# USE OF MODERN COOLING TOWERS WITH NANOFLUIDS IN INDUSTRY SECTOR: AN APPROACH TO PROTECT RIVERINE AQUATIC LIFE ENVIRONMENT OF BANGLADESH

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## Introduction

Cooled water is necessary for manufacturing processes, power generation, aquatic life environment, storage of nuclear waste and many other purposes. Generally, thermoelectric power plants boil water to create steam, which then spins turbines to generate electricity. The heat used to boil water comes from burning of a fuel, from nuclear reactions, or directly from the sun or geothermal heat sources. However, the steam released from the turbine must be cooled back into water before reusing to make the system efficient or draining to the any aquatic life environment. Usually, wet-recirculating systems are used in cooling tower to expose water to ambient air otherwise it will cause thermal pollution. Some of the water evaporates but rest is sent back to the condenser in a power plant. In this system, heat transfer process is very important since the heat comes from steam after spinning turbine must be removed otherwise the aquatic life environment will be threatened or the plant system will collapse due to overheating. Therefore, cooling tower is an essential equipment used to reduce the temperature of water by extracting heat from water and emitting it to the atmosphere (Kulkarni S.J, Goswami A.K 2015). Cooling tower is able to lower the water temperatures more than other devices that uses only air to reject heat, like the radiator in a car and is therefore more cost-effective and energy efficient system which plays an important role due to its wide applicability in many engineering applications.

## Thermal Pollution and Aquatic Life Environment of Bangladesh

Alterations to natural temperature regimes of freshwater habitats by the uncontrolled cause thermal pollution. Thermal pollution is any deviation from the natural temperature in a habitat and can range from elevated temperatures associated with industrial cooling activities to discharges of cold water into streams below large impoundments. Alterations to normal water temperature regimes have myriad biological effects, including interfering with temperature cues for spawning fishes, facilitating establishment of exotic species, and altering growth and development of aquatic organisms (Langford, 1990). Further, aquatic organisms evolved in relatively thermally buffered environments, and thus they are generally more sensitive to temperature fluctuations than their terrestrial counter parts.Most forms of thermal pollution involve temperature increases, and while the effects of extreme temperature increases are obvious, relatively small changes can also be biologically significant. Temperature increases as little as 1 to 2°C can alter communities because they are lethal to some species and can affect growth and reproduction of others. Raising water temperatures just 2 to 3°C above the optimal for some aquatic insects can greatly reduce the number of eggs produced by females because more energy is used to support higher metabolic rates and less is available for egg production (Vannote and Sweeney, 1980; Firth and Fisher, 1992). Temperature tolerances among species of freshwater organisms are highly variable, but all have an optimal range and low and high limits within which they can survive. Increases in temperature cause an increase in growth rate up to a point. Above some threshold, damage occurs. Because temperature governs rates at all levels of biological organization changes in temperature associated with thermal pollution ultimately influence rates of ecosystem processes and functions such as nutrient cycling and decomposition. Due to thermal pollution as released into wetlands, trees can be killed by the bacteria. One of the key issues in thermal pollution is the replacement of cold water fishes with warm-water fishes. Power plants and industrial factories are the major point source contributors to thermal pollution. In this case, cool water is withdrawn from streams, used for cooling of generators and other machinery, and then returned to the stream at elevated temperatures. Rapid changes in temperature associated with power plant operations can kill fishes by thermal shock (Ottinger *et al.*, 1990). Mitigating the thermal effects of power plant effluent obviously has a significant financial cost. Impoundments that release water from the surface can result in higher stream temperatures during warm periods because water velocity is decreased and solar penetration enhanced in the impounded water. Along with the direct effects of warmer temperatures on aquatic life, the solubility of $O_2$ in water decreases with increasing temperature, and thus $O_2$ stress increases as temperatures rise. During cold periods when stream water temperatures are normally near freezing, hypolimnetic releases can artificially warm streams(Walter K. Dodds *et al.* 2010).

## Ecological Effects

The effects of thermal pollution are diverse, but in short, thermal pollution damages water ecosystems and reduces animal populations. Plant species, algae, bacteria, and multi-celled animals all respond differently to significant temperature changes. Organisms that cannot adapt can die of various causes or can be forced out of the area. Reproductive problems can further reduce the diversity of life in the polluted area.

## Warm Water

Elevated temperature typically decreases the level of dissolved oxygen of water, as gases are less soluble in hotter liquids. This can harm aquatic animals such as fish, amphibians and other aquatic organisms. Thermal pollution may also increase the metabolic rate of aquatic animals, as enzyme activity, resulting in these organisms consuming more food in a shorter time than if their environment were not changed (Goel, P.K. et al. 2006). An increased metabolic rate may result in fewer resources; the more adapted organisms moving in may have an advantage over organisms that are not used to the warmer temperature. As a result, food chains of the old and new environments may be compromised. Some fish species will avoid stream segments or coastal areas adjacent to a thermal discharge. Biodiversity can be decreased as a result. (Kennish, Michael J. et al.1992). High temperature limits oxygen dispersion into deeper waters, contributing to anaerobic conditions. This can lead to increased bacteria levels when there is ample food supply. Many aquatic species will fail to reproduce at elevated temperatures. (Goel, P.K. et al. 2006). Primary producers (e.g. plants, cyanobacteria) are affected by warm water because higher water temperature increases plant growth rates, resulting in a shorter lifespan and species overpopulation. This can cause an algae bloom which reduces oxygen levels.

## Cold Water

Releases of unnaturally cold water from reservoirs can dramatically change the fish and macroinvertebrate fauna of rivers, and reduce river productivity. In Australia, where many rivers have warmer temperature regimes, native fish species have been eliminated, and macro invertebrate fauna have been drastically altered. This may be mitigated by designing the dam to release warmer surface waters instead of the colder water at the bottom of the reservoir. (Mollyo, Fran 15 September 2015).

