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Optimum Design of Evaporative Air Cooler
التصميم الامثل لمبردة هواء تبخيرية

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Abstract

In this paper, the parameters affecting thermal performance of evaporative air cooler was studied using experimental data of A.T.,Marouky[4]. Also, the research including studying the time that needed to keep the packing of air cooler wetted enough to reach the suitable temperature to avoid water growling. This was performed by using different types of packing like (carton, foam filter, palm fiber, palm pinnae, palm rachis and wooden packing).

الخلاصة

يهدف هذا البحث لدراسة العوامل التي تؤثر على الاداء الحراري لمبردة الهواء التبخيرية بالاعتماد على نتائج عملية قام بها احد الباحثين(4) وكذلك في هذا البحث تمت دراسة الوقت الازم لبقاء حشوة المبردة رطبة اطول فترة للوصول الى درجة الحراة الملائمة لتجنب الهدر في الماء باستخدام انواع مختلفة من الحشوات (الكارتونية، الاسفنجية، ليف النخيل ,خوص النخيل، جريدة النخيل والحشوة الخشبية)

Introduction:-

The human race has been able to use up a great portion of the natural resources of the earth and has proceeded to pollute the air we breathe and (according to the experts) burn a hole in the zone layer in the over use of chloro fluoro carbons (CFC's) which many cause global warming. Conventional air conditioning is one of the major contributors of CFCs into the atmosphere. An alternative type of cooling, which does not expel CFCs is highly desirable as one important step in the correction of this problem. So, this is why adiabatic cooling is environmentally friendly because it is a passive cooling method that does not expel CFCs. It is 100% fresh air-cooling which even helps to clean the air it cools. (Robert E. Frost, 1996) [6].

Adiabatic cooling is the use of adiabatic process to cool the air passing through a wetted cooling media or a spray of water. The ancient Egyptians hung wet mats on their doors and windows, and wind blowing through the mats cooled the air-the first attempt at air conditioning. This basic idea was refined through the centuries: mechanical fans to provide air movement in the 16th century, cooling towers with fans that blew water cooled air inside factories in the early 19th century, swamp coolers in the 20th century. Modern technology has dramatically increased the efficiency and effectiveness of adiabatic cooling. (WESCOR, 1992)[5]

Adiabatic saturation are good for those who wants cost cutting budgets because it is designed without a refrigerant, condenser, pressurized pipes to provide comfort cooling, not only the materials are cheap but lesser energy consumption. Another is it uses 100% fresh air so it is healthy because it brings in outside air and exhaust stale air, smoke, odors and germs. It helps maintain natural humidity levels, which benefits both people and furniture and cuts static electricity. Lastly it does not need an air tight structure for maximum efficiency, so building occupants can open doors and windows.(VehiCool, 1999)[8]

Shakerin and Contreras (1998) [7], an instrumented evaporative cooler was developed for use in an undergraduate laboratory in psychrometrics. The air temperature and relative humidity at the inlet and outlet, and the air flow and water consumption rates were measured. Given the experimental data for the inlet air and water, the outlet air properties were predicted using psychrometric equations, and a good comparison was found with the experimental result.

Qureshi and Zubair (2007) [12], the accurate prediction of various aspects of thermal behavior of evaporative fluid coolers is very important for both design and rating calculations. Exactly predicting evaporation losses is significant since the process fluid is cooled primarily by evaporation of a portion of the recirculating water that causes the concentration of dissolved solids and other impurities to increase. An empirical relation to predict evaporation losses is developed on the basis of the rule of thumb recommended by manufacturers, which is simple and accurate with a wide range of applicability. The predicted values are in good agreement with the numerical values obtained from the calibrated model where the maximum error was found to be approximately 4% but often s of heat and mass transfer in primary and secondary air and water flows

GH. Heiderinejad and M. Bozorgmehr (2007) [11], indirect evaporative cooling in an air cooler has been modeled. This model has been obtained from the governing equation of heat and mass transfer in primary and secondary air and water flows. Factors affecting on evaporative cooling performance such as mass flow rates, geometry and flow configuration has been investigated. Results shows that cooling efficiency considerably depends on mass flow rates ratio of primary and secondary air flows and spacing between plates of wet and dry passages. The performance of this cooling system for typical conditions of some cities has been investigated. Using a first stage indirect evaporative cooling prior to conventional direct evaporative cooling systems in most regions of Iran will provide cooling comfort conditions as a low energy consumer alternative.

