EXERGY, PERFORMANCE AND ENVIRONMENTAL IMPACT ANALYSIS OF COMPRESSION REFRIGERATION SYSTEMS

D.S Adelekan[1*], O.S Ohunakin[1], K. M. Odunfa[2] and T.O Babarinde[1]

[1]Mechanical Engineering Department, Covenant University, Canaanland, Ota, Ogun State, Nigeria

[2]Mechanical Engineering Department, University of Ibadan, Ibadan, Oyo State, Nigeria

Corresponding Author: damola.adelekan@covenantuniversity.edu.ng

Abstract

Major concern in refrigeration hinges largely on energy conservation, environmental safety and efficient cooling system. The concept of quality of useful energy which invariably leads to energy conservation is naturally related to exergy. This study therefore experimentally conducts exergy, performance and environmental impact analysis of compression refrigeration systems using R134a, R410a and R407c, refrigerants. The experiment was performed using a modified exiting R134a refrigerating system. The refrigerator was built with Scroll compressor, 48m^3 evaporator space, 1m throttle length and 0.2mm array of rods in the condensing unit coupled with thermocouple K attached at the various components and a digital 10^-3 accuracy weighing scale for charging refrigerant in the required grams. The results show that for 100 grams charge of the refrigerants, the exergetic efficiency**,** coefficient of performance (COP) and the degree of environmentally friendliness of each of the refrigerants are of order R410a > R407c,> R134a and for 80 grams charge of the refrigerants, the order of performance is R410a > R134a> R407c. While for 60 grams charge of the refrigerants, the exergetic efficiency**,** coefficient of performance and the degree of environmentally friendliness of each of the refrigerants are of order R407c> R410a > R134a, that of 40 grams charge of the refrigerants is of order R134a> R407c> R410a. The study therefore established that irrespective of the grams charge values of the investigated refrigerants used, R410a is the best, closely followed by R134a and lastly R407c.

Keywords: Exergetic efficiency, Coefficient of performance (COP), Impact analysis, Refrigeration, Environmental

1.0 INTRODUCTION

Researches in present science and technology as it pertains to refrigeration are based on factors like ozone layer depletion concern, energy conservation possibility and majorly improvement of performance of components of refrigeration system (compressor, condenser and evaporator). The aforementioned factors with ozone layer depletion factor being chiefly in accordance to the Air Clean Act in Montreal September 16, 1987 where CFC (Chloroflurocarbon) emitting gases/compounds/refrigerants was unanimously banned after the establishment of its adverse effect on ozone layer which is responsible for the protection/shielding of the earth surface from harmful ultraviolet rays with damaging effects including; development of cancerous cell in human (cancer disease), global warming, climate change and sea level rise with effects of destructive flood [1,2]. The Montreal Act therefore led to the emergence of HFCs (Hydroflourocarbon) based refrigerants which had no destructive potential to Ozone layer after it officially enacted the Acts' partial restriction of production and import of HCFCs refrigerants in January 1, 2010 and further projected that in January 1, 2015 the sale and use of HCFCs refrigerants would be totally prohibited except for services of existing refrigeration system till January 1, 2020 [3].

The establishment of the prohibitive use of both CFCs and HCFCs refrigerants has drawn concerns to the performance of market available replacement of HFCs based refrigerants with interest of scholarly research including; the comparison of R22 and R410a in air conditioning operating at high ambient temperature by W. Vance Payne and Piot A Domanski, R410a is azeotropic mixture of R32 and R125 refrigerants with a non ozone layer depleting capability, high efficiency and low power consumption rating created with a view of replacing R22 a highly reacting ozone depleting refrigerant [4]. R134a (1,1,1,2 tetrafloroethane) refrigerant is a class of haloalkane with partial Ozone layer depleting potential but due to its numerous application and efficiency in refrigeration systems is still in use as a replacement for R12 refrigerant. R407a The highly competitive industrial applications of refrigerants cannot therefore be

The coefficient of performance (COP) and evaporator temperature factor are efficiency related parameter on which therefore are the reasons for which pioneering refrigerant like R152, R22 and R12 were worked on for the new era of refrigerant like R134a, R410a and R407c but this newly developed ozone friendly replacement are not in totality to be embraced for the ever competitive industrial applications where high profit margin factor cannot be compromised.

The Objective of this work therefore is to compare three pivotal factors including; evaporator temperature, coefficient of performance and exergetic efficiency on which refrigeration systems performance are hinged.

2.0 MATERIALS AND METHOD

This experiment was performed using a modified exiting R134a refrigerant refrigerator. The refrigerator was built with Scroll compressor, $48m^3$ evaporator space, 1m throttle length and 0.2mm array of rods in the condensing unit. The experimental modified refrigerator had thermocouple K attached at the various components (compressor inlet and outlet, evaporator space, condenser outlet for the collection of data and a digital 10^-3 accuracy weighing scale was used for charging refrigerant in required grams.

3.0 RESULT AND DISCUSSION

As shown in fig 1 below the result of 100 grams charge compares favoured the selection of both R134a and R407c with both refrigerants having evaporator temperature of -15 °C unlike R410a that had -1 °C after 180mins observation time.

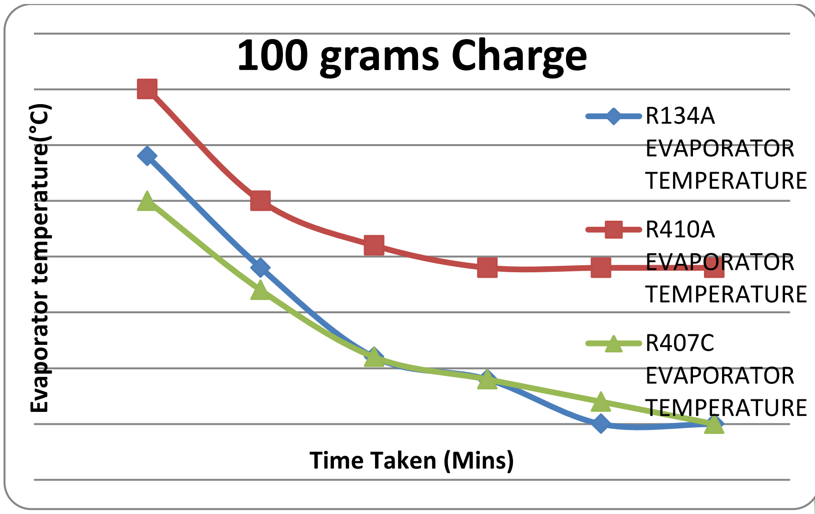

Fig 1: Graph of 100 grams charge of R134a, R410a and R407c evaporator temperature against time taken (mins)

Fig 2 below however, skewed selection R134a followed by the selection R410a and lastly R407c with temperature range of -25 °C, -11 °C and -7 °C for 80 grams charge. This further proves that the charging of 80 gram charge of R410a has better performance in terms of evaporator temperature than its 100 grams charge as shown from performance of evaporator temperature of -11 °C as opposed to -1 °C given in its 100 grams charge. Furthermore, Fig 3 below showed 60 grams charge with R134a with -11 °C, R410a with 5 °C and R407c with 7 °C.

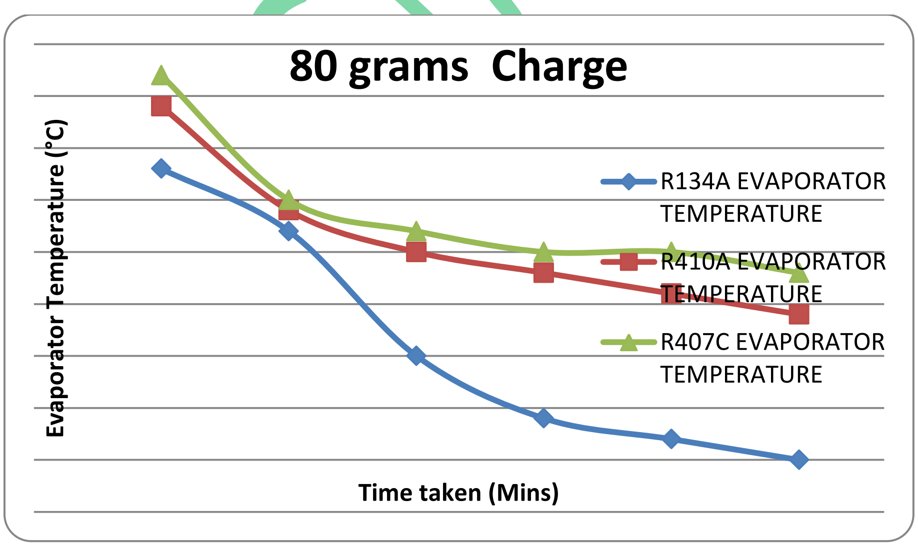

Fig 2: Graph of 80 grams charge of R134a, R410a and R407c evaporator temperature against time taken (mins)

