Effect of changing packing shapes on the evaporation rates using different combination arrangements of dry-wet cooling towers systems

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Abstract

The aim of this study is reduce the evaporation rate from dry-wet cooling tower combination system through using different shapes and different arrangements between dry and wet cooling towers.

Four shapes of corrugated packing were used in the study with all arrangements combination between dry and wet cooling towers in order to get the shape that give minimum evaporation rate (loss).

Four arrangements combination of dry-wet cooling tower, two of arrangement were series (AS_1, and AS_2), and two of arrangements were parallel (AP_1, andAP_2).

The variables for this study were obtained from North Oil Company (N.O.C.) in the Ministry of Oil of Iraq; these data included temperatures, flow rate, packing types, ambient conditions, pressure, and fan parameters.

The results show that AS_1 configuration produces lower evaporation rates by about 58 % reducing in percent, and then followed by the other configuration. The corrugated types 1 and 4 gives the minimum amount of evaporation losses then the other types of corrugated by about 40 %. The corrugated types 1 and 4 operated with a minimum cost of operation.

Keyword: **Cooling, wet, dry, corrugated, evaporation rate, and combination**

الخلاصة

الغرض من البحث تقليل معدل التبخر من منظومة ابراج التبريد الجافة-الرطبة و ذلك من خلال استعمال اشكال مختلفة من الحشوات المتموجة و كذلك من خلال الربط المختلف بين ابراج التبريد الجافة-الرطبة.

تم استعمال اربعة اشكال مختلفة من الحشوات المتموجة لهذه الدراسة مع مختلف انواع الربط بين ابراج التبريد الجافة و

الرطبة وذلك لغرض الحصول على الشكل المتموج الذي يعطي اقل معدل تبخير(فقدان).

تضمن الربط بين الابراج الجافة و الرطبة ،ربطين على التوالي (AS_1,AS_2) و ربطين على التوازي (AP_1,AP_2).

المتغيرات لهذه الدراسة بمعطيات من شركة نفط الجنوب العائدة لوزارة النفط العراقية و شملت هذه المتغيرات كل من الحرارة و نعدل الجريان و شكل الحشوات و الظروف الجوية والضغط و معاملات المروحة.

بينت النتائج ان الربط AS_1 ينتج اقل معدل فقدان تبخيرمن ابراج التبريد و ذلك بمعدل 40% و ثم يليه باقي انواع الربط الاخرى.بينت النتائج ان الاشكال المتموجة رقم 1 و رقم 4 تعطي اقل معدلات فقدان تبخير بمقدار 40% عن باقي انواع الاخرى من الاشكال المتموجة،كذلك لوحظ ان الشكلين المتموجين 1 و 4 يعملان باقل كلفة تشغلية للابراج .

Nomenclature

A Area of air-cooled heat exchanger(m^2)

C_{ao} Unit cost of air cooled heat exchanger($/unit area)

Q_{tower} The heat load on the tower

$w_{evap.}$ The evaporation rate

w_{circ} The water circulation rate(t/h)

h_{fg} Latent heat of vaporization (Btu/lbm); ~1000 Btu/lbm

f_{latent} Fraction of total heat rejected by latent heat transfer.

Cp Specific heat Btu/lb-°F

T Temperature °C

T_{do} Outlet dry bulb temperature °C

$T_{ref.}$ Reference temperature °C

C_c Capital cost of cooling tower, $/year

F_{in} Cooling system inlet water flow rate (t/h)R_T Range (°C), (T_h-T_c)

A_T Approach (°C), (T_C-T_{wb})

PP Pumping power

M_{air} Mass air flow rate (t/h)

M Make up rate (t/h)

NTU Number of transfer units

B Blow down rate (t/h)

U Overall heat transfer coefficient in dry cooling(Btu/hr.°F.ft^2)

H Humidity of air

Cp Specifi heat

λ Latent heat of evaporation

Subscripts

w water

a air

c cold

h Hot

Introduction

[Shan,2000, and *ASHRAE Handbook 1995*], considering the fact that the wet cooling tower was a steady flow device that uses a combination of mass and energy transfer to cool water by exposing it as an extended surface to the atmosphere. The water surface was extended by filling, which presents a film surface or creates droplets. The airflow may be cross flow or counter flow and caused by mechanical means, convection currents or by natural wind.

[Ala, 2002] said that In mechanical draft towers, air is moved by mechanically driven fans to provide a constant air flow.

[Gao, 2009] recorded that the wet cooling towers were considered the ultimate water conservation machine providing the amount of water needed to replace evaporation and other losses.

[Qi and Liu, 2008] refer to that in wet cooling the major two way of loosing water are evaporation and blow-down .The benefit of blow-down is to prevent the scaling due to increase the amounts of dissolved solids to the point where they began to precipitates.

[Sarker, 2008] considering the fact that the combination of dry and wet cooling tower provide as a good way to reduce evaporation. There are many advantages for the combination of wet cooling and dry cooling, the first was reducing the make-up water consumption ,second reducing the plumes emitted from the cooling tower(avoiding environmental impact), and third reducing the cost of operation, finally increasing the variety of material that using for construction of cooling tower.

[Gardner, 1975] studied the performance and economic design on different configurations based on operation parameters, the variable that this search take in account were the height of packing, types of tubes, velocity, and air conditions.

Marcel, 1984 studied the combination of dry and wet cooling tower, and they found that the wet-dry cooling tower can be constructed either as separated dry and wet towers.

[Nakkash, 1994] studied the effects of different variables (water to airflow ratio, humidity, and temperatures) on the amounts of evaporation rates.

[Gan and Riffat, 1999] have been developed computer models to study the thermodynamic and economic performance of various types of combination dry-wet cooling towers. These models consider the basic thermodynamics of wet and dry heat transfer, steam turbines, and condensers, the influence of different power loading patterns and changing meteorological conditions, and the various economic parameters.

[*Hossein,* 2011] used the cooling water system of Tabriz refinery as a case study. For this purpose, a data collected from Weather Meteorological Organization and process cooling water system of the refinery in a one-year period were collected. The methods in this paper, studied the conditions of dry cooling tower replacement instead of wet rather than a general or conditions and different scenarios, with analysis advantages and disadvantages of each mode and compare the technical and economic methods to achieve an optimal state of proposed economic and will.

Dutta, 2007 considering the fact that in dry cooling towers circulatory cooling water temperature lower than the temperature of the bubble is not possible; with recognizing losses in water systems, cooling tower replacement conditions dry instead of wet cooling tower more general, or at least part of the year will examine. An economical method to determine the replacement cost, which includes replacement (the cost of construction, installation and commissioning of dry cooling tower, pumps and related pump and fan electricity costs) cost of water is decreased due to compensatory replacement of whole or part year and compared in terms of replacement cost less than compensatory cost savings by water, the alternative methods will used.

The aim of this research was to reduce the evaporation rate (loss) from dry-wet cooling tower combination system through using different shapes and different arrangements combination between dry and wet cooling towers. Four shapes of corrugated packing were used in the study with all arrangements between dry and wet cooling towers in order to get the shape that give minimum evaporation rate.

Experimental procedures

In this work, different ways used to reducing the evaporation rate by connection dry with wet cooling towers, and in this work one can show the effects of changing the power of fan and the indirect surface area in dry cooling towers.

Four arrangements of dry-wet cooling tower used in this search, two of arrangement were series (AS_1, and AS_2), and two of arrangements were parallel (AP_1, andAP_2)(figures(1.a, 1.b, 2.a, and2.b)).

In parallel arrangements the humidity of the exit air from wet tower must be estimate (equation (1) (Marcel, 1984)) and the humidity inlet equal the humidity outlet, the wet bulb temperature can estimated by trial and error. In series arrangements, only one fan was provided for each dry-wet cooling system.

$$H_o = \frac{h_{ao} - Cp_a(T_{do} - T_{ref.})}{Cp_w(T_{do} - T_{ref.}) + \lambda} \qquad (1)$$

For configuration represented in figure (2.a), where air and water come contact first in dry sections then in wet section. One can notice that dry bulb temperature entering to the dry section equal to the dry bulb temperature exiting from the wet section. The configuration in figure (2.b), where air and water coming contact first in wet sections first then in dry section. One can notice that dry bulb temperature entering to the dry section equal to the dry bulb temperature exiting from the dry section.

