Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

Analysis Studying For Improving Cooling Tower

Saad A. Jafar[1] , Sanarya k. Kamal[2]
[1,2]Tikrit University / College of Engineering – Chemical Dept.
drensaadaj@yahoo.com[1] , sanaria_kamil@yahoo.com[2]

Received date : 28 / 2 / 2016 **Accepted date : 22 / 5 / 2016**

ABSTRACT

The present investigation includes a detailed study of the proposed equation for counter flow wet cooling tower using Merkel and Poppe models to show the difference and solutions techniques of the proposed models . A mathematical model has been suggested to construct computer software MATLB R2013 program for simulation of natural draft wet cooling tower for summer (hot and dry) and winter (cold and wet) weather according to Iraqi weather . The fill height changed from (0.2 -1.4)m at different water inlet temperature (37 ،40 ، 45)^{o}C and constant mass flow rate of air .It was found that the range of cooling increases when the fill is high and the cooling range ,relative humidity ,cooling approach ,air temperature change are higher at winter than at summer while the effectiveness and enthalpy change show higher value at summer than winter . Also the mass flow rate of water changed from(1- 7.5) kg/s with water inlet temperature 45 ^{o}C with constant fill height 1.2 m the result obtained show that tower range ، air temperature change ,are higher in winter than at summer where the enthalpy change and effectiveness show higher values at summer than at winter which matches with the other experimental researches.

Keywords: *Cooling tower, Heat transfer and mass transfer, Film fill ,Hot weather*

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

دراسة تحليلية لتحسين اداء ابراج التبريد

سعد احمد جعفر[١] ، سناريا كامل كمال[٢]

[١،٢]جامعة تكريت / كلية الهندسة / قسم هندسة الكيمياوية

drensaadaj@yahoo.com[1] , sanaria_kamil@yahoo.com[2]

تاريخ استلام البحث: ٢٨ / ٢ / ٢٠١٦ تاريخ قبول البحث: ٢٢ / ٥ / ٢٠١٦

الملخص

الدراسة الحالية تشمل دراسة مفصلة للمعادلات المفروضة لبرج التبريد الرطب ذو الجريان المتعاكس باستخدام موديل ميركل ويوب لإيجاد الاختلاف وتقنيات الحلول للموديلات المفروضة . تم استخدام موديل رياضي للتنبؤ بإداء ومحاكاة برج التبريد الرطب ذو السحب الطبيعي باستخدام برنامج (MATLAB R2013) ماتلاب لفصلي الصيف (حار وجاف) والشتاء (بارد ورطب) حسب اجواء العراق .تم تغير ارتفاع الحشوة من (١.٢ –٠.٢) م باختلاف درجة حرارة الماء الداخل (٣٧، ٤٠، ٤٥)°مئوية بثبوت معدل التدفق الكتلي للماء، حيث وجد ان حدود التبريد تزداد بزيادة ارتفاع الحشوة ووجد ان(الرطوبة النسبية ، نهج التبريد ،التغير بدرجة الهواء) أظهرت قيم أعلى في فصل الشتاء مقارنة بفصل الصيف بينما اظهرت (الكفاءة، تغير في المحتوى الحراري) قيمة أعلى في فصل الصيف مقارنة بفصل الشتاء. كذلك تم تغير معدل التدفق الكتلي للماء (٧.٥–١)كغم /م بدرجة حرارة الماء الداخل٤٥°مئوية وبثبوت ارتفاع الحشوة عند (١.٢) م وبينت النتائج ان حدود التبريد ، وسعة التبريد والتغير بدرجة الهواء تعطي قيم أعلى في فصل الشتاء مقارنة بفصل الصيف بينما وجد ان التغير المحتوى الحراري و الكفاءة أظهرت قيم أعلى في فصل الصيف مقارنة بالشتاء وهذه النتائج اظهرت تطابق مع البحوث العملية السابقة.

الكلمات الدالة: ابراج التبريد، انتقال الحرارة وانتقال الكتلة، حشوة الفلم ، الجو الحار.

1.INTRODUCTION

Cooling towers are main part of various industrial process such as oil refineries, thermal power plants, petrochemical and chemical plants and HVAC(heating ,venting air condition) system for cooling buildings , it's widely used to reject waste heat into the atmosphere from

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

condenser .This study is concerned with natural draft wet cooling towers (NDWCT) . Economically ,it has to be used with long-term project and has operate effectively for 365 day/year. In a NDWCT in counter flow configuration, there are three heat and mass transfer zones, the spray zone, the packing (fill)zone and the rain zone. The main objective of fill is to offer big surface area and so increase contact surface between air and water and to decrease reduction speed for water drops so more time is available ,where 80–90%of the total heat transfer is rejected [1], the heat transferred in the rain zone comprises 10–20 % of the total heat transfer and the least significant is the spray zone with importance of a few percent.

Air and water flow paths/patterns through the fill depend basically on the fill type used in a cooling tower, film fill is offer both thin film of water and breaking water into small drops.

Through hot weather, NDWCT is lower effective because of the low draft force which can draft air inside cooling tower, therefore it is used in zone of cold weather over all days in the year . Any intends to use NDWCT in hot zones must be taken in account about the air relative humidity or going to use hybrid cooling tower where the use of fan to assist draft is likely. The weather in Iraq is so hot at summer with major advantage for NDWCT which is the dryness of air along all hot season. According to Iraqi weather, worse states are at summer season (hot and dry), where weather changed to be cold and wet at winter. Main different between both states are the amount of heat transfer and mass transfer (sensible and latent heat transfer). High heat transfer ,Less mass transfer at winter, opposite state is noted at summer.