This further proves that R134a refrigerant can still selected in application but not R407c and R410a as performance based on evaporator temperature dismay their usage.

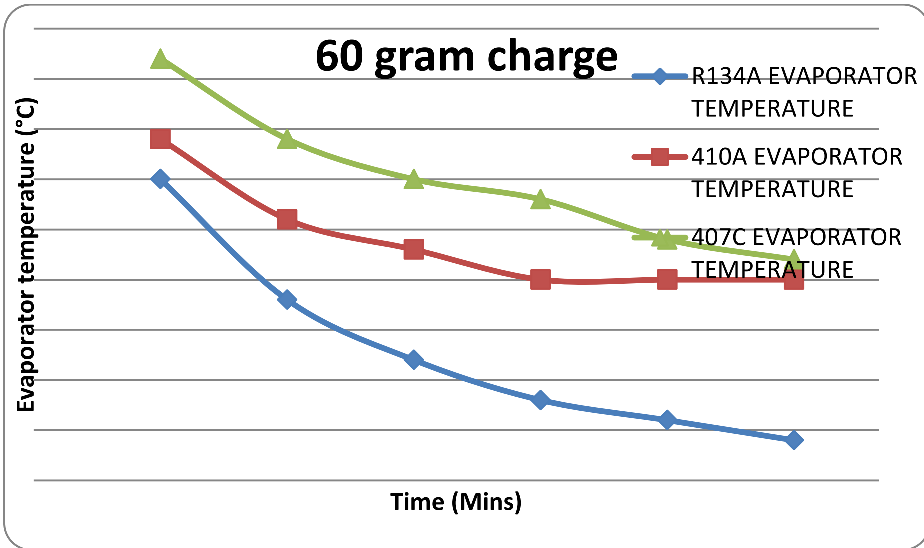

Fig 3: Graph of 60 gram charge of R134a, R410a and R407c evaporator temperature against time taken (mins)

Fig 4 furthermore, revealed that 40 gram charge of all selected refrigerants not sufficient a charge for efficient cooling evaporator temperature. Hence 40 grams charge is not to be charged if optimum - maximum efficiency value forms fundamental design parameter of refrigeration system under scrutiny.

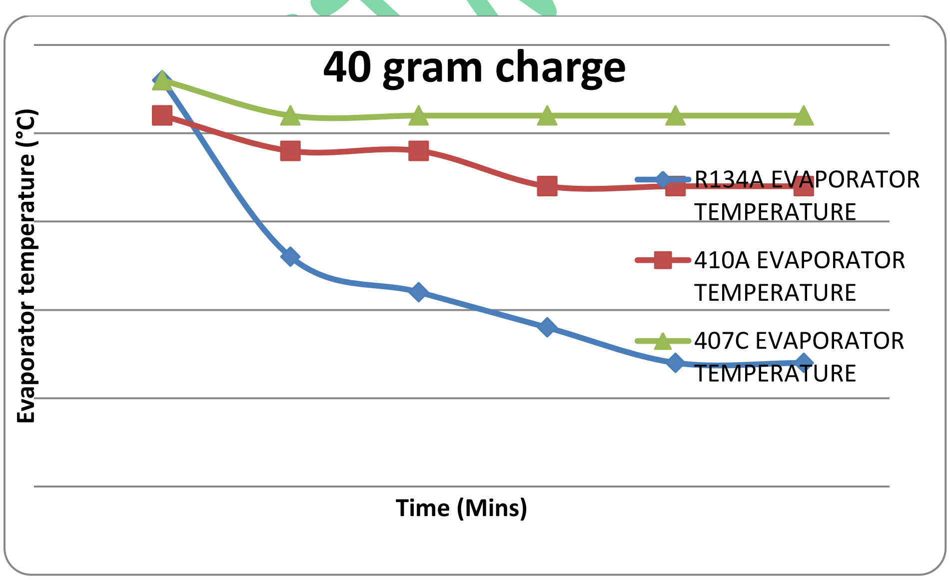

Fig 4: Graph of 40 grams charge of R134a, R410a and R407c evaporator temperature against time taken (mins)