Mizushina (2008) [13], developed two different rating methods for evaporative coolers; one, a numerical procedure and the other, a straightforward analytical model

Finlay and Grant (2009) [14], simplified the equations describing the mass transfer in an evaporative cooler by assuming that the vapor pressure of saturated moist air is a linear function of temperature. The model can be expected to be very accurate, as this is the only major assumption made in the analytical formulation. The final design equations are somewhat complicated and therefore require a numerical solution procedure.

R. Effatenjad and A. B. Salehian (2009) [15], a new method for energy labeling of evaporative air coolers in Iran with national standard number of 4910-2. Procedure of test has been developed typically in Iranian standard IS3315-1974 and Australian Standard AS 2913-1978. The criteria are calculate based on energy consumption and evaporative air cooler test results in the past three years and have developed experimentally and analytically. EER (Energy Efficiency Ratio) is defined for energy labeling in Iran. Index of the previous standard of energy consumption and cooler label is used sensible cooling capacity of air power of the total input. EER is the sensible cooling capacity of air power of the total input power as well.

The purpose of this study is to evaluate the time keeping the packing wetted in the adiabatic saturation. Water is used as cooling agent. This study analyses the falling of temperature as the unsaturated air passes the spray of water in packing and leaving as a saturated air with a lower temperature comparing to the temperature when enters the adiabatic air cooling.

In this paper the instrument used an window of air cooler as shown in figs (1), (2) and put the measurement devices to measure the temperatures (input dry and wet bulb and output dry and wet bulb), mass flow rate of water by using rotameter, heaters used in the input of air to give wanted temperature, pitot static tube to measure the flow rate of air and voltmeter and electrical supply wattmeter and in fig(3) shows the methods that used to distribution water on pad.

Governing Equations:

Evaporative air cooler are an efficient and effective machine for cooling. As a direct placement for air conditioning in dry climates like Iraq, it is an example of how man can work with nature. Being so much less expensive than air conditioning. Re circulated spray of water is used to provide cool air. In order to perpetuate the process it is necessary to use a water pump to continuously re circulated spray of water.

After the adiabatic saturation has achieved a steady state condition, certain combinations of air will result in a given wet bulb temperature and can be defined by writing an energy balance about the saturation. This energy balance, written on the basis of unit mass flow of air.

$h_1 = h_2 - (w_o - w_i) * h_f$ [8] ….. (1)

If the heat exchange contact between the air and water spray is 100%, the dry bulb temperature of the entering air should drop down to its wet bulb temperature, the air should become fully saturated. This is however never achieved because of the bypass factor, a small portion of the air will not come in contact with spray and so it comes out of the saturated at the same condition as it entered. Hence the total air quantity at the outlet of the saturated is a mixture of the by passed and the saturated air. Thus the evaporative cooler efficiency (or saturation efficiency) of the saturation is expressed as %.[4]

$$\eta = \frac{t_{dbi} - t_{dbo}}{t_{dbi} - t_{wbi}} * 100\% \quad ..... (2)$$

The mass flow rate of air that exit from evaporative cooler can be calculated

$$m_o = \rho_o * Q_o \quad ..... (3)$$

The air that enter the cooler include quantity of water vapor calculated by equation (4)

$$m_i = m_{wi} + m_a \quad ..... (4)$$

Divide equation (4) on (m_a) to get

$$m_a = \frac{m_i}{1 + w_i} \quad ..... (5)$$

Where $w_i = \frac{m_{wi}}{m_a}$

By the same method that apply on air that exit from air cooler to get

$$m_a = \frac{m_o}{1 + w_o} \quad ..... (6)$$

Where $w_o = \frac{m_{wo}}{m_a}$

Therefore we can calculate the water evaporative in the air through the Packing from the relationship

$$m_v = m_a * (w_o - w_i) \quad ..... (7)$$

The optimum time that needed to reach for the suitable temperature of air that exit from air cooler calculated from this relationship

$$\tau = \rho_w * \frac{V}{m_v * 60} \quad ..... (8)$$

The electrical power required to move a volume rate of air through the Packing (p_s) is define the power that consumption air cooler engine to decrease the one kilogram temperature of air one siliceous degree.

