Nanofluid Applications of the Thermal Performance of a Forced Cooling Tower: A Review

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Most industrial processes require temperature control.Cooling towers are vital to many power plants. A cooling tower uses cool, dry air to reject heat from hot water. This analysis examines cooling tower types, applications, performance, uses, and operating principles, which may be useful in nuclear and other power plants. Studies have been conducted to determine the distinctions between towers for cooling, and with modern technology, towers can be made more efficient in production. This analysis examines vertical and horizontal gaskets and their effects on cooling tower thermal performance. Nanofluid thermophysical characteristics, nanoparticle manufacturing, and preparation are also covered in this article. Nanofluid heat transfer efficiency research was also discussed. This article reviews the literature's experimental and theoretical methods and nanofluid thermal characteristics under different flow conditions. The final section of this review discusses nanofluidic cooling tower research.

Keywords: Cooling Tower, Packing, Nanofluid, Thermal performance, preparation

1. Introduction

There are several historical uses for Other methods of evaporative heat removal, such as cooling towers devices, industrial operations, refrigeration cycles, and power generation all produce significant amounts of waste heat. Cooling towers and other evaporative cooling systems work by exposing water to air that is not completely saturated. When a gas and a liquid have different vapour pressures, mass transfer occurs. The air gets hotter and more humidified as water evaporates and cools [1].

The three main types of cooling towers are those that use parallel, cross, or counter flow patternsWithin wet cooling towers, mass and heat transfer occur in the fill, spray, and rain zones. Two options are available main kinds of cooling systems that make use of fans: utilizing both mechanical and natural drafts for cooling purposesr [2].

Because of their significance and the fact that many different industries depend on them, cooling towers have long piqued the curiosity of researchers looking for methods to improve them. The study looked at how various nanofluid concentrations and flow rates affected various tower performance indicators, including cooling extent, efficacy, and rate of tower evaporation. It appears from the results that nanoparticles in solutions with a molecular weight of 0.085 outperform water alone in a Low-flow cross-flow cooling towers, which are becoming more cooling by 15.8% and 10.2%, respectively. Economic optimization revealed that an accumulation of 0.07 weight percent and the rate of flow of 2.249 kilograms per minute were optimal[3].

One device that can lower the temperature of a fluid is a cooling tower, which works by transferring heat from the fluid to the air around it [4].

Goshaichi [et al]. built numerically film-type cooling that is counter-flow towers with film-type packing.. to maximize evaporation and cooling efficiency. The film-shaped packaging's heat and mass transfer mechanism was tested at the lab. [5].

Some groups investigated spray nozzles and the results of using various materials beyond the scope of traditional packaging Spraying Nozzles [6].

Cooling towers blend hot water with cold air coming from the atmosphere. Convection uses air to cool the working fluid. Evaporation of the working fluid contributes to overall heat rejection. As seen in Figure(1),a cross-flow cooling procedure. Chemical companies, refineries, nuclear power plants, commercial buildings, airports, and retail centers are just some of the many places you can find a cooling tower. Classification of a cooling tower as dry or wet indicates the nature of the process of transferring heat from cooled air to heated water [7].

Research into cooling towers has been extensive. The impact of operational conditions has been a primary focus of performance enhancement efforts. There are many factors to consider while designing a cooling tower, Water temperature, water flow rate, ambient environment's conditions of heat and moisture level. sort of filler, and tower dimensions. Increasing the condensation tower's thermal efficiency has become more focused on by adding nanoparticles to various basic fluids[8].

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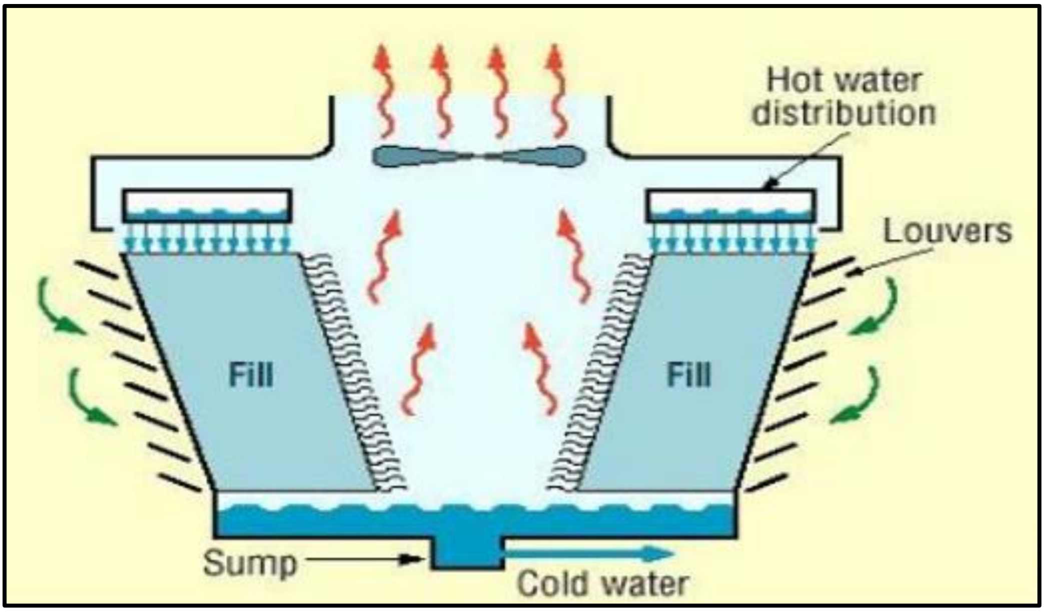

Figure 1: Cross-flow of cooling procedure [6].

When MWCNT-based nanofluid was used instead of the base fluid, significant improvements were seen in three key performance measures. There is a 20% rise in thermal conductivity, 40% expansion in cooling capacity, and a 10% decrease in water loss. Despite the promising findings, more research is needed into this specific application. Numerous studies have been conducted. into other nanoparticles. Advanced Fluids that Include (ZnO / water) and Al2O2/water.Al2O3/EG,an CuO have also demonstrated promising results in heat transfer[9].

Al-Askari et al. added nanoparticles of copper (Cu) and alumina (Al2O3) to a heat exchanger at volume ratios of 0.5 to 3.0%. It was demonstrated that adding 1.5% nanoparticles to water improves the efficiency of a home water heat exchanger system [10]. Imani, et al. investigated how aqueous Al2O3 nanofluids affected the radiator's heat transmission efficiency. Nanoparticles increased the heat transfer coefficient by 45 percentage points when only water was considered[11].

Al-Husseini[et] alinvestigated carbon nanotube effects (CNTs). By making use of carbon nanotubes with many walls (MWNT) and nanofluids produced from graphene, researchers have built a tubular cooler with a 67% improvement and 40% increase in cooling range (NPN). The researcher discovered that each nanoparticle consumes 10% and 19% water, respectively. The research used a weight ratio of 0.1 nanofluid concentration and an input temperature of 45 °C [12].

TiO2 nanoparticles are used for better heat transmission qualities. The potential is currently demonstrated by the medium in solar collectors[13].

Carbon nanoparticles (MWCNTs and SWCNTs) have been shown to have an influence on temperature sensitivity. According up to the findings, the thermal conductivity of 1% SWCNT, and 43.9% MWCNT . nanoparticles could be enhanced, respectively.

The subject of another investigation was the use of carbon nanotubes with many walls and graphene nanosheets to enhance the outcome of diesel oil. As a result, both nanofluids' thermal and electrical conductivity was improved over pure diesel oil [14].

Al-Saied et al. examined how various nanoparticles affected cooling tower performance, including grapheme, zinc oxide, Al2O3, and SiO2. These findings suggest that the graphene nanoparticle-containing nan fluid improved cooling tower performance even further. As a result, adding 0.02% by weight of grapheme The cooling tower's efficiency rose by 36.2%, the thermal transfer coefficient within a given volume by 8.3%, and the properties by 36% after adding nanoparticles to the core fluid [15].

Rahmati and colleagues conducted mechanical research in order to explore the impact of a "ZnO/water" a The water-cooled tower's thermal performance using nanofluids. The the very step was examining the effects in three different densities (layer counts) of beds filled with 0.1%w nanofluid and selecting the bed that produced the greatest temperature performance. Next, the effect of the tower's nanofluid concentration (0.02, 0.04, 0.06, 0.08, and 0.1 weight per cent) was investigated using the chosen filled bed. The findings demonstrated that when the quantity of mattress layers, and the level of Nano fluidization grew, the tower's cooling range, efficacy, and tower features rose as well, improving the tower's thermal performance [16].

