



Cairo University

**PROCESS ENGINEERING DESIGN OF TOBACCO
WASTES INCINERATOR WITH UTILIZATION OF
COMBUSTION GASES HEAT ENERGY**

By

ASMAA ELMANSY IBRAHIM IBRAHIM

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
CHEMICAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

**PROCESS ENGINEERING DESIGN OF TOBACCO
WASTES INCINERATOR WITH UTILIZATION OF
COMBUSTION GASES HEAT ENERGY**

By

ASMAA ELMANSY IBRAHIM IBRAHIM

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
CHEMICAL ENGINEERING

Under the Supervision of

**Prof. Dr.
Nabil M. Abd El-Monem**

Professor of Chemical Engineering
Chemical Engineering Department
Faculty of Engineering,
Cairo University

**Prof. Dr.
Ahmed Farid Shaaban**

Professor of Chemical Engineering
& Pilot Plant
National Research Center
(NRC)

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

**PROCESS ENGINEERING DESIGN OF TOBACCO
WASTES INCINERATOR WITH UTILIZATION OF
COMBUSTION GASES HEAT ENERGY**

By

ASMAA ELMANSY IBRAHIM IBRAHIM

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
CHEMICAL ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Nabil M. Abd El-Monem , **Thesis Main Advisor**

Prof. Dr. Ahmed Farid Shaaban , **Member**

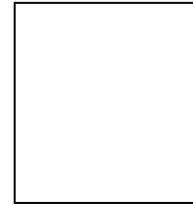
Professor of Chemical Engineering & Pilot Plant, National Research Center (NRC)

Prof. Dr. Mohamed Hanafy , **Internal Examiner**

Prof. Dr. Abd El-Ghany G. Abo Elnoor , **External Examiner**
Professor of Chemical Engineering, National Research Center (NRC)

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Engineer's Name: Asmaa El Mansy Ibrahim Ibrahim
Date of Birth: 9 / 9 /1984
Nationality: Egyptian
E-mail: Asmaa_elmansy@hotmail.com
Phone: 01117028320
Address: 18 st, Teraat Elkhashab st, Hadayek Helwan
Registration Date: 1 /10 / 2013
Awarding Date: / / 2018
Degree: Master of Science
Department: Chemical Engineering
Supervisors: Prof. Dr. Nabil M. Abd El-Monem
Prof. Prof. Dr. Ahmed Farid Shaaban



Examiners:

Prof. Dr. Abd El-Ghany G. Abo Elnoor (External examiner)
Professor of Chemical Engineering, National Research Center (NRC)

Prof. Dr. / Mohamed Hanafy (Internal examiner)
Prof. Dr. Nabil M. Abd El-Monem (Thesis main advisor)
Prof. Prof. Dr. Ahmed Farid Shaaban (Advisor)
Professor of Chemical Engineering & Pilot Plant, National Research Center (NRC)

Title of Thesis:

Process engineering design of tobacco wastes incinerator with utilization of combustion gases heat energy

Key Words:

Summary:

The objective of this thesis is to develop an integrated incineration unit which is technically and economically capable for the efficient handling of tobacco-waste processing plant with the subsequent utilization of the heat content of combustion gases. The incinerator engineering design is based on the composition of solid wastes disposed from the tobacco processing plants of the Eastern Company in 6th October city. The basis of design depends on feeding the incinerator with 1 t/h of solid waste consisting of: 50% tobacco, 20% paper& cartons, 20% wooden boxes, and 10% plastic materials. The remaining ash after the incineration process does not exceed 5% of the original volume of feed stock. The overall material & energy balances reveals discharging combustion gases at mass flow rate of 25490 kg/h with heat content of 20 092 348 kJ. Flue gases energy is utilized either in generating saturated steam or producing hot water. An engineering design is given for: (i) a fired-tube boiler capable to generate 7 t/h saturated steam at 185 °C & 10 bar, and (ii) 1- 4 shell and tube heat exchanger that produces hot water rated 80 t/h at 85 °C. The temperature of the exhaust effluent combustion gases vented to the atmosphere is 200 °C, that proves a highly efficient utilization of their original heat content. The calculated results are in excellent conformity with the data given in the fabricator incinerator manual already installed in the Eastern Company plants.