The performance of cooling tower for wet and dry cooling towers ,evaporation rate for wet cooling tower, air rates for dry cooling tower, surface area of dry cooling tower, cost cooling tower, and water to air flow in wet cooling tower were estimated for each types of corrugated cooling tower and combination of wet-dry cooling tower. The wet bulb temperature, dry bulb temp., humidity, and relative humidity with different height were considered for cooling tower.

In dry cooling tower the fins were made of aluminum while the tubes made of copper, the space of tubes had the shape of triangular pitch in order to increase the heat transfer between fluids.

Four types of corrugated packing were used with all combinations between dry and wet cooling towers in order to get the shape that give minimum evaporation rate (loss). The corrugated shape gave as maximum transfer of mass and heat transfer due to the good contacts between water and air in wet cooling tower, also it is so simple to make maintained or repaired it. The material of packing were made of from poly vinyl chloride, The poly vinyl chloride prevents bio-growth in the surface of packing, the dimensions of the four types (shapes) of corrugated packing can be noticed in table(1) .

Mathematical calculations

The basic function of a wet cooling tower (fig. 3) is to cool water by intimately mixing it with air. This cooling was accomplished by a combination of sensible heat transfer between the air and the water and the evaporation of a small portion of the water. This type of transfer is represented by equation(2),[Dutta, 2007];

$$\frac{KaV}{L} = \int_{T_c}^{T_h} \frac{dT}{h_W - h_A} \qquad (2)$$

This equation is commonly referred to as the Merkel equation. The left-hand side of this equation is called the "tower characteristic," which indicates the 'degree of difficulty to cool' the water or the 'performance demand' of the tower. The Driving force depending on the difference between the temperature and enthalpy of the saturated air.
The tower characteristic (KaV/L), can be calculated through the Merkel Equation[Marcel, 1984].

$$\frac{KaV}{L} = C.FH.\left(\frac{L}{G}\right)^n \qquad (3)$$

The fill height (FH), depends on the fill characteristic and L/G, and is computed by equation (3): Where ‘C’ and ‘n’ are constants, which depend on the tower, fill. These both factors are determined through fill test. The constants for equation (3) for the case of corrugated packing are listed in table (2).

The rate of evaporation of water from the tower is related to the heat load on the tower, Q_{tower}, and determined by he following equations.

$$Q_{tower} = w_{circ} . Cp . (T_h - T_c) \qquad (4)$$

with the evaporation rate given by

$$w_{evap} = Q_{tower} . (f_{latent}/h_{fg}) \qquad (5)$$

The percentage reduction in evaporation rate gives very important indication about the benefit of combined system because it takes account the evaporation losses when just wet cooling tower is used, this percentage can be expressed in equation(6);

$$reduction\ in\ evaporation = \frac{evap\ rate_{.wet} - evap\ rate_{.com.}}{evap\ rate_{.wet}} \qquad (6)$$

In design targeting, the objective is to minimize the total annual cost (Kim *et al.*, 2001). Consequently, the defined objective function of the introduced design methodology was to determine total annual cost of the cooling tower including operational and capital cost (Kaiser *et al.*, 2005). The capital cost of (C_C) cooling tower is as follows:

$$C_C = 746.75(w_{circ})^{0.79}(R_T)^{0.57}(A_T)^{-0.9924}(0.022T_{wb} + 0.39)^{2.447} \qquad (7)$$

As shown in equation (7), the capital cost in \$/y, including chemical engineering index and annualisation factor, a function of water flow rate in t/h. The approach, range and wet bulb temperature are in ºC. The operating cost (O_C) of cooling tower: pumping cost + fan cost + make-up cost + chemical treatment cost + blow-down treatment cost.

$$O_C = 2.409 * 10^{-3}(PP) + 44(M_{air}) + 110(w_{circ}) + 2275(M) + 1138(B) \quad (8)$$

The total annual cost (T_C) could be state as follows. The operating cost and capital cost of the cooling tower differently affect the overall cost of cooling water systems, as shown in equation(9).

$$T_C = C_C + O_C \qquad (9)$$

The dry cooling tower (heat exchanger), where the water was flowing inside tubes and air was flowing outside the tubes. The heat transfer was determining by the logarithmic mean temperature between the air and water(Hans D.B. & Karl S.(2006)).

$$Q_d = U\ A\ log_m.T \qquad (10)$$

The capital cast of dry cooling tower was written as follows;

$$C_{Cd} = A\ \ K_f C_{ao} C_N \qquad (11)$$

The annual cost could for dry cooling equal to the summation of operation cost plus the capital cost as listed in equation (12), so the total annual cost for dry-wet (T_{CT}) cooling tower can be shown in equation (13).

$$T_{Cd} = C_{Cd} + O_{Cd} \qquad (12)$$

$$T_{CT} = T_{Cd} + T_C \qquad (13)$$

A computer program was written by visual basic program to calculate and optimize the combination arrangements in cooling system.

