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Study of Specific Work Changes with Number of Feed Water Heaters in BANDI-60S Steam Turbine Cycle

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1. Introduction

One of the primary considerations for utilizing a Small Modular Reactor (SMR) for a marine application is to ensure that the volume of the entire power conversion system, spanning from reactor to turbine, remains as compact as possible. If the reactor-related space takes up too much space on the vessel, this will eventually make the system less economical.

The 'BANDI-60S' is a Small Modular Reactor (SMR) being developed by KEPCO E&C. It is designed as a marine power generation reactor, featuring a thermal output of 200 MWth and an electrical output of 60 MWe. The 'BANDI-60S,' developed by KEPCO E&C, is an SMR designed for marine power generation, featuring a thermal output of 200 MWth and an electrical output of 60 MWe. According to the published data on the BANDI-60S, the power conversion system includes four Feed Water Heaters (FWH). If one needs to further reduce the size of the BANDI-60S to make the marine vessel more compact without significant modifications to the existing system, One easy design option to explore is to optimize the number of FWHs to reduce the volume of the power conversion system.

From this perspective, this study modeled the power conversion system of the existing BANDI-60S using the in-house code ‘KAIST-CCD’, and observed the trend of how the specific work of the BANDI-60S changes depending on the number of FWHs

2. BANDI-60S Steam Cycle Modeling

‘KAIST-CCD’ is an in-house code developed by the KAIST research team, based on MATLAB, which allows for the design of thermodynamic cycles. After selecting the points within the cycle that require analysis, the cycle layout can be constructed in MATLAB code using the functions of components such as a turbine, pump, and FWH. From cycle calculations, it is possible to determine properties for each point, as well as the mass flow rate, turbine work, pump work, and efficiency of the entire cycle. Fluid property information for the code calculation is provided by the NIST database (REFPROP). [1]

The power conversion cycle schematic diagram of BANDI-60S and key values for cycle calculation is shown in Fig 1, which is publicly available information [2], and Table 1. BANDI-60S operates on a saturated steam cycle with its maximum temperature and pressure near the saturation state. The BANDI-60S steam cycle consists of a steam generator (SG), turbine, condenser, and four FWHs. As the fluid passes through the turbine, it branches into four streams, each of which enters the four FWHs to perform the function of heating feedwater.

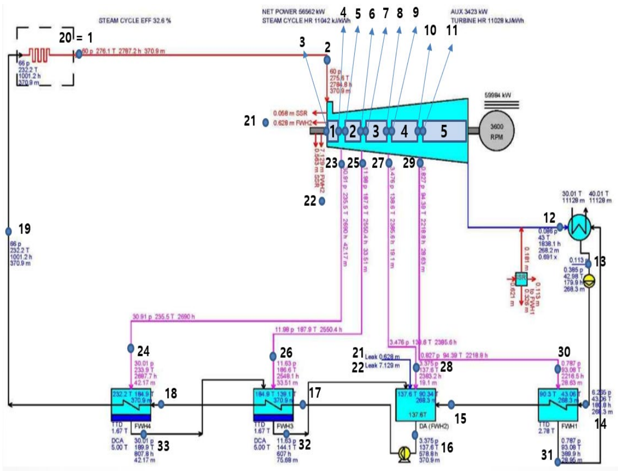


Figure 1. BANDI-60S Steam Cycle [2]

Table 1. Key values for Cycle Calculation

Steam Generator Outlet Temperature (˚C)		275.8
Steam Generator Inlet Pressure (bar)		66
Condenser Outlet Temperature (˚C)		42.98
Condenser Outlet Pressure (bar)		0.086
Turbine	Efficiency (%)	75.4 ~ 82.4
	Pressure Ratio	1.94 ~ 9.62
	Bypass Ratio	0.066 ~ 0.116
Pump	Efficiency (%)	63.5 / 65.6
	Pressure Ratio	19.56 / 72.85
FWH Effectiveness (%)		93 ~ 98

It is determined that there are 33 stations in the cycle to identify the thermodynamic state. Since the first goal is to replicate the power conversion system of BANDI-60S so that the cycle calculation can be verified, specific values such as the efficiency of major components and the branching mass flow rate within the turbine were determined to match the open information of BANDI-60S

As a result of the cycle modeling, the cycle efficiency and output of the modeled cycle were calculated to be identical to those of the reference cycle.

