# PROCEEDINGS OF 14th INTERNATIONAL EXERGY, ENERGY, AND ENVIRONMENT SYMPOSIUM

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PROCEEDINGS BOOK

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# Thermodynamic Analysis of Desalination System on Combined Cycle Power Plants Through Throttling Process Method by Using a Vapor Compressor

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**Abstract**

Innovative strategies are being developed to concurrently address the urgent needs for freshwater resources and power due to the ever-increasing worldwide demand for both resources. One method offers a sustainable response to the rising demand for clean water and electricity by integrating desalination systems with combined cycle power plants (CCPP). As a result, this study aims to provide the thermodynamic analysis of desalination systems in CCPP, emphasizing the throttling process method in conjunction with a vapor compressor. The entire understanding of the energy interactions and efficiency gains possible in these interconnected systems is provided by this novel technique. Desalination integrated with CCPP presents a promising synergy in which waste heat from power generation is used to fuel the desalination process, resulting in higher overall system efficiency. When combined with a vapor compressor, the throttling process approach improves desalination efficiency and assures optimal utilization of available energy resources. Briefly, the method employed in this research is a thermodynamic simulation that uses the throttle valve temperature and the percentage of water discharged into the sea to determine the amount of aquadest generation and the Specific Energy Consumption (SEC) in this combined system. In this study, lowering the condenser pressure from 10.89 to 8.43 kPa increases the power of the steam turbine to 2.18%, allowing the temperature of water discharged to seawater to drop to 32.5°C eco-friendly with a Pinch Point Temperature Difference (PPTD) of 10. It generated vapor that could be condensed into aquadest with an SEC (Specific Energy Consumption) of -1423.36 kJ/kg of distilled water at best conditions, a mass flow rate of 3.63 kg/s at a pressure on the throttle valve of 2.65 kPa, and a mass of water discharged to the sea of 99.5%.

**Keywords:** Combined Cycle Power Plants, Desalination System, Energy Consumption, Freshwater, Waste Heat.

## I. Introduction

The ever-increasing worldwide demand for freshwater resources and power has driven novel techniques to meet both essential demands simultaneously (Di Martino et al. 2021; Zikri et al. 2020; Zikri et al. 2021). One option combines desalination systems with combined cycle power plants (CCPP), providing a long-term solution to freshwater scarcity and energy efficiency concerns. In this context, thermodynamic analysis is critical in optimizing the performance of such integrated desalination systems inside CCPP, particularly in applying the throttling process approach in conjunction with a vapor compressor. This novel technique thoroughly explains the energy interactions and efficiency gains possible in these integrated systems (Shokri and Fard 2022).

Desalination removes salts and other contaminants from seawater or brackish water to generate freshwater suitable for drinking, agriculture, and industrial uses (Kosasih et al. 2021; Zikri et al. 2020; Dzaky et al. 2020). Desalination operations have traditionally been energy-intensive, relying on multi-effect distillation (Farsi and Rosen 2022; Liponi, Wieland, and Baccioli 2020) & reverse osmosis technologies (Di Martino et al. 2021). However, these systems frequently require large amounts of electricity, resulting in significant running costs and carbon emissions.

Several other studies on the thermodynamic analysis of desalination systems have been conducted, including Dzaky et al.'s research, which resulted in distilled water production with a mass flow rate of 0.996 kg/s and SEC (Specific Energy Consumption) of -1194.02 kJ/kg when using heat from a steam power plant's condenser (Dzaky, Kosasih, and Zikri 2022). Another study examined how cyclone separation pressure and the amount of water extracted affected energy use. The lower the temperature in the cyclone separator, the greater the aquadest output. Conversely, the bigger the volume of water dumped into the sea; the less SEC will receive. The mass flow rate achieved for producing 0.86 kg/s distilled water with SEC at the same water discharged at 99% is -1137.62 kJ/kg (Dzaky, Kosasih, and Zikri 2020).

Integrating desalination systems with CCPP provides a one-of-a-kind chance to address the main dual concerns of water scarcity and power-generating efficiency. In addition, this study also emphasizes the environmental and economic benefits of combining desalination with CCPP. These integrated systems can minimize greenhouse gas emissions and operational costs by efficiently utilizing waste heat and decreasing energy losses. The CCPP are very efficient and use waste heat from the power generation process to improve total energy efficiency, often via a steam cycle. When combined with a vapor compressor, the throttling process method improves the efficiency of the desalination process and ensures the optimal utilization of available energy resources.

