Experimental Investigation of the Performance Characteristics of NDWCT Assisted with Fan Driven by Water in Iraq

Qasim Saleh Mahdi, Muwafaq Rahi Al-Hachami

Abstract-Natural Draft Wet Cooling Tower (NDWCT) is a device with high initial cost used to cool water by the mean of a combination of heat and mass transfer project. It is used normally with long term projects. The use of NDWCT is limited by weather conditions where cold and dry weather is the best one. Experimental test done using Water Driven Draft Assistance Fans (WDDAF) mechanism to increase NDWCT efficiency. The mechanism shows a good enhancements in tower parameter where water to air mass flow rate decreases by about (28.33%), tower range is enhanced by (11.54%), cooling capacity enhanced by (14.8%), and air relative humidity and total pressure drop are enhanced by (8.66) and (2.44) respectively. This kind of enhancements can be used to decrease tower shell size, increasing efficiency, increase air mass flow rate in specific areas, and decreasing costs. The mechanism can cover wide weather condition where FAND is required and can use with mechanical towers with some manipulations.

Keywords- Cooling tower, FAND, Natural draft, NDWCT, pressure drop, tower range, WDDAF.

Nomenclature

Symbols		Greek Symbols	
C1-C9	Coefficients	Δ	Differential
Cp	Specific heat kJ/kg.℃	ρ	Density (kg/m^3)
G	Air, water mass flow rate, kg/s	**Subscripts**	
k	loss coefficient	a	Air
L	Water mass flow rate, kg/s	fi	Fill
L	Length , m	in	Inlet
$\dot{m}$	Mass flow rate, kg/s	out	Outlet
p	Pressure mmH2O, Pa	cons	Consumed
Q	Cooling capacity, kW	w	Water
T	Water temperature, C	sp	Spray zone
		fsp	Fill and spray zone
v	Air velocity, m/s	**Abbreviations**	
Z	Packing high, m	FAND	Fan Assisted Natural Draft
		NDWCT	Natural Draft Wet Cooling Tower
		WDDAF	Water Driven Draft Assistance Fans

INTRODUCTION

Air inside tower shell of Natural Draft Wet Cooling Tower (NDWCT) is drafted naturally, mainly due to air density deference at different elevations. No mechanical fan used to accelerate air so as not to spend power which will be uneconomical way at long term projects. Water should be sprayed to small size drops using nozzles over a packing fill. The spray zone which is limited between nozzles and packing fill contribute about 15% of heat rejection in large towers where packing fill zone is the main zone in heat rejection [1]. Water drips after fill zone in relatively big size droplets [2] in a zone which called as rain zone. Rain zone participates about (10-20%) of the total heat and mass transfer in large towers [2]. The main target behind using packing fill is to increase area and time of contact between falling water and drafted up air to increase heat rejection. So increasing either thickness, density, or both of packing fill will surely increase both time and surface area between working fluids. Up to some design limits, increasing fill density will increase pressure drop inside this zone and clog air. Because of the use of fans in mechanical draft tower, more thickness or more density packing fill relatively can be used.

Air density difference between air at top of tower and surrounding environment weather represents driving force for drafting in NDWCT while mechanical draft cooling towers using fan to increase pressure difference to draft air. In some applications where the height of tower shell is limited or outside environment conditions do not produce enough draft force to draw air out of tower, Fan Assisted Natural Draft (FAND) is used. It seems like a natural draft setup with a smaller shell than natural one, its airflow assisted by the use of fans.

A Ph.D. research is led in Iraq to study NDWCT according Iraqi Weather which is described as (hot and dry) at summer, (cold and wet) at winter [3, 4, 5, and 6]. It was concluded that an enhancement in NDWCT performance is required according this kind of weather.

In this paper, a new mechanism of (WDDAF) is used where the water is sprayed from nozzles fixed at the ends of each fan blade so as the reaction forces can drive these fans. The main targets are to decrease initial tower size and cost, overcome weather problems either hot or wet, enhance tower performance, and change cross section of heat profile.

