Parametric Analysis and Improvement of Mist Fan Operation for Indoor Cooling

1Odi Samuel T.,2Thomas Okechukwu Onah, 3Nwankwojike B.N.
1Principal Technical Officer,2Doctor,3Professor
1Standards Organisation of Nigeria, North Central Regional Office,
2Enugu State University of Science and Technology Agbani,
3Micheal Okpara University of Agriculture, Umudike

Abstract- **The research Parametric analysis and improvement of mist fan operation for indoor cooling redesigned a mist fan nozzle arrangement to ascertain the effects of nozzle arrangement on cooling efficiency while emphasizing on temperature distribution, velocity distribution and water mass fraction distribution was accomplished. A comparative analysis was carried on 5 different nozzle arrangement to determine the arrangement with the highest efficiency. An experimental setup of a mist fan with a nozzle size of 10µm, 50 µm and 100 µm but varying arrangement. Temperature readings was taken at varying velocities. The analysis was done experimentally and also using computational fluid dynamics. The result shows a cooling efficiency of 66%, 67%, 68%, 70% and 63% for nozzle arrangement 1,2,3,4 and 5 respectively. The same experiment was carried out physically using the same values. Nozzle 4 arrangement shows a temperature reduction of 303.4K which lesser when compared with the 4 other nozzles which temperature is higher. The experimental and CFD result shows 96% correlation.**

keywords- water use efficiency, wet bulb temperature, dry bulb temperature, misting system

I.INTRODUCTION

A misting system consists of a high-pressure pump and a brass and stainless steel nozzle that produce micro droplets by forcing water through an orifice of about 5 micrometers. The water droplets that create the mist are so small that the instantaneous flash evaporate. Flash evaporation can lessen the surrounding air temperature by as much as (20 °C) in seconds (Kheirabadi*et al* 1991*).*

A misting fan has the following advantages over conventional fan. Misting fans work in a similar way as a conventional fan, Misting fan does its job when it utilizes thermal dynamics which consequently creates cooling effect upon evaporation. A standard misting fan needs a water supply which is connected to a high-pressure pump capable of supplying around 1000 psi. Water is sprayed from these very small openings, squirting out as mist. By blowing the mist over a large area, a cooling effect can be felt anywhere the mist reaches. There are different types of misting systems – Low Pressure, Mid Pressure and High-Pressure line systems, also we have Low Pressure, Mid Pressure, and High-Pressure Misting Fan Systems. There are advantages and disadvantages to each of these misting systems. In low, medium and high pressure misting line systems, evaporation is employed to cool the air around the perimeter of the cooling area around the misting lines.

It is a principle of misting fan systems that convective cooling or cooling of moving air is made more effective when evaporative cooling or line misting is combined with evaporative cooling or line misting. The air is cooled by the mist, and cooling is intensified by the fan. As an example, imagine the ocean where the breeze blows over evaporating water, giving nature its most effective cooling system. Among the most notable benefits of misting systems with low pressure are their cost-effectiveness and ease of installation. You do not need to buy any additional equipment since all of them utilize your existing water pressure from your faucet to create mist. Mid pressure misting line systems work by combining low-pressure misting systems with a small booster pump with a pressure of 120 to 160 psi. As a result, fewer droplets remain after the mist evaporates. Outdoor events are best served by high-pressure misting line systems. This includes the misting systems that you see and enjoy in outdoor restaurants and amusement parks. High pressure misting systems create tiny droplets of water that evaporate immediately using pumps that produce 1000 psi or more.

Misting fans operate at ¼ of the capacity of air-conditioner, so the misting fan saves the maximum household power. The misting fan's cost is much lower than the cost of buying, installing and maintaining air conditioner. So many people choose to buy misting fan rather than air conditioners when in need. Effective moisture balance of fan helps balance humidity in your home space, increasing the moisture of your skin, not causing respiratory diseases. If your home uses air conditioning, combine it with misting fan because fan can overcome dehumidification of air conditioner very well.

