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Energy Consumption Minimization of a New Desalination System

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Abstract_ **Demand for fresh water has increased very dramatically in recent years due to the huge increase of the population and the great development in industry and agriculture. Among many water treatment technologies, seawater desalination process is the ideal solution to address the problem of the shortage of fresh water in many places around the world. However, energy consumed in the desalination process is the major challenge which faces its success in solving the problem of the shortage of fresh water. Generally, desalination process consumes a very large amount of energy. The majority of this energy comes from fossil fuel sources, which is the main source of environmental pollution and global warming. Reducing the energy consumed in the desalination process is a key factor for cutting the cost of fresh water produced by the desalination process. For this purpose, a new system has been developed for water desalination through integration of the heat pump system and humidification and dehumidification technology. The energy consumption in the desalination process was minimized by controlling the water and air flow rates in the new system. The results showed that 1.71 kg/hr of fresh water can be produced using only 0.726 kWhr. This result is an important achievement in reducing the energy consumed in the desalination process.**

Keywords—component; Humidification-Dehumidification, Desalination, Minimum Energy , Heat pump,

I- INTRODUCTION

Global demand for freshwater is increasing rapidly due to the significant soaring of the rate of population growth. However, the available freshwater is already a scarce resource and does not satisfy the global increasing need of fresh water. Many think that fresh water shortages will cause the next great global crisis. Furthermore, recent research show that around 25% of the world population does not have an adequate supply of fresh water, both in terms quantity and quality [1].

With scarcity in freshwater resources, mankind has tapped into other sources, such as, seawater and brackish water. Through the process of desalination, situations of water shortages have been alleviated in many countries. Desalination has been used regularly over the past fiftieth years in different regions of the world. However, desalination processes are energy-intensive and the cost of desalinated water hinge on the cost of fuel, which has been rising steadily over the years. These factors are; the level of salinity of feed water, energy consumption, the required quality of produced water and finally the cost of construction and unit size. Generally, desalination process consumes a very large amount of energy. Reducing the energy consumed in the desalination process is a key factor for cutting the cost of fresh water produced by the desalination process

Nowadays, there are many desalination methods uses around the world. All these methods require a pre-treatment for the feed water to prevent scaling, biological growth, foaming, fouling and corrosion. These desalination processes can be categories under two main types; thermal and membranes as shown in fig.2.1 [2]. Thermal desalination processes involve phase changes and requires significant amount of energy input. This energy is commonly obtained through the burning of fossil fuels. Thus, increasing the capacity of the plant would likely means increasing the severity of environmental pollution. Also, the cost of water which is produced by burning of fossil fuels is highly susceptible to the fluctuations of fuel prices in the market.

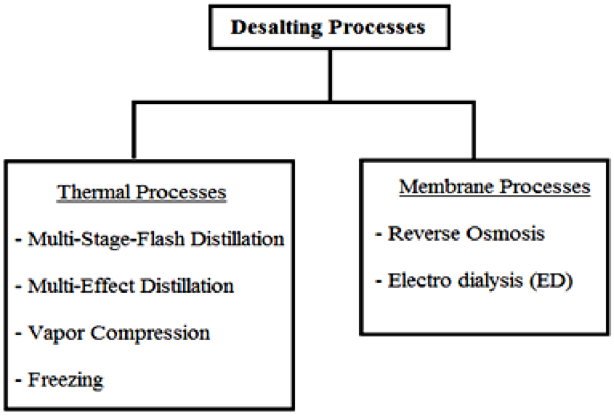


Fig1-3 Desalination technologies

These factors have called for solution by utilizing new technologies for desalination leads to reducing the energy consumed in the desalination process which is a key factor for cutting the cost of fresh water produced by the desalination process. Desalination by heat pump has been carried out in Mexico since 1981by Siqueiros et al.[3]. The heat pumps used were initially of the mechanical vapor compression type, which were later replaced by absorption heat pumps. They concluded that, from a thermodynamic point of view, it is much more appropriate to use waste heat to operate water desalination systems than using high grade energy such as electricity, natural gas, or oil with its associated environmental problems.

Slesarenko [4]. Investigated the application of the absorption heat pump in power stations. Power stations used seawater to condense steam from turbines. In a typical condenser, seawater temperature is increased by 10-20°C. To make use of this energy, a low temperature vacuum desalting installation and heat pumps were introduced. The heat pump used is of the absorption type, where it consumes less electrical energy. Further studies showed that the specific thermal energy consumption at desalination units with absorption heat pumps is 2-2.5 times lower than other power systems.

Reali[5]. Proposed a desalination method called the refrigerator-heat pump desalination scheme (RHPDS). In this study, sea water was evaporated and condensed using a vapor compression heat pump. The system consists of two tanks, to contain salt and fresh water ,connected at the top part. The tanks were evacuated, and seawater entered the salt water tank at atmospheric pressure. The heat pump will provide the heat to evaporate seawater, and cooling to condense the vapor into the fresh water tank. The system was designed to operate with small temperature difference, around 5°C, for the water tanks. Thus high energy efficiency was expected. Hawlader et al.[6]. Conducted a study on a solar assisted heat pump desalination system. The system consists of a solar assisted heat pump, a distillation chamber, and a solar water preheating unit. The heat pump used an unglazed, serpentine tube solar evaporator collector. A performance analysis showed that the PR of the system ranges from 0.77 to 1.15.

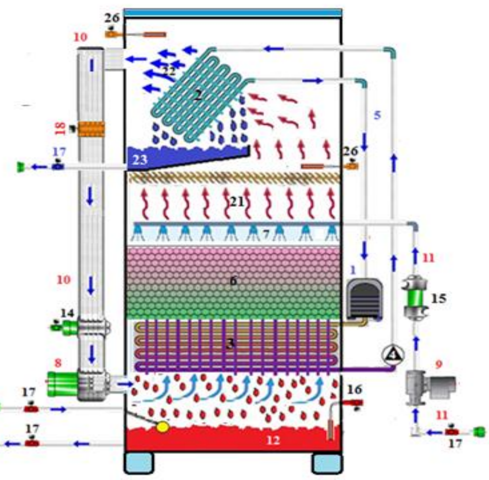
Huang and Chyng[7].Investigated the characteristics of an integral-type solar-assisted heat pump (ISAHP), which integrated a Rankine refrigeration cycle and a thermosyphon loop. A performance model was derived for the ISAHP system, and the COP values of the system are found to be in the range of 2.5 to 3.7, depending on the temperatures of water. Gao et al.[8].Presented a new method desalination system driven by a mechanical vapor compression pump. The unit utilized heating from the condenser and cooling from the evaporator adequately. More latent heat has been reclaimed. A simulation model of the system is presented, in which the hydrokinetic manner was used to study the mass and heat transfer and the flow rate inside the affiliate humidifier. The effects of some of the operating conditions, such as flow rates of air and water, temperatures of cooling water, were studied in detail.

It is clear from the literature review above that the desalination process by solar assisted-heat pump systems represents a potential alternative to be used in desalination systems. However, only few studied were conducted on the use of solar assisted-heat pump in the desalination system. Further study is therefore needed in this field to determine the full potential for desalination by using heat pump. Thus, an economical and effective new desalination technology has been developed. A desalination unit based on humidification dehumidification technique and assisted by the heat pump as source of water evaporation and condensation have been designed and sat up. The experiments and measurements were conducted on the new desalination system.

II- EXPERIMENTAL SET-UP

The present system has been mainly conceived on two ideas of air humidification and dehumidification process using the heat pump as a cooling and heating sources in the system. Fig. 2.1 illustrates a schematic of the desalination unit .The desalination unit consists from a vertical tower containing the dehumidification chamber in the upper part and the humidification chamber in the lower part. The humidification chamber contains the water distribution tray , packing material and the condenser heat pump. The dehumidification chamber contains an evaporator heat pump and a distillate collector tank. The system also consists from a water pump, a feed water tank and an air blower. The HP-HDH system consists of two loops, one for water and the other for air with an interface of the humidification chamber. In the water loop, the saline water is delivered from the feed tank using a submersible water pump. The saline water is sprayed at the top of the humidification chamber. The water falls down to the bottom of the humidification chamber where it is pumped again by another submersible water pump. In the air loop, air is drawn using a centrifugal blower (installed at inlet of the dehumidification chamber). The air flows through the humidification chamber where the evaporated water is carried to the dehumidification chamber. At the dehumidification chamber, the air is cooled and dehumidified then recycled again.

The water desalination is achieved by the HDH- HP technique, which requires a heating unit for producing vapor and a cooling unit for condensation of vapor. Therefore, the new system integrates the heat pump and the humidification-dehumidification system. The heating unit is in the condenser side of the heat pump and the cooling unit is in the evaporator side of the heat pump.



1-Compressor 2-Evaporator 3-Condenser 4-Capillary tube 5-Heat pump pipes 6-Packing material 7-Water distributor 8-Air blower 9-Water pump 10-Air duct 11-Water pipes 12-Feed water tank 13-Distillate collector 14-Rotameter 15-Anemometer 16-Thermometer 17-Water valve 18-Air valve 20-Droplet eliminator 21-Humid air 22-Dry air 23-Fresh water 24- Makeup water 25-Brine 26- Hygrometer.

Fig.1.2. Illustrates a schematic of the desalination unit.

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In order to performance evaluation of a new system for water desalination different combinations of input parameters were studied. Although there are several factors that affect the efficiency of the unit, the parameters chosen to vary in this experimental work are the most crucial and most easily controlled and adjusted which the varying parameters include mass flow rates of the air and water[9].

III- Performance Parameters for Desalination System.

Several tests will be performed to determine the effects of different variables and the performance of the system is evaluated by the set parameters of the system which are carefully chosen to perform a detailed system analysis. Where there are several ways to characterize performance in desalination systems the performance parameters that are chosen and studied to evaluate the system are: The outlet temperature of Air of humidifier, productivity, the performance ratio, power consumed in the desalination process and the coefficient of performance.

A. The Gain Output Ratio (GOR)

The GOR which is defined as the amount of the energy consumed in the production of the fresh water to the energy input by external energy source is always used as a measure of the overall performance of the humidification and dehumidification systems[10].

$$GOR = \frac{m_{fresh}.h_{fg}}{Q_{in}} \quad .... \quad (1)$$

B. Refrigeration unit coefficient of performance

The COP is a dimensionless value defined as the energy transferred for cooling by the refrigeration unit (in watts) divided by the energy consumed by compressor of heat pump (in watts). COP represents the efficiency of refrigeration unit coefficient a heat pump[11]. are calculated from the following equation:

$$COP = \frac{Q_{Evapartor}}{Q_{in}} \quad .... \quad (2)$$

C. Power Consumed in the Desalination Process

Defined as the total amount of power required to produce one kilogram of fresh water from salt water, which represents the economic feasibility of the process of desalination water. It is measured by the units (kJ/kg) and can be calculated using the following equations:

$$P_{Cons} = \frac{P_{Tinput}}{m_{fresh}} \quad .... \quad (3)$$

IV- Results and Discussion

In the close air open water (CAOW) system, the air is recycled in closed loop, while water is drained after leaving the humidifier, as shown in Fig.2.1. In order to study and evaluate the performance of the CAOW system. The system has been tested at constant feed water temperature of 25 ºC and different the water and air mass flow rates .The effects of the water and air mass flow rates on different parameters have been studied. These parameters are; the temperature of outlet air of humidifier, productivity, GOR, energy consumed in the desalination process and COP.

