



Ain Shams University
Faculty of Engineering
Mechanical Power Engineering Department

**PERFORMANCE OF REFRIGERATION SYSTEM USING
ENVIRONMENTALLY FRIENDLY REFRIGERANT**

A Thesis Submitted in Partial Fulfillment for the Requirements of the
Degree of Master of Science in Mechanical Engineering

By

Tamer Mahmoud Aly Hassan
Bachelor of Science in Mechanical Engineering
Supervised by

Prof. Dr. Nabil Abdel-Aziz Mahmoud

Mechanical Engineering Department

Faculty of Engineering

Ain Shams University

Dr. Mohamed Saad El-Din El-Morsi

Department of Mechanical Engineering

School of Sciences and Engineering

The American University in Cairo (AUC)

Dr. Mohamed Hamdy Salama

Miraco Carrier - Misr Refrigeration & Air Condition

Egypt

Egypt- Cairo 2019

LIST OF PUBLICATIONS

Tamer M. Hassan, M.S. El-Morsi, N. A. Mahmoud, "Energy performance of Hydrocarbon Refrigerant as a possible alternative refrigerant to R134a in domestic refrigerators," Journal of Al Alzher University Engineering Sector, JAUES, ISSN: 1110-6409, 2018

CERTIFICATION STATEMENT

This thesis is submitted in partial fulfillment for the degree of Master of Science in Mechanical Power Engineering to the Faculty of Engineering, Ain Shams University.

The work included in this thesis was carried out by the author, primarily at the laboratories of the Mechanical Engineering Department, Faculty of Engineering, Ain Shams University.

No part of this thesis has been submitted for degree or qualifications at any other universities.

Signature

.....

Tamer Mahmoud Aly Hassan

RESEARCHER DATA

Name : Tamer Mahmoud Aly Hassan

Date of birth : 14/10/1979

Place of birth : CAIRO-EGYPT

Academic degree : Bachelor degree in mechanical power and energy

Field of specialization : Electromechanical projects-army engineering authority

University issued the degree: Military technical college.

Date of issued degree : 2001

Current job : Officer in the engineering authority for army forces

BOARD OF SUPERVISORS

The undersigned certify that they have read and recommended to the Faculty of Engineering, Ain Shams University, for acceptance a thesis entitled “**Performance of Refrigeration System Using Environmentally Friendly Refrigerant**”, submitted by **Tamer Mahmoud Aly Hassan**, in Partial Fulfillment for the Requirements of the Degree of Master of Science in Mechanical Engineering.

1. Prof. Dr. Nabil Abdel-Aziz Mahmoud

Mechanical Power Engineering Department
Faculty of Engineering
Ain Shams University

2. Dr. Mohamed Saad Eldin El-Morsi

Department of Mechanical Engineering
School of Sciences and Engineering
The American University in Cairo (AUC)

3. Dr. Mohamed Hamdy Salama

Miraco Carrier - Misr Refrigeration & Air Condition
Egypt

Date: / /2019

EXAMINERS COMMITTEE

The undersigned certify that they have read and recommended to the Faculty of Engineering, Ain Shams University, for acceptance a thesis entitled “**Performance of Refrigeration System Using Environmentally Friendly Refrigerant**”, submitted by **Tamer Mahmoud Aly Hassan**, in Partial Fulfillment for the Requirements of the Degree of Master of Science in Mechanical Power Engineering.

Signature

1. Prof. Dr. Salah Mahmoud El-Haggar

.....

Department of Mechanical Engineering
School of Sciences and Engineering
The American University in Cairo (AUC)

2. Prof. Dr. Mahmoud Abdel Rasheed Nosseir

.....

Mechanical Power Engineering Department
Faculty of Engineering
Ain Shams University

3. Prof. Dr. Nabil Abdel-Aziz Mahmoud

.....

Mechanical Power Engineering Department
Faculty of Engineering
Ain Shams University

4. Dr. Mohamed Saad el Din El Morsi

.....

