MODELLING AND PERFORMANCE ANALYSIS OF V-BAR SPLASH FILLS IN WET COOLING TOWERS

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PhD Thesis Abstract

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July 2024

ABSTRACT

Splash fills are preferred in mechanical draft wet cooling towers commonly used in power plants because they are much less susceptible to clogging and fouling due to debris, algae, and salts compared to film fill. In cooling towers, the fill zone plays a predominant role in heat and mass transfer compared to the spray and rain zones. Consequently, having precise understanding of the characteristics of the fill zone becomes essential. Challenges in testing v-bar splash fills, their anisotropic flow resistance, and limited numerical modelling approaches necessitate a detailed numerical methodology. This research evaluates v-bar splash fill's performance using three-dimensional (3-D) numerical methodology, validated against experimental data. In the numerical methodology, the continuous air phase has been solved using the Eulerian approach, while the stochastic gravity-driven droplet trajectory for the water phase has been predicted using the Lagrangian approach. The study also employs the Eulerian wall film (EWF) model in conjunction with the Discrete Phase Model (DPM) to forecast the formation and movement of thin liquid films on splash fills. For the modelling of turbulent airflow, the standard k-ε turbulence model is selected. The computational cost and time associated with the complex splash fill geometry have been reduced by geometry simplifications and judicious meshing strategies. A parametric study has also been carried out to evaluate the impact of droplet diameter and air flow rate on the flow and thermal performance of the fill. Findings highlight the importance of droplet diameter in both thermal and flow performance. Increasing droplet diameter from 2 mm to 4 mm decreases the fill Merkel number by 0.13/m, while the average fill loss coefficient reduces by 2.2/m.

Another study investigates the impact of louvers on airflow distribution, aiming to optimize the angle of air intake louvers for uniform airflow beneath the fill pack. The airflow distribution within cooling tower significantly impacts their performance, and achieving uniform airflow is crucial for establishing performance correlations, particularly for v-bar splash fills. Area-weighted and mass-weighted uniformity indices, along with the loss coefficient of the air inlet, are utilized to gauge airflow uniformity and performance. CFD simulations investigate cooling towers with and without louvers, assessing various louver angles including 30°, 50°, and 70°. Among these angles, louvers set at a 50° angle demonstrate the most effective enhancement in achieving uniform airflow with minimal pressure drop.

This thesis also presents the development and utilization of an experimental facility to validate an updated numerical methodology for cooling tower fills. A 500×500 mm^2 counter-flow test rig with v-bar splash fill is employed, featuring an axial fan for airflow induction and a water distribution system for uniform water dispersion. The facility includes instrumentation for measuring air temperatures, pressure drops, water temperatures, and flow rates. Validation of tests depends on adhering to specified

limits outlined in [CTI ATC-105], ensuring consistent test conditions. The experimental setup allows for the determination of Merkel number with end effects included and loss coefficient through measured quantities. Furthermore, it describes the validation of numerical methodology, which incorporates an induced draft configuration and improved geometric details compared to previous methodology. The updated numerical methodology incorporates axial fan geometry for induced draft and modelled using the Multiple Reference Frame (MRF) approach. Boundary conditions and grid independence studies are discussed, ensuring accuracy and reliability of numerical simulations. The experimental setup validates numerical predictions, showing errors below 5% across the tested range. Numerical analysis of the test-rig zones highlights the significance of the spray and rain zones, contributing approximately 17% to the overall heat and mass transfer from water to air. Additionally, migration effects in v-bar splash fills are analysed, revealing non-uniform water temperature distribution and recirculation zones.

Numerical correlations have been developed to calculate the fill Merkel number and fill loss coefficient as measures of the fill's thermal and flow performance, respectively. These correlations, while independent of factors such as the heights of the spray zone and rain zone results in more standardized and accurate fill characteristic curves. However, it's important to acknowledge that these factors may indirectly affect performance by influencing droplet's sizes, thereby impacting the overall heat and mass transfer rate. Investigating the impact of air and water flow rates on fill performance reveal non-linear relationship between flow rate and performance and hot water temperature (HWT) and wet-bulb temperature (WBT) inversely affect thermal performance, with minimal impact on airflow resistance. The method of least squares is utilized to correlate the numerically determined data, resulting in equations for Me_{fill} and K_{fill} with high R_2 values of 0.984 and 0.996 respectively.

Another aspect addressed in present study is understanding the distribution of droplet sizes and water flow in the context of fill's performance which was studied using a hybridVolume of Fluid (VOF)-Discrete Phase Model (DPM) simulation to assess these distributions and their impact on cooling tower operation under non-uniform conditions. The methodology involves simulating the nozzle behaviour to obtain droplet size and water flow distributions, followed by an evaluation of v-bar splash fill performance using the obtained data. The hybrid VOF-DPM model integrates both VOF and DPM models, employing dynamic mesh adaption to capture complex flow fields and droplet formation. Experimental validation is conducted, including a mesh-independent study to ascertain model reliability. Results indicate that the droplet size distribution follows a Rosin-Rammler distribution, with a mean diameter of 1.15 mm and a spread parameter (n) of 3. Comparison of cooling tower performance under uniform and non-uniform water distribution conditions reveals insights into the impact of distribution variation. While thermal performance decreases by approximately 8.9% under non-uniform water distribution, flow performance remains minimally affected. The absence of drift eliminators led to a substantial drift loss of approximately 0.58% of the total water flow rate in the test rig. Hence, the study highlights the importance of drift eliminators in mitigating drift loss, especially with small droplet sizes below 0.3mm.

Overall, the above work addresses challenges in testing and modelling v-bar splash fills, employing a numerical methodology validated against experimental data. Furthermore, it establishes numerical correlations for calculating fill performance and compares fill performance under conditions of non-uniform distribution.