© 2017 IJSRST | Volume 3 | Issue 4 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Performance Characteristics of Refrigerants

Ajoko, Tolumoye John

Department of Mechanical/Marine Engineering, Faculty of Engineering. Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

ABSTRACT

The increasing concern of climate change is the alarming issue to the designers, distributors and end time users of refrigeration and air conditioning systems. The continuous use of convectional refrigerants with chlorine molecules has been the bottleneck and drawbacks set to cover by research. Thus, the current study is designed to bridge some of these research gaps. Therefore, a detailed evaluation of refrigerants with the aid of a training simulator capable of analysing the thermo-physical properties and performance of some selected blend of refrigerants is the focal point of the study. The study creates decision policies on the selection of the best and ecofriendly refrigerant(s) to be used in the refrigeration/air conditioning systems. However, simulated results confirm HFC – R_{134a} blend of refrigerants as the best due to its high proficient coefficient of performance (COP) value of 3.23 and 2.84 against 2.88 and 2.38; 1.33 and 2.53; 1.40 and 1.85 for R_{12}, R_{22} and R_{600a} respectively for thermostatic expansion valve (TEV) and Capillary tube operation modes. It also attests that R_{134a} and R_{12} as established from the practical results are the most appropriate refrigerants for domestic and industrial heating respectively. Hence, results are justifiable and the process of this study could be used as tool for the selection process of refrigerants with zero ozone depleting potentials.

Keywords: Air-Conditioning, Capillary tube, Coefficient of Performance, Refrigerants, Refrigeration cycle, Stabilization point, Thermostatic Expansion Valve, TPS Simulator.

I. INTRODUCTION

Refrigeration over the years has developed to be a very important process needed around the globe due to its wide range of usefulness and importance. It has impacted positively on industrialization, agricultural sector, preservation of medical and surgical aids, oil refining and synthetic rubber manufacturing/metals treatment, conservation of food products/beverages and finally for the comfortability of man. Though with this numerous benefits attached to the refrigerating process; the challenges from this system to the environment cannot be over emphasized or forgotten in haste.

Several reports by scholars have shown that the various working fluids used in the refrigeration system have contributed majorly on the depletion of the ozone layer. These global harmful scenarios of refrigerants have destroyed the stratospheric region leading to serious issues of global warming [1-4]. Due to this catastrophe, conventional refrigerants with chlorine molecules as found in the halocarbons such as the chloro fluoro carbon (CFC), hydro chloro fluoro carbon (HCFC) and unsaturated organic compounds with chlorine radical all of primary refrigerant class should be avoided and allow to phase out from the system. However, in a reviewed research work; mathematical modelling process has been developed to check zero tolerance of ozone depleting refrigerants in the refrigeration systems.[5, 6]. Meanwhile, the availability of wide range of refrigerants is quite tasking to ascertain the suitable refrigerant for a particular refrigeration system and process for a certain working conditions, since different fluids (refrigerant) have the desirable properties and characteristics in different degree. Hence, the study for the performance characteristics for refrigerants has become necessary in order to evaluate an ecofriendly refrigerant which is bound to protect the environment from dreadful substances.

In this direction, many positive contributions have so far been made. As established in a reviewed literature, a refrigerant could be considered for selection to be used if it meets the three basic criteria – it must be safe, be environmentally friendly, and must provide excellent performance benefit [7]. Consequently, different analysis and experiments have been carried out over the years to determine the best refrigerants to be used for a particular refrigeration system considering either one or the entire criterion as stated above. In line with this perspective, it is unveiled that theoretical investigation for the performance of R_{410a} in replacement of R_{22} in an air conditioner with the same heat exchangers and compressors of the same efficiency is tested feasible with the following reasons. The COP of R_{410a} is proven to be better than R_{22} at all pressures, with less harmful influence on the environment though their thermo-physical properties seems to be similar, hence substitution requires minimal alterations in the refrigeration system [8].