- *Qasim Saleh Mahdi, Professor, Mechanical Engineering Dept., Al-Mustansiriyah University, Iraq. E-mail: qasim602006@yahoo.com*
- *Muwafaq Rahi Al-Hachami, Lecturer, Mechanical Engineering Dept., Wasit University, Iraq. PH-009647821215050. E-mail: Muwafaq-phd@hotmail.com*

MOTIVATION

A high pressure pump is used to pump water to the spray nozzles, this pressure can be used to drive fans by locating spray nozzles at the blades of fans. This mechanism having many advantage including:

Ability to produce useful pressure difference to draft air where the location of these fans upper than spray zone will drop pressure at a proper location (spray zone area) to stand in front of the high pressure area at top of packing fill area.

Blades rotation will increase turbulence of air at spray zone area which increase heat and mass transfer rate at this zone.

Locating nozzles at rotating blades will spray water in different directions following spiral path which increase time required to across spray zone and also better water distribution.

The mechanism can be used to improve heat performance for any built cooling tower by adding fans to the areas where (L/G) is high to increase air mass flow at specific area by measuring air velocity and temperature profiles above eliminators for any built tower. This kind of measurements are done by [7, and 8]. The mechanism can be used as a design parameter either to decrease tower size or to increase performance. It can be also used at the center of any NDWCT to change the heat profile which has a higher temperature at center [9, and 10] because of the less quantity of air flow at center. It can be used as one big fan with mechanical cooling towers or as multi fans with NDWCT. It can be used also in FAND instead of electrical fan driven.

Adding the advantage of power free and low maintenance if required, this mechanism can represent a good solution for using NDWCT in hot or wet weather conditions. In hot weather, the ratio of water to air mass flow rate (L/G) is higher than it at cold weather [3]. Using Water Driven Draft Assistance Fans (WDDAF) s, the air mass flow will be increased.

BACKGROUND AND THEORETICAL ANALYSIS

The present work focuses on improving heat transfer inside NDWCT by the use of Water Driven Draft Assistance Fans (WDDAF)s. (WDDAF)s location effects the value of critical pressure drop.

Pressure drop through any type of fills may be measured along fill thickness.

Fill loss coefficient and pressure drop across fill are related as followed:

$$\Delta P_{fi} = k_{fi}\left(\frac{\rho v^2}{2}\right) \quad \text{…….(1)}$$

Loss coefficient can be define as a function of air and water mass flow rate across fill by many relations. Researchers tried to find empirical relations to predicate either pressure drop or loss coefficient depending on type of fill. Some constants are added to these relations while air and water mass flow rates are used as variables.

The following empirical relation is used by [11] to represent the loss coefficients for two fill types which are splash and film types.

$$k = c_1\left(\frac{G_w}{G_a}\right) + c2 \quad \text{……..(2)}$$

Pressure drop for different arrangements of film fill is presented by [12]:

$$\Delta P = C_1 G_w^{C2} G_a^{C3} \qquad \text{.......(3)}$$

Johnson [13] presented fill loss coefficient for counter flow cellular type fills using same general shape of relation which is used before by to describe pressure drop by [12] adding fill thickness as a variable also.

$$k = C_1 G_w^{C2} G_a^{C3} L_{fi}^{c4} \qquad \text{.....(4)}$$

The general shape of formula is changed by [14] where same number of constants and variables.

$$\frac{\Delta P}{Z} = C_1(1+G_w^{C2})G_a^{C3} = C_1 G_a^{C3} + C_1 G_w^{C2} G_a^{C3} \qquad \text{.....(5)}$$

Kloppers and Kröger [15] presented a form of empirical equation that correlates fill loss coefficient data more effectively when compared to other forms of empirical equations commonly found before.

$$\mathrm{K}_{\mathrm{fi}} = c_1 G_w^{C2} G_a^{C3} + c_4 G_w^{C5} G_a^{C6} \qquad \text{.....(6)}$$

A general equation with six constants and two variables representing water and air mass flow rate are used to correlate measured pressure loss coefficients accurately for three kinds of packing fills (trickle, splash, and film). According to all above empirical relations, increasing water mass flow rate will increase pressure drop.