Titanium dioxide (TiO2) materials such as nanofluids, MWCNTs, and six varieties of filled layers were employed in two categories of patches and films. MWCNTs, TiO2/water aqueous nanofluid through a 0.05 concentration weight per cent were used to assess the impact of these layers about CFCT's thermal performance composites and help identify the ideal Layer. As the results demonstrated,using nanofluids as the working fluid rather than water in most cases enhances CFCT's thermal performance. For water and nanofluids, beds 3 and 5 were determined to be appropriate, respectively. Improving tower performance, for instance, can be greatly enhanced by utilising a properly filled bed with a low flow ratio. As an illustration, employing layer 3 resulted in a 28% increase in tower efficiency over pure water with the same amount of MWCNTs / nano water, compared to just 7% at L/G = 2. Furthermore, there were gains in cooling range, efficacy, and Merkel parameters of 28%, 85%, and 131%, respectively, when Layer The condition of no bed No. 3 was used instead of bed No. 3. When employing nanofluids, our findings emphasize how crucial a proper bed is [16]. Cheng et al [17].

studied experimental investigation to learn how Al2O3/aqueous microfluid with a 50 nm average diameter effected how well a heat exchanger with two tubes transfers heat that works against the flow of electricity. A mixture of Al2O3 nanofluid and aqueous nanofluid (0.25% to 0.5%) created a chilly, nanoparticle-filled fluid.Good consensus on established in the midst of simulated and data from experiments, and the findings show that the Nusselt number..

Nusselt values obtained from experiments were 12.8% off from those obtained by simulations. In conclusion, the CFD approach reflects the efficiency with which the double tube exchanger by means of Al2O3/aqueous particles in a fluid [18].

Relative humidity responded proportionally to shifts in water temperature, and this relationship was named the Merkel number. Specific heat capacity testing was performed on cooling tower gaskets. Moisture in the air, the Merkel number, and the system's specific enthalpy rose when the water temperature was raised. However, the specific enthalpy increases when the system is filled. It has been shown that using nanoparticles with A system's efficiency may be enhanced by effective heat dissipation. Jiang et al, investigated the modification of Micro-AARS by incorporating TiO2 nanofluids at concentrations of 0.1%, 0.3%, and 0.5%, as well as 0.5 weight percent TiO2 and 0.02 weight percent SDBS combined. The temperatures for evaporation From -18 °C to 0 °C, 105 °C to 150 °C for generating, and 22 °C to 33 °C for the input cooling water..This nanofluid blend of 0.5 wt% TiO2 and 0.02 wt% SDBS outperforms many otherswas shown to have the most significant impact on improving COP. An increase in COP is proportional as a function of nanoparticle quantity uniformly distributed throughout the base fluid. COP performance can be increased by up to 27% when TiO2 nanoparticles are used in AARS [19].

Hui used methods involving microscopic nanobubbles (MNBs) in his research. It has received great attention due to its potential impact in various scientific and technological fields. Due to their small size and high internal pressure, MNBs can greatly enhance gas solubility and ozone condensation in water treatment. This study aims so that we can assess the benefits of using freshwater cooling towers for HVAC systems and highlight key obstacles that must be addressed in further studies and development. Evidence suggests that low bubble size, moderate rate of rise, and high friction are key characteristics of MNCs contributing to their potential benefits. The bubble contains a huge volume of low pressure (self-pressure effect). Due to its large surface area and great gas solubility, dissolution and shrinkage, MNB technology has promising prospects for improving the efficiency of ozone and cooling water treatment processes [20].

Hua [et al]. looked at how well nanofluid flow including alumina and water performed in cooling hot copper. Nanoparticle concentrations from 0 to 10%, Reynolds numbers from 168 to 2031, fluid temperatures from 25 to 50 °C, and applied heat fluxes from 3979 to 7957 W m^{-3} were performed in a number of experimental settings. The findings corroborate the theoretical facts discovered in published works, showing that transmission of heat, effectiveness ratio, and gain index all improve with increasing fluid input temperature.

In addition, Because of how concentrated nanoparticles grows, the efficiency of heat transmission also increases. A ratio of 1.105 for heat transfer efficiency was achieved using nanofluid. With a 10% centrifugation and an input temperature of 50°C, indices as high as 1.065 are achievable[21]. Karthikeyan and colleagues He looked at the CLPHP's less-than-ideal thermal performance via experimental experimentsm Using a two-stage copper nanofluid preparation and a mixture of fluids used for operation (distilled water, silver nanoparticles, and copper nanofluid), nanoparticles are dispersed using a dynamic light scattering approach. By using charged nanofluids with CLPHPs, experimental results revealed the evaporator wall temperature is lower and the heat transfer limit is 33.3% higher than that of DI water. When comparing DI water with nanofluidics, the nanofluidic device demonstrated superior temperature management capabilities [22].

The researchers measured pressure drop while researching how cooling tower thermal performance is affected by gasket design. The appropriate rate of tower dampening was found by calculating the diameter of the hole, which is six millimeters. Observations were made inside a climate-controlled cooling tower. using a slurry that was filled with corrugated water.

So that the air and water may interact uniformly, the plate is slanted and vents are placed underneath it. An important factor in a cooling tower's thermal performance is the layout of the gaskets [23].

The process involves, the circulation of frigid and arid air using cooling towers. Most plants utilize direct contact refrigeration, although a few employ indirect contact refrigeration [24].

The cooling capacity is significantly affected by the kind of fill material and the direction of flow [25].

The gadget extracts and dissipates thermal energy from the wet surroundings, decreasing water temperature. They may be utilized for many applications, including electricity generation and cooling. Various types of towers are necessary for industrial and refrigeration applications[26].

This study explores how different nanofluids affect the water-cooling towers' thermal efficiency, using a unique method to reduce environmental factors [27].

The efficiency of heat transfer systems may need some work to introducing solid nanoparticles with a nanometer or smaller size to the core fluids, creating nanofluids. This colloidal combination of The temperature and transport properties of the nanoparticles and the base fluid are changed. A basic feature of nanofluids is Brownian agitation, which cancels any settling motion due to gravity. The resulting For nanofluids to remain stable, the particles are kept to a manageable size (often around 100 nm) [28].

Nanofluids" are synthetic liquids with solid particles smaller than a nanometer. Nanoparticles have the ability to considerably improve thermal conduction capabilities of basic fluids. It solves the problems of pressure loss and sedimentation caused by both large and small particles [29].

The water flows with the air currents when the tower is lifted and against them when it is lowered through the use of nozzles that are vertically coordinated and on the ground level below the tower. A piece of the tower's cooling system known as a "drift eliminator" collects water droplets that are too big [30-31]. The structural features of carbon nanotubes were used to talk about how well nanofluids transfer heat [31].

It experimentally investigated how changing the weight ratio, core fluid temperature, and external magnetic field affected multi-walled carbon nanotubes (Ni-np@MWCNT). Nanofluids and other chemical methods were used in the synthesis of Ni-np@MWCNT nanoparticles. The studies also demonstrated it is possible to significantly alter nanofluids' thermal conductivity by use of a magnetic field. The study's author stated that magnetic nanofluids may be used to fabricate intelligent gadgets[32]. Magnetic nanoparticles are commonly based on transition metal components. When exposed to surfactants or oxidation, the magnetic properties are reduced, leading to high reactivity. Enclosing nanoparticles within tubular nanostructures is a feasible and effective technique for maintaining their magnetic properties [33].

Another factor that might influence nanofluids' heat conductivity determined by carbon nanotubes is the presence of surfactants[34]. Figure (2) shows the classifications of cooling towers.

