Performance Evaluation of a Refrigerator with Assorted Operating Parameters

Chilagani Akhila[1], K Vijaya Kumar Reddy[2], Gugulothu Ravi[3]

[1,2,3] *Department of Mechanical engineering, Jawaharlal Nehru Technological University Hyderabad, Teangana*

Abstract: **Sustainable economic development is largely dependent on energy conservation and environmental protection. This study aims to enhance the comparative performance analysis of a domestic refrigerator utilizing R134a and R600a refrigerants by adjusting the mass charge under steady-state conditions. Results show that R134a with 70grms mass charge achieves 48% higher mass flow rate, while the pull-down time differs by 11% in comparison to charges of 60 and 80grms. ForR600a, 40grms charge leads to a 56% increase in mass flow rate compared to 30 and 50grms, while the 50grms charge takes 35% longer to achieve the desired cooling. By ensuring efficient heat transfer, achieving the desired cooling capacity, and minimizing energy consumption, an optimal refrigerant charge promotes effective heat exchange and enhances the longevity of the system.**

Keywords: Refrigeration, R134a&R600a refrigerants, mass flow rate(m), Coefficient of Performance (COP).

I. INTRODUCTION

Refrigeration has existed since ancient times, utilizing water vaporization, stored ice, and other evaporative processes to achieve cooling. Refrigerants, the working medium in refrigeration systems, remove heat through evaporation, creating a cooling effect. In the 1600s and 1700s, extensive research on phase change physics by scientists from different nations provided the foundation for artificial refrigeration[1]. The development of refrigerants has been driven by factors such as stability, durability, economic viability, and environmental concerns. As a result, ongoing research has led to the creation of more efficient and safer refrigeration technologies. The evolution of refrigerants over time can be categorized into several generations[2]

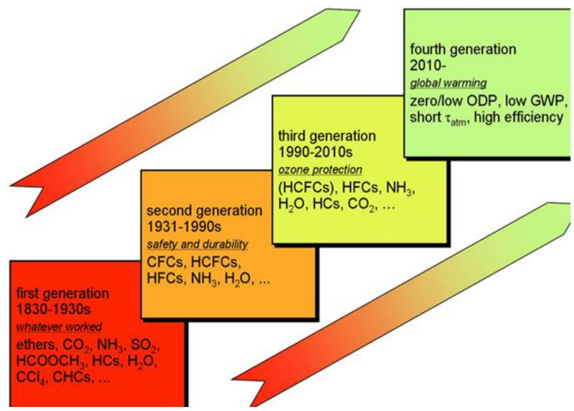

Fig.1: Historical view of Refrigerants [1]

1.**First Generation:** For the first 100years, well-known solvents and other volatile fluids were the most often used refrigerants. These made up the first generation of refrigerants, which essentially included anything that was practical and readily available[1].The utilization of natural refrigerants was a defining feature of the early 19th- century mechanical refrigeration revolution. The first generation of refrigerants, such as methyl chloride, ammonia and sulfur dioxide, were utilized in refrigerators constructed between the late 1800s and 1929. The majority of first-generation refrigerants were poisonous, combustible and several of them are extremely reactive[2].

2.Second Generation: The second generation was marked by a transition to fluorochemicals, enchasing both safety and durability. Thomas Midgley and his colleagues made important observation in 1928, regarding the flammability and toxicity of compounds comprising elements such as carbon, nitrogen, oxygen, sulfur, hydrogen, fluorine, chlorine and bromine[1].Their work on Fluro-Chloro refrigerants demonstrated how the different chlorination and fluorination of hydrocarbons affects the refrigerant’s boiling point, flammability and toxicity. CFC refrigerants, thus comprised the second generation of refrigerants.

3.Third Generation: Hydrofluro-Olefin (HFO), a fluorocarbon refrigerant with a decreased GWP and developed potential, is called the third generation of refrigerants. Fundamentally, these are low-ozone depleting potential refrigerants. This refrigerant's primary benefit is that it can be used with the current refrigeration system architecture. Growing with political pressure aims to phase it out of production, compelling the industry to develop even lower-impact refrigeration technology. Thus, the search persists[2].