ΔP represents the measured pressure drop in which (k) value is usually correlated by empirically due to air and water mass flow rates, [16].

Generally, ΔP and k are given as absolute values for constant fill thickness otherwise thickness can be added for equations as in [13, and 14].

Cale [17], described loss coefficient at spray zone area by:

$$\mathrm{K}_{\mathrm{sp}} = L_{sp}[0.4(G_w / G_a) + 1] \qquad \text{.....(7)}$$

Using any correlation formula, pressure drop increases by increasing thickness and water mass flow rate or decreasing air mass flow rate while the constants are related by fill design.

Researchers tried to describe pressure drop and loss coefficient so as to calculate the critical pressure for design and so far suitable fill type, thickness, and water mass flow rate.

So far, fill design and fill zone length effecting tower range gathering with water mass flow rate both are meeting the tower cooling capacity, so the best way to overcome the pressure drop is by increasing air mass flow rate. Wang [18] and Chen [19] manipulate wind direction at tower entrance using guiding plates or cross walls to increase air mass flow rate.

When WDDAF mechanism is used, the increasing of water mass flow rate will increase fans velocities and so air draft velocity will increase and produce a useful pressure drop through fans. This means that some another expression should be added to any of these empirical relation. Expression will contain constants related by water and air mass flow rate as a variable, remembering that increasing water mass flow rate here will be reversely related with pressure drop.

Constants should cover at least fan losses, blade design parameters, number of blades, number of nozzles at each blade, nozzles design parameters, and reaction force direction.

The effect of WDDAF is not limited at spray zone but it expanded down to fill zone and up to eliminators and so to the top of tower.

So, equations (6) and (7) will be:

$$\mathrm{K}_{\mathrm{fi}} = (c_1 G_w^{C2} G_a^{C3} + c_4 G_w^{C5} G_a^{C6}) L_{fi} + L_{fi}\left(\frac{c_7}{G_w^{C8} G_a^{C9}}\right) \qquad \text{..... (8)}$$

$$\mathrm{K}_{\mathrm{sp}} = L_{sp}[0.4(G_w / G_a) + 1] + L_{sp}\left(\frac{c_1}{G_w^{C2} G_a^{C3}}\right) \qquad \text{..... (9)}$$

For pressure drop calculation, equation (10) can be used to find losses coefficient at both spray and fill zones;

$$\mathrm{K}_{\mathrm{fsp}} = (c_1 G_w^{C2} G_a^{C3} + c_4 G_w^{C5} G_a^{C6}) L_{fi} + L_{sp}[0.4(G_w / G_a) + 1] + (L_{sp} + L_{fi})\left(\frac{c_7}{G_w^{C8} G_a^{C9}}\right) \qquad \text{..... (10)}$$

The mechanism effects also water distribution system loss coefficient.

Temperature difference between water inlet and water outlet is called tower range. The difference between water outlet and wet bulb temperature for air inlet is the tower approach. For a given heat load, flow rate, and air condition, larger cooling tower produces a closer approach (colder outlet water). The best performance is the lowest approach and the highest range.

If evaporated water is not neglected, cooling capacity can be calculated as [20];

$$Q_w = Cp_w[(\overset{\circ}{m}_w T_{win}) - (\overset{\circ}{m}_w - \overset{\circ}{m}_{wcons}) \times T_{wout}] \qquad \text{.....(11)}$$

EXPERIMENTAL WORK

Experimental test rig is designed in simulations according to reference tower, located at Mt. Piper Power Station - Delta Electricity in Australia, as shown in Fig.1, similarity and dimensions are detailed in [4] using a net of (2) mm nozzles. Fig.2 shows full rig using WDDAF as a spray mechanism.