$$p_s = \frac{P}{m_i * (t_{dbi} - t_{dbo})}$$ ….. (9)

The relative density of packing is the ratio between the density of packing to the material density that manufacturing from her packing.

$$\rho_s = \frac{\rho_a}{\rho_p}$$ ….. (10)

Where $\rho_a = \frac{m_p}{V_t}$, $V_t = A_t * t$

The total volume of packing (V_p) $V_p = \frac{m_p}{\rho_p}$ ….. (11)

The mean velocity of air that passes the packing calculate from relationship

$$U_{ap} = \frac{Q_a}{A_a}$$ ….. (12)

Where $A_a = A_t - A_p$ ….. (13)

To find the (A_p) equals the ratio between total volume of packing to total volume of window and ratio between section area of packing material to section area of window orifice.

$$\frac{V_p}{V_t} = \frac{A_p}{A_t}$$ [4] ….. (14)

Discussion:

The results show, the water distribution method effects on optimum time to reach the comfortable cooling temperature and efficiency of cooler. Tube with two ends closed method; distribute the water directly to the packing from the upper edge of window without distributed channel. These tubes had holes (1.5 mm diameter) and the space between two holes (1.8 cm). Therefore this method gave less wanted time and more efficiency than method of tube with two holes provides the water directly from upper window to the packing from the holes inside the distributed channel. The temperature regularity of outer air passing through evaporative cooler in cross flow with water in window in first method, lead to increase the efficiency by ratio exceed (8%) because the water in the second method is concentrating in the middle of window. This fact is illustrated in figures (4) and (5).

Studying the effect of changing water flow rate that using for wetting the packing from ($9.2 * 10^{-6} m^3/sec$) to ($35 * 10^{-6} m^3/sec$). The results show change of water flow rate effects on water evaporative rate, cooler efficiency, and specific electrical power, optimum time for cooling and specific packing density. Increasing water flow rate increases the efficiency, decreases the specific power and the specific packing, because the increasing of water flow rate increases the wetted surface area therefore the time that required for cooling decrease as shown in figures (6) and (7).

The efficiency of cooler decreases when increases the volumetric air flow rate in one water flow rate that water using to wetted the packing of air cooler because the efficiency related with water evaporative rate and the evaporative related with air velocity. Also the results shows the increasing of volumetric air flow rate decreasing the time required to cooling in one water flow rate as shown in figures (6) and (7).

Study the effect of wood packing thickness at constant mass and effect of mass at constant thickness are very important to get the optimum performance of packing. When increasing the thickness of packing at constant mass, the efficiency increasing because increasing the time interval of air that required to passing the packing called (contact interval). This fact means increasing the wetted surface area by water and continuity evaporating. In addition the efficiency increasing, decrease the specific density and specific electrical power because decreasing the packing resistance to passing the air. Increasing the mass of packing at constant thickness increase the efficiency of cooler because increasing the surface area of wetted parts of packing and decreasing of specific electrical power, when increase the mass of packing that mean increase the contact between parts of packing that work to decrease the wetted surface area which contact the passing air through the packing therefore few amount of water evaporate. Figure (8) show increasing the mass of packing and thickness decrease the optimum time.

In the research using different types of packing as alternatives packing to wood packing. The results appears that some of these packing has high ability to keep the water therefore increase the humid efficiency as palm fiber, carton and palm pinnae but palm rachis and foam filter has little ability to keep the water. The results had shown when increase the thickness and mass of packing the efficiency increase the wetted surface area by water and mannequin for evaporate. And increasing of specific mass extrusive with increasing the thickness and mass of packing and from the results find decreasing the time wanted to cooling as shown in figure (9) and decreasing the specific electrical power when the mass and thickness of packing increased.

results show that the palm rachis packing is the best between the other packing and using commercial alternative packing from wood packing because the constant validity of packing as the efficiency, specific electrical power, specific packing mass and the time wanted to cool when compared with wood packing in the same water and air flow rate and thickness and mass of packing. The palm fiber and palm pinnae packing are a good from ability to keeping the water and wetting but the need electrical power to pass the same quantity of air through the packing is high as compared with wood packing.