Acknowledgement

Praise to "Allah", the Most Gracious and the Most Merciful Who Guides Us to the Right Way

I would like to extend my sincere thanks and appreciation to my supervisors:

Prof. Dr. Nabil Mahmoud Abd El-Monem, Professor at Chemical Engineering Dept., Faculty of Engineering, Cairo University. For his great supervision, provides continuous encouragement, kind support and great guidance me during this thesis. No words can adequately express my deepest gratitude for his encourage.

Prof. Dr. Ahmed Farid Shaaban, Professor of Chemical Engineering, National Research Center. For his great effort, continuous assistance, kind support and valuable advices that have been reflected to this thesis.

Additionally, I would deeply express my gratitude to him for not only for his positive direction in delivering professional thesis, but also for the ethical values and manners that I have learned from him.

Finally, I would express my ultimate gratitude to my parents who are the main support and prayers.

Contents

Acknowledgement.....	I
Contents.....	ii
List of Tables.....	v
List of Figures	viii
Symbols and Abbreviations	ix
Abstract	x
Chapter one Introduction.....	1
Chapter two Literature Review	3
2.1.Introduction	3
2.2.Waste Management in the World.....	3
2.3.Solid Wastes Facts and Figures.....	5
2.4. Composition of Wastes	8
2.5. Types of wastes	8
2.5.1. Municipal Solid Waste	9
2.5.1.1. Residential Waste	9
2.5.1.2. Industrial and Commercial Wastes	9
2.5.1.3.Construction and Demolition Wastes	9
2.5.2. Hazardous medical Waste.....	9
2.5.3. Agricultural Wastes	10
2.5.3.1. Tobacco Waste	10
2.5.3.1.1.Chemical Composition of Tobacco	12
2.5.3.1.2 Calorific Value of Tobacco.....	12
2.6.Waste Management and Disposal	13
2.6.1. Waste Management Hierarchy	14
2.6.1.1. Waste Decreasing	15
2.6.1.2. Composting	15
2.6.1.3. Landfill	15
2.6.1.4. Incineration.....	16
2.6.1.4.1. Incineration Process.....	17
2.6.1.4.2. Characteristics of Waste Suitable for Incineration.....	18
2.6.1.4.3. Assessment of Waste Parameters	19
2.6.1.4.4. Kinds of Incinerator	19
2.6.1.4.4.1. Rotary Kiln Incineration	19
2.6.1.4.4.1.1. Advantages and Disadvantages Rotary Kiln Incineration.....	21

