# Modelling of a Solar Energy driven Water Desalination System using TRNSYS.

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***Abstract*—The overall broad purpose of this paper is to develop and evaluate a small scale solar humidification dehumidification water desalination system using a graphical tool TRNSYS and assess its thermal behavior. Considering the intense need for the development of alternate technologies for energy deficient and impoverished countries of the world like Pakistan, this model is in particular anticipated for underprivileged communities where pure and uncontaminated drinking water as well as modern technologies are not accessible. The system consists of isolated components for heating, evaporation and condensation, in order to lower the thermal losses. The weather file used was in standard TMY 2 format for Asian data. A flat plate solar collector, humidifier and dehumidifier are to be integrated in an open air open water configuration. The simulations for a water heated cycle revealed that the output water temperature be reliant strongly on the incident solar radiations and inlet water temperature. Collector area and inlet water flow rate also had a considerable impact on productivity. A significant increase in efficiency was observed by using a water storage tank and pre heating the feed water favorably influenced the output.**

***Index Terms*—Solar thermal energy, solar water desalination, humidification-dehumidification, solar collector, water flow rate, water cycle.**

### ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| HDH | Humidification-dehumidification |
| CAOW | Closed Air Open Water |
| CWOA | Closed Water Open Air |
| OAOW | Open Air Open Water |
| CACW | Closed Air Closed Water |
| RH | Relative Humidity |
| TRNSYS | Transient System Simulation |
| HAP | Hourly Analysis Program |

## I. INTRODUCTION

Water scarcity and contamination are the swiftly growing global challenges that are increasingly posing a threat to mankind. This is especially problematic for underprivileged areas where people are not facilitated with modern purification technologies and still they can't even afford to imagine having it.

The best possible solution to meet the high safe water demands is harnessing the huge potential of sea water. All that needed to be done is using the efficient and cost effective technology for salt and impurities removal that is what we generally refer to as desalination. Lot of research is being done in this regard but the most common technologies being used now a days are mostly cost and energy intensive. In order to balance the economics and efficiency, the most promising technology so far is solar energy driven HDH water desalination which has the potential to provide clean water consuming the ecological, cheap and abundant natural energy.

### A. Need of Desalination in Pakistan

Pakistan lies at number 80 among 122 countries regarding water quality [1]. About one third of 200 million people don't have access to clean drinking water. According to UNICEF, almost 40% of patients in Pakistan are being suffered from water-related problems [2].

Keeping in mind the current scenario of Pakistan's energy crisis, there is intense need to explore alternate cheap energy sources and water purification technologies.

### B. Solar Energy Status in Pakistan

Solar energy is the most reliable, cleanest, cheapest and abundant source of energy that could be efficiently utilized in thermal processes. Pakistan has a strong potential for solar power, as we are lucky enough to enjoy radiations from sun throughout the year with 10 sun shine hours on average and average global insolation is almost 5-7 kWh/m$^2$/day [3].

## II. Solar Desalination

The basic principle in the thermal energy driven HDH desalination process is to recuperate fresh water condensate from moist air coming from humidifier. The moisture absorbing capacity of air increases with the increase in air temperature [4].

The system consists of three main components; Solar collector for water or air heating, humidifier to humidify the dry air and dehumidifier or heat exchanger for condensation.

The process relies on the evaporation of the feed water in the humidifier and consecutive condensation of the humidified air inside the dehumidifier [5]. Pre-heated sea water is introduced into the condenser (dehumidifier) and is distributed through the solar collector to get higher temperature. From the other end, in the humidifier, dry air is pumped in which extracts water vapours from the incoming hot water stream when comes in contact with it and the remaining brine is collected at the bottom. Then the humid air carries the vapours to the condenser where fresh water vapours are recovered and air cools down by losing its heat to the incoming feed water [6].