A similar study examines the performance analysis of two sub-classes of the Freon group; CFC-12 and HFC-134a. At the end of the performance investigation, report attests that even though the CFC-12 class is widely used in both residential and commercial applications, the international law set forth in the Montreal Protocol has put CFC-12 on a phase out schedule due to its Ozone Depletion Potential. However, HFC-134a has been established as a drop-in-substitute for CFC-12 on the bases of their similarities in thermodynamic properties and performance [9]. Also a theoretical assessment of different commercial refrigeration systems in terms of annual energy consumption and environmental impact was investigated by researchers. In their study, it was defined that R_{744} inorganic refrigerant should be employed back for subcritical conditions in the refrigeration system from the thermo-physical point of view. Thus, the refrigerant is of fairly better thermodynamics properties than HFCs as reported in their studies [10],[11]. Meanwhile the evaluation performance of different refrigerants such as R_{600a}, R_{134a}, R_{290}, R_{22}, R_{410a}, and R_{32} in a study was carried out in an optimized evaporator to determine the impact on the system COP. Report from that study reveals a high spread of COP up to 11.7% for a theoretical cycle analysis without accounting for the evaporator effects [12].

Thus, to maintain emission free environment, it is necessary to analyze the performance characteristics of refrigerants that passes through a refrigeration cycle. Therefore this process is carried out with the aid of simulation models known as Theorem Proving System (TPS) Simulator.

II. SETUP OF PRACTICAL STIMULATOR

As stated earlier that the primary purpose of this study is to identity and evaluate the performance characteristics of refrigerants as they pass through a refrigeration process or cycle. Thus, in accomplishing this objective, the selected refrigerants will be tested using a TPS simulator. However, refrigerants for this purpose are selected randomly from different classes and groups of refrigerants which absolutely possess different chemical formulation and structure. Apparently, results obtained from the simulation may be used to represent all the refrigerants in that class or group since they have similar characteristics and chemical structures.

Hence, refrigerants with the following chemical names and formulas are used to represent refrigerant under the halocarbon compounds. Dichloro-difluoro methane (CCl_2F_2) - R_{12}, monochloro-difluoro methane ($CHClF_2$) – R_{22} and tetrafluoroethane (CH_2FCF_3) – R_{134a} representing CFC, HCFC, HFC groups respectively; while butane (C_4H_{10}) - R_{600a} stands for the hydrocarbon compounds (HC). Figure 1 show a diagram of the TPS simulator used for the simulation process.

Figure 1: Refrigeration and Air Conditioning TPS Simulator. *source*: [13]

The simulator is incorporated with some mechanical components such as compressor, condenser, expansion system and an evaporator; and other devices.

III. THE WORKING PRINCIPLES

The compressor device shown is figure 2 bears the responsibility of compressing the refrigerant so as to increase its temperature and pressure to enable it move from a low temperature region to a high temperature region as it is stated in Clausius statement on the second law of thermodynamics that *"it is impossible for a self-acting machine working in a cyclic process unaided by any external agency, to convey heat from a body at a lower temperature to a body at a higher temperature"* [14].

Figure 2: Compressor of a refrigeration system

The condenser or condensing coil as shown in figure 3 condenses the refrigerant from its gaseous to liquid state by cooling process. This is done by getting rid of heat extracted from the interior section of the unit to the outside air. Thus, receiving the refrigerant as a gas from the compressor at a high temperature and pressure and converts it to liquid at the outlet of the condenser by giving out its heat to the surrounding with the aid of a fan.

Figure 3: Condenser of a refrigeration system *source*: [13]

The expansion component for this operation is usually grouped into a capillary (orifice) tube or thermostatic expansion valve (TEV). In a general note, they have triple function such as reducing refrigerant temperature in the cooling circuit as it moves to the evaporator. It also determines the refrigerant flow intensity through the cooling circuit and enables the compressor to accomplish its compressing action by restricting the refrigerant flow. Figure 4 is a presentation of an expansion unit in the training simulator