2.6.1.4.4.2. Moving Grate Incineration.....	21
2.6.1.4.4.2.1. Advantages and Disadvantages Moving Grate Incineration	22
2.6.1.4.4.3. Fluidized Bed Incineration.....	23
2.6.1.4.4.3.1. Advantages and Disadvantages Fluidized Bed Incineration	23
Chapter Three Materials and Equipments	25
3.1. Materials for Combustions	25
3.1.1. Tobacco	25
3.1.2. Paper	26
3.1.3. Wood	26
3.1.4. Plastic	27
3.1.5. Natural Gas.....	27
3.2 Equipment	28
3.2.1. Incinerator.....	28
3.2.1.1. Characteristics of the incinerator.....	28
3.2.2. Fire-Tube Boiler	28
Chapter Four Results and Discussions	33
4.1 Feed Composition of Waste	33
4.1.1. Feed Composition of Tobacco.....	33
4.1.2. Feed Composition of Paper.....	33
4.1.3. Feed Composition of Wooden Boxes.....	35
4.1.4. Feed Composition of Plastic	35
4.2. Combustion of Waste Material	37
4.2.1. Combustion of Tobacco Waste.....	37
4.2.1.1. Air required for Combustion of Tobacco Waste.....	38
4.2.1.2. Weight of Combustion Products from Ignition of Tobacco.....	39
4.2.2. Combustion of paper waste	40
4.2.2.1. Air required for Combustion of paper waste	40
4.2.2.2. Weight of Combustion Products from Ignition of paper	41
4.2.3. Combustion of Wood Waste.....	41
4.2.3.1. Air required for Combustion of Wood Waste.....	43
4.2.3.2. Weight of Combustion Products from Wood Ignitiono.....	44
4.2.4. Combustion of Plastic Waste.....	44
4.2.4.1. Air required for Combustion of Plastic Waste.....	45
4.2.4.2. Weight of Combustion Products from Plastic Ignitiono.....	46
4.2.5. Combustion Products from Ignition Waste Material.....	46
4.3. Heat Balance	47

4.3.1. Overall Heat Balance.....	47
4.3.2. Gross Heat of Combustion.....	48
4.3.2.1 Gross Heat of Combustion of Tobacco.....	49
4.3.2.2 Gross Heat of Combustion of Paper.....	53
4.3.2.3 Gross Heat of Combustion of Wood.....	56
4.3.2.4 Gross Heat of Combustion of Plastic.....	59
4.4.Natural Gas Required.....	62
ξ.4.1.Natural Gas for Primary Burner.....	62
ξ.4.1.1. Natural Gas Required for Tobacco Combustion.....	62
ξ.4.1.2. Natural Gas Required for Paper Combustion.....	63
ξ.4.1.3. Natural Gas Required for Wood Combustion.....	63
ξ.4.1.4. Natural Gas Required for Plastic Combustion.....	64
ξ.4.2. Natural Gas Required for Secondary Burner.....	64
ξ.4.2.1. Natural Gas Required for Combustion gases from tobacco.....	64
ξ.4.2.2. Natural Gas Required for Combustion gases from paper.....	64
ξ.4.2.3. Natural Gas Required for Combustion gases from wood.....	65
ξ.4.2.4. Natural Gas Required for Combustion gases from plastic.....	65
4. ξ.3. Ignition of Primary Natural Gas.....	65
4.4. 3.1. Air Required for Combustion of P.N.G.....	68
4.4. 3.2. Weight of Combustion Products from Burning P.N.G.....	69
4. ξ.4. Ignition of Secondary Natural Gas.....	70
4.4. 4.1. Air Required for Combustion of S.N.G.....	73
4.4. 4.2. Weight of Combustion Products from Burning S.N.G.....	74
4.5. Calculation of Composition of individual Streams.....	75
4.5.1. Stream 1.....	76
4.5.2. Stream 2.....	76
4.5.3. Stream 3.....	77
4.5.4. Stream 4.....	77
4.5.5. Stream 5.....	78
4.5.6. Stream 6.....	78
4.5.7. Stream 7.....	79
4.5.8. Stream 8.....	79
4.5.9. Stream 9.....	80
4.6. Applications for Utilization of Combustion Gases Heat Content.....	81
4.6.1. Production of Saturated Steam.....	81
4.6.1.1. Energy Balance to Generate Steam.....	81
4.6.1.2. Design of Fire-Tube Steam Boiler.....	83