Conclusions:

1. Evaporative air cooler can achieve comfort cooling with the use of water as the cooling agent.
2. The best time wanted to keep the packing wetted for suitable cooling is 28 minutes in any type of packing by using control system.
3. The best type of packing is palm rachis because the falling of temperature and consumption of electrical power.
4. The best method to distributed water is the porous closed tube because it distributed water on all packing therefore it’s give the optimum design of packing.

Symbols:

A_a	Area of space in packing	(m^2)
A_p	Packing cross section area	(m^2)
A_t	Packing area (cooler window)	(m^2)
h1	Specific enthalpy of saturated moist air at temperature t*	(kj/kg)
h2	Specific enthalpy of saturated moist air entering the evaporative cooler	(kj/kg)
hf	Specific enthalpy of water at temperature t*	(kj/kg)
m_{-}	Output air mass flow rate	(k_g/s)
m_a	Dry air mass flow rate	(k_g/s)
m_i	Inlet air mass flow rate	(k_g/s)
m_p	Packing mass	(k_g)
m_v	Water evaporative rate	(k_g/s)
m_{wi}	Inlet water vapor flow rate in air	(k_g/s)
m_{wo}	Outlet water vapor flow rate in air	(k_g/s)
P	Electrical power consumption	(W)
p_s	Specific power	$(W/k_{ga.}{}^{\circ}C/s)$
Q_{-}	Volumetric flow rate of output air	(m^3/s)
Q_a	Volumetric flow rate of air	(m^3/s)
t	Thickness of packing	(m)
t_{dbi}	Inlet dry bulb temperature of air	$(^{\circ}C)$
t_{dbo}	Outlet dry bulb temperature of air	(ºC)
t*	Temperature of adiabatic saturation	$(^{\circ}C)$
U_{ap}	Mean velocity of air pass through the packing	(m/s)
V	Volume of water consumption	(m^3)
V_p	Total volume of packing	(m^3)
V_t	Total volume of air cooler window	(m^3)
wi	The humidity ratio of moist air entering evaporative cooler	(kg/kgd.a)
wo	The humidity ratio of moist air at temperature t*	(kg/kgd.a)
w_i	Inlet moisture content	$(k_g/k_{g\ dry\ air})$
w_o	Outlet moisture content	$(k_g/k_{g\ dry\ air})$
η	Efficiency of air cooler	(%)
ρ_{-}	Outlet air density	$(k_g/m^{3)}$
ρ_a	Air density	(k_g/m^3)
ρ_p	Density of packing	(k_g/m^3)
ρ_s	Specific density of packing	(k_g/m^3)
ρ_w	Water density	(k_g/m^3)
τ	Water density	(k_g/m^3)