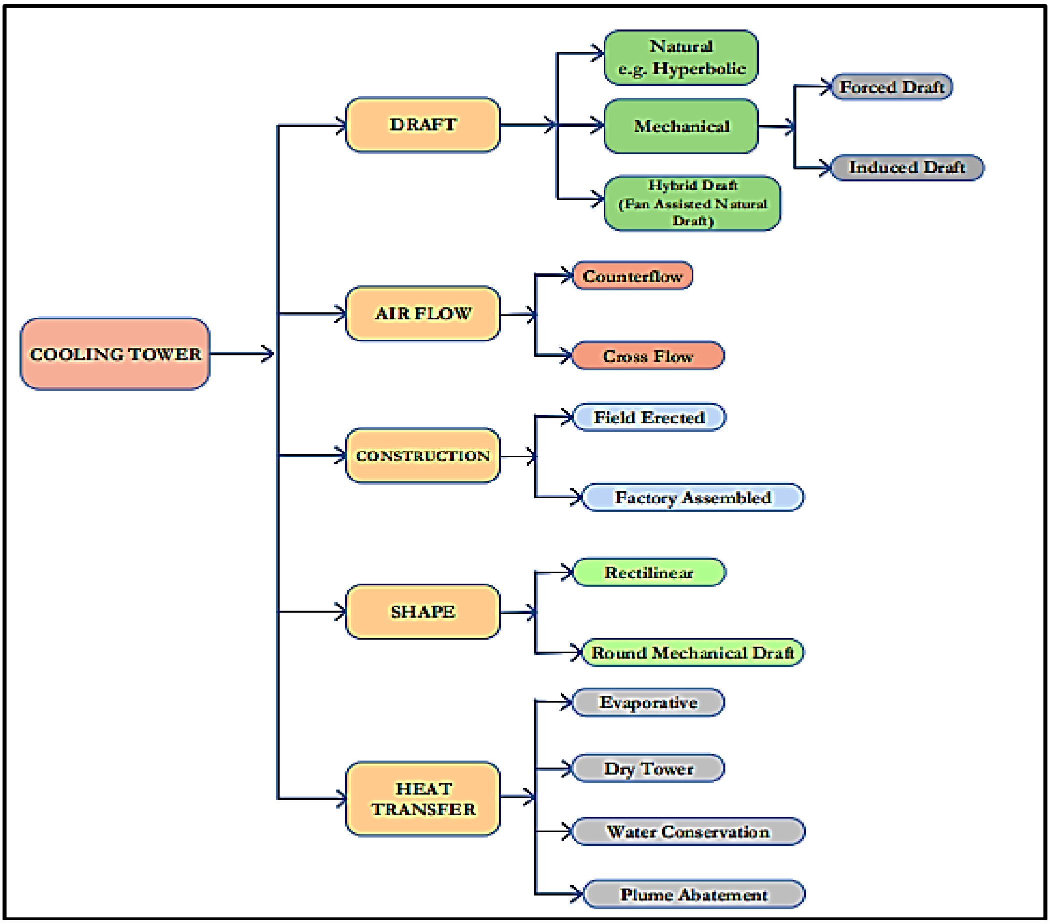

Figure 2: Classification of cooling towers[35]

2. Classification of Mechanical draft cooling towers

2.1 Forced draft

Every tower is equipped with a tall intake and a low exhaust. Forced draught fans can create an imbalance when they are used to circulate air that includes natural or recycled moisture and is subsequently exposed to the cold outside air. Centrifugal fans are employed in forced draught towers because of their superior power and ability to endure higher static pressures in the ductwork. To reduce the volume of trash produced during the recycling process, it is possible to store the materials indoors, provided there is sufficient space, or in a container particularly constructed for this purpose (see Figure 3) [36].

Wet cooling towers are the only means of transferring waste heat in thermodynamic cycles in the industrial sector. Managing and improving their account situation is challenging. Air and water have notable differences in how mass and heat are transported. This research involved the analysis of atmospheric mass. Experiments were undertaken to determine the effects of, the water's flow rate, the hot water's temperature, and the fill stage number a cooling tower's functioning. The significance of phase numbers and their correlation with the impact of packing density is underscored. The results demonstrated a clear and straightforward correlation between efficiency factor. Heating the water causes a decrease in the rate of air mass flow and filling stages. Feasible techniques for achieving the optimal score exist. Employing a wet cooling tower with force[37].

Kloppers and Krüger examined the process of heat transmission efficiency in natural and used wet cooling towers under pressure to study the impact of the Lewis factor. International trade agreements are purported to function as a paradigm for effectively coordinating thermal and mass-energy exchange [38].Lemori et al [39].

examined the Employing exergy analysis and the concepts of the second law of thermodynamics, the effects of inlet temperature and humidity on the performance of a WCT flow meter are investigated. The study focuses on a cooling tower with a closed cross-flow architecture, distinguished by a finned tube configuration. The study is founded on both experimental and numerical methods. The researchers conducted a comparative analysis to evaluate the relative benefits of the bare tube and finned tube designs regarding thermal efficiency. Moreover, the study examined the influence of spray-type rotary packing on the counterflow dynamics of forced draft. The publication is entitled "Wireless charging technologies" and was authored by Lavasani et al [40].

A computational model was built to evaluate the performance of NDWCTs using 3D numerical analysis. Measurements were conducted on Under constant working conditions, important factors for both high-level and regular NDWCTs involving air temperature, air pressure decrease, air mass flow rate, and others. With reference to Al-Rahmati and colleagues[41].

Analyzed the effectiveness of trickle, film, and splash fills in a forced draught wet cooling tower. Taking into account the air and water mass flow rates, researchers could establish strong correlations for performance indicators using experimental data. Furthermore, When optimizing the forced draught WCT, they used a Non-Dominated Sorting Genetic algorithm. Scientists Shahali et al[42].

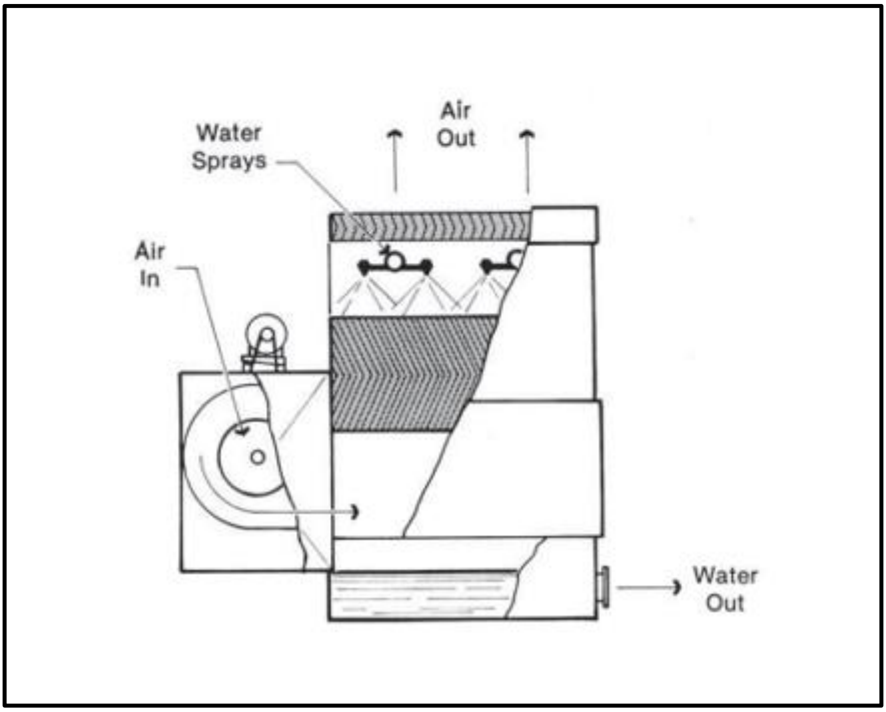

Figure 3: Counterflow forced draught blower fan tower [36]

2.2 Induced draft

A crucial function of the one purpose of one purpose of a cooling tower is to reduce the heat of the discharged water by dissipating heat into the atmosphere. As it increases the surface surface area where air and water come into contact, filler is a crucial component that substantially impacts the efficacy by use of an IDCT cooling tower. By increasing frigid air cold, the properties of a tower are enhanced. Even so, implementing wave padding configuration yields a more substantial enhancement [43].

This device transfers energy transfer from heated water to cooled air, including mass. Humidification system gaskets facilitate heat transformation of heated water into cold air when water passes over them. As a result of the ongoing movement of the moist molecules, the two liquids make contact with each other when the layer becomes completely fluid. Moreover, the liquid confined within the column extends the contact time between the two phases. The tower's high heat transfer coefficient is attributed to these two properties, at least in part. The hot water is lowered in a cooling tower by evaporative heat transfer, which involves releasing some of the water's heat into the air around it.

the tower's fill material is significant because of its extensive surface area for evaporation. The thermal performance of the packing zone is the primary factor affecting efficiency, according to a prior research. Seventy percent of the overall ability to dissipate heat is attributable to the packing area[44] . Effective airflow[45].

An analysis is conducted on many induced draught cooling towers to identify the optimal approach for constructing a model predictive control. The cooling towers maintain the common collecting basin's discharged water temperature. Each cooling tower may use bypass, showers, and ventilation to reject heat. To discover the cooling tower mode and fan speed is optimal, we recommend use mixed-integer programming for model predictive control (MIP). This method takes into account weather changes and active heat load, addressing the complex link between dynamics and logic. Dwell length is limited to prevent excessive and possibly harmful mode transition. The recommended equation accommodates cooling tower efficiency variations. Equalizing cooling tower operating time with an adjustable penalty. The cooling process's intrinsically over-actuated configuration enhances resistance against losing a cooling tower's operational mode. The effectiveness Utilising experimentally validated models of induced draught cooling towers, the suggested approach is shown. The findings of the simulation show that performance and a reduction in energy usage compared to the conventional heuristic techniques used as a baseline [46]. Cooling capacity is a critical facility provider in the process industries for manufacturing specified products.

