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Development of Model of Cooling Tower for Experimental Studies

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ABSTRACT: Cooling towers are essential heat rejection devices that are widely employed in thermal power plants and other industries to disperse waste heat from process water through evaporative cooling. The design, construction, and experimental assessment of a laboratory-scale induced draft cooling tower are presented in this work. Polyvinyl chloride (PVC) materials, a submersible pump for water circulation, and a direct current fan for counterflow-induced airflow were used in the prototype's construction. Heat transfer calculations based on the basic energy balance equation were incorporated into the design process, and corrugated fill packing was used during construction to improve air-water contact. For educational laboratory use, the prototype is far more affordable than commercial options because it was manufactured at nominal cost.

KEYWORDS: Induced draft cooling tower; evaporative cooling; heat and mass transfer; cooling effectiveness; PVC prototype.

I. INTRODUCTION

Warm water and ambient air are brought into direct contact for evaporative cooling in a cooling tower, a type of specialised heat exchanger. It maintains a low air-side pressure drop while offering superior air-water contact in terms of interfacial area and mass transfer coefficient. Water droplets can transfer latent and sensible heat simultaneously to the surrounding air stream because the enthalpy of the incoming air is lower than that of the heated water [1, 2]. Hot water from an industrial heat exchanger or condenser is typically sprayed at the top of a cooling tower. Louvres on the sides or bottom allow ambient air to enter. It carries the rejected heat as it escapes at the top after passing through fill media in counterflow or crossflow contact with the descending water. One to two percent of the circulating water evaporates during the cooling process [3].

The entire development process of a prototype induced draft counterflow cooling tower intended for laboratory usage is presented in this study. The work includes identifying and fixing pre-existing system failures, choosing and defending a design configuration, analysing the system's thermodynamics and heat transfer, fabricating the system using materials that are readily available locally, and conducting thorough experimental evaluations of thermal performance parameters.

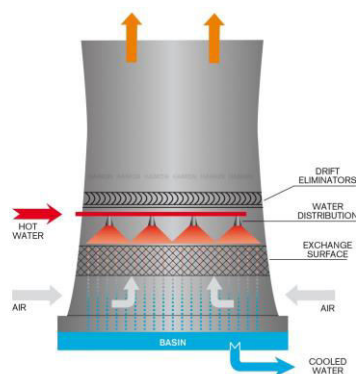


Fig. Schematic Diagram of cooling tower

II. LITERATURE SURVEY

The historical development of cooling towers dates to the Industrial Revolution in the mid-19th century. Early industries discharged process waste heat directly into natural water bodies, leading to thermal pollution. The first enclosed spray chambers appeared in Britain and the Netherlands during the 1860s and 1870s, primarily to cool condenser water from steam engines. The first formal patent for a cooling tower design was filed in Germany in 1894, and the iconic hyperboloid natural draft tower design was patented in 1918 [9]. The theoretical foundation for cooling tower analysis was established by F. Merkel in 1925, whose paper 'Verdunstungskuhlung' (Evaporative Cooling) provided the first rigorous mathematical framework relating heat and mass transfer using the enthalpy potential driving force. The Merkel equation and the concept of Number of Transfer Units (NTU) derived from it remain the universal standard for cooling tower design and performance evaluation to this day [10, 11]. Baker and Shryock [12] extended Merkel's work by introducing the Chebyshev numerical integration method for more accurate evaluation of the NTU integral, particularly for towers with wide cooling ranges. The emergence of mechanical draft technology in the early 20th century enabled more compact and controllable cooling towers. Forced draft and induced draft configurations were commercialized, with induced draft towers proving superior in terms of airflow uniformity and reduced warm air recirculation [4]. The Marley Company in the United States became one of the earliest major manufacturers and contributed significantly to standardizing tower design and performance testing protocols [9].

III. PROPOSED METHODOLOGY AND DISCUSSION

The development of the present cooling tower prototype involved the restoration and redesign of an existing but non-operational induced draft cooling tower unit available in the college laboratory. A systematic fault diagnosis was conducted, revealing several major failure categories including motor and fan degradation, structural failures, and water distribution issues.