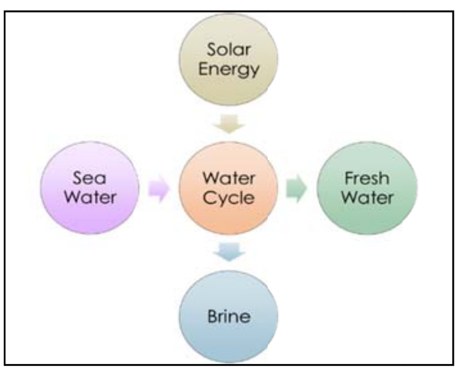



*Figure 1: Basic HDH principle*

### A. Classification of Desalination Processes

Solar desalination systems are categorized into two systems [7];

Direct desalination systems in which solar energy is directly used to produce fresh water using solar water/air heaters or solar collectors.

Indirect desalination systems may involve transformation of solar energy into some other form of energy which is then used for desalination.

Solar stills, solar humidification dehumidification desalination systems and solar chimneys are included in the direct desalination systems [8].

Indirect systems are further divided into three categories; Thermal processes, membrane based processes and chemical processes [9].

These technologies have lot of drawbacks like high capital cost and power consumption. Instead, direct desalination systems are more feasible [10].

## III. Classification of Solar HDH systems

Solar HDH systems can be classified under two broad categories on the basis of configuration and heating fluid [11].

On the basis of heating fluid, two types of solar HDH systems are water heated systems and air heated systems. The behaviour of the system is altered critically depending on the heated stream type. Either of them could be integrated in four different configurations [4] [12].

1. Closed air open water system (CAOW)
2. Closed water open air system (CWOA)
3. Closed air closed water system (CACW)
4. Open air open water system (OAOW)

In the CAOW systems, air is circulated between humidifier and dehumidifier in a closed loop, and sea water is extracted from humidifier as waste brine in each cycle. Such systems are mostly water heated systems but research has also been done on air heated closed air systems.

CWOA works with closed water loop and the dehumidified air is released back to atmosphere. But in such systems, the recovery rate is relatively low due to heat loss by humid air during dehumidification.

In OAOW-air heated systems, air stream makes a single pass through the system. Hence, the connection between humidifier and dehumidifier is not established. Same is the case with water heated systems.

Literature suggests that closed air open water system is the most suitable system [4].

## IV. Literature review

Muller Holst et al. [5] optimized a decentralized small scale thermal desalination system using TRNSYS simulation tool, based on principle of multi-effect humidification (MEH) system inside a thermally shielded box at atmospheric pressure. The air was naturally circulated and condensate produced was 0.5-2m$^3$/day.

M.M. Farid et al. [13] also evaluated performance of an MEH unit and studied the influence of inlet water flow rate on the system's productivity. Mathematical modelling was done with forced air convection and assuming that air temperature was fluctuating linearly from bottom to top.

They reported that the humidifier area's consequences were significant only for large values of collector area and for smaller collector area, the productivity slightly increases with increase in condenser area.

Nafey, Fath et al. [14] considered closed air and closed water loop configuration using flat plate solar heaters for water and air heating and found greater effects of solar water heater area than the air heater area. Strong effects of solar intensity and water and air temperature were observed at higher flow rate values of water.

E. Chafik [15] designed a new type of four-fold-web-plate collector to be used for MEH desalination system with optimally designed pad humidifier and tube-fin heat exchanger. A transient simulation program was developed in TRNSYS and predicted operating data was compared with experimental tests and a desalination plant with 10m$^3$/d productivity was constructed using these results.

Yamali and Solmus [16] numerically investigated the solar desalination system for Ankara, Turkey and observed the strong influence of water and air flow rates and temperatures on the system productivity. Solar air heater area also had a strong impact but effect of wind speed variations influenced slightly the system's performance.

Juma Yousuf Alaydi [17] modelled solar desalination system using parabolic solar collector for water heating. Different parameters for collector's performance like rim angle, collector's aperture and receiver's diameter were analysed and optimized for large scale water production.

A closed air water heated cycle with single effect was studied by Stefania Cherubini and Antonio Perdichizzi [18] in TRNSYS. Two different configurations were analysed, 1st was based on direct desalination system with solar collector to heat up the feed water, but the 2nd was an integrated cooling desalination system where the heat from solar collector was being absorbed by LiBr absorption chiller and the heat rejected by chiller was utilized to drive the process. The system performance in both cases was strongly affected by inlet feed water temperature. For case 1, the performance was improved but it was decreased in the 2nd case for higher water temperatures.