Most of researchers concentrated on studying cooling towers at cold weather where it is more usable. Mainly the researches divided into studying the internal parameters inside tower and studying the environment effects on towers. Kloppers and Kröger [2, 3],have concentrated on studying internal parameters and parts to find empirical correlations that figure out fill loss coefficient data and showed the effect of the Lewis factor (which is relate the heat and mass transfer coefficients) , or Lewis relation, on the performance prediction of natural draft and mechanical draft wet-cooling towers. Qureshi and Zubair [4] showed that a considerable section of the total heat rejected is happen in the spray and rain zones and studied all zones decrease error in heat rejection calculations from 6.5% to 2.65%. Zhai and S. Fu [5] concentrated on the wind effect on cooling tower, showed that wind-break walls placed at the lateral sides of cooling towers perpendicular to the cross-wind is a simple and effective method , and it can recover about 50% of the reduced cooling capacity. Facao and Oliveira [6],focused their attention on the computational analysis of heat and mass transfer in an indirect contact cooling towers. Heidarinejad et al. [7], characterized cooling tower zones, modeled the spray, packing and rain zones, and solved the problem numerically. The authors concluded that in cooling towers a significant portion of the rejected total heat may occur in the zones mentioned .The models developed for these zones are validated by experimental data. Lemouari et al [8], an experimental analysis of simultaneous heat and mass transfer phenomena between water and air by immediate contact in a packed cooling tower has been studied. .Smrekar et al. [9] tried to show how the efficiency of a natural draft cooling tower can be improved by optimizing the heat transfer along the cooling tower packing. Yaqub and Zubair [10],used detailed model of counter flow wet cooling towers in investigating the performance characteristics. The validity of the model is checked by experimental data The thermal performance of the cooling towers is clearly explained in terms of varying air and water temperatures. Reuter and Kröger [11], presented a computational model to calculate the fill performance in a wet cooling tower. When using the methods of the CFD to model the NDWCT performance with isotropic fill resistance, two- or three dimensional models are required , The numerical investigation uses (FLUENT) as a CFD code. Williamson et al. [12] focused on the performance predictions of a simple one-dimensional model and of a two-dimensional axisymmetric numerical model of the NDWCT are compared as to the range of design parameters. The objective of this study is to simulate the effect of the air and water flow rates on the heat and mass transfer coefficient in natural draft wet cooling tower using different inlet water temperatures. Also comparing between different season(winter and summer) using MATLB tools .

2.MATHEMATICAL MODEL

The processes heat and mass transfer through the counter flow cooling tower are mathematically modeled, it is require to simulate the heat and mass transfer problem in the fill zone and requires a solution of the mass and energy transfer equations in the air and water which are numerically solution is developed. There are two basic mathematical model for heat and mass transfer , denominated as Merkel and Poppe models which are used for performing numerical simulations of counter flow cooling towers. The simplest model of heat and mass transfer in the fill is the Merkel's model developed the theory of the evaluation of the thermal performance of cooling tower in 1925 (Osterle, 1991), it relies on some

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

assumptions are :Lewis factor equal to 1, the air at the exit of the tower is saturated and the reduction in the flow of water due to evaporation is neglected in energy balance.

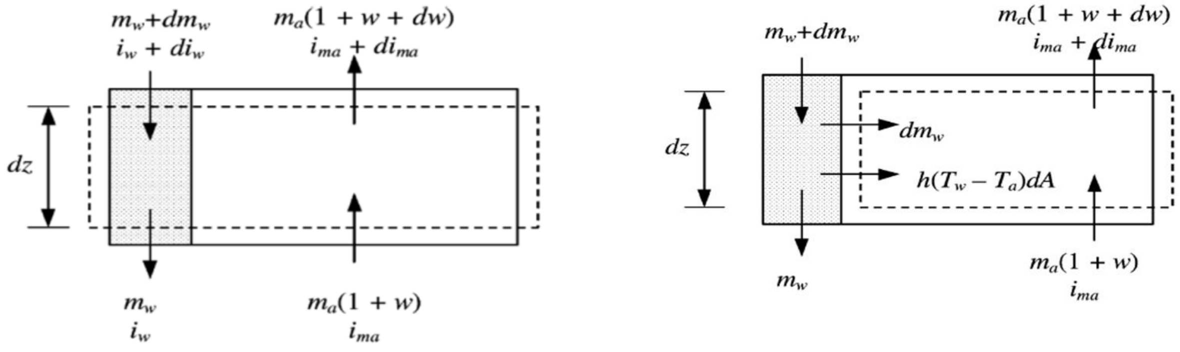

Fig. (1):Contact of air and water in counter flow cooling tower [13]

Applying the mass and energy balance based on figure(1) we get the equations below. For more detail in [14]

$$\frac{di_{ma}}{dz} = \frac{h_m}{m_a}(i_{masw} - i_{ma}) \quad ..(1)$$

i_{ma} is the enthalpy of the air/water vapor mixture(J.Kg^{-1}) ,m_a is mass flow rate of air (Kg.s^{-1}), h_m is mass transfer coefficient (Kg. m^{-2}.s^{-1}) and i_{masw} is enthalpy of supersaturated air (j.kg^{-1}).

$$\frac{dT_W}{dz} = \frac{m_a}{m_W}\frac{1}{cp_W}\frac{di_{ma}}{dz} \quad ..(2)$$

T_w is represent the temperature of water(K) ,m_w is the mass flow rate of water (Kg.s^{-1}) and CP_w is specific heat of water (J.kg^{-1}.K^{-1}) .