## II. Methodology

This study explores the thermodynamic analysis of a desalination system integrated into CCPP through the throttling method with a vapor compressor, as shown in Figure 1 below. In a CCPP, power generation typically involves both gas and steam cycles. The gas turbine cycle operates at a higher temperature, generating electricity by expanding high-pressure gas, as shown in process lines D and E in Figure 1. The exhaust heat from the gas turbine to HRSG 1 and 2 is then used to produce steam, which drives a steam turbine for additional power generation in process lines C combined with a desalination system on process lines A and B. This combination enhances the overall efficiency of power production.

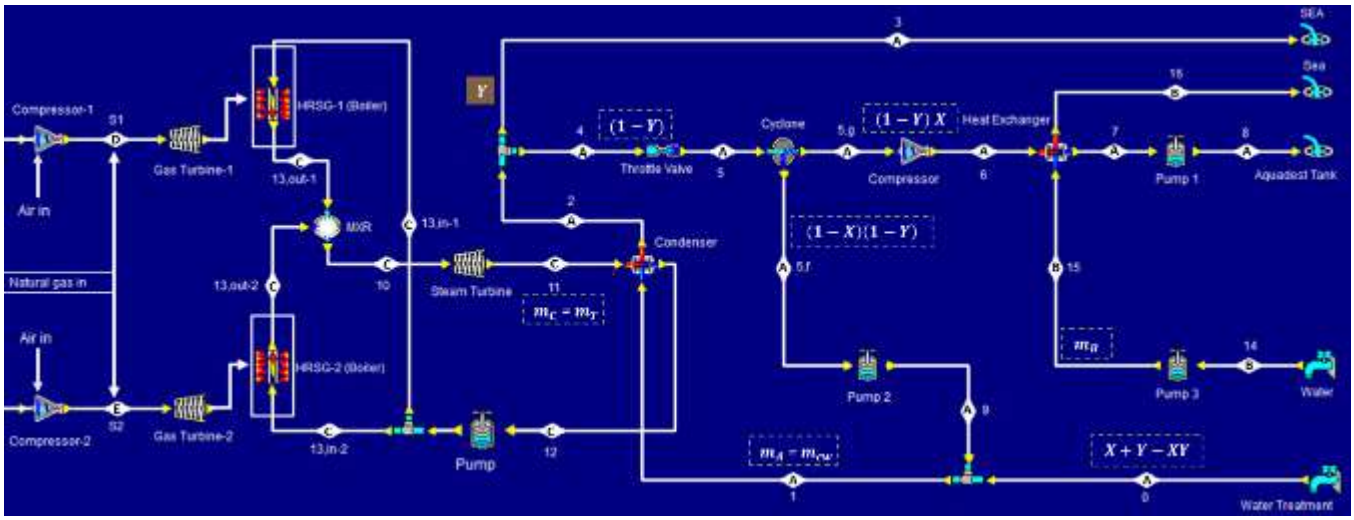



Fig. 1. Schematic diagram of a combined desalination system with a CCPP

Integrating the thermodynamic simulation method, which relies on theoretical calculations, into a power plant, specifically the CCPP in Bursa City, Turkiye (Unver and Kilic 2007). This study consistently applies the analysis parameters outlined in Table 1 below.

Table 1. Constant parameters used during integration of the thermodynamic simulation

| | Parameter | Value | | Parameter | Value |
|---|---|---|---|---|---|
| **Power Plant Side** | **Gas Power Plant capacity** | *239 MW* | **Desalination Side** | $\boldsymbol{T_0 = T_{14}}$ | *30 ℃* |
| | **Steam Power Plant capacity** | *237,5 MW* | | $\boldsymbol{p_0 = p_{atm}}$ | *101.325 kPa* |
| | $\boldsymbol{T_{10}}$ | *535 ℃* | | $\Delta \mathbf{T}_{\boldsymbol{condenser}}$ | *10 ℃* |
| | $\boldsymbol{p_{10}}$ | *11960 kPa* | | $\boldsymbol{T_7}$ | *44 ℃* |
| | $\boldsymbol{\eta_{i,Turbine}}$ | *0.85* | | $\boldsymbol{\eta_{i,\mathrm{Pump}}}$ | *0.85* |
| | $\boldsymbol{\dot{m}_T}$ | *1* | | $\boldsymbol{T_5}$ | *2-22 ℃* |
| | $\boldsymbol{T_{11,\mathrm{old}}}$ | *47.5 ℃* | | $\boldsymbol{Y}$ | *90-99.5%* |
| | $\boldsymbol{T_{11,\mathrm{new}}}$ | *42.5 ℃* | | $\boldsymbol{p_{14} = p_{atm}}$ | *101.325 kPa* |

## III. Analysis

In this exploration, we delve into the principles of thermodynamics, analyzing how energy is transferred and transformed within the integrated system. We investigate the fundamental components, such as the vapor compressor, heat exchangers, and turbines, that facilitate the conversion of thermal energy into both electricity and fresh water. To calculate energy consumption in systems integrating desalination systems with CCPP, we must calculate the increase in turbine power. The increase in steam turbine power is the effect of decreasing the temperature in the condenser in a steam power plant, which can be calculated using the following formulation.

$$\Delta W_T = \left(h_{10} - h_{11,new}\right)\dot{} - \left(h_{10} - h_{11,old}\right) \quad (1)$$

where $\Delta W_T$ is the increasing of turbine power, $h$ is the specific enthalpy (kJ/kg) for the given state point.