Results & discussion

The study for reducing evaporation rates was done by using four combination arrangements, two arrangements as series and two arrangements as parallel (AS_1, AS_2, AP_1, andAP_2).

The ability of reducing evaporation rate in cooling towers using different shapes of corrugated packing and combination between dry and wet cooling tower was studied. Four packing shapes of corrugated packing are take for each the four arrangements. The results show that for short height of packing the evaporation rate would be at minimum value and minimum cooling tower cost, this is because the short height mean short time of contact between air and water (reducing mass transfer of water vapor) as cleared in table(3) .

The effect of water to air ratio on the performance of cooling tower and design of combined dry-wet cooling tower shows that increasing the ratio, and the height of packing increase depends on the type of corrugated packing and as the air flow decrease the pressure drop increases, thus the evaporation losses decreases, as shown in (figures 4,5,and 6) and listed in table(4).

The evaporation loss is affected by the connection arrangements according to the change position of cooling tower due to the change in the temperature and humidity according to equation (5), as shown in table (5).

In table (6), the results prove that as the outlet water temperature from dry part increases, the area of dry part decreases and the airflow rate decreases. This because of the decrease in heat load .The cost decreases due to the decrease in area of dry part.

The results show that the configuration AS_1 gives a higher evaporation percentage reduction and lower total annual cost as a comparing with the other configuration arrangements (AS_2,AP_1, andAP_2),as shown in figures(7,8).While the other types of configuration operated with high total annual cost.

The corrugated types 1 and 4 gives the minimum amount of evaporation rates then the other types of corrugated. The corrugated types 1 and 4 operated with a minimum cost of operation (Fig. 9).

Conclusion

From the study, it can be concluded that the percent of reduction in the evaporation and the cost gives a good indication about the benefit of combination arrangements systems.

The shape of the corrugated packing affecting on the amount of evaporation also, the height of packing related with the amount of evaporation retrogradly.

The configuration AS_1 gives a higher evaporation percentage reduction and lower total annual cost as a comparing with the other configuration arrangements (AS_2,AP_1, andAP_2),while the other types of configuration operated with high total annual cost.

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Table(1):Types of corrugated packing

Type of corrugated	surface	Pitch of packing(mm)	Distance between the packing(mm)
Type1	Rough	50	40
Type2	Rough	45	40
Type3	Smooth	40	30
Type4	Rough	40	25

Table(2):The constants for equation (3) (Nagam (2002))

Height(cm)	Corrugated shape	$C.FH.$	n
150	Type 1	0.28	-0.44
140	Type2	0.41	-0.58
120	Type3	0.27	-0.75
100	Type4	0.37	-0.81

Table (3): Packing height ver. evaporation loss and reduction for config. AS_1

Shape of corrugated	Height(Z),m	Evap. Loss(kg/s)	Reduction%
Type1	1.1	43.3	57
Type2	1.2	44.2	55
Type3	1.3	44.8	53
Type4	0.8	40	64

Table(4):Performance of cooling tower for different combinations arrangements

Performance of cooling tower($\frac{KaV}{L}$)				
R=L/G	AP_1	AP_2	AS_1	AS_2
1.51	0.59	0.68	1.24	0.61
1.625	0.58	0.64	1.15	0.60
1.628	0.55	0.61	1.09	0.51
2.14	0.53	0.59	0.99	0.44
2.24	0.50	0.57	0.95	0.43
2.63	0.48	0.53	0.89	0.39

Table(5):Evaporation loss at different combination(R=1.58)

No.	Connection(combination)	Evaporation loss(Kg/s)
1	AP_1	66
2	AP_2	69
3	AS_1	48
4	AS_2	70