Several other methods can be used to assess the potentials and performance of evaporative cooling by mist spray systems in indoor environments. These methods include (i) full-scale measurements, (ii) wind tunnel measurements, and (iii) numerical simulation with Computational Fluid Dynamics (CFD). Real scale-measurement offers the advantage that real situations can be studied and the complexity of problems can be considered in full. However, full-scale measurements are usually only performed in limited number of points in space. Additionally, there is little or no control over boundary surroundings. Strong degrees of control over boundary conditions are allowed by reduced scale wind tunnel measurements, however at cost of –

sometimes incompatible – similarity requirements. Additionally, wind-tunnel measurements are more often than not performed in limited set of points in space. CFD provides whole-flow field figures, i.e. data on relevant parameters in all points of the computational field (Chen, 2009). CFD does not suffer from incompatibility issues like wind-tunnel testing because simulations can be done at full scale. The objective of this paper is to validate by experiment, CFD model for predicting air velocity and temperature distributions for nozzle equipped mist fan.
Feasibility of evaporative cooling and the parameters that influence the cooling needs to be determined specifically for each individual location and climate condition.

II.MATERIALS AND METHODS

Materials

The materials involved in the improvement of proposed mist fan are as follows:

1. 12v pedestal standing fan: A fan is machine used to generate flow within fluid, typically gas like air. Essentially, the fan is made up of rotating vanes or blades that push fluid through. An impeller, rotor, or runner is a rotating assembly of blades and hub. The assembly is usually enclosed in some sort of housing. Directing airflow or making sure objects do not make contact with fan blades may increase safety. The flow of air produced by fans is high volume but low pressure (but still higher than ambient pressure), in contrast to the flow of air created by compressors at high pressure and relatively low volume.
2. Collecting tank: In water collecting tank, fresh water in the tank whose capacity is between (10 -20 lit) of water. The size of collecting tank is in any shape such as rectangle, square, cylindrical etc. The collecting tank should have no leakage.
3. 12v water pump: Pumps are mechanical devices that move fluids (liquids and gases), or sometimes slurries.
4. Nozzle: As fluid leaves (or enters) an enclosed cavity or pipe, a nozzle is intended to control the directions or characteristics thereof (basically boasting velocity).
5. High pressure hose and tee nozzle: These include the pressure pipe in which the water will flow to the 0.2mm diameter nozzle. The hose for this project is 0.4mm diameter coupled with tee nozzle

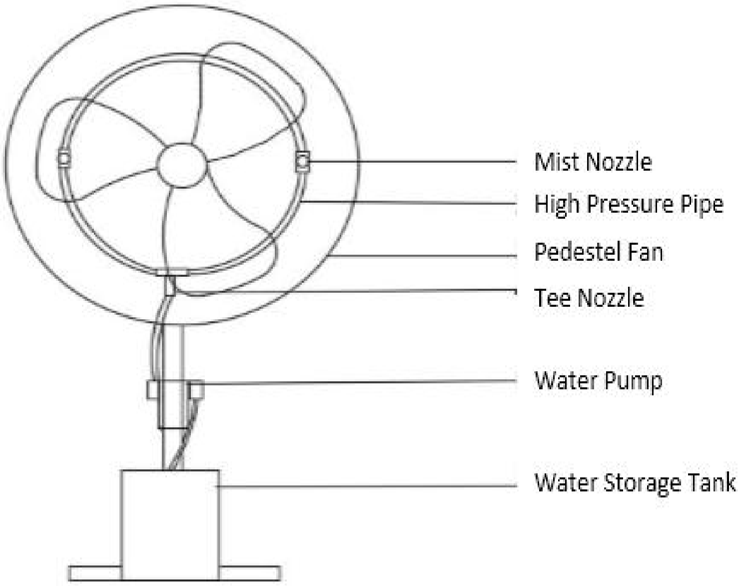


Fig. 1. Schematic diagram of the assembled mist fan

Methods

The following methodologies are put in to achieve results in the work:

1. Computational geometry and grid
2. Grid- Sensitivity Analysis
3. Development of Ansys based mathematical model
4. Discrete phase model
5. Psychrometric calculation
6. Evaluation of cooling efficiency
7. Experimental setup

III.RESULTS AND DISCUSSION

Nozzle arrangement

The number of nozzles and their arrangement play a pivotal role in the cooling effect on a mist spraying system. For this work I conducted simulations for 1,2,3,4 and 5 nozzles and results obtained showed that optimum performance was achieved and uniform distribution of temperature for 4 nozzle, contrary to nozzle arrangement 1,2,3&5.