A solar liquid desiccant air conditioning (SLDAC) desalination system was evaluated by M. Elhelw [19] for Borg Al-Arab, Egypt. Simulations were carried out by TRNSYS and for hourly cooling loads determination, Hourly Analysis Program HAP 4.7 was used. In July and August, the vapour desorption in the regenerator was highest and was increased by increasing the solar collector area. But the collector area doesn't affected the amount of vapour absorbed in the conditioner.

## V. Proposed Model

A Transient System Simulation Tool for solar systems called TRNSYS was used for modelling of a water heated single stage HDH desalination system. The components called types were dropped from TRNSYS 17 library in the simulation studio.

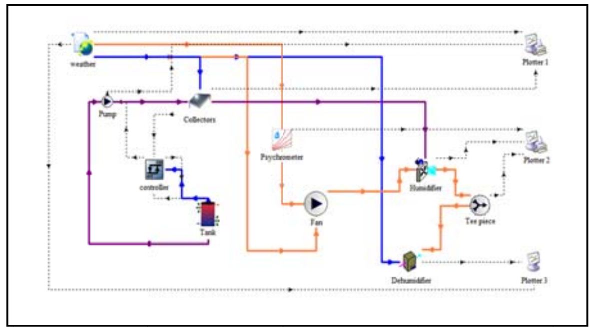



*Figure 2: TRNSYS Model*

A solar flat plate collector to heat the feed water is used with a water storage tank. The air circulation was forced convection type and a variable speed fan was used for this purpose. A type 641 humidifier is used with a psychrometer (mode 2) which takes dry bulb temperature and percent relative humidity from the weather file and calculates other properties of moist air to provide at the humidifier inlet. The outlet saturated moist air from the humidifier outlet is modelled by a tee piece (mode 6) and after being mixed it is sent to a type 688 unitary dehumidifier at ambient pressure.

The standard TMY 2 weather file for climate conditions of Pakistan was called and the data for wind and solar radiations was used in different components via connections between Types.

Different parameters for each component were analysed and optimized for required results. Major performance effecting constraints were; water inlet temperature, inlet water and air flow rate, solar collector area and percent relative humidity of air.

The final parameters for proposed model are given in the table below.

*Table 1: Parameters used for modelling*

| Parameter | Value |
|---|---|
| **Flat Plate Collector** | |
| Collector area | 1.5 m$^2$ |
| Flow rate | 10 kg/h.m$^2$ |
| Collector slope | 45° |
| **Humidifier** | |
| Inlet Air Temperature | 20°C |
| Inlet Air % Relative Humidity | 20 |
| Inlet Water Temperature | 100°C |
| **Dehumidifier** | |
| Rated Air Flowrate | 50 kg/h |
| **Water Storage Tank** | |
| Tank volume | 3 m$^3$ |

## VI. Results & Discussions

Daily and hourly simulations were performed by an online plotter in TRNSYS for the whole year and specifically for the month of June in Islamabad, Pakistan.

Temperature values are specified on the left side of graph, while right hand side shows heat transfer rates.

The meteorological parameters such as ambient temperature, solar radiations and percent relative humidity are used as input. The solar radiation trend for a 45° tilted surface for the first week of June are given in fig. 3.

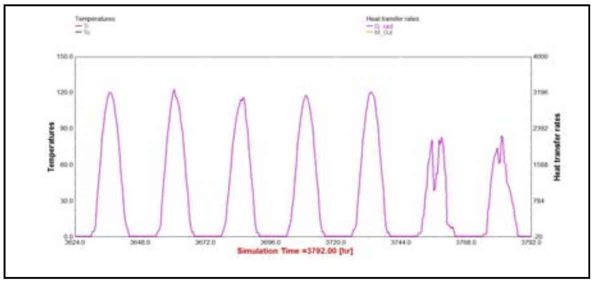



*Figure 3: Global radiations for June*

Fig. 4 is showing the trend of dry bulb temperature of air for June. Ambient air shows greater temperatures in June and July, i.e. up to 40°C.

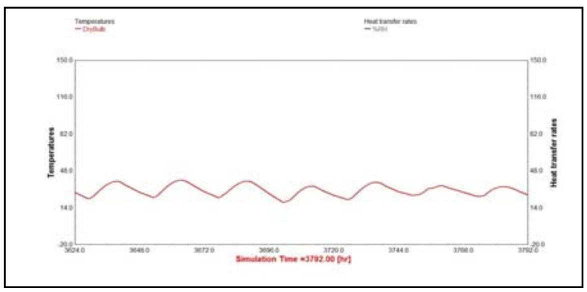



*Figure 4: Dry Bulb temperature in June*

Collector outlet temperature with optimized values for collector area and inlet mass flow rate is shown in fig. 5. The outlet temperature is greatly influenced by global radiations and dry bulb temperature of air and follows the same trend as both. In June and July, the ambient air temperature and solar radiations are maximum, so the collector output temperature goes higher.

Similar trend has been observed for daily results, i.e. for peak radiations during mid-day, the output temperature is maximum and then goes on decreasing as sun sets in the evening.

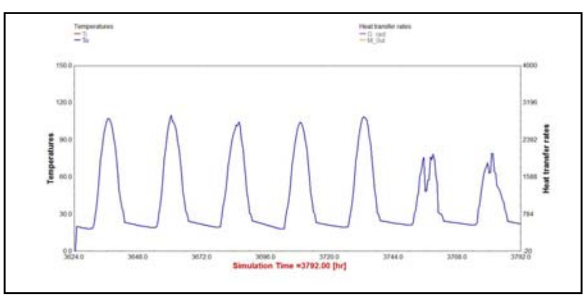



*Figure 5: Collector outlet temperature*

Water inlet temperature, inlet mass flow rate and solar collector area also have strong impact on the outlet temperature of water. The effects are being discussed in fig. 6, where the outlet temperature is shown as a function of inlet temperature. The results are good enough for 20°C inlet water temperature.

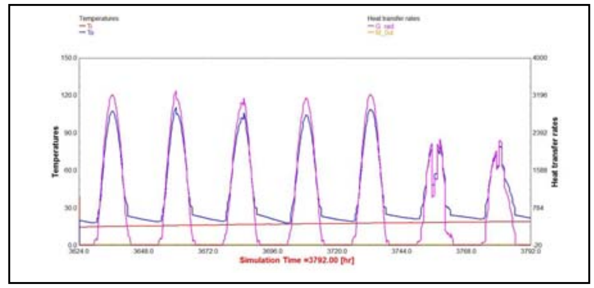



*Figure 6: T outlet Vs T inlet*

Collector area was also a very important parameter. For $1m^2$ area, the output was between 50 to 70°C, as in fig. 9, which is too low for the system's requirement. But by increasing the area up to $2m^2$, (see fig. 10) the maximum temperature at the collector outlet was exceeding 120°C, slightly higher than the required temperature. So, $1.5m^2$ was found to be the optimum value for collector area.

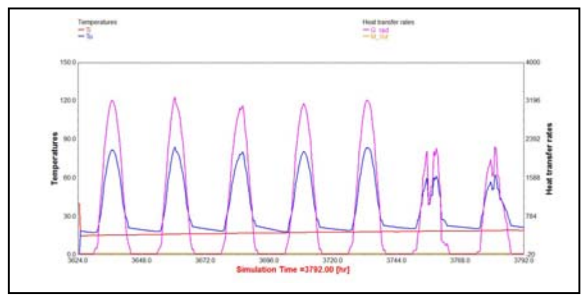



*Figure 9: For $1m^2$ collector area*

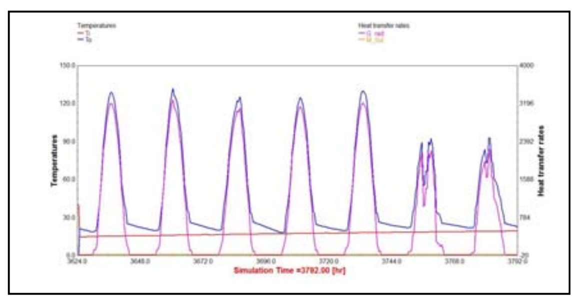
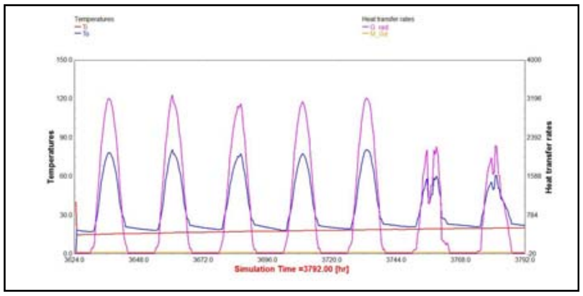