Having compared the evaporator temperature over observation period of 180 mins for 100, 80, 60 and 40 grams of R134a, R410a and R407c refrigerants it was observed that 80 grams of R134a had best evaporator temperature of -25°C, followed by 100 grams charge of R407c with -15°C and lastly 80 grams charge R410a refrigerant with -11°C.

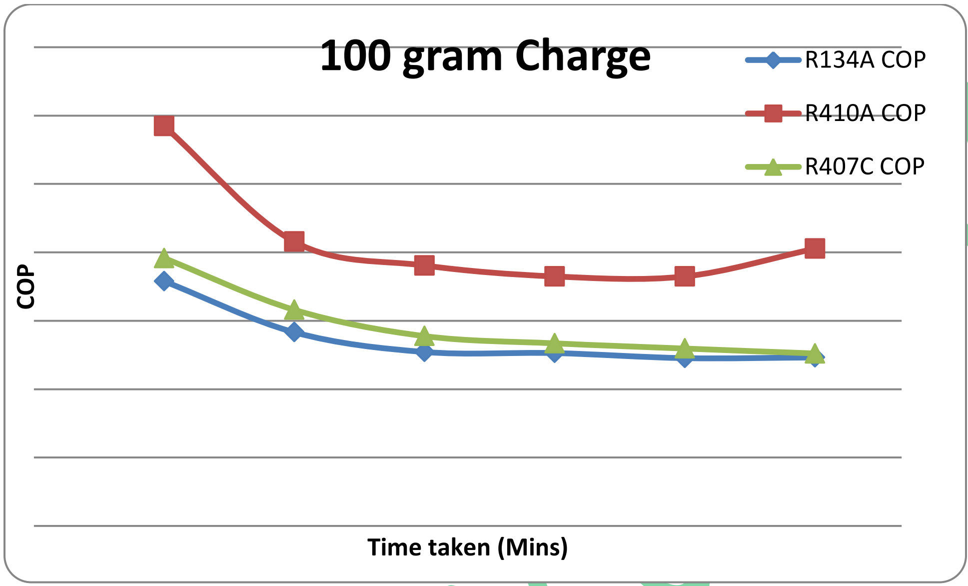

Fig 5: Graph of 100 grams charge of R134a, R410a and R407c COP against time taken (mins)

Fig 5 above shows the result of comparative analysis based on COP of all three refrigerants following a decline in COP value over the observation period of 180 mins favouring the selection of R410a COP value of 2.027 followed by R407c COP value of 1.261 and lastly R134a COP value of 1.232 for 100 grams charges of same. Fig 6 below however revealed result with a favourable selection of R407c of COP value of 1.474 followed by R410a with COP value of 1.454 and lastly R134a with value of 1.025 for 80 grams charge respectively.