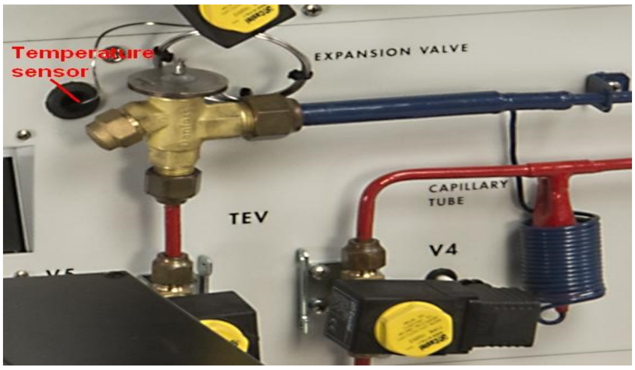

Figure 4: Expansion component of a refrigeration system. *source*:[13]

The refrigerating effect takes place in the evaporator which is done by the evaporator blower. It sucks the unwanted air out from the refrigerated area and blows it through the evaporator fins. However as the air passes through the fins and gives up its heat, it returns to the refrigerated area lot cooler and drier. A typical sample of evaporator is shown in the figure 5.

Figure 5: Evaporator of a refrigeration system. *source*:[13]

IV. EXPERIMENTATION WITH BASIC REFRIGERATION SYSTEM

In order to operate economically, the refrigerants are used repeatedly. For this reason, the simulator is operated in a closed circuit either in a TEV or capillary mode with the support of the four major stages; that is the compression, condensation, expansion and evaporation. Figure 6 shows the operation of the simulator in Skill 'G' laboratory of Niger Delta University.

Figure 6: Simulator Assembly

TEV mode of Operation:

The TEV is used to gauge the liquid refrigerant flow entering the evaporator at a rate equivalent to the amount of refrigerant being evaporated in the evaporator. The valves regulating this flow as shown in figure 7 provides a pressure drop in the system, separating the high-pressure side of the system from the low-pressure side of the system, allowing the low-pressure refrigerant to absorb heat onto itself.

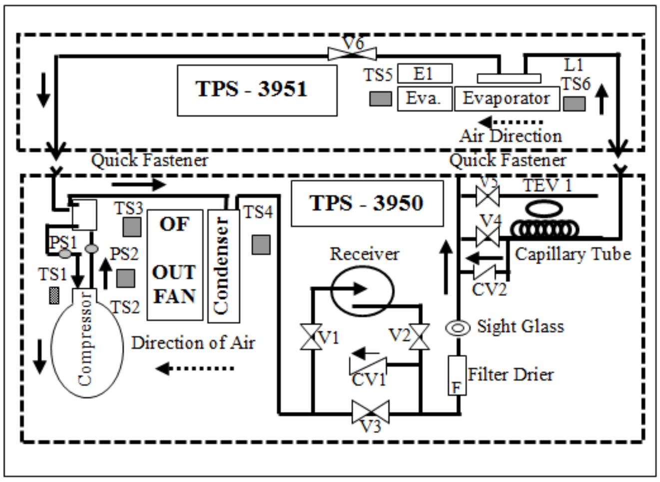

Figure 7: Refrigerant Flow Path Chart

Capillary mode of Operation:

The capillary tube is designed to lower the cooling liquid pressure which was raised during the compression process. Thus, the pressure drop on the tube depends on the internal diameter and length of the tube, the flow speed, the cooling material specific weight and the friction coefficient between the cooling material and the tube. This is a fix control element, which depends on its dimensions and material.

V. RESULT PRESENTATION

Results obtained are based on the operation mode of the system. Hence two sets of results are presented for each refrigerant which is used to determine their coefficient of performance (COP). This will help in the comparison and justification of results to establish the best state of refrigeration system and subsequently the best refrigerant to use for a desired operating. Tables 1 – 4 is the simulation results for R_{134a}, R_{12}, R_{22} and R_{600a} respectively while figures 8 – 11 shows graphical plot of results.

