



# **Optimal Solid Wastes Mixture for the Production of Solid Fuel**

**A Thesis  
Submitted To Faculty of Engineering  
Ain Shams University for the Fulfillment  
of the Requirements of M.Sc. Degree  
in Civil Engineering**

Prepared by  
**Eng. Maged Abdallah Hussieny Mahmoud**  
B.Sc. Civil Engineering, June 2012  
Faculty of Engineering, Ain Shams University – Cairo, Egypt

Supervisors  
**Prof. Dr. Mohamed Hassan Abdel-Razik**  
Professor of Environmental Engineering  
Faculty of Engineering, Ain Shams University, Cairo, Egypt

**Prof. Dr. Ahmed Hassan Gaber Hamoda**  
Professor of Chemical Engineering  
Faculty of Engineering, Cairo University, Cairo, Egypt

**Dr. Sherien Ali Elagroudy**  
Associate Professor of Environmental Engineering  
Faculty of Engineering, Ain Shams University, Cairo, Egypt

**2017**

# *Dedication*

*This thesis is dedicated to those who contributed to educating, raising and supporting me to be able to accomplish in this picture.*

*A special dedication to*

**MY SUPPORTIVE PARENTS**

*and to*

**My wonderful  
Sisters and Relatives**

*and finally*

*special dedication to*

**MY LOVELY WIFE AND HER  
MOTHER**

*for encouraging me to complete this work and for  
always being there for me.*

## STATEMENT

This dissertation is submitted to Ain Shams University, Faculty of Engineering for the degree of M.Sc. in Civil Engineering.

The work included in this thesis was carried out by the author in the department of Public Works, Faculty of Engineering, Ain Shams University, from October 2013 to December 2016.

No part of the thesis has been submitted for a degree or a qualification at any other University or Institution.

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others

Date: - ---/-- /2017

Signature: - -----

Name: - *Maged Abdallah Hussieny Mahmoud*

## **ACKNOWLEDGMENTS**

First, thanks are all direct to Allah, for blessing this work until it has reached its end, as a part of generous help throughout my life.

I would like to express my gratefulness to ***Prof Dr. Mohamed Hassan Abdelrazik*** Professor of Environmental Engineering Faculty of Engineering, Ain Shams University for providing me a chance to pursue my Masters degree.

It is with immense gratitude that I acknowledge the support and help of ***Prof Dr. Ahmed Hassan Gaber Hamouda*** Professor of Chemical Engineering Faculty of Engineering, Cairo University for his efforts and true encouragement

Also, I wish to express my sincere gratitude for ***Dr. Sherien Ali Elagroudy*** for her insightful comments and constructive suggestions. Her enthusiastic guidance and generous support are greatly appreciated.

Last but not least, I wish to thank ***My Parents, My Sisters and My Wife*** to whom this thesis is dedicated to. They tried to help me in every possible means. Their unfailing love and support have been my source of strength with which I am able to pass through times of doubts and despair and continue my pursuit of truth through failures.

## **ABSTRACT**

**Name: Maged Abdallah Hussieny Mahmoud**

**Title: Optimal Solid Wastes Mixture for the Production of Solid Fuel**

**Faculty: Faculty of Engineering, Ain Shams University**

**Specially: Civil Eng., Public Works, Sanitary & Environmental Eng.**

### **Abstract:-**

Municipal Solid Waste (MSW) in Egypt is generated in huge amounts and has become one of the most serious current environmental problems. Egypt is suffering from waste disposal problems and fuel shortages. In a way to partially solve both waste and energy problems, some types of waste can be utilized as alternative fuels (AFs) in energy intensive industries such as cement industry. With limited fossil fuel resources and high energy costs combined with the fight against climate change and mismanagement of wastes, AF represents a real substitution to conventional fuels. This study aims at the determination of optimum mix of non-hazardous MSW to be utilized as AF.

Survey on different types of waste in the Egyptian market, their availability and applicability to produce AF is conducted, and eight SW materials are selected: rice straw, cotton stalk, olive pomace oil, used tires, wood, paper, plastics, and dried digested sludge. Waste analysis is carried out on each type of waste to determine their characteristics: calorific value (CV), moisture content (MC), density, and gas emissions.

