

**Suez Canal University**  
**Faculty of Agriculture**  
**Agricultural Engineering Department**



# **Some Engineering Factors Affecting Solar Drying of Date**

**By**

**SALWA OSMAN SOLIMAN**

B.Sc., Agric Engineering, Suez Canal University, 2011

**Thesis**

Submitted in Partial Fulfillment of  
the Requirement for the Degree of

Master of Science

In

Agricultural Science  
(Agricultural Engineering)

Agricultural Engineering Department  
Faculty of Agriculture  
Suez Canal University

**2016**

# **SOME ENGINEERING FACTORS AFFECTING SOLAR DRYING OF DATE**

**By**

**SALWA OSMAN SOLIMAN MOUSA**

**B.Sc. Agric. Engineering, Suez Canal University, 2011**

**Thesis**

Submitted in Partial Fulfillment of  
the Requirements for the Degree of

**MASTER OF SCIENCE**

**In**

**Agricultural Sciences  
(Agricultural Engineering)**

## **SUPERVISION COMMITTEE**

**Prof. Dr. Sherif M. Abd EL-Hak Radwan** .....  
Professor of Agricultural Engineering  
Faculty of Agriculture, Suez Canal University

**Prof. Dr. Mohamed M. Yasen El-Kholy** .....  
Professor of Agricultural Engineering  
Agricultural Engineering Research Institute

**Prof. Dr. Islam H. Hassan El-Sheikh** .....  
Professor of Agricultural Engineering  
Faculty of Agriculture, Suez Canal University

**Agricultural Engineering Department  
Faculty of Agriculture  
Suez Canal University  
2016**

## APPROVAL SHEET

**Name :** SALWA OSMAN SOLIMAN MOUSA  
**Title of thesis :** SOME ENGINEERING FACTORS AFFECTING SOLAR DRYING OF DATE

### Thesis

Submitted in Partial Fulfillment of  
the Requirements for the Degree of

**MASTER OF SCIENCE**  
**In**  
**Agricultural Sciences**  
**(Agricultural Engineering)**

### Approved by:

**Prof. Dr. Tarek Zaki Hasan Ali Fouda** .....  
Professor of Agricultural Engineering and vice dean,  
Faculty of Agriculture, Tanta University.

**Prof. Dr. Youssef Farag Sharobeem** .....  
Professor of Agricultural Engineering and deputy director  
Agricultural Engineering Research Institute

**Prof. Dr. Sherif M. Abd EL-Hak Radwan** .....  
Professor of Agricultural Engineering and dean,  
Faculty of Agriculture, Suez Canal University

**Prof. Dr. Mohamed Moustafa El-Kholy** .....  
Professor of Agricultural Engineering and deputy director  
Agricultural Engineering Research Institute

**Committee in charge**  
**Date: 3/ 11/ 2016**

<b>Name</b>	<b>Salwa Osman Soliman Mousa</b>
<b>Title of thesis</b>	<b>Some Engineering Factors Affecting Solar Drying of Date</b>
<b>University</b>	<b>Suez Canal University</b>
<b>Faculty</b>	<b>Faculty of Agriculture</b>
<b>Department</b>	<b>Agricultural Engineering Department</b>
<b>Degree</b>	<b>M.Sc</b>
<b>Date</b>	<b>- - 2016</b>
<b>Language</b>	<b>English</b>
<b>Supervision Committee</b>	<b>Prof. Dr. Sherif M. Abd El-Hak Radwan Prof. Dr. Mohamed M. El- Kholly Dr. Islam H. El-Sheikh</b>
<b>Abstract</b>	
<p>The present study was carried out through the period of September 2015 at the Department of Agricultural Engineering, Faculty of Agriculture, Suez Canal University to evaluate the effect of three different geometric shapes of solar dryers on drying behavior of date palm (Hayani) at three different levels of air velocities (0.5, 1, 1.5 m/s) and two different date conditions (peeled and unpeeled date). The studied different dryers shapes are, Quonset shape (SD1), gable-even-span shape (SD2) and pyramidal shape (SD3). The dryers thermal performance was also analyzed. The tested dryers were operated under two different conditions; the first one was without load (1) the second was loaded with freshly harvested date (2). The obtained results revealed that for the dryers operated without load, the overall thermal efficiency were (55.6, 52.2 and 51.1%), (62.04, 58.6 and 57.1%) and (50.6, 47.6 and 46.2% for the three studied dryer (SD1, 2 and 3) at air velocity of 0.5, 1, 1.5 m/s, respectively. However, the daily average thermal efficiency for the three loaded solar dryers (SD1, SD2 and SD3) were (29.67, 28.11 and 24.63%), (31.85, 30.54 and 29.95%) and (19.29, 18.45 and 18.14%) in case of drying peeled date at air velocity of (0.5, 1, 1.5 m/s), respectively. While the corresponded values for the un-peeled date were (24.73, 22.96 and 20.18%), (26.18, 26.01 and 24.56%) and (18.06, 17.45 and 17.04%) respectively. Meanwhile, for the loaded dryers, the recorded drying times ranged from (13 to 18 h), (15 to 20 h) and (16 to 21 h) for the peeled date dried at the (SD1, 2 and 3) dryers respectively. The corresponding drying times for the un-peeled date ranged from (16 to 23 h), (18 to 25 h) and (19 to 27 h) respectively compared with 43 and 51h for peeled and un-peeled date dried by the traditional sun drying method. In general, the Quonset shape solar dryer (SD1) operated at air velocity of 1 m/s showed the best results in terms of highest thermal efficiency, shortest drying time and best final quality of the dried dates.</p>	
<b>Keywords:</b> Greenhouse type solar dryer - Thermal performance analysis - Date	

# TABLE OF CONTENTS

<b>1. INTRODUCTION.....</b>	<b>1</b>
<b>2. REVIEW OF LITERATURE .....</b>	<b>5</b>
2.1. Nutritional value and Benefits of the Date.....	5
2.2. Importance and Fundamentals of drying process .....	6
2.3. Classification of Drying Methods .....	9
2.3.1. Natural drying (sun drying).....	9
2.3.2. Mechanical drying.....	11
2.3.3. Solar drying .....	14
3.3.3.1. classification of solar dryers .....	16
2.4. Utilization of Greenhouse type Solar Dryers in Drying Agricultural crops .....	19
2.5. Solar Drying of Date Palms .....	25
2.6. Effect of Parameters on Drying Process .....	27
2.6.1 Air temperature .....	27
2.6.2. Air velocity (air flow rate).....	30
2.6.3 Relative humidity of Air .....	32
2.6.4 Moisture content of the drying product .....	34
2.7. Quality Changes of Date During the Drying Process .....	35
<b>3. MATERIALS AND METHODS.....</b>	<b>38</b>
3.1. Solar Drying Methods .....	38
3.1.1.The Greenhouse type solar dryers with different geometric shapes.....	38
3.1.1.1. the Quonset shape solar dryer .....	39
3.1.1.2. the gable-even-span shape solar dryer.....	39

3.1.1.3. the pyramidal shape solar dryer .....	39
3.1.1.4. Frame structure and drying beds of the studied dryers.....	40
3.1.1.5. working principle of the studied dryers .....	40
3.1.2. Traditional sun drying method .....	45
3.2. Experimental Treatments and Test Procedure .....	46
3.2.1. Experimental treatments .....	46
3.2.2. Experimental procedure .....	47
3.2.2.1. preparation of the samples.....	47
3.2.2.2. the solar drying method .....	47
3.2.2.3. the traditional sun drying method .....	49
3.3. Instruments and data acquisition .....	50
3.3.1. Meteorological data .....	50
3.3.2. Air temperature, relative humidity and date temperature .....	51
3.3.3. Air velocity .....	51
3.3.4. Date moisture content .....	51
3.3.5. Weight of fruits .....	46
3.4. Quality Evaluation Tests of Dried Date.....	54
3.4.1. Determination of antioxidant compounds .....	54
3.4.2. Determination of total phenolic compounds .....	54
3.4.3. Determination of total sugar content .....	54
3.5. Mathematical Modeling.....	55
3.5.1. Thermal performance analysis without load.....	56
3.5.2. Heat energy balance for the studied solar dryers with load.....	61
<b>4. RESULTS ANDN DISCUSSIONS .....</b>	<b>65</b>
4.1. Thermal Performance Analysis of the Greenhouse type Solar Dryers without Load .....	65
4.1.1. Solar energy available .....	65

4.1.2. Air temperature .....	70
4.1.3. Air relative humidity.....	72
4.1.4. Useful heat gain for the studied dryers .....	74
4.1.5. Total heat losses from the studied dryers .....	75
4.1.6. Thermal efficiency of the studied solar dryers .....	75
4.2. Solar Drying of Dates .....	81
4.2.1. Air temperature and relative humidity.....	81
4.2.2. Date temperature.....	85
4.2.3. Changes in date moisture content during the drying process.....	86
4.3. Heat Energy Balance during the Drying Process.....	97
4.4. Quality Evaluation of Dates.....	104
<b>5. SUMMARY AND CONCLUSIONS .....</b>	<b>106</b>
<b>6. REFERENCES .....</b>	<b>111</b>
<b>7. APPENDIX .....</b>	<b>125</b>
<b>8. ARABIC SUMMARY</b>	

