Enhanced Performance of Desalination by Air Passing Through Saline Water Using Humidification and Dehumidification Process

تحسين أداء الاعذاب بامرار الهواء داخل المياه المالحة باستخدام عمليتي الترطيب والتجفيف

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ملخص البحث

يقدم هذا البحث نظام مقترح للاعذاب بامرار الهواء خلال المياه المالحة داخل غرفة التبخير باستخدام عمليتي الترطيب والتجفيف. الهدف الرئيسي من هذه الدراسة هي تحديد سلوك الهواء الرطب خلال مرحلة واحدة من نظام اعذاب المياه. وتم دراسة تأثير ظروف التشغيل مثل درجة حرارة الماء، وارتفاع المياه داخل غرفة التبخير ومعدل تدفق الهواء على أداء نظام التحلية الجديد. وأظهرت النتائج أن إنتاجية النظام تزيد مع زيادة درجة حرارة المياه وتناقص معدل تدفق الهواء. وان إنتاجية النظام تتأثر بدرجة حرارة المياه ومعدل تدفق للهواء و تتأثر قليلا بارتفاع المياه داخل غرفة التبخير، وكفاءة الاعذاب عالية عند معدل تدفق للهواء M_a=12.6 and M_a=14 kg/hr لكل ارتفاعات المياه داخل غرفة التبخير. وعند 80 °C درجة حرارة للمياه وجد ان إنتاجية النظام عالية عند مختلف ارتفاعات المياه داخل غرفة التبخير ومعدل تدفق الهواء لها. و الإنتاجية القصوى وصلت إلى 0.81 kg_w/kg_a عند 87 °C درجة حرارة للمياه و معدل تدفق الهواء M_a=4.2 and M_a=8.4 kg/hr

Abstract

Experimental and theoretical work investigates the principal operating parameters of a proposed desalination process working with an air humidification-dehumidification method. The main objective of this work was to determine the humid air behavior through single-stage of desalination system. The experimental work studied the influence of the operating conditions such as the water temperature, the saline water level and the air flow rate to evaporator chamber on the desalination performance. The experimental results show that, the productivity of the system increases with the increase of the water temperature and the decrease of the airflow rate. The productivity of the system is moderately affected by the water temperature and airflow rate and slightly affected by the water level. The efficiency of the desalination system is higher for M_a=12.6 and M_a=14 kg/hr at different water levels. At 80 °C, the productivity of the system is higher at different water levels and airflow rate. Within the studied ranges, the maximum productivity of the system reached to 0.81 kg_w/kg_a at 87 °C for water and M_a=4.2 and M_a=8.4 kg/hr. A good agreement had been achieved with productivity calculations.

Keywords: Air humidification and dehumidification process, Desalination system

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Accepted May 6, 2009.

1. Introduction:

Humidification - dehumidification desalination (HDD) process is viewed as a promising technique for small capacity production plants. The process has several attractive features, which include operation at low temperature, ability to combine with sustainable energy sources, i.e., solar, geothermal, and requirements of low level of technical features. The humidification–dehumidification process is an interesting technique, which has been adapted for water desalination, where air is used as a carrier gas to evaporate water from the saline feed and to form fresh water by subsequent condensation. The HDD process functions at atmospheric pressure so the components are not submitted to mechanical solicitations. The only characteristic required is resistance to corrosion. Water desalination by humidification and dehumidification has been the subject of many investigations. Different experimental data are available for using HDD at the pilot or industrial scale. An inspection of these data allows establishing many perspectives for this process.

Careful review of previous literature studies show that a major part of these studies is focused on performance evaluation of the HDD system combined with solar energy , Farid and Al-Hajaj [1], Farid et al [2], Nafey et al [3,4] and Nawayseh et al [5]. Dai and Zhang [6] utilized structured packing in the humidification unit. The unit was $1 \times 1 \times 1.5$ m in dimension. They replaced the collector by a boiler to provide the hot water, which was sprayed at the surface of honeycomb packing of the humidifier. A fan was used to force the process air to flow through the humidifier in a cross flow arrangement. The results show that, the thermal efficiency and water production increases with increase of mass flow rate of water to the humidifier. The thermal efficiency and water production increase significantly with temperature of inlet water into humidifier. An efficiency of 80% was obtained using hot water feed from a boiler. This corresponds to about 68% only when a solar collector is used. Productivity achieved was around 6.2 kg/m^2/d.

It is also of interest to mention the multiple effect humidification solar desalination technique presented by Ben-Amara et al. [7], Chefik [8,9], and Ettouney [10]. This technique consists of several steps of air heating and humidification and leads to high vapor concentration in the airflow. Vlachogiannis et al. [11] presented a novel concept that includes air humidification followed by mechanical compression. This configuration is reported to have very large specific power consumption, which is almost 100 times greater than that consumed by the conventional mechanical vapor compression process Ettouney et al [12]. Other literature studies of the HDD system includes performance evaluation by Al-Hallaj et al [13], correlation development for the heat and mass transfer coefficients by Nawayseh et al [14] or mathematical modeling by Nawayseh et al [15], Orfi et al. [16], Xiong et al. [17], Younis et al. [18], Yuan and Zhang [19]. Yamali and Solmus [20] investigated theoretically the effect of different system operating conditions, types of air heater, and some different design parameters and a weather condition on a solar water desalination system performance under the climatologically conditions. The desalination unit is configured by a double-pass flat plate solar air heater with two glass covers, humidifying tower, storage tank and dehumidifying exchanger. The system used in this work is based on the idea of closed water and open-air cycles. Air is heated by using a double-pass solar air heater whereas water is not heated. The system productivity is increased up to 8% by using a double-pass solar air heater compared to a single pass solar air heater and decreased about 30% without double-pass solar air heater under the same operating conditions. It is also found that, the system performance is strongly affected by the double-pass solar air heater area and slightly influenced by the bottom heat loss coefficient of the solar air heater and storage tank. Finally, the productivity of the unit that consists of a double-pass solar air heater with two glass covers is not influenced by the wind speed variations as much as double-pass solar air heater with one glass cover. Garg et al. [21] studied the experimental design and computer simulation model of a multi-effect humidification/dehumidification (MEH) solar desalination system. The heat collection part is geared to provide the hot water to the distillation unit uninterruptedly. The distillation chamber consists of humidifier and dehumidifier towers. The circulation of air in the two towers is by natural convection. Modeling is based on various heat and mass transfer equations and their numerical solutions by finite difference technique. The developed model is useful in sizing associated components of the system viz. solar water heater, humidification chamber, and condensation chamber. The results show that, the increases of hot water temperature at the inlet of the humidifier increase of the vapour content difference in the air.