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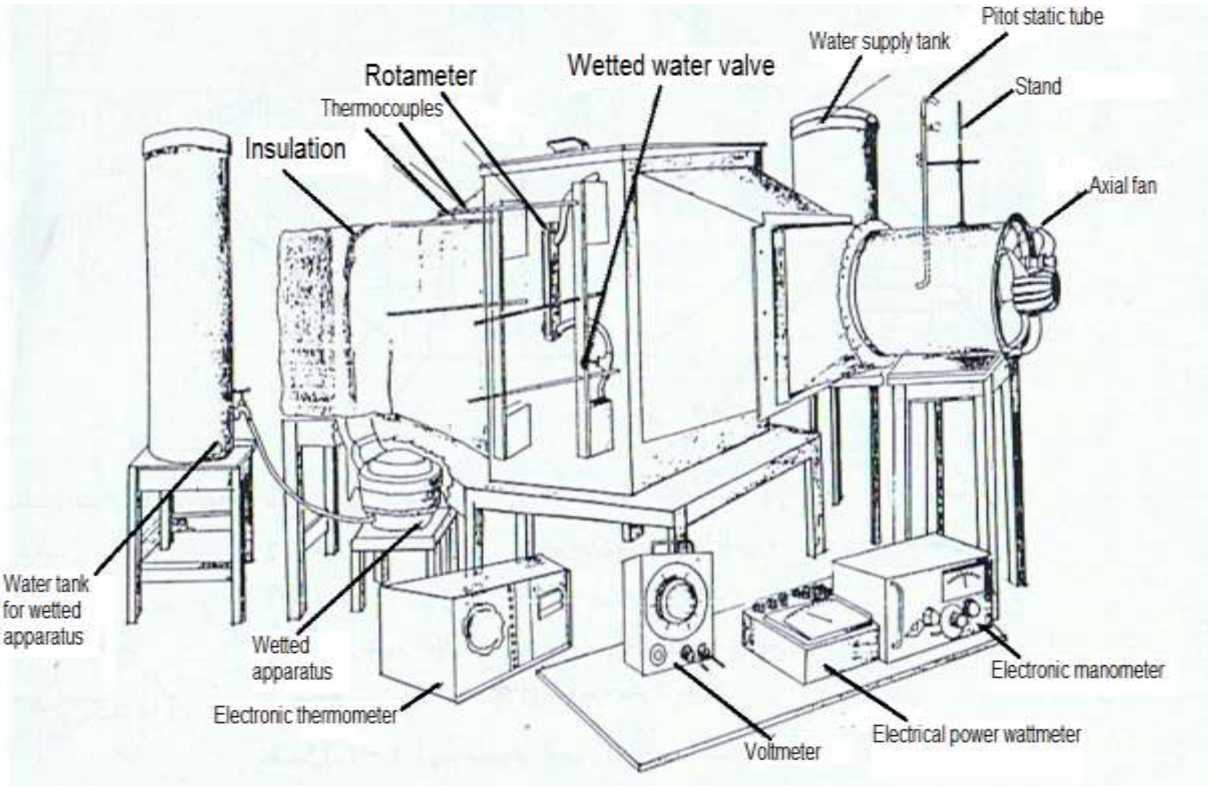
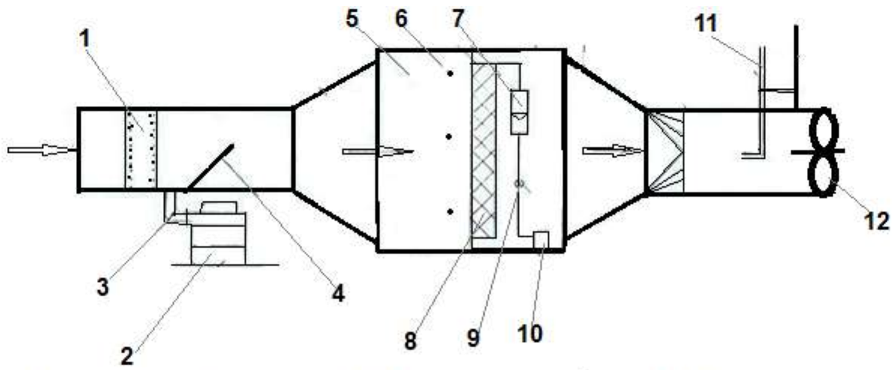


Fig. (1): Schematic drawing for equipment



1. Electrical heaters
2. Wetted apparatus
3. Valve
4. Inclined plate
5. Wood box
6. Thermocouples
7. Rotameter
8. Pads
9. Valve
10. Water pump
11. Pitot static tube
12. Axial fan

Fig. (2): Schematic sketch for equipment

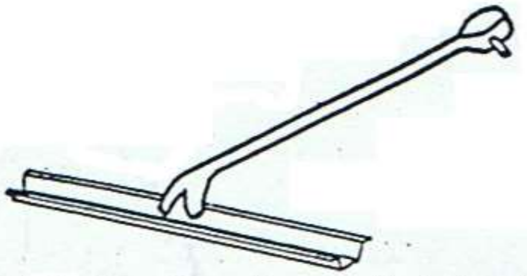


Fig (3a): One tube with two orifaces provide distributed channel

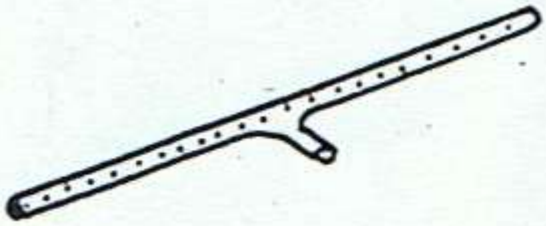


Fig (3b): Porous closed tube

Fig. (3): Water distribution methods that used to wet the pad

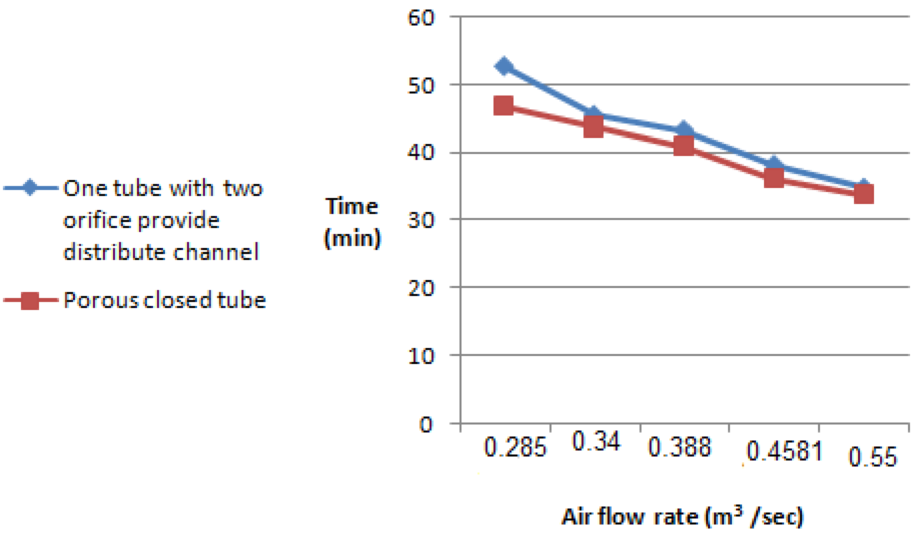


Fig. (4): Changing time wanted to cool with air flow rate by using the method1and method2

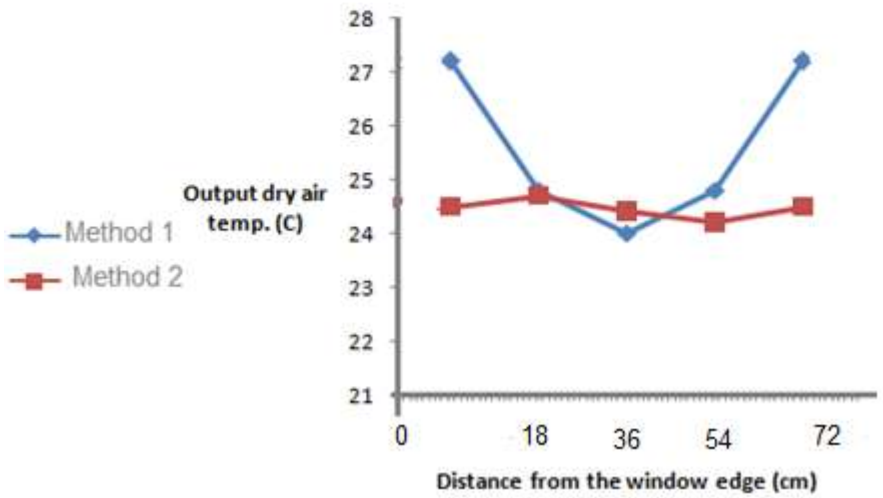


Fig. (5): Changing dry air temperature that output from air cooler with Distance from the window edge by using the
method1 (one tube with two orifices provide distribute channel)
method2 (Porous closed tube (without distribute channel)

