

Design, Fabrication and Determination of Performance of a Cooling Tower

Wadzani, S. G.
Training Department
Sci Equip Dev Inst, Enugu, Nig
swadzani@yahoo.com

Agu-Bruno Christiana
Electroplating Department
Sci Equip Dev Inst, Enugu, Nig
agu.christy@yahoo.com

Ugwueze, S. O
Machine Design/Building R & D
Sci Equip Dev Inst, Enugu, Nig
ogooougwueze@gmail.com

Imoh, R. U.
Plastic Recycling Department
Sci Equip Dev Inst, Enugu, Nig
imo_uchechi@yahoo.com

Afulike, N.
Electrical R & D Department
Sci Equip Dev Inst, Enugu, Nig
afulykens@yahoo.com

ABSTRACT

The essence of this research is to study the basic principles and characteristics of evaporative water cooling tower system and to investigate cooling tower performance and key design factors. Also, to make available the experimental set up for the demonstration of the cooling process using a cooling tower. The performance or effectiveness of the cooler tower fabricated is about 54.84%, thus, it can be comfortably deduced that the cooling tower so fabricated is within the desired effectiveness value, as determined by literature which the recommended industrial value should not be less than 40%. As determined by the experiments carried out, it has been established that for cooling towers, the outlet temperature can never be less than the ambient temperature, it has also verified that the best temperature difference cooling towers can give is a temperature difference between the outlet temperature and the ambient temperature. The material of choice for the fabrication which is Perspex was chosen because of its environmentally friendly nature, light weight and financially inexpensive, not disregarding its transparent nature which gives the researcher the opportunity to appreciate the process as it occurs in the system. The efficiency of the cooling tower fabricated relies on the accurate and reliable outdoor wet bulb temperature instruments. Shortcomings can result in cooling tower overuse, leading not only to increased water and energy usage but also reduced lifetime of fans and pumps.

Keywords: Design, Cooling tower, Range, performance, effectiveness

INTRODUCTION

Cooling towers are a very important part of many chemical plants. The primary task of a cooling tower is to reject heat into the atmosphere. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water (Ronak and Trupti, 2012).

In comparison with most other industrial equipment, the water cooling tower is a simple device, based on the direct contact of two of the earth's most common substances: air and water (Mortaza and Mosen, 2011).

The basic principle of the cooling tower operation is that of evaporative condensation and exchange of sensible heat. The air and water mixture releases latent heat of vaporization which has a cooling effect on water by turning a certain amount of liquid into its gaseous state thereby releasing the latent heat of vaporization (Khan, Qureshi and Zubair, 2004).

The capability of the cooling tower is a measure of how close the tower can bring the water temperature to the Wet Bulb Temperature of the entering air. A larger cooling tower (i.e., more air and/or more fill) will produce a closer approach (colder leaving water) for a given heat load, flow rate and entering air condition. (Smrekar, Kuštrin and Oman, 2011).

Literature Review

Several authors in the field of cooling towers dedicated their researches to the development of cooling systems performance. Barile Dengler and Hertwig (1974) studied the performances of a turbulent bed cooling tower. They correlated the tower characteristic with the water/air mass flow ratio. El-Dessouky (1993) studied the thermal and hydraulic performances of a three-phase fluidized bed cooling tower. He used spongy rubber balls 12.7 mm in diameter and with a density of 375 kg/m³ as a packing, and developed a correlation between the tower characteristic, hot water inlet temperature, static bed height, and the water/air mass flux ratio.

Bedekar, Nithiarasu and Seethatamu (1998) studied experimentally the performance of a counter flow packed bed mechanical cooling tower, using a film type packing. Their results were presented in terms of tower characteristics, water outlet temperature and efficiency as functions of the water to air flow rate ratio, L/G . They concluded that the tower performance decrease with an increase in the L/G ratio, however they did not suggest any correlation in their work. Goshayshi and Missenden (2000) also studied experimentally the mass transfer and the pressure drop characteristics of many types of corrugated packing, including smooth and rough surface corrugated packing in atmospheric cooling towers. Their experiments were conducted in a $0.15\text{ m} \times 0.15\text{ m}$ counter flow sectional test area with 1.60m packing height. From their experimental data, a correlation between the packing mass transfer coefficient and the pressure drop was proposed. Milosavljevic and Heikkila (2001) carried out experimental measurements on two pilot-scale cooling towers in order to analyze the performance of different cooling tower filling materials. They tested seven types of counter flow film type fills and correlated their pressure drop data as well as the volumetric heat transfer coefficient with the water and air flow rates.

More recently, Klopper and Kroger (2005) studied the loss coefficient for wet cooling tower fills. They tested trickle, splash and film type fills in a counter flow wet cooling tower with a cross sectional test area of $1.5\text{ m} \times 1.5\text{ m}$. They proposed a new form of empirical equation that correlates fill loss coefficient as a function of the air and water mass flow rates. There are several other mathematical models which can correlate heat and mass transfer processes occurring in wet cooling towers, such as the models proposed and discussed by Khan *et al.* (2004) and Kloppers and Kroger ((2003), "V.G.A." type packing. This type of packing was first proposed for the mass transfer processes between gas and liquid and has not been used in cooling water systems using direct contact between water and air. Lemouari and Boumaza (2003; 2005), used this packing in an evaporative cooling system to study its thermal and hydraulic performances.

Jorge and Armandos (2000) studied the thermal performance of the cooling tower in chilled ceiling conditions. A mass transfer coefficient correlation is developed, and new variables are defined. Naphon (2005) performed a study on the heat transfer characteristics of an evaporative cooling tower. The tower had $0.15\text{ m} \times 0.15\text{ m}$ internal cross section and 0.48 m in height packed with eight layers of the laminated plastic plates. He presented theoretical and experimental results of the heat transfer characteristics of the cooling tower by making a comparison between them. However, the author did not suggest any empirical correlation for the heat transfer characteristics of the tower.

El-Sarrag (2006) presented an experimental study and predictions of an induced draft ceramic tile packing cooling tower. He used a tower of 0.64 m^2 cross section area and 2m height with a filling portion of 0.8 m. Burned clay bricks were used as the packing material in his work. The author pointed out that the factors affecting the heat and mass transfer coefficients are the water to air flow rate ratio, the inlet water temperature and the inlet air enthalpy. Gharagheizi, Hayati and Fatemi (2007) presented an experimental and comparative study on the performance of mechanical cooling tower with two types of film packing. They used vertical corrugated packing (VCP) and horizontal corrugated packing (HCP) having 0.64 m in high and 0.25 m^2 cross section area. These authors reported that the performance of the cooling tower is affected by the water/air mass flow ratio, the type and the arrangement of the packing. Besides the early experimental investigations, there exist several other mathematical models that correlate heat and mass transport phenomena and performance characteristics relative to direct-contact counter flow wet cooling towers, such as the models described in Wei (1995), Kloppers (2003), Fisenko, Brin and Petruichik (2004) Fisenko and Petruichik (2004; 2005), Khan *et al* (2004), Qureshi and Zubair (2006) and more recently, Heidarinejad, Karami and Delfani (2009).

Su (1999) studied the performance of cooling towers considering the thermo-hydraulic aspects of the cooling devise. He developed a general mathematical model where the optimal ratio of water and air flow in order to maximize efficiency of the cooling system was determined.

Al-Nimr (1998) presented a simple mathematical model to describe the thermodynamic performance of a counter flow induced draft cooling towers, allowing the determination of the height of the tower in which the water and air temperature reach the same value. Khan *et al* (2004) developed serious analysis of the clogging phenomena including the effect of fouling on system cooling efficiency

Sutherland presented the pressure effect on thermal performance of the cooling system, and showed that air temperature and humidity have a significant effect on cooling tower performance. Merkel (1925), Sutherland (1983) developed the principles of mathematical equations of thermal and mass exchanges using different values of Lewis

number describing evaporative cooling processes. Khan *et al* (2004) presented the performance characteristics of the cooling tower using the same hypothesis presented by Khan *et al* (2003) Dreyer and Erens (1996) developed a mathematical model for the modeling of counter flow cooling tower splash pack thermal performance allowing predicting the correct trends for both the transfer characteristics and the pressure drop across the packing material. Al-Sulaiman (2002) evaluated the performance of palm fibers (stem), jute and luffa to be used as wetted pads in evaporative cooling including cooling efficiency, material performance and cooling efficiency degradation. Seetharamu and Swaroop (1991) have studied the performance of smaller sized fluidized-bed cooling towers and Sisupalan and Seetharamu (1992) have examined the performance variation of a fluidized-bed cooling tower for different static bed heights.

Some studies have been performed in the areas where weather conditions are affecting the cooling efficiency of dry cooling towers, however, a very few of them incorporate experimental studies on cooling process using palm trees as packing material.

The theory of cooling towers has been studied in some depth since the first work of Merkel in 1925. It is a reasonably accurate and relatively simple mathematical description of the heat and mass transfer phenomena in a counter current tower. Jorge and Armando (2000) presented an effectiveness-number of transfer units (e-NTU) method of analysis which is particularly useful for cross flow cooling towers. Wang (2010) studied the performances of forced draft cooling towers with a 1.05m packing height consisted of wood slats. Klapper and Kroger (2005) studied the heat transfer and pressure drop characteristics of splash gritty precooling tower packing.

MATERIALS AND METHODS

Materials of Fabrication

The material used for the fabrication of the cooling tower in no definite order is as outlined below:

Cooling Tower Frame. The cooling tower wall was made by using 5mm transparent Perspex, this material was chosen because of the fact that a transparent material makes the cooling process inside the tower visible, thus appealing and at the same time, it makes the process interactive. A 5mm thick Perspex was chosen because of its poor conduction of heat, thus, it prevents heat lost to the walls and the surroundings of the cooling tower.

Also, a one inch mils steel angle iron was used to reinforce the frame of the tower, thus, making the fabrication more, rigid and solid. Same material was also used for the cooling tower stand.

Fan. A Spacetek Ventilating fan was bought from local electronics supplier with the following Capacity as shown in table 1 below:

Table 1: The capacity of the fan used in the design

Size	300mm (12 inch)
Model	HEX-1201
Voltage	230V
Frequency	50Hz
Phase	Single Phase
Power Rating	120W
RPM	1 200
Air Delivery	

Fillings. The Filling material is either PVC or wood, PVC was thought to be the most suitable for this work, however, industrial filings could not be assessed within the region and for this reason, a suitable alternative was used, which is plastic beads obtained from the local market.

The beads have average dimensions as tabulated in table 2 below:

Table 2: Data of the fillings used in the design

Height	12.5mm
External Diameter	9.5mm
Internal bore diameter	2.5mm
Cross-sectional Area	29.85
Colour	milk
Thickness	3mm

Piping. For water distribution into and out of the cooling tower, PVC pipes, valves and taps and fittings were used specifically of one quarter dimension (that is, 19.05mm external diameter), based on the design. PVC was considered the best choice because of its poor ability to conduct heat, thus reducing heat lost.

Nozzle. The nozzle for distributing water in the cooling tower is made of PVC which is the most suitable material in such industry at the moment.

The dimensions of the nozzle are as tabulated in table 3 below:

Table 3: Dimensions of the nozzle used in the design

Cross-sectional area	85
Average pour slots	150 (with 1.5mm pore diameter)

Water Basin. Based on choice and for simple design, same material that was used for the cooling tower frame was used for the water basin.

The Cooling Tower Stand. The cooling tower unit stands on a frame made of one-inch mild steel angle iron

Air Vent. Perforations of 5mm diameter were made to serve as air vent for the process since the design in mind is a counter current flow system.

Design Calculations and Dimensions of the Cooling Tower

From literature, it has been discovered that there are no definite or direct detailed formulas for the design of cooling towers, with the aim of fabrication. On the course of the research some tabulated design data of some industrial cooling towers were obtained and interpolation method was used to arrive at the exact dimensions of the one fabricated. The design calculations are as shown below.

Table 4 below is a table of data used in interpolating during the design of the cooling tower, the key factor used was a table of data of typical comparisons between various fill media

	Splash Fill	Film Fill	Low Clog Film Fill	Interpolation Data Generated
Possible L/G Ratio	1.1 – 1.5 m	1.5 – 2.0	1.4 – 1.8m	Not Applicable
Effective Heat Exchange Area	30-45	150	85-100	0.5
Fill Height Required	5 – 10m	1.2 – 1.5m	6 – 9m	0.345m
Quantity of Air Required	High	Much Low	Low	Low

Other fabrication parameters include:

Length of cooling tower = 750mm

Width of the cooling tower = 460mm

Height of water basin = 420mm

Width of water basin = 460mm

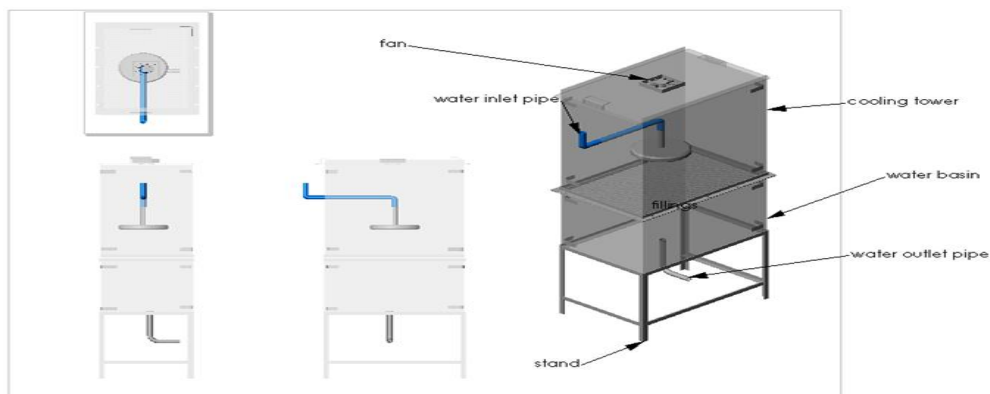


Figure 1: The 3-D solidworks labeled diagram of the cooling tower

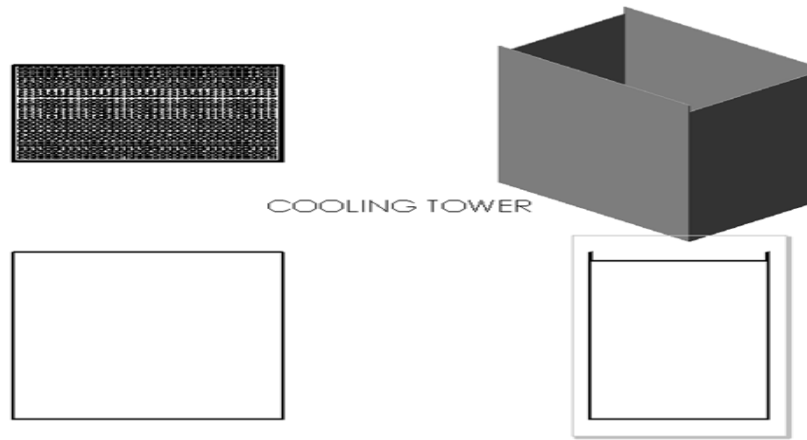


Figure 2 (a): The perforated bottom of the cooling tower section (b) the cooling tower frame in orthographic projection (c) the front view (d) the side view

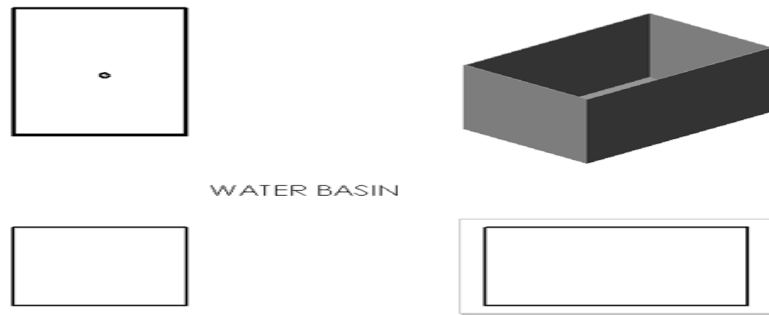


Figure 3 (a): The water basin bottom (b) the orthographic projection of the water basin in solidworks (c) the side view (d) the front

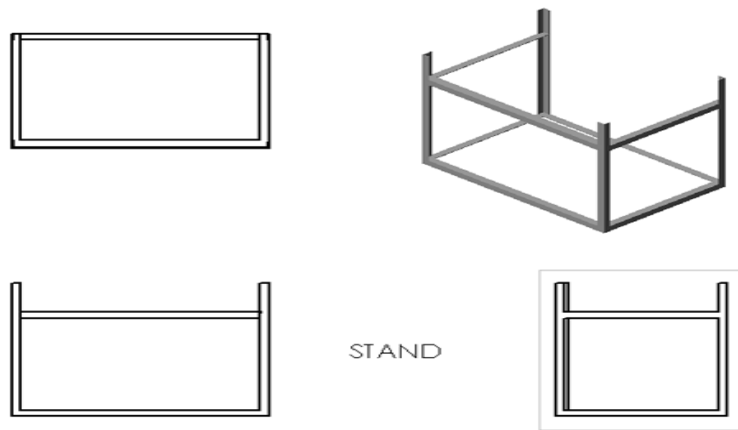


Figure 4: The stand of the cooling tower (a) top view (b) the orthographic view (c) side view (d) the front view

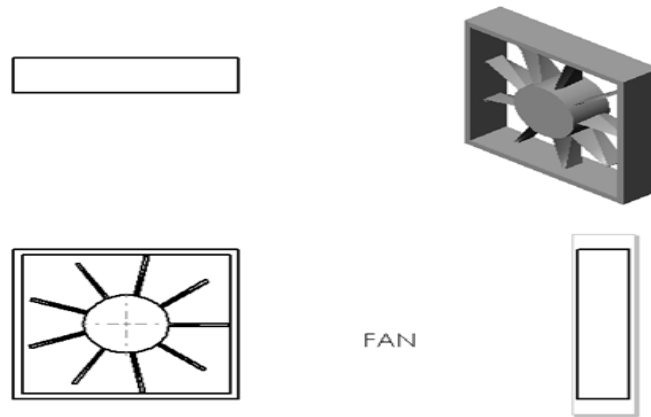


Figure 5: The fan or blower (a) side view laying vertically (b) the orthographic view (c) the front view (d) the side view lying horizontally

Procedures

After assembling the cooling tower and ensuring that there are no leakages, ensure that the equipment is seated on a flat surface.

In operating the equipment, the fan plug has to be connected to a 13amps socket; the socket is then switched on. Ensure that the fan is rotating.

Set the hot (warm) water inlet valve on “open”, after checking to be sure that the connection to the inlet source is in order and without leakages.

Place the temperature sensor probe into “its” slot just close to the body of the cooling tower on the water inlet pipe (to ensure accurate reading of the water inlet temperature).

Similarly, place the outlet temperature sensor probe into “its” slot just by the exit of the water outlet pipe.

Repeat a series of test and take average value, record and compute the effectiveness of the cooling tower.

RESULT AND DISCUSSION

Recall that the objective of this work is to fabricate and determine the performance of a cooling tower. In determining the performance of a cooling tower the important parameters checked are as outlined below

- a. The “range” is the difference between the cooling tower inlet and outlet temperature (see Figure 6).
- b. The “approach” is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature (see Figure 6).
- c. The cooling tower effectiveness or performance (in percentage) is the ration of range, to the ideal range, that is, difference between cooling water inlet temperature and ambient wet bulb temperature, or in or the words, mathematically

Cooling Tower Effectiveness or performance = 1.1

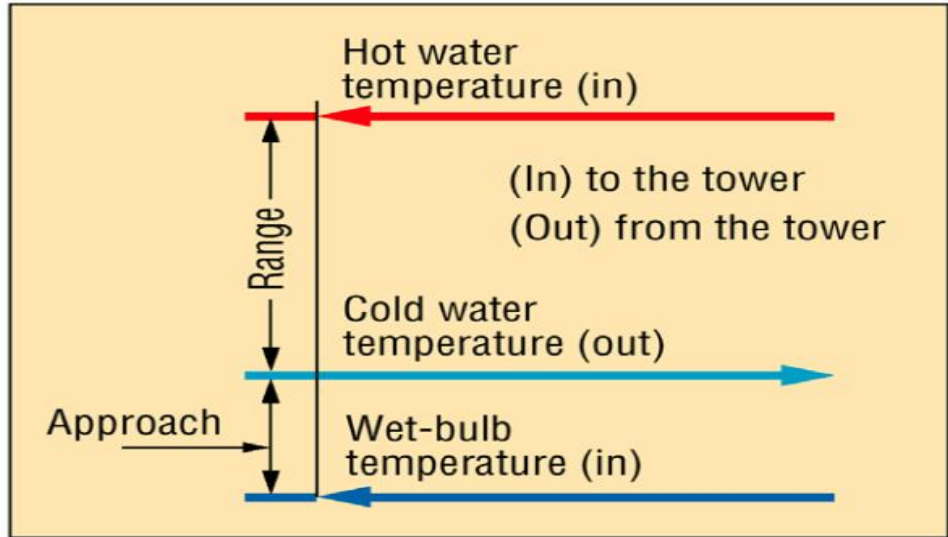


Figure 6: Performance determination factors in Cooling Tower

A series of experiments were carried out and average inlet water temperature defined as T_{in} , water outlet temperature defined as T_{out} , and ambient temperature defined as T_{amb} were taken. The values are as given below.

T_{in} = (Average)

T_{out} = (average)

T_{amb} = on the day the experiment was carried out

Using equation 1.1 above

The range = $T_{in} - T_{out} = 63 - 46 =$ 1.2

The approach = $T_{out} - T_{amb} = 46 - 32 =$ 1.3

On substituting values obtained from equations 1.2 and 1.3 into equation 1.1 above

The performance of the cooling tower = $\frac{1.2}{1.2 + 1.3} = 54.84\%$

Thus, the performance (effectiveness) of the cooling tower is 54.84%

From the result obtained above, that is a performance of 54.84% it can be comfortably deduced that the cooling tower so fabricated is within the desired effectiveness value, as determined by literature which the recommended industrial value should not be less than 40%.

CONCLUSION

Also, as determined by the experiments carried out, it has been verified that literature statements that the outlet temperature can never be less than the ambient temperature is validated, it has also been validated that the best cooling towers can give is a temperature difference between the outlet temperature and the ambient temperature

REFERENCES

- Al Nimr, M. (1998). Dynamic thermal behavior of cooling towers. *Energy conversion management*, 39: pg 631-636.
- Al-Sulaiman, F. (2002). Evaluation of the performance of local fibers in evaporative cooling. *Energy conversion and management*, 43(16): pg. 2267-2273.
- Barile, R.G. Dengler, J.L. & Hertwig, T.A. (1974). Performance and design of a turbulent bed cooling tower, *AIChE Symposium Series*, 70, pg. 154-162.
- Bedekar, S.V., Nithiarasu, P & Seetharamu, K. N. (1998). Experimental investigation of the performance of a counter flow packed bed mechanical cooling tower, *Energy*, 23 pg. 943-947.
- Dreyer, A.A. & Erens, P.J. (1996). Modeling of cooling tower splash pack. *International journal of heat mass transfer*, 39: pg 109-123.
- El-Dessouky, H. (1993). Thermal and hydraulic performance of a three phase fluidized bed cooling tower, *Exp. therm. fluid sci.*, 6, Pg. 417-426.
- El-Sarrag, E. (2006). Experimental study and predictions of an inclined draft ceramic tile packing cooling tower, *Energy conversion management*, 47, pg 2034-2043.
- Fisenko, S.P., Brin, A.A. & Petruichik, A.I. (2004). Evaporative cooling of water in a mechanical draft cooling tower, *International journal of heat mass transfer*, 47 pg 165-177.
- Fisenko, S.P. & Pitruichik, A.I. (2005). Toward the control system of mechanical draft cooling tower of film type, *International journal of heat mass transfer*, 48 pg 31-35.

- Gharagheizi, F., Hayati, F. R. & Fatemi, S. (2007). Experimental study on the performance of mechanical cooling tower with two types of film packing, *Energy conversion management*, 48 pg 277–280.
- Goshayshi, H.R & Missenden, J.F. (2000). The Investigation of cooling tower packing in various arrangements, *Applied thermal engineering*, 20 pg. 69–80.
- Heidarnejad, G. M. Karami, M.S. & Delfani, S. (2009). Numerical simulation of counter flow wet cooling towers. *International journal refrigeration*, 32 pg. 996–1002.
- Ignatenkov, Y.I. (1979). Study and elaboration of a method for calculating optimum parameters of mass exchange apparatus with vertical grids, *Doctoral thesis, Institute of Leningrad, Russia*.
- Khan, J.R. B.A. Qureshi, B.A. & S. Zubair, S. (2004). A Comprehensive design and performance evaluation study of counter flow wet cooling towers, *International journal of refrigeration*, 27: pg 914-923.
- Khan, J.R. Yaqub, M & Zubair, S.M. (2003). Performance characteristics of counter flow wet cooling towers, *Energy conversation and management*, 44(13): pg 2073-2091.
- Kloppers, J.C. (2003). A Critical evaluation and refinement of the performance prediction of wet cooling towers. Doctoral thesis, mechanical engineering, University of Stellenbosh, South Africa.
- Kloppers, J.C. & Kroger, D.G. (2003). Loss coefficient correlation for wet cooling tower fills, *Applied thermal engineering*, 23. pg 2201–2211.
- Kloppers, J.C. & Kroger, D.G. (2005). A Critical investigation into the heat and mass transfer analysis of counter flow wet- cooling towers, *International journal heat mass transfer*, 48, pg. 765–777.
- Jorge, F. & Armando, C.O. (2000). Thermal behavior of closed wet cooling towers for use with chilled ceilings, *Applied thermal engineering*, 20 pg.1225–1236.
- Lemouari M. (2001). Experimental study of the air/water heat transfer by direct contact in a column packed with vertical grids- application to the water cooling. MSc. thesis, University of Bejaia, Algeria.
- Lemouari, M. & Boumaza, M. (2003). Experimental study of the air/water heat transfer by direct contact in a column packed with vertical grids application to the water cooling, pp. 457–464 in *proceeding 11th International meeting on heat transfer jith2003*. France.
- Lemouari, M. and Boumaza, M. (2005). An Experimental investigation of thermal characteristics of a mechanical draft wet cooling tower, pp. 111–120 in *proceedings 13th iahr.*, poitiers, France.
- Merkel, F. (1925). Evaporative cooling, *Journal of German engineers*, VDI (German), 70: pg 123-128.
- Milosavljevic, N. & Heikila, P. (2001). A Comprehensive approach to cooling tower design, *applied thermal engineering*, 21, 899–915.
- Mohiuddin A.K.M., & Kant K. (1995). Knowledge base for the systematic design of wet cooling towers. part I: selection and tower characteristics, *International journal of refrigeration*, 19(1), pp. 43-51
- Naphon, P. (2005). Study on the heat transfer characteristics of an evaporative cooling tower, *Int. comm. heat mass transfer*, 32, 1066–1074. pg. 19.
- Qureshi, B.A. & Zubair, S.M. (2006). A Complete model of wet cooling towers with fouling in fills, *Applied thermal engineering*, 26 pg 1982–1989.
- Ronak, S. & Trupti, R. (2012). Thermal design of cooling tower, *International journal of advanced engineering research and studies*, ijaers/ 1 (3), 26-29. e-issn 2249–8974.
- Seetharamu, K.N. & Swaroop, S. (1991). The Effect of size on the performance of a fluidized bed cooling tower” heat and mass transfer. 26(1): pg 17-21.
- Sisupalan, N. & Seetharamu, K.N. (1992). Heat transfer and pressure drop in fluidized bed cooling tower. *heat and mass transfer*. 27(8): pg 499-503.
- Smrekar J., Kuštrín I., & Oman T. (2011). Methodology for evaluation of cooling tower performance – part 1: description of the methodology, *Energy conversion and management*, 52, pg. 3257–3264.
- Su, M.D., Tang, G.F. & Fu, S. (1999). Numerical simulation of fluid flow and thermal performance of a dry-cooling tower under cross wind condition, *Journal of wind engineering and industrial aerodynamics*. 79(3): pg 289-306.
- Sutherland, J.M. (1983). Analysis of mechanical draught counter flow air/water cooling towers, *Asme journal of heat transfer*, 105: pg.576-583.
- Wang, k., Sun, F. Z., Zhao Y. B., Ming Gao, M. & Ruan, L. (2010). Experimental research of the guiding channels effects on the thermal performance of wet cooling towers subjected to crosswinds – air guiding effect on cooling tower, *Applied thermal engineering*, 30, pg. 533–538.
- Wei, Q., Zhang, K., Liu, K. & Du, X. (1995). A study of the unfavorable effects of wind on the Cooling Efficiency of DryCooling Towers *Journal of wind engineering and industrial aerodynamics*. 54: pg 633-643.