Fig.3.1 describes the effect of feed water and air flow rate on outlet air temperature of the humidifier. It can be noticed that temperature of the outlet air decreases with the increase of feed water flow rate. The reason is that the increase in the feed water flow rate leads to an increase in the heat transfer coefficient and then an increase of the cooling rate of condenser coils. Therefore, air outlet temperature decreases with decreasing of the condenser temperature. It also can be noticed that the outlet air temperature decreases with increasing of air mass flow rate because that the increase in mass flow rate of air leads to an increase in the mass transfer coefficient which leads to the increase of water evaporation rate conducted on the condenser surface. Thus, the condenser temperature decreases causing outlet air temperature of the humidifier to decrease.

Productivity is an important parameter in the evaluation of the efficiency and economic of the desalination process. Fig. 3.2 shows the effect of feed water and air flow rates on fresh water productivity. It can be noticed that the productivity directly proportional with the increase of mass flow rates of feed water and air until reaching the maximum productivity value of 1.71kg/hr. After that, the productivity starts to decrease with increasing of feed water and air flow rates. The reason of the increase in the productivity in the first step comes from the increasing of feed water flow rate. This leads to enhanced distribution of water within the humidifier which produces large surface area for evaporation and it leads to an increase of evaporation rate. As a results of increasing evaporation rate, moisture content of the air increases.

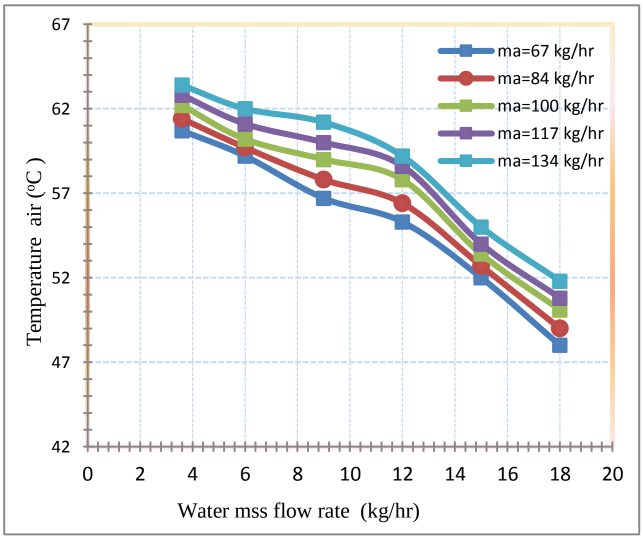

Fig.3.1 Effect of mass flow rate of recycled water on temperature air outside humidifier at different flow rate of air.

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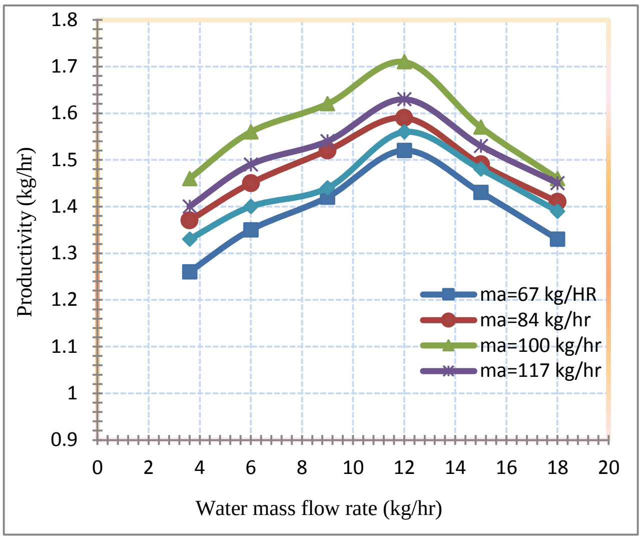

Fig.3.2 Effect of mass flow rate of recycled water on productivity at different mass flow rate of air.