Department of Mechanical Engineering
School of Sciences and Engineering
The American University in Cairo (AUC)

Date: / /2019

ABSTRACT

The aim of this study is to experimentally investigate the usage of liquefied petroleum gas (LPG) as a substitute refrigerant for R134a in a household refrigerator and identify the most suitable charge and capillary tube length. The gravimetric composition of the locally available LPG by weight is (R290- 25.98%, R600-41.17%, R00a-9.99%, R601a-0.64%, R170-0.11%, R744-0.01%, butene-22.10%), Appendix D.

Five different charges at which LPG and R134a are charged and tested. The charges are 40 g and 50 g for LPG and 130 g, 150 g and 170 g for R134a. Four capillary tubes of 0.7 mm inner diameter, 1.9 mm outer diameter and 1.5 m, 2 m, 2.5 m and 3 m length each are used during experimentation at different thermostat positions (1, 2, and 3).

REFPROP-6.0 software is used to determine the thermodynamic properties of LPG and R134a.

The results indicate that maximum COP and minimum irreversibility for R134a is attained at a charge of 130g, capillary tube length 1.5m and consequently the maximum exergy efficiency. On the other hand, the best performance for LPG is attained at a charge of 50 g and capillary tube length 1.5m. Relative to R134a, LPG has a COP and exergy efficiency that are lower by an average of 24% and 49%, respectively, within the range studied. However, LPG consumes less power and has more on time ratio compared to R134a. Also, LPG is cheap, available in great amounts and has a very low GWP and zero ODP.

Key words: Refrigerant, Hydrocarbon, R134a, LPG, Energy and Domestic refrigerator

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisors; **Prof. Dr. Nabil Abdel-Aziz Mahmoud**, **Dr. Mohamed Saad Eldin El-Morsi** and **Dr. Mohamed Hamdy Salama**, for their supervision, guidance and continuous support during the course of the research work presented in this thesis.

Thanks for the technical staff of the air conditioning and refrigeration laboratory, Ain Shams University, whom helped me in constructing the test rig.

I would like to express my sincere appreciation and gratitude to my father, late **Prof. Dr. Mahmoud Aly Hassan**, may God bless his soul, for his constant encouragement and his guidance that aims me to study this work.

TABLE OF CONTENTS

List of Publications	i
Certification Statement	ii
Researcher Data	iii
Board of Supervisors	iv
Examiners Committee	v
ABSTRACT	VI
Acknowledgements	VII
List of Figures.....	XI
List of Tables	XIV
Symbols and Abbreviations	XV
Nomenclature.....	XV
Greek letters.....	XV
Subscripts.....	XV
Abbreviations.....	XVI
Chapter 1 Introduction.....	1
1.1. Refrigerants History	1
1.2. CFC and HCFC Refrigerants.....	1
1.3. HFCs Refrigerants	1
1.4. HFC Refrigerants and their Substitutes	2
1.5. Hydrocarbons (HCs) Refrigerants	2
Chapter 2 Literature Survey.....	4
2.1. Replacement of R12 with HC.....	4
2.2. Alternative Refrigerants to R134a system.....	11
2.3. Compatible of HC with Oil, Filters and Compressors Materials.....	15
2.4. Flammability and Safety of HC	16
2.5. Scope of the Present Work	18

4.3. Comparison between Thermodynamic Properties of R134a and LPG.....	34
4.3.1. Pressure-temperature variation	35
4.3.2. Specific volume	36
4.3.3. Latent heat.....	38
4.3.4. Dynamic viscosity.....	38
Chapter 5 Results and Discussion	40
5.1. Introduction	40
5.2. Refrigerant Mass Flow Rate	40
5.3. Rate of Heat Transfer at Evaporator	46
5.4. Rate of Heat Transfer at Condenser	51
5.5. Compressor Work.....	56
5.6. Coefficient Of Performance, COP	61
5.7. Pressure Ratio (Pr).....	66
5.8. Volumetric Refrigeration Capacity, VRC	71
5.9. ON Time Ratio	76
5.10. Exergetic Efficiency	81
5.11. Total irreversibility	86
5.12. Uncertainty Analysis	91
Chapter 6 Conclusions and Recommendations	92
6.1. Conclusions	92
6.2. Recommendations for Future Work	93
References	94
Appendix A.....	106
Appendix B.....	117
Appendix C.....	125
Appendix D.....	129