Equation (1) represent the variation of air-water vapor mixture, obtained from the mass and energy balance equations for the mixture. Equation (2) represent variation obtained from the energy balance in differential element dz.

By substituting Eq.(2) in Eq.(1) and integrating we get :

$$Me_m = \frac{h_d A}{m_w} = \frac{h_d\, a_{fi} L_{fi} A_{fr}}{m_w} = \int_{T_{wo}}^{T_{wi}} \frac{cp_w\ dT_w}{(i_{masw} - i_{ma})} \quad ..(3)$$

Me_m is Merkel number dimensionless ,a_{fi} is the fill area density (wetted area divided by volume of fill), A_{fr} is the frontal area of the fill(m^2), and subscript (i inlet and o is outlet).

Merkel number is dimensionless coefficient of performance .Eq.3 can solved when the inlet and outlet temperatures of water, mass flow rates of water and air and air inlet conditions in the cooling tower are known. Merkel number where calculated by numerical method such as Chebyshev integration method using MATLAB.

Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

Without assuming the simplification adopted by Merkel ,Poppe sujested that the mass and energy balances originated in Fig.(1) for the saturated and unsaturated air give rise and after algebraic manipulation ,to three differential equations [13]:

$$\frac{d\omega}{dT_w} = \left[\frac{cp_w \left(\frac{m_w}{m_a}\right)(\omega_{SW} - \omega)}{i_{masw} - i_{ma} + (Le_f - 1)\left[i_{masw} - i_{ma} - (\omega_{SW} - \omega) i_v\right] - cp_w\, T_w\, (\omega_{SW} - \omega)}\right] \quad ..(4)$$

ω is specific humidity of air(Kg water/kg air), ω_{sw} specific humidity of saturated air(Kg water/kg air),L_{ef} Lewis factor (relates the heat and mass transfer coefficients) and i_v is the enthalpy of the water vapor.

$$\frac{di_{ma}}{dT_w} = cp_w \frac{m_w}{m_a}\left[1 + \frac{(cp_w\, T_w\, (\omega_{SW} - \omega))}{i_{masw} - i_{ma} + (Le_f - 1)\left[i_{masw} - i_{ma} - (\omega_{SW} - \omega) i_v\right] - cp_w\, T_w\, (\omega_{SW} - \omega)}\right] \quad ..(5)$$

$$\frac{dMe_p}{dT_w} = \left[\frac{cp_w}{i_{masw} - i_{ma} + (Le_f - 1)\left[i_{masw} - i_{ma} - (\omega_{SW} - \omega) i_v\right] - cp_w\, T_w\, (\omega_{SW} - \omega)}\right] \quad ..(6)$$

The Lewis factor can be calculated according to [14]

$$Le_f = 0.865^{\frac{2}{3}} \left(\frac{\frac{\omega_{sw} + 0.622}{\omega + 0.622} - 1}{\ln\left(\frac{\omega_{sw} + 0.622}{\omega + 0.622}\right)} \right) \quad ..(7)$$

The ratio between the mass flow rate of air and water changes as the air moved toward the exit of the tower .This change may by calculated according to the control volume in Fig.(2):

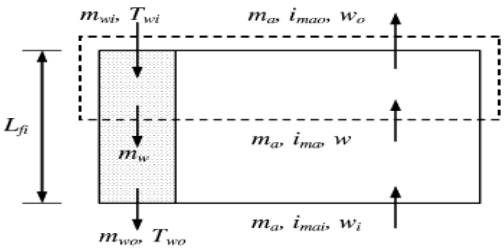

Fig.(2): Control volume of the fill in counter flow cooling tower [13]

$$\frac{m_w}{m_a} = \frac{m_{wi}}{m_a}\left(1 - \frac{m_a}{m_{wi}}\,(\omega_o - \omega)\right) \quad ..(8)$$

For the model proposed by Poppe ,the numerical method used is Runge-Kutta method fourth order.

3.RESULTS AND DISCUSSIONS

In this work ,one dimensional model for the fill zone has been implemented to describe the fill performance for the film fill type .The operating condition and module parameters using in simulation calculation have been taken from North Gas Company.

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

[13] reported that the characterization of the number of differential interval in the cooling tower, ni ,it is required of 5 sub-divisions of the tower to get an appropriate result. In this work were adopted 10 intervals ,as shown in Fig.(3) and Fig.(4)