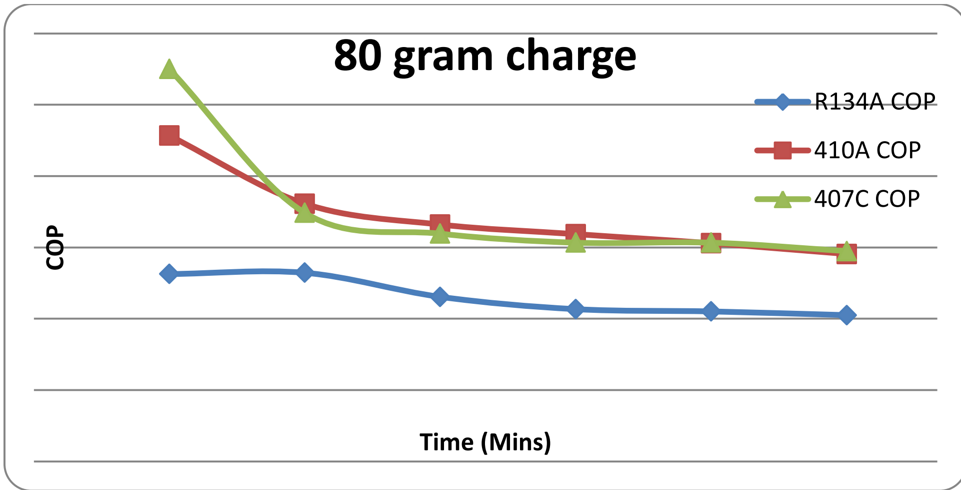

Fig 6: Graph of 80 grams charge of R134a, R410a and R407c COP against time taken (mins)

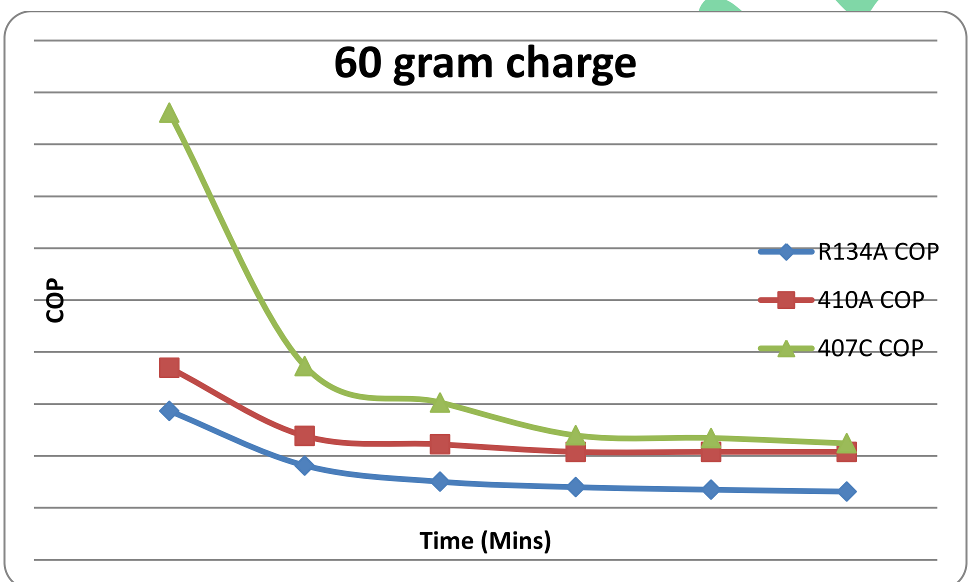

Fig 7: Graph of 60 grams charge of R134a, R410a and R407c COP against time taken (mins)

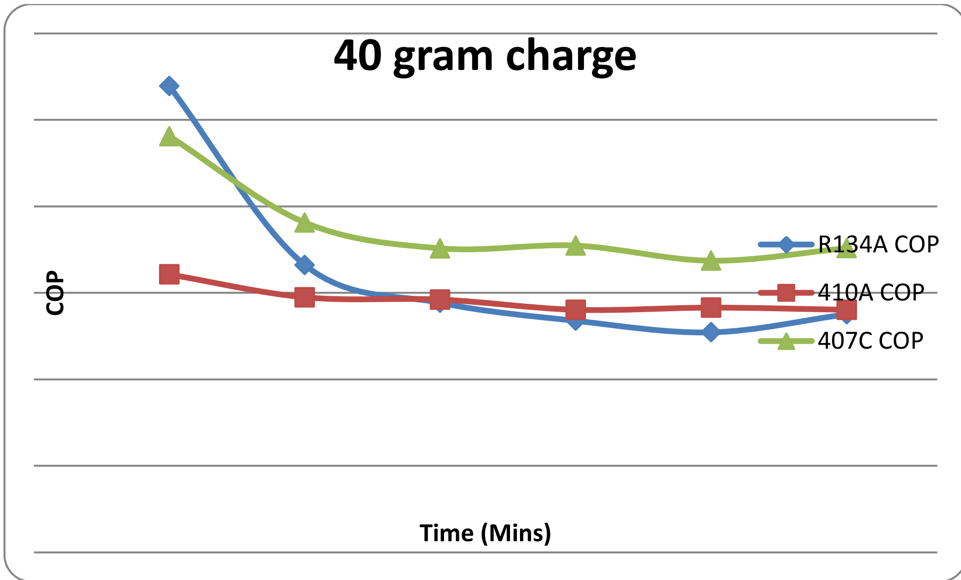

Fig 8: Graph of 40 grams charge of R134a, R410a and R407c COP against time taken (mins)

