 to 4 are a fixed amount of Waste heat from Turbine cycle and supplied to the generator as a heat source. For each case, 3a and 3b cases belong to saturated water supply, and other cases supplies saturated or a little superheated steam [4].

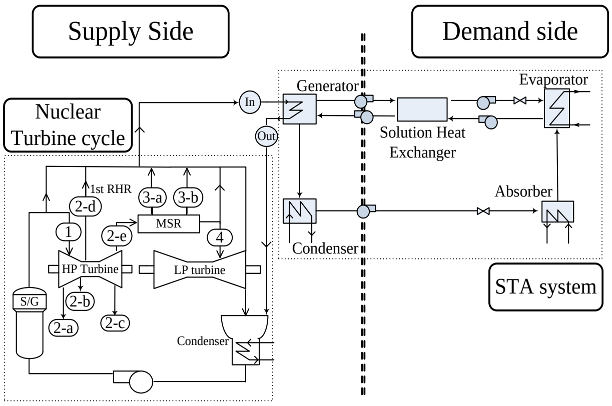

Figure 2. Schematic diagram of the STA system with nuclear Turbine cycle

We simulated the turbine cycle of OPR-1000 using PEPSE. PEPSE is a steady-state energy balance software program that calculates the performance of electric generating plants. PEPSE can model "what if" studies to test potential efficiency improvements and perform many engineering analyses that will detect abnormal operating conditions and lower plant operating costs [1]. PEPSE is limited to use the thermal properties of the working fluids such as NH_3 or LiBr in the STA system. Thus, the STA system in the combined system was simulated by EES. EES is able to provide various thermal properties and calculate the thermal properties of their mixture [5]. Figure 3 shows the modeling results of the STA system using EES.

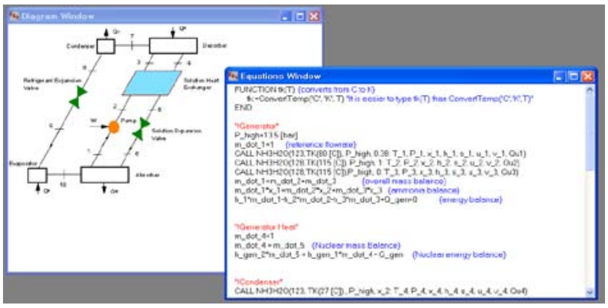

Figure 3. EES model of the STA system

2.3 Simulation Results

We selected NH_3-H_2O as a working fluid of the STA system. It has advantages in terms of crystallization, capacity, cost, and transportability as compared to H_2O-LiBr. The design parameters of the STA system were taken from Kang et. al. for the case of 1RT. The significant parameters and conditions are listed in Table I and Table II [6].

The STA system modeled by EES was tuned using the design values in Table I and II, and the turbine cycle was simulated such that the model can implement the heat balance diagrams provided by the manufacturer. Their integration was also performed so the results of the turbine cycle model and the STA system model can be interchangeable as the other one's input.

Table I. Baseline conditions for cycle modeling of 1RT STA system

Component	Flow rate (kg/s)	UA Values (kW/K)
Condenser	5.47×10^{-2}	1.51
Evaporator	4.02×10^{-1}	1.61
SHX	-	1.66×10^{-1}
Absorber	3.92×10^{-1}	4.61×10^{-1}
Generator	2.26×10^{-3}	9.72×10^{-3}

Table II. Physical properties of transportation fluids

Fluids	Mass Fraction	Density (kg/m^3)	Viscosity (cP)	Temperature (°C)
Strong solution	0.64	774.2	0.5	26.0
Weak solution	0.10	956.7	1.0	26.0
Chilled water	-	1000.0	5.9	7.0

3. Conclusions

We attempted to analyze the feasibility of the combined cycle consisting of a nuclear turbine cycle and an STA system. As further works, the design optimization of each component by sensitivity studies and the efficiency analysis of the combined system according to the waste heat sources will be conducted.

ACKNOWDEMENT

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REFERENCES

[1] G.C. Alder, B. Blakeley, D.R. Fleming, W.C. Kettenacker, G.L. Minner, Manuals for PEPSE® and PEPSE® -GT, ScienTech, USA(1999).

[2] D.W. Wu, R.Z. Wang, Combined Cooling, Heating and Power: A Review, Progress in Energy and Combustion Science, 28 February 2006, P. 9 ~ 13.

[3] K.E. Herold, R. Radermacher, S.A. Klein, Absorption Chillers and Heat Pump, CRC PRESS, Boca Raton (1996).

[4] H.M. Kim, G. Heo, Conceptual Design of Nuclear CCHP Using Absorption Cycle, IAEA, 27-30 October 2009.

[5] S.A. Klein, EES for Microsoft Windows Operating System Commercial and Professional Version, F-Chart Software, April 2002.

[6] Y.T. Kang, A. Akisawa, Y Sambe, T. kashiwagi, Absorption Heat Pump Systems for Solution Transportation at Ambient Temperature – STA cycle, Energy, 7 December 1998, P.335-370.