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CFD Analysis of Shower Cooling Tower with Varying the Inlet Air Relative Humidity for Industrial Application

Mohammad Zunaid
Department of Mechanical Engineering, Delhi Technological University, Delhi

Abstract: The present analysis shows Computational fluid dynamics analysis of three-dimensional shower cooling tower with varying the inlet air relative humidity. The SCT operates without fill, and impaction pin nozzle used to disintegrate inlet water into water spray droplets. The water droplets and air come in contact at the top of SCT, after heat and mass transfer the water droplets become cool down and hot air exit from the bottom of the tower to the atmosphere. The thermal efficiency of SCT increases and its second law efficiency decreases with increasing the inlet air relative humidity.
Keywords: SCT; Ansys, Fluent, Three dimensional, SLE.

NOMENCLATURE			
I	total exergy destruction per unit time (W)	m	mass flow rate (kg/s)
T	Temperature (°C)	X	exergy (W)
Greek letters			
ϕ	relative humidity of air (%)	ω	specific humidity (kg_w/kg_a)
η_{th}	thermal efficiency (%)	η_{II}	second law efficiency (%)
Subscripts			
a	air	c	convective
d	droplet	e	evaporative
in	inlet	l	evaporative loss
out	outlet	t	total
x	horizontal coordinate	y	vertical coordinate
Abbreviations			
CFD	computational fluid dynamics	SLE	second law efficiency
SCT	shower cooling tower	3-D	three dimensional

I. INTRODUCTION

The conventional cooling tower used for reducing inlet water temperature when it comes contact with atmospheric air. Energy and exergy of inlet water are reduced along the height of tower when it comes in contact with air. Due to fouling on the fill the performance of conventional cooling tower has deteriorated, so overcome this problem SCT has developed which operate without fill.

Nenad Milosavljevic et al. [1] have investigated a numerical model for a counter flow wet cooling tower and found that exit air temperature is declines with decrease the inlet air velocity. Ardekani et al. [2] investigated inlet and outlet water temperature change for the wind facing sector was about twice that of the peripheral sectors. Kumar and Pant [3] investigated as Reynolds number increases flow pattern changes. Heidarnejad and Delfani [4] studied that Reynolds number changes with variation in changes the geometrical and physical perimeters of flow. Zunaid et al. [5-6] numerically studied SCT, and found that air temperature decreases and specific humidity of air increases with in increase the water droplet temperature. Hanno Carl Rudolf Reuter [7] has analyzed

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cooling tower by using FLUENT. He suggested that the performance of a cooling tower can be improved by reducing droplet size. D. J. Viljoen [8] studied the performance of cooling tower using FLUENT; he reported the collision of water droplets has no a major impact on water distribution pattern in the cooling tower. M.N.A. Hawlader et al. [9] examined evaporative cooling tower and said the percentage of evaporative heat transfer is about 83% in the fill region and about 90% in the rain region. Zunaid et al. [10-14 reported that exergy destruction is high at the top of SCT and it is decreased along the height of the tower. In this work, CFD analysis of 3-D SCT has been done with the help of Ansys Fluent. The study has been performed to determine the effect of variation in inlet air relative humidity on outlet parameters of SCT. An experimental study has also been carried out for study performance of SCT under different conditions. The results from the experimental study have been used for validation of numerical results.

II. EXPERIMENTAL FACILITY FOR SPRAY CHARACTERIZATION

Fig. 1 shows 3-D parallel flow SCT. The reciprocating pump used for supply water. The impaction pin nozzle used to convert inlet water into droplets. When atmospheric air come in contact with inlet water droplets, the temperature of water become reduced, and this cold water sends for industrial used, and hot air expelled into the atmosphere.

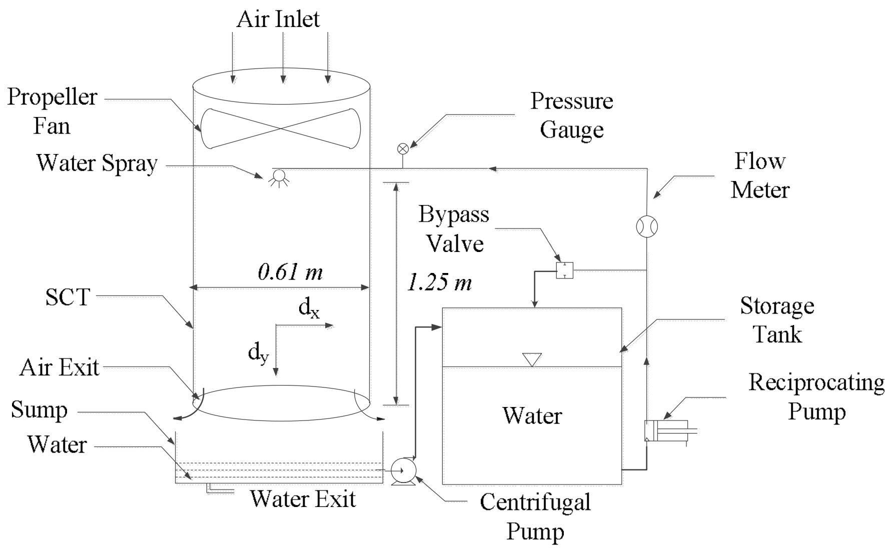

Fig.1 Three dimensional parallel flow SCT

III. RESULT AND DISCUSSION

A. Model validation

The experimental data of a parallel flow down draft SCT has been used for model validation. Comparison of exit specific humidity obtained from the experiment and those obtained from the computational work are shown in Fig. 2. It can be seen that the majority of the data fall within ±10% of the model.