LIST OF FIGURES

Figure 3-1 Schematic diagram of the test rig	21
Figure 3-2 Real photo of the test rig.....	22
Figure 4-1 Schematic diagram of a vapor compression refrigeration cycle used in domestic refrigerators.....	31
Figure 4-2 Pressure enthalpy diagram with liquid sub cooling and vapor super heating.....	31
Figure 4-3 Pressure-temperature variation	36
Figure 4-4 Specific volume of the saturated liquid for LPG and R134a.....	37
Figure 4-5 Specific volume of the saturated vapor for LPG and R134a	37
Figure 4-6 Latent heat of vaporization /condensation of LPG and R134a.....	38
Figure 4-7 Dynamic viscosity of saturated liquid for LPG and R134a	39
Figure 4-8 Dynamic viscosity of saturated vapor LPG and R134a.....	39
Figure 5-1 Mass flow refrigerant versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	42
Figure 5-2 Mass flow refrigerant versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	43
Figure 5-3 Mass flow refrigerant versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	44
Figure 5-4 Mass flow refrigerant versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	45
Figure 5-5 Rate of heat transfer of evaporator versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	47
Figure 5-6 Rate of heat transfer of evaporator versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	48
Figure 5-7 Rate of heat transfer of evaporator versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	49
Figure 5-8 Rate of heat transfer of evaporator versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	50
Figure 5-9 Rate of heat transfer for condenser versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	52
Figure 5-10Rate of heat transfer for condenser versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	53
Figure 5-11Rate of heat transfer for condenser versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	54
Figure 5-12Rate of heat transfer for condenser versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	55

Figure 5-13Rate of work for compressor versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	57
Figure 5-14Rate of work for compressor versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	58
Figure 5-15Rate of work for compressor versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	59
Figure 5-16Rate of work for compressor versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	60
Figure 5-17COP versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	62
Figure 5-18COP versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	63
Figure 5-19COP versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	64
Figure 5-20COP versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	65
Figure 5-21Pr versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	67
Figure 5-22Pr versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	68
Figure 5-23Pr versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	69
Figure 5-24Pr versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	70
Figure 5-25VRC versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	72
Figure 5-26VRC versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	73
Figure 5-27VRC versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	74
Figure 5-28VRC versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	75
Figure 5-29On time ratio versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	77
Figure 5-30On time ratio versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	78
Figure 5-31On time ratio versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	79

Figure 5-32 On time ratio versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	80
Figure 5-33 Exergetic efficiency versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	82
Figure 5-34 Exergetic efficiency versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	83
Figure 5-35 Exergetic efficiency versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	84
Figure 5-36 Exergetic efficiency versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	85
Figure 5-37 Total irreversibility versus thermostat positions for different refrigerant mass charge at capillary tube length 1.5m	87
Figure 5-38 Total irreversibility versus thermostat positions for different refrigerant mass charge at capillary tube length 2m	88
Figure 5-39 Total irreversibility versus thermostat positions for different refrigerant mass charge at capillary tube length 2.5m	89
Figure 5-40 Total irreversibility versus thermostat positions for different refrigerant mass charge at capillary tube length 3m	90

LIST OF TABLES

Table 2-1 Compatibility of different lubricants with HC refrigerants, [90]	16
Table 2-2 Properties of some HC refrigerants, [88]	17
Table 2-3 Flammability characteristics of some HC refrigerants, [89]	17
Table 3-1 LPG Compositions by country, [95]	19
Table 3-2 LPG composition studied in the present work, Appendix D.....	20
Table 3-3 Capillary tube dimensions	24
Table 3-4 Control system connected to sensors and other measuring devices.	28
Table 4-1 The thermodynamic states of the refrigeration cycles.....	31
Table 4-2 LPG composition studied in the present work, Appendix D.....	35
Table 5-1 Uncertainty of calculated variables	91