Al-Enezi et al [22] evaluated the characteristics of the humidification dehumidification desalination process as a function of operating conditions. A small capacity experimental system is used to evaluate the process characteristics as a function of the flow rate of the water and air streams, the temperature of the water stream and the temperature of the cooling water stream. The experimental system includes a packed humidification column, a double pipe glass condenser, a constant temperature water circulation tank and a chiller for cooling water. The water production is found to depend strongly on the hot water temperature. Also, the water production is found to increase upon the increase of the air flow rate and the decrease of the cooling water temperature.

El-Agouz and Abugderah [23] presented an experimental investigation of humidification process by air passing through saline water. The study presented the behaviour of humid air through single-stage of heating-humidifying processes. There experimental work studied the influence of the operating conditions such as the water temperature, the headwater difference, the air velocity and the inlet air temperature to evaporator chamber on the vapor content difference and humidification efficiency. The different air inlet temperatures are studied. The experimental results show that, at 75 °C, the maximum vapor content difference of the air was about 222 gr_w/kg_a. The inlet air temperature to evaporator chamber variation was found to have a small affect on the vapour content difference.

The main objective of this work is to experimentally and theoretically, investigate the principal operating parameters of a desalination process working with an air humidification-dehumidification method. The experimental work studied the influence of the operating conditions such as the water temperature, the saline water level and the airflow rate to evaporator chamber on the desalination system performance.

2. Experimental Setup and Procedure

2.1. Experimental setup

Fig. 1 illustrates a schematic diagram and Fig. 2 shows a photograph of the experimental setup. The system main components are air compressor (1), evaporator chamber (5) and dehumidifier (12).

The desalination system consists of two loops, one for cold saline water and the other for air. In the water loop, the cold saline water for evaporator chamber (5) and dehumidifier (12) is supplied from an external source. The water level in the evaporator chamber is controlled by external graduate level (9) and three electric heaters (6) of 1.2 kW power each heat the water. The water level in evaporator chamber is maintained constant and is regulated by a control valve (10). The cold-water passes through inner tube of the dehumidifier and is regulated by a control valve (15). *In the air loop*, air for the evaporator chamber (5) is taken from the air compressor discharge, is regulated by a control valve (2), and then is passes through flow meter (3) The airflow enters into the evaporator chamber from forty-four holes (7) of 15 mm diameter located at top side of the copper pipe, which is submersed in the water of the evaporator chamber. The air flows through water level in evaporator chamber and carries the evaporated water to dehumidifier (12), where the air is cooled and dehumidified and produced water through a tube to the desalinated water tank (17). The detailed descriptions of the system main components are as follows.

Evaporator chamber

The evaporator chamber (5) is consisted of lower and upper parts. *The lower part* is made of steel sheet of 1mm thickness with 400×300 mm cross section and 250 mm height. It is insulated by glass wool layer insulation with thickness 20 mm, the thermal conductivity 0.036 W/m K. There are three electric heaters installed in it and forty-four holes (7) located at top side of the copper pipe as shown in figure (2). *The upper part* is made of thermal glass of 10 mm thickness with 400×300 mm cross section and 1000 mm height. It is covered by polyurethane foam layer insulation with thickness 10 mm, the thermal conductivity 0.023 W/m K and glass wool layer insulation with thickness 20 mm, the thermal conductivity 0.036 W/m K. The glass box is closed by sheet metals of steel of 3 mm thickness that has a hole to exit humid air from humidifier. This hole is connected with a PVC pipe of 75 mm diameter that connects the humidifier with dehumidifier.

Dehumidifier

A two shell and tube heat exchangers connected respectively is used as a dehumidifier. The condensed fresh produced water is directed through tube to the desalinated water tank. The cooling water flows inside the tubes and the total number of passes is 30 for every the heat exchanger. The tubes are made of copper of 9.525 mm diameter. The extended surface is made of 1 mm thick aluminum sheet. The total surface area of every the heat exchanger is 4.6 m^2.

2.2. Experimental procedure

The experimental runs are carried out considering the following procedure:

- The temperatures of the system are measured before heating to ensure a uniform temperature of the system.
- The temperature of the water in evaporator chamber is adjusted to the desired temperatures.
- The flow rates of the air stream and the water level in evaporator chamber are adjusted to the desired conditions.
- The system is left to reach steady state conditions. During this period, the water temperature and the valves controlling the flow rates of the air and water are continuously monitored and adjusted to the desired flow and temperature.
- The desalination system is operated at the set conditions for a period of 1.5 hours. During this period, the values of productivity, airflow rate, water level, water temperature, air dry-bulb/ wet-bulb temperatures at inlet and outlet evaporator chamber and outlet dehumidifier are recorded

at intervals of 5 min and their mean values are calculated.

- Experimental measurements are performed for a new set of conditions.

2.3. Data acquisition system

For the measurement of the humidity by the dry-bulb/wet-bulb temperature method, resistance thermometers are used because of their high accuracy. The humidity and enthalpy of the air at the different points are calculated by Computer-Aided Thermodynamic Tables2 [24]. The vapor content difference in evaporator chamber is defined as:

$$\Delta\omega)_{ev} = \omega_{ev})_{out} - \omega_{ev})_{in} \qquad (1)$$

where: $\omega_{ev})_{in}$, $\omega_{ev})_{out}$ are the inlet and outlet air humidity of the evaporator chamber

The humidification effectiveness of the evaporator chamber is given by:

$$\eta_{hu} = 100\frac{\omega_{ev})_{out} - \omega_{ev})_{in}}{\omega_{out})_{sat} - \omega_{ev})_{in}} \qquad (2)$$

where: $\omega_{out})_{sat}$ is the outlet saturation air humidity of the evaporator chamber

The power input to the evaporator chamber is defined as

$$Q_{in} = \dot{m}_{air}\ [h_{air})_{out} - h_{air})_{in}] + \Delta\omega)_{ev} C_p[T_w)_{ev} - T_w)_{in}] \qquad (3)$$

Where: $h_{air})_{in}$, $h_{air})_{out}$, $T_w)_{ev}$, $T_w)_{in}$, $\Delta\omega)_{ev}$ and C_p are the inlet air enthalpy of the evaporator chamber, the outlet air enthalpy of the evaporator chamber, the water temperature in evaporator chamber, the temperature and mass rate of water inlet evaporator chamber as makeup and specific heat of water respectively.

The efficiency of the desalination system is given by:

$$\eta_d = 100(\dot{m}\, L_{w)vap}/Q_{in}) \qquad (4)$$

where: $\dot{m}$ is the productivity of system, $L_{w)vap}$ is the latent heat of vaporization of water

2.4. Measurement devices

As shown in Fig. 1, the air mass flow rate is measured by using flow meter in a range from 0 to 18 kg/hr with accuracy of ± 0.05 g/s. Digital thermometers (4), (11) and (16) are indicated dry-bulb and wet-bulb air temperatures at inlet evaporator chamber, outlet evaporator chamber and outlet dehumidifier respectively. Digital thermometers (14) and (13) are indicated saline water temperatures at inlet and outlet of the water respective. The digital thermometers are of the range from -50 to 150°C with accuracy of ±0.1 °C. The voltage and current of the electric water heaters (6) is measured by using digital clamp meter type (KSR-266) with accuracy of ±0.1 Volt and Ampere. The water level head is measured by using graduate lever with accuracy of ±1 mm. The desalinated water is measured by using graduate tank in a range from 0 to 15 litres with accuracy of ± 0.05 liter. To estimate the uncertainties in the results presented in this work, the approach described by Barford [25] was applied. The uncertainty in the measurements is defined as the root sum square of the fixed error of the instrumentation and the random error observed during different measurements. Accordingly, the resulting errors are ±2.74%, ±1.67%, ±1.014% and ±0.3% in the calculated vapour content difference, humidification efficiency, the power input to the evaporator chamber and the efficiency of the desalination system.

3. Model validation

The present experimental results are verified by comparing the obtained results with other published experimental results by Dai and Zhang [6] and Garg et al. [21]. Fig. (3) shows good agreement between Dai and Zhang [6] and Garg et al. [21] results and the present results under the same operating water temperature. The present results show that the productivity is approximately 0.27 kg_w/kg_a at 70 °C and 0.75 g_w/kg_a at 85 °C. The results showed that productivity is approximately 0.1745 kg_w/kg_a at 85 °C by Dai and Zhang [6], and the productivity is approximately 0.066 kg_w/kg_a at 70 °C by Garg et al. [21]. Thus, the productivity for the present is increased around 4.3 and 4.1 times than Dai and Zhang [6] and Garg et al. [21] results. In addition, El-Agouz and Abugderah [23] presented more details for this model.

4. Results and discussion

The effect of water temperature and level increase in the evaporator chamber on the productivity of the system is shown in Figs. 4-7. It is evident from the figures at constant airflow rate that as the temperature and level of the water increase, the productivity is increased. On the other band, the productivity is slightly affected by the inlet airflow rate and water level at low water temperatures less than 70 °C and the productivity is increased at water temperatures higher than 70 °C. In addition, as the inlet airflow rate increases, the productivity is decreased. This increase in the system output is due to the decrease of the difference between the air dry-bulb/ wet-bulb temperatures.

The effect of water temperature and airflow rate increase in the evaporator chamber on the productivity of the system is shown in Fig. 8. It is clear from the figure that as the water temperature increases, the average productivity is increased. As the temperature of the saline water in evaporator chamber is increased from 55 °C to 85 °C, the increase of average productivity of the system is 540% and 440%.

Since the productivity is slightly affected by the increase of water level in evaporator chamber. Therefore, the average productivity, $\dot{M}_w)_{av}$, of the system for different air flow rate can be correlated as a function of the temperatures of saline water with maximum deviation 3% as follows:

$$\dot{M}_w)_{av} = A \ T_w^{\ B} \qquad kg_w/kg_a \qquad (5)$$

Table 1 show constants (A, B) of Eq. 5.

M_a, kg/hr	A	B
4.2	1.967E-10	4.96
8.4	1.95E-10	4.95
12.6	8.187E-9	4.04
14	4.444E-9	4.19

The effect of water temperature and airflow rate increase in the evaporator chamber on the relative humidity of the system is shown in Fig. 9. It is clear from the figure that as the water temperature increases, the average relative humidity is increased. On the other hand, the average relative humidity increased with the increase of airflow rate.

Figs. 10-13 show the relationship between the humidification effectiveness and the temperatures of water at different airflow rate and water level. From the figures, the humidification effectiveness increases with the increase of water temperature and airflow rate at different water level. The humidification effectiveness is higher for M_a=14 kg/h at different water level.

Figs. 14-17 present the effect of the water temperature at different water level and airflow rate on the efficiency of the desalination system. As can be seen from Fig. 14, the increasing the water temperature and water level increases the efficiency expect at h=60 cm decrease efficiency of the desalination system. From Fig. 15, the increasing the water temperature and water level increases the efficiency of the desalination system. From the figs. 16-17, the efficiency of the desalination system decreases with the increase of water temperature and water level. The efficiency of the desalination system is higher for M_a=12.6 kg/h and M_a=14 kg/h at different water level.

The effect of water level and airflow rate increase in the in evaporator chamber on the productivity of the system at T_w=50, 60, 70 and 80 °C is shown in Fig. 18. It is evident from the figure that as the level of the water increases, the productivity is increased at all water temperature. On the other hand, as the airflow rate increases, the productivity is increased at T_w= 60, 70 and 80 °C except for T_w= 50 °C is decreased.

At T_w=50 °C, as the water level in evaporator chamber is increased from 20 to 60 cm, the increase in productivity of the system is 7.75%, 11.41%, and 2.95 % at airflow rate 4.2, 8.4 and 14 kg/hr. In addition, at water level 60 cm, the increase of airflow rate from 4.2 to 8.4 kg/hr resulted in an decrease of 1.81 % in the productivity and it is increased from 4.2 to 14 kg/hr resulted in an increase of 8.15 % in the productivity.