Then, the power of pump 1 ($W_{P,1}$), pump 2 ($W_{P,2}$), pump 3 ($W_{P,3}$), and the vapor compressor ($W_C$) can be calculated by the equation below.

$$W_{P,1} = \dot{m}_{Aq}\, v_f (p_{atm} - p_7) \quad (2)$$
$$W_{P,2} = \dot{m}_{cw}\,(1-X)(1-Y)(h_9 - h_{5,f}) \quad (3)$$
$$W_{P,3} = \dot{m}_B\, v_f (p_{atm} - p_{15}) \quad (4)$$

where $\dot{m}_{Aq}$ is the mass flow rate (kg/s) of aquadest production, $\dot{m}_{cw}$ is the mass flow rate (kg/s) of cooling water, $\dot{m}_B$ is the mass flow rate (kg/s) of cooling water to the pump 3. Before calculating each pump power, we should calculate the heat capacity on the heat exchanger ($Q_{HE,Aq}$) using the equation below.

$$Q_{HE,Aq} = \dot{m}_{Aq}\, c_p\, \Delta T \quad (5)$$

where $c_p$ is the specific heat (kJ/kgK), and $\Delta T$ is the different temperature (°C) in the heat exchanger. Furthermore, the vapor compressor power ($W_C$ ) can be calculated by the equation below.

$$W_C = X(1-Y)\dot{m}_{cw}\left(h_6 - h_{5,g}\right) \quad (6)$$

where $X$ is the essential vapor fraction, and $Y$ is the mass discharged to the sea.

On the other hand, water that enters the condenser absorbs latent heat from the fluid that works in the CCPP. The following equation, the heat capacity on the condenser ($Q_c$) can express this heat release from a CCPP can be calculated by the equation below.

$$Q_c = \dot{m}_{cw}\,(h_2 - h_1) \quad (7)$$

$$Q_c = \dot{m}_T\,(h_{11} - h_{12}) \quad (8)$$

where $\dot{m}_T$ is the turbine mass flow which is assumed of 1 kg/s. By substituting method, we can obtain the mass flow of cooling water ($\dot{m}_{cw}$ ). Then it can calculate the water mass ($\dot{m}_{Aq}$ ) using the equation below.

$$\dot{m}_{Aq} = \dot{m}_{cw}\,[X(1-Y)] \quad (9)$$

Thus, we can obtain energy consumption which is all of the power requirements used in integrating desalination systems with CCPP. Besides that, the SEC can be determined by the following equation below.

$$EC = W_{P,1} + W_{P,2} + W_{P,3} + W_c \quad (10)$$

$$SEC = \frac{EC - \Delta W_T}{\dot{m}_{Aq}} \quad (11)$$

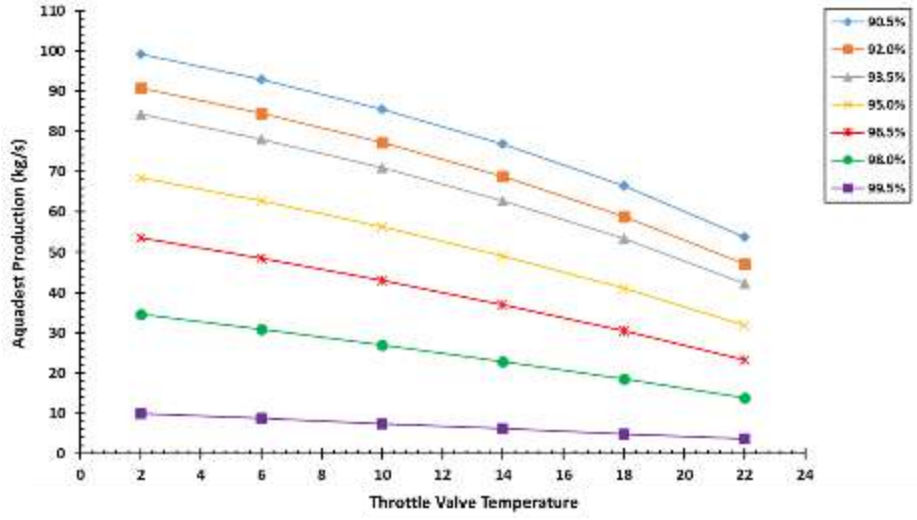
where $EC$ is energy consumption (kW), and $SEC$ is specific energy consumption (kW/kg).