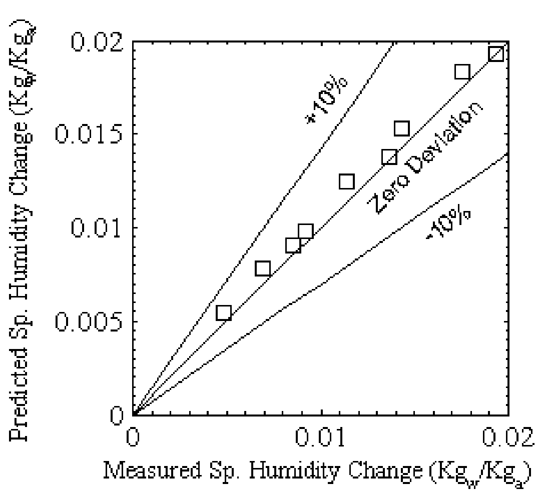

Fig. 2 Comparison of predicted and measured specific humidity

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B. Parametric study

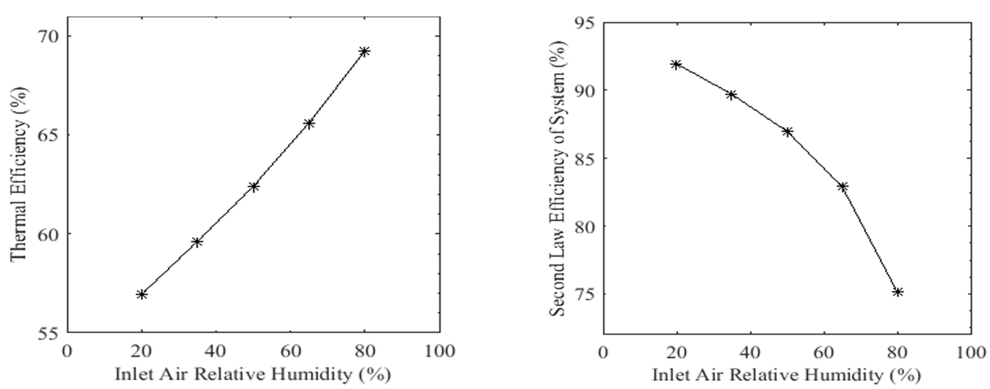
The parametric study has been completed to conclude the effect of variation in inlet air relative humidity on SCT exit parameters. Primary conditions used for CFD analysis of SCT are droplet diameter 250 µm, water temperature 56 ˚C, DBT of air 36˚C; relative humidity of air were 20, 35, 50, 65, and 80%, and water to air mass flow rate 0.5. The distance between spray water inlet to bottom of tthe ower (tower height) 1.25 m (along with the direction of y-coordinate) and tower diameter 0.61 m. Inlet droplet velocity was 20 m/s, inlet air volume flow rate was 400 m^3/h, and droplet angle of projection at ithe nlet was 45˚. The reference temperature and relative humidity are same as inlet condition and acceleration due to gravity is 9.81 m/s^2.

C. Effect of variation in inlet air relative humidity

This study presents deviation in outlet SCT parameters with varying the inlet air relative humidity from 20% to 80% at constant inlet air DBT (36 ˚C), water temperature (56 ˚C), droplet diameter (250 µm) and RLG (0.5). Table 1 shows exit air DBT, specific humidity, droplet temperature and thermal efficiency of SCT increased with increasing the inlet air relative humidity. Table 1 also shows 20% relative humidity air produce maximum cooling, i.e. up to 20.63 ˚C and 80% relative humidity air give maximum efficiency (Fig. 3a). Table 1 also indicates as the relative humidity of air increases the change in total exergy of air, exergy of water, and SLE of SCT (Fig. 3b) decrease because evaporative heat and mass transfer between air and water droplet decreased with increase the inlet air relative humidity. As relative humidity of air increases, the destruction in total exergy of the system relatively less because low relative humidity air absorbs more amount of water from droplets.