The optimum AF mix is determined based on technical and financial evaluations. Technical evaluation is based on the maximization of CV, and minimization of MC, density, and gas emissions; whereas financial evaluation is based on the market price of SW material. The optimal mix is found to be: rice straw (22.36%), wood (19.04%), plastics (24.25%), cotton stalks (17.90%), and used tires (16.45%). The optimum mix is found to have CV of 5353 cal/g, moisture content of 1.90%, and density of 330.70 kg/m<sup>3</sup>.

Economic feasibility study is conducted for an AF plant with production capacity of 50 ton/d. The study considered capital, operation and maintenance costs with NPV of 38,647,565 EGP. At a proposed selling price of 1500 EGP/ton, the plant can achieve IRR of 29%, B/C ratio of 1.163, and payback period of 4 years.

## **Supervisors**

**Prof. Dr. Mohamed Hassan Abdelrazik**

Professor of Environmental Engineering, Ain Shams University

**Prof. Dr. Ahmed Hassan Gaber Hamouda**

Professor of Chemical Engineering, Cairo University

**Dr. Sherien Ali Elagroudy**

Associate Professor of Environmental Engineering, Ain Shams University

## **Key Words:**

Municipal Solid Waste, Solid Fuel, Solid Recovered Fuel, Refuse Derived Fuel, Cement Manufacturing, Economic Feasibility Study

## **TABLE OF CONTENTS**

<b>LIST OF FIGURES</b>		<b>xii</b>
<b>LIST OF TABLES</b>		<b>xiii</b>
<b>LIST OF ABBREVIATIONS</b>		<b>xvi</b>
<b>CHAPTER [1]</b>		<b>1</b>
1.1	BACKGROUND	1
1.2.	PROBLEM STATEMENT	2
1.3.	OBJECTIVES	3
1.4.	METHODOLOGY	3
1.5.	THESIS OUTLINE	4
<b>CHAPTER [2]</b>		<b>5</b>
2.1.	GENERAL	5
2.2.	WORLD ENERGY CONSUMPTION	5
2.3.	ENERGY OVERVIEW IN EGYPT	6
2.3.1.	OIL	7
2.3.2.	NATURAL GAS	7
2.4.	RENEWABLE ENERGY SOURCES	8
2.5.	WORLD CEMENT PRODUCTION	8
2.6.	EGYPT CEMENT PRODUCTION	11
2.7.	ENERGY PROBLEM	12
2.8.	THE COAL OPTION	14
2.9.	OVERVIEW OF INTERNATIONAL EXPERIENCE ON ALTERNATIVE FUELS	14
2.9.1.	ALTERNATIVE FUELS USED IN THE CEMENT INDUSTRY	15
2.10.	OVERVIEW OF EGYPT'S EXPERIENCE IN ALTE RNATIVE FUELS	17
2.11.	ADVANTAGES AND DISADVANTAGES OF AF	19
2.12.	MUNICIPAL SOLID WASTE IN EGYPT	19
2.12.1.	WASTE GENERATION	19
2.12.2.	MUNICIPAL SOLID WASTE COMPOSITION	21
2.12.3.	MUNICIPAL SOLID WASTE COLLECTION	22
2.13.	WASTE TO ENERGY TECHNOLOGIES	22
2.13.1.	THERMAL TECHNOLOGY	23