At T_w=60 °C, as the water level in evaporator chamber is increased from 20 to 60 cm, the increase in productivity of the system is 7.42%, 5.55%, and 4.39 % at airflow rate 4.2, 8.4 and 14 kg/hr. In addition, at water level 60 cm, the increase of airflow rate from 4.2 to 8.4 and from 4.2 to 14 kg/hr resulted in a decrease of 4.7% and 6.67 % in the productivity.

At T_w=70 °C, as the water level in evaporator chamber is increased from 20 to 60 cm, the increase in productivity of the system is 10.33%, 10.5%, and 3.8 % at airflow rate 4.2, 8.4 and 14 kg/hr. In addition, at water level 60 cm, the increase of airflow rate from 4.2 to 8.4 and from 4.2 to 14 kg/hr resulted in a decrease of 6.4% and 17.65 % in the productivity.

At T_w=80 °C, as the water level in evaporator chamber is increased from 20 to 60 cm, the increase in productivity of the system is 11%, 10%, and 6.24% at airflow rate 4.2, 8.4 and 14 kg/hr. In addition, at water level 60 cm, the increase of airflow rate from 4.2 to 8.4 and from 4.2 to 14 kg/hr resulted in a decrease of 5.8% and 26 % in the productivity.

4.1. The comparison between experimental measured and experimental calculated productivity

Figs 19-22 show the comparison between the experimental measured and experimental calculated productivity. The approximated agreement between the experimental measured and experimental calculated productivity is good and the shift between results is about average 7.7%, 8.5%, 9.94% and 4.5% at airflow rate 4.2, 8.4, 12.6 and 14 kg/hr. This is due to the change of surrounding conditions, losses in system and error in measurement. The decreases between the experimental productivity measurement and calculation due to the increase of mass of air which increase air velocity and decrease vapor condensations in evaporator chamber.

4.2 Present correlations

It is very important to correlate numerical results. If the design equation is general, it will be more useful in engineering applications. The general correlation of productivity of the system as function of water temperature, water level and airflow rate are obtained by use the Microsoft Office Excel Solver tool which, uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code, which was developed by Leon Lasdon, University of Texas at Austin, and Alan Waren, Cleveland State University. The productivity of the system can be correlated with maximum deviation 7% as follows:

$$\dot{M}_w = 1.597\times10^{-7}\,(T_w)^{3.971} \times(0.127+2352\times10^{-7}\,h) \times(0.87231-0.02473\,\dot{M}_a) \quad (6)$$

At: $50 \le T_w \le 87$;

$20 \le h \le 30$;

$4.2 \le \dot{M}_a \le 14$

5. Conclusions

The experimental and theoretical investigation of the principal operating parameters of a desalination process working with an air humidification-dehumidification method is studied. The effects of the water temperature, water level and airflow rate on the humidification effectiveness, productivity and efficiency of the system were observed during the present experiments and the following points were concluded:

The productivity of the system increases with the increase of the water temperature and the decrease of the airflow rate. The productivity of the system is moderately affected by the water temperature and airflow rate and slightly affected by the water level. The humidification effectiveness is higher for M_a=14 kg/h at different water temperature and level. The efficiency of the desalination system is higher for M_a=12.6 kg/h and M_a=14 kg/h at different water level. At 80 °C, the productivity of the system is higher at different water level and airflow rate. The experimental measured agreed well with experimental calculation productivity. Within the studied ranges, the maximum productivity of the system reached to 0.81 kg_w/kg_a at 87 °C for water and M_a=4.2 kg/h and M_a=8.4 kg/h.

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Nomenclature

$\dot{m}$	Productivity of system
C_p	Specific heat of water
h	Enthalpy
L	Latent heat
Q	Power
T	Temperature

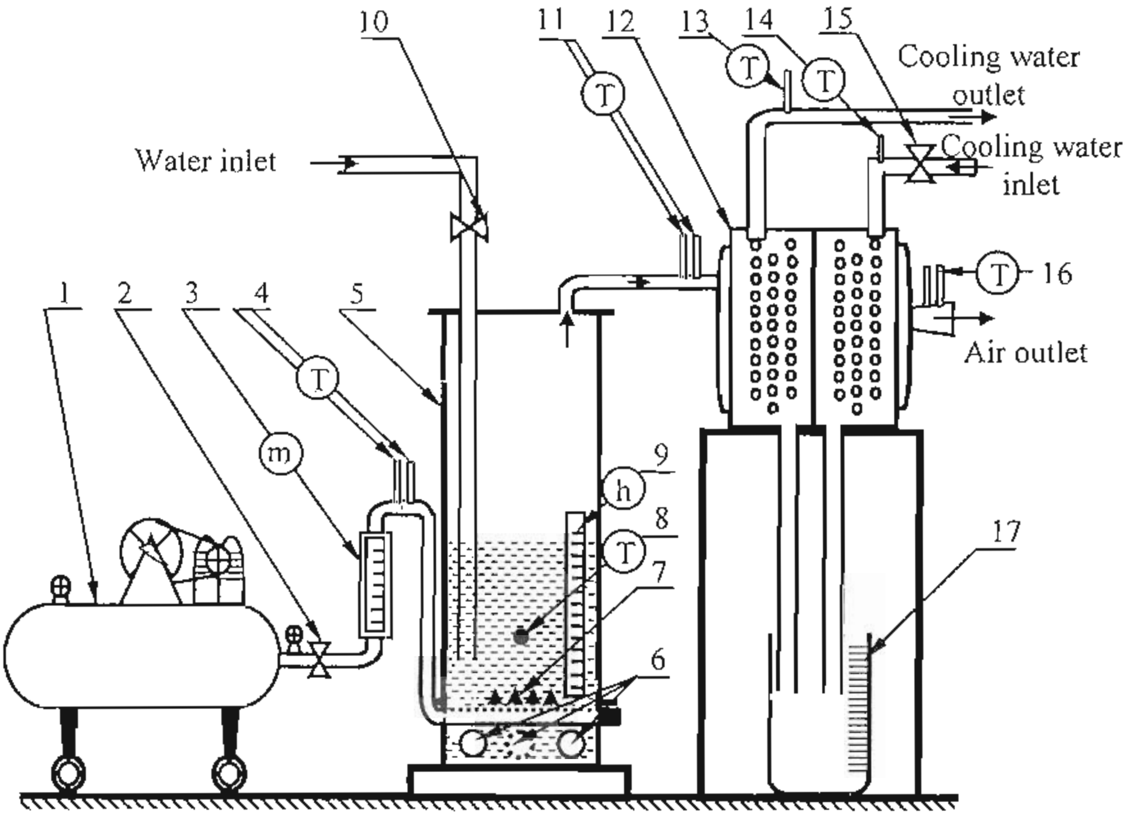
Greek

ω	Humidity
$\Delta\omega$	Vapor content difference
η_d	Efficiency of the desalination system
η_{hu}	Humidification effectiveness

