The Impact of Cooling Water Way Length on Thermal Effluent Temperature Reduction in Coal-fired Steam Power Plants: The Case Study of the 2×150 MW Jeneponto Power Plant

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ABSTRACT

The thermal pollution caused by the usage of fossil energy sources has a significant impact on aquatic ecosystems that requires effective cooling systems for the reduction of temperatures such as the Cooling Water Way (CWW). This study examines the correlation between CWW length and temperature reduction at the Jeneponto power plant (2×150 MW) in Indonesia, focusing on two sections: box culvert (0-359 m) and open channel (359 m-1068 m). The box culvert segment, with minimal air-water interaction, achieves a temperature reduction gradient of 0.0006 °C/m, while the open channel segment shows a higher gradient of 0.0022 °C/m due to the enhanced cooling by convection, evaporation, and radiation. Linear regression models for both segments (R^2 is 0.9586 and 0.9961, respectively) highlight the important role of channel configuration in cooling efficiency. These findings provide valuable insights for optimizing CWW designs for effective thermal pollution control in coal-fired power plants worldwide.

Keywords-water cooling; Cooling Water Way (CWW); thermal pollution; temperature reduction

I. INTRODUCTION

The increase of thermal waste, produced by coal-fired power plants, can harm aquatic ecosystems if discharged without further cooling [1-3]. When the water temperature rises the dissolved oxygen levels in water are reduced, threatening the survival of aquatic organisms and altering ecosystems by changing species diversity, reproductive cycles, and migration patterns. Moreover, increased water temperatures can result to the growth of invasive species, further destabilizing aquatic environments [4-6]. For example, oxygen-sensitive species such as trout and salmon will be greatly affected by the increase of water temperatures while heat-tolerant organisms such as certain algae will grow, disrupting food chains, leading to biodiversity loss. To address these challenges, cooling systems, such as CWW, are commonly used to reduce wastewater temperatures before released into the environment [7]. The CWW is an open channel structure designed to release heat through natural processes such as conduction, convection, and evaporation as water flows through it [8, 9]. Several studies have examined the effectiveness of cooling systems in managing thermal pollution. Authors in [10] evaluated the performance of cooling towers and their energy consumption, while authors in [11] examined the effect of operating parameters on the thermal efficiency of open channel cooling systems. Authors in [12] used remote sensing to monitor temperature variations in cooling channels in Gujarat, India, and showed that longer channels achieved greater temperature reductions (~3°C), although seasonal variations and tidal conditions affected their performance. Authors in [13] evaluated the influence of wind speed, solar radiation, and air temperature on water temperature at Lake Laut Tawar, Aceh, and showed that water temperature exhibited daily variations and developed a mathematical model to predict these changes. Authors in [14] analyzed the effects of channel dredging on water temperature in Louisiana river systems and found that while dredging increased daily temperature fluctuations, it contributed to long-term cooling benefits. Similarly, authors in [15] evaluated the effect of channel length on water temperature at the Muara Karang power plant in Indonesia and reported modest cooling effects (≤ 0.24 °C) with higher efficiency during the rainy season.

Despite these findings, most of the above mentioned studies focused on general cooling systems and environmental parameters without specifically addressing the role of CWW length in determining thermal dissipation. The present study examines the influence of CWW length on thermal cooling in the Jeneponto Power Plant (2×150 MW) in Indonesia emphasizing the role of CWW length as a key parameter for thermal cooling efficiency. By providing empirical data specific to the Jeneponto power plant, this study aims to fill a critical knowledge gap in the optimization of open channel cooling designs. The novelty of this research lies in the empirical analysis of CWW length and cooling performance under site-specific conditions. This study differs from previous research by integrating real-world operational data with a focus on the specific design and environmental context of the Jeneponto power plant. Unlike generalized studies, it explores the direct correlation between duct length and cooling efficiency, providing insights for customized cooling system optimization. By leveraging real-world data, this study provides practical insights for optimizing CWW designs, contributing to strategies for minimizing environmental impact and improving the efficiency of cooling systems in coal-fired power plants worldwide.

