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Experimental Study of the Thermal Performance for the Natural Draft Wet Cooling Tower

Qasim S. Mahdi[1], Wael N. Abdalla[2]
[1,2]Faculty of Engineering, Al-Mustansiriyah University
([1]qasim602006@yahoo.com, [2]eng.waeel@yahoo.com)

Abstract-In the present paper an experimental investigation has been made to evaluate the thermal performance for a natural draft wet cooling tower (NDWCT). Experiment part is carried out when the tower has a natural draft and is assisted by fans, with using of the packing fill type (honey cell). Operational parameters studied are; the thickness of the fill 15cm, inlet water temperature (40, 45, 50 ,55 and 60°C) and inlet water mass flow rate (5.68, 7.75, and 9.46) L/min. The experimental results showed that the thermal performance is improved when assisted fans are used with the NDWCT. The cooling range and effectiveness increase by (35) % and (37.2) % respectively.

Keywords- *Natural Draft Wet Cooling Tower (NDWCT), Fans Assisted, Thermal Performanc*

I. Introduction

Cooling tower is a device to reduce inlet water temperature through heat reject to the ambient air. Cooling tower is complement to the following systems power generation units, nuclear reactor, chemical and petrochemical industry, and air conditioning plants [1]. To improve the efficiency of these systems the researchers and designers focus on developing the thermal performance of the cooling tower because of their great influence to increase the efficiency of these mentioned systems [2]. Cooling hot water inside the tower is by distribute it through the spray zone by nozzles so the water falls down from top to the bottom of the tower. Ambient air moved inside the tower by fans or by nature draft. Air and water movement inside the tower leads to evaporate part of the water and increase the humidity of the outlet air and cooling the fallen water [3]. One of the ways to improve efficiency of cooling tower is used fans assisted natural draft, It's look like a natural draft design but with less height for the chimney than the natural draft one, with the assist of fans at the base of the chimney the air flow inside the cooling tower. This type is likely used when hot weather with high relative humidity, also when it is need a certain cooling capacity and when a certain heights should be applied. The advantages are compact circular arrangement and saving power because of the natural draft [4]. Lemouari et al., carried out an experimental analysis of concurrent heat and mass transfer between air and water by direct contact in a filled cooling tower. This research studied the influence of air and water flow rate on the standard heat and mass transfer coefficient, and the evaporation rate of water in the air flow. Two operational procedures detected during the air, water contact inside the tower, a Pellicular Regime (PR) and Bubble and Dispersion Regime (BDR) are applied. These two operational methods can detect the best way to improve the heat and mass transfer in such temperature variation and effectiveness of the cooling tower. The conclusions of this study are when the water and air contact through the filling inside the tower, two operational hydrodynamic methods of the cooling tower were detected; a Pellicular method conducted with the low water flow rates, and a bubble and dispersion method shows for relatively bigger water flow rates [5]. According to Alok all thermodynamics properties changes after rain zone either increase or decrease, temperature is reach its higher value in center line and lower near the wall, pressure decrease to the value from 7 Pa to zero at fill zone then increase a little according to height [6]. An experimental analysis for Natural Draft Wet Cooling Tower (NDWCT) performance was applied using trickle fill under the effect of cross wind. Tests were done in summer season in Iraq, using (5 and 10) cm trickle fill. Changing mass flow rate of water from (0.8 to 2.4) gpm, and changing cross wind from (0 to 1) m/s. The obtained results state that cooling capacity, heat rejection and air enthalpy change will increase whenever fill thickness or even water flow rate are conditions by wind-creator setup provided so as to implement actual characteristics of the natural wind speed profile specifically, actually this research interested in effectiveness of cross-wind velocity, inlet water temperature and water mass flow rate on the water investigated NDWCT. The objective of the present paper is to evaluate the thermal performance of natural draft wet cooling tower (NDWCT) with and without assisted fans. The studied parameters are: fill thickness, inlet increased. Yet, increasing cross wind shows that a knee point is found at critical cross wind at bottom of the tower equal to (0.6) m/s [7]. According to Seyed this research investigate the performance of heat transfer in counter-flow NDWCT, under cross-wind and windless water temperature and water mass flow rate [8]. Saad et al., interested in the performance of NDWCT, using a convenient technique. This technique considered the effects of fill type, nozzle hole and water mass flow rate on the performance of cooling tower. The model dimensions were: top outlet diameter (370 mm), bottom diameter (680 mm) and height (850 mm). Three cases were investigated for film and splash fill, where for film the heights were (60, 90 and 120mm) and for splash fill (30, 45 and 60mm) heights. The performance parameters of the tower such as range, approach, and effectiveness and Merkel number were investigated. Eighteenth new experimental relation was suggested for Merkel number and water to air mass flow rate ratio.