Subscript

air	Air
ev	Evaporator chamber
in	Inlet
out	Outlet
sat	Saturation
vap	Vaporization

w Water



1) air compressor
2) flow control valve
3) air flow meter
4) digital thermometer
5) evaporator chamber
6) electric water heaters
7) forty-four holes
8) thermometer PT-100
9) graduate lever
10) flow control valve
11) flow control valve
12) digital thermometer
13) dehumidifier
14) digital thermometer
15) digital thermometer
16) digital thermometer
17) desalinated water tank

Fig. 1 Schematic diagram of the experimental setup

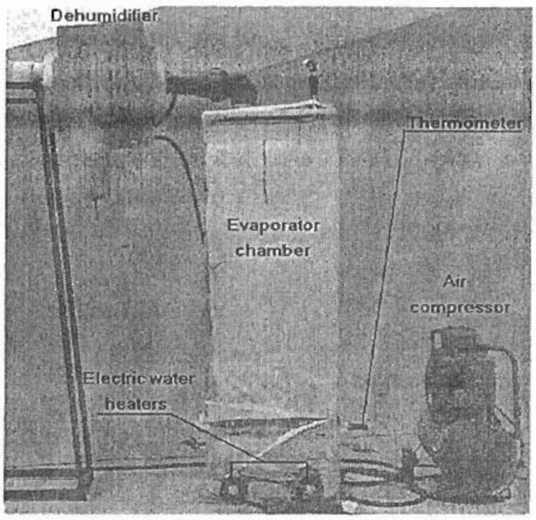


Fig. 2. Photograph of the experimental setup

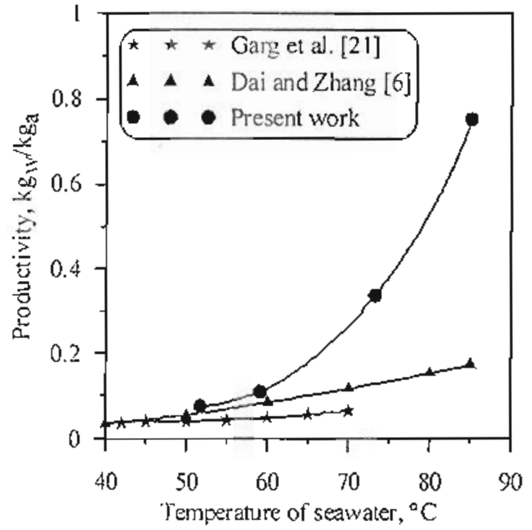


Fig. 3 The comparisons between the present results and those of the, Garg et al. [21] and Dai and Zhang [6]

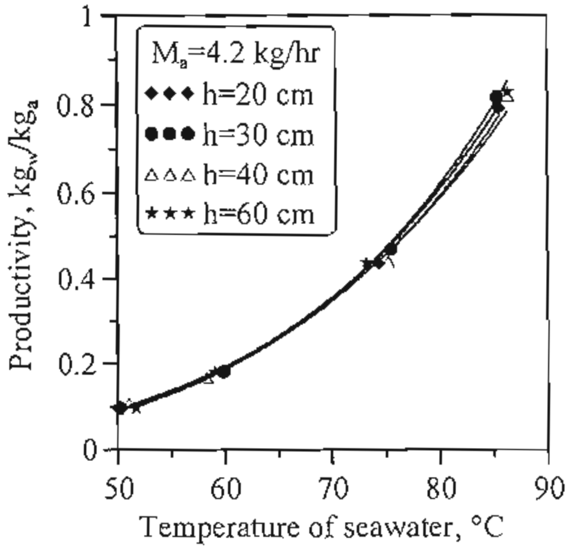


Fig. 4 The effect of the temperatures of saline water on productivity at M_a= 4.2 kg/hr

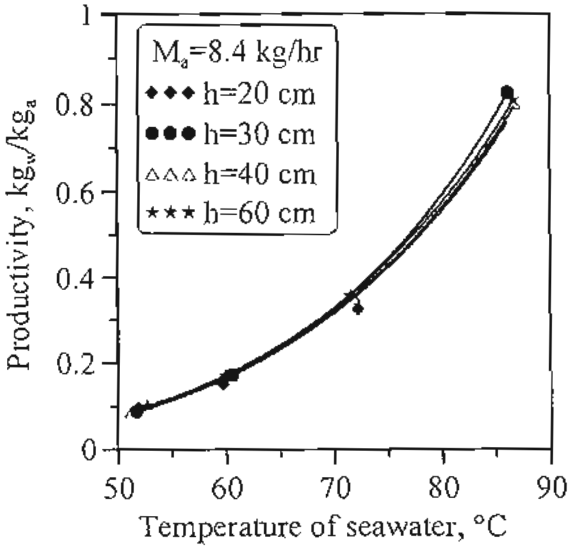


Fig. 5 The effect of the temperatures of saline water on productivity at M_a= 8.4 kg/hr

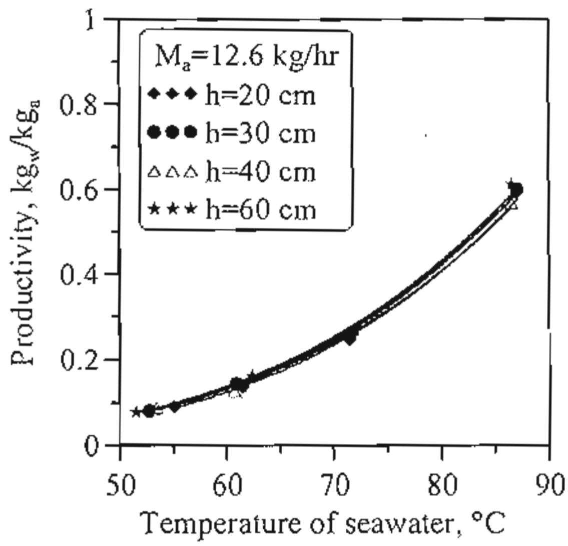


Fig. 6 The effect of the temperatures of saline water on productivity at M_a= 12.6 kg/hr