*Figure 10: For $2m^2$ collector area*

Considerable results were witnessed by changing the inlet flow rate of feed water. Flow rate was adjusted according to collector area. For smaller areas, flow rates values should be small. For collector area $1.5m^2$, flow rate 15kg/h, the output temperature was decreased up to 50, as in fig. 11.

Similarly for smaller flow rate values up to 5kg/h, as depicted in fig. 12, the result was again abnormal, i.e. the outlet temperature became too high, beyond our system requirements. For this value of inlet mass flow rate, $1m^2$ collector may be significant, but to have more output




production, 10kg/h mass flow rate with 1.5 $m^2$ area is more attractive option.

*Figure 11: At 15kg/h flow rate*

*Figure 12: At 5kg/h mass flow rate*

Fig. 13 shows the temperature of air leaving the dehumidifier. This parameter is helpful in estimating the recovery rate of condensate in the dehumidifier. Smaller values of outlet air temperature means that maximum heat has been released by air that is to be absorbed by feed water for a closed cycle case.

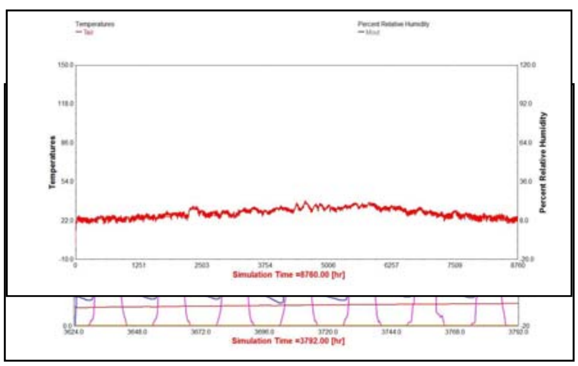



*Figure 13: Outlet air temperature from dehumidifier*

The figure shown below presents the output condensate mass flow rate from the dehumidifier, which is between 3 to 4 kg/h in this case. This parameter was greatly influenced by the temperature of water at inlet and condensate recovery rate. The output was surprisingly increased by introducing a water storage tank in the system that could pre heat the water before it enters the dehumidifier, hence increasing the overall efficiency.

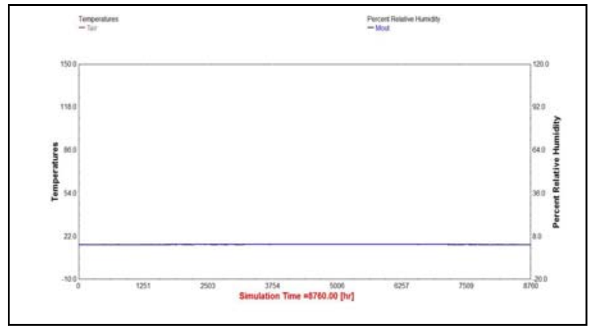



*Figure 14: Mass flow rate of condensate*

## VII. CONCLUSION

A Transient Simulation Model for the single stage, water heated solar HDH desalination system has been presented for Islamabad, Pakistan. The air was circulated in forced convection in an open air open water configuration in which a flat plate solar collector, humidifier and a unitary mode dehumidifier were integrated along with other components like fan, pump and controller. A mode 2 Psychrometer was used for moist air properties calculations. Daily simulations were performed by an online plotter and following results were concluded:

- System's performance is greatly influenced by inlet water and air temperatures and for a good system, water storage tank must be used to enhance productivity.
- Solar collector area and inlet mass flow rate also had a strong impact on productivity and both parameters are optimized according to system's requirement.
- Both output temperatures from collector and dehumidifier are the function of ambient temperature and global solar radiations and follow the same trend.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