**IV. Results and discussion**

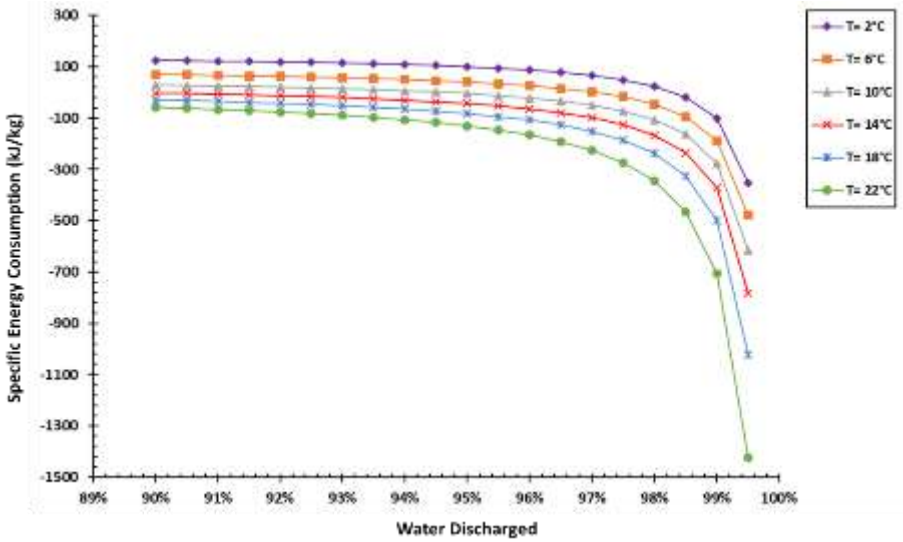
The thermodynamic analysis of a desalination system integrated into CCPP through the throttling method with a vapor compressor, which in this research has looked at the impact of aquadest production on water discharged and throttle valve temperature, as well as analyzing how much energy is transferred and transformed (in this case SEC) on the desalination system integrated into CCPP.

Based on Figure 2.a, increasing the percentage of water discharged and throttle valve temperature impacts decreasing aquadest production. Suppose the rate of water discharged is 90%, and the throttle valve temperature is 2°C. In that case, the aquadest production is 101.71 kg/s, while the same percentage of water discharged and the throttle valve temperature is enlarged to 11 times, the aquadest production becomes 9.97 kg/s. This case is because the ratio of water discharged is constant, but the temperature at the throttle valve is increased; this causes $h_{5,g}$ (in saturated vapor) to decrease while $h_5$ remains constant because it uses the throttle valve principle. Therefore, the greater the temperature of the throttle valve with a consistent percentage of water discharged, the smaller the aquadest produced.

On the other hand, if we look at the relationship between SEC with the percentage of water discharged and throttle valve temperature, we can see Figure 2.b below. The ratio increased of water discharged at a constant throttle valve temperature result in lower SEC and aquadest production. This case is because less water flows into the cyclone separator. Similarly, the temperature of the throttle valve increases at a constant percentage of water discharged. If the ratio of water discharged is 99.5% and the throttle valve temperature is 22°C then the SEC is -1423.36 kJ/kg, while the same rate of water discharged at the throttle valve temperature is reduced to 11 times, then the SEC becomes 125.05 kJ/kg.




(a)




(b)

Fig. 2. Water discharged and throttle valve temperature versus (a) aquadest production and (b) SEC

This case is because SEC is inversely proportional to the mass flow rate of aquadest. In addition, lowering the condenser pressure from 10.89 to 8.43 kPa increases the power of the steam turbine to 2.18%, allowing the temperature of water discharged to seawater to drop to 32.5°C eco-friendly with a PPTD of 10°C.

**V. Conclusion**

Based on the results of the thermodynamic simulation of the integration of the desalination system with CCPP, it can be concluded that the effect of reducing condenser pressure will increase the steam turbine power by approximately 2.18% and cause the temperature of the water discharged into the sea to be eco-friendly, namely 32.5°C. In addition, decreasing the percentage of water discharged and throttle valve temperature impacts increasing aquadest production. On the other hand, the relationship between SEC with the rate of water discharged and throttle valve temperature, in which the ratio increased of water discharged at a constant throttle valve temperature, results in lower SEC and aquadest production. Therefore, it can provide a more energy-efficient (ensuring optimal utilization of available energy resources) and cost-effective approach to desalination within CCPP.

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