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Optimal design of forced-draft counter-flow evaporative-cooling towers through single and multi-objective optimizations using oppositional chaotic artificial hummingbird algorithm

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ABSTRACT

In this study, single-objective (SOP) and multi-objective (MOP) design optimization problems have been solved for mechanical forced-draft counter-flow wet-cooling towers using an enhanced-search variant of a recently proposed swarm-intelligence based metaheuristic, artificial hummingbird algorithm (AHA). Incorporating the oppositional rule to ensure a faster convergence by avoiding unnecessary search of the space, and with chaos-embedded sequences to obtain more diversifying search-population towards more accuracy in the obtained solutions, the proposed oppositional chaotic artificial hummingbird algorithm (OCAHA) has been implemented for effective design optimizations of cooling towers. In SOP, six number cases of literature have been algorithmically experimented for minimizing the total annual cost TAC as the single-objective function with mass flow rate of cooling air and cross-sectional area of tower fill as the two decision variables and with fourteen number of design inequality constraints based on the process temperatures and enthalpies. Merkel's method has been used for deriving the tower geometrical dimensions from empirical correlations of overall mass transfer-coefficient and loss-coefficient for the specified type of tower fill-packing. In MOP, range, tower characteristic ratio, effectiveness are the three objective functions, which have been maximized simultaneously with minimizing the water evaporation rate as the fourth objective for the problem. Mass flow rates of cooling air and circulating water are the two decision variables with the required input parameters of recent literature have been considered for multi-objective problem. The obtained designs through SOP and MOP have been analyzed with the competing designs, and a superior performance of OCAHA in both the optimizations have been validated.

1. Introduction

Circulating water through the cooling networks absorbs the waste or excess heat from hot process fluids of the industries [1,2] like, thermal power plants, chemical and petrochemical processing plants, food processing industries, natural gas processing units, refrigeration and air conditioning systems etc. Afterwards, it is cooled with the direct contact of cold air by evaporative and sensible cooling in a wet or evaporative cooling tower [3], and then recirculated through the cooling network and thereby maintaining a cyclic flow of water circulation [4] to run the mentioned industrial operational processes normal. Natural-draft and mechanical-draft are the two major classifications of these wet cooling towers [5,6]. After absorbing the required heat from the hot processing fluid of a plant, the hot water enters at the top of a cooling tower and flows downward through the tower fill packing, while the cooling air flows upward from the bottom to the top of a tower in the counter-flow arrangement or flows horizontally in the cross-flow arrangement of a tower. Uniformly distributed water through the fill packing [7] directly comes into contact with the cooling air, and simultaneous mass and heat transfer processes take place through the larger water-air interface. As a result, water gets partly evaporated into the air and gets cooled. Fresh make-up water is constantly supplied to the cooling tower to compensate the water losses through evaporation, drift eliminators and blow down loss of water particles.

In the natural-draft cooling towers [8], the natural buoyancy of warm air inside the tower drives the ambient air to flow through the tower, whereas in mechanical-draft cooling towers, an electrically driven fan either force the air from the tower inlet or bottom to upward direction in

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