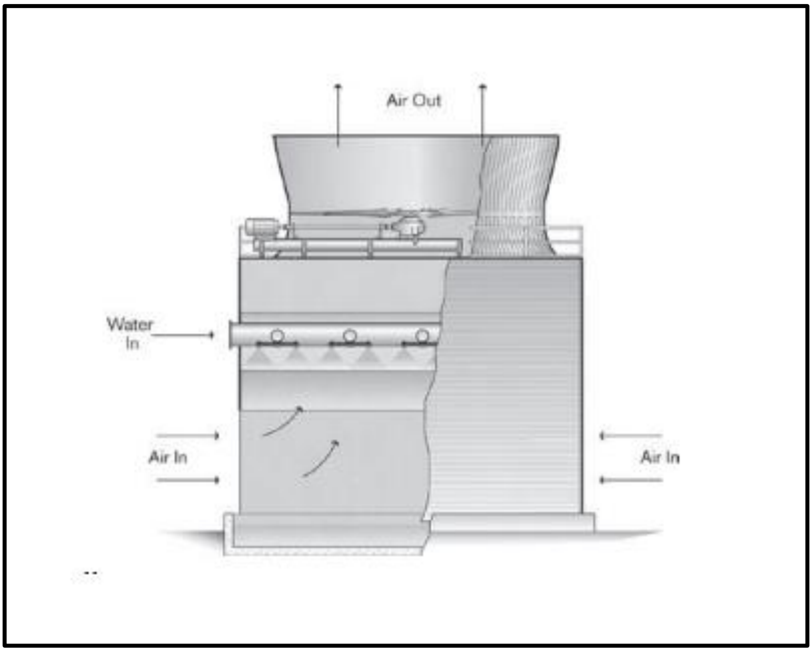

Figure 4: A counterflow tower using an induced draught system [36]

The cooling water network is crucial to the cooling system facility. Eleven parallel heat exchangers, two parallel cooling water compressors, and three parallel cooling towers comprise the model of a cooling water circuit presented in this paper. The developed model represents the non-linear, dynamic characteristics of the plant and is founded upon first principles. The hybrid characteristics of the model are evident in the simulated plant's utilization of continuous and Boolean process variables. Due to the critical nature of energy consumption to the effective operation of the facility, it is incorporated into the model. Particle swarm optimization is employed to adapt the model to industry-specific data. The model is capable of serving both optimization and control purposes[47].

The authors Zhang et al. Most studies have been on natural draft cooling towers instead of artificial ones. Experts have used various strategies, including dry and wet hybrid rain zones, air ducts, wind deflectors, and strategically placed fans inside the tower. The research aims to optimize Increase airflow and reduce water temperature in the tower under adverse wind conditions [48].

Mechanical draught cooling towers (MDCTs) primarily function as cooling devices, facilitating the passage of heat from flowing water (known as heat water) to the surrounding air. Forced Mechanical draught cooling towers include FDCTs and IDCTs.(MDCTs) that differ based on the position of the tower's fan[49].

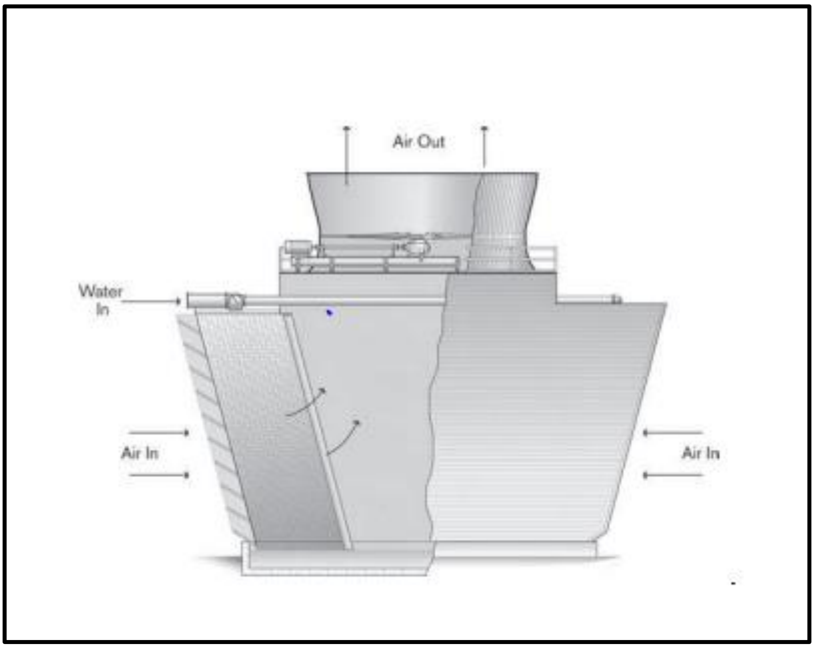

Figure 5: Double-flow, crossflow, induced-draft tower [36]

3. Packing cooling tower

The fascinating system for the transport of heat and mass between a film of a cascade of liquid over a vertical surface and air traveling upwards directly hitting the film is the basis of cooling towers and other industrial equipment. A staggering 96% of cooling towers still use smooth and cross-ribbed PVC packing. more details about liquid flow over a flat vertical wall needs to be published. Only a little investigation has been conducted on their efficacy in contact heat exchangers[50].

Ragupathi et al. identified two distinct operational states during the interaction between air and water. An investigation assessed the efficiency of a forced counterflow cooling system that utilizes expanded wire mesh packing.The wire mesh packing was arranged in both vertical and horizontal orientations[51].

Different packing methods in the cooling towers have recently been investigated for their effects on mass and heat transport [52].

To improve how well heat and mass transfer work , it is essential to pack cooling towers so that the surface area from the air to the water interfaces is maximized[53].

In order to determine features of pressure drop and mass transfer several gasket type, encompassing both soft-surface and hard-surface corrugated gaskets used in AC towers, Milosarjevic et al. performed an experimental study [54].

Figure 6: Packing materials for cooling towers (EWM, GI, PVC)[55]

Ning et al. conducted a study to examine how a counterflow mechanical water-cooling tower's thermal performance is affected by spray-type rotary packing.They concluded that using a faster rotary jet filling method could improve the heat transfer mechanism. They then performed an experimental investigation to determine how packing or nozzle affects the thermal performance of the WCT [56].

There are two major ways to create packaging. The first method is splash packing, which causes droplets to form as hot water descends down the tower. Figure(7) summarizes how droplets cause cooling.The second design technique utilizes the film principle, which allows heated water to spread and create a thin film over a surface. This creates the maximum surface area for evaporation, allowing cooling[57].

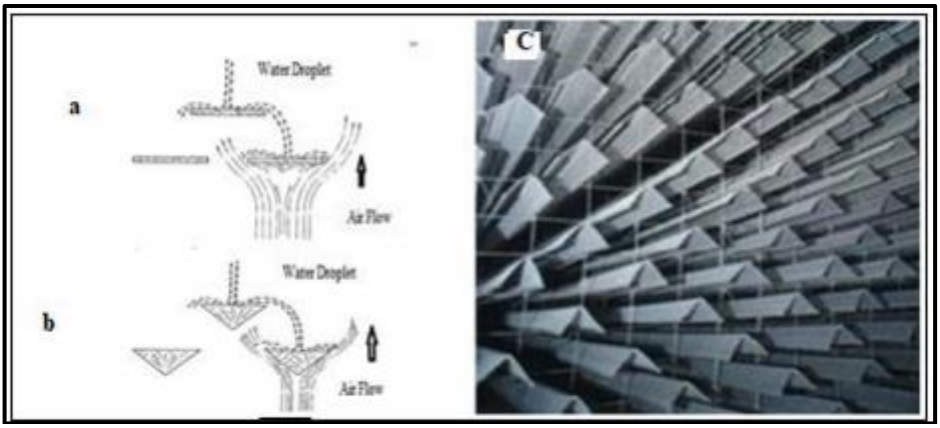

Figure (7) : identified three types of timber lath splash packing: rectangular, triangular, and splash.

The two most prevalent packing types are film and splash. Cooling tower packaging has an immediate influence on their performance. Early fillers were uncomplicated, such as wooden splash barriers. Water splits into small droplets as it flows through the splash-filled tower, forming a region where air and water may exchange heat. Due to the spherical form and surface tension of the droplets, these fillers do not provide the most surface area. Currently, most splash fillers are built of extruded PVC forms in a range of sizes and designs[58]. Some types of fillings, see the following figures(7).

In order to determine how The pressure drop and mass transfer are impacted by the surface roughness and spacing in plastic packaging, Terblanche et al. performed an empirical investigation. Their findings indicate that the mass transfer efficiency equation drops significantly with boosting the density of packing [60].