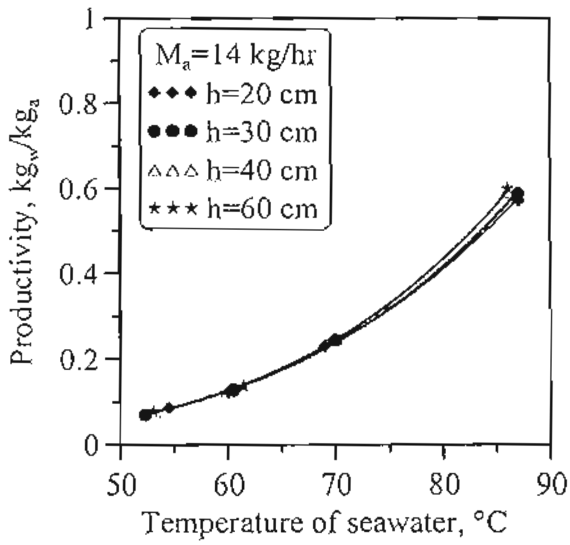


Fig. 7 The effect of the temperatures of saline water on productivity at M_a= 14 kg/hr

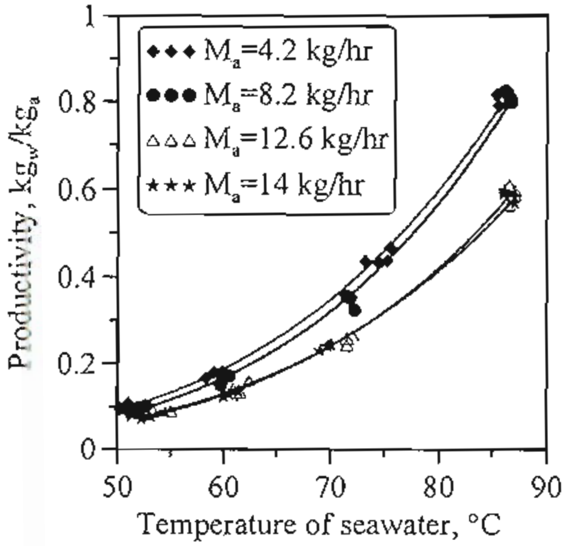


Fig. 8 The effect of the temperatures of saline water on productivity at different air flow rate

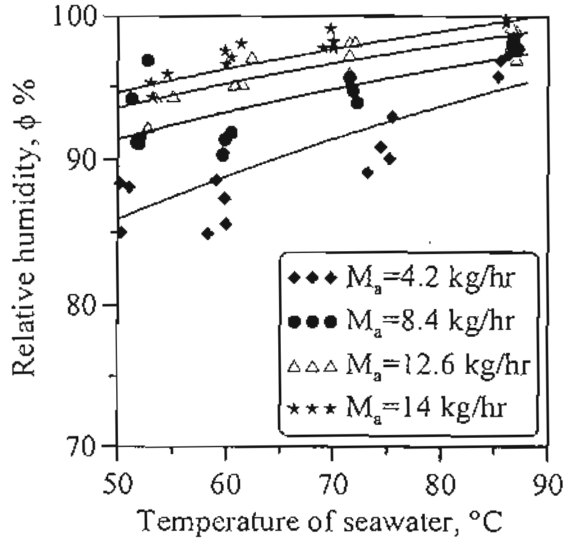


Fig. 9 The effect of the temperatures of saline water on relative humidity at different air flow rate

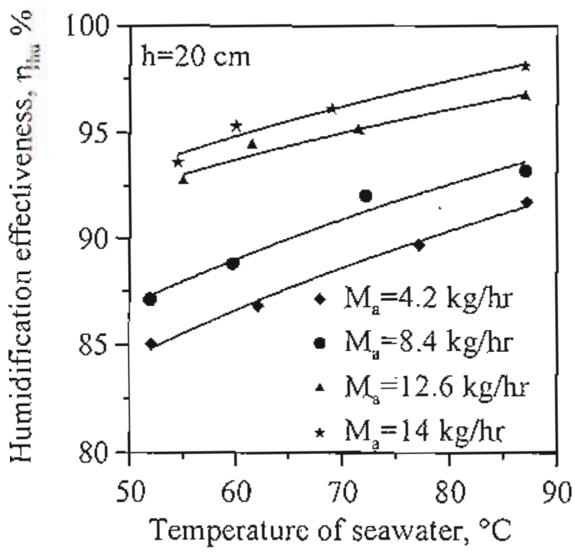


Fig. 10 The effect of the water temperature on the humidification effectiveness at h=20 cm for different air flow rate

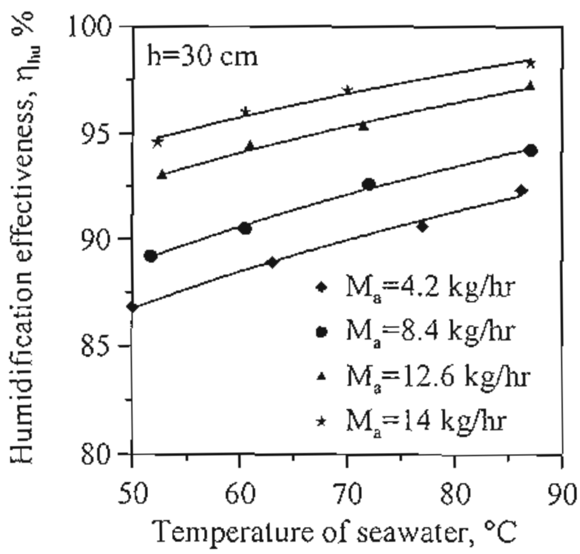


Fig. 11 The effect of the water temperature on the humidification effectiveness at h=30 cm for different air flow rate