Table 1: Results for R134a

R134a (TEV Mode)												
Stabilization Point Value at (°C)												
NO	COM	LOAD	E1	LP	HP	T1	T2	T3	T4	T5	T6	cop
1	ON	OFF	LO	115	73	91	87	77	64	69	115	3.14
2	ON	OFF	HI	115	69	91	87	77	69	68	115	2.96
3	OFF	OFF	LO	103	68	93	84	80	73	71	103	3.23
4	OFF	OFF	HI	105	61	96	86	78	71	69	105	2.56
5	ON	ON	LO	113	71	96	86	75	64	69	113	2.56
6	ON	ON	HI	115	71	95	86	77	68	69	115	2.65
7	OFF	ON	LO	105	64	100	86	75	60	68	105	2.13
8	OFF	ON	HI	103	62	102	86	77	64	68	103	2.00
R134a (Capillary Tube Mode)												
1	ON	OFF	LO	33	133	48	104	93	82	60	66	1.74
2	ON	OFF	HI	33	135	44	104	95	84	62	66	1.81
3	OFF	OFF	LO	79	103	68	96	87	84	69	71	2.84
4	OFF	OFF	HI	57	123	51	102	93	84	64	66	1.83
5	ON	ON	LO	30	133	8	38	35	29	17	22	1.38
6	ON	ON	HI	33	133	7	39	35	29	18	22	1.29
7	OFF	ON	LO	57	125	9	41	36	29	18	22	1.16
8	OFF	ON	HI	66	121	14	40	34	30	20	23	1.35

Table 2: Results for R12

R22 (TEV MODE)												
Stabilization Point Value at (°C)												
NO	COM	LOAD	E1	LP	HP	T1	T2	T3	T4	T5	T6	COP
1	ON	OFF	LO	11	109	33	74	33	33	35	37	1.00
2	ON	OFF	HI	18	125	37	92	37	34	36	48	1.09
3	OFF	OFF	LO	64	67	38	63	37	35	37	36	1.33
4	OFF	OFF	HI	64	67	39	68	38	36	37	36	1.13
5	ON	ON	LO	16	123	37	87	37	34	37	36	0.71
6	ON	ON	HI	16	123	37	90	37	34	37	36	0.67
7	OFF	ON	LO	66	69	38	68	38	35	37	37	1.19
8	OFF	ON	HI	64	67	39	63	39	36	37	36	1.33
R22 (CAPILLARY TUBE MODE)												
1	ON	OFF	LO	115	125	37	42	36	35	38	38	1.52
2	ON	OFF	HI	86	123	37	41	36	34	38	38	1.58
3	OFF	OFF	LO	45	51	37	40	36	35	37	37	2.53
4	OFF	OFF	HI	42	49	37	41	36	35	37	37	1.48
5	ON	ON	LO	58	123	37	42	36	37	37	37	1.42
6	ON	ON	HI	58	123	37	41	35	34	38	37	1.48
7	OFF	ON	LO	42	49	37	44	36	35	38	37	1.28
8	OFF	ON	HI	45	49	37	42	36	35	38	38	1.52

Table 3: Results for R22

R12 (TEV Mode)												
Stabilization Point Value at (°C)												
NO	COM	LOAD	E1	LP	HP	T1	T2	T3	T4	T5	T6	cop
1	ON	OFF	LO	32	106	67	82	80	71	59	60	2.74
2	ON	OFF	HI	32	106	63	84	80	71	63	60	2.53
3	OFF	OFF	LO	68	95	63	86	77	74	67	64	2.88
4	OFF	OFF	HI	61	97	56	88	79	72	65	60	2.12
5	ON	ON	LO	28	104	65	88	79	69	59	60	2.12
6	ON	ON	HI	30	106	65	87	79	71	63	60	2.19
7	OFF	ON	LO	34	97	59	92	79	69	55	59	1.80
8	OFF	ON	HI	48	95	57	94	79	71	59	59	1.71
R12 (Capillary Tube Mode)												
1	ON	OFF	LO	86	91	37	60	37	35	38	38	1.73
2	ON	OFF	HI	86	93	36	63	37	36	38	37	1.42
3	OFF	OFF	LO	35	43	37	54	37	35	38	38	2.38
4	OFF	OFF	HI	30	39	37	59	37	36	39	38	1.81
5	ON	ON	LO	72	94	36	65	37	36	38	38	1.41
6	ON	ON	HI	86	95	37	66	37	35	38	38	1.36
7	OFF	ON	LO	30	39	37	57	37	36	39	39	2.17
8	OFF	ON	HI	30	39	37	57	37	36	40	39	2.17