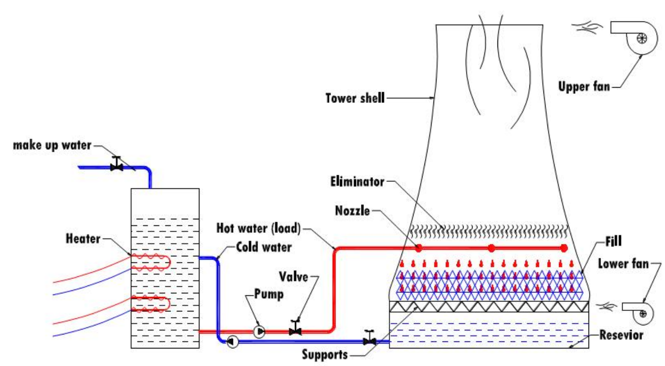

Fig.1 Schematic diagram for experimental test rig [4, and 5].

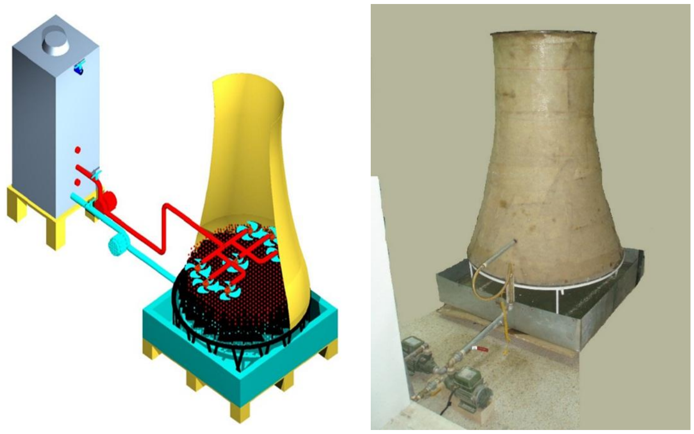

Fig. 2 a-Test rig using WDDAF b- Actual rig

One nozzle arrangement at the end of each blade (3 blades fan) is used in this test where different arrangements can be used as shown in Fig.3 a, b, c and d.

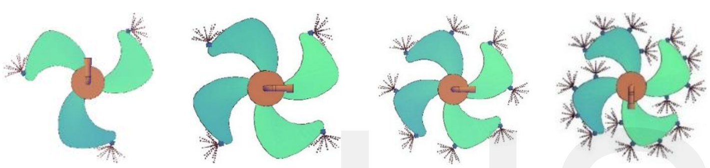

Fig. 3, a, b. One nozzle at each blade, c. Two nozzles, d. four nozzles

To distribute water, a set of fans and nozzles are used as shown in Fig. 4.

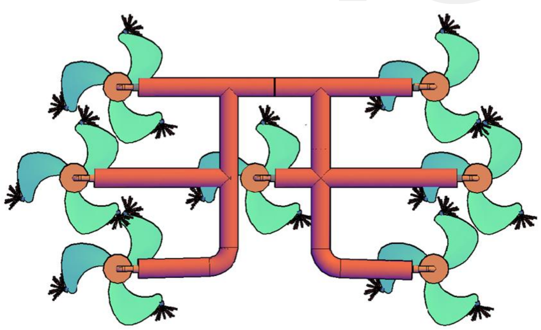

Fig. 4.Fans and nozzles net.

The tests are done in Iraq at winter season using (10) cm thickness of cylindrical trickle fill, where water mass flow rate is changed as (0.8, 1, 1.2, 1.6, 2, and 2.4) GPM and it is heated up to (50℃) to simulate load.

Same procedure of tests are done; firstly with a net of (2) mm nozzles to spray water and secondly using WDDAF with one nozzle at each blade.

Results and Discussion

A comparison between two sets of experimental tests will be shown in this paper to show the enhancement in different tower parameters.

Enhancement percentage = (bigger value- smaller value) / smaller value

Starting results with Fig.5 where results show that water to air mass flow ratio decreases using WDDAF which mean that fans are successfully accelerate air inside tower and so air mass flow rate increased. Target of water outlet temperature is to reach until wet bulb temperature of air enters to tower.

Increasing air mass flow rate, effects heat transfer rate with water and so many tower parameters can be improved. Tower range and approach are improved also using WDDAF, as shown in Fig. 6 and Fig. 7.