Thermodynamic states at each station were also obtained reasonably. However, the enthalpy error in station 12 was exceptionally large, and it appears to be an error in the reference cycle layout. This is because when calculated based on the reference properties of station 12, the isentropic efficiency of the turbine exceeds 1 and the cycle output is calculated to exceed 60 MWe. After, considering this fact, the corrected properties of station 12 were applied to the model. Fig. 2 is the final T-S diagram comparing the designed cycle with the reference cycle.

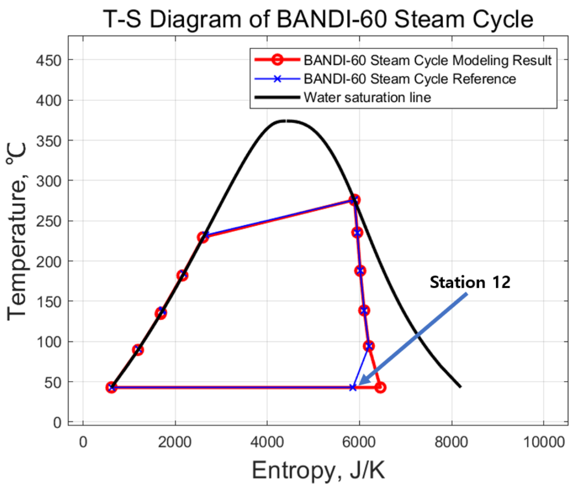
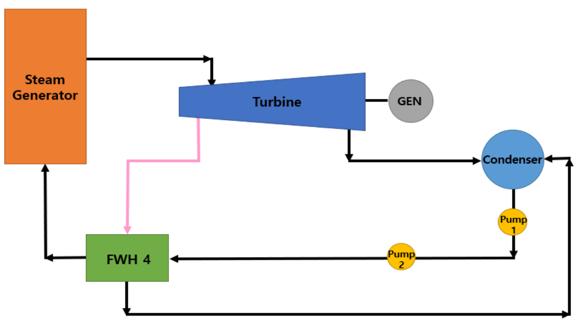


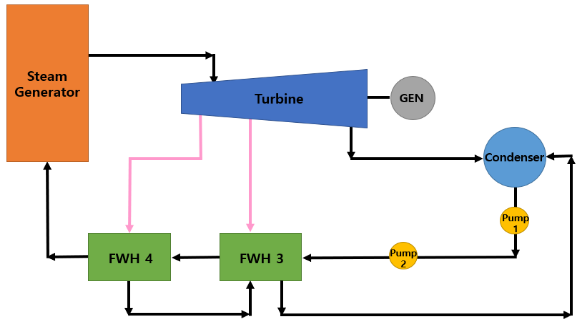
Figure 2. T-S Diagram Comparing the modeled Cycle with the Reference Cycle

3. Analysis of Specific Work Changes with the Number of FWHs

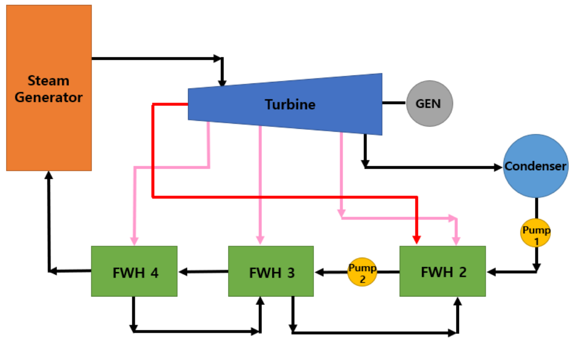
The analysis was conducted further on three modified cycle layouts, each with 1, 2, and 3 FWHs. In the modified cycle layouts, the key values of other components were not changed, and the structure of the existing cycle was maintained as much as possible. If there was no FWH, the mass flow rates branching from the turbine into the FWH would also be removed. It is assumed that the hot flow rate from the FWH enters the condenser if there is no other FWH to re-enter after the heat exchange. Fig 3. shows three simple schematic diagrams of the modified layouts.



< 1 FWH BANDI-60S Steam Cycle >



< 2 FWH BANDI-60S Steam Cycle >



< 3 FWH BANDI-60S Steam Cycle >

Figure 3. Simple Schematic Diagrams of Modified Cycle Layouts

The modified cycle layouts were also modeled using KAIST-CCD, and code calculations were performed for properties at each station, mass flow rates, output, and efficiency.