II. PHYSICAL MODEL

At wet cooling towers, the inlet water cooled until its temperature is close to the wet ambient air temperature. The cooling process is to spray and distribute hot water from the top of the tower as droplet to be falling down, and this droplet will be coated with uniform spherical saturated air film, the temperature of the water droplet surface supposed to be equal to the temperature of the section. Basically, the cooling of the water is done base on the heat and mass transfer phenomena inside the cooling tower through direct interface between water and air while part of the water evaporate into the air, [10].

Merkel theory declares that the heat transfer rate at any position of the tower is suitable to the difference between the temperature of the bulk air stream and the temperature of saturated air at the water temperature. The above declaration is given as the following equation, [11].

$$q'' = hde\ (ias - ia) \qquad (1)$$

Where (hde) is an empirical mass transfer coefficient which can be obtained from the experimental work and (ias – ia) is the difference between enthalpy of saturated air and dry air. Where the cooling tower effectiveness (ϵ) is define as the ratio of the actual energy transfer to the optimum possible energy transfer. Therefore, the tower effectiveness is obtained from equation.

$$\text{Effectiveness } (\epsilon) = \frac{(Tw)\,in - (Tw)\,out}{(Tw)\,in - (\,Twet)in} \qquad (2)$$

III. EXPERIMENTAL TEST RIG

Schematic diagram for the test rig parts shows in (fig. 1) and its parts are the tower shell, the base tower, nozzles system, packing, water heating system, fan assisted attached to its holder, and measuring equipment. The test rig can be operated in two ways, a natural draft wet cooling tower and fan assisted wet cooling tower. Tower shell dimensions (98, 131, 58) cm (bottom base diameter, tower height, the upper base diameter) respectively. The base manufactured to compatible the tower shell as a circular shape (diameter 100 cm), attached to the base eight fans holder which distributed equally on the base. These fans allow the air to pass through the tower from the fan slot (diameter 20cm). In the spray zone at (85cm) diameter of the tower shell the nozzles has been distribute water to cover all the area above the packing fill. Honey cell packing is used in the cooling tower which is the most common used in cooling towers. Two thicknesses are used (10, and 20) cm during the tests. To represent heating load, two electrical heaters has been used, and two tanks have been used primary and main tank for hot water, to insure continues flow of the hot water in constant temperature during the test with values (40, 45 and 50) °C. Three centrifugal pumps have been used. Two pumps pumping the cold water from cold water tank under NDWCT to the primary hot tank and the third pump pumping hot water from main water tank to the nozzles set inside cooling tower.