Tower range enhancement reaches up to (11.54%). Expanding the effect of tower range and by measuring consumed water as shown in Fig.8, tower cooling capacity can be calculated.

Tower cooling capacity results are shown in Fig.9 where total enhancement using WDDAF is (14.8%).

With the increase in air mass flow rate, turbulence, spiral path, and good water spray distribution helps to increase air humidity change inside tower as shown in Fig.10, where the enhancement is (8.66%).Total pressure drop between entrance at lower side of tower and exit at upper side enhanced by (2.44%).

Conclusion

Water Driven Draft Assistance Fan (WDDAF) mechanism is used in this experimental work to study its effects on tower parameters.

1-air mass flow ratio increased to show decreasing in water to air mass flow rate by about (28.33%).

2-Tower range is enhanced by (11.54%) where approach shows better results also.

3-Cooling capacity enhanced by (14.8%) where air relative humidity and total pressure drop are enhanced by (8.66) and (2.44) respectively.

The total enhancements in different tower parameters motivate to use this mechanism in either mechanical, FAND, or NDWCT to improve efficiency, reduce power, and decrease tower size. It can be used also to increase air flow rate at any cross section like center area of towers.

Acknowledgment

To extend research, support is required.

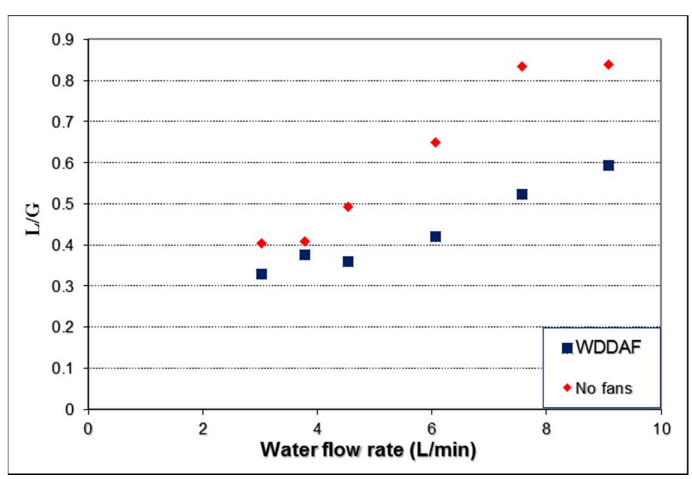

Fig. 5. Water to air mass flow ratio.