The governing energy balance is expressed as:

$$Q_{\text{rejected}} = m_w \cdot C_{p-w} \cdot (T_1 - T_2)$$

where m_w is the mass flow rate of water (kg/s), C_{p-w} is the specific heat capacity of water (4.186 kJ/kg·K), T_1 is the inlet water temperature (°C), and T_2 is the outlet water temperature (°C) [2].

The induced draft counterflow configuration was selected based on a systematic comparative analysis. The prototype was fabricated using locally available materials and commercially sourced components. The main structural casing was constructed from polyvinyl chloride (PVC) panels. Corrugated fiber fill packing was selected to maximize the air-water interfacial area while maintaining a low air-side pressure drop. Complete component specifications are listed in Table 1.

Table 1: Specifications of Cooling Tower Components

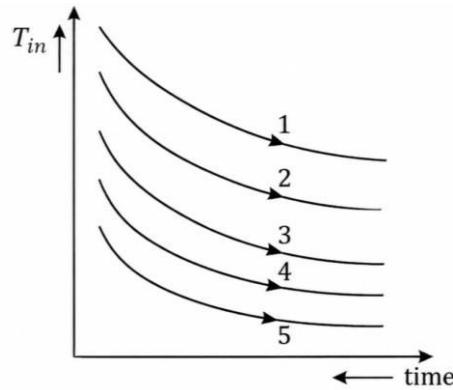
Component	Specification
Fan (Axial, Induced Draft)	95 W, 230 V AC, 1300 RPM
Pump	0.5 HP, 2850 RPM, Inlet/Outlet Dia. = 1 inch
Fill Media	Corrugated Fiber (Film Type)
Temperature Sensors	NTC Type, Range: -50°C to +85°C (±0.5°C)
Casing Material	Polyvinyl Chloride (PVC)
Water Distribution	Spray Nozzles on Cross-Pipe Headers
Cold Water Basin	PVC Basin with Epoxy Waterproof Lining

IV. RESULTS

Experimental tests were conducted under controlled indoor laboratory conditions. The tower was operated in steady-state conditions before recording measurements. Five test runs were conducted, varying the inlet water temperature from 35°C to 55°C while maintaining a constant fan speed of 1300 RPM and ambient conditions.

The experimental data recorded across five test runs are presented in Table 2. The ambient dry bulb temperature was maintained at 37.5°C and wet bulb temperature at 22.8°C throughout all tests, ensuring that variations in cooling performance could be attributed solely to changes in inlet water temperature rather than ambient fluctuations.

Table 2: Experimental Observations for All Test Runs



The graph represents the variation of inlet temperature (T_{in}) with respect to time for five different cases, labelled 1 to 5. In all cases, the temperature decreases over time, indicating a cooling process. Each curve has a different slope, which reflects the rate of temperature change $\left(\frac{dT}{dt}\right)$. Curve 1 shows the steepest decline, meaning it has the highest rate of cooling, while curve 5 is the flattest, indicating the slowest cooling rate. The relation

$$\left(\frac{dT}{dt}\right)_1 > \left(\frac{dT}{dt}\right)_2 > \left(\frac{dT}{dt}\right)_3 > \left(\frac{dT}{dt}\right)_4 > \left(\frac{dT}{dt}\right)_5$$

Table 2: Experimental Observations for All Test Runs

Test Run	T_1 (°C)	T_2 (°C)	Tdb (°C)	Twb (°C)	Fan (RPM)	RH (%)
1	35	28.7	37.5	22.8	1300	54
2	40	31.6	37.5	22.8	1300	54
3	45	33.2	37.5	22.8	1300	54
4	50	35.9	37.5	22.8	1300	54
5	55	38.8	37.5	22.8	1300	54

T_1 = Hot Water Inlet Temperature; T_2 = Cold Water Outlet Temperature; Tdb = Dry Bulb Temperature; Twb = Wet Bulb Temperature; RH = Relative Humidity.