Table(6):Performance of dry cooling section AS_1

Outlet water temp.(^oC)	$log_m.T$	NTU	Area(m^2)	Δp (pressure drop) (torr)	Air flow(kg/s)	C_{ao}(\$/m^2)	Pp(Pumping power)
30	4.1	2.3	1800	0.87	2502	3954320	30225
32	5.6	1.4	8800	0.91	1198	1754923	6923
34	6.9	1.2	3780	0.90	521	795434	1497
36	8.1	0.99	3800	0.85	79	204355	50.44

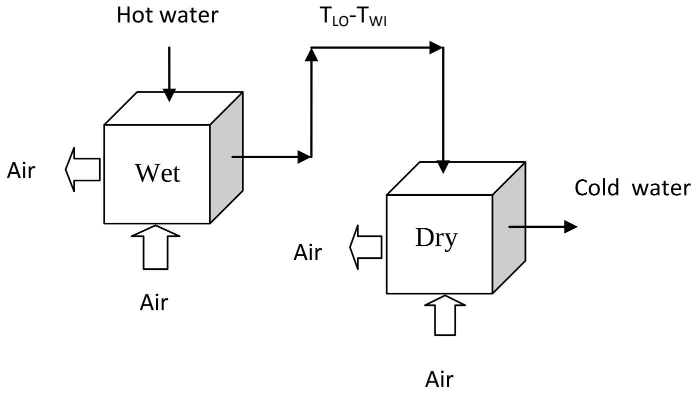


Fig.(1.a):Parallel combinations of Wet-dry cooling tower (AP_1).

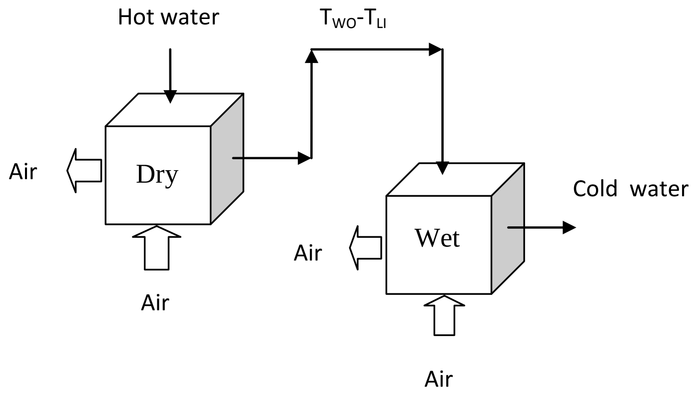


Fig.(1.b):Parallel combinations of Dry-wet cooling tower (AP_2).

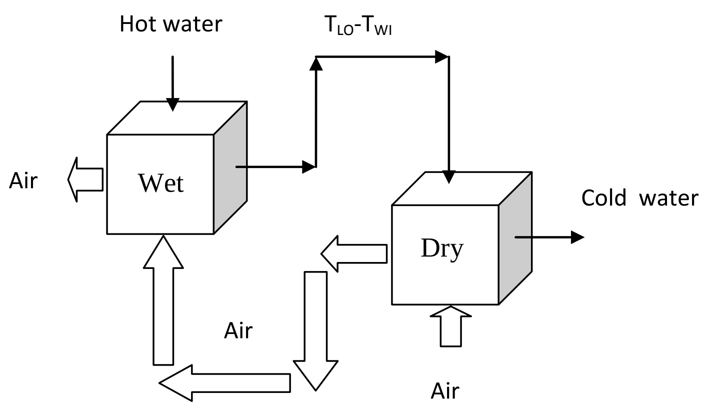


Fig.(2.a):series combinations of Wet-dry cooling tower (AS_1).

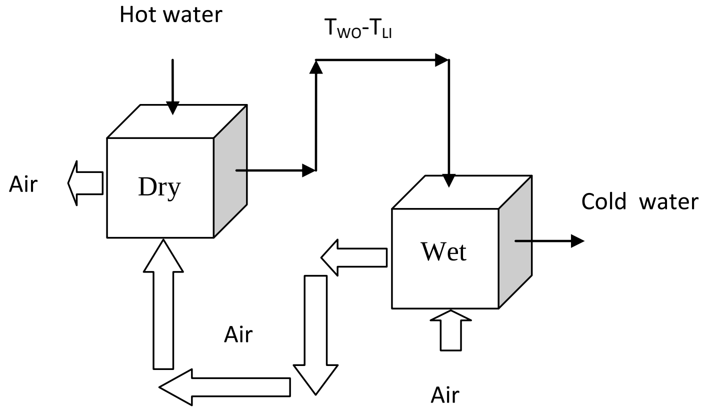


Fig.(2.b):series combinations of Dry-wet cooling tower (AS_2).