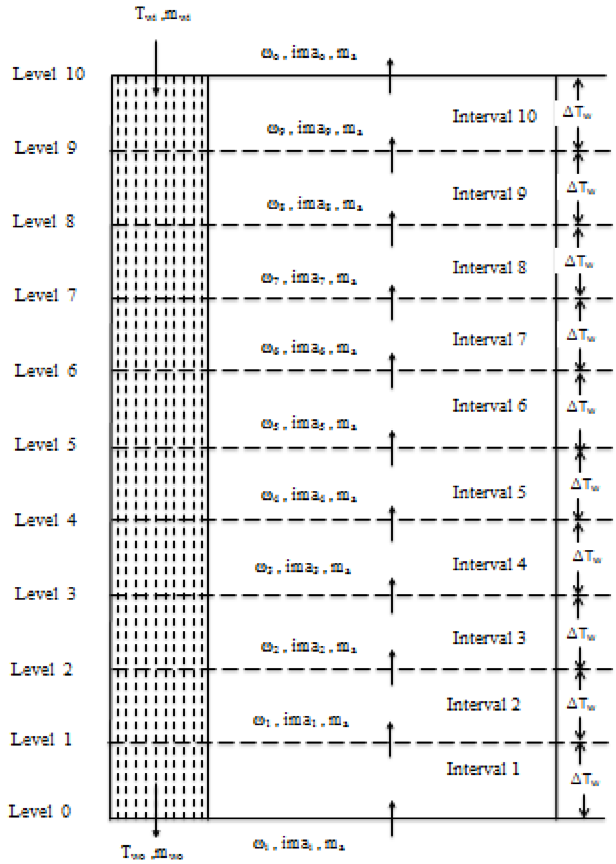

Fig.(3): Counterflow fill divided into ten intervals.

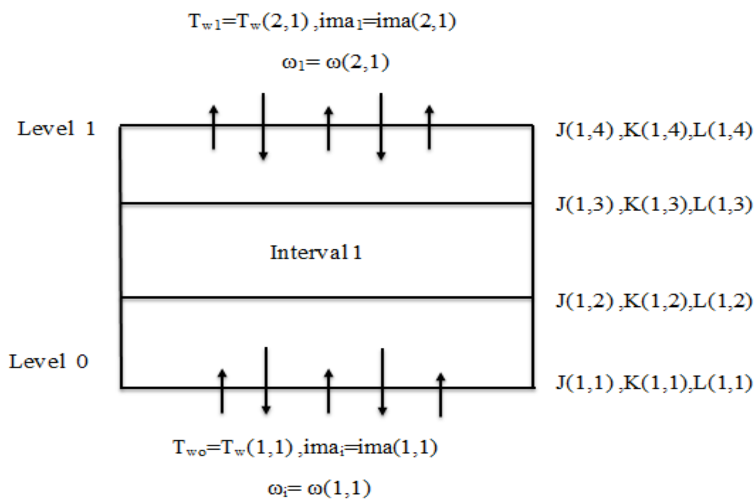

Fig.(4): Subdivision of interval 1 of the fill

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

3.1. The effect of fill height and water inlet temperature

Tables (1),(2) represent the initial condition to predicts the water outlet temperature with different fill height .Water inlet temperature through two different months represent (summer and winter) and the air property calculated from psychometric chart.

Figures (3),(4) represent the influence of the fill height on the prediction water outlet temperature with different initial condition and different water inlet temperature with constant water and air mass flow rates ,it is noticed that the water outlet temperature decrease and the range of cooling increasing with increasing the fill height because of increasing the surface area for heat and mass transfer through the fill.

Table (2): Initial condition for January

Conidition	
Average T_{ai} (^{o}C)	12.65
T_{wb} (^{o}C)	9.38
m_w (Kg/s)	3
m_a (Kg/s)	3
Pressure(pa)	101325
interval	10
Average RH%	66%

Table (1): Initial condition for July

Conidition	
Average T_{ai} (^{o}C)	32.69
T_{wb} (^{o}C)	17.78
m_w (Kg/s)	3
m_a (Kg/s)	3
Pressure(pa)	101325
interval	10
Average RH%	21%

Figures (5),(6) represent the influence of the fill height on the humidity out of air, it is noticed that the humidity ratio increased with increasing the fill height and water inlet temperature cause humidity define as water particles in air and its function of air inlet temperature and relative humidity and according to Eq.(4) its increased with increasing the height of the fill and water temperature.

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

Figures (7),(8) represent the influence of the fill height on the specific enthalpy out of air, it is noticed that the specific enthalpy increased with increasing the fill height and water inlet temperature .

Fig.(9) represent the influence of the fill height on the Merkel number , it is noticed that Merkel number increased very little (approximately constant) with increasing the fill height and water inlet temperature according to empirical equation relate between them .[14]

$$Me/L_{fi} = c^{1}\, G_{w}^{c2}\, G_{a}^{c3}\, Lf_{i}^{c}{}_{4}\, T_{wi}^{c5} \quad (9)$$

Fig.(10) represent the influence of the fill height on the loss coefficient (its loss coefficient of the fill as a function of air and mass flow raters) ,it is noticed that the loss coefficient decrease with increasing the height of fill.

3.2. The Effect of Fill Height on the Performance of The NDWCT at Different Weather Condition.

This study of the research is to find the best operating conditions of Kirkuk weather for the film fill type .The comparison included many tower parameters using many thickness of fill at different water inlet temperature .

1.Cooling tower range

The target of water outlet temperature is to reach till wet bulb temperature of the air enters the tower. Temperature difference between water inlet and water outlet is called tower range. Range (R)=$Tw_{in} - Tw_{out}$. High tower range (>10 ^{o}C) is an indication of good performance of cooling tower.

Fig.(11) represent the range of cooling at 45^{o}C water inlet temperature, the range is higher at the height of the fill up to 1.2 m because when increasing the fill height increases the surface area for more heat and mass transfer. At T_{wi}=45 ^{o}C highest range at summer is (20.1565 ^{o}C) where it is (23.6542 ^{o}C) at winter .It is noticed that the cooling range in winter is higher than in summer .

