A Study on the Cycle Analysis of a Cryogenic Refrigerator for the CNS in the HANARO

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1. Introduction

The HANARO, a multi-purpose research reactor of a 30 MWth, open-tank-in-pool type, has been under normal operation since its initial criticality in February, 1995. Thermal neutrons which are generated by the nuclear fission can be transformed into cold neutrons by using a moderator such as liquid hydrogen. In order to produce the cold neutrons continuously, it is essential to use the cryogenic refrigerator which has a role to adequately remove the heat of a moderator. This paper describes the cycle analysis of the cryogenic refrigerator implemented by a numerical method. Also, it represents the results of the optimal conditions for the respective state in the refrigerator.

2. System Modeling

For the cycle analysis of the refrigerator, it is assumed that the refrigerator is composed of two heat exchangers and two turbines containing a He compressor and condenser. Fig. 1 shows the system modeling of the cryogenic refrigerator

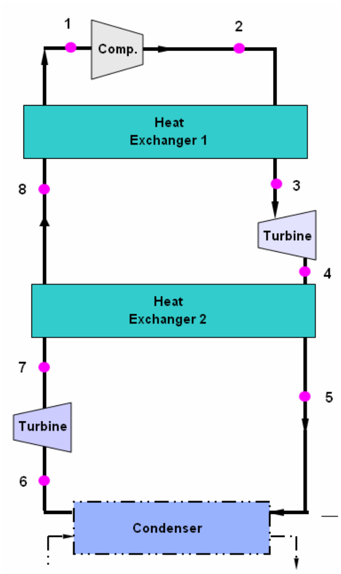

Figure 1. System modeling of the cryogenic refrigerator

This system carries out the heat transfer process to the condenser, which transforms hydrogen gas into liquid hydrogen by using the cryogenic helium generated by the refrigerator. For the normal thermo-siphon effect, it is reported that the inlet temperature of helium at the condenser must be 14K±0.5K, outlet temperature of helium must be 18K±0.5K and the heat capacity should be over 1500W.

3. Analysis Method

3.1 Assumptions

System variables are the effectiveness of the heat exchangers and adiabatic efficiencies of the turbines. The mass flow rate of helium, compression work and ratio and the initial state of helium are known. It is assumed that pressure drop at the condenser and dissipated heat due to the turbines is ignored respectively. State numbers are defined as the helium flow of the cycle process program.

3.2 Numerical methods of the Cryogenic Refrigerator

The system simulation program was created by a numerical method. This program consists of two programs that are a main and a sub program. Sub program calculates the respective helium state by the state postulate in the thermodynamics and the main program calculates all the results by using the results of the sub program. Fig. 2 shows the flow chart of the cycle analysis

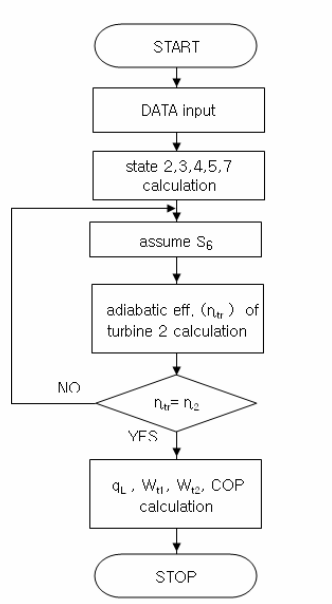

Figure 2. Flow chart of the cycle analysis program

4. Analysis Results

By using the above method, system analyses for a cycle are simulated with the different values of the variables (effectiveness and adiabatic efficiency). For example, Fig. 3 represents the relation between COP and the adiabatic efficiency of turbine 2 in the case that the effectiveness of the heat exchangers are 0.965, 0.92 respectively and the adiabatic efficiency of turbine 1 is 0.7.