The packing material's vast surface area allows for the transfer of heat and mass from the water to the air via evaporation.and prolonging the contact between the two [61]. Plastic packaging has low fouling resistance and short service life. Since PVC is environmentally harmful and has a short lifespan, scientists and entrepreneurs have been looking for alternatives. Recently, many hyperbolic cooling towers in China have begun using bamboo as a packaging material [62].

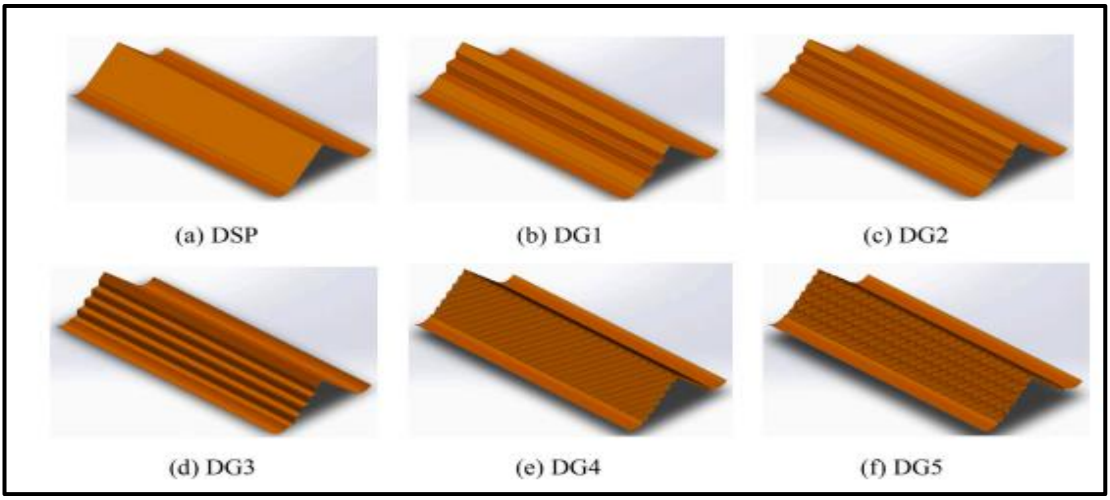

Figure 8: Schematic depiction of a packing structure corrugated and has minute grooves [63]

4. Nanofluids

Nanofluids are composed of solid particles that are very small in size and are evenly distributed inside a basic liquid. Incorporating fine solid particles into power transmission fluids improves thermal conductivity and offers a cost-effective and creative method to boost heat transfer qualities greatly. Nanofluids have applications in several technical and industrial sectors, that are used for heat exchange, cooling towerschemical procedures, electrical devices, This contrasts the often encountered liquids such as ethylene glycol, water, and oil of various kinds.Hybrid nanofluids are an ebook category of very effective fluids. Hybrid nanofluids are adaptable in thermal applications and provide exceptional cooling capabilities at elevated temperatures[64].

Figure 9: Examples of the materials used to create nanofluids [65]

Figure 10: Nanofluid thermal conductivity is affected by the aforementioned factors [62]

5. Physical and thermal characteristics of nanofluids

The amount of nanoparticles the rate of heat transmission compared to ordinary particles of millimeter or micrometer size. Nanofluids have garnered substantial attention among researchers due to their enhanced thermal characteristics.

5.1. Thermal conductivity

Numerous investigations regarding nanofluids' heat conductivity, there have been conducted in recent years. Nanoparticles, including ferrous, nonferrous, and oxidesused to improve the heat resistance of the base fluid. Several studies utilized nanoparticles with dimensions below 100 nm, including cylindrical and spherical shapes. When examining the thermal properties of nanofluids, the concentration in volume is also of utmost importance. For both theoretical and experimental purposes, the effective thermal conductivity of liquid-solid combinations. Maxwell proposed the solid-liquid mixture model as a means to nvestigate thermal conductivity. The solid particles in this model were of significant size. To solve this model, we need to consider the equation that describes the heat transfer rate via spherical solids suspended in liquid at rest in a random fashion via conduction medium. Previous studies employed the subsequent calculation to ascertain the ultimate or functional thermal conductivity [66].

$$k_{eff} = \frac{k_p + 2k_{bf} + 2\emptyset(k_p - k_{bf})}{k_p + 2k_{bf} - \emptyset(k_p - k_{bf})} k_{bf} \quad (1)$$

Here,

keff = The thermal conductivity of the mix of nanoparticles with a base fluid is known as a nanofluid, is referred to as the effective thermal conductivity.

Kp= represents the nanoparticles' ability to transfer heat disseminated in the base fluid.

Kbf= refers to the thermal conductivity of the base fluid,

whereas Ø represents the proportion of nanoparticles floating in the base fluid by volume. Multiple investigations indicate that the thermal conductivity of nano-fluids rises as the size of nanoparticles decreases. This finding is theoretically supported by two mechanisms: the layering of liquid around nanoparticles and the Brownian motion of nanoparticles. The following table represents the heat transfer properties of several nanoparticles Table (1).

Table (1) Varieties of nanoparticle thermal conductivity [67]

Nanoparticles	Thermal conductivity W/(m·K)
Diamond	3300
MWCNT	2000-3000
SiC	490
Ag	429
Cu	398
Au	315
Al	247
Si	148
MgO	54.9
Al2O3	40.0
CuO	32.9
ZnO	29.0
TiO2	8.4

While several studies have examined the heat conductivity of different nanofluids, rheological investigations into viscosity have been few. Several approaches for determining nanofluid viscosity from changes in nanoparticle volume fraction have been proposed in various research. Einstein found that nanoparticles suspended in nanofluids with varying volume percentages may change their thermal properties. A volume percentage of less than 5% of spherical nanoparticles was the primary focus of this investigation. You can see the equation that was used in the past studies down below[68].

$\mu_{\text{eff}} = (1 + 2.5\emptyset)\mu_{bf}$ ………2

The effective nanofluid viscosity in this scenario is denoted by μeff = the base fluid viscosity is denoted by μbf, and the volume fraction of nanoparticles floating in the base fluid is represented by ∅.

5.3. Specific heat and density

With the two-phase nature of nanofluids considered, the specific heat and density are calculated by using the well-established correlations of Pak and Cho (1998)[69].and Xuan and Roetzel (2000) [70]respectively. These correlations have been widely employed in previous studies [71] in order to study how nanofluids' thermal characteristics are affected by their volume concentration. What follows equations are provided:

$$(\rho C_p)_{\text{eff}} = (1-\emptyset)(\rho C_p)_{\text{bf}} + \emptyset(\rho C_p)_p \quad (3)$$

$$\rho_{\text{eff}} = (1-\emptyset)\rho_{\text{bf}} + \emptyset\rho_p \quad (4)$$

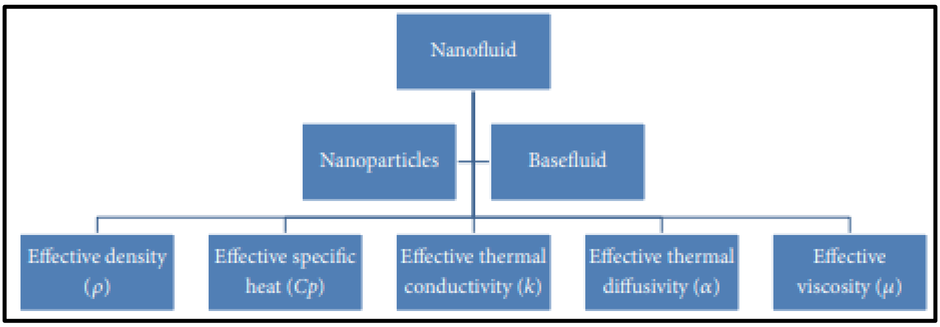

Figure 11: Thermophysical characteristics of a nanofluid [63]

6. Preparation of Nanofluid

Nanofluids cannot be created via a mere combination of solids and liquids. However, the combination must satisfy many other criteria, including uniformity, stability in both physical and chemical aspects, long-lasting properties, and the capacity to disperse, for nanoparticles to be formed efficiently. Nanofluids are often synthesized using either a "bottom-up" or "one-step" approach or a "top-down" or "two-step" approach[72].

Nanofluid is a promising study area because it represents an ideal working fluid for direct absorption solar collectors [73].

An electrostatic contact between colloidal particles may be measured by calculating their zeta potential. Therefore, it indicates that the nanofluid is stable at the colloidal level. [74].

Ghademi [et al]. Strong suspension can be achieved by increasing the electrostatic repulsion between molecules, which occurs at high values of the zeta potential, depending on whether it's negative or positive. Highly charged particles are unable to cluster together due to opposite contact. It summarized the generally accepted values of Zeta's potential [75].