2. .Tower approach

The contrast between water outlet temperature and wet bulb temperature of air inlet is called tower approach .Tower approach is a function of cooling tower capability. Fig.(12) represent the tower approach at 45^{o}C water inlet temperature . At T_{wi}=45 ^{o}C the highest approach at summer is (7.0635 ^{o}C) where it is (11.9658 ^{o}C) at winter. It is noticed that the tower approach in summer is lower than in winter . the best execution is lowest approach and the highest temperature range of the cooling tower.

3. Tower effectiveness (η)

It represents the ratio of tower range to the total difference between water inlet temperature and wet bulb temperature of air inlet (tower range + tower approach).

$$\eta = (T_{wi} - T_{wo})/(T_{wi} - T_{awb}) \tag{10}$$

Maximum value of tower effectiveness is one when water temperature at outlet equal wet bulb temperature for air at inlet and this can be achieved theoretically only by using infinity fill thickness.[15].Fig.(13) show effectiveness due to fill height. The climacteric relation that made both range and approach are higher at winter made effectiveness higher at summer. At T_{wi}=45 ^oC effectiveness at summer is (0.740503) where it is (0.664071) at winter at 1.2m fill height .It is noticed that tower effectiveness is higher in summer than in winter .

4.Heat and mass transfer

It is impact by rising air enthalpy .Change in enthalpy can be higher at winter or summer depends on the aggregate energy added to air. It is obvious that mass transfer plays the main role at summer while heat transfer plays that role at winter .Fig.(14) show that the air enthalpy change is mostly higher at summer .Results show that at T_{wi}=45 ^oC air enthalpy change at summer is (101.5702 kj/kg) where it is (87.55769 kj/kg) at winter .

5.Dry bulb temperature change

It is higher at winter and can be negative value at summer. The temperature of cold air at winter will increase due to heat transfer with hot water inside cooling tower at interface area. At summer, inlet air temperature is already high and may decrease because of the big change in humidity due to high mass transfer. Change in air temperature inside tower is shown in Fig.(15) the temperature at T_{wi}=45 ^oC at summer is (3.4345 ^oC) where it is (22.269 ^oC) at winter .The validation of the present work with the experimental data of [16] is shown in table below for the effect of water flow rate change on the cooling range , tower approach , effectiveness and air temperature change in the tower , the inlet water temperature 45 ^oC while the experimental work done at(50 ^oC) used .The data was taken from the cooling tower of North Gas Company. The figures (16,17,18,19) shows good agreement through different season .

Table (3): Comparison of experimental result with the peresent simulation result

Parameter	(Mahdi and Al-Hachami) [16]		Present work	
Season	summer	Winter	Summer	Winter
Average range of cooling (°C)	9.117	9.817	17.8665	21.1662
Tower approach (°C)	24.38	29.58	14.1021	19.4435
Effectiveness %	27.2	24.9	65.6375	59.4222
Enthalpy change of air (kj/kg)	42.45	35.67	114.0104	106.7796
Average air temperature increase (°C)	1.4	7.85	23.7363	37.934

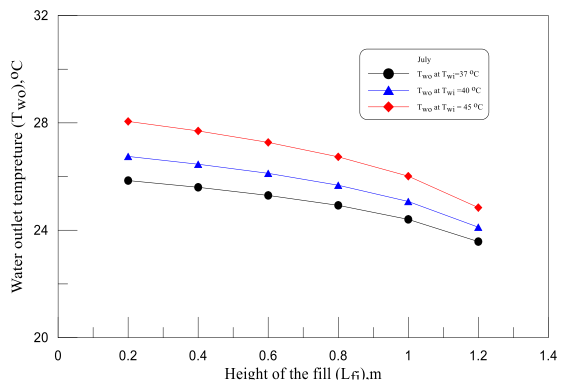

Fig.(3): The effect of fill height on predicted water outlet temperature for different water inlet temperature at constant water and air flow rates for July

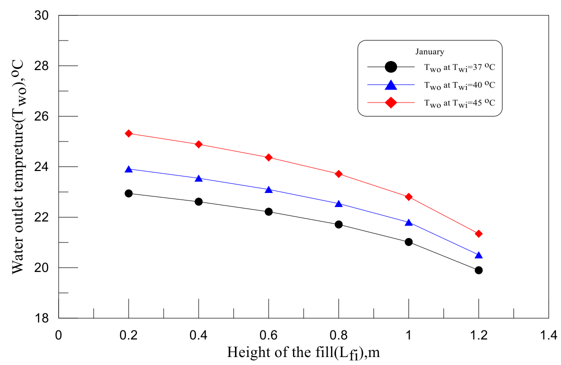

Fig.(4): The effect of fill height on predicted water outlet temperature for different water inlet temperature at constant water and air flow rates for January

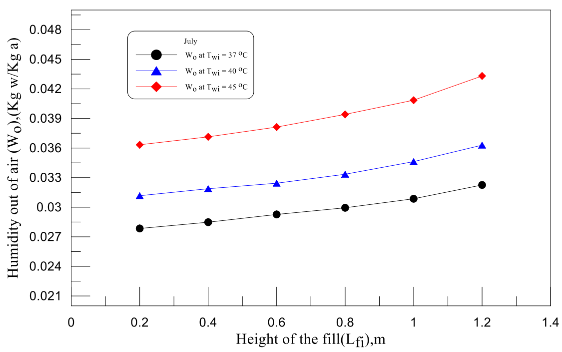

Fig.(5): The effect of fill height on predicted humidity out of air for different water inlet temperature at constant water and air flow rates for July