II. MATERIALS AND METHODS

A. Research Location

This research focuses on analyzing the relationship between the length of the CWW and the decrease in thermal outflow temperature at the Jeneponto Steam Power Plant (2×150 MW) located in Punagaya Village, Bangkala District, Jeneponto Regency, South Sulawesi Province. The cooling water channel installation consists of a siphon well, a box culvert, an open canal, and an outlet. The box culvert has dimensions of 3.8 m width and 2.8 m height, with a total length of 359 m, consisting of 18 segments with 3 manholes located in segment 3, segment 7, and segment 12. The open channel has dimensions of 3.8 m width and 3.8 m to 4.35 m height, with a length of 704 m, consisting of 29 segments. The outfall is the end of a channel placed at the receiving water body. The structure of the outfall is similar to a drop structure, as the end point of the channel is usually located at a higher elevation than the surface of the receiving water body [16]. The outlet structure is built of concrete and stone masonry (either river stone or split stone) with a sky-jump design. The outlet consists of a layer of broken stone, rubble, and geotextile that acts as a wave breaker or tidal protection for the outlet structure, as shown in Figure 1. The method of temperature data collection is the utilization of a water quality monitoring device designed to measure water temperature, as shown in Figure 2. The readings taken are temperature measurements with 5 trials made at the siphon well, box culvert (at each manhole), and open channel in each segment. The findings from the water temperature measurements were mapped with the assistance of Surfer and Autodek AutoCAD Civil 3D software, simplifying the process, editing, and visualizing the geometric and hydraulic data. The analysis of the thermal distribution of wastewater from the power plant in the study area was conducted with Autodesk Civil 3D and Surfer software. The resulting data included channel coordinates, channel dimensions, surface temperatures of the wastewater, and thermal distribution maps of the wastewater in the cooling system, with the thermal distribution following the direction and speed of the current. Temperature patterns of the hot wastewater were presented as average surface temperatures throughout the study period. Furthermore, the final stage of this research was to find the relationship between the length of the cooling water way and the decrease in thermal waste temperature with regression analysis.

III. RESULTS AND DISCUSSION

A. Installation of Wastewater Temperature Measurement

The results of the implementation of temperature measurements at Jeneponto plant revealed the presence of five observations in each segment, as shown in Figures 3 and 4. Within the box culvert segment, measuring 0-359 m in length, the decline in water temperature is minimal, approximately 0.15 °C. This slight gradient is due to the closed channel configuration of the box culvert, which reduces the interaction between water and air, thereby limiting the processes of convection and evaporation. Conversely, in the open channel segment, which ranges from 359 m to 1068 m in length, a more considerable temperature decline is observed, reaching approximately 1.54 °C. This is explained by the fact that the open channel allows direct interaction between water and air, thereby accelerating heat release through convection, evaporation, and surface radiation. Authors in [17] employed Computational Fluid Dynamics (CFD) to model the temperature distribution in a power plant cooling canal, thereby demonstrating that open channels are more effective in lowering water temperature. The data gathered, support the conclusion that channel length has a direct relationship with temperature reduction. This suggests that open channels are more effectively used in CWW systems to enhance cooling efficiency, particularly in open channel configurations. The selection of channel type and length emerges as a significant factor that must be considered in the design of the CWW system to achieve the optimal temperature reduction.

B. Modeled Relationship of Temperature Drop

The decrease in water temperature along the CWW can be analyzed through linear modeling based on channel segments, specifically box culvert and open channel. The relationship between CWW length and temperature decline is shown in Figure 5. It is evident that there are differences in the temperature drop characteristics of the two segments and the relationship model is expressed by a linear equation with a high coefficient of determination (R^2). In the box culvert segment (0-359 m), the temperature drop follows a linear model:

$$TD = 0.0006L + 0.0124 \qquad (1)$$

with an R^2 of 0.9586.