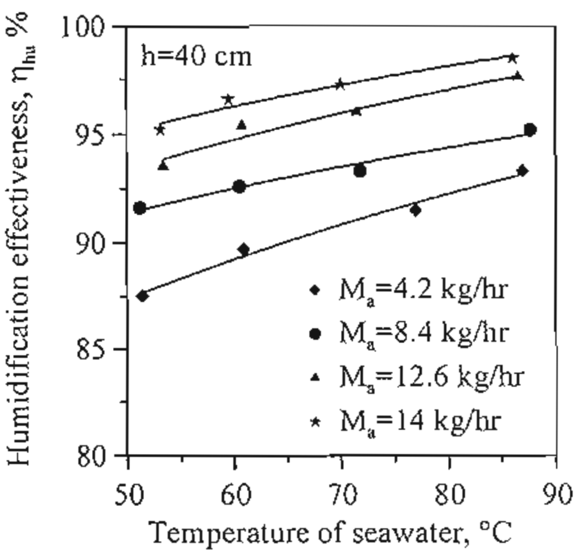


Fig. 12 The effect of the water temperature on the humidification effectiveness at h=40 cm for different air flow rate

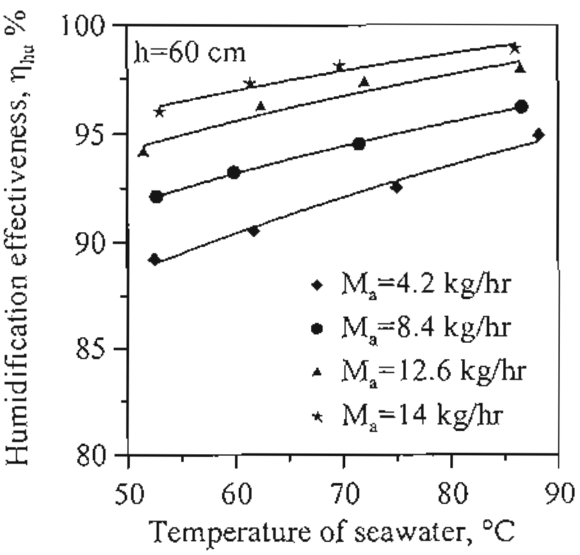


Fig. 13 The effect of the water temperature on the humidification effectiveness at h=60 cm for different air flow rate

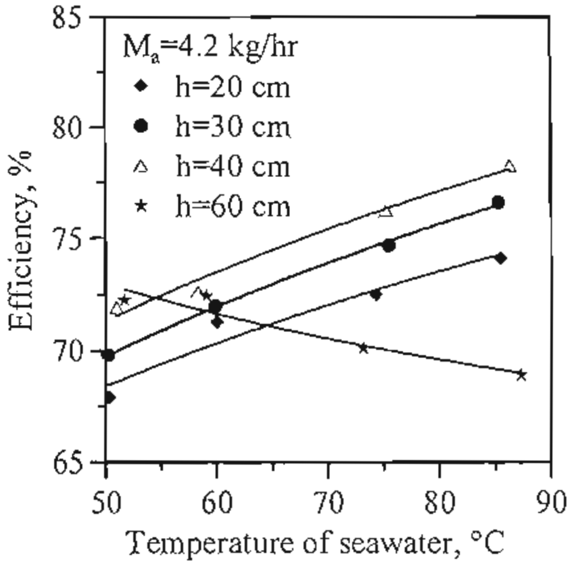


Fig. 14 The effect of the temperatures of saline water on efficiency of the desalination at M_a= 4.2 kg/hr

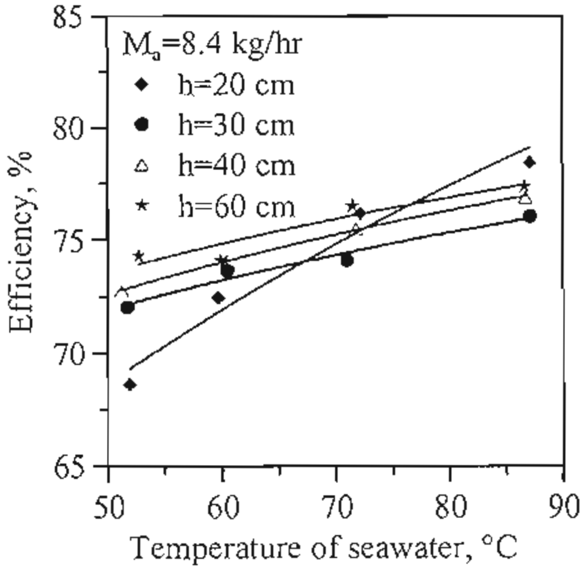


Fig. 15 The effect of the temperatures of saline water on efficiency of the desalination at M_a= 8.4 kg/hr

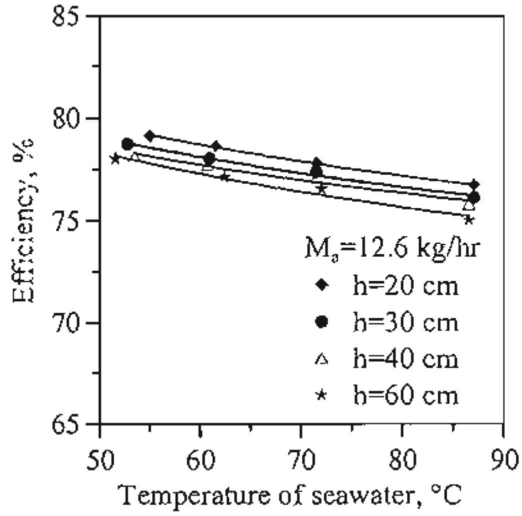


Fig. 16 The effect of the temperatures of saline water on efficiency of the desalination at M_a= 12.6 kg/hr

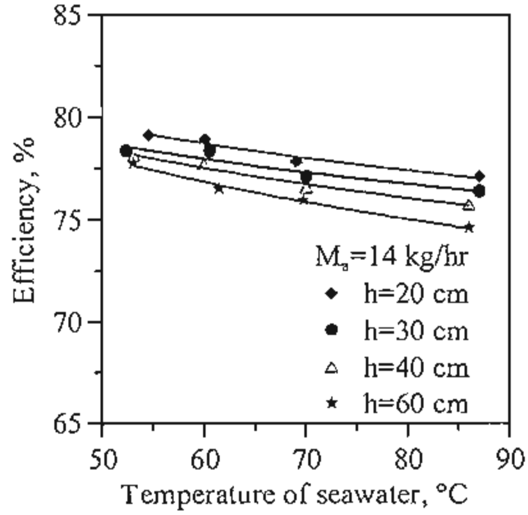


Fig. 17 The effect of the temperatures of saline water on efficiency of the desalination at M_a= 14 kg/hr