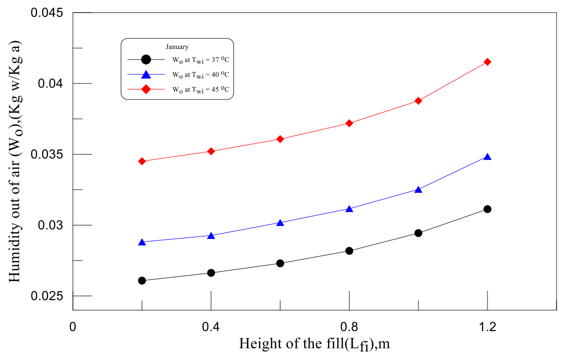

Fig.(6): The effect of fill height on predicted humidity out of air for different water inlet temperature at constant water and air flow rates for January

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

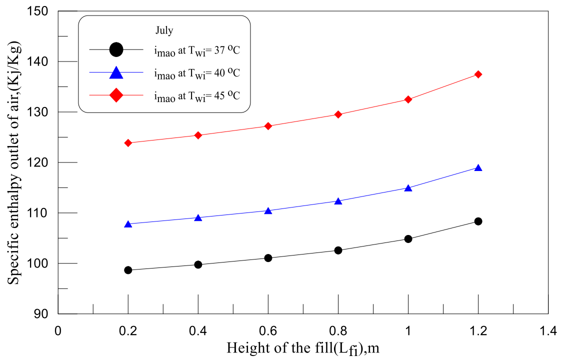

Fig.(7): The effect of fill height on predicted specific enthalpy outlet of air for different water inlet temperature at constant water and air flow rates month July

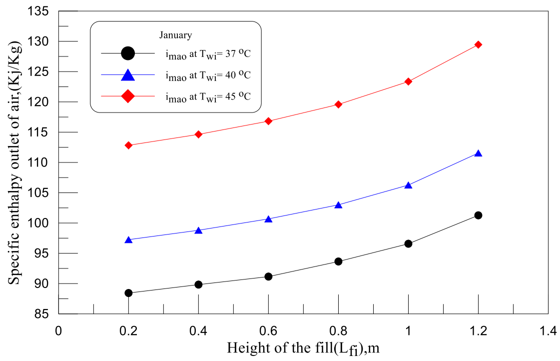

Fig.(8): The effect of fill height on predicted specific enthalpy outlet of air for different water inlet temperature at constant water and air flow rates for January

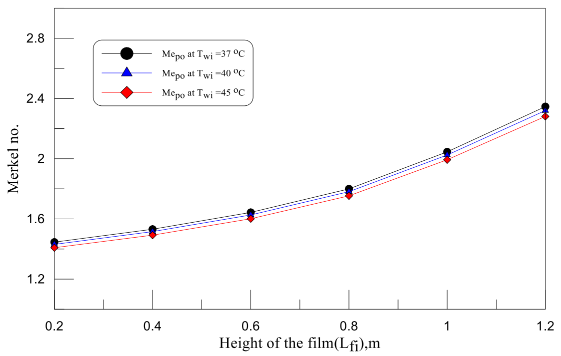

Fig.(9): The effect of fill height on Merkel number for different water inlet temperature at constant water and air flow rates.

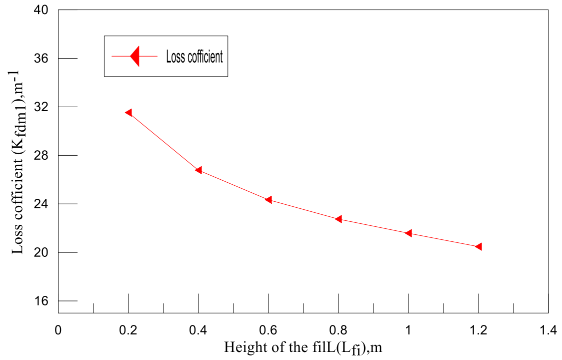

Fig.(10): The effect of fill height on loss coefficient with different water inlet temperature at constant water and air flow rates

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

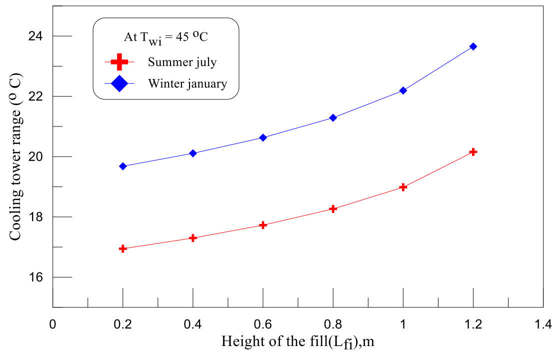

Fig.(11): The effect of fill height on the range of cooling at T_{wi}= 45°C during different season.