Table 1 Effect of variation in inlet air relative humidity

ϕ_{in} (˚C)	$T_{a,out}$ (˚C)	$\omega_{a,out}$ (kg_w/kg_a)	$T_{d,out}$ (˚C)	$m_{d,l}$ (kg/s)	η_{th} (%)	$X_{c,out}$ (W)	$X_{e,out}$ (W)	$X_{a,out}$ (W)	$X_{d,out}$ (W)	$X_{t,out}$ (W)	I_t (W)	η_{II} (%)
20	35.38	0.0345	35.37	0.0036	56.94	0.10	274.51	274.60	13874.21	14148.81	1240.38	91.94
35	36.84	0.0380	36.83	0.0032	59.61	0.46	152.93	153.39	9103.54	9256.93	1061.64	89.71
50	38.24	0.0415	38.23	0.0029	62.39	1.85	97.40	99.25	6074.02	6173.27	923.16	86.99
65	39.55	0.0452	39.54	0.0025	65.60	3.31	135.12	138.43	3787.48	3925.91	808.34	82.93
80	40.81	0.0489	40.81	0.0024	69.23	5.23	34.43	39.67	2122.41	2162.08	715.45	75.14



(a) (b)

Fig. 3 Variation in thermal efficiency (a), and variation in SLE (b), with varying the inlet air relative humidity

IV. CONCLUSION

Three dimensional CFD analysis of SCT has been done to finding out the effects on SCT exit parameters by varying the inlet air relative humidity. It is found that exit water droplet temperature and thermal efficiency of tower increase with increasing the inlet air relative humidity. The SLE of SCT decrease with increasing the inlet air relative humidity because exergy destruction also reduces by increase the inlet air relative humidity.

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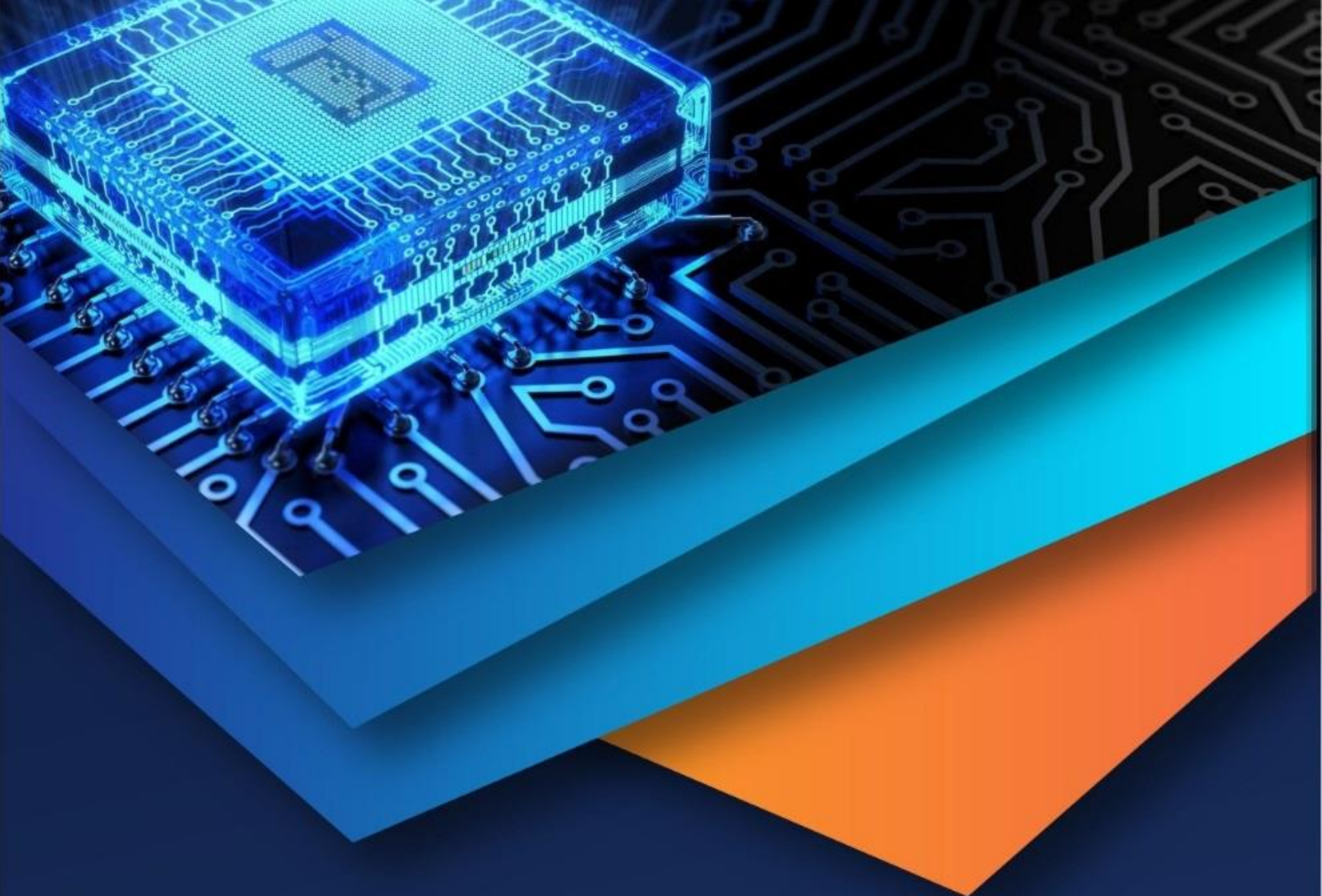

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