Table 4: Results for R600a

R600a (TEV MODE)												
Stabilization Point Value at (°C)												
NO	COM	LOAD	E1	LP	HP	T1	T2	T3	T4	T5	T6	COP
1	ON	OFF	LO	58	79	32	60	32	32	33	32	1.14
2	OFF	OFF	HI	58	81	34	66	34	32	35	34	1.06
3	OFF	OFF	LO	52	57	34	60	34	33	36	35	1.40
4	OFF	OFF	HI	54	59	35	57	34	33	36	36	1.71
5	ON	ON	LO	86	85	35	60	34	33	36	36	1.50
6	ON	ON	HI	58	83	35	66	34	32	37	36	1.20
7	OFF	ON	LO	54	59	35	63	34	33	37	36	1.33
8	OFF	ON	HI	54	59	36	60	34	34	37	37	1.61
R600a (CAPILLARY TUBE MODE)												
1	ON	OFF	LO	86	97	36	58.5	34	34	37	36	1.60
2	OFF	OFF	HI	58	97	36	60	34	33	37	37	1.61
3	OFF	OFF	LO	52	57	36	57	34	33	37	37	1.85
4	OFF	OFF	HI	52	55	36	57	34	33	37	36	1.71
5	ON	ON	LO	58	95	36	58.5	34	33	37	37	1.72
6	ON	ON	HI	86	97	36	61.5	34	33	37	37	1.51
7	OFF	ON	LO	50	55	36	60	34	33	37	37	1.61
8	OFF	ON	HI	50	55	36	60	34	33	38	37	1.61

