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Effect of Black Carbon and Alumina Nanofluid on Thermal and Dynamic Efficiency in Upward Spraying Cooling Tower

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Abstract

In cooling water systems, cooling towers play a critical role in removing heat from the water. Cooling water systems are commonly used in industry to dispose the waste heat. An upward spray cooling water systems was especially designed and investigated in this work. The effect of two nanofluids (Al_2O_3/ water, black carbon /water) on velocity and temperature distributions along reverse spray cooling tower at various concentrations (0.02, 0.08, 0.1, 0.15, and 0.2 wt.%) were investigated, beside the effect of the inlet water temperature (35 ,40, and 45 °C) and water to air flow ratio (L/G) of 0.5, 0.75, and 1. The best thermal performance was found when the working solution contained 0.1 wt.% for each of Al_2O_3 and black carbon nanoparticles, with a maximum drop in temperature drops (i, e. range) of (16 °C) and (20 °C), respectively. The temperature of the tower's outlet water was decreased as the inlet working fluid increased, and the thermal efficiency declined with the increasing of the L/G by about 5%. However, the drop in the outlet temperature caused by the nanofluid is more than that of pure water at every point by about 6 °C.

Keywords: cooling tower, Nanofluid black carbon, Thermal efficiency.

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1- Introduction

Reducing water temperature is accomplished through the employment of a device that removes heat from the water and releases it into the atmosphere. Power generation and refrigeration are only a few examples of their many applications. In industrial facilities, cooling towers are designed in many types and sizes in order to produce cold water. Water is typically used to cool a condenser in a power plant [1, 2].

"Nanofluids" are industrial fluids with solid particles smaller than a nanometer. It has been demonstrated that the heat transfer characteristics of base fluids may be significantly improved by nanoparticles. It lessens the pressure drop and sedimentation issues that bigger particles and microparticles often experience [3].

The heat from hot water is dissipated by direct contact with cool and dry air in cooling towers. Direct contact cooling is used by the majority of plants, whereas indirect contact cooling is used by a minority [4].

It has been discovered that adding nano-sized (100 nm) solid nanoparticles to base fluids results in nanofluids, which boost thermal performance in heat transfer systems by increasing thermal conductivity. The properties of both the nanoparticles and the base fluid alter their transport and thermal characteristics, making nanofluid a colloidal mixture. Any settling motion brought on by gravity is resisted by Brownian agitation, which is the essential characteristic of nanofluids. A stable nanofluid should be achievable as long as the particles remain small (usually about 100 nm) [5].

However, nanofluids are produced by stabilizing and suspending nanometer-size particle in standard heat transfer fluids (ethanol, water, etc.) Nanofluids, including multi-wall graphene and carbon nanotube, increased heat transmission when used to replace nano fluorocarbon in an experiment cooling towers [6].

Additionally, utilizing a unique method of balancing ambient factors, the impact of various nanofluids on the thermal effectiveness of a wet cooling towers was explored [7]. The mixes of Alumina/water, silica/water, zinc oxide/water, and graphene/water were all studied in a wet cooling tower with crossflow. Based on their results, the fluid of the graphene/water produced maximum efficiency and increased the tower's characteristics efficiency [8, 9].

The type of the cooling tower plays an essential rule in the performance, and the especially the direction of movement of the two fluids [10]. The type of the fills or the direction of flow is very effective on the cooling range [11]. The spray cooling tower is one of the used towers in which the water and the air is in direct counter current contact [12].

The effect of working fluid type on reverse spray cooling tower performance and the problems of operation has only been the subject of so few researches [13, 14]. Also, the shape of the tower plays a crucial rule in the

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performance [15]. As a result of the cooling tower's importance and applicability in various industries, as well as the particular properties of nanofluids, additional research on this type of reverse spray cooling tower is required.