Therefore, the fresh water productivity increases in this step. However, in the second step, the increase of feed water flow rate leads to a large decrease in the condenser temperature which also causes a decrease in heating rate of both conducted air and water within the humidifier. This cause the evaporation rate to decrease which results in decreasing of productivity.

The Gain Output Ratio (GOR) changes proportionally with the productivity and inversely with the consumed power. The increase of PR represents the increase of the unit efficiency in the desalination process. Fig.3.3 show the effect of the mass flow rate of the feed water on PR at different air flow rates. It is seen that the increase of PR continues with increasing of feed water mass flow rate until reaching the water flow rate of 12 kg/hr where the PR reaches maximum values at different airflow rates. PR then starts to decrease with the increase of feed water flow rate. In the first stage, the increase of water flow rate leads to an increase of productivity as explained previously.

The condenser cooling rate also increases which leads to a decrease in pressure of the refrigerant inside the condenser and thus, the energy consumed by the compressor decreases. Consequently, GOR increases at this stage. On the other hand, further increase of water flow rate leads to the productivity decrease and an increase of consumed power by the water pump. As a result, GOR starts to decrease with the increase mass flow rate of the water at this stage.

Fig.3.4 describes the relationship between the flow rate of feed water and consumed power to produce 1kg of fresh water. From this figure, it is observed that the consumed power decreases with increasing of water mass flow rate until the minimum value of 1528 kJ/kg where water mass flow rate reaches 100 kg/hr. After that, the consumed power increases with the increase of water flow rate. The reason for this behavior is that an increase of water flow rate leads to an increase of productivity and a decrease of power consumed by the compressor. Thus, the consumed power decreases. If the increase of water mass flow continues, productivity decreases and air blower power consumed increases as previously explained. Thus, the consumed power increases.

The Coefficient Of Performance (COP) is one of the important factors that describes the efficiency of the heat pump system. Its increasing means increasing of the energy recovery efficiency of the heat pump system. Fig.3.5 describes the effect of air flow rate on the COP of the heat pump at constant water temperature and different water feed flow rates. It can be noticed that the COP increases directly with the increasing of air flow rate until the air flow rate reaches 100 kg/hr where COP almost stays constant with further increasing of air flow rate at all different feed water flow rates. The reason of this behavior is the inverse relationship between the enthalpy of outlet air of the humidifier and air residence time in the evaporator and the air flow rate.

In the first stage, the low air flow rate increases the outlet air enthalpy and also increases the residence time of air in the evaporator.

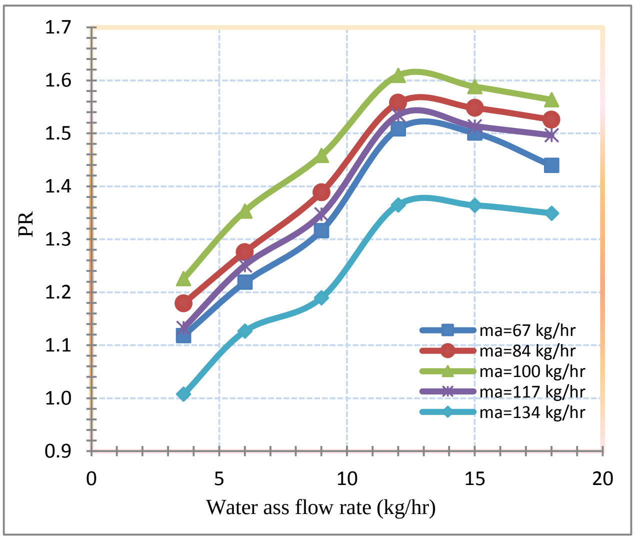

Fig.3.3 Effect of mass flow rate of recycled water on the (PR) at different mass flow rate of air.