The following figures illustrate the relationship between hot water inlet temperature and the key experimental parameters — cooling range and approach temperature — observed during the five test runs.

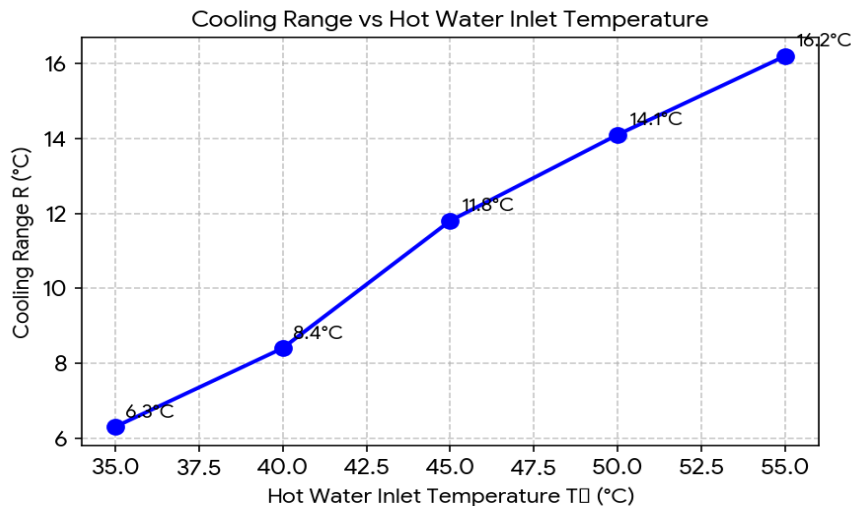


Figure 1: Cooling Range vs Hot Water Inlet Temperature

Figure 1 shows a clear and consistent increase in cooling range with increasing inlet water temperature. The cooling range rose from 6.3°C at $T_1 = 35^\circ\text{C}$ to 16.2°C at $T_1 = 55^\circ\text{C}$, representing a 157% increase. This behavior is consistent with thermodynamic predictions: higher inlet water temperatures produce greater enthalpy differences between the saturated air at the water surface and the bulk air stream, thereby increasing the driving force for both evaporative and convective heat transfer.

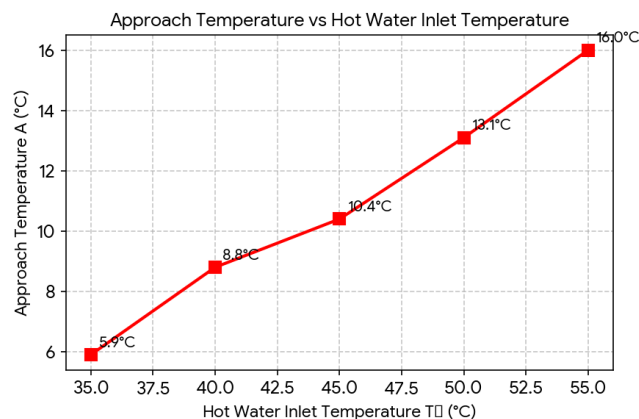


Figure 2: Approach Temperature vs Hot Water Inlet Temperature

Figure 2 demonstrates that the approach temperature also increases with rising inlet water temperature, from 5.9°C to 16.0°C across the test runs. This reflects the finite contact area and height of the fill media, which limit the approach achievable for a given set of operating conditions. Industrial towers with taller fill sections achieve approach temperatures as low as 3°C to 5°C [14, 15].

V. CONCLUSIONS

This study successfully fabricated a laboratory-scale induced draft counterflow cooling tower prototype using PVC materials at nominal cost. Experimental observations confirm stable and repeatable performance across five test runs with inlet temperatures ranging from 35°C to 55°C. The cooling range increased from 6.3°C to 16.2°C, and the approach temperature ranged from 5.9°C to 16.0°C. The prototype demonstrates strong potential as a hands-on educational tool for demonstrating evaporative cooling and heat transfer principles to undergraduate engineering students.

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