



Ain Shams University
Faculty of Engineering
Mechanical Power Engineering Department

**STUDY OF WATER DESALINATION USING A SOLAR
ENERGY SYSTEM WITH HUMIDIFICATION AND
DEHUMIDIFICATION**

By

Mohamad Ragaie Mohamad ElHelaly

B.Sc. of Mechanical Power Engineering, 2010

Thesis submitted in partial fulfillment of the requirements for
the Degree of M.Sc. in Mechanical Power Engineering

Under Supervision of

Prof. Dr. Mahmoud Abu ElNasr

Professor of Mechanical Power Department
Faculty of Engineering
Ain Shams University

Dr. Mahmoud Mohamed Kamal

Associate Professor of Mechanical Power Department
Faculty of Engineering
Ain Shams University

Dr. Hany El-Sayed Abdel Halim Saad

Assistant Professor of Mechanical Power Department
Faculty of Engineering
Ain Shams University

Ain Shams University – Faculty of Engineering
Mechanical Power Engineering Department

Cairo, Egypt

2015



Faculty of Engineering
Mechanical Power Engineering Department

Examiners Committee

The undersigned certify that they have read and recommended to the faculty of Engineering, Ain Shams University for acceptance a thesis entitled “**STUDY OF WATER DESALINATION USING A SOLAR ENERGY SYSTEM WITH HUMIDIFICATION AND DEHUMIDIFICATION**”, submitted by **Mohamad Ragaie Mohamad ElHelaly** in partial fulfillment of the requirements for the degree of M.Sc. in Mechanical Power Engineering.

Date: 29 / 12 / 2015

Name

Signature

Prof. Dr. Mohamed Fatouh Ahmed

Professor of Mechanical Power Department

Faculty of Engineering at El Mattaria - Helwan University

Prof. Dr. Adel Abdel Malek El Ahwany

Professor of Mechanical Power Department

Faculty of Engineering - Ain Shams University

Prof. Dr. Mahmoud Abu El Nasr

Professor of Mechanical Power Department

Faculty of Engineering - Ain Shams University

Dr. Mahmoud Mohamed Kamal

Associate Professor of Mechanical Power Department

Faculty of Engineering - Ain Shams University

STATEMENT

This thesis is submitted as a partial fulfilment of M.Sc. in Mechanical Power Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Name:

Mohamad Ragaie ElHelaly

Signature

Date: 29 / 12 / 2015

ACKNOWLEDGEMENT

I would like to take this opportunity to express my deep appreciation and gratitude for my advisory committee; **Prof. Dr. Mahmoud Abu ElNasr, Dr. Mahmoud Kamal** and **Dr. Hany Saad**. Thanks for taking the time to supervise my Master's Thesis, for taking the time to revise it and approve it. It has been an honor working with you.

Special thanks to **Dr. Hany Saad** for the continuous support throughout my research, for helping me and for pushing me to success.

My gratitude also goes to the Combustion Lab in the Faculty of Engineering – Ain Shams University, especially to **Mr. Amin Abdel Latif** – The Lab Supervisor. There are not enough words to describe your hard work, dedication and experience.

Finally, I would like to show and express my deepest gratitude to my parents for supporting me throughout my life and throughout my studies from

kindergarten to Master's degree. I would have never been able to make it without you.

ABSTRACT

The present work is an experimental investigation of a water desalination system using solar energy that applies the humidification and Dehumidification principles. A prototype/test rig was designed, fabricated and assembled in order to study the effect of water flow rate and the humidifier inlet water temperature against desalinated water productivity. The system consists of a spray type with no packing bed humidifier, a copper coiled Dehumidifier, a flat plate solar water heater, an air blower, a water pump, a water flow meter, a water tank, three thermocouples and four gate water valves. The system is based on an open water- closed air cycle.

A new approach is used such that the humidifier, dehumidifier and the connecting duct between them are made of Poly Vinyl Chloride (PVC) pipes; which makes the system lighter in weight, doesn't need insulation unlike metal sheets and anti-rust.