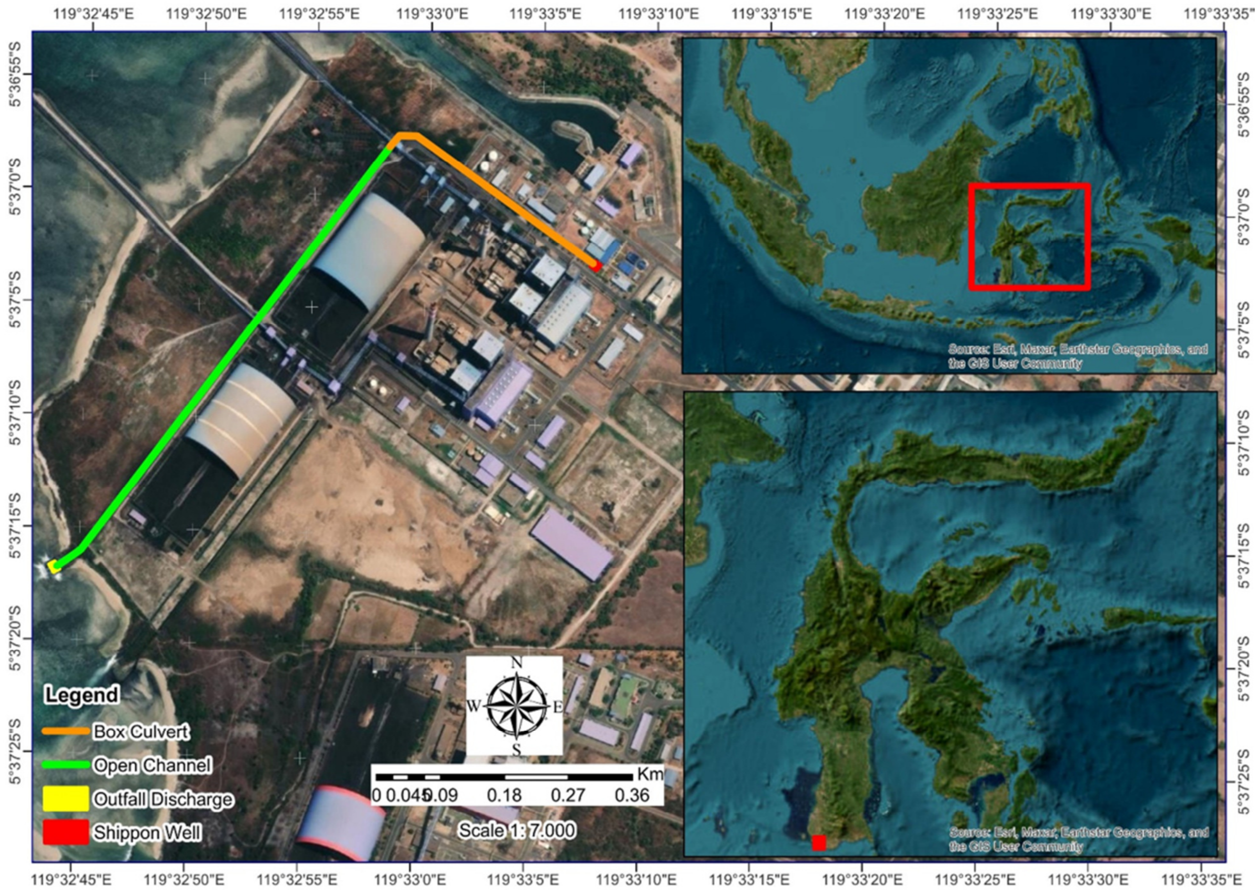

Fig. 1. Layout CWW system of Jeneponto steam power plant.

Fig. 2. Water quality monitoring.

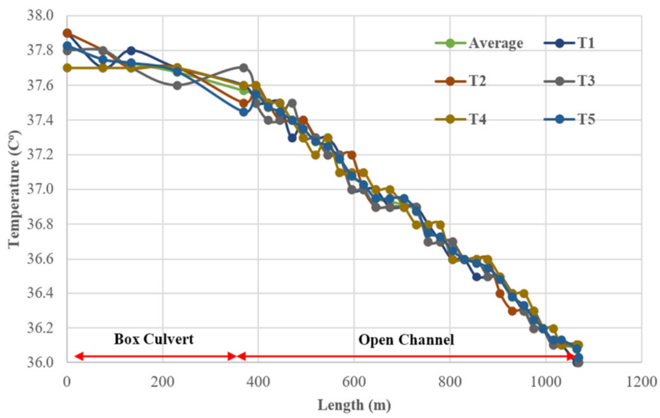

Fig. 3. Temperature distribution graph along the CWW channel.