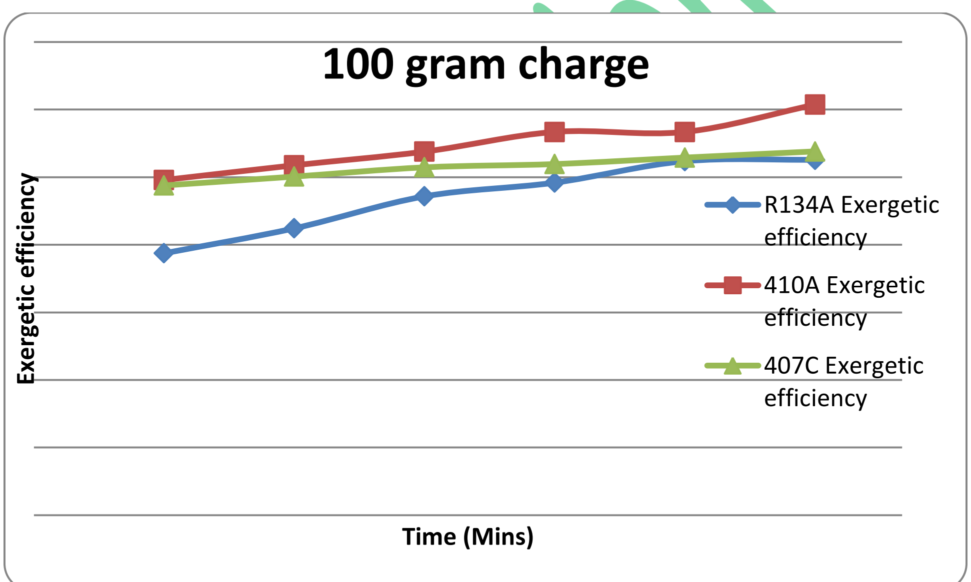

Fig 9: Graph of 100 grams charge of R134a, R410a and R407c Exergetic efficiency against time taken (mins)

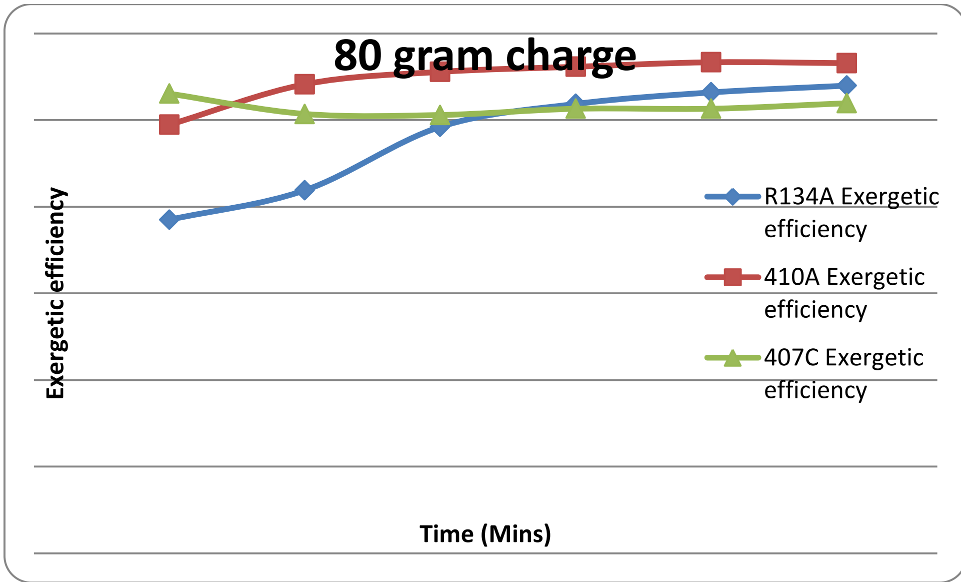

Fig 10: Graph of 80 grams charge of R134a, R410a and R407c Exergetic efficiency against time taken (mins)