This prototype is expected to be a platform to drive the commercialization of a new solar desalination system based on humidification and dehumidification principle. This will be especially beneficial to face the shortage of fresh water supply in future, specifically in remote areas, with a simple design.

The effect of operating parameters on the system characteristics has been controlled, measured and investigated. It was found that the hot inlet water to the humidifier has a significant impact on the water productivity; they are relatively proportional, thus, the more the hot inlet water temperature increases, the more the water productivity increases. It was also found that Saline water flow rate has an impact on the water productivity but inversely proportional.

LIST OF TABLES

Table 1: Previous Researches Values and Comparison

Table 2: Thermocouple 1 readings

Table 3: Thermocouple 2 readings

Table 4: Thermocouple 3 readings

LIST OF PICTURES & FIGURES

Picture 1: Actual photograph of the Test Rig/Prototype

Figure 1: Distribution of water availability across the world

Figure 2: Natural hydrological cycle

Figure 3: Illustration of HDH system

Figure 4: Classification of HDH system

Figure 5: Schematic diagram of the Test Rig/Prototype

Figure 6: Isometric of the Test Rig/Prototype

Figure 7: Effect of hot inlet water temperature to the humidifier (T_{hot}) against Water Productivity at $T_{amb}=17\text{ }^{\circ}\text{C}$

Figure 8: Effect of hot inlet water temperature to the humidifier (T_{hot}) against Water Productivity at $T_{amb}=21\text{ }^{\circ}\text{C}$

Figure 9: Effect of hot inlet water temperature to the humidifier (T_{hot}) against Water Productivity at $T_{amb}=25\text{ }^{\circ}\text{C}$

Figure 10: Effect of hot inlet water temperature to the humidifier (T_{hot}) against Water Productivity at $T_{amb}=29\text{ }^{\circ}\text{C}$

Figure 11: Effect of hot inlet water temperature to the humidifier (T_{hot}) against Water Productivity at $T_{amb}=33\text{ }^{\circ}\text{C}$

Figure 12: Effect of cold water temperature leaving the copper coil of the dehumidifier (T_{cold}) against Water Productivity at $T_{amb}=17\text{ }^{\circ}\text{C}$

Figure 13: Effect of cold water temperature leaving the copper coil of the dehumidifier (T_{cold}) against Water Productivity at $T_{\text{amb}}=21\text{ }^{\circ}\text{C}$

Figure 14: Effect of cold water temperature leaving the copper coil of the dehumidifier (T_{cold}) against Water Productivity at $T_{\text{amb}}=25\text{ }^{\circ}\text{C}$

Figure 15: Effect of cold water temperature leaving the copper coil of the dehumidifier (T_{cold}) against Water Productivity at $T_{\text{amb}}=29\text{ }^{\circ}\text{C}$

Figure 16: Effect of cold water temperature leaving the copper coil of the dehumidifier (T_{cold}) against Water Productivity at $T_{\text{amb}}=33\text{ }^{\circ}\text{C}$

Figure 17: Thermocouple 1 Calibration Curve

Figure 18: Thermocouple 2 Calibration Curve

Figure 19: Thermocouple 3 Calibration Curve

LIST OF APPREVIATIONS

| | |
|------|--|
| CAOW | : Closed Air Open Water |
| COP | : Coefficient of Performance |
| CWOA | : Closed Water Open Air |
| ED | : Electro Dialysis |
| FFWP | : Four Fold Web Plate |
| GOR | : Gain over Recovery |
| HDH | : Humidification and Dehumidification |
| IDA | : International Desalination Association |
| MED | : Multi Effect Desalination |
| MEH | : Multi Effect Humidification |
| MSF | : Multi Stage Flash |
| MVC | : Mechanical Vapor Compression |
| OAOW | : Open Air Open Water |
| PVC | : Poly Vinyl Chloride |
| RO | : Reverse Osmosis |
| TDS | : Total Dissolved Salts |
| TVC | : Thermal Vapor Compression |
| VC | : Vapor Compression |
| WHO | : World Health Organization |