Nanoparticles tend to disperse rapidly due to their low density. Nanofluid stability is a key issue in this research area. The research community has presented several methods to increase nanofluid stability. Particles can be thoroughly dispersed by using ultrasonic vibration, changing the liquid's pH (hydrogen potential), or adding surfactants to increase stability between particles. Particle size also helps keep nanofluids stable; it has been discovered that smaller particle sizes result in higher stability [76].

Preparing nanoparticles for research involves scattering them in a basic liquid (water) at various weight concentrations. After introducing the nanofluidic solution to the ultrasonic device for 2–4 hours, a mechanical stirrer is employed for 15–20 minutes to ensure that all nanofluid samples have a uniform solution. We vigorously mix the solution to ensure that the nanoparticles in the nanofluidic solution are dispersed uniformly and that there are no clumps [77].

The cooling tower tank is filled with the solution of nanofluids at the given mass fraction.The nanofluid is continuously flipped using the agitator motor to maintain its homogeneity during the experiment. Both nanoparticles are utilized in 0.1, 0.5, and 1% concentrations. The following equation determines how much nanoparticle mass is required to achieve a specific nanofluid mixture concentration [78].

Nanofluids may be prepared in two different methods. Two-stage process versus one-stage process The two-step approach is widely used since it is efficient and inexpensive. Before dispersing the powder in the base fluid, the nanoparticles, nanotubes, or nanofibers are first synthesised, either chemically or physically. Methods of mixing include homogenization, high shear mixing, powerful magnetic agitation, ultrasonic, ball, and other similar processes. The nanomaterial is then distributed throughout the base fluid in the subsequent phase. Since nanoparticle powders are already mass-produced, this approach finds extensive application. Incorporating surfactants into different changes to the particles' chemical and physical properties, or controlling their prices are some of the new technologies being developed to overcome the method's drawback—nanoparticles' strong agglomeration tendency—and keep the nanofluid stable. The element hydrogen. By adding and mixing nanoparticles incorporated into the base fluid simultaneously with the synthesis, a more stable nanofluid may be created in a single step[79].

To maximise heat transmission in a wide variety of contexts, nanofluids need to have a very low pH[80]. Despite the advantages of the one-step method, It's not practical for widespread usage due to its several drawbacks; also, this approach is more costly than the two-step procedure[81]. As he explains Figure (12) How to prepare the nanofluid. The volumetric concentration % is determined using the equation (5).

$$\text{"Volume concentration"}, \phi = \left[\frac{\frac{W_{sp}}{\rho_{np}}}{\frac{W_{np}}{\rho_{sp}}+\frac{W_{br}}{\rho_{br}}}\right] \times 100 \quad (5)$$

Where : where Wnp stands for the density of nanofuid, Wbf for the weight of base fluid, and

Below, we will quickly go over these steps. ρbf for the density of the base fluid

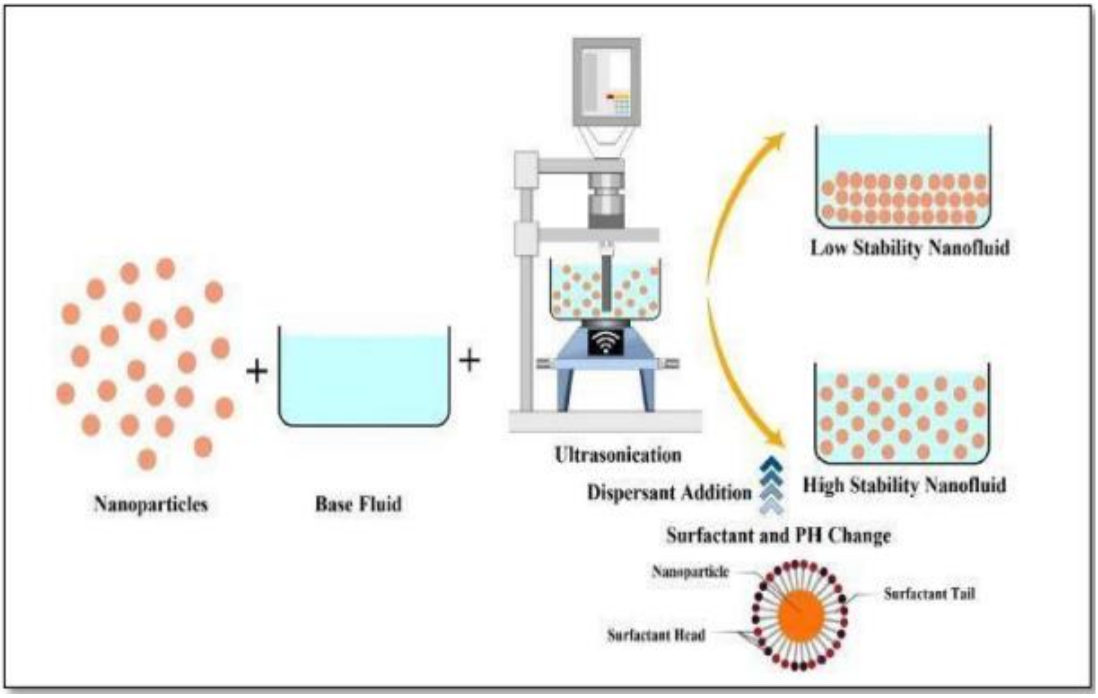

Figure 12: Mechanism of nanofluid preparation[82]

Table 2: Experiments with different nanofluids, with their summarized results

Refrences	Nano particles	Particle volume concentration	Results
[9]	MWCNT	-	Significant improvements were seen in three key performance measures. There is a 20% improvement in thermal conductivity, a 40% improvement in cooling capacity, and a 10% reduction in water loss.
[10]	Al2O3/Cu	0.5-0.3 %	Research has shown that boosting the nanoparticle content in water by 1.5% can increase the efficiency of a home's water heat exchanger system
[12]	CNTs/	0.1	Improved by 67% and the cooling range was increased by 40% (NPN). Each nanoparticle absorbs 10% and 19% of its weight in water, respectively, as a same study

[14]	GNP/ MWCNT	0.05%- 0.1% - 0.2%- .5%	All concentrations of nanofluids tested showed greater thermal and electrical conductivity than pure diesel oil. Another interesting fact is that Both electrical and thermal conductivities rise as temperature rises, despite the fact that they both start out very low.
[15]	Al2O3/ SiO2/Zno	0.02%	The cooling tower's performance, volumetric heat transfer coefficient, and properties were all improved by 36.2%, 8.3%, and 36.0%, respectively, after treatment with a nanofluid containing graphene oxide particles.
[3]	MWCNT	0.085%	Nanofluids have been demonstrated to improve thermal performance at low flow rates, expandingcooling range by 15.8 percent and increasing their inefficiency 10.2 percent.
[16]	ZnO / H_2O	0.1%- (0.02, 0.04, 0.06, 0.08, and 0.1)%	The cooling range, efficiency, and tower features were all enhanced by increasing the concentration of nanofluids and the number of filled bed layers, which increased the thermal performance of the tower.
[18]	Al_2O3	0,25%- 0,5 %	There was a 12.8% decrease in the experimental outcomes. Using Al2O3/aqueous nanofluids When it comes to heat transfer performance in a two-tube heat exchanger, the computational fluid dynamics (CFD) method is the way to go.
[19]	TiO2	0.1%-0.3%- 0.5%	The largest effect on COP improvement was observed with a mixture comprising 0.5 weight percent TiO2 and 0.02 weight percent SDBS; the amount of nanoparticles that are steadily distributed in the base fluid is directly related to the rise in COP. When TiO2 nanoparticles are included into AARS, the COP performance can be improved by as much as 27%
[21]	Alumina/ water	(0-10) %	The results revealed heat transfer, efficiency ratio, gain index all improve as the fluid inlet temperature increases

7. Thermal performance by using nanofluid

Figure (13) demonstrates that when the concentration of nanofluid grows, the temperature reductions at an input working temperature of 35°C also increase. The outlet temperatures of water solutions containing nano Al2O3 at concentrations of 0.05, 0.08, 0.1, 0.15, and 0.2 wt%

were reduced to 24.8, 24.4, 24, 23.5, 24.5, and 24.6 °C, respectively. As seen in the diagram, the augmentation in nanofluid concentration leads to a rise in absorbing energy and then releasing it into the air. An second research provides more evidence of this behaviour.

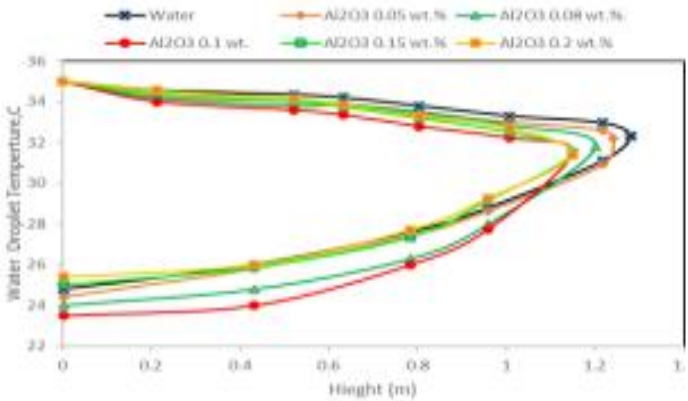

Figure 13 shows how nanofluid (Al2O3/Water) affects droplet temperature distribution at 35°C inlet water temperature[83].

Water and nanofluid (BlackCarbon/water) concentration droplet velocities are shown in Fig. 14 There were no noticeable differences in the water/BlackCarbon spray's downstream direction. Black carbon had the slowest droplet velocity at 0.05 weight percent.followed by 0.08 and 0.1 wt%. Researchers found that nanofluids with greater concentrations generated droplets with lesser velocity. The impact the effect of the concentration of black carbon on the velocity of discharge droplets is similar to that of Al2O3/water. Results indicate that when water temperature rises, temperature lowers, especially around 45C. Water is typically airborne until it reaches the temperature of a wet bulb, allowing the cooling tower to operate at peak efficiency. When compared to water, the cooling range of a cooling tower that uses nanofluids is much greater. The basic fluid's heat transmission properties are enhanced by the inclusion of carbon nanoparticles. Because of their increased surface area, convective heat transfer coefficient, and thermal conductivity, nanofluids improve heat transmission in fluid-air flows. Black carbon nanofluid and water had temperature variances of 10.2–19.4 degrees Celsius at 35, 40, and 45 degrees Celsius, respectively.

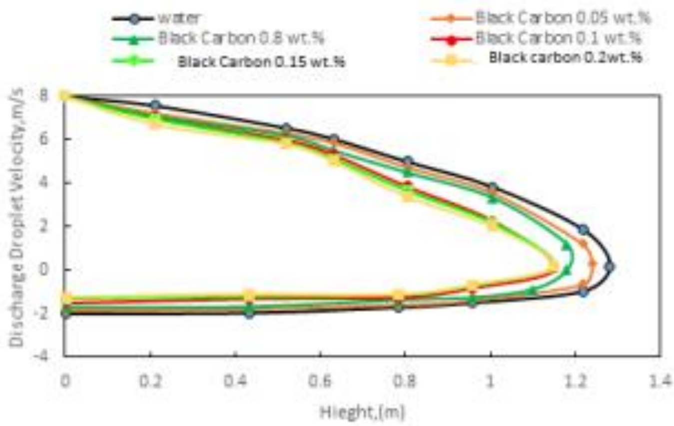

Figure 14: The Impact of a Nanofluid Concentration on the Distribution of Droplet Velocity at an Inlet Water Temperature of 35°C [83].

Two nanofluids and water were tested in the identical settings with a continuous heater output of 4000 W. using bed(3) to determine how flow ratio affects CFCT thermal performance. Figs 15 illustrate the tower water temperature, cooling range, and CFCT efficacy depending on the ratio of flow. A reduction in(L/G) increases airflow and decreases tower operating fluid flow. In contrast, increasing air flow velocity in the tower boosts heat transmission and evaporation. As the rate of water flow rises, the amount of time fluid spends in bed lowers due to velocity, and water outlet temperature falls less due to decreased mass and heat transfer. With less time and less energy used, the water in the heater tank progressively cools as the flow rate of moving about water increases beside the heater power remains constant.

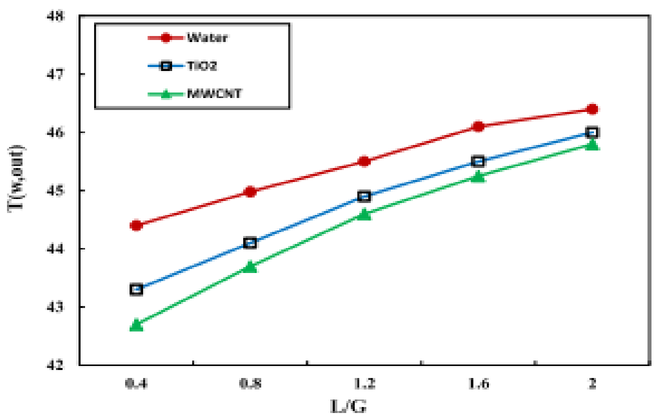

Figure 15: Various flow ratios and the temperature of the working fluid's output[84].

The efficiency of the cooling tower declines against decreasing cooling range. Lowering the exit cold fluid temperature reduces approach, improving CFCT efficiency. Thus, lowering the process temperature reduces the gap between the output fluid temperature and the ambient air wet bulb temperature, improving CFCT performance despite reducing the cooling range. This conclusion is supported by the efficiency graph's smaller concavity than the cooling range diagram. Fig. 16 shows that the optimal working fluid (a nanofluid comprising microwafers and water) with the optimal flow ratio (L/G = 0.4) increases cooling tower efficiency by 28% two times the amount of improvement in the cooling range. When added to water, nanoparticles work best at lower flows. ratios than higher ones.

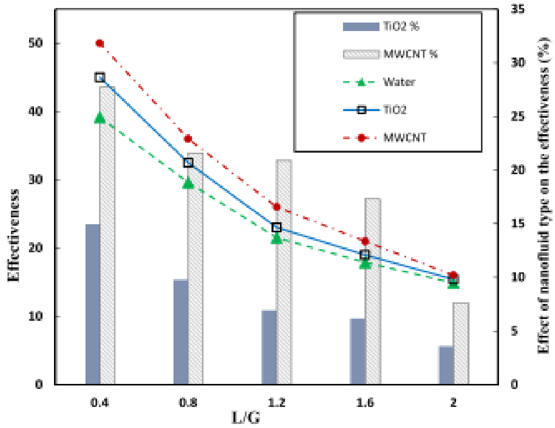

Figure 16: Illustrates the efficacy of nanofluids at various flow ratios and how they differ from water[84].

Small concentrations of nanoparticles enhance base fluid conductivity and boost convective heat transfer. Cooling towers use three modes for cooling: mass transfer (evaporation), convection, and conduction. Figure 17 shows the efficiency of cooling towers was improved with nanofluids containing MWCNT nanoparticles compared to nanofluid of titanium dioxide and water in any flow ratio. Greater ratios of flow resulted in a steady decrease in curve slope without substantial modification. Increasing the flow ratio significantly lowered cooling tower performance and range. Increased concentration increases cooling range, but higher flow ratios limit it.

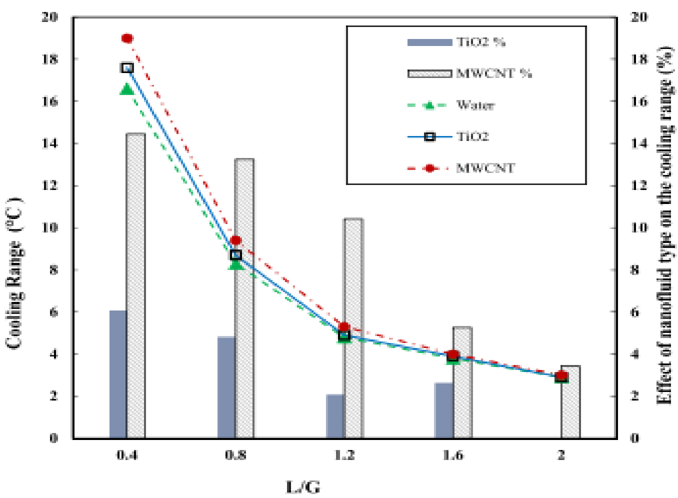

Figure 17: shows the cooling range at various flow ratios and how nanofluid type affects it

when compared to water[84].

In cooling towers, the elusive heat that evaporates is crucial for the purpose of cooling the water. An enhancement to when the water flows through a cooling tower efficiently evaporation rate is increased. Nanofluids A comparison of COOH-MWCNTs/H2O, OH-MWCNTs/H2O, and MWCNTs/H2O; is shown in Fig.. 18 (a), (b), and (c) with their respective actual and theoretical evaporation rates. There was a satisfactory match between the calculated and theoretical evaporation rates for nanofluids, and the results were quite consistent across all concentrations. This proved that the results of the experiments were correct. Estimated rates of evaporation were marginally inferior to experimentally reported evaporation rates throughout the board. This was in reference to the heating tank's incalculably slow rate of evaporation.