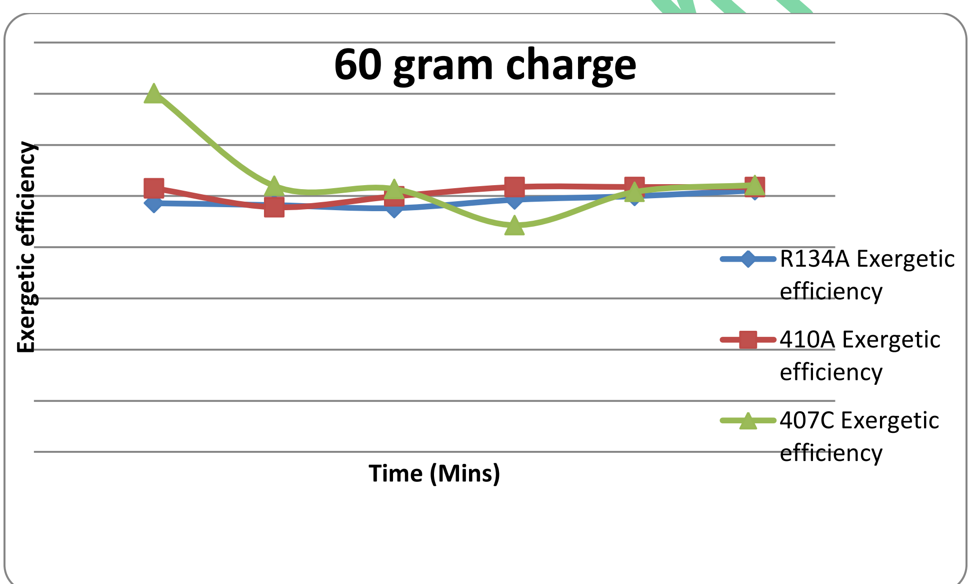

Fig 11: Graph of 60 grams charge of R134a, R410a and R407c Exergetic efficiency against time taken (mins)

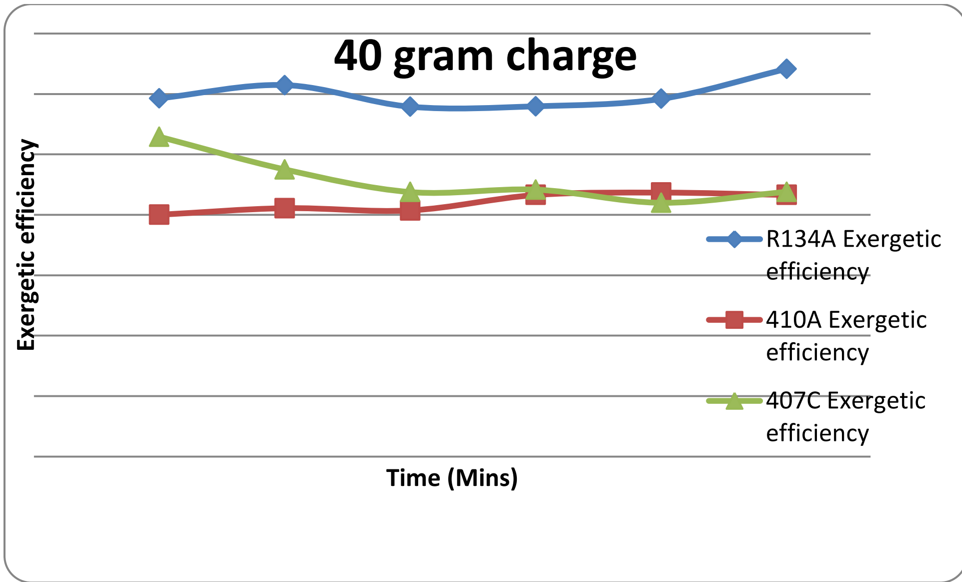

Fig 12: Graph of 40 grams charge of R134a, R410a and R407c Exergetic efficiency against time taken (mins)