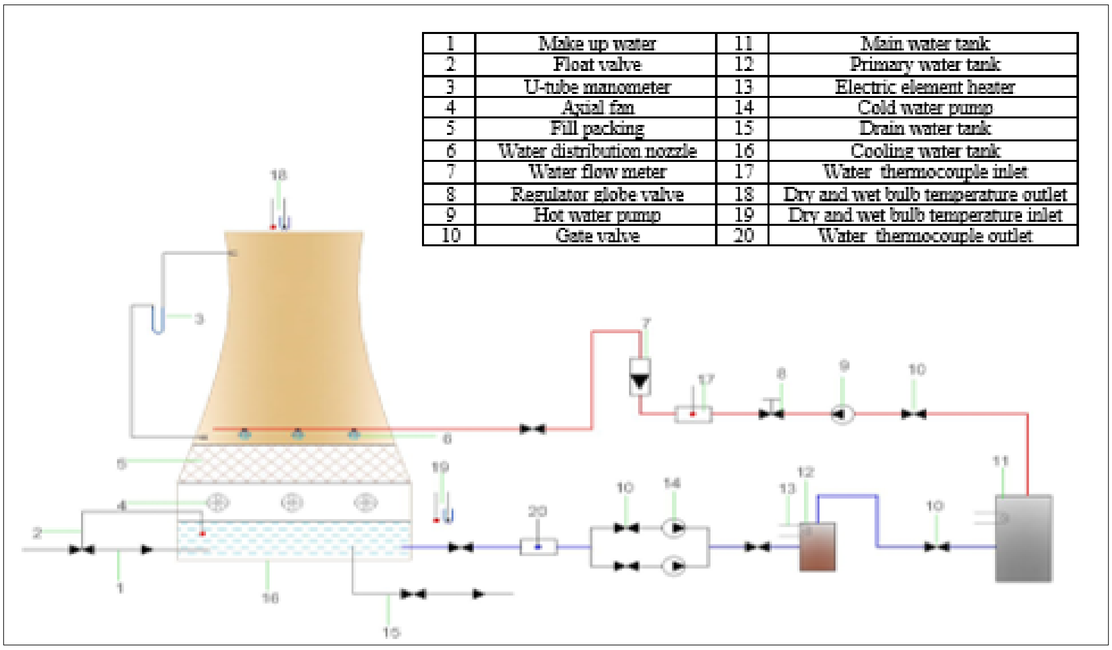

Figure 1. Schematic diagram of the experimental test rig

IV. RESULTS AND DISCUSSIONS

A. Cooling range

Figures (2, 3) the x-axis represent the value of water flow rate (Liter/min) while y-axis represents the cooling range (°C), with inlet water temperature (35, 40, 45, 50, 55 and 60°C).

Figure (2) shows the change in cooling range at the case of natural draft air, figure shows that when the water flow rate increases the cooling range decreases, because the heat and mass transfer is limited base on the following factors, the surface contact area between air and water is fixed and the inlet air flow rate is almost constant. When inlet water temperature increases the behavior of the cooling rage gets higher. For instance when inlet water temperature (40, 55 °C) and at water flow rate (5.68 L/min) the cooling range (4.084, 5.67°C). Figure (3) show the change in tower range at the case of forced draft air (fan assisted), on the contrary of previous figure (2) this figure shows that, when inlet water flow rate increases the cooling range increases quietly, due to the increases of mass and heat transfer and that's because the increases of the inlet air flow rate due to the effect of the assisted fans. For instance when inlet water temperature (40, 55 °C) and at water flow rate (5.68 L/min) the cooling range (5.285, 6.086°C).

Both figures (2) and (3) are similar in their cooling range curve which gets higher when inlet water temperature increases.

B. Tower approach

Tower approach can be obtained from outlet water temperature minus inlet wet air bulb temperature of air (Tw_{out} – T air_{wb}). In Figures (4) to (5) x-axis represents water flow rate while y-axis represents tower approach value at inlet water temperature (35, 40, 45, 50, 55 and 60 °C).

Figure (4) shows the change in tower approach for NDWCT without assisted fan. When water flow rate increases the tower approach value increases slightly. When the inlet water temperature increases, the tower approach curve gets higher. The reason of that is the outlet water temperature affected by the inlet water temperature, so when inlet water temperature increases the outlet water temperature increase too, for instance when inlet water temperature (40, 55 °C) and at water flow rate (5.68, 9.46 L/min) the tower approach value equals (21.042, 21.093 °C) and (34.218, 43.266 °C)..

For the best performance, water should be cooled to the inlet air wet bulb temperature. This is possible theoretically when the fill thicknesses approaching to infinity.

Figure (5) shows the NDWCT with assisted fan, noticing that when water flow rate increase the tower approach slightly change. And when inlet water temperature increases the tower approach increases too, for instance when inlet water temperature are (40, 55 °C) and at water flow rate (5.68, 9.46 L/min) the tower approach value equals (19.479, 19.578 °C) and (33.941, 33.023 °C).

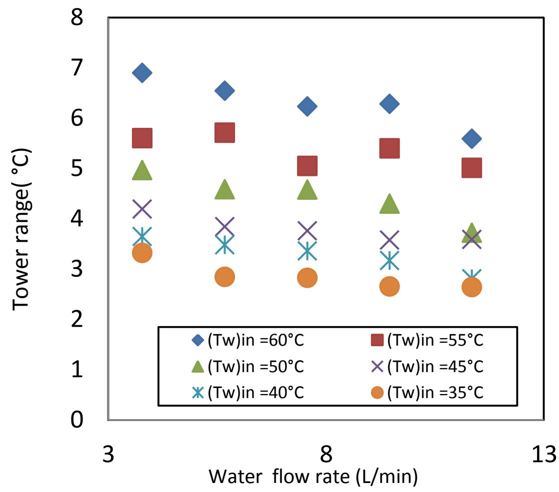

Figure 2. Variation of cooling range with water flow rate for different inlet water temperature, without assisted fans