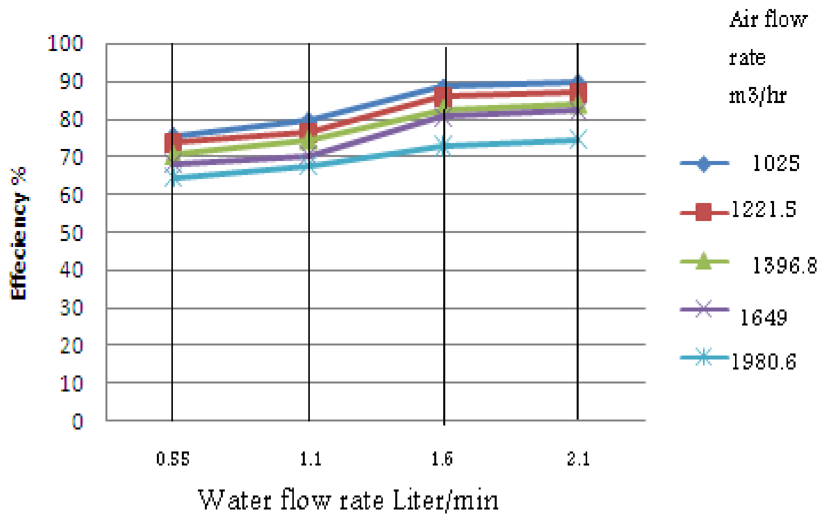


Fig. (6): Relationship between efficiency and water flow rate and air flow rate

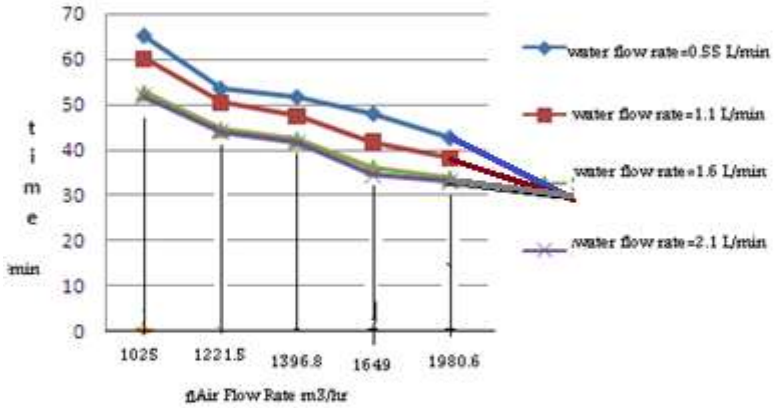


Fig. (7): Relationship between Time and water flow rate and air flow rate.

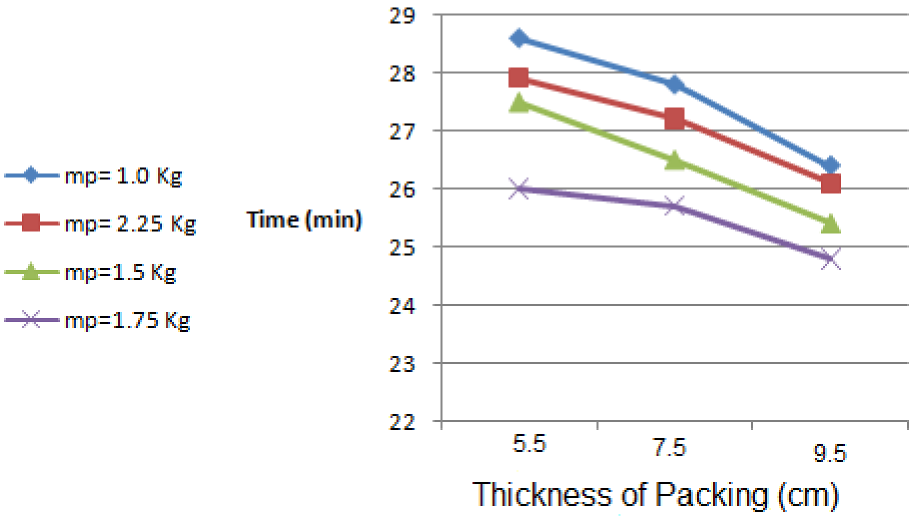


Fig. (8): The effect of thickness and mass of packing on time.

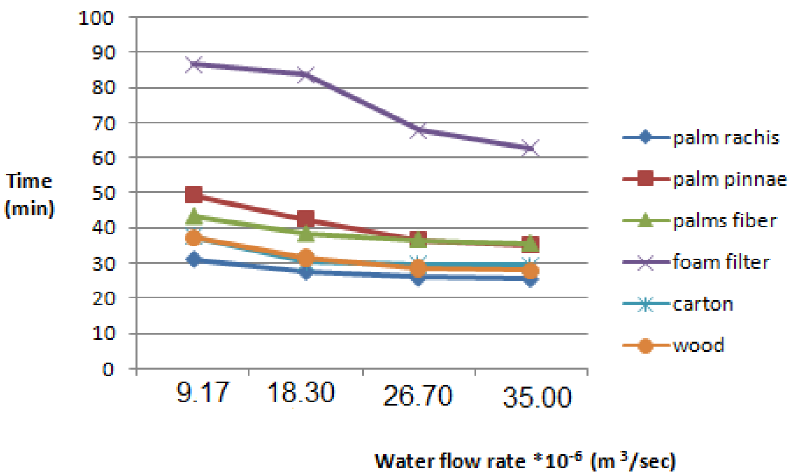


Fig. (9): Time Changing with Types of Packing.