The analysis of comparison of R134a, R410a and R407c was done in four categories of charging within the range of 40 - 100 grams charge at 20 grams charge increment. The results showed that at 100 grams charge of the refrigerants an excellent evaporator temperature behaviour of both R134a and R407c refrigerant of -15°C from a starting environmental/ambient temperature of 34°C after 180 minutes unlike R410a that had a maximum evaporator temperature of -1°C. The result of 80 gram charged skewed performance in favour of both R134a and R410a with evaporator temperature of -25°C and -11°C respectively unlike R407c with -7°C. The 60 grams charge still proved R134a refrigerant performed with temperature of -11°C while R410a and R407c had evaporator temperature of 5°C and 7°C respectively. The 40 grams charge of the refrigerant however showed a poor performance of all the refrigerants used with R134a having 7°C, R410a was having 17°C and R407c having 21°C.

The refrigerants COP of 100 grams charge having established better evaporator temperature with both R134a and R407c tilted performance in favour of R407c with COP value of 1.261 while R134a having a COP value of 1.232 and R410a COP value of 2.027. The refrigerant COP of 80 grams charge based on evaporator temperature favoured R410a with COP value of 1.454 followed by R134a COP value of 1.025 and R407a COP value 1.474. The refrigerant COP of 60 grams charge based on evaporator temperature favoured R134a with COP value of 1.313 followed by R407c COP value of 1.241 and R410a COP value 2.078. The refrigerant COP of 40 grams charge based on evaporator temperature favoured R134a with COP value of 2.752 followed by R410a COP value of 2.804 and R407c COP value 3.516.

Finally, the refrigerant exergetic efficiency of 100 grams charge revealed R410a had 30.37% while R407c had 26.91% and R134a had 26.29%. The 80 grams charge revealed R410a had 28.28% while R134a had 27% and R407a had 25.97%. The 60 grams charge revealed R407c had 26.08% while R410a had 25.88% and R134a had 25.55%. The 40 grams charge revealed R134a with 32.08% while R407c had 21.90% and R407a had 21.64%.

If the three aforementioned parameters were to be represented in a scale of reference range of 1-3 based on performance rating, the following result were obtained.

100 grams Charge

Title	COP	Evaporator Temperature (°C)	Exergetic efficiency
Performance rating	R410a	R134a/ R407c	R410a
	R407c	R410a	R407c
	R134a		R134a

R410a had 8 units; R407c had 7 units while R134a had 5 units respectively.

80 grams Charge

Title	COP	Evaporator Temperature (°C)	Exergetic efficiency
Performance rating	R407c	R134a	R410a
	R410a	R410a	R134a
	R134a	R407c	R407c

R410a had 7 units; R407c had 5 units while R134a had 6 units respectively.

60 grams Charge

Title	COP	Evaporator Temperature (°C)	Exergetic efficiency
Performance rating	R407c	R134a	R407c
	R410a	R410a	R410a
	R134a	R407c	R134a

R410a had 6 units; R407c had 7 units while R134a had 5 units respectively.

40 grams Charge

Title	COP	Evaporator Temperature (°C)	Exergetic efficiency
Performance rating	R407c	R134a	R134a
	R410a	R410a	R407c
	R134a	R407c	R410a

R410a had 5 units; R407c had 6 units while R134a had 7 units respectively.

Conclusion

100 grams charge favoured the selection of R410a followed by R407c and lastly R134a. 80 gram charge favoured selection of R410a followed by R134a and lastly R407c. 60 gram charge favoured selection of R407c followed by R410a and lastly R134a. 40 gram charge favoured the selection of R134a followed by R407c and lastly R410a.

References

Kim, Y.; and Park, I. (2000). Development of performance analysis program for vapour compression cycle based on thermodynamic analysis *Journal of Industrial and Engineering Chemistry*, 6(6), 385-394

UNEP (2003). *Handbook for international treaties for protection of the ozone layers* (6th ed). United Nation Environment Program, Nairobi, Kenya

www.epa.gov/ozone/title6/download/EPAhomeowners.9-06-06.Pdf http://en.wikipedia.org/wiki/R-410A

The Essentials Of Working With R-410A". Florida State College at Jacksonville. p. 7. Retrieved November 21, 2013.