TABLE OF CONTENTS

| | |
|--|-----------|
| STATEMENT | 2 |
| ACKNOWLEDGEMENT | 3 |
| ABSTRACT | 5 |
| LIST OF TABLES | 7 |
| LIST OF PICTURES & FIGURES..... | 8 |
| LIST OF APPREVIATIONS | 10 |
| CHAPTER 1: INTRODUCTION | 13 |
| 1.1. GENERAL | 13 |
| 1.1.1. WATER SHORTAGE AND CONSUMPTION..... | 15 |
| 1.1. CONVENTIONAL DESALINATION TECHNOLOGIES ... | 20 |
| 1.1.1. LIMITATIONS OF CONVENTIONAL TECHNOLOGIES | 24 |
| 1.2. SOLAR DESALINATION | 27 |
| 1.3. PROBLEM STATEMENT..... | 29 |
| 1.4. OBJECTIVE..... | 30 |
| CHAPTER 2: LITERATURE REVIEW | 31 |
| 2.1. HUMIDIFICATION DEHUMIDIFICATION DESALINATION | 31 |
| 2.1.1. CLASSIFICATION OF HDH SYSTEMS..... | 37 |
| 2.2. SUMMARY OF PREVIOUS WORKS | 41 |
| CHAPTER 3: TEST RIG/PROTOTYPE | 55 |
| 3.1. TEST RIG/PROTOTYPE | 55 |
| 3.2. EXPERIMENTAL SETUP AND OPERATION..... | 59 |
| CHAPTER 4: RESULTS AND DISCUSSIONS | 63 |
| 4.1. INTORUDCTION..... | 63 |
| 4.2. RESULTS, GRAPHS & DISCUSSIONS | 65 |
| 4.3. PREVIOUS RESEARCH VALUES AND COMPARISON.... | 75 |

| | |
|---|-----------|
| 4.4. UNCERTAINTY ANALYSIS..... | 78 |
| CHAPTER 5: CONCLUSION AND RECOMEDNATION..... | 81 |
| REFERENCES..... | 85 |
| APPENDIX 1: Thermocouples Calibration..... | 94 |

CHAPTER 1: INTRODUCTION

1.1. GENERAL

Water is one of the most abundant resources on earth which is essential to life, covering three-fourths of the earth's surfaces. About 97% of the earth's water is salt water in the oceans with salinity up to 30,000 parts per million of total dissolved solids (ppm TDS) and 3% is fresh water contained in the poles (in the form of ice), ground water, lakes and rivers, which supply most of human and animal needs. A Freshwater body contains low concentrations of dissolved salts and other total dissolved solids. Freshwater according to the World Health Organization (WHO) can be defined as water with less than 500ppm TDS.

Man has been dependent on rivers, lakes and underground water reservoirs for fresh water requirements in domestic life, agriculture and industry. The ultimate source of fresh water is the precipitation of atmosphere in the form of rain and snow [1].

There have been various estimates of the global water resource base on different calculation

methods [2]. The total volume of water in the world was calculated to be approximately $1.4 \times 10^{18} \text{ m}^3$. Surface freshwater is $1.05 \times 10^{14} \text{ m}^3$ or 0.3% of the world's freshwater [3]. It was estimated that more than 50% of the surface freshwater as non-renewable water [4]. The amount of renewable water is therefore around $4.2 \times 10^{13} \text{ m}^3$ per year which replenishes groundwater source or returns to the oceans by rivers. Most of it (around $3 \times 10^{13} \text{ m}^3$ per year) is in flush flows that are not captured by man. It is assumed that the available renewable freshwater resource is between 9×10^{12} and $14 \times 10^{12} \text{ m}^3$ per year. However around 70% of is required for the ecosystem and thus only 30% or $4.2 \times 10^{12} \text{ m}^3$ per year is available for human consumption [5]. The balance between availability of fresh water and demand has reached critical level. If the world is to depend only on freshwater source, soon any form of life will face extinction.