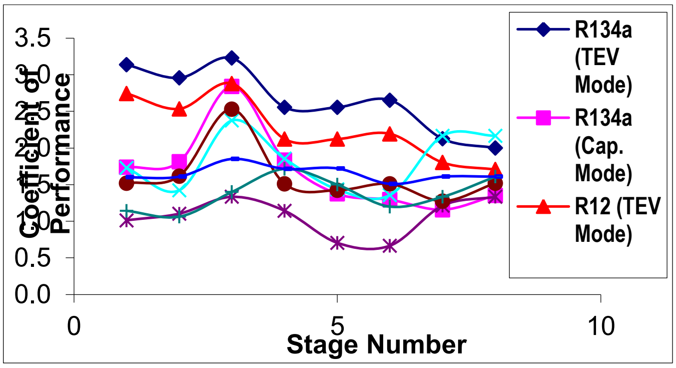

Figure 8: Star-pot of COP versus Stage number

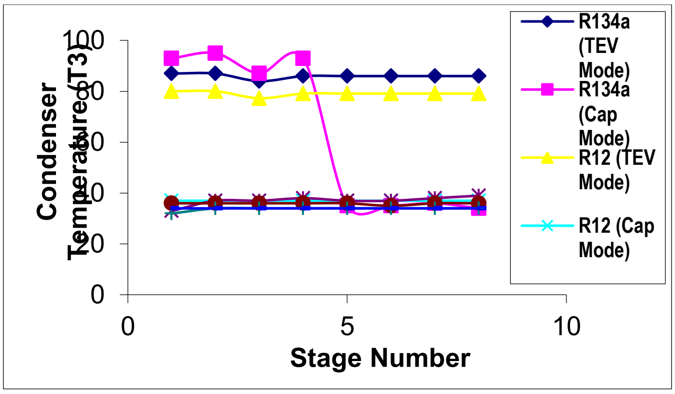

Figure 9: A graph of Condenser Temperature (T_3) against Stage number

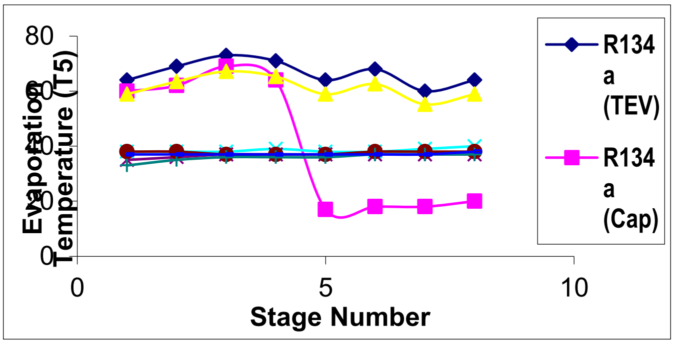

Figure 10: Star-pot of Evaporation Temperature against Stage number

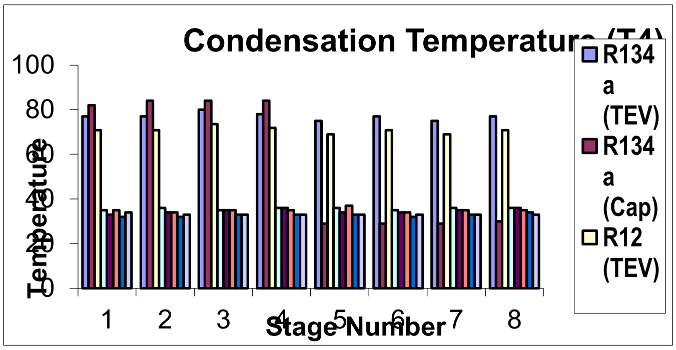

Figure 11: Condensation Temperature difference with respect to Stage number

VI. DISCUSSION OF RESULTS

The analyzed results of the COPs are obtained using the different p – h charts for the refrigerants under study. The corresponding thermodynamic properties of the refrigerants for each process in the refrigeration system are estimated where values are evaluated using the equations below for the derivation of the COPs in the graphical plots.

$$COP = \frac{Q_o}{W_{net}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots i$$

$$COP = \frac{h_{Evap \cdot in} - h_{Evap \cdot out}}{h_{Comp \cdot out} - h_{Comp \cdot in}} \quad \ldots\ldots\ldots\ldots\ldots ii$$

$$COP = \frac{T_L}{T_H - T_L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots iii$$

Established results as shown in figure 8 displays the highest COP of 3.23 of the refrigeration system as obtained in R_{134a} (TEV mode) at stage 3 where compressor and evaporator load are in “off – mode” with evaporator fan operated at low condition. Meanwhile, a reverse condition of the operating components of the system is observed in R_{22} with 0.67 COP (TEV mode) at stage 6.

Consequently, the revealed results in figures 9 and 11 shows that the R_{134a} (Cap mode) is capable of emitting up to 95°C capacity of heat from the condenser to the surrounding air. Similarly, the results in figure 10 displays heat absorption in the evaporator. It is obvious that good refrigerating effect is observed in R_{134a} (TEV mode), R_{12} (Cap mode) and R_{134a} (Cap mode) operated in temperature range of 60 - 71°C, 38 - 40°C and 62 - 69°C respectively. The capillary mode of operation for the last four stages of R_{134a} experiences a drastically fall in temperature from 64 - 17°C. This is as a result of over loading of the compressor component with application of load at the evaporator. However, as the compressor is put off in stage 8, gradual increase from 18 - 20°C is seen.

One common occurrence observed is the unchanged suction pressure (LP) at stabilization point from the TPS simulator. At this stage the cooling effect is observed in the evaporator, and also along the low pressure pipes in the system. This is the ultimate objective of the refrigerating system.

VII. CONCLUSION

A close look of results as obtained from the study with the varying operational stages of the different refrigerants leads to the following conclusions:

- The best condition to determine the highest COP of a refrigerator is when the following components such as compressor, evaporator load and fan are at relaxation condition.
- R_{134a} refrigerant is identified as the refrigerant with the highest COP, thus it is considered the best refrigerant for the system. This is also in-line with the desirable properties for the selection of refrigerants where R_{134a} is a member refrigerant of HFC group considered most environmental friendly with little or zero level of ozone depleting potentials. Therefore, other refrigerants under the HFC group are considered creditable since they all share the same thermodynamic properties.
- The R_{134a} and R_{12} are confirmed as the most suitable refrigerants to be used for domestic and industrial heating purposes respectively from established results.
- Results attests that at stabilization point, the pressure of the system are good enough for suitable cooling of the system or devices, the refrigerant and the environment, etc.