4.6.1.3. Analysis and Calculations of Fire-tube Steam Boiler	83
4.6.2. Combustion Gas Cooler (Production Hot Water).....	86
4.6.2.1. Energy Balance.....	86
4.6.2.2. Calculation of Log-Mean Temperature Difference, ΔT_{LMTD}	87
4.6.2.3. Design of Heat Exchanger.....	88
4.6.2.3.1. Calculation of Overall Coefficient of Heat Transfer, U	91
4.6.2.4. Pressure Drop	92
4.7. Comparison between the Performance of Actual Incinerator and Designed incinerator	95
Chapter Five Economic Study.....	97
5.1. Capital Investment.....	97
5.1.1. Fixed Capital Investment.....	97
5.1.2. Working Capital Investment.....	98
5.2. Profitability Evaluation t	100
Chapter six Conclusions and Recommendations	103
6.1. Conclusions	103
6.2. Recommendations	103
Refrences	104
APPENDIX	

List of Tables

Table 2.1: Generated Solid Waste in Egypt, 2001, 2006 and 2012	5
Table 2.2: The daily generated municipal solid waste in 2012.....	7
Table 2.3: Chemical Composition of Tobacco Plants.....	12
Table 3.1:The Chemical Composition and Calorific Value of Tobacco.....	25
Table 3.2:The Chemical Composition and Calorific Value of Paper.....	26
Table 3.3: Chemical Composition of Wood.....	26
Table 3.4: Characteristics of the Natural Gas National Grid in 2004/2005	27
Table 4.1: Feed Composition of Tobacco Waste	33
Table 4.2: Feed Composition of Paper Waste.....	33
Table 4.3: Feed composition of Paper Waste.....	34
Table 4.4: Feed Composition of Wooden Boxes Waste	35
Table 4.5: Feed Composition of Polyvinylchloride Waste	36
Table 4.6: Feed Composition of Polypropylene Waste.....	36
Table 4.7:Feed Composition of Plastic Waste	36
Table 4.8: Final Composition of the Feed of Waste	37
Table 4.9: Weight of Combustion Products from Ignition of Tobacco	39
Table 4.10: Weight of Combustion Products from Ignition of Paper	41
Table 4.11: Weight of Combustion Products from Wood	44
Table 4.12:Weight of Combustion Products from Plastic Ignition.....	46
Table 4.13:Specific Heat Coefficients	49
Table 4.14:Energy released due to chemical reaction (ignition of tobacco).....	49
Table 4.15:Energy consumed in first chamber to raise temperature of combustion products up to 850 °C (tobacco).....	50
Table 4.16a: Specific Heat of Combustion Products of Tobacco at 850 °C.....	51
Table 4.16b :Mass Flow Rate and Specific Heat of Combustion Products of Tobacco at 850°C	51
Table 4.17a: Specific Heat of Combustion Products of Tobacco at 1200 °C.....	52
Table 4.17b : Mass flow rate and specific heat of Combustion Products of Tobacco at1200°C	52
Table 4.18: Energy released due to chemical reaction (ignition paper).....	53
Table 4.19: Energy consumed in first chamber to raise temperature of combustion products up to 850 °C (paper).....	53
Table 4.20a : Specific Heat of Combustion Products of Paper at 850 °C	54
Table 4.20b : Mass Flow Rate and Specific Heat of Combustion Products of Paper at at 850°C	54
Table 4.21a: Specific Heat of Combustion Products of Paper at 1200 °C	55
Table 4.21b : Mass Flow Rate and Specific Heat of Combustion Products of Paper at at1200°C	55
Table 4.22: Energy released due to chemical reaction (ignition wood).....	56
Table 4.23: Energy consumed in first chamber to raise temperature of combustion products up to 850 °C (wood).....	56
Table 4.24a : Specific Heat of Combustion Products of Wood at 850 °C	57

Table 4.24b : Mass Flow Rate and Specific Heat of Combustion Products of Wood at 850°C	57
Table 4.25a: Specific Heat of Combustion Products of Wood at 1200 °C	58
Table 4.25b : Mass Flow Rate and Specific Heat of Combustion Products of Wood at at1200°C	58
Table 4.26: Energy released due to chemical reaction (ignition plastic)	59
Table 4.27: Energy consumed in first chamber to raise temperature of combustion products up to 850 °C (plastic)	60
Table 4.28a : Specific Heat of Combustion Products of Plastic at 850 °C	60
Table 4.28b : Mass Flow Rate and Specific Heat of Combustion Products of Plastic at 850°C	61
Table 4.29a: Specific Heat of Combustion Products of Plastic at 1200 °C	61
Table 4.29b : Mass Flow Rate and Specific Heat of Combustion Products of Plastic at1200°C	62
Table 4.30: The Composition Feed of Primary Natural Gas.....	66
Table 4.31: The Combustion Products from Burning Primary Natural Gas	70
Table 4.32: The Composition Feed of Secondary Natural Gas.....	70
Table 4.33: The Combustion Products from Burning Secondary Natural Gas	74
Table 4.34: Streams of Flowchart for Incinerator	75
Table 4.35: The Feed Composition of Waste.....	76
Table 4.36: The Feed Composition of Primary Natural Gas.....	76
Table 4.37: Feed Composition of Air For First Burner.....	77
Table 4.38: The Composition of Combustion Products from the First Chamber	77
Table 4.39: T The Feed Composition of Secondary Natural Gas	78
Table 4.40: The Feed Composition of Air for Second Burner.....	78
Table 4.41: Total Feed of N.G (Primary & Secondary).....	79
Table 4.42: Total Air (Through Primary & Secondary burner)	79
Table 4.43: Total Composition of Combustion Products from The Second Chamber ..	80
Table 4.44: Boundary Conditions of Heat-Exchanger	87
Table 4.45: The comparison between the Performance of Actual Incinerator and Boiler in the Eastern Company and The Designed Incinerator and Fire Tube Boiler ger....	96
Table 5.1: Breakdown of fixed capital investment items for incinerator	99
Table 5.2: Annual Return on Investment for Production of Steam r	102

List of Figures

<u>Figure 2.1</u> : Generated Solid Waste in Egypt, 2001, 2006 and 2012.....	6
<u>Figure 2.2</u> : Figure 2.2: Composition of Solid Waste in Egypt.....	8
<u>Figure 2.3</u> : Average (HHV) Values (MJ/kg) for Types of Tobacco Plants.....	13
<u>Figure 2.4</u> : Solid waste management hierarchy.....	14
<u>Figure 2.5</u> : Rotary Kiln Incineration	20
<u>Figure 2.6</u> : Internal Sector Rotary Kiln Incineration.....	21
<u>Figure 2.7</u> : Moving Grate Incineration	22
<u>Figure 2.8</u> : Fluidized Bed Incineration	27
<u>Figure 3.1</u> : Standard Design of the Multiple-Chamber Retort Incinerator.....	30
<u>Figure 3.2</u> : Multiple-Chamber Waste Incinerator.....	31
<u>Figure 3.3</u> : Fire Tube Boiler	32
<u>Figure 4.1</u> : The Volumetric Flow Rate from Burning Waste.....	47
<u>Figure 4.2</u> : Flowchart of Incinerator.....	75
<u>Figure 4.3</u> : Three Passes Fire Tube Boiler	82

Symbols and Abbreviations

NSWMP	National Solid Waste Management Programmer
GDP	Gross Domestic Product
GNI	Gross National Income
EAEA	Egyptian Environmental Affairs Agency
PCDFs	Polychlorinated dibenzodioxins
PCB	Polychlorobiphenyls
HHV	High Heating Value
LHV	Low Heating Value
C.V	Calorific Value
PVC	Polyvinyl Chloride
PP	PolyPropylene
CO ₂	Carbon Dioxide
CH ₄	Methane
C ₂ H ₆	Ethane
C ₃ H ₈	Propane
iC ₄ H ₁₀	<i>i</i> -Butane
nC ₄ H ₁₀	<i>n</i> -Butane
iC ₅ H ₁₂	<i>i</i> -Pentane
nC ₅ H ₁₂	<i>n</i> -Pentane
C ₆ H ₁₄	Hexane
M _{wt}	Molecular weight
M ^C _{dry}	Mass Flow Rate of Dry Waste
M ^o _{wet}	Mass Flow Rate of Wet Waste
m ^o	Mass Flow Rate
V ^o	Volume Flow Rate
NO ₂	Nitrogen Dioxide
SO ₂	Sulfur Dioxide
HCl	Hydrogen Chloride