A)	COMBUSTION	23
B)	PYROLYSIS AND THERMAL GASIFICATION	23
C)	PLASMA-ARC GASIFICATION	23
2.13.2.	BIOLOGICAL TREATMENT	24
A)	METHANE CAPTURE - LANDFILL GAS.	24
B)	BIOGAS PLANTS.	25
C)	FERMENTATION.	25
2.13.3.	MECHANICAL BIOLOGICAL TREATMENT ALTERNATIVES	25
2.13.3.1.	AIM OF MBT PROCESSES	25
2.13.3.2.	PHYSICAL TECHNOLOGY	29
2.14.	SOLID RECOVERED FUEL	30
2.14.1.	SRF CLASSIFICATIONS	30
2.14.2.	THE BENEFITS OF SRF	31
2.14.3.	APPLICATION OF SRF	33
2.15.	PRODUCTION OF ALTERNATIVE FUEL	34
2.15.1.	RECEIVING AREA (BUNKER)	34
2.15.2.	PRE-SORTING	35
2.15.3.	FEEDING EQUIPMENT	35
2.15.4.	COMMINUTION (SIZE REDUCTION)	35
2.15.5.	METAL SEPARATION	36
A)	SEPARATION OF FERROUS METALS	36
B)	OVERBAND MAGNETIC SEPARATOR	36
C)	MAGNETIC DRUM SEPARATOR	36
D)	NON-FERROUS METALS SEPARATION WITH EDDY CURRENT SEPARATOR	36
2.15.6.	CLASSIFICATION	37
A)	DRUM SCREENS	37
B)	FLIP-FLOP SCREENS	38
2.15.7.	AIR CLASSIFICATION	38
2.15.8.	NEAR INFRARED SPECTROSCOPY	38
2.15.9.	AUTOMATIC PICKING	39
2.15.10.	COMPACTING (PELLETISING)	39
2.15.11.	STORAGE AREA	39
<b>CHAPTER [3]</b>		<b>41</b>
3.1.	INTRODUCTION	41
3.2.	SELECTION OF WASTE TYPES	41
3.3.	CHARACTERISTICS OF SELECTED WASTES	43
3.3.1.	RICE STRAW	43



3.3.2.	OLIVE POMACE OIL	43
3.3.3.	WOOD	43
3.3.4.	PLASTIC	44
3.3.5.	DRIED DIGESTED SLUDGE	44
3.3.6.	COTTON STALKS	44
3.3.7.	PAPER WASTE	44
3.3.8.	USED TIRES	45
3.4.	WASTE ANALYSIS	45
3.4.1.	CHEMICAL ANALYSIS	45
3.4.1.1.	PROXIMATE ANALYSIS	45
3.4.1.2.	ULTIMATE ANALYSIS	46
3.4.1.3.	ENERGY CONTENT (CALORIFIC VALUE) – (ASTM ABBE)	46
3.4.2.	PHYSICAL ANALYSIS	46
3.5.	CRITERIA OF ALTERNATIVE FUEL	46
3.6.	MIXING CRITERIA	47
3.7.	GAS EMISSIONS CALCULATIONS	48
3.8.	PLANT DESIGN	49
3.9.	ECONOMIC ANALYSIS	49
3.9.1.	COST STREAM	49
3.9.2.	BENEFIT STREAM	50
3.9.3.	ECONOMIC MEASURES	50
<b>CHAPTER [4]</b>		<b>52</b>
4.1.	INTRODUCTION	52
4.2.	SOLID WASTE MATERIALS ANALYSIS	52
4.2.1.	CALORIFIC VALUE	52
A)	LAB MEASUREMENT	52
B)	USING DULONG EQUATION:	53
C)	DATA FROM LITERATURE REVIEW	53
4.2.2.	MOISTURE CONTENT	54
4.2.3.	DENSITY	54
4.3.	SOLID WASTE MATERIALS MIXING CRITERIA	55
4.4.	NO MIX RANKING	56
4.5.	CANDIDATE SOLID WASTE MIXES	56
4.6.	TECHNICAL EVALUATION OF CANDIDATE MIXES	58
4.7.	FINANCIAL EVALUATION	61
4.8.	OVERALL EVALUATION AND SELECTION OF OPTIMUM MIX	62