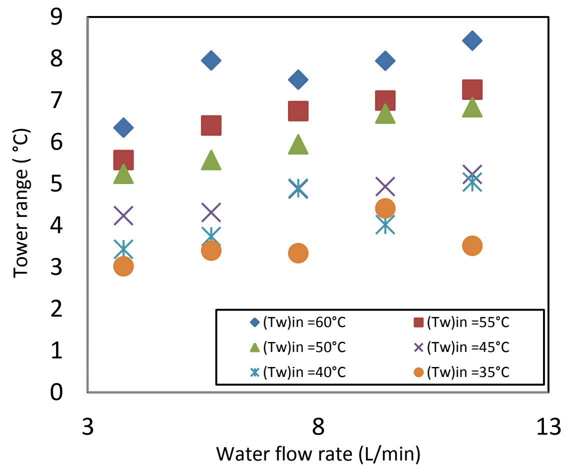

Figure 3. Variation of cooling range with water flow rate for different inlet water temperature, with assisted fans

C. Cooling tower effectiveness

Figure (6) show the effectiveness change for NDWCT without assisted fans. When water flow rate increase the effectiveness decreases. The reason of that is inlet wet bulb temperature is almost constant during the test and cooling range decrease with the increases of the water flow rate and when water flow rate increase (3.78 to 11.35 L/min) at the inlet water temperature (55°C) the. Figure (7) show the effectiveness change NDWCT with assisted fans. When water flow rate increases the effectiveness increases too. This behavior is on the contrary of NDWCT without assisted fans. But they are similar when inlet water temperature increase, effectiveness increases too.

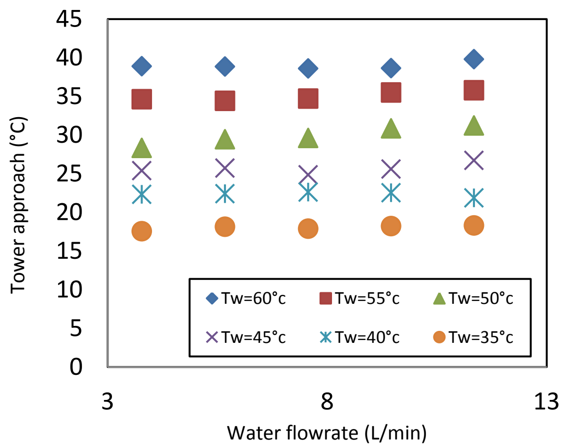

Figure 4. Variation of tower approach with water flow rate for different inlet water temperature, without assisted fans

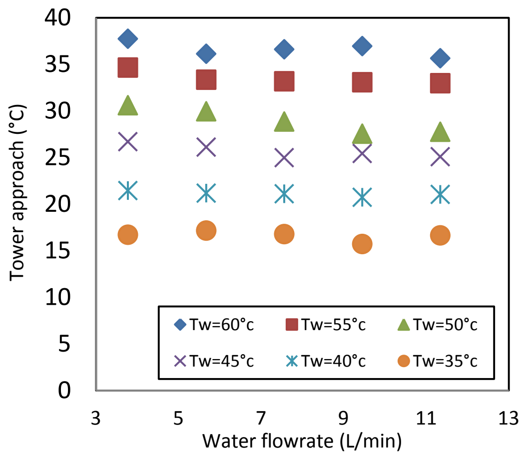

Figure 5. Variation of tower approach with water flow rate for different inlet water temperature, with assisted fans

D. Cooling capacity

Cooling capacity represents the amount of heat rejected to the environment from the hot water entered to the cooling tower. It is the obtained from cooling range multiply by water mass flow rate and water specific heat. So increasing any of them increases the cooling capacity.