Therefore, the study is justifiable hence the TPS simulator machine used for the study is a replica of the real refrigeration system for basic operation; hence results should be treated as such.

VIII. ACKNOWLEDGMENT

Author sincerely acknowledged Prof. E. A. Ogbonnaya, former Head of Department of Mechanical/Marine Engineering; Niger Delta University for his unrelenting encouragement.

NOMENCLATURE

COP	Coefficient of Performance
Q_o	Heat Extracted from cold body per cycle
W_{net}	Work done per cycle
h	Enthalpy
T_L	Temperature at lower source
T_H	Temperature at higher source
CFC	Chloro Fluoro Carbon
HCFC	Hydro Chloro Fluoro Carbon
HFC	Hydro Fluoro Carbon
R	Refrigerant
E1	Evaporator Fan
Com	Compressor
Eva	Evaporator

IX. REFERENCES

[1]. Ajoko, T.J., Refrigeration Systems for University Students. 2015, No 8 Otiotio Road, Yenegoa, Bayelsa State, Nigeria: Oshe Printing Press/Publications.

[2]. Elumalai, P., R. Vijayan, P. S.S. Srinivasan and C. Chinnaraj, An Investigation on the Performance Characteristics of Environment-Friendly Refrigerant Mixtures in a Window Air Conditioner. Middle-East Journal of Scientific Research, 2015. 23 (5): p. 987-992.

[3]. Allgood, C.C. and C.C. Lawson, Performance of R-438A in R-22 refrigeration and air conditioning systems. 2010.

[4]. Munasinghe, M. and K. King, Protecting the ozone layer. Finance and Development, 1992. 29(2): p. 24-5.

[5]. Grace, I. and S. Tassou, Simulation of the performance of alternative refrigerants in liquid chillers. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 2001. 215(4): p. 429-441.

[6]. Janković, Z., I. Matić, and M. Živić, Mathematical Model of Complete Vapor Compression Refrigeration System with Helical Coil Evaporator Flooded in the Water. Transactions of FAMENA, 2016. 40(SI-1): p. 33-46.

[7]. Gullo, P., B. Elmegaard, and G. Cortella, Energy and environmental performance assessment of r744 booster. Thermal Engineering, 2015. 87: p. 633-647.

[8]. A. Pavani, P.M. Reddy, and G.M.P. Yadav, Performance Analysis of Refrigeration System Using Various Alternative Refrigerants. Advanced Engineering and Applied Sciences: An International Journal, 2014. 4(1): p. 12-16.

[9]. Nagalakshmi, K. and G.M. Yadav, The Design and Performance Analysis of Refrigeration System Using R12 & R134a Refrigerants. Mechanical engineer at St. Jhons College of Engg &Technology, Yemmiganur-518360, A. P, India, 2014. 2.

[10]. Gullo, P., B. Elmegaard, and G. Cortella, Energy and environmental performance assessment of R744 booster supermarket refrigeration systems operating in warm climates. international journal of refrigeration, 2016. 64: p. 61-79.

[11]. Ge, Y. and S. Tassou, Thermodynamic analysis of transcritical CO 2 booster refrigeration systems in supermarket. Energy Conversion and Management, 2011. 52(4): p. 1868-1875.

[12]. Domanski, P., D. Yashar, and M. Kim. Performance of HC and HFC refrigerants in a finned-tube evaporator and its effect on system efficiency. in Natural Working Fluids Conference, 6th IIR Gustave Lorentzen. Proceedings. 2004.

[13]. National Universities Commission (NUC), and Skill 'G' Nigeria Ltd, Science and Technology Education Training Manual on Air-Conditioning and Refrigeration Training Systems for Higher Educational Institution (HEIs) and Technical Vocational Educational Training (TVET). 2015, Abuja - Nigeria: Scientific Educational Systems (SES).

[14]. Rajput, R., Thermal engineering. 2010: Laxmi Publications.