## LIST OF FIGURE

Figure (3.1): Schematic diagram of the greenhouse type solar dryer (Quonset shape).....	41
Figure (3.2): General view the Quonset shape greenhouse type solar dryer.....	41
Figure (3.3): Schematic diagram of the greenhouse type solar dryer (Gable-even-span shape).....	42
Figure (3.4): General view of the gable-even-span shape greenhouse type solar dryer .....	42
Figure (3.5): Schematic diagram of the greenhouse type solar dryer (Pyramidal shape).....	43
Figure (3.6): General view the Pyramidal shape greenhouse type solar dryer.....	43
Figure (3.7): Drying air movement through the greenhouse type solar dryers during the experimental work.....	44
Figure (3.8): The wooden frame used for traditional sun drying of dates.....	45
Figure (3.9): The experimental treatments used for the experimental work..	46
Figure (3.10): Measuring points of air temperature and relative humidity inside the three studied solar dryer .....	48
Figure (3.11): The three green-house type solar dryers with traditional sun drying method.....	49
Figure (3.12): Meteorological station used to measure meteorological data.....	50
Figure (3.13): Data logger system (lab-Jack).....	52
Figure (3.14): Relationship between the output data of the thermocouple in milli-volt and the electronic thermometer in °C.....	52



Figure (3.15): The van type anemometer (model YK-80AM).....53

Figure (3.16): The electrical oven used to measure date moisture content...53

Figure (3.17): Simplified flowchart for MATLAB program.....60

Figure (3.18): Simplified flowchart for developed MATLAB program .....64

Figure (4.1): Hourly average solar radiation flux incident outside ( $SR_{out}$ ) and inside ( $SR_{in}$ ) the solar dryer (SD1) at air velocity of 0.5, 1 and 1.5 m/s.....67

Figure (4.2): Hourly average solar radiation flux incident outside ( $SR_{out}$ ) and inside ( $SR_{in}$ ) the solar dryer (SD2) at air velocity of 0.5, 1 and 1.5 m/s.....68

Figure (4.3): Hourly average solar radiation flux incident outside ( $SR_{out}$ ) and inside ( $SR_{in}$ ) the solar dryer (SD3) at air velocity of 0.5, 1 and 1.5 m/s.....69

Figure (4.4): Air temperatures outside and inside the three studied solar dryers at different levels of air velocity .....71

Figure (4.5): Air relative humidity outside and inside the studied solar dryers at different levels of air velocity.....73

Figure (4.6): The measured heat energy available versus that predicted inside the three studied solar dryers at air velocity of 0.5 m/s..... 78

Figure (4.7): The measured heat energy available versus that predicted inside the three studied solar dryers at air velocity of 1m/s..... 79

Figure (4.8): The measured heat energy available versus that predicted inside the three studied solar dryers at air velocity of 1.5m/s..... 80

Figure (4.9): Air temperature and relative humidity as related to drying time inside the three solar dryers at air velocity of 0.5 m/s..... 82

Figure (4.10) : Air temperature and relative humidity as related to drying time inside the three solar dryers at air velocity of 1 m/s..... 83

Figure (4.11) : Air temperature and relative humidity as related to drying time inside the three solar dryers at air velocity of 1.5 m/s.....84

Figure (4.12): Date temperature as related to drying time for the three solar dryers at the minimum air velocity of 0.5 m/sec.....87

Figure (4.13): Date temperature as related to drying time for the three solar dryers at the air velocity of 1m/sec.....88

Figure (4.14): Date temperature as related to drying time for the three solar dryers at the maximum air velocity of 1.5 m/sec.....89

Figure (4.15): Change in date moisture content versus drying time for the three studied solar dryers at air velocity of 0.5 m/s.....91

Figure (4.16): Change in date moisture content versus drying time for the three studied solar dryers at air velocity of 1 m/s.....92

Figure (4.17): Change in date moisture content versus drying time for the three studied solar dryers at air velocity of 1.5 m/s.....93

Figure (4.18): Drying time of date for the three solar dryers compared with the traditional sun drying method .....95

Figure (4.19): Change in date moisture content versus drying time for the open sun drying method .....96

Figure (4.20): Measured and predicted solar energy available inside different solar dryers shapes at air velocity of 0.5 m/s.....101

Figure (4.21): Measured and predicted solar energy available inside different solar dryers shapes at air velocity of 1 m/s.....102

Figure (4.22): Measured and predicted solar energy available inside different solar dryers shapes at air velocity of 1.5 m/s.....103

## LIST OF TABLES

Table (3.1): Parameters required as input and variables output by MATLAB program.....	59
Table (3.2): Parameters and variables required as input and variables output by MATLAB program.....	63
Table (4.1): Daily average solar energy available outside and inside the three studied solar dryers.....	66
Table (4.2): The daily average total heat losses and the overall thermal efficiency of the three studied solar dryers.....	76
Table (4.3): Average drying rate of dates using different shapes of solar dryers and different air velocity compared with the open sun drying method.....	90
Table (4.4): Thermal efficiency of peeled date (T1) and un peeled date (T2) using the solar dryer Quonset shape (SD1).....	98
Table (4.5): Thermal efficiency of peeled date (T1) and un peeled date (T2) using the solar dryer gable even span shape (SD2).....	98
Table (4.6): Thermal efficiency of peeled date (T1) and un peeled date (T2) using the solar dryer paramedical shape (SD3).....	99
Table (4.7): Total sugar, antioxidant and phenolic compounds of the dried date.....	105