Figures (8 and 9) show the cooling capacity at inlet water temperature (35, 40, 45, 50, 55 and 60°C), where x-axis represent water flow rate (L/min) while y-axis represent the cooling capacity (kw), mass flow rate values are controlled during tests to reach the better cooling which leads to the better cooling capacity. By increasing water flow rate, contact area surface increases so more heat and mass transfer increasing which means hotter and wetter outlet air. Heat and mass transfer from hot water to air will increase air enthalpy and produce less density air, so more buoyancy force and more drafted air. Heat rejected increases by the increase of one or both enthalpy change and air velocity at outlet of tower. Figure (8) show cooling capacity variation, NDWCT without assisted fans. Noticing that when water flow rate, inlet water temperature increases the cooling capacity increases.

Figure (9) show cooling capacity variation, NDWCT with assisted fans. Noticing that when water flow rate increase the cooling capacity increases significantly, the reason of that is the major mass and heat transfer due to the increase of contact area surface and the long stream of air and water droplet falling down.

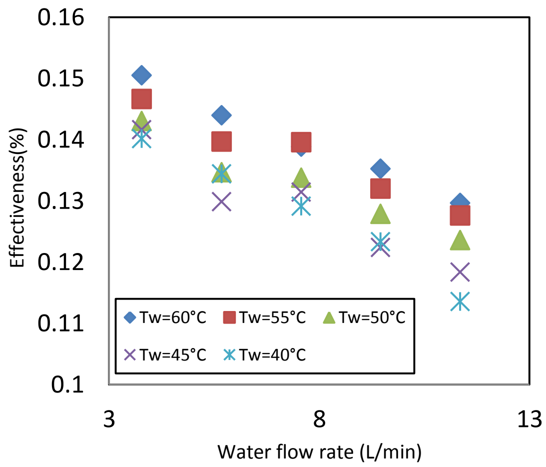

Figure 6. Variation of effectiveness with water flow, for different inlet water temperature, without assisted fans

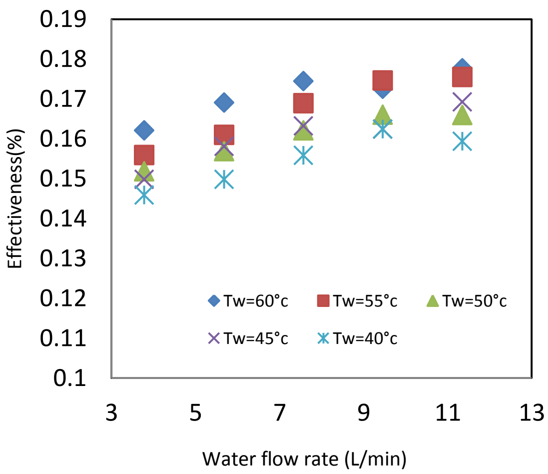

Figure 7. Variation of effectiveness with water, for different inlet water temperature, with assisted fans

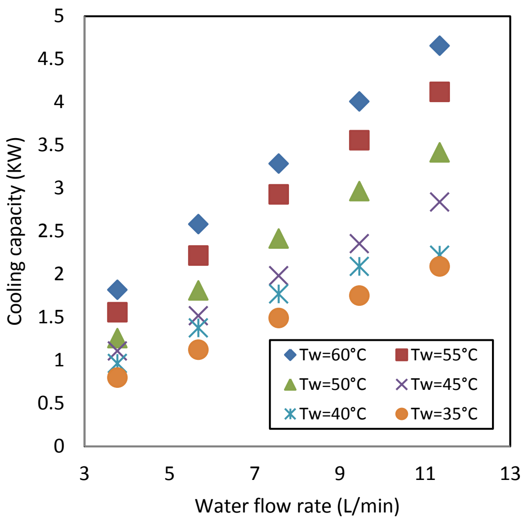

Figure 8. Variation of cooling capacity with water flow rate, for different inlet water temperature, without assisted fans

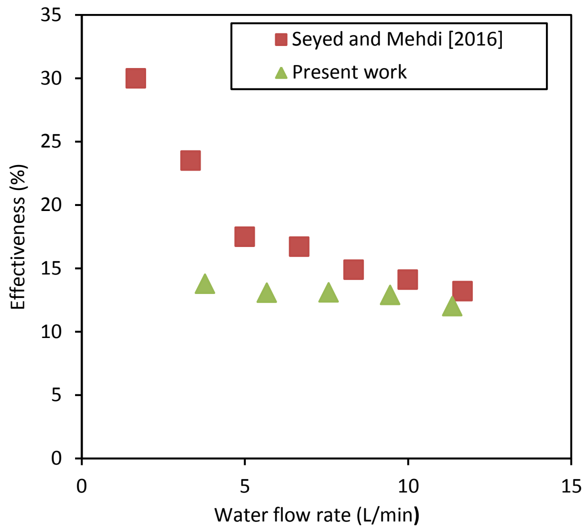

Figure 10. Comparison between the effectiveness results of the present work and reference results