4.Fourth Generation: Many of the most commonly used HFCs being phased out have been replaced by a variety of low GWP alternatives known as fourth generation blends. After 2010, a fourth generation of refrigerants was created, focusing on the usage of refrigerants with short lifespans, low ozone depletion (ODP), and low global warming potential (GWP) to reduce greenhouse gas emissions. HCFCs have less chlorine than CFCs, hence their ODP is lower[1]

Refrigerants Used:

R134a:(1,1,1,2-Tetrafluoroethane)

R-134a refrigerant, also known as 1,1,1,2-Tetrafluoroethane, is a commonly used hydrofluorocarbon (HFC) refrigerant in cooling and refrigeration systems. It is valued for its non-toxic and non-flammable nature, as well as its efficient thermodynamic properties. However, its environmental impact has raised concerns, prompting scrutiny and calls for alternative solution.

R-600a:(Isobutane)

R600a, also known as isobutane, is a hydrocarbon refrigerant widely used in various cooling and refrigeration systems. It has gained popularity as an alternative to traditional refrigerants due to its low environmental impact and excellent thermodynamic properties.

Fig.2: R134a

Fig.3:R600a

II. EXPERIMENT AND METHODOLOGY

Experimental setup

An experimental setup of a single-door household refrigerator working with R134a and R600a, with a total capacity of 182L as shown in Fig.4, includes a deep freezer, a hermetically sealed reciprocating compressor, and an air-cooled condenser. The compressor is adaptable with valves and equipped with pressure gauges to measure suction and discharge temperatures. Thermocouples are strategically placed throughout the setup to ensure accurate temperature measurement.

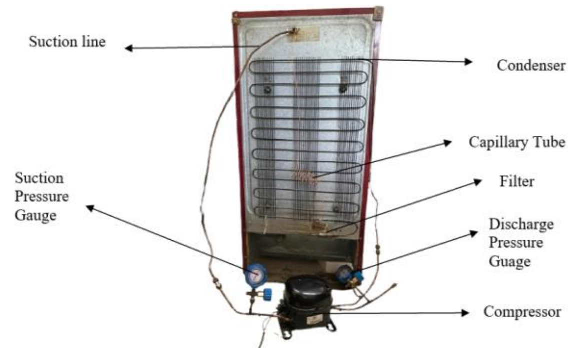

Fig.4: Experimental setup

Fig.5:R134a compressor

Fig.6:R600a compressor

Table 1 Compressor specification of R134a&R600a

Range	Specification
Brand	LG
Ampere	2.4
Voltage	220V
Frequency	50Hz
Model	Power cool comp R134a G1-1+CAPCT
Dimensions	0.201*0.164*1.175m3
No. of Door	1
Compressor type	Hermetic sealed compressor
Displacement	4.6cc
Refrigerant	R134a

Range	Specification
Brand	Godrej
Ampere	0.7
Voltage	220
Model	GDP195/2013 R600A Oil charged I8
Dimensions	0.175*0.158*0.155m3
No. of Door	1
Compressor type	Hermetic sealed compressor
Displacement	4.9cc
Refrigerant	R600a

Experimental Procedure

For R134a

1. The system was first evacuated using a vacuum pump to a pressure of 30 psi to eliminate air and moisture, achieving a vacuum level of at least 500 microns. Leak detection was conducted using a soap water test. Pressure gauges were installed at the compressor inlet and outlet to monitor suction and discharge pressures, and thermocouples were placed at the compressor inlet, compressor outlet, and evaporator for temperature readings.
2. The refrigerant was manually charged, beginning with 60g of R134a, while maintaining a capillary tube length of 3m and a diameter of 0.031". Subsequent tests were conducted with refrigerant charges of 70g and 80g.
3.The refrigerant mass was accurately measured and introduced into the system. A pull-down test was then performