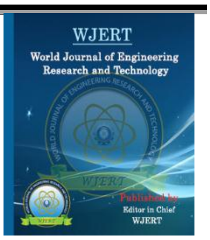
wjert, 2017, Vol. 3, Issue 6, 83 -92. *Original Article* ISSN 2454-695X

World Journal of Engineering Research and Technology

WJERT

www.wjert.org SJIF Impact Factor: 4.326



DEVELOPMENTS OF LABORATORY COOLING TOWER MODEL

Ajayi I. S.*, Oladimeji E. A. and Fatona A. S.

Department of Mechanical Engineering Federal Polytechnic, Ado – Ekiti, Nigeria.

Article Received on 20/08/2017 **Article Revised on 10/09/2017** **Article Accepted on 01/10/2017**

***Corresponding Author**
Ajayi I. S.
Department of Mechanical Engineering Federal Polytechnic, Ado – Ekiti, Nigeria.
peterajewole@gmail.com,

ABSTRACT

Cooling tower is a device employed to extract heat from either power plants or processes that generate large amount of heat and hence reduce the heat to a barest minimum. In this work a laboratory cooling tower was developed to aid the teaching of cooling tower and also espouse the various operational techniques associated with it. The developed cooling tower was based on the principle of mechanical draft. The fan incorporated has a capacity of 0.5 horse power which induces air from the surrounding and uses same to extract heat from the hot water. A 0.31 horse power pump in accordance with the designed values was incorporated to pump the hot water from the tank to the cooling tower chamber. With estimated values of water mass flow rate of 200 kg/hr and air mass flow rate of 1.33 (kg/hr.) the developed cooling tower efficiency, range and cooling capacity were found to be 64%, 18^{0}C and 8.50 (kg/s) respectively. These values of efficiency and range compared well with that for standard industrial cooling towers.

KEYWORDS: Cooling tower, cooling capacity, Range, Evaporation and efficiency.

INRODUCTION

Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature or, in the case of closed circuit dry cooling towers, rely solely on air to cool the working fluid to near the dry-bulb air temperature (Snow, 2008).

The cooling water system is one of the most important in power plant and commercial refrigerating unit and its availability predominantly decides the plant site. Arora and Domkundwar (1998) noted that the cooling water requirement in an open system is about 50 times the flow of a steam to the condenser, even with closed cooling system using cooling towers, the requirement for cooling tower is also considerably large as 5 to 8 kg/kW-hr. This means a 1000 MW station will require about 100 thousand tons of circulating water per day even with the use of cooling tower. The world largest cooling tower is the 202 meters tall that is the cooling tower of Kalismdh Thermal power plant in Jhalawa, Rajasthan, India (Thomas *et al*, 2005).

Cooling towers are heat extraction devices use to transfer process waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cool water is needed for example in air-conditioners, power generation or manufacturing process. In refrigeration and air-conditioning system, condenser has been known to be the major medium for heat rejection, but the efficiency of these condensers is best when they serve small units. In case of large units like, refrigeration, air-conditioning, plants and boilers, the heat rejection is higher and the quantity of heat rejected is very large, this renders condenser non-efficient and thus give rise to what is known as cooling tower. The primary use of large industrial cooling towers is to remove the heat absorbed in the circulating cooling water systems used in power plants, petroleum refineries, petrochemical plants natural gas processing plants, food processing plant, and semiconductor plants and for other industrial facilities (EPA, 2003). The circulation rate of cooling water in a typical 700 MW coal-fired power plant with at cooling tower amounts to 71,600 cubic meters an hour and the circulating water requires a supply water make up rate perhaps 5 percent (Thomas et al, 2005). The circulation rate of cooling water in a typical 700m coal-fired power plant with a cooling tower amounts to 71,600 cubic metres an hour and the circulating water requires a supply water make-up rate of perhaps 5 percent (Thomas *et al* 2005). Biocides are often used in coolig towers to prevent the growth of Legiunella including species that cause legionellosis disease (Ryan and Ray, 2004).

There are two principal types of cooling tower; viz, Natural draft cooling tower and mechanical draft cooling tower. In natural draft cooling tower, the air flows naturally without fan and through it and provides the required cooling. The mechanical draft cooling towers use fans to move the air through it instead of depending on natural draft or wind velocity. This speeds up cooling and increase the efficiency of the cooling tower by increasing the air velocity through it. With the use of mechanical draft cooling tower, much smaller equipment can be used to handle air-flow under fairly well controlled operational conditions. Qualitatively material balance around wet evaporative cooling tower system is governed by the operational variables of make-up flow rate, evaporation and windage losses, draw-off rate and the concentration cycles (EPA, 1997). Thermal efficiencies up to 92% have been observed in hybrid cooling towers (Guls, 2015).

The laboratory cooling tower is a cooling tower unit from a commercial air conditioning system used to study the principles of cooling tower operation. It is used in conjunction with a residential size water heater to simulate a cooling tower used to provide cool water to an industrial process. In the case of the laboratory unit, the industrial process load is provided by the water heater. The laboratory cooling tower allows for complete control of the speed of the fan used in cooling the warm return water and the pump used to life the warm water to the cooling tower. Cooling towers found their applications mostly in thermal stations and industrial set-up. In this work, the laboratory tower developed is a model which if developed further could be used in an industry. Inadequate funding in the higher institutions which has made it difficult to import most laboratory equipment has necessitated this work.

Theoretical background

The theory behind the operation of the cooling tower is the First Law of Thermodynamics, which is the conservation of energy. In simple terms, the energy that enters the system must exit the system; energy can neither be created nor destroyed, but can be transformed from one form to another (Rajput, 2008).

Energy that enters the cooling tower is in the form of hot water. Other energy contributions such as heat generation from friction of both air and water and energy losses from pipes are ignored to ease analysis. This hot water was cooled from temperature T_1 to a temperature of T_2. The cooling of the hot water was in the form of forced convection by which ambient air at T_1 was blown over the hot water and exited the cooling tower at some temperature T_2. Both the entrance and exit temperatures of the air and water were recorded. Once this data was recorded, an energy balance could be conducted on the system.

An energy balance is a form of bookkeeping that accounts for the energy entering and leaving the system. The main component of the energy balance is enthalpy which is defined as:

$$h = u + pv. \quad (1)$$

Where h is enthalpy, u is internal energy, p is pressure, and v is volume.

The combined terms U+PV is enthalpy, which means to heat.[1] Enthalpy can be calculated or referenced from tables of data for the fluid being used. In the Engineering laboratory, the fluids used by the cooling tower are air and water, whose enthalpy values can be obtained from a thermodynamics textbook. For example: Since both the initial and final temperatures of the input hot water and the output cool water were measured, the temperature T_{in} can be referenced and the enthalpy (kJ/kg) can be recorded. The enthalpy of the output cooled water can be similarly referenced and an energy balance can be conducted for the water (Sharon, et al 1996).

The change in enthalpy for air can be determined form either of two methods. Since the air is at low pressure, it can be treated as an ideal gas and the enthalpy change can be calculated through the use of the following equation:

$$\Delta H = C_p \Delta_T \quad (2)$$

Where ΔH is the change in enthalpy, ΔT is the change in temperature, and C_p is the specific heat with respect to constant pressure.

Since the specific heat relation does not take into account the percentage of water in the air, a psychrometric chart is used to determine the enthalpy change between the entrance and exit air. In order for the psychrometric chart to be used effectively, some information is needed about the input and output air. The information needed to reference the psychrometric chart is the dry bulb and wet bulb temperatures of the inlet and outlet air. Both the input and output air flow is measured with a sling psychrometer. The sling psychrometer is an instrument that has two thermometers. Once the wet and dry bulb temperatures of the inlet and outlet air have been measured, each can be referenced on the psychrometric chart and the enthalpies obtained. Once the enthalpies for the inlet and outlet water and air conditions are known, energy balance can be conducted on the system

MATERIALS AND METHOD

In this work, various parameter were designed using appropriate formulas from standard text and Journals.

Water flow through the pipe was estimated to be 200 kg/hr using equation (3), (4) and (5)

$V = 0.85\ CR \times S^{0.54}$ (3)

Where V = velocity of flow in the pipe, C = function coefficient of the pipe, R= hydraulic means radius of the pipe, S= hydraulic gradient

$MW = Lw * \rho w$ (4)

Where M_W=mass flow rate of water, LW =density of water, ρw=flow rate of water.

$\rho w = AV$ (5)

The air mass flow rate was estimated to be 133.4 kg/hr. using equation (6)

$Ma = Qa \times La$ (6)

The Fan Power Requirement was estimated to be 0.56 using equation (7)

$\text{Fan Power} = \text{Q}(\text{P}_2$ $- Fan\ Power = Q(P2 - P1) + (wv^2)/2\ (watt)$ (7)

Where Q=volume flow rate, P2-P_1=pressure differential, v=linear velocity, w=angular velocity.

The pump capacity was estimated to be 0.31 hp using equation (8)

Pump capacity = $\frac{\rho QgH}{100\in}$ (8)

Where ρ= density of water, Q = quantity of water, H= head pump, g=acceleration due to gravity.

The temperature range is estimated to be 18K using equation (9)

Range = T_{in} - T_{out} (9)

Where T_{in}= inlet temperature and T_{out} = outlet temperature

Cooling capacity is estimated to be 8.50 kJ/kg/s using equation (10)

Cooling capacity = $mc\Delta T$ (10)

The efficiency of the cooling tower was estimated to be 64% using equation (11) given by Arora and Domkundar (1998).

Efficiency =$\frac{t1-t0}{ti-twb}$x100 (11)

Where ti = inlet temperature, t_0 = outlet temperature and t_{wb}=wet bulb temperature of air

Range is the difference between the cooling water inlet and outlet temperature while approach is the difference between the cooling tower outlet cold water temperature and ambient wet-bulb temperature. The lower the approach the better the cooling tower performance. Cooling tower effectiveness (in percentage) is the ratio of range to the ideal range i.e. difference between cooling water inlet temperature and ambient wet-bulb temperature. Cooling capacity, is the heat rejected in kcal/kg, given as product of mass flow rate of water, specific heat and temperature difference. The construction was carried in accordance to the design value, see figure1 and plate 1.

Water from the water tank heated to an elevated temperature with the aid of heater having the initial temperature T_1 is pumped to the cooling tower chamber with the aid of pump which capacity has been determined. The water from the tank is denoted hot water (HW). The pumped water reaching the cooling tower is further atomized by nozzle and the atomized water flows down the tower over a series of baffles made from a glass material which further increased the surface area of the water. Behind the glasses in the cooling chamber is a fan that blows away the heat from the hot water. The temperature of the water is taken with the aid of three thermometers which are situated at surfaces of the three glass plate that are consecutively positioned on inclination. This recorded temperature are T_2, T_3, and T_4. Ambient air is blown through a duct perpendicular to the flow of water by the fan. This air interacts with the water resulting in a net transfer of heat from the water to the air by the vaporization of some of the water. The cooled water at the base of cooling tower is allowed to flow back to the tank, thus the temperature of the water is further taken as T_5 before entering the tank which is denoted as cooled water (CW). The experiment is repeated five times and the enthalpies of hot (h_1) and cooled water (h_5) are determined using thermodynamics table.

The following procedures are taken during the experiments to ensure safe operations:
The water going into the cooling tower loses energy. The enthalpy of the water going into the tower can be determined by using the enthalpy of saturated liquid water in a steam table. The enthalpy of the water coming out of the tower can be determined in the same way. The data in steam tables are usually not given for every temperature so linear interpolation must be performed to determine the enthalpy at the desired temperature. Then the enthalpy of the water is multiplied by the mass flow rate. A basis of an operation of 1 minute was chosen to make the calculation easier. The change in enthalpy for the water is determined by

$$\Delta H_{Water} = \Delta H_{Water-Out} - \Delta H_{Water-In} . \quad (16)$$

RESULTS AND DISCUSSION

The performance evaluation of the laboratory cooling tower model was conducted by pouring water into the water tank and heated with the aid of heater for 20 minutes during which an elevated temperature was attained. The pump was switched on, hot water of about 50^0C was pumped into the cooling tower compartment and steady state operation was obtained. The experiment was conducted at a maximum fan speed (60 Hz) and maximum pump speed (60 Hz). The temperature of the hot water supply and the cooling water return both reached a steady value. The results from this experiment are shown in the table below.

Table 1: Temperature gradients of laboratory cooling Tower.

	T_1	T_2	T_3	T_4	T_5
A	50	47	42	38	34
B	51	47	43	38	33
C	50	48	43	37	34
D	51	47	43	38	33
E	50	48	42	37	34

Table 2: Temperature difference of Lab cooling Tower.

	Q_{IN}	Q_{OUT}	$\Delta T\ ^0C$
A	50	34	16
B	51	33	18
C	50	34	16
D	51	33	18
E	50	34	16

Using this data, the enthalpy of the different streams were calculated.

Table 3: Enthalpies of Air and Water.

	In	Out	Change
Water	2341.2	2075.7	-265.5
Air	4756.3	5132.2	375.9

Table 1 shows the gradual reduction of temperature of the stream at different part of the cooling tower which attest to the fact that cooling takes place at every point of the laboratory cooling tower model operation. The loss in temperature of first cycle A shows the cooling effectiveness of the tower which correspond to the result of Sharron and Scott (1996) on Laboratory experiment on cooling tower. The temperatures of the stream reduced gradually as it passes through the cooling compartment because heat were driven out of the water by the positioned fan. The external works done were the blowing of the fan and the pump to achieved result which is in accordance to Clausious statement of the second law of thermodynamics. Table 2 show the temperature difference of the pumped water and returned water which is very significant. The temperature differences lie between 16^0C and 18^0C. Table 3 shows the enthalpies of the water and the air with temperature based. This was deduced from thermodynamic steam table.