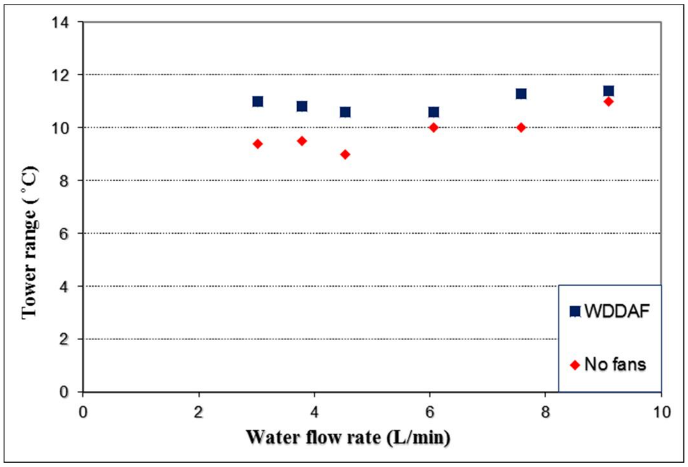

Fig. 6. Tower range

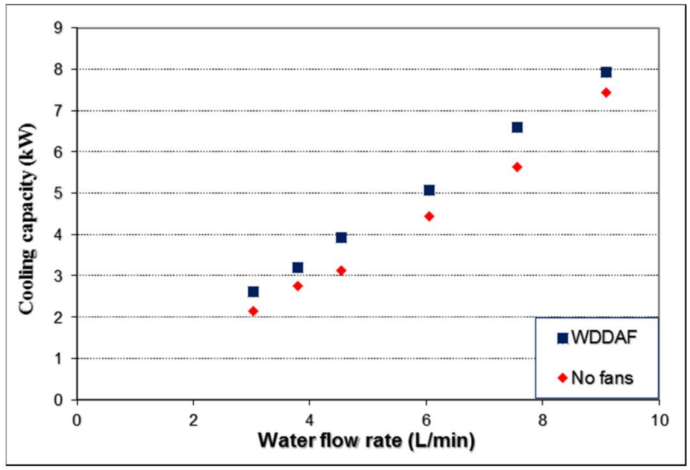

Fig. 9. Tower cooling capacity

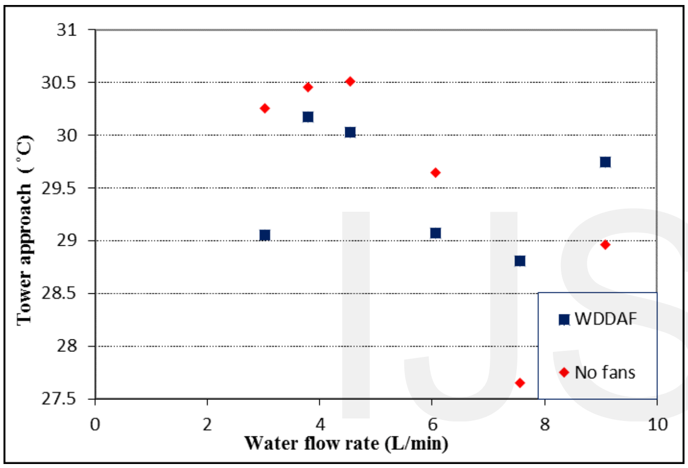

Fig. 7. Tower approach.

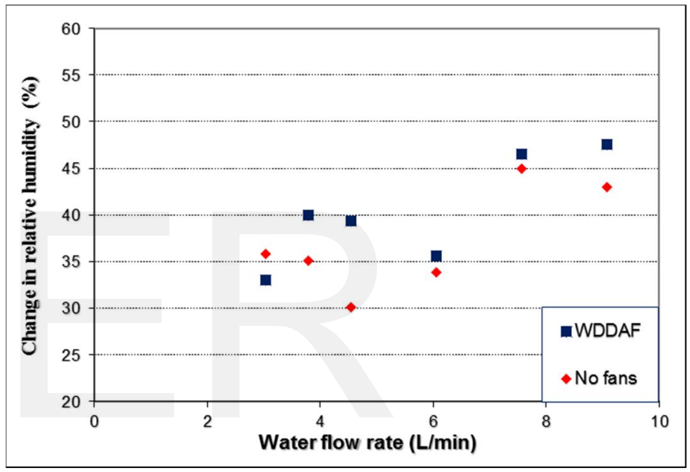

Fig. 10. Air relative humidity change.

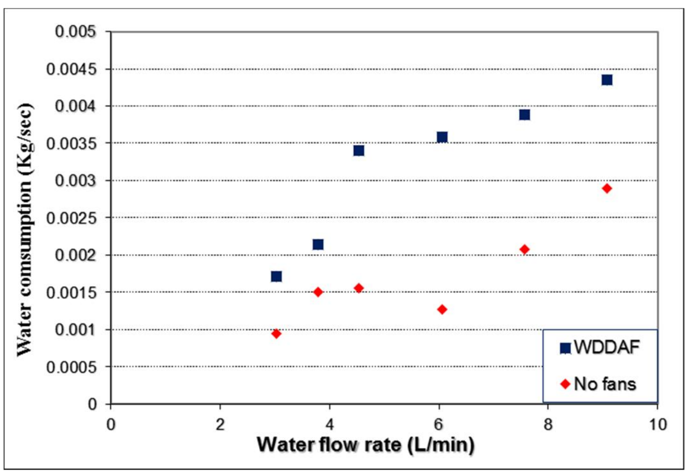

Fig. 8. Water consumed by evaporation.

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