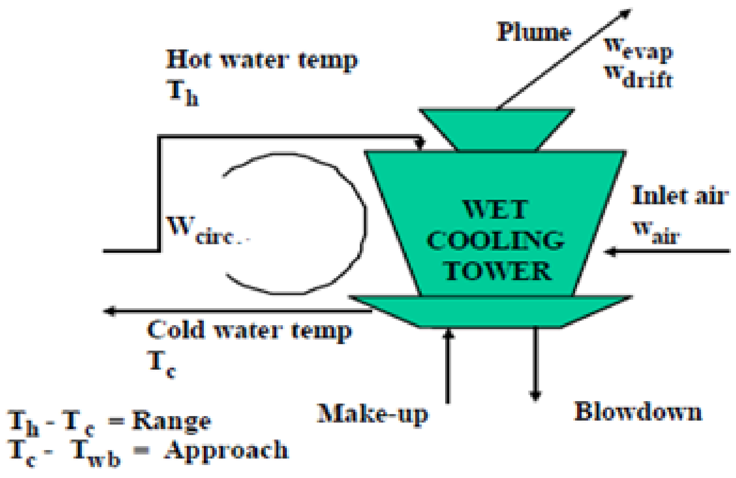


Fig.(3):Cooling tower heat and mass balance.

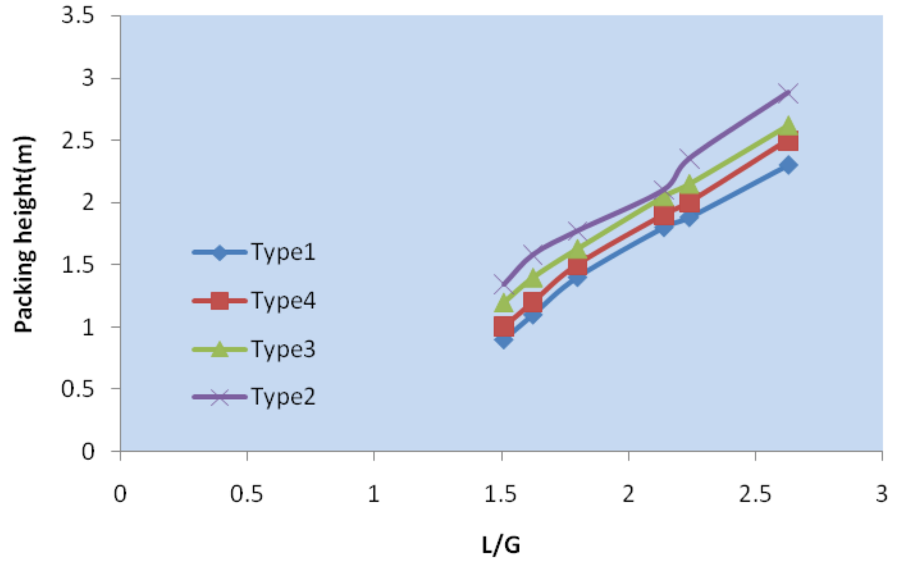


Fig.