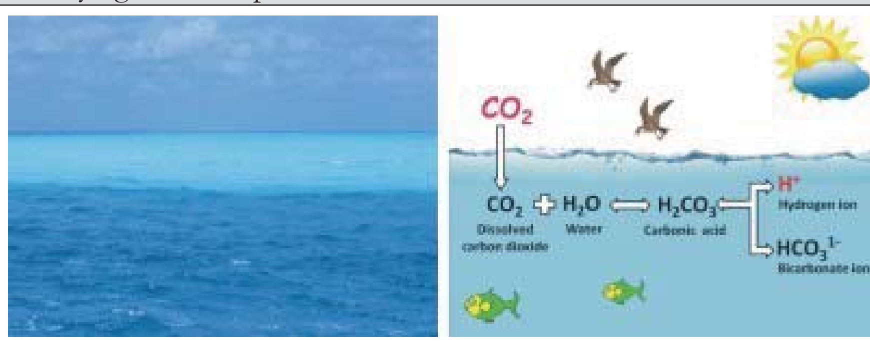
## Thermal Shock

When a power plant first opens or shuts down for repair or other causes, fish and other organisms adapted to particular temperature range can be killed by the abrupt change in water temperature, either an increase or decrease, known as "thermal shock" (Laws, Edward A et al. 2000)

## Decreased Dissolved Oxygen

Warm water preserves less oxygen than cool water. If the oxygen level goes down animals that cannot move to another area may begin to die. In deeper bodies of water, the injection of warm water can keep oxygen from dispersing into deep water, which is potentially good for bacteria but dangerous for aquatic animals. The decreased oxygen can cause algae blooms that pose a threat to aquatic plants and animals. This algae bloom problem is probably the most common and best-known side effect of thermal pollution.

**Figure 1:** Now the ocean suffers from rising level of CO2. The underlying chemical process behind ocean acidification




## Migration

Fish and amphibians may move away from the warm water to a more-suitable location, disrupting the ecosystem for animals that remain. Birds may also be forced to leave in search of areas with more food. Plants and certain animals will be stuck in the area, which can lead to huge losses. Migration away from the polluted area contributes to a dramatic loss of biodiversity at sites where thermal pollution happens.

## Increased Toxins

Toxins in the water are more a side effect of dumping waste water than a direct effect of thermal pollution. Chemical pollution is an almost inevitable side effect of using water for cooling. Solvents, fuel oil, and dissolved heavy metals end up in the lake or river where the cooling water gets dumped. Nuclear power plants can also release slightly radioactive cooling water. The chemicals may have a range of toxic effects on plants and animals, from fatal poisoning to mutations and sterilization.

## Ecological Impacts

The local aquatic ecosystem can be damaged by thermal pollution, especially if it is dramatic, as in copious amounts of warm water being dumped into a chilly pond or bay or river. "Thermal shock" can kill off insects, fish, and amphibians. This sudden loss of life causes further issues with the ecosystem. Key food sources are no longer adequate. A threatened or endangered local population may be wiped out or put under even more pressure. Coral reef bleaching has also been observed when a power plant or factory is dumped into coastal water. Coral bleaching happens when the coral organisms die.

## Reproductive Effects

A significant temperature increase in the water can cause reproductive problems. Warmer water can reduce the fertility of some organisms. Other species may suffer birth defects or lay deformed eggs because of chemical changes in the body caused by warmer water. Defective eggs and birth defects hurt the overall reproductive fitness of the animal population and can reduce the population. Thermal pollution can change the biology of aquatic organisms in a variety of ways.

## Causes of Thermal Pollution

Thermal pollution occurs when an industry removes water from a source ( e.g river ) uses the water for cooling purposes and then returns the heated water to its source. Power plants heat water to convert it into steam to drive the turbines, the steam is condensed into water after it leaves the turbines. This condensation is done by taking water from a body to absorb the heat. This heated water which is at least 150 celcius higher than the normal, is later discharged back into the water body. The major sources of thermal pollution are discharge of heated water or hot waste material into water bodies from:

- Nuclear power plant
- Industrial effluents
- Domestic sewage
- Hydro-electric power
- Coal fired power plants
- Thermal shock
- Deforestation
- Soil erosion

## Sources and Control of Thermal Pollution

Every year the temperature of river and sea water of Bangladesh is increasing very rapidly which will reach to a alarming state very soon for the unplanned and uncontrolled growth of power plants and other industries. cooling ponds, man-made bodies of water designed for cooling by evaporation, convection, and radiation

- cooling towers, which transfer waste heat to the atmosphere through evaporation and/or heat transfer
- cogeneration, a process where waste heat is recycled for domestic and/ or industrial heating purposes. EPA (August 1999).

## Environment Flow Assessment

The entire range of species in a river ecosystem has posed a problem for resource managers in attaining the optimal conditions for all species at a certain time. To overcome this problem, attention has shifted from a minimum flow approach to an approach that uses the "natural" regime of the river as a starting point. Environmental flow assessment (EFA) deals with the required river flow regime that can be achieved without causing any negative effects.

## Sustainable Water Management

Many factors, such as water quality, sediments, food supply and biotic interactions, are important determinants in aquatic ecosystems. However, an overarching variable is the river's flow regime. The natural flow paradigm, in which the natural flow regime of a river is recognized as vital to sustaining ecosystems, has now been widely accepted. This recognition of flow as a key driver of aquatic ecosystems has led to the development of the environmental flows concept, which now serves to enhance informed, equitable and sustainable decision making in water management.[Google Scholar] studied the effects of river regulation on aquatic invertebrate fauna and identified lack of water in the upper river reaches. This situation, associated with organic pollution, variability in water temperature and oxygen availability, was found to be the main cause of environmental disturbance.