Table 1. Cooling efficiency, average air temperature and humidity for five different nozzle arrangements in "Plane_0.9"

Nozzle Arrangement	1	2	3	4	5
η_c	66%	67%	68%	70%	63%
T (K)	304.2	303.7	303.6	303.4	303.8
Ψ	74%	78%	88%	90%	88%

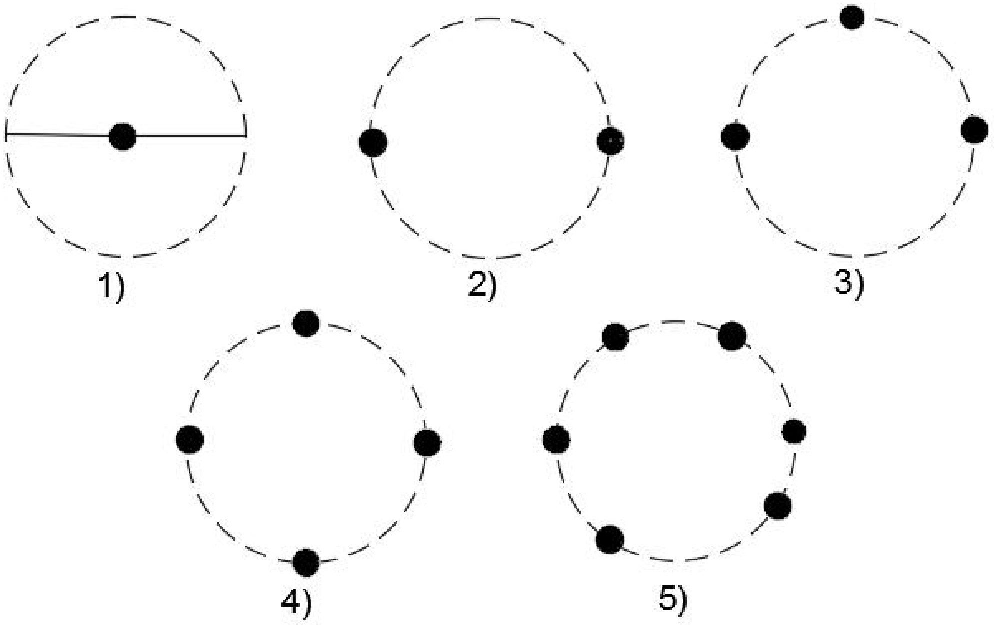


Fig. 2. Different Types of Nozzle Arrangements

Air velocity and temperature distribution

The liquid water concentration in air is relatively large close to nozzle and therefore momentum exchange is more pronounced in the area. (Ghosh et al., 2017) said that, apart from nozzle air and droplets act almost independently regarding momentum exchange. In addition, from Fig. 3 and Fig.4 the symmetric velocity, temperature and mass fraction distributions can be clearly observed close to nozzle, which is extended until about half length of domain. The haughty inertia of droplets results in symmetric trajectories of droplets close to nozzle. Nevertheless, beyond downstream nozzle, by the decreasing momentum of droplets, gravity becomes relatively more pronounced, consequential in downward movement of droplets. This leads to asymmetric distributions of speed and temperature. The larger number of droplets is in lower part of domain, results in more cooling effects in the area.