G.H.V	Gross Heating Value
Q°	Heat Transfer Rate
C_p	Specific Heat
H_{fi}°	Standard Enthalpy of Formation
H	Heat of Reaction
A , B, C and D	Constant values
T	Temperature
P.N.G	Primary Natural Gas
S.N.G	Secondary Natural Gas
$M_{c.g}$	Mass flow Rate for Combustion Gases
$C_{p.c.g}$	Average Specific Heat of Combustion Gases
T_g	Temperature of Gases
M_w	Mass Flow Rate of Water
C_{p_v}	Specific Heat of Water Vapor
T_s	Temperature of Saturated Steam
T_{air}	Temperature of Air
T_w	Temperature of Water
h_{air}	Heat Transfer Coefficient of Air
h_w	Heat Transfer Coefficient of Water
t_{tube}	Thickness of tubes
K_{tube}	Thermal conductivity of carbon steel
A_{tube}	Area of tube
FCI	Fixed-Capital-Investment
PEC	Purchased Equipment
DPC	Total Direct Plant Cost
IDPC	Total Indirect Plant Cost
λ	Rate of Return on Investment
τ	Period of Return

Abstract

The objective of this thesis is to develop an integrated incineration unit which is technically and economically capable for the efficient handling of tobacco-waste processing plant with the subsequent utilization of the heat content of combustion gases. The incineration process is conducted in successive chambers that withstand high temperatures generated by natural gas firing burners. The engineering assembly of the incinerator compartments allow sufficient flying time for the waste-combustion gases to ensure complete the incineration process.

The incinerator engineering design is based on the composition of solid wastes disposed from the tobacco processing plants of the Eastern Company in 6th October city. The basis of design depends on feeding the incinerator with 1 t/h of solid waste consisting of: 50% tobacco, 20% paper& cartons, 20% wooden boxes, and 10% plastic materials. The remaining ash after the incineration process does not exceed 5% of the original volume of feed stock.

The incinerator consists mainly of a primary ignition chamber where whose temperature could reach 850 °C, followed by secondary combustion chamber in which flue gases temperature is increased to 1200 °C. The proposed reliable engineering assembly of the combustion chambers will verify flue gases residence time of 2 & 0.5 s in primary and secondary ignition chambers respectively to ensure complete combustion of all waste-components. The heat energy required to reach such high destructive temperatures is supplied by: (i) natural gas burners located in both primary and secondary ignition chambers, and (ii) high calorific values of waste constituents.

The overall material & energy balances reveals discharging combustion gases at mass flow rate of 25490 kg/h with heat content of 20 092 348 kJ/h. Flue gases energy is utilized either in generating saturated steam or producing hot water. An engineering design is given for: (i) a fired-tube boiler capable to generate 7 t/h saturated steam at 185 °C & 10 bar, and (ii) 1- 4 shell and tube heat exchanger that produces hot water rated 80 t/h at 85 °C. The temperature of the exhaust effluent combustion gases vented to the atmosphere is 200 °C, that proves a highly efficient utilization of their original heat content. The calculated results are in excellent conformity with the data given in the fabricator incinerator manual already installed in the Eastern Company plants.

A economic study including profitability analysis has been conducted. The study is based on equipment offers from specialized suppliers for the incinerator and its accessories, together with updated utilities prices. The results prove an annual return on investment of 5 % with a payback period of 8 years. When the environmental return is taken into account the annual return is increased to 20% while the payback time is reduced to 4 years