<b>CHAPTER [5]</b>		<b>69</b>
5.1.	INTRODUCTION	69
5.2.	ALTERNATIVE FUEL PRODUCTION BLOCK FLOW DIAGRAM (BFD)	69
5.3.	PROCESS DESCRIPTION	69
5.4.	PROCESS FLOW DIAGRAM (PFD)	71
5.5.	MASS BALANCE OF ALTERNATIVE FUEL PRODUCTION	71
5.6.	ENERGY BALANCE OF ALTERNATIVE FUEL PRODUCTION	71
5.7.	EQUIPMENT USED IN ALTERNATIVE FUEL PRODUCTION PLANT DESIGN	72
A)	SHREDDER	72
B)	ROTATING MIXER	72
C)	COOLER	72
D)	PELLET MILL	72
5.8.	ALTERNATIVE FUEL PRODUCTION PLANT	73
<b>CHAPTER [6]</b>		<b>80</b>
6.1.	INTRODUCTION	80
6.2.	CAPITAL COSTS	80
A)	LAND COST	80
B)	MACHINES COST	81
C)	SERVICE BUILDING COST	81
D)	SITE WORKS	81
E)	TOTAL CAPITAL COST	81
6.3.	OPERATION COST	81
A)	RAW WASTE MATERIAL	81
B)	POWER CONSUMPTION	82
C)	SALARIES	82
D)	MAINTENANCE COST	83
E)	TOTAL OPERATION COST	83
6.4.	SALES	83
6.5.	ECONOMIC MEASURES	83
<b>CHAPTER [7]</b>		<b>87</b>
7.1.	GENERAL	87
7.2.	CONCLUSION	87
7.3.	RECOMMENDATIONS AND FUTURE WORK	88
LIST OF REFERENCES		89

## **LIST OF FIGURES**

### **List of Figures**

#### ***Chapter 2***

Figure 2.1: World Energy Consumption	05
Figure 2.2: Egypt's Oil Remaining Reserves	07
Figure 2.3: Egypt's Natural Gas Reserves	07
Figure 2.4: World cement production 2013	09
Figure 2.5: Average Egyptian urban municipal solid waste composition	21
Figure 2.6: Waste to Energy Technologies	22
Figure 2.7: An illustration of the potential Mechanical Biological Treatment options composition	26
Figure 2.8: The four main options of MBT	27
Figure 2.9: Option A processes	27
Figure 2.10: Option B processes	28
Figure 2.11: Option C processes	28
Figure 2.12: Option D processes	28
Figure 2.13: Physical Technologies	29
Figure (2.14a): Cascade mode	37
Figure (2.14b): Cataract mode	37

#### ***Chapter 3***

Figure 3.1: Thesis Methodology	42
--------------------------------	----

#### ***Chapter 4***

Figure 4.1a: Financial Score versus Overall Score of Trial 1	63
Figure 4.1b: Financial Score versus Overall Score of Trial 2	64
Figure 4.1c: Financial Score versus Overall Score of Trial 3	65
Figure 4.1d: Financial Score versus Overall Score of Trial 4	66
Figure 4.1e: Financial Score versus Overall Score of Trial 5	67

#### ***Chapter 5***

Figure 5.1: Block Flow Diagram of Alternative Fuel Production	70
Figure 5.2: Process Flow Diagram of AF Plant	74
Figure 5.3: Receiving Area	75
Figure 5.4: Plant Layout	76
Figure 5.5: Mass Balance Flow Sheet	77
Figure 5.6: Energy Balance Flow Sheet	78
Figure 5.7: Block Flow Diagram	79

## **LIST OF TABLES**

### ***Chapter 2***

Table 2.1: Cement production in the G20	09
Table 2.2: Location & production of the cement factories in Egypt	11
Table 2.3: Replacement ratios of fossil fuels with waste materials in selected European countries, 2010–2011 in different countries	16
Table 2.4: Percentage of different type of waste used as AF	17
Table 2.5: Amounts and Percentages of municipal solid waste generation in Egypt.	20
Table 2.6: SRF Properties Classification Limits	31
Table 2.7: Analyses of waste characterization	33