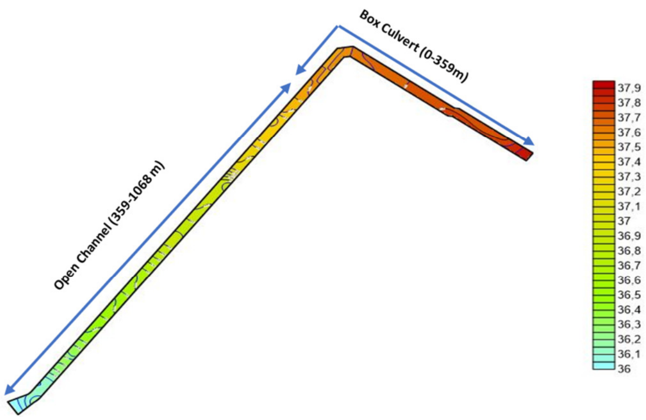

Fig. 4. Temperature distribution map along the CWW channel (average).

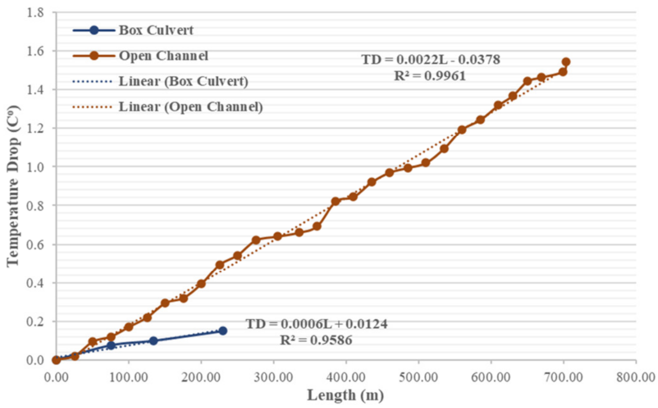

Fig. 5. Relationship of temperature drop to CWW length.

The model shows that the temperature drop in this segment is modest, with a gradient of 0.0006 °C/m. This is due to the closed channel nature that limits the interaction of water with air, resulting in a slower cooling process. In contrast, in the open channel segment (359 m-1068 m), the temperature drop follows a linear model:

$$TD = 0.0022L + 0.0378 \quad (2)$$

with an R^2 of 0.9961. The model exhibits a steeper downward gradient of 0.0022 °C/m, due to the nature of the open channel, which allows direct interaction between water and air, thereby enhancing the cooling process through convection, evaporation, and surface radiation. The difference in gradients between the two segments indicates the effect of channel type on water cooling efficiency. The length of the CWW directly correlates with the magnitude of the temperature decline, with the environmental interaction within the open channel playing a crucial role in the cooling process. This model can serve as a foundational framework for the design and optimization of CWW systems, aiming to achieve optimal cooling efficiency.

IV. CONCLUSIONS

This study examines the relation between the length of the Cooling Water Way (CWW) and the effectiveness of thermal wastewater temperature reduction at the Jeneponto Steam Power Plant (PLTU) in Indonesia. The findings indicate that the reduction in temperature is dependent on the type of channel, whether it is a box culvert or an open one. In the box culvert, with lengths ranging from 0 to 359 m, the temperature decline exhibits a gradient of 0.0006 °C/m, due to the characteristics of closed channels, which restricts the interaction between water and the surrounding environment, reducing the process of convection and evaporation. In contrast, the segment of the channel that is open, ranging from 359 m to 1068 m in length, exhibits a steeper decline in temperature, with a gradient of 0.0022 °C/m. This channel allows direct interaction between water and air, leading to convection, evaporation, and surface radiation. This research developed a channel length and temperature drop relationship model that exhibited a strong correlation, with a coefficient of determination (R^2) of 0.9586 for the box culvert and 0.9961 for the open channel. The findings indicate that the open channel configuration is more effective in improving cooling efficiency compared to the closed channel configuration. Consequently, the resulting linear equations can serve as a reference for designing and optimizing CWW systems in steam power plants. In conclusion, the channel length, especially in the open channel configuration, has a direct influence on the improvement of temperature reduction efficiency. This is of great importance to the design and optimization of CWW systems in thermal power plants and supports efforts to reduce environmental impacts due to thermal pollution.

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