First, it was confirmed that the SG inlet temperature tended to decrease as the number of FWH was reduced. If the temperature difference between two fluids is large when they exchange heat, energy loss due to increased entropy also increases. The purpose of FWH is to increase the feedwater temperature from the condenser to the SG as much as possible through multiple heat regeneration. Therefore, it is obvious that as the number of FWH is reduced, the SG feedwater temperature decreases. The numerical values in the modified cycle layouts are shown in Fig. 4

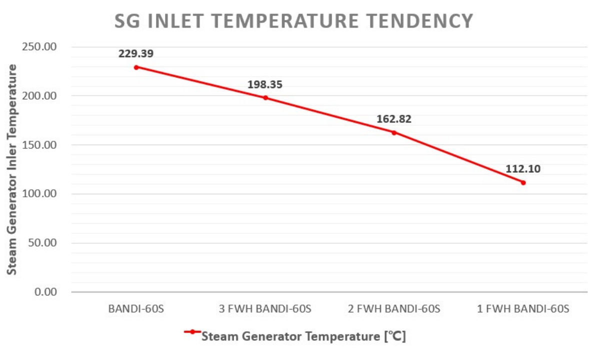


Figure 4. SG Inlet Temperature in Modified Cycles

Since the heat input (Qin) and outlet temperature of the SG are fixed, a decrease in the SG inlet temperature results in a decrease in the required mass flow rate for the cycle to converge. Although the output and efficiency of the cycle decrease, the change in the specific work is opposite. The results indicate that the decrease rate (59.99 MW → 54.22 MW) in output is smaller than the decrease rate (102.28 kg/s → 79.58 kg/s) in mass flow rate. Therefore, it can be seen that the specific work tends to increase as the number of FWH decreases. The specific work calculation results are shown in Fig 5

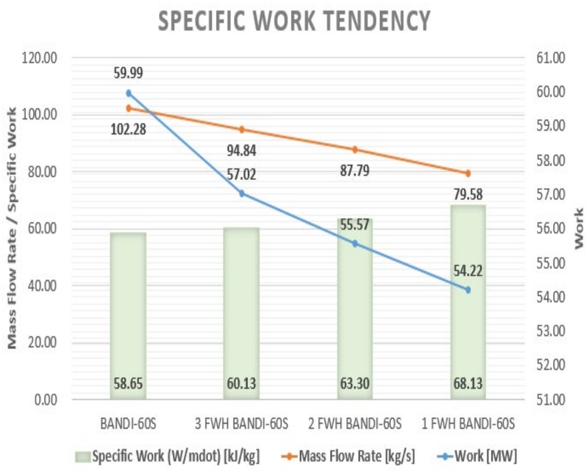


Figure 5. Specific Work in Modified Cycles

4. Conclusions

A modified cycle calculation of the BANDI-60S was performed, and in terms of specific work, which is the power generated per unit mass flow rate, the steam cycle of the BANDI-60S was found to be advantageous with less FWH. This suggests that, although there is a slight disadvantage in the reduction of total output, there is a significant advantage in removing FWHs and reducing the size of the power conversion system.

The BADNI-60S, as it is currently being designed, is intended for offshore power generation. The entire space of the ship-like platform itself can be only utilized for the reactor. However, if the BANDI-60S is to be used for other marine applications, space on board the ship can be limited, and the power conversion system will have to be downsized.

This study has identified the possibility that reducing the number of FWHs within the BANDI-60S power conversion system could be an option. Depending on the vessel's specifications, methods to reduce FWH for the BANDI-60S should be considered, or if output reduction is not acceptable, redesigning the power conversion system for specific application may be necessary. Trade-off assessments should be conducted to determine the most suitable approach.

REFERENCES

[1] Min Seok Kim, Yoon han Ahn, Beom joo Kim, Jeong Ik Lee. “Study on the supercritical CO2 power cycles for landfill gas firing gas turbine bottoming cycle” Energy, Volume 111, 2016, Pages 893-909, ISSN 0360-5442,

[2] B. J. Lee, IAEA Webinar: Advances in Reactor Technologies for Marine-based Small Modular Reactors, BANDI-60: Technology Features and Deployment Pathway