In this study the performance of reverse upward spray cooling tower especially designed will be investigated to examine the usage of two type of nanofluid at various concentration (which are (Al_2O_3/ water, black carbon /water)) (0.02, 0.08, 0.1, 0.15, and 0.2 wt.%) on velocity and temperature distributions along the height of the tower at different inlet temperature of the nanofluid (35,40, and45 ∘C) and different water to air flow ratio L/G (0.5, 0.75, and 1).

2- Experimental Work

2.1. Reverse Spray Cooling Tower

A schematic diagram of the reverse spray cooling tower specifically designed and used in our experiments are shown in Fig. 1. The length is (2 m) and have a diameter of (0.7 m). Air is drawn into the cooling tower through a fan, where it passes through two holes, the diameter of the hole is 20 cm. At the point of entry, it passes through a channel of silica gel made of acrylic material, which is placed on a perforated plate to give constant air humidity during the operation process [14, 16]. Functional segment, a number of nozzles are placed and coordinated vertically at the bottom of the tower, so that when the water is in the ascendant motion it will flow co-currently with the air, but when it in the descendant movement it will flow counter-currently with the up-word air. Large water droplets in the air stream of a cooling tower can be collected using a section called a “drift eliminator.” The eliminators keep the mist and water droplets inside the cooling tower [17].

2.2. Air System

Two layers of silica gel are sandwiched between two punctured acrylic plate screens to maintain a constant level of humidity in the operating area of the tower from the outside air. The air is supplied by a variable-speed fan. For the cooling tower's incoming and output air, temperature and humidity sensors are used.

2.3. Water System

As depicted in Fig. 1, this experiment utilized a water supply system. Pump, high-pressure piping, and spray nozzle are all included in the system's construction. There is only one water tank in the entire setup. Pumping water from the main tank to the spray nozzles will use a variable speed, a high-pressure water pump that can produce up to 8 l/min of flow throughout the experiment. The flow rate to the spray nozzle is controlled by a bypass valve, with excess water being routed to the auxiliary water tank upstream of the nozzle.

2.4. Spray Nozzle System

In the studies, various spray nozzles were used. The choice of nozzle is a critical part of the experiment. When selecting a spray nozzle, the following are the most important considerations: Size distribution, flow velocity, and spray cone angle are all things to keep in mind while deciding on a droplet size distribution [18]. The spray cooling tower's thermal performance dictates the droplet size, liquid flow rate, and spray angle. This experiment used hollow cone nozzles only. Humidification systems frequently employ this design. For adequate saturation of the inlet air, spray nozzles with the highest water flow rate, lowest droplet size dispersion, and widest spray cone angles were selected.

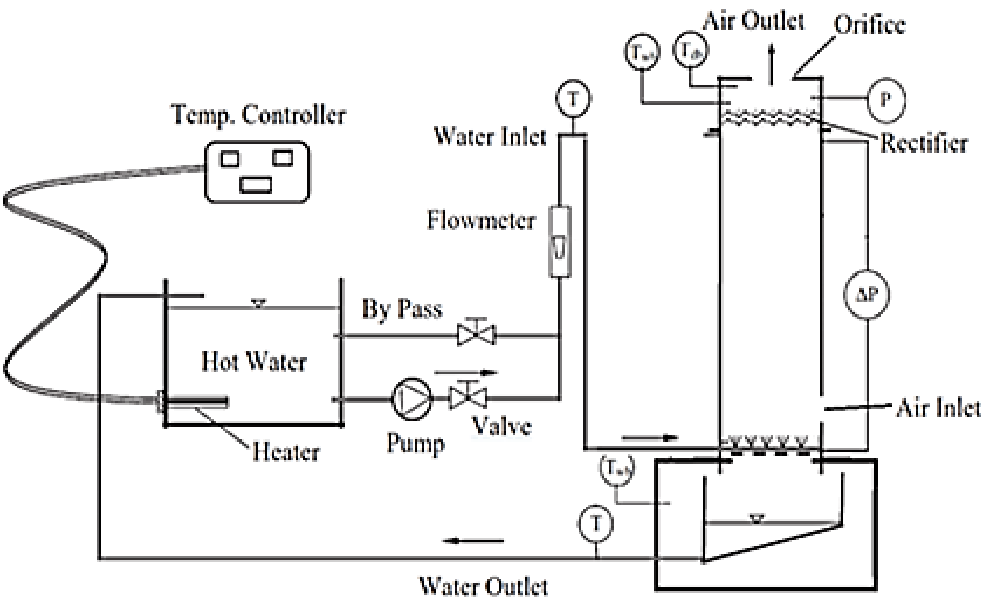

Fig. 1. Schematic Diagram of Experimented Cooling Tower

2.5. Preparation of the Nanofluids

Compared to other nanoscale items, Alumina nanoparticles are highly stable and can be easily distributed in water to generate colloidal nanofluids. In this study, and based on the required weight concentration of the nanofluid, a precise amount of Al_2O_3 and black carbon nanoparticles manufactured by "Ireej Al-Fourt Co." were chosen for the spray cooling investigation and their specification are illustrated in Table 1. The nano fluid solution had been prepared by adding the specific weight of the nanoparticles to pure water inside and ultrasonic bath (working frequency: 28 kHz) for 1.5 hr, this had been done to obtain suspended particles in stable situation. Gum Arabic (GA) had been added also to improve the stability of the suspension of the nano particles in water. It had been noted at the end of each run that there is no participation which guarantee the stability of the nanofluid.

Table 1. General Characteristics of the Al_2O_3 and Black Carbon Nanoparticles Utilized in the Research

Nanoparticle	Aluminum oxide	Black Carbon
Average diameter (nm)	20-40	10-20
Chemistry formula	Al_2O_3	C
Special area (m^2 /g)	90-220	90–160
Color	White	Black
Morphology	Sphere	spherical
Purity	> 99.99%	99.7%
Density (g/cm^3)	3.65	0.07-0.32

3- Results and Discussions

Fig. 2 to Fig. 10, show the effects of various water/Al_2O_3 nanofluid concentrations (0.05, 0.08, 0.1, 0.15, 0.2 wt. %) on the droplet velocities and temperatures distributions along the tower for various inlet working fluid temperatures (35,40, and45 °C).

More specifically, Fig. 2, draws attention to the droplet velocities of the water and nanofluid, when the nano concentration is 0.05 wt. %, there is no noticeable difference, especially in the descent stage (except 0.05). The spray with the highest droplet velocity is water, whereas the spray with the lowest droplet velocity is 0.1wt.% nanofluid. The droplet velocities of the remaining mass concentrations (0.08, 0.05, 0.15 and 0.2 wt%) of the nanofluids are intermediate, and there are no significant differences between them.

At an inlet working temperature of 35°C, Fig. 3, shows that the temperature drops increase as the nanofluid concentration increases. The water solutions with nano Al_2O_3 of 0.05, 0.08, 0.1, 0.15, and 0.2 wt% concentrations, their outlet temperatures had been decreased to 24.8, 24.4, 24, 23.5, 24.5, and 24.6 °C, respectively. As shown in this figure, increasing nanofluid concentration increases energy absorption and release it to the air. This behavior is also confirmed by another study [7, 19].

Three mechanisms were accomplished, convective mass transfer, heat transfer, and convective heat transfer. Therefore, increasing the nanofluid concentration increases heat transmission through conduction and convection. Also, the increase in the concentration of the nano particles in the water will increase the solution viscosity, and this will slow down the motion of the solution which will lead to increase the contact time between the two fluids, but after a certain concentration, this decrease in the velocity will have a negative effect on the heat transfer. Fig. 3, illustrates that the outlet working fluid has increased to greater than 0.1 wt% as concentration has increased.

The primary challenge associated with applying nanofluids is the aggregation of particles, which can reduce their heat transmission capabilities. The probability of agglomeration increases as the nanofluid concentration rises. The cooling range decrease may be due to this phenomenon. Although with the reduced range.

Utilizing pure water and 0.1 wt% Al_2O_3/water nanofluid at inlet operating fluid temp of 35, 40, and 45°C, the impacts of inlet operating fluid temp on exit operating fluid temperature were examined. Fig. 3, Fig. 5, and Fig. 7 display the impact of nanofluid (Al_2O_3/Water) on droplet temperature distribution at an Inlet water temperature of 35°C. The nanofluid exit temperature is lowest than that of pure water. Alternatively, the cooling tower rejects more heat when a nanofluid is utilized.

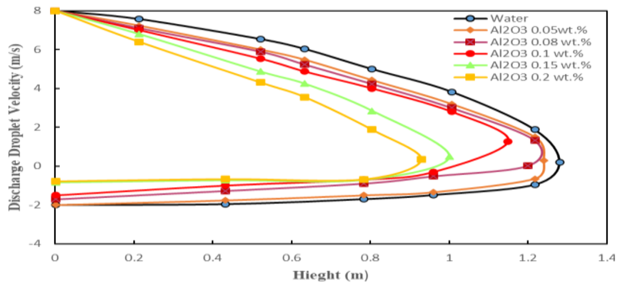

Fig. 2. Effect of Nanofluid (Al_2O_3/ Water) Concentration on Droplet Velocity Distribution at Inlet Water Temperature 35 °C

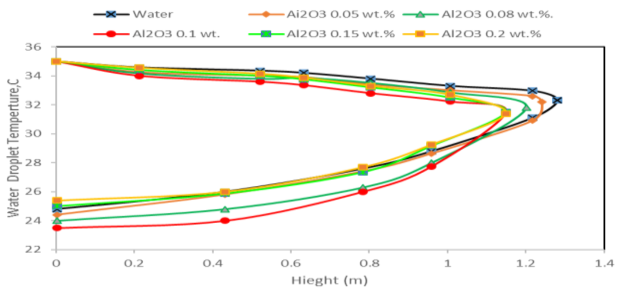

Fig. 3. Effect of Nanofluid (Al_2O_3/ Water) on Droplet Temperature Distribution at Inlet Water Temperature 35 °C

In addition, when the working fluid's inlet temperature is increased, the nanofluid's temperature decrease is significantly more significant than that of water. For instance, for Discharge droplet velocity of 8 m/s with inlet operating fluid temps of 35, 40, and 45C, the output operating fluid temperatures for pure water and nanofluid, respectively, are 24.8, 28.6, and 31 °C. These Figures also show that the cooling range is improved by raising the working fluid's inlet temperature. In particular, the cooling range increases as the nanofluid's inlet temperature increases, while the working fluid's output temp essentially remains unchanged. The cooling range was expanded by 2.21 °C for water and by 2.80 °C for nanofluid by rising the operating fluid inlet temperature 40 - 45C.

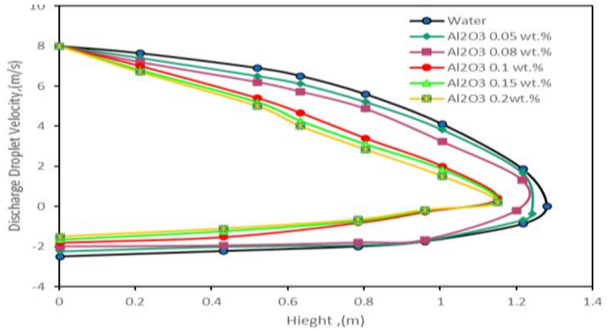

Fig. 4. Effect of Nanofluid (Al_2O_3 /Water) Concentration on Droplet Velocity Distribution at Inlet Water Temperature 40 °C

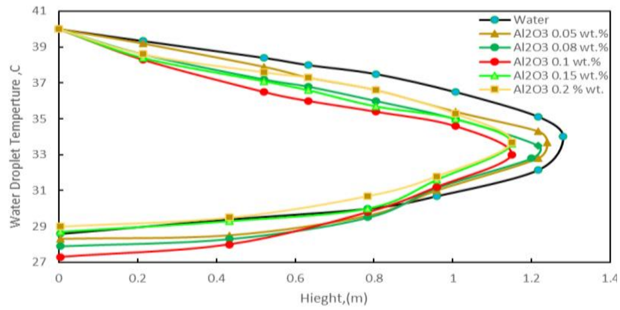

Fig. 5. The Effect of Nanofluid (Al_2O_3 /Water) Concentration on Droplet Temperature Distribution at Inlet Water Temperature 40 °C

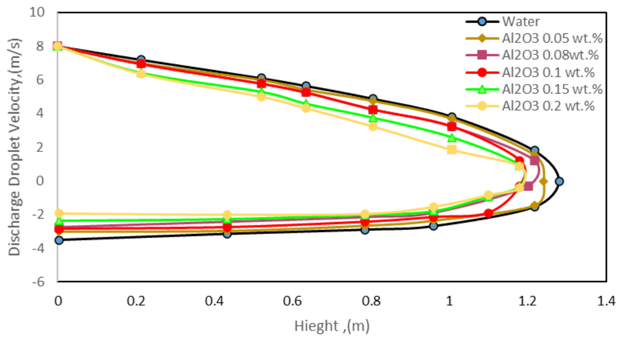

Fig. 6. Effect of Nanofluid (Al_2O_3/ Water) Concentration on Droplet Velocity Distribution at Inlet Water Temperature 45 °C

Fig. 8 to Fig. 13, show the effects of various Black carbon/ water nanofluid concentrations (0.05, 0.08, and 0.1,0.15, and 0.2 wt. %) on droplet velocity and temperature distributions along tower height for various inlet working fluid temperatures (35, 40, and 45 °C).

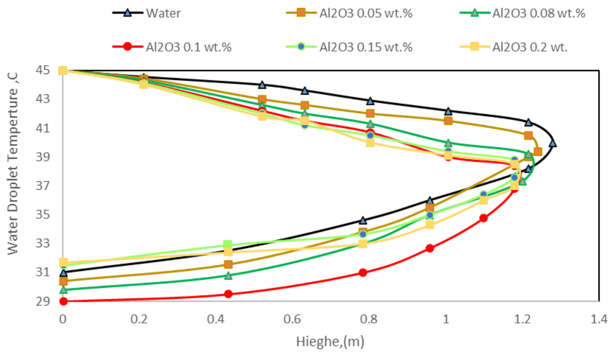

Fig. 7. Effect of Nanofluid (Al_2O_3/ Water) Concentration on Droplet Temperatures Distribution at Inlet Water Temperature 45 °C

Fig. 8 displays the droplet velocities of water and nanofluid (BlackCarbon/water) concentration. There were no apparent variations, particularly in the spray downstream of BlackCarbon/ water. Droplet velocity was lowest in Black Carbon with 0.05 wt%, then by 0.08 wt% and 0.1wt%. These results showed that higher concentration nanofluids formed droplets with lower droplet velocity. This means that the effect of Black Carbon/ water concentration on discharge droplet velocity is not significantly different from that of Al_2O_3 /water.

Regarding these results, as the temperature of the entering water increases, the temperature drops increases, particularly at (45° C). It is generally known that water would be cooled to the wet-bulb temperature before entering the air for optimal cooling tower operation. When using nanofluids in a cooling tower, the cooling range is more significant than when using water. This is because the presence of carbon nanoparticles enhances the base fluid's properties for heat transfer. By improving thermal conductivity, the convection heat transfer coefficient, and surface area, nanofluids improve heat transfer between air and liquid flows. The temperature differences increase from 10.2° C, 11.4° C, and 14 C for water to 12° C, 13 C, and 19.4 C for Black Carbon nanofluid at 35, 40, and 45C.

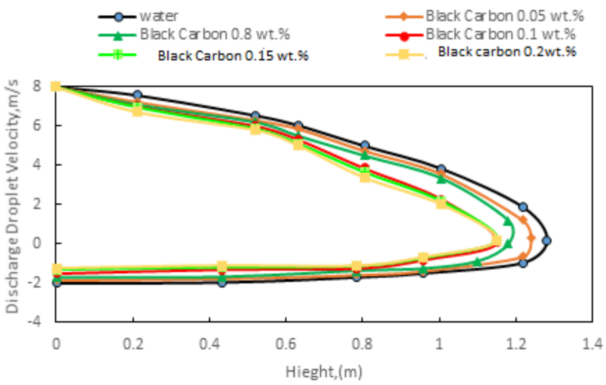

Fig. 8. Effect of Nanofluid (Black Carbon/ Water) Concentration on Droplet Velocity Distribution at Inlet Water Temperature 35 °C

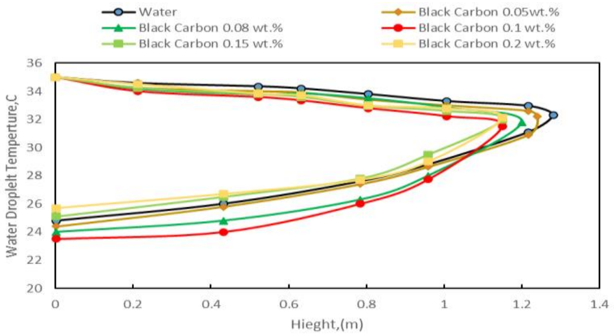

Fig. 9. Effect of Nanofluid (Black carbon/water) on Droplet Temperature Distribution at Inlet Water Temperature 35 ˚C

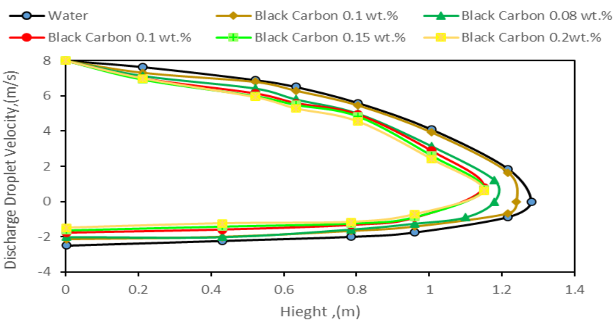

Fig. 10. Effect of Nanofluid (Black Carbon/ Water) Concentration on Droplet Velocity Distribution at Inlet Water Temperature 40 ◦C

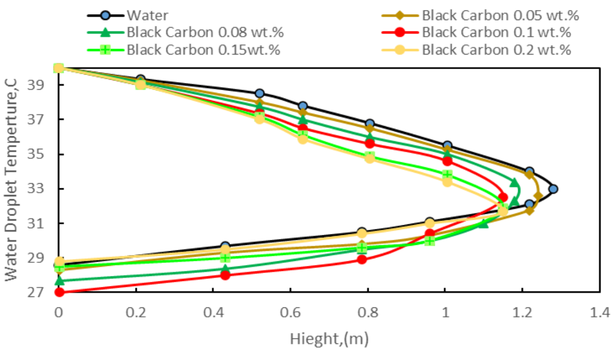

Fig. 11. Effect of Nanofluid (Black Carbon/ Water) Concentration on Droplet Temperature Distribution at Inlet Water Temperature 40 ˚C

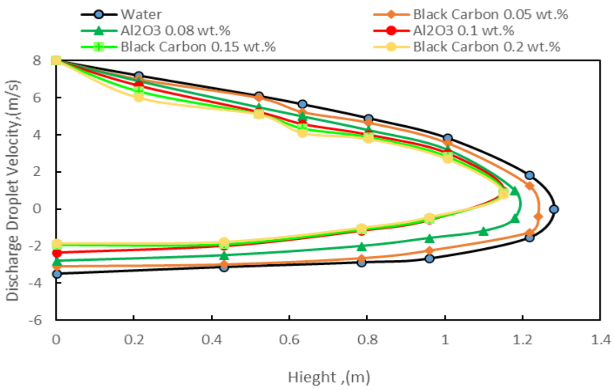

Fig. 12. Effect of Nanofluid (Black Carbon/ Water) Concentration on Droplet Velocity Distribution at Inlet Water Temperature 45 ˚C

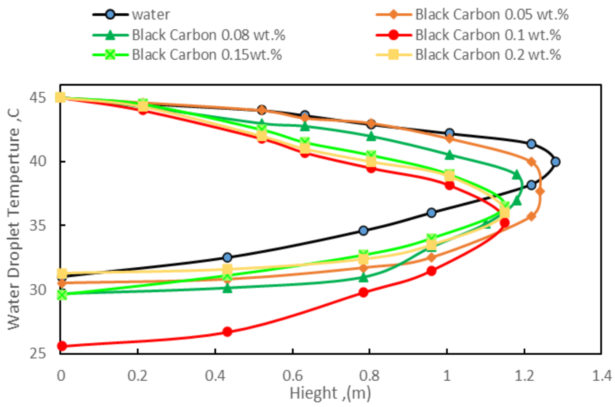

Fig. 13. Effect of Nanofluid (Black Carbon/ Water) Concentration on Droplet Temperature Distribution at Inlet Water Temperature 45 ˚C

The finding in Fig. 14 demonstrates that the cooling tower thermal efficiency is influenced by the mass flow ratios of the flowing fluid/air (L/G). Raising the ratio often results in a decline in the cooling tower's thermal effectiveness and water temp drop, and this is in agree with other studies [4, 11]. The tower's efficiency decreased from 46% to 41% when using Al_2O_3/water nanofluid at 45 °C with an L/G ratio of 0.5-1, also for thermal efficiency for black carbon as shown in Fig. 15. The use of nanofluids enhances the cooling tower's effectiveness. When nanoparticles are dispersed in water, the surface area available for heat transfer increases, the thermal conductivity rises which will improve heat transfer. Also, the increase in the nano concentration to a certain limit will increase the solution viscosity, and this will slow down the motion of the solution which will lead to increase the contact time between the two fluids and this will also be decreasing the temperature difference between fluid layers. Consequently, the cooling tower conditions improve, and the heat transfer is enhanced. Greater efficiency may be attained at lower L/G and higher inlet water temperatures because nanofluids have better available thermal characteristics, these results are in agreement with another study [11, 19].

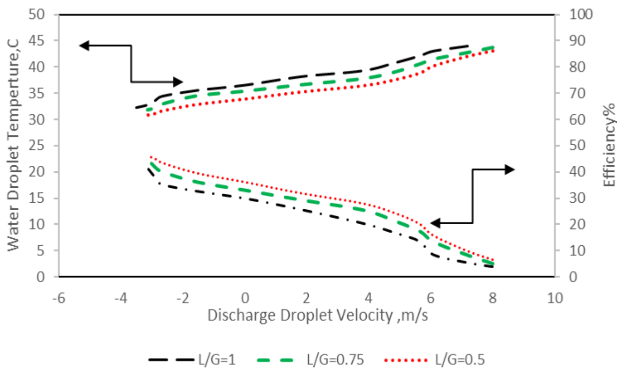

Fig. 14. Effects of Discharge Droplet Velocity (8m/s) at (45◦ C) on Efficiency of Various Al_2O_3/water to Mass Flow Rate of Air

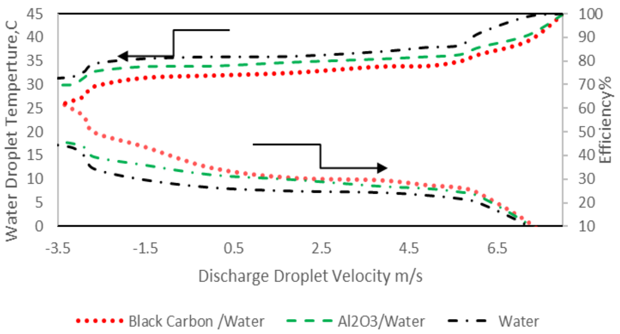

Fig. 15. Effects of Discharge Droplet Velocity (8m/s) at (45° C) on nanofluid (Black Carbon/water) Droplet Temperature and Efficiency for Different (L/G) Ratios

4- Conclusions

Effect of two nanofluids (Al_2O_3/ water, black carbon /water) on velocity and temperature distributions through the height of reverse spray cooling tower at various concentrations (0.02, 0.08, 0.1, 0.15, and 0.2 wt.%) had been investigated for different inlet solution temperature. The best thermal performance is seen in the solution that contains 0.1 wt.% of both Al_2O_3 or black carbon, with temperature drops of about (16° C) and (20° C) from the inlet temperature of the water, respectively.

The use of nanofluids has greatly increased the cooling tower thermal performance. This performance improvement changes according to the nanoparticle type (both black carbon and Al2O3), nanofluid concentration, inlet working fluid temperature (35,40,45° C), and working fluid mass flow ratio to air. For example, at 45 °C, utilizing black carbon /water nanofluid (0.1 wt%) increases efficiency by 44.3% to 63.2% over pure water in the same temperature and circumstances. The effect of using nano carbon was more pronounced in comparison to Al_2O_3

The temperature of the tower's outlet water decreases as the inlet working fluid increases and the thermal efficiency declines with the increase in the L/G. However, the drop in the outlet temperature caused by the nanofluid is more than that of pure water.

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تأثير النانو فلود (الكربون الأسود والألومينا) على الكفاءة الحرارية والديناميكية في برج التبريد باستخدام الرش بالاعلى

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٣ قسم هندسة العمليات والهندسة الكيمياوية، جامعة سري، سري، المملكة المتحدة

الخلاصة

في انظمة تبريد المياه, برج التبريد يلعب دور مهم في العملية لتبديد الحرارة من المياه. يستخدم برج التبريد بكثرة في العمليات الصناعية. تم تصميم ودراسة نوع خاص من ابراج التبريد من نوع الرذاذ نحو الاعلى. تم دراسة تاثير تركيز المواد النانوية من نوعين (اوكسيد الالمنيوم و الكاربون) و بتراكيز مختلفة (٠,٠٠٢, ٠,٠٨ , ٠,١, ٠,١٥, و ٠,٢ %) علي توزيع السرعة و الحرارة على طول البرج الرذاذ نحو الاعلى، بالاضافة الى دراسة تاثيركل من درجة حرارة المحلول النانوي الداخل (٣٥ , ٤٠, و ٤٥ درجة مئوية) ونسبة جريان السائل الى الهواء (٠,٥ , ٠,٧٥, و ١). لقد وجد ان افضل كفاءة حرارية تم الحصول عليها عندما كان المحلول يحتوي مواد نانوية بتركيز ٠,١% لكن من اوكسيد الالمنيوم او الكاربون حيث وصل اعلى هبوط لدرجة الحرارة الى ١٦ و ٢٠ درجة مئوية على الترتيب. درجة حرارة المحلول النانوي الخارج تقل ايضا مع زيادة درجة حراة المائع الداخل، بينما الكفاءة الحرارية تقل مع زيادة نسبة جريان السائل الى الهواء (L/G) حوالي ٥%، عموما فأن الهبوط في درجة الحرارة ب استخدام مواد نانوية كان اكثر من استخدام الماء الصافي ب حوالي ٦ درجات عند كل نقطة من نقاط البرج.

الكلمات الدالة: ابراج التبريد، نانو الكاربون الاسود، الكفاءة الحرارية لابراج التبريد.