### ***Chapter 3***

Table 3.1: Weighting Factors of each Parameter	47
--	----

### ***Chapter 4***

Table 4.1: Calorific values measured in lab	52
Table 4.2: C, N, S, H, and O weight percentages for each material and its calorific values	53
Table 4.3: Calorific values in literature	53
Table 4.4: Moisture content of Different Waste Types	54
Table 4.5: Materials Density Results	54
Table 4.6: Solid Waste Materials Analysis Results	55
Table 4.7: Criteria of Waste Mixes Evaluation	55
Table 4.8: Score of Each Waste Material as	

a One Mix and Its Rank	56
Table 4.9a: Trial 1 Possible Mixes	56
Table 4.9b: Trial 2 Possible Mixes	57
Table 4.9c: Trial 3 Possible Mixes	57
Table 4.9d: Trial 4 Possible Mixes	58
Table 4.9e: Trial 5 Possible Mixes	58
Table 4.10a: Technical evaluation and the ranking of Trial 1 possible mixes	59
Table 4.10b: Technical evaluation and the ranking of Trial 2 possible mixes	59
Table 4.10c: Technical evaluation and the ranking of Trial 3 possible mixes	60
Table 4.10d: Technical evaluation and the ranking of Trial 4 possible mixes	60
Table 4.10e: Technical evaluation and the ranking of Trial 5 possible mixes	61
Table 4.11: Price of solid waste material	61
Table 4.12: Price of each mixture and its financial score	62
Table 4.13a: Overall scores at different mixing ratios of Trial 1	63
Table 4.13b: Overall scores at different mixing ratios of Trial 2	64
Table 4.13c: Overall scores at different mixing ratios of Trial 3	65
Table 4.13d: Overall scores at different mixing ratios of Trial 4	66

Table 4.13e: Overall scores at different mixing ratios of Trial 5	67
---	----

## ***Chapter 5***

Table 5.1: Mass Balance of AF Plant	71
-------------------------------------	----

Table 5.2: Energy Balance of AF Plant	71
---------------------------------------	----

## ***Chapter 6***

Table 6.1: Land Area Budget	80
-----------------------------	----

Table 6.2: Price and power consumption of machines	81
--	----

Table 6.3: building area budget	81
---------------------------------	----

Table 6.4: The cost of each raw waste material of mix No.5	82
--	----

Table 6.5: Employee salaries	82
------------------------------	----

Table 6.6: Cash Flow	83
----------------------	----

Table 6.7: Cash Flow “Inflation Rate”	84
---------------------------------------	----

Table 6.8: Calculation of NPV	85
-------------------------------	----

Table 6.9: Calculation of B/C	86
-------------------------------	----

## **LIST OF ABBREVIATIONS**

AF	Alternative Fuel
DOE/EIA	Department of Energy/Energy Information Administration
JCEE	Egyptian-German Joint Committee on Renewable Energy, Energy Efficiency and Environmental protection
EIA	Energy information administration
IMF	International Monetary Fund
USGS	U.S. Geological Survey
BP	British Petroleum Corporation
EGAS	The Egyptian Natural Gas holding organization
ENCC	Egyptian national competitiveness council
CEO	Chief Executive Officer
EPAs	Environmental protection agencies
WBCSD	The World Business Council for Sustainable Development
RDF	Refuse Derived Fuel
EEAA	Environmental Affairs Agency
EIAs	Environmental Impact Assessments
MSW	Municipal Solid Waste
ERF	Energy Rich Fraction
MBT	Mechanical Biological Treatment
C&D	Construction and Demolished
MRF	Materials Recovery Facilities
BMW	Biodegradable Municipal Waste
ABT	Anaerobic Biological Treatment
SRF	Solid Recovered Fuel
MPT	Mechanical Physical Treatment
NCV	Net Calorific Value
CV	Calorific Value
ERFO	European Recovered Fuel Organization
NIR	Near Infrared Spectroscopy
SW	Solid Waste
FAO	Food and Agriculture Organization
NSWMP	National Solid Waste Management Programme
GIZ	<i>Gesellschaft für Internationale Zusammenarbeit</i>
WWTPS	Wastewater Treatment Plants
ENCPC	The Egypt National Cleaner Production Centre
ASTM	American Society for Testing and Materials
NPV	Net Present Value
ROI	Return on Investment
B/C	Benefit To Cost Ratio
CC	Capital Costs