## Purpose of Cooling Tower

The purpose of a cooling tower model is to be able to predict the cooling tower performance. However not all models are suitable for an average user to utilize and determine energy use and possible saving measures. This thesis and chapter focusses on the existing models capability to meet the needs of a user to easily estimate cooling tower energy use and look at possible energy savings. Drawbacks of Thermodynamic Models In the literature review it was observed that there were numerous models to predict cooling tower performance through thermodynamics and heat transfer principles. Before moving on to create a new model, a few of the drawbacks of such models will be discussed. Amongst the thermodynamic models found in literature, the simplest one was seen to be the Merkel method. Kloppers (Kloppers, J and Krogger D, 2004) also states that it is difficult to evaluate the surface area per unit volume of fill due to the complex nature of the two phase flow in fills. However it is not necessary to explicitly specify the surface area per unit volume or the mass transfer coefficient since the value of the Merkel number can be obtained by integrating the right hand side of the equation above. Further it is to be noted that the exact state of the air leaving the fill cannot be calculated and is assumed to be saturated with water vapor so that temperature of water leaving the fill may be calculated. Bourillot (Bourillot, C at el 1983) has stated that the Merkel method is simple to use and can correctly predict the cold water temperature when an appropriate value of coefficient is used but is insufficient for estimating the characteristics of warm air leaving the fill and for calculation of changes in the water flow rate due to evaporation. Using the equation above requires quite a few parameters that are not easily available to an average person and if we are looking at information on how air flow rate will affect the temperature of water leaving the tower (to determine 19 savings possible through VFD operation of the tower fan) it is impossible to proceed without having even more information.

## Experimental Design

Numerical investigation is to be conducted to examine the effect of with and without nanofluid on the developed cooling tower. A set of governing equations and the complementary boundary conditions are to be used to represent the physical problems mathematically. Furthermore, the work is also to be carried out to analyze natural convection heat transfer and fluid flow in a cooling tower filled with copper-water nanofluid at which the effect of various governing parameters including solid volume fraction, Rayleigh number and dimensionless time will be investigated thoroughly. Subsequently, enhancing thermal conductivity of the fluid is one of the ways to increase heat transfer performance of fluids. Thus, suspending micro- or larger-sized solid particles in fluids are to be attempted in order to enhance the thermal conductivity of base fluids. However, the main problem caused by the high density and large size of the particles is how fast these particles could settle in fluids and there is no good way to prevent it from settling. Preparation of nanofluids is necessary since nanofluids are not just simple mixtures consisting of liquids and solids. In order to produce nanofluids, there are two main methods available namely, the two-step method and the one-step method. Hence, nanofluids are to be produced by suspending nanoparticles with average sizes below 100 nm into base fluids such as water, ethylene glycol (EG), oil, etc. Nanofluids are to be compared to conventional fluids and fluids containing micro-sized metallic particles to identify good properties by dispersing uniformly and suspending stably in the base fluids. Several experiments are to be conducted by changing the ratio of water flow rate and air mass flow to observe the behaviour of different characteristics, represented in graphical form. The performance prediction of cooling tower related with the performance curves by means of the simple method is to be made by a few design parameters as well as water flow rate, range, cold water temperature, wet bulb temperature, and so on. The efficiency obtained from the experiments is to be validated to show the good performance of the developed system with water and copper-water Nano fluid.

## Methodology

Merkel developed a theory for cooling tower heat transfer process based on enthalpy difference as driving force. Each water particle is assumed to be surrounded by air film. The enthalpy difference between the film of air and surrounding air is driving force of heat transfer in cooling tower. The integrated form of Merkel equation is (Khairul M. A and Saidur R 2014)

Ldt = kadv(h-h')= Gdh (1)

$$\frac{KaV}{L} = \int_{T_{water\ out}}^{T_{water\ in}} \frac{dT}{h\prime - h} \quad (2)$$

$$\frac{KaV}{G} = \int_{h_1 at\ A}^{h_2 at\ B} \frac{dh}{h\prime - h} \quad (3)$$

Where,

k= mass transfer coefficient, ($kg_{water}/m^2s$); $\frac{dry\ air\ (kg)}{water\ (kg)}$

a = contact area per unit volume, ($m^2/m^3$)

V= active cooling volume, ($m^3/m^2$)

L= water flow rate, (kg/$m^2s$)

h'= enthalpy of saturated air at temperature, (kJ / kg)

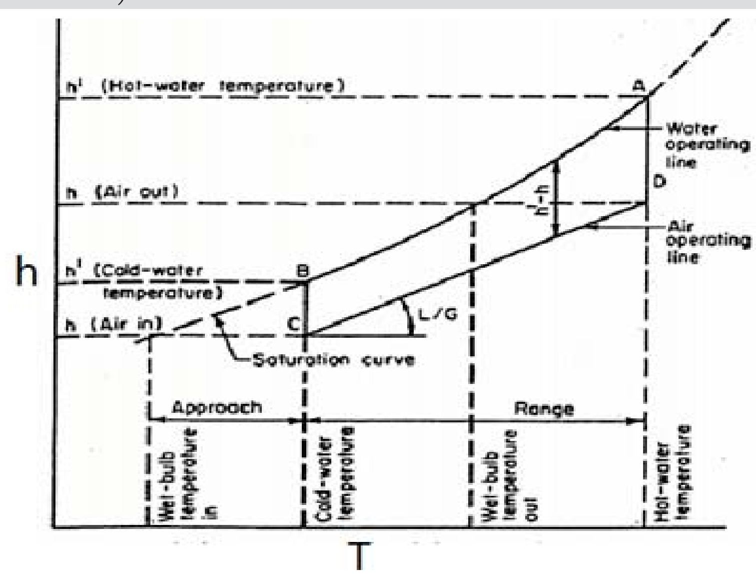
h= enthalpy of air steam, (kJ / kg)

G= air flow rate, (kg/s$m^2$)

Integrated value or $\frac{KaV}{L}$is known as tower characteristics.

Let us see cooling diagram of counter flow cooling tower.

**Figure 2:** Cooling Tower Process Heat Balance (Khairul M. A and Saidur R 2014)



This diagram is important to understand cooling process take place in cooling tower. C is the point of cold air in. So the enthalpy difference between point B and C (h-h')is the driving force for heat transfer taking place. Air takes heat from water and reach along straight line up to D. And slope of straight line (L/G) which is the ratio of total mass flows of water and dry air in cooling tower.

The coordinates of figure indicates directly enthalpy and temperature of any point on the Water operating line. And on air operating line, temperature and enthalpy is found by projecting the point horizontally to saturation curve then vertically to saturation curve, then velocity of saturation curve.

$$\frac{L}{G} = \frac{\text{kg of water circulated}\,/m^2 s}{\text{kg of dry air}/m^2 s} \tag{4}$$

When $\frac{L}{G}$ decreases, CD approaches towards BA.

The Maximum $\frac{L}{G}$& minimum air flow rate will occur when water inlet temperature & air outlet wet bulb temperature are equal. There fore $(\frac{L}{G})$ max is the slope of line that connects A with C in the figure.

Inlet Driving force = BC = (h'-h) inlet

Outlet Driving force = AD =(h'-h) outlet

So the driving force for cooling process in cooling tower is the vertical difference between the water operating line and air operating line ( Khairul M.Aand Saidur R 2014).

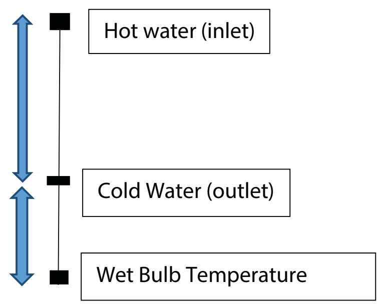
So tower characteristics,

$$\text{NTU} = \frac{KaV}{L} = \int_{T_{water\ out}}^{T_{water\ in}} \frac{dT\ (C_p=1)}{h\prime - h}$$

$$= \int_{T_{water\ out}}^{T_{water\ in}} \left(\frac{1}{h\prime - h}\right) dT \qquad (5)$$

This value $\frac{KaV}{L}$ is called tower characteristics which vary with $\frac{L}{G}$

## Cooling Range & Cooling Tower Approach




## Cooling Range

Difference between the water inlet & outlet temperature is known as cooling range.

$$R_{th} = T_{w_i} - T_{w_o} \qquad (6)$$

## Cooling Tower Approach

The difference between water outlet temperature and entering air wet bulb temperature.

$$R_a = T_{w_i} - T_2 \qquad (7)$$

## NTU of Transfer Unit (NTU)

NTU stands for number of transfer unit. It means cooling tower characteristics ( Khairul M.Aand Saidur R 2014)

$$\frac{KaV}{L} = \int_{t_{water\ out}}^{t_{water\ in}} (h' - h)dT \qquad (8)$$

NTU can be evaluated by following methods ( Khairul M.Aand Saidur R 2014)

Let us assume humidification is an adiabatic process.

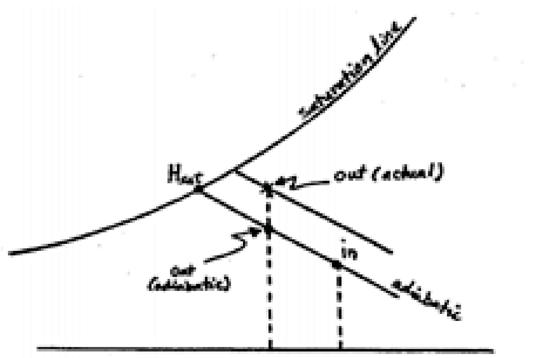
Now based on mass transfer

$$\text{NTU} = \ln\left(\frac{H_{sat\ inlet} \quad H_{air\ in}}{H_{sat\ inlet} - H_{air\ out}}\right) \qquad (9)$$

Base of heat transfer,

$$\text{NTU} = \ln\left(\frac{T_{air\ in\ dry} - T_{sat\ inlet}}{T_{air\ out\ dry} - T_{sat\ inlet}}\right) \qquad (10)$$

On psychometric chart note the following: (Khairul M. A and Saidur R 2014)




## Heat load

Heat load is the total load that is removed from the cooling water per unit time. Hence, Heat load=heat lost to the atmosphere

This can be found as follows

Based on inlet and out cooling water temperature.

Heat load, $Q_1$ = L$C_{p_w}(T_{w_i} - T_{w_o})$ (11)

Based on heat gained by air.

Heat load,$Q_2$= G($h_1 - h_2$) +$m_{water\ loss}\alpha_{avg}$ (12)

Assuming air flow rate is constant.

$\dot{m}_{water\ loss}\alpha_{avg}$ = Evaporation loss

Where,

$\dot{m}_{water\ loss}$ = make up water

$X_{avg}$ = latent heat of water

Cooling Efficiency= $\frac{Range}{Approach}$×100% (13)

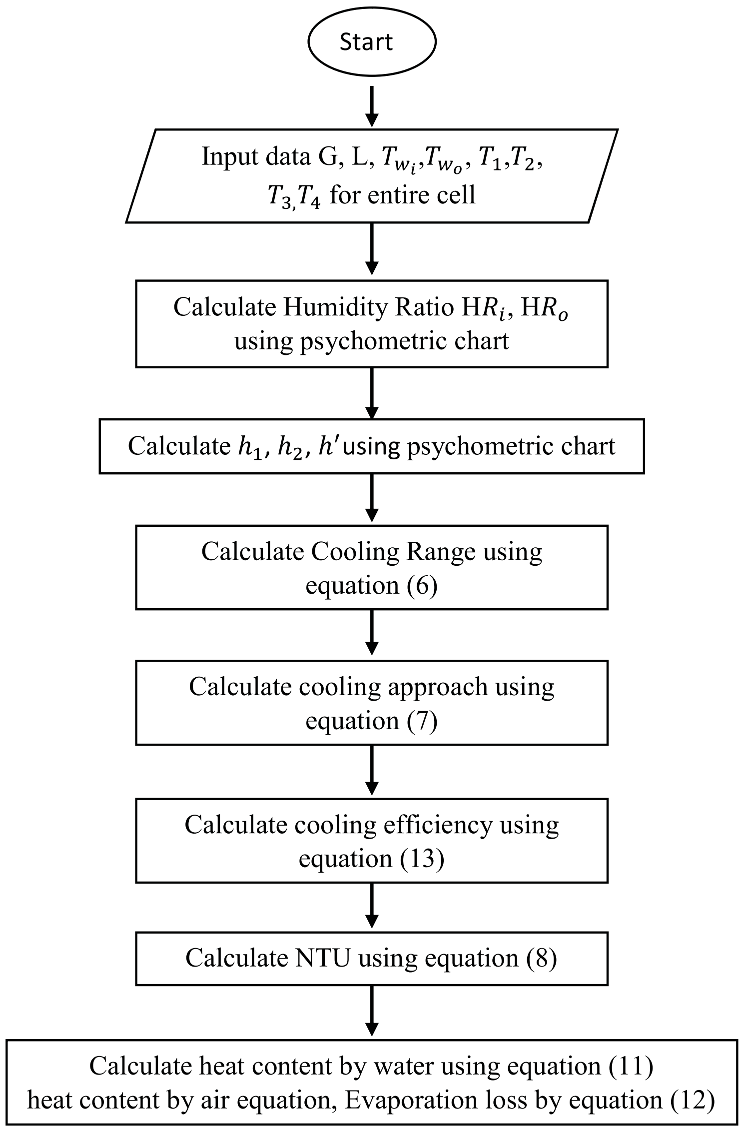
Rate of water loss and the make up

Cooling tower water loss is due to evaporation loss mainly. Besides there is drift loss, windage, blow down, leakage etc.

The rate of water loss (lb/hr.) = (Humidity Out – Humidity in) (14)

The water that is added to the circulating water system to replace the water lost is called make up water.

Rate of make-up water = rate of the loss




## Experimental Set Up and Procedure

A proto type cooling tower has been made on the roof top of Mechnical Department of MIST. A drum has been considered as reservoir and hot water circulated with the support of pump to the top of cooling tower.

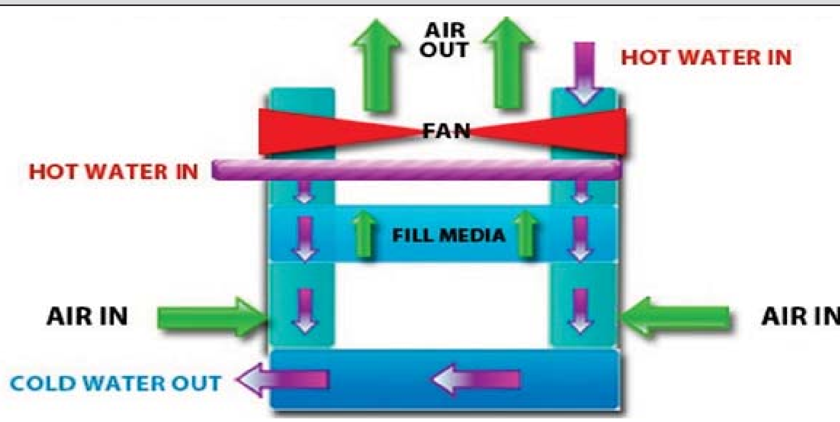
Hot water is being cooled in the cooling tower and cold water is being drained out to the reservoir agai

**Figure 3:** Developed Experimental Setup

## Schematic Diagram

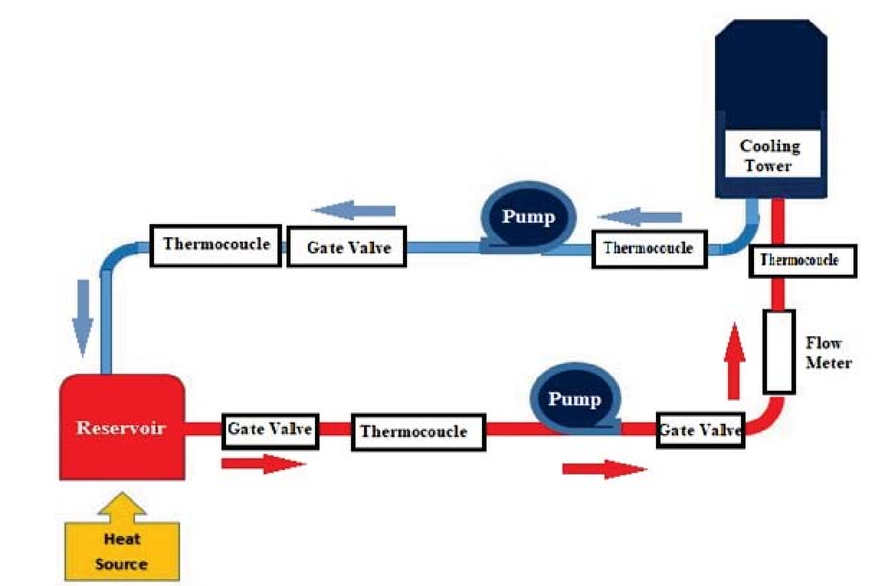
Schematic Diagram of Induced Draft Counter Flow Cooling Tower is shown as bellow:

**Figure 4:** Schematic Diagram of Induced Draft Counter Flow Cooling Tower



## Water Circuit

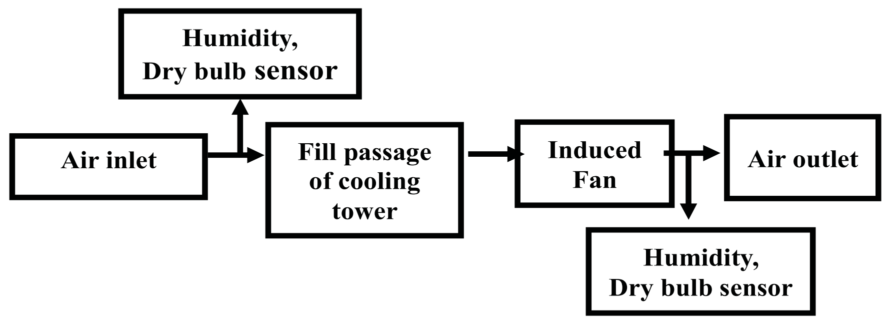
**Figure 5:** Water Circuit




In this circuit a heat source is used to heat the water present in the reservoir. Here as a heat source gas burner and immersion rod is used. When the water being heated then the flow started. A gate valve is used to control the speed of the water. Just after gate valve a thermocouple is placed to measure the inlet hot water temperature of the water. A pump is used to circulate the flow of water and another gate valve is used to control the speed of the water. A flow meter is used to measure the flow rate of the water and a thermocouple is used to measure the inlet hot water temperature once again before it passes through cooling tower. During passes through cooling tower the temperature of the hot water is reduced. Then outlet temperature of cold water is measured through thermocouple just after the water passed through cooling tower. Again a pump is used to ensure the circulation of water through pipe and a gate valve is used to control the speed of the water. Then cold water temperature is measured once again and water returns to reservoir and cycle continues.

## Air Circuit

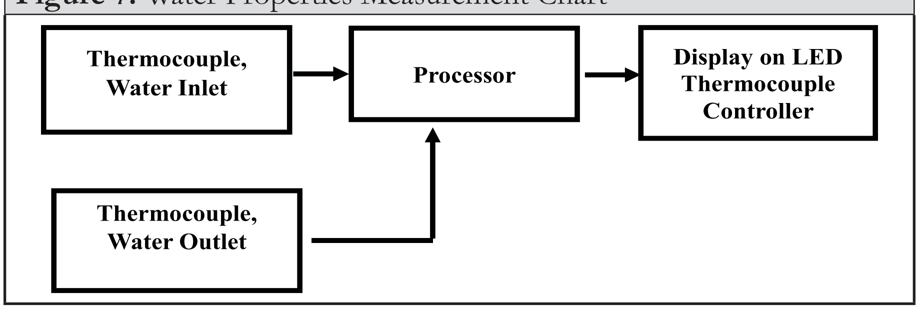
**Figure 6:** Air Circuit




Air enters through the lower passage of the cooling tower, while entering through the passage there is a dry bulb sensor which gives us the value of humidity of air entering the passage. Continuous air goes through the fill of the cooling tower and it cools down while the induced fan dissipates the heat from the air. Heated air is then goes out through the upper portion of the cooling tower and into the atmosphere. With the help of another dry bulb sensor we get the value of humidity of the air going out in the atmosphere.

## Water Properties Measurement

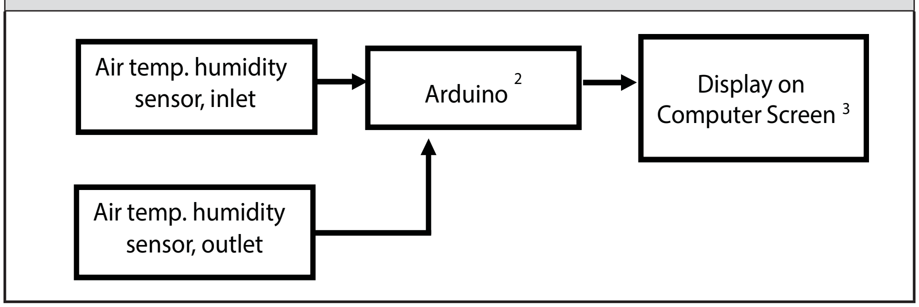
**Figure 7:** Water Properties Measurement Chart




Water enters through the inlet of cooling tower from a reservoir via a pump of 0.5 hp capacity. There is a water proof temperature sensor which gives us the reading of temperature. An arduino (which is an open source computer hardware and software company, project and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical world) is used here. The water proof sensor which is connected with the arduino gives us the water properties of the inlet water and displays on the computer screen. Another water proof temperature sensor is attached with the outlet and that is connected with the arduino and gives us the water properties of the outlet water in the computer display.

## Air Properties Measurement

**Figure 8:** Air Properties Measurement Chart




Air enters through the lower part of the cooling tower and through an air temperature humidity sensor (which is connected with an arduino) we get the air properties at the inlet in the computer display. Another air temperature humidity sensor is at the upper portion of the cooling tower connected with the arduino gives us the air properties at the outlet in the computer display.

## Introduction of Nanofluid

Energy concerns have come up as the most important problem for the world's scientists and engineers. Thermal loads are increasing day by day and have wide variety of use in electronics, transportation, power plants, food industry, air conditioning, refrigeration, etc. The conventional heat transfer fluids, such as water, oil, ethylene glycol, propylene glycol are mostly used in industries. These fluids contain poor thermal properties. In order to increase heat transfer rates, the use of extended-surface thermal control technologies such as fins and micro channels, vibration of heated surface, injection or suction of fluid and applying electrical or magnetic fields has reached to the bottleneck. Therefore, new technologies with the potential to improve the thermo-physical properties of the conventional cooling fluids have been an area of great potential for researchers. The solids have better thermal properties than fluids. (Ahuja at el 1975) and Liu et al. (2999) carried experiments to enhance the thermophysical properties of fluids by adding micrometre- and millimetre-sized solid particles in the base liquids. However, real-world applications of these fluids are fewer due to the reasons, i.e. large-sized particles tend to quickly settle out of suspension and thereby, in passing through micro channels, cause clogging and a considerable rise in the pressure drop. Furthermore, the abrasive actions of these particles cause erosion of components and pipelines. To overcome these problems, nanosized particles dispersed in the base fluid known as nanofluids, were firstly introduced by Choi (1995) at the Argonne National Laboratory. These novel fluids indicated improved heat transfer properties such as higher thermal conductivity, long-standing stability and uniformity along with the negligible obstruction in flow channels due to very small sizes and large specific areas of the nanoparticles. The nanoparticles used to prepare the nanofluids are basically metals (e.g. Cu, Ni, Al), oxides (e.g. Al2O3, TiO2, CuO, SiO2, Fe2O3, Fe3O4, BaTiO3) and some other compounds (e.g. CNT, TNT, AlN, SiC, CaCO3, graphene) with a size of 1 to 100 nm. The great quantum of research on heat transfer enhancement shows the appreciable growth and the necessity of heat transfer enhancement technology in the field of nanofluids. This paper presents the comprehensive review of various experimental investigations in convective heat transfer with the use of nanofluids in laminar and turbulent flow regimes under constant wall temperature and constant heat flux boundary conditions. Further, a detailed review on the use of nanofluids in different types of heat exchangers has been presented. It is vital for reliable applications in engineering thermal systems.

## Calculation

Cooling Range: using Equation-(6)

Cooling Approach: using Equation-(7)

Cooling Efficiency: using Equation-(13)

L/G : using Equation-(4)

NTU: using Equation-(5)

Change in Specific Humidity, = $SH_o - SH_i$

Make up Water, $M_w = \Delta w \times \dot{m}_a$

% Make up Water = $\frac{\Delta w \times \dot{m}_a}{\dot{m}_w}$

Change in Heat Content Water, $Q_1 = \dot{m}_w \times c_p \times \Delta T$

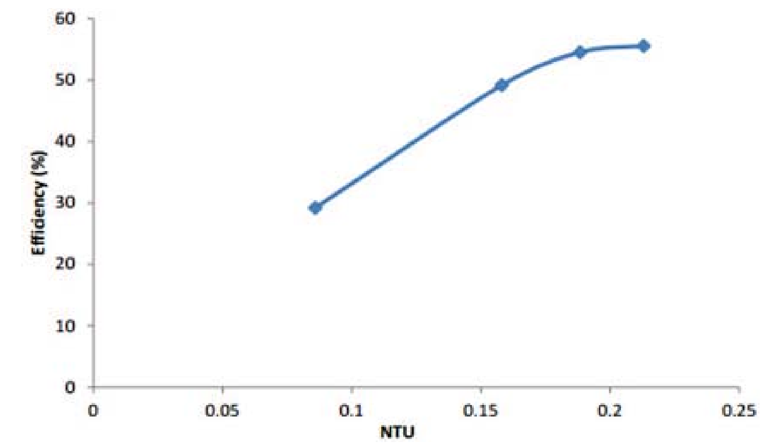
Change in Heat Content Air, $Q_2 = \dot{m}_a(ha_o - ha_i)$

Evaporation loss, $Q_3 = \Delta w \times \dot{m}_a \times l_f$

## Cooling Tower Characteristics Analysis

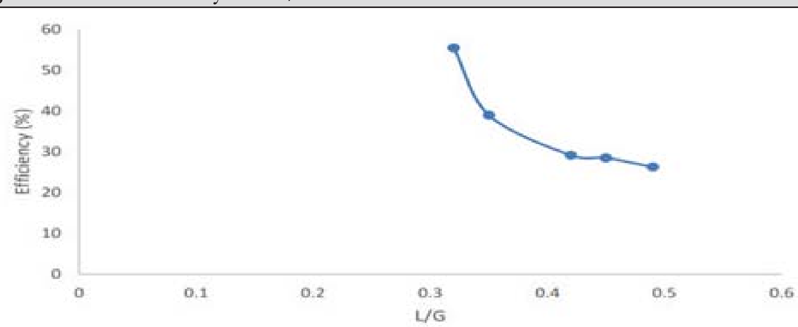
In this experiment we have determined tower characteristics at varying air and water flow rate ratio. The NTU or tower characteristics was determined by using equation (4). Enthalpy of saturated air at hot water temperature was determined by using saturated air properties table. Enthalpy of air stream was calculated from psychometric chart. Using equation (1) cooling efficiency was determined.

**Figure 9:** Efficency vs NTU



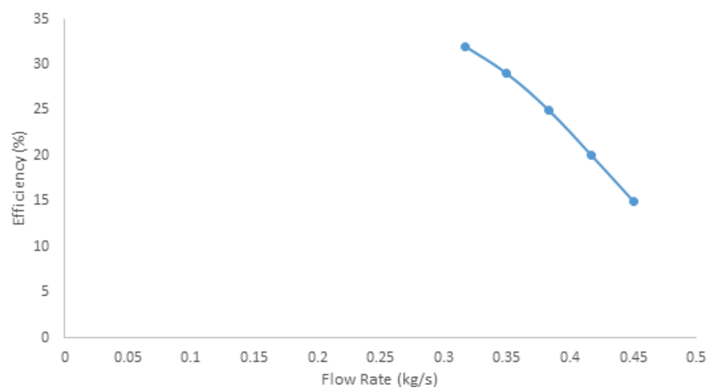

In figure (9) we can explicitly see a direct relation between tower characteristics and tower efficiency. With tower characteristics increase the latent heat and sensible heat transfer is also increased so the efficiency is also increased

**Figure 10:** Efficiency vs L/G



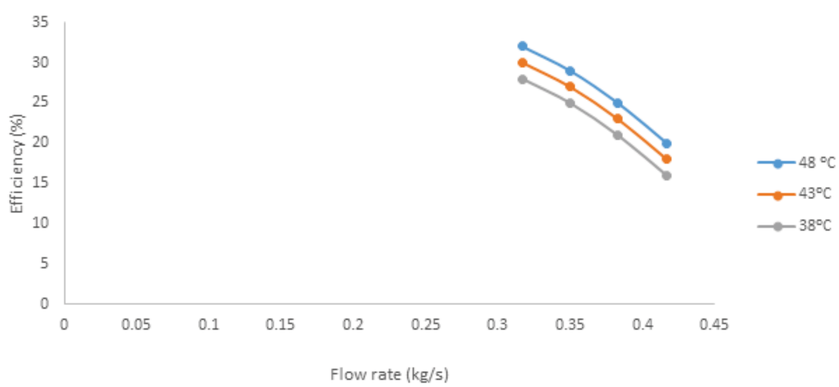

From figure (10) as the  ratio increase the tower efficiency decrease. This is because with increase hot water flow rate increase and with unabundant present air flow to cool it. In figure (9) and (10) error bars is their due to inherent error is anemometer in air speed reading and human error in taking dry bulb and wet bulb temperature from psychrometer.

**Figure 11:** Efficiency vs Flow Rate at Constant Inlet Temp. 38 0C




From the above figure we can see that with the decrease of flow rate efficiency increases.

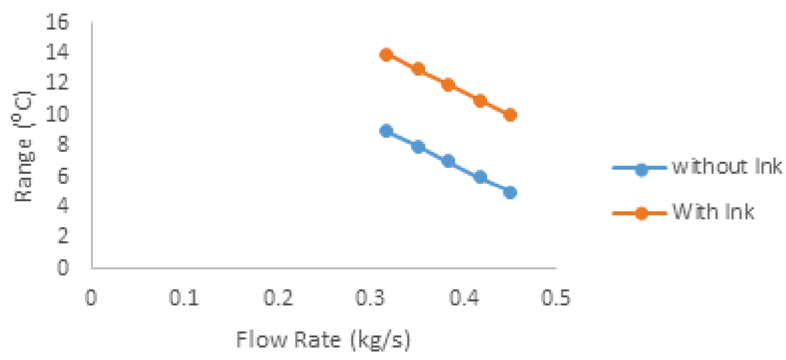
**Figure 12:** Efficiency vs Flow Rate at different Inlet Temp.




In this figure we can see that the efficiency of the cooling tower at different inlet temperature with the decrease of water inlet temperature efficiency also decreases.

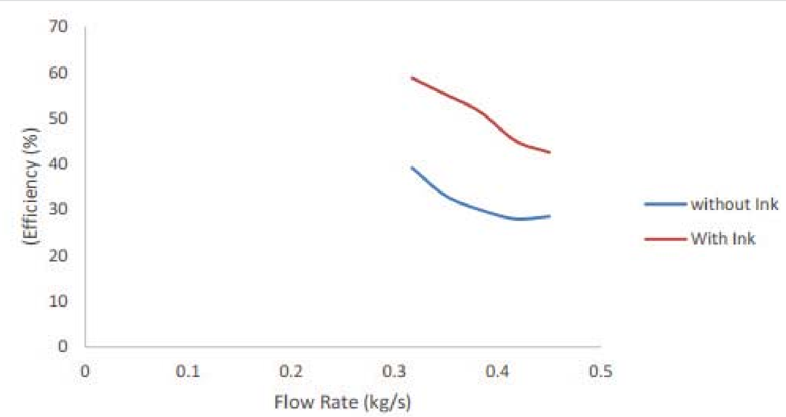
## Comparison of Cooling Tower Performance with Cooling Fluid of Various Qualities

**Figure 13:** Range vs Flow Rate of Induced Draft




From the above figure it has been observed that range increases due to the addition of ink. The value in average is 9 0C in case of induced draft cooling tower whereas without ink it is 5 0C.

**Figure 14:** Efficiency vs Flow Rate of Induced Draft




From the above figure it has been observed that efficiency increases due to addition of ink. The values of Efficiency vary from 28.5 % to 39.15 % in case of induced draft cooling tower with water whereas with ink it is 42.55 % to 58.42 %.

## Conclusion

The tower characteristics, efficiency, make up water and heat loss due to evaporation of natural and induced draft cooling with different quality of circulating fluids were evaluated. It was found that when L/G increases it was observed that both efficiency and cooling tower characteristics increase. So we can see with decrease of flow rate efficiency and cooling tower characteristics decreases. It was found that with the increase of humidity, cooling tower efficiency decrease. It was found that due to addition of toner with water the efficiency, range, evaporation heat loss increases. For induced draft efficiency and range increase by 8% & 4°c in average respectively and for natural draft range efficiency and range increase by 5% & 2° respectively. With the increase of percentage of toner in water it was observed that efficiency and range increase which has been shown graphically. A comprehensive review on forced convection heat transfer characteristics with different nanofluids based on experimental investigations with constant heat flux, constant wall temperature boundary conditions and in heat exchangers is presented in this review paper. Most of the experimental studies showed that nanofluids demonstrate an improved heat transfer coefficient compared to its base fluid. Further it increases significantly with increasing concentration of nanoparticles as well as Reynolds number. The use of nanofluids in a broad range of applications is promising but there is lack of agreement between experimental results from different research groups. Hence, experimental studies are desired to understand the heat transfer characteristics of nanofluids and recognize innovative and unique applications for these fields.

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