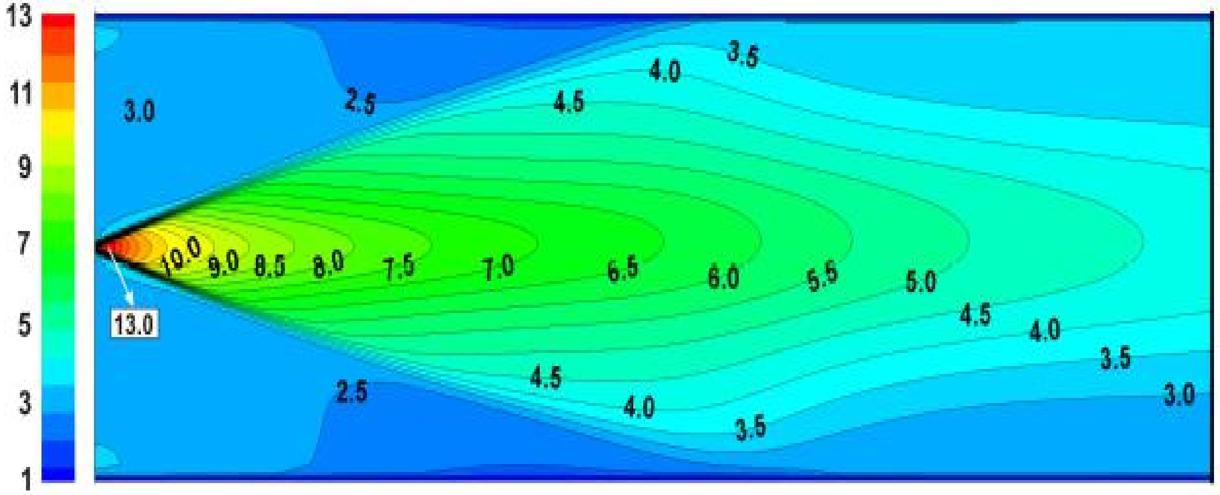


Fig. 3. Velocity distribution

Air velocity has huge control on spray cooling efficiency and droplet transport. Droplet residence time (point in time which the droplets expend before full evaporation or before getting to the outlet section, unless evaporated) is affected. Additionally, it affect droplet dispersion which influence exposure area of spray because of momentum exchange. Considering nozzle arrangement 4, humidity, average temperature and cooling efficiency in "Plane_0.9" are generated for velocities: 2.0, 5.96, and 10.0 m/s, as depicted in Table 2.

Table 2. Cooling efficiency, average temperature and humidity for different air velocities in “Plane_0.9” for nozzle arrangement 4

Air velocity	2.0 m/s	5.96 m/s	10.0 m/s
η_c	71%	59%	35%
T (K)	302.3	303.7	306.5
Ψ	73%	68%	53%

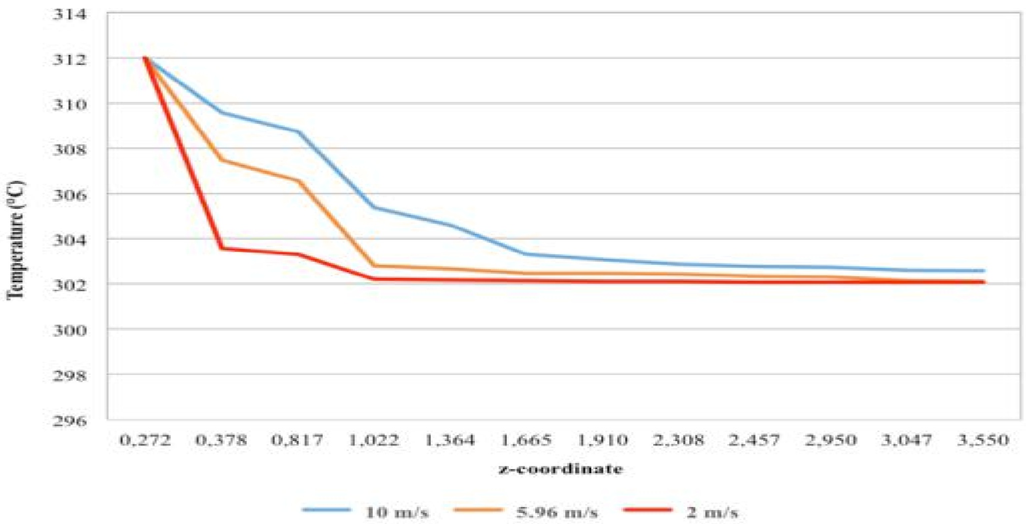


Fig. 4. Comparison of average temperature for different air velocities in “Middle_Plane”

As expected, spray cooling efficiency decreases as air velocity increases, because of residence time influence. Lesser air velocity implies longer droplet travelling time for droplets. In addition, lower air velocity means larger coverage area because of time for droplets to drop in momentum and follow air stream is longer, which results in better coverage area. Fig.4. confirms results obtained: drop temperature increases for lower velocities.

Fig. 5. Shows the temperature distribution of mist fan using number 4 arrangement method of nozzle. Simulation was done using an ambient temperature of 39, this shows that mist gets cooler along the distance from the nozzle. The temperature reduces along the distance from its core. This implies that greater cooling is being achieved after droplet are being blown to a distance.

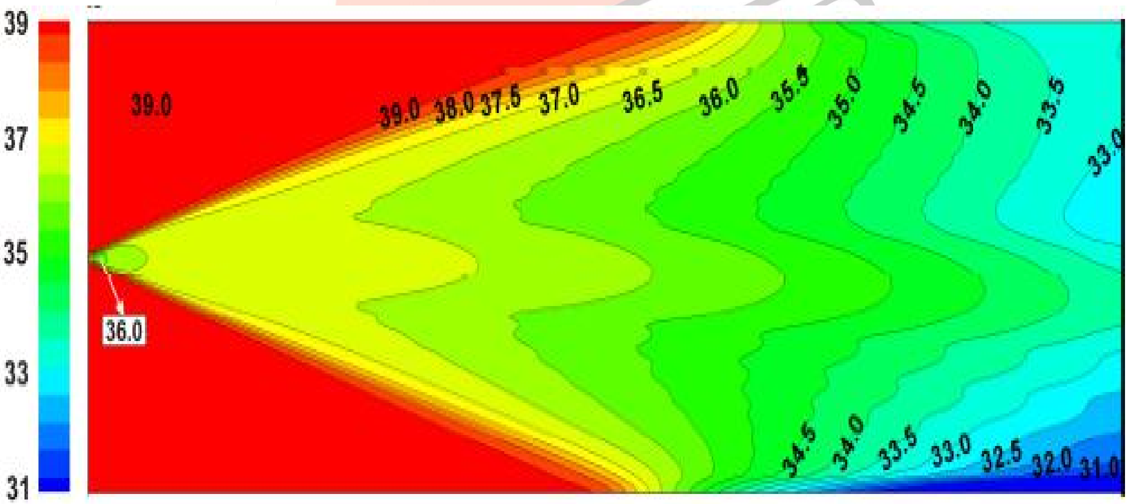


Fig. 5. Temperature distribution

Fig. 5. Shows water mass fraction distribution, it can be seen that the water air mixture increases with distance from nozzle. Mass of water is higher at nozzle but the immediate effect of air suppresses water droplet into a streamlined shape and it increases in weight when the velocity of air has been reduced along the distance.

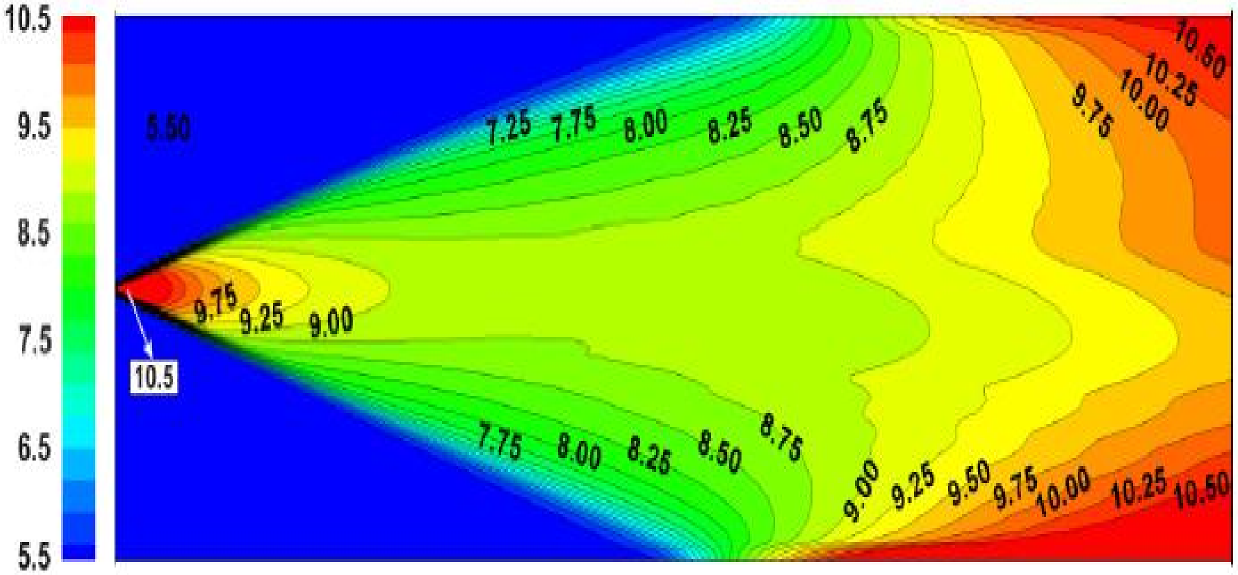


Fig. 5. Water mass fraction distribution

Spray cone angle effect on spray cooling efficiency.

The influence of spray cone angle is investigated by inspecting the results for different half-cone angles, 30°, 45° and 60°. The efficiencies of cooling, the temperature and humidity of air in nozzle arrangement 4, and the air velocity of 2m/s in "Plane_0.9" are shown in Table 3. As shown in Fig.6, spray cone angle has little effect on spray output.

Table 3. Cooling efficiency, average air temperature and humidity for different spray angle in "Plane_0.9" for air velocity of 2m/s for 4 nozzle arrangement

Spray angle	30°	45°	60°
η_c	69.40%	69.40%	69.30%
T (K)	303.6	303.6	303.7
Ψ	78%	78%	78%

The plot in Fig. 6. shows an overlapping line for the angles compared. Which implies that the effect spray angle at air velocity 2m/s for 4 nozzle arrangement is negligible.

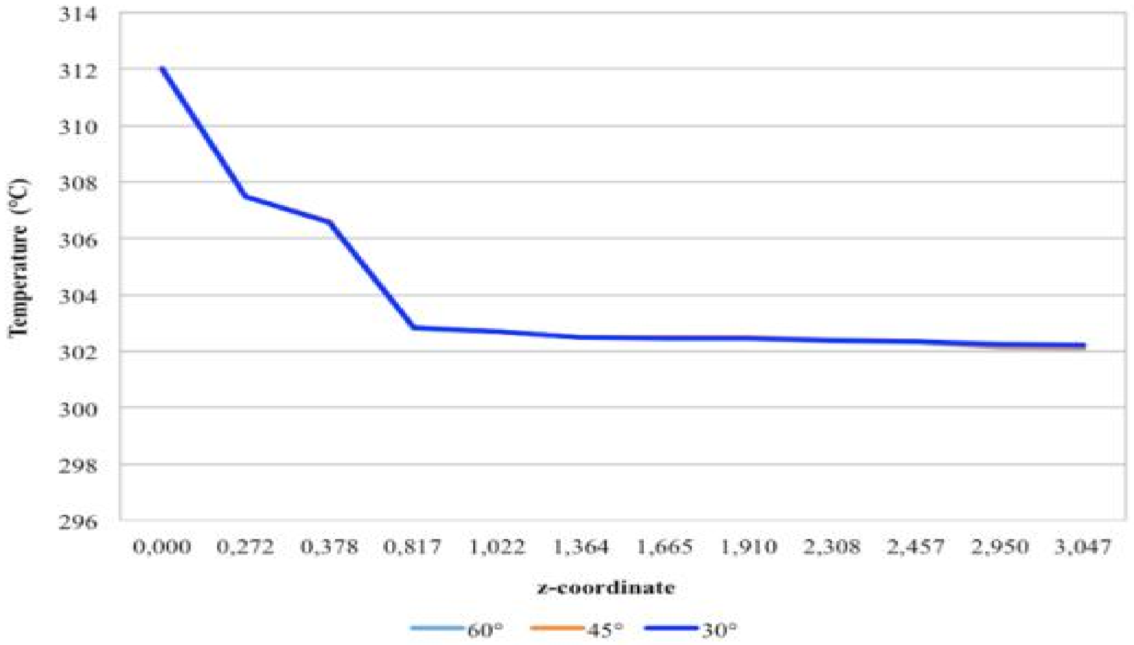


Fig. 6. Comparison of average temperature for different spray angle in "Plane_0.9" for air velocity of 2 m/s for 4 nozzle arrangement.

Effect of droplet size on spray cooling efficiency

Spray cooling efficiency is also affected by droplet size. Droplets of smaller sizes have more surface area per unit volume than large ones, and evaporation only occurs when water and air come in contact. It can be observed that the evaporation rate per unit volume of droplets in gaseous media increases in proportion to the square of the droplet diameter when the diameter of the droplet is decreased. A comparison is done with an air velocity of 2 m/s for a 4 arrangement of 4 nozzles. For various droplet diameters of 10, 50, 100μm, Table 4 displays spray cooling efficiency and climate conditions in "Plane_0.9".

Table 4. Cooling efficiency, average air temperature and humidity for different droplet diameter in "Plane_0.9" for air velocity of 2 m/s and for 4 nozzle arrangement

Diameter	10 μm	50 μm	100 μm
η_c	69%	54%	46%
T (K)	303.7	305.6	306.4
Ψ	78%	67%	63%

According to the above table, smaller droplet diameters result in higher evaporation and, therefore, higher cooling at the same air velocity. The reason for this performance is that sprays with smaller droplets have a larger surface area exposed between the water and the air flow. This results in a higher rate of evaporation. Fig. 7 agreed with previous results.

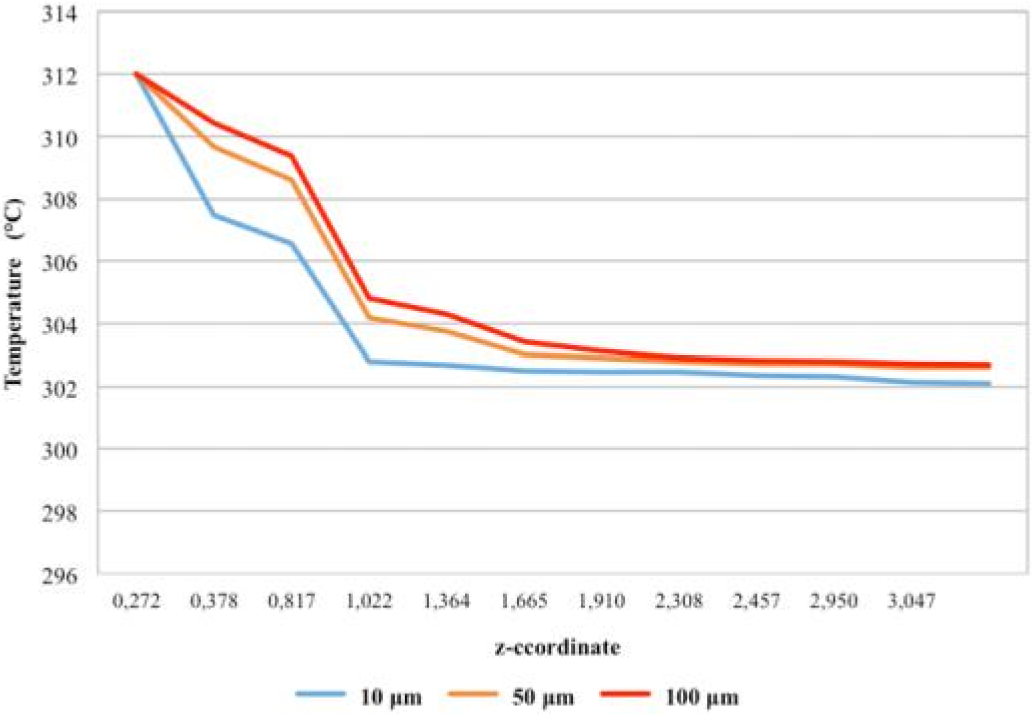
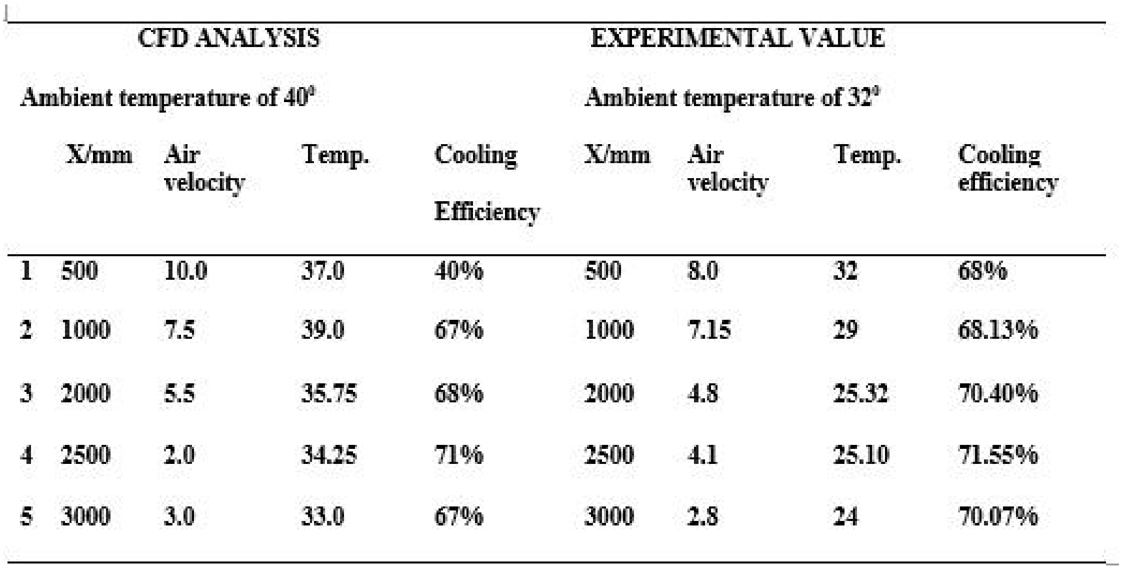


Fig. 7. Evaluation of average temperature for different droplet diameter in "Plane_0.9" for air velocity of 2 m/s and for 4 nozzle arrangement

IV.EXPERIMENTAL VALIDATION

The study shows that CFD analysis is accurate when compared to experimental data. Also, it is observed that at 2.5m away from fan cooling efficiency is achieved the most.

Table 4.Showing comparison of generated experimental values and CFD analysis



	CFD ANALYSIS				EXPERIMENTAL VALUE			
	Ambient temperature of 40^0				Ambient temperature of 32^0			
	X/mm	Air velocity	Temp.	Cooling Efficiency	X/mm	Air velocity	Temp.	Cooling efficiency
1	500	10.0	37.0	40%	500	8.0	32	68%
2	1000	7.5	39.0	67%	1000	7.15	29	68.13%
3	2000	5.5	35.75	68%	2000	4.8	25.32	70.40%
4	2500	2.0	34.25	71%	2500	4.1	25.10	71.55%
5	3000	3.0	33.0	67%	3000	2.8	24	70.07%

V.CONCLUSION

Ascertaining the viability of evaporative cooling using water sprays. As a function of some parameters, like spray cone angle, air velocity, droplet size, and nozzle arrangement, droplet evaporation and air cooling were calculated. The cooling efficiency factor was used to estimate the cooling process. As a result, when considering nozzle arrangement, the best configuration is number 4 with a smaller droplet size. As air velocity increases from 2.0 m/s to 10.0 m/s, cooling efficiency decreases significantly. Due to its effect on residence time and final temperature, air velocity has an important impact on cooling performance.

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