(4):Packing height versus water to air ratio,AS_1

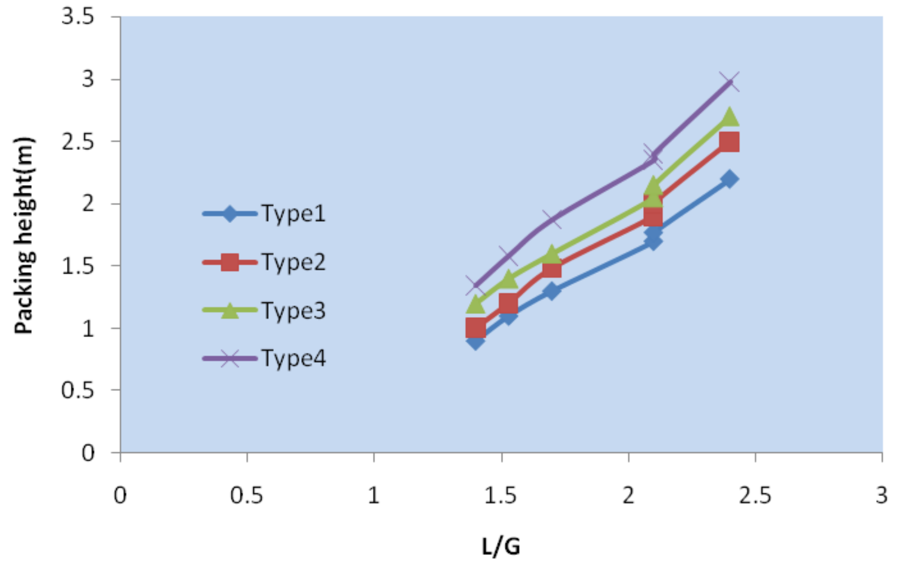
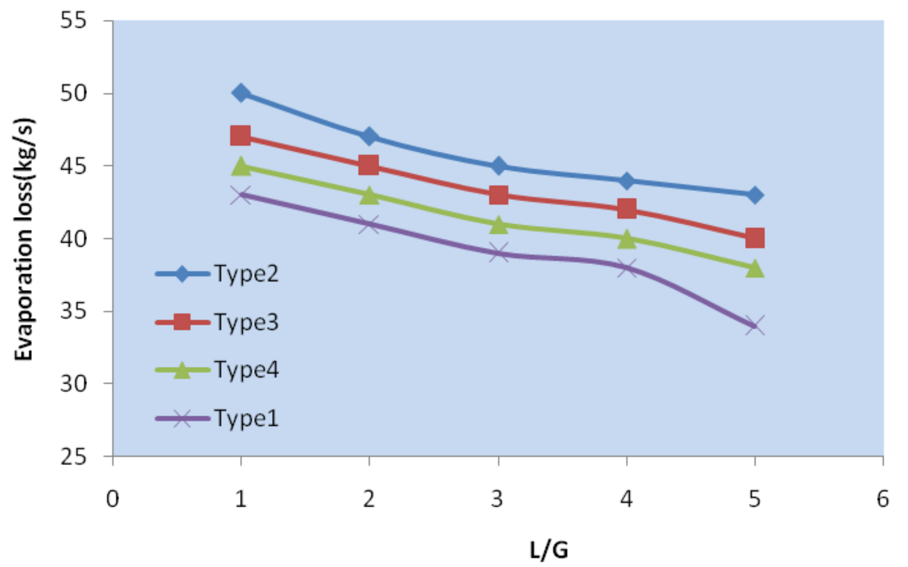
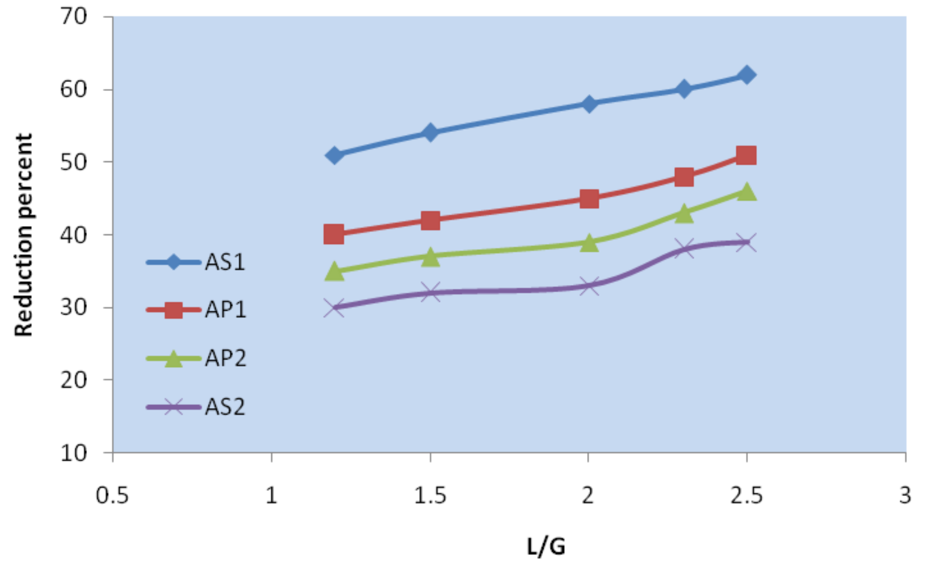