Group Five : Palms pinnae Packing

table (13): Porous closed tube (without distribute channel)

mp= 1.0 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C

1. t= 4 cm P=268 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	33.1	22.5	22	54.1	0.0026	10.108	3.774	49.5	1.12
2	18.3	31.4	22.5	22.5	61.8	0.0031	8.849	3.269	42.4	1.12
3	26.7	30.5	22.8	22.5	65.9	0.0035	8.289	3.081	36.4	1.12
4	35	30	22.8	22.5	67.2	0.0036	8.115	3.017	35.1	1.12

table (14): Porous closed tube (without distribute channel)

mp= 1.5 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C

2. t= 5 cm P=289 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	31.9	22.8	22.5	59.5	0.0032	9.882	5.129	40.5	1.17
2	18.3	29.9	23	23	68.8	0.004	8.552	4.439	33.2	1.17
3	26.7	29.2	23	23	71.8	0.0041	8.159	4.235	31.7	1.17
4	35	28.8	23	22.9	73.6	0.0043	7.949	4.125	30.9	1.17

table (15): Porous closed tube (without distribute channel)

mp= 1.75 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C

3. t= 5.5 cm P=300 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	31.7	22.8	22.5	60.4	0.0033	10.101	5.892	39.8	1.2
2	18.3	29.6	23	22.5	70	0.0041	8.693	5.072	32.6	1.2
3	26.7	29	23.1	22.5	72.7	0.0044	8.363	4.879	30.7	1.2
4	35	28.7	23	22.5	74.1	0.0045	8.206	4.787	29.8	1.2

Group Six : Palm rachis Packing

table (16): Porous closed tube (without distribute channel)

mp= 0.5 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C

1. t= 4.5 cm P=229 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	30.1	23	23	67.7	0.004	6.896	1.499	33.65	1
2	18.3	29	23	23	72.7	0.0043	6.369	1.384	31.3	1
3	26.7	28.3	23.1	23	75.9	0.0047	6.137	1.334	29.4	1
4	35	28	23.1	23	77.2	0.0047	6	1.31	28.9	1

table (17): Porous closed tube (without distribute channel)

mp= 0.7 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C

2. t= 5.5 cm P=237 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	28.5	22.8	22.5	75	0.0041	6.35	1.875	31.7	1.01
2	18.3	27.5	23	23	79.5	0.0047	6.014	1.776	28.6	1.01
3	26.7	26.8	23.2	23	82.7	0.0051	5.78	1.707	26.5	1.01
4	35	26.5	23.2	23	84.1	0.0052	5.682	1.678	26.1	1.01

table (18): Porous closed tube (without distribute channel)
mp= 0.8 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C
3. t= 6 cm P=243 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	27.9	23	22.8	77.7	0.0045	6.318	2.08	29.3	1.01
2	18.3	26.9	23.2	23	82.2	0.005	5.958	1.962	26.6	1.01
3	26.7	26.4	23.3	23	84.5	0.0053	5.793	1.907	25.5	1.01
4	35	26.2	23.3	23	85.4	0.0053	5.73	1.886	25.2	1.01

table (19): Porous closed tube (without distribute channel)
mp= 0.9 kg Qa=0.55 m^3/sec tdbi=45 C twbi=23C
3. t= 6.5 cm P=250 Watt

	Qw*10^{-6} m^3/sec	tdbo C	twbo C	Tw C	eff %	mv Kg/sec	Ps *10^3 w/kga.C/hr	Ms*10^5 Kg/Kga.C/hr	Time min	Uap m/sec
1	9.17	27.8	22.7	22.5	78.1	0.0043	6.45	2.322	31.1	1.02
2	18.3	26.8	23	22.6	82.7	0.0048	6.092	2.193	27.5	1.02
3	26.7	26.3	23.2	22.8	85	0.0053	5.927	2.134	25.8	1.02
4	35	26.1	23.2	22.8	85.9	0.0054	5.86	2.11	25.5	1.02