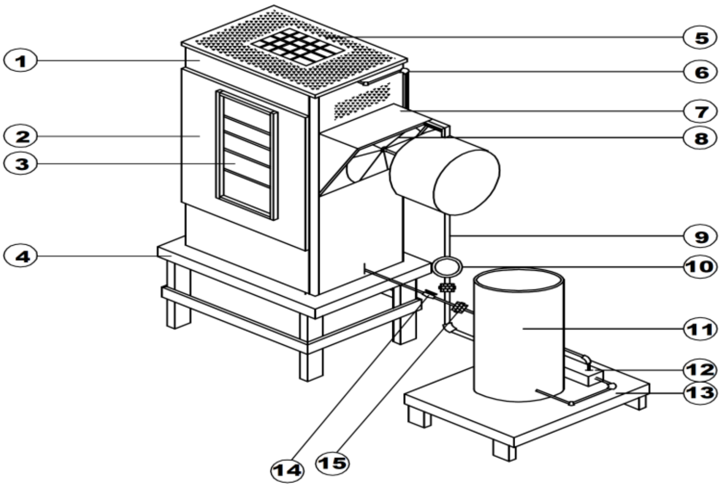


Figure 1: Schematic view of Laboratory cooling Tower.

1=Plate cover, 2=Side frame, 3=Cooling chambers, 4= Cooling chamber stand, 5= Head cover, 6=Angular Support, 7=Fan shield, 8=Fan, 9=Steel hose, 10=Pressure gauge, 11=Water tank, 12 =Pipe Support, 13=Tank stand, 14=Valve, 15=Valve.

Plate 1: Pictorial view of Laboratory cooling tower model.

CONCLUSIONS

In this research work, a cooling tower laboratory tower model was developed and experimented. Local materials were used for the fabrication and in accordance to the designed values. Adequate precautions were taken to ensure accurate results. The results were compared with the standards which show close intimacy.

There were many different things that were discovered while conducting these experiments. One thing that was learned was to always make sure the system is running at steady state before collecting data. If it is not at steady state, the different measurements that are being made are continually changing. When these numbers are used in calculations, they do not work like they should because everything in the system was changing. Another thing learned was that models do not always fully describe real situations. Several recommendations have been generated as a result of the experiences with the cooling tower. The first is a recommendation that the auxiliary heaters always be used during experiments in order to increase the temperature difference between the return water from the water heater and the cool supply water. This increase in temperature difference will allow for a larger enthalpy difference and will decrease the possibility of the enthalpy difference being negligible.

REFERENCES

1. Arora S.C. and Domkundwar A.V Power Plant Engineering, 4th Edition, P18.1-11. DhanpatRai and Co. (P) Ltd, 1998.
2. Balchandra K and Robert K. “Heat Transfer” West Publishing New York, 1997.
3. Bureau of Energy efficiency, Ministry of power, India cooling Towers in Energy efficiency in electrical Utilities, 2004; 135-151.
4. Boles, M. A. and Gengel, Y. A “Thermodynamics: Engineering Approach”, 2nd ed., McGraw Hill Book Company, St. Louis, MO, 1994; 8-12.
5. Environmental Protection Agency Workshop on cooling water intake Technologies, John Maulbetsch consulting, May, 2003.
6. Guls E. “Optimizing the Performance of Hybrid Induced-Forced Draft Cooling Tower” Journal of the Pakistan Institute of Chemical Engineers, 2015.
7. Harriot, P., McCabe, W. L. and Smith, J. C. Unit Operations of Chemical Engineering, 5th ed., McGraw-Hill Book Company, St. Louis, MO, 1993; P330-340.

8. Snow, W. B. The Steam Engine: A practical Guide to the Construction, Operation, and care of Steam Engines, Steam turbines, and Their Accessories.Chigago: American School of correspondence, 2008; 43-46.
9. {Occupational Safety and Health Standards for Genreal Industry, 29CFR Part 1910.303.}, 1994
10. Thomas J. F, Lindsay, G. J, Murphy, J. H. and Barbara, A. C. Department of Energy/office of fosil fuel Energy power plant water management, program, US Depatrment of Energy, July, 2005.
11. Lebeder J.C Refrigeration Engineering Longman Group U.K Limited, McGraw-Hill Book Company, St Lious, Mo, 2006; 8-12.
12. Rajput R.K Engineering Thermodynamics, 3rd Edition, P114. Laxmi Publications, 2008.
13. Ryan K. J. and Ray C. G., Sherris Mechanical Microbiology (4th ed) McGrawhill ISBMO-8385-8529-9, 2004.
14. Sharon L, Scott D, Austin N Cooling tower experiments, Project Work Unpublished. College of Engineering, University of Tennessee, Chattanooga, 1996.
15. US Environmental Protection Agency EPA Profile of the fossil fuel Electric power generation Industry Report. Washinton D.C Document N0 EPA/310-R-97-007, P79, 1997.