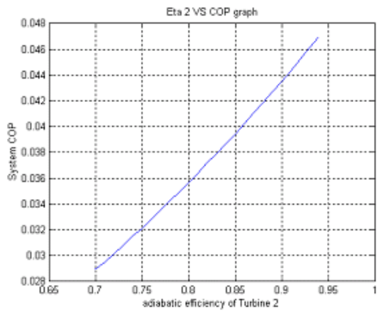

Figure 3. The relation graph between COP and adiabatic efficiency of turbine 1

This graph shows that the COP of the system is proportional to the adiabatic efficiency of turbine 1. But the temperature of states 5, 6 are more important than any other values of the states, the calculations are iterated many times in order to find the optimal conditions for the temperatures of state 5and 6. Therefore, the results are as follows

No.	η_1	η_2	T_5(K)	T_6(k)	q_L(KW)	*COP*
1	0.7	0.7	31.75	44.15	4.784	0.02008
2	0.72	0.72	39.55	56.7	6.597	0.02791
3	0.73	0.78	42.85	64.25	8.232	0.03507
4	0.73	0.785	18.1	25.25	2.919	0.01216
5	0.72	0.78	39.55	59.1	7.537	0.03201
6	**0.724**	**0.785**	**13.85**	**18.1**	**1.84**	**0.00764**
7	0.72	0.785	12.15	15.1	1.347	0.00558
8	**0.721**	**0.785**	**13.9**	**18.1**	**1.823**	**0.00756**
9	**0.722**	**0.785**	**13.9**	**18.1**	**1.829**	**0.00759**
10	**0.723**	**0.785**	**13.85**	**18.1**	**1.836**	**0.00761**

Figure 4. The results of the states for the cryogenic refrigerator to the variable parameters

For the above results, the first and second columns represent the adiabatic efficiencies of turbine 1 and 2 respectively. Here, effectiveness of the heat exchangers are fixed (0.965, 0.96). As a result, for test numbers 6, 8, 9, 10, the calculation results are very close to the optimal conditions. But in the case of No. 10, the COP value is lower than that of No. 6 in spite of the high efficiency of the turbines. Therefore it shows that the system COP is not proportional to the efficiency of the turbines. In addition to the results, the efficiency of turbine 1 has an effect on the temperature of state 5 (without the efficiency of turbine 2) and in case of No. 7, the temperature of state 5 is not suitable for the system condition because the efficiency of turbine 1 is much lower than that of the other cases (No. 6, 8, 9, 10).

As reference data, the calculation values of No. 8 are as follows

state	Temperature(K)	Pressure(kPa)	Enthalpy(kJ/kg)	Entropy(kJ/kg.K)
1	297.0000	140.0000	1557.5233	30.7387
2	309.0000	1325.0000	1624.0000	26.2030
3	55.0500	1325.0000	304.7747	17.2051
4	43.8000	662.5000	244.6542	17.5345
5	13.9000	662.5000	80.4728	11.2338
6	18.1000	562.5000	104.7865	13.2466
7	10.2500	140.0000	74.1165	13.8866
8	42.6500	140.0000	238.2980	20.6538
W_comp(kW)	247.98575			
W_exp1(kW)	4.50903			
W_exp2(kW)	2.30024			
q_L(kW)	1.82353			
COP	0.00756			

Figure 5. The calculation results for the case of No. 8

5. Conclusions

In this paper, a cycle analysis was carried out to find the optimal condition by using a computer simulation method. And adequate values of the states for the refrigerator were calculated. Consequently, system variables (efficiencies and effectiveness) are so sensitive that they affect other values such as the temperature of state 5 and COP. It is estimated that all the system variables are not independent of each other and have an influence on the system via complicated functions.

Acknowledgements

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REFERENCES

[1] Steven W. Van Sciver, Helium Cryogenics, pp. 382-395.

[2] B. S. Kim, et al. Fundamental Design of Systems and Facilities for Cold Neutron Source in the HANARO, KAERI/TR-3126/2006 pp.15-17, 2006.

[3] Chang, H.M, Cycle Analysis of 2-Stage Expansion Claude Refrigerator with Turbo expanders, Society of Air-Conditioning and Refrigerating Engineers of Korea, vol. 6, No 2, pp. 130-139, 1994.

[4] Chang, H. M, Basic design of hydrogen liquefier precooled by cryogenic refrigerator, Society of Air-Conditioning and Refrigerating Engineers of Korea, vol. 9, No. 3, pp.389-400, 1997.