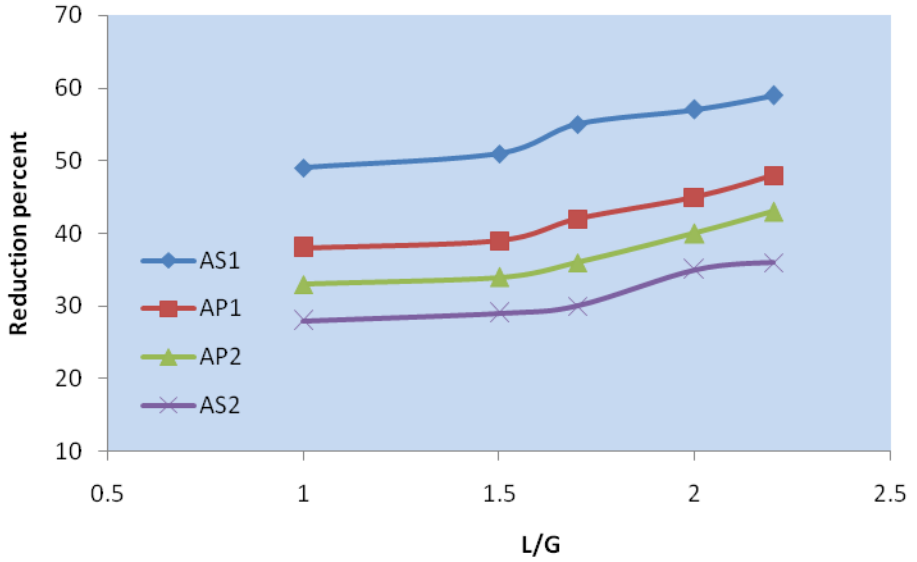
Fig.(5):Packing height versus water to air ratio,AP_1



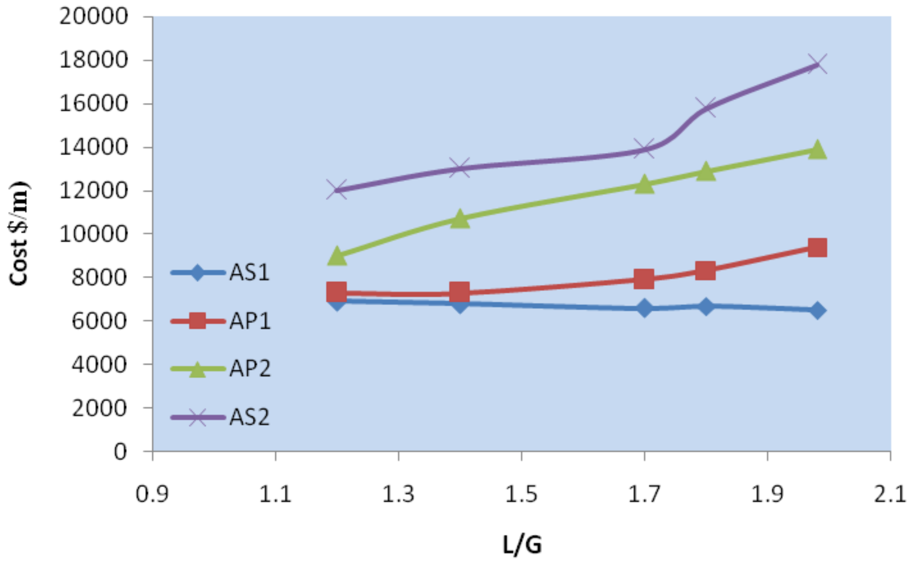
Fig(6):The effect of water to air ratio on the evaporation loss,AP_1



Fig(7):Reduction percent versus water to air ratio,packing type 1



Fig(8):Reduction percent versus water to air ratio,packing type 3



Fig(9):Relation between the water to air ratio and cost