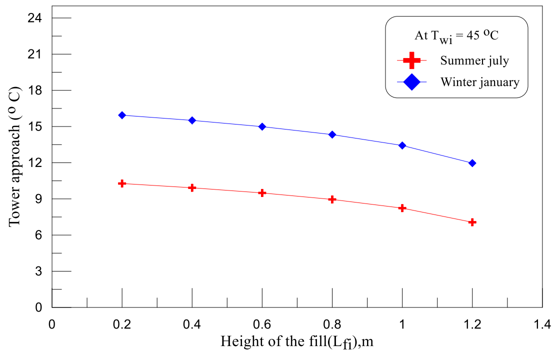

Fig.(12): The effect of fill height on the tower approach at T_{wi}= 45°C during different season.

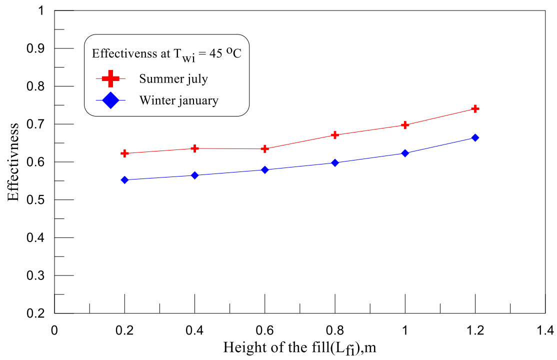

Fig.(13): The effect of fill height on the effectiveness at T_{wi}= 45°C during different season.

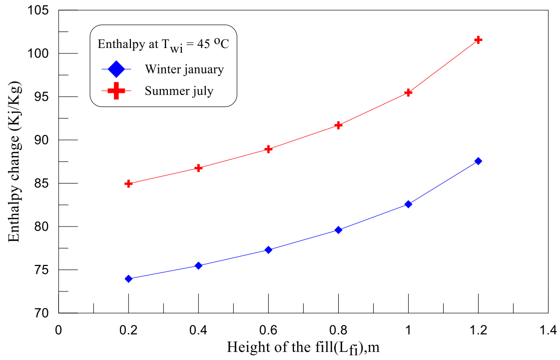

Fig.(14): The effect of fill height on the enthalpy change of air at T_{wi}= 45 °C during different season.

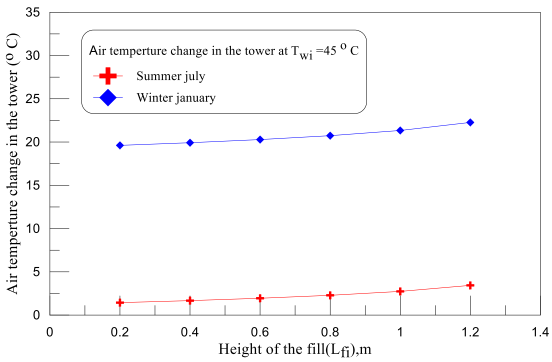

Fig.(15): The effect of fill height on air temperature in the air change at T_{wi}= 45 °C during different season.

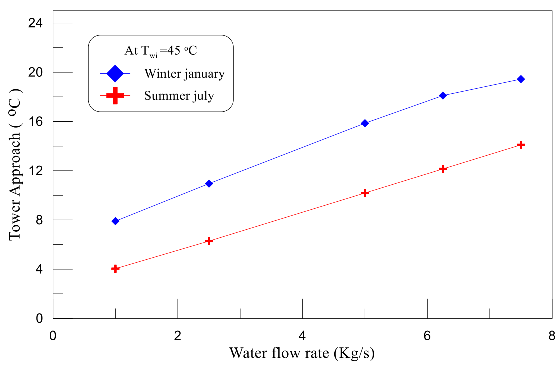

Fig.(16): The effect of water flow rate change on tower approach at T_{wi}=45 °C using film fill.

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

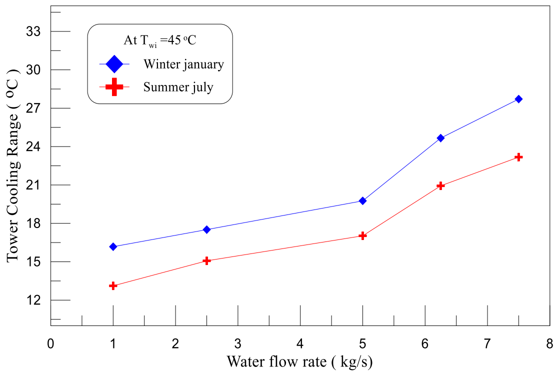

Fig.(17): The effect of water flow rate change on cooling range at T_{wi}=45 ^{o}C using film fill.

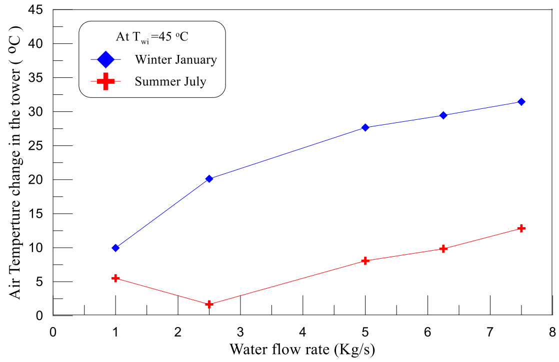

Fig.(18): The effect of water flow rate change on air temperature change at T_{wi}=45 ^{o}C using film fill.