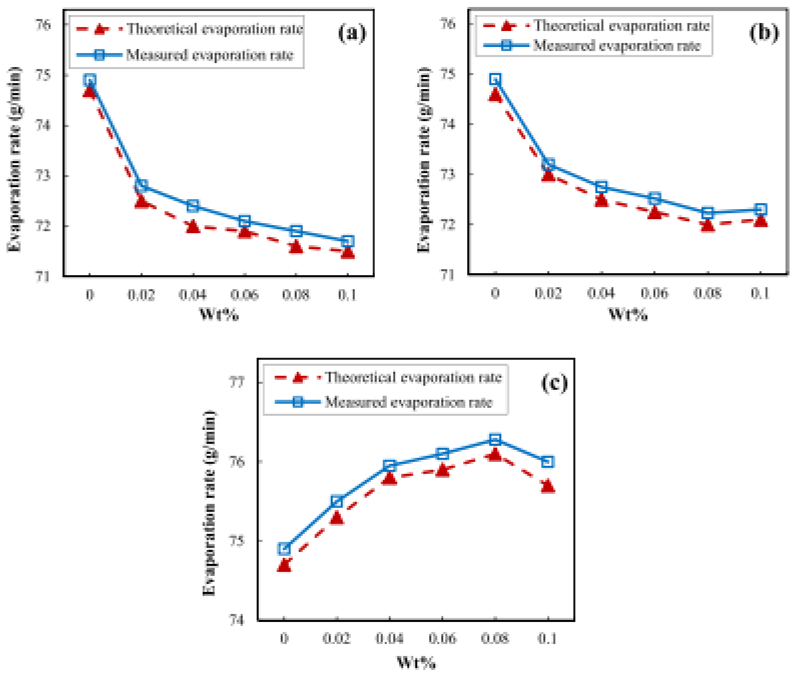

Figure 18: shows an examination of observed, and hypothesized concentration-dependent rates of nanofluid evaporation. There are three types of Organic/H2O, OH/H2O, and MWCNTs[85].

Figure 19: (a) compares all nanofluids and 10(b) compares the CFWCT to pure water. Increased MWCNTs-COOH/H2O nanofluid concentration improved CFWCT. Integrating MWCNTs-COOH /H2O CFWCT performance was enhanced at all doses when added to clean water, with the greatest tower value of features of 0.338 at 0.1 wt%. The graph slanted most at 0–0.02%. Concentration over 0.02 wt% gentled tower performance. CFWCT with MWCNTs-OH/H2O conducted using nanofluids poorer than the tower with COOH/H2O. CFWCT performance increased and decreased from 0 to 0.08 wt%. Tower size, fluid flow, and mass and heat transfer coefficients influence CFWCT characteristics. Fluid flow and

CFWCT dimensions were unaltered throughout the case study. Increased mass and heat transfer coefficients are CFWCT improvements. Aqueous carbon nanotube nanofluids with functional groups (MWCNTs-COOH/H2O and MWCNTs-OH/H2O) performed better than MWCNTs/H2O. CFWCT performance is poorer because MWCNTs/H2O nanofluid is less stable than the other two, reducing heat and mass transfer coefficients. With a nanofluid of 0.06 weight percent MWCNTs/H2O, the tower properties rose before declining. Highest characteristic was 0.316 for MWCNTs/H2O nanofluid towers.In all nanofluid concentrations, Fig. 19 (a) outperforms pure water. MWCNTsCOOH/H2O nanofluid changed 17.1% more than pure water, followed by MWCNTs-OH/11.7%) and MWCNTs/H2O (8.2%). MWCNTs-OH/H2O and 0.08 wt% lowered nanofluid CFWCT characteristics. Compared to MWCNTs-OH/H2O, nanofluid lowered tower characteristics more.Increased nanofluid concentration decreased the cooling performance of CFWCT by 0.6% when using MWCNTs-OH/H2O nanofluid, but by over 2% when using MWCNTs alone, at a concentration of 0.02 wt% (0.08 to 0.1 wt%).

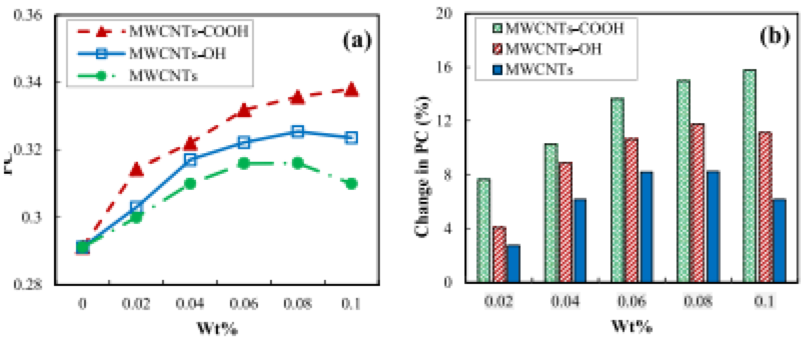

Figure 19 : shows the metrics for performance of nanofluids at various concentrations, as well as the percentage changes when compared to water[85].

Figure 20(a) displays the results. Fig. 19(b) illustrates the decrease in tower temperature for each nanofluid, as to that of water. The amount of MWCNTs -COOH/H2O nanofluid was raised, resulting in a drop in tower temperature Fig. 20 (a). The study discovered a modest increase in concentrations in close proximity to one another. The temperature decrease of the counterflow water-cooled condenser tube (CFWCT) employing MWCNTs-OH/H2O nanofluid was divided into three distinct phases. The concentration rose from 0 to 0.06 wt%, stayed constant from 0.06 to 0.08 wt%, and then declined from 0.08 to 0.1 wt%. The temperature drop in the CFWCT increased from 0 to 0.06 wt% with the use of MWCNTs/H2O nanofluid, and then decreased from 0.06 to 0.1 wt%. The temperature reduction showed a steeper slope while transitioning from 0.08 to 0.1 wt% compared to the transition from 0.06 to 0.08 wt%. The temperature drop exhibited the greatest rise between 0 and 0.02 wt% for all concentrations of nanofluids. The presence of carbon nanotubes in water modifies the thermal conductivity of CFWCT. Nanofluid has a lower heat capacity compared to water. As the input energy remained constant, the rise in inlet fluid temperature resulted in an accelerated temperature decrease in the CFWCT. The drop in CFWCT temperature increases the cooling capacity, hence enhancing the thermal performance of the tower. The heat transfer of nanofluids is influenced by Brownian motion, which refers to the stochastic motion of particles. As the size of particles increases, the occurrence of Brownian motion decreases as it is only observed in very small particles inside the fluid. In addition, nanoparticles enhance nanofluid heat transfer by augmenting the region in which heat may be transferred and the coefficient of thermal convection. The improved heat transfer characteristics of nanofluids, as contrasted with the base fluid, include lower heat capacity and higher convective and conductive heat transmission, result in improved cooling tower performance. This leads to a more efficient cooling process, lower temperatures, and increased cooling capacity. The cooling capacity of MWCNTs-COOH/H2O was much higher than that of water, with a value of 15.89% at a concentration of 0.1 wt% Fig.20 (b)). The nanofluids (MWCNTs-OH/H2O and MWCNTs/H2O) saw a maximum temperature decrease of 11.9% and 7.28%, respectively, at a concentration of 0.06 wt%. Functionalized carbon nanotubes without surfactants exhibit greater stability compared to unmodified ones.

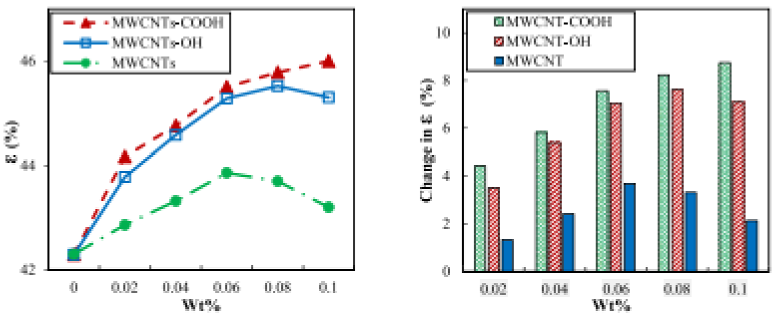

Figure20: shows efficiency (a) between different concentrations of nanofluids and water, and (b) the percentage change between these concentrations [85].

8. Conclusion

The main characteristics of several types of cooling towers were investigated using literature references, revealing disparities in form, use, and cooling principles. Cooling towers, an important component of power facilities such as nuclear reactors, chemical plants that process petroleum, industries, and food processing plants, were discussed. A comparison was made between mechanical cooling towers and those that rely on natural draft. This study also looked at several types of cooling systems including wet towers. Finally, this article includes a brief description of several experimental and practical research so that the cooling tower may function more efficiently, by managing some of the relevant elements that assist improve cooling tower thermal performance, such as ways of installing the filling.

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