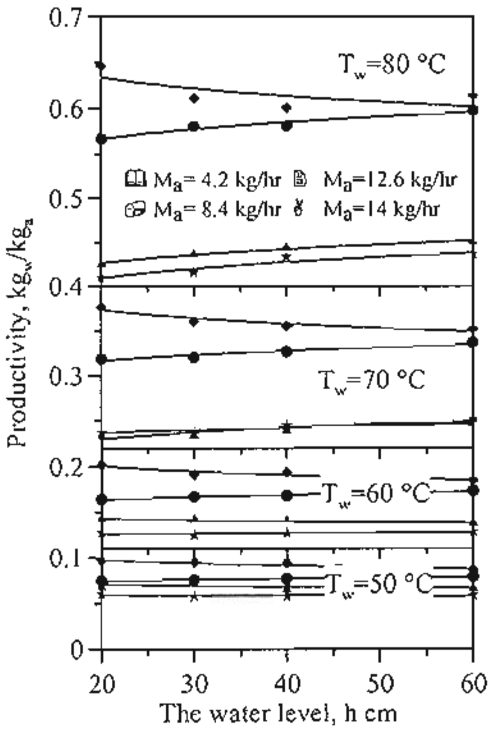


Fig. 18 The effect of the saline water lever on productivity at M_a= 4.2, 8.4, 12.6 and 14 kg/hr for different water temperatures

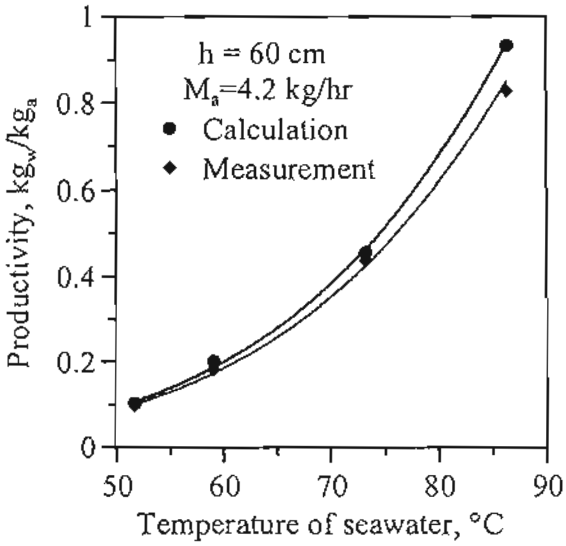


Fig. 19 The comparison between the experimental measurement and calculation productivity at M_a= 4.2 kg/hr and h=60 cm

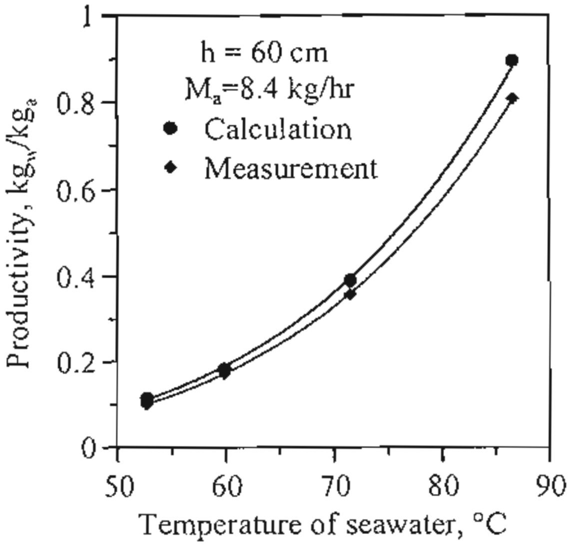


Fig. 20 The comparison between the experimental measurement and calculation productivity at M_a= 8.4 kg/hr and h=60 cm

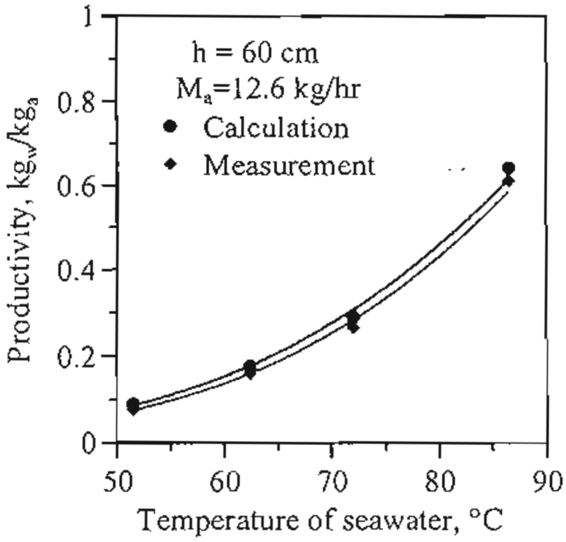


Fig. 21 The comparison between the experimental y measurement and calculation productivity at M_a= 12.6 kg/hr and h=60 cm

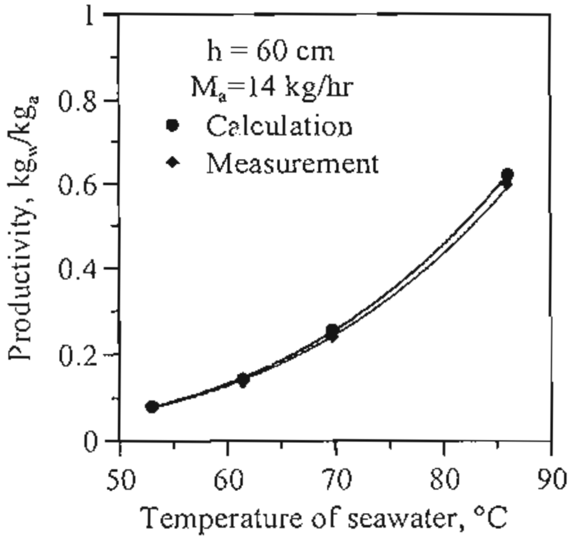


Fig. 22 The comparison between the experimental measurement and calculation productivity at M_a= 14 kg/hr and h=60 cm