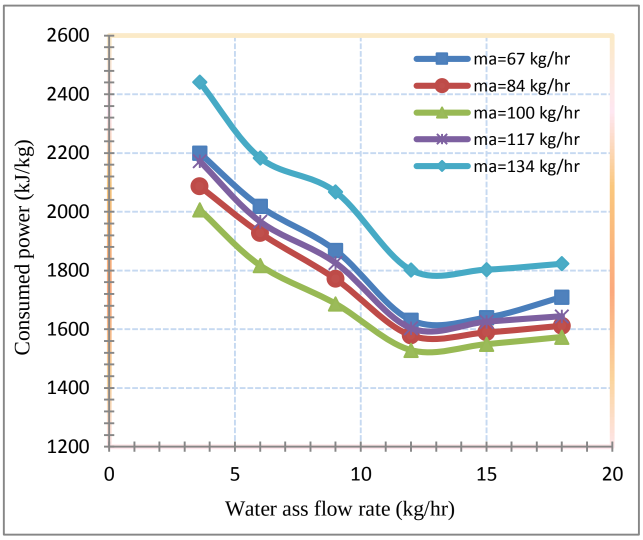

Fig.3.4 Effect of mass flow rate of recycled water on the consumed power (kJ/kg) at different mass flow rate of air.

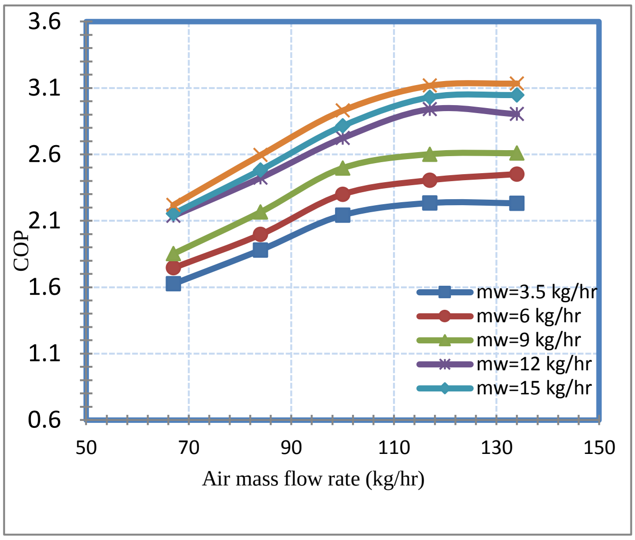

Fig.3.5 Effect of mass flow rate of air on the (COP) at different mass flow rate of the recycled water.

This causes the rate of energy absorbed by refrigerant in the evaporator to increase, thus COP increases. In the second stage, the increasing of the air flow rate leads to the decrease of outlet air enthalpy. The residence time of air in the evaporator and the consumed energy by the compressor also decreases. These factors lead the COP to be almost flat with the increase of air flow rate.

V- CONCLUSIONS

A new desalination system using a heat pump has been introduced as an efficient desalination process for fresh water production. The new desalination system has many advantages such as a small size, portable design and low temperature operation. This makes it suitable for most domestic uses. Furthermore, it has been found that this system exhibits great potential for future developments and will likely to be more economically feasible, reasonable and technically attractive toward solving of energy and water problems. The experimental results gave maximum values of the GOR and COP of about 1.61 and 3.1 respectively. The energy required was only 1528 kJ per kg of fresh water produced. The new desalination system would be a potential alternative for the conventional desalination technologies.

NOMENCLATURES AND SYMBOLS

RHPDS	Scheme Refrigerator-heat pump desalination.
ISAHP	Integral-type solar-assisted heat pump.
HDH-HP	Humidification and Dehumidification process using the Heat Pump.
CAOW	The closed air open water system.
COP	Coefficient Of Performance
GOR	The Gain Output Ratio.
m_{fresh}	Mass flow rate of fresh water,(kg/hr)
h_{fg}	Enthalpy of vaporization, kJ/kg
Q_{in}	Energy input to unit,(kJ)
m_w	Mass flow rate of feed water.
m_a	Mass flow rate of air.(kg/hr)
P_{cons}	Power Consumed in the Desalination Process,(kJ/kg)

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