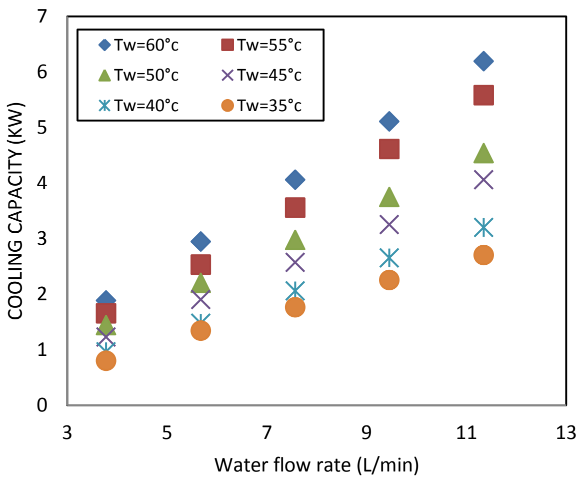

Figure 9. Variation of cooling capacity with water flow rate for different inlet water temperature, with assisted fans

V. COMPARING

From comparing these results with results from previous references which showed a good agreement with the present work. Knowing that the comparison at the same operational parameters; inlet water temperature (45°C), the type of the fill (honey cell) and inlet water flow rate from (2 to 12 L/min). A good agreement observed between the present work and the previous references shown as figure (10).

VI. CONCLUSIONS

From the experimental results and the NDWCT with and without assisted fans, and from comparing these results with results from previous references which showed a good agreement with the present work. The main conclusions are listed below:

1. The use of assisted fans increase air mass flow rate ($\dot{m}_a$), this leads to decrease the temperature of outlet water, so as a result the cooling range, effectiveness and cooling tower capacity improves by (23%,21.2% and 22.9%) respectively at$(T_w)_{in}$=(50)°C.
2. The increase of ($\dot{m}a$) by the effect of the assisted fans at $(T_w)_{in}$ =(50)°, decreases the wet bulb temperature difference between the inlet air and the outlet air by(34%).
3. When ($\dot{m}_w$) increase from (3.78 to 11.35 L/min) at $(T_w)_{in}$=(50°C) and with the use of assisted fans the outlet water temperature decrease by (3.6%). While without assisted fans the outlet water temperature increase by (2.7%).
4. While the minor increase is with the assisted fans. For instant at $(T_w)_{in}$=(45°C), and mass flow rate (11.35 L/min), the percentage of increase is (62%) without assisted fans and (57%) with assisted fans.
5. The increase of fill thickness increases air relative humidity at the exit, at any inlet air temperature and any fill thickness.
6. The difference between inlet and outlet air temperature is small with assisted fans, while without the assisted fans the difference is bigger.

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NOMENCLATURE

A	Area	m^2
C_P	Specific heat	kJ/kg k
h	heat transfer coefficient	W/m2K
i	enthalpy	kJ/kg
$\dot{m}$	Mass flow rate	kg/s
P_a	Pressure	Pa
w	Air wetness	kg water/kg air

GREEK SYMBOLS

ϵ	effectiveness	%
ω	Humidity ratio	$kg_{vapor}/kg_{dry\ air}$
ρ	Fluid Density	kg/m^3

SUBSCRIPTS

a	Air
°C	Temperature Celsius
L	Liter
in	Inlet
M_e	Merkel number
min	Minute
out	Outlet
Ta	Air temperature
Tw	Water temperature

ABBREVIATIONS

ANSYS	Analysis System
ASHRAE	American Society for Heating Refrigeration and Air-Conditioning Engineering.
BDR	Bubble and Dispersion Regime
CFD	Computational Fluid Dynamics
CWCT	Close wet cooling tower
FAND	Fan assisted Natural Draft
RH	Relative Humidity %
Ka	Standard heat and mass transfer coefficient
Le_f	Lewis factor
NDDCT	Natural Draft Dry Cooling tower
NDWCT	Natural Draft Wet Cooling Tower
PR	Pellicular Regime