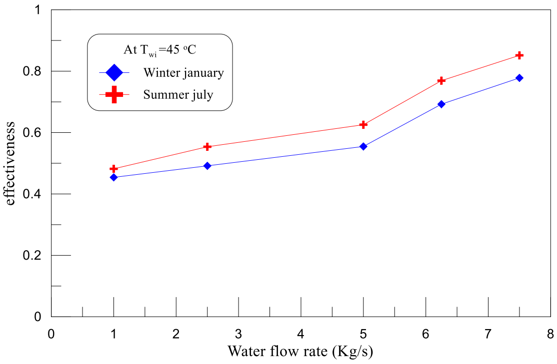

Fig.(19): The effect of water flow rate change on effectiveness at T_{wi}=45 ^{o}C using film fill.

4.CONCLUSION

1. When the fill height increase with different water inlet temperature the water outlet temperature decrease. The outlet humidity ,the outlet enthalpy of air and the range of cooling are increase ,it is noticed that the cooling range ,tower approach ,heat rejected and air temperature change are in winter higher than in summer while air enthalpy and effectiveness is higher at summer .

2. The loss coefficient decrease with increasing the height of the fill.

3. Natural draft wet cooling tower can be utilized at both (cold , wet) and (hot ,dry).

4. Air enthalpy change ,and effectiveness with change in mass flow rate are higher at summer than at winter which can recorded as a feature at summer and that mean high latent transfer, the cooling efficiency difference between summer and winter season is= 6.2153% when the water mass flow rate change and the difference between summer and winter is about 7.6432% when the fill height change .

5. Cooling range and cooling capacity are the main feature for the tower ,the larger cooling range produces a closer approach (colder outlet temperature) and they are higher at winter when the water mass flow rate is increase with different initial condition.

6. Relative humidity is higher in winter so the losses of the cooling tower is higher in winter compare to summer season ,it may conclude that by increasing the efficiency of the cooling tower is built in non-coastal area (humidity is low) we increase the cooling tower efficiency **.**

REFERENCES

[1] D.G. Kröger, ***Air-cooled heat exchangers and cooling towers***. Vol. 1. 2004: PennWell Books.

[2] J.C. Kloppers, and D.G. Kröger, ***The Lewis factor and its influence on the performance prediction `of wet-cooling towers***. International Journal of Thermal Sciences, 2005. **44**(9): p. 879-884.

[3] J.C. Kloppers, and D.G. Kröger, ***Loss coefficient correlation for wet-cooling tower fills.*** Applied Thermal Engineering, 2003. **23**(17): p. 2201-2211.

[4] B. A. Qureshi, and S.M. Zubair, ***A complete model of wet cooling towers with fouling in fills.*** Applied Thermal Engineering, 2006. **26**(16): p. 1982-1989.

[5] Z. Zhai, and S. Fu, ***Improving cooling efficiency of dry-cooling towers under cross-wind conditions by using wind-break methods.*** Applied Thermal Engineering, 2006. **26**(10): p. 1008-1017.

[6] J. Facao, and A.C. Oliveira, ***Heat and mass transfer in an indirect contact cooling tower: CFD simulation and experiment***. Numerical Heat Transfer, Part A: Applications, 2008. **54**(10): p. 933-944.

[7] G. Heidarinejad, M. Karami, and S. Delfani, ***Numerical simulation of counter-flow wet-cooling towers.*** International Journal of Refrigeration, 2009. **32**(5): p. 996-1002.

[8] M. Lemouari, and M. Boumaza, ***Experimental investigation of the performance characteristics of a counterflow wet cooling tower***. International Journal of Thermal Sciences, 2010. **49**(10): p. 2049-2056.

[9] J.Smrekar, J. Oman, and B. Širok, ***Improving the efficiency of natural draft cooling towers.*** Energy Conversion and Management, 2006. **47**(9): p. 1086-1100.

[10] M. Yaqub, and S.M. Zubair, ***Performance characteristics of counter flow wet cooling towers.*** energy conversion and management, 2003. **44**(13): p. 2073-2091.

[11] H.C. Reuter, and D.G. Kröger, ***Computational models for predicting cooling tower fill performance in cross-counterflow configuration.*** Journal of Thermal Science and Engineering Applications, 2012. **4**(2): p. 021003.

[12] N.Williamson, S. Armfield, and M. Behnia, ***Numerical simulation of flow in a natural draft wet cooling tower–The effect of radial thermofluid fields***. Applied Thermal Engineering, 2008. **28**(2): p. 178-189.

[13] J.C. Kloppers, and D. Kröger, ***A critical investigation into the heat and mass transfer analysis of counterflow wet-cooling towers.*** International Journal of Heat and Mass Transfer, 2005. **48**(3): p. 765-777.

[14] K. K.Sanarya , Simulation model for improving cooling tower , 2016 Msc thesis.

[15] F. Bošnjaković, ***Technical thermodynamics***. 1965: Holt, Rinehart and Winston.

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 11, Issue 3, September 2016 , p.p(186-202)
ISSN 1992 – 0849

[16] Q.S.Mahdi, and M.R. Al-Hachami, ***Performance Comparison for NDWCT Using Trickle Fill at Different Weather Conditions.*** International Journal of Engineering Trends and Technology. **19**: p. 134-139 .

[17] J.H. Mathews, ***Numerical methods for mathematics, science and engineering*.** 1992: Prentice-Hall.

AUTHOR

Sanarya K. Kamal: received B.Sc in Chemical Engineering /University of Tikrit / Tikrit-Iraq in 2013.She is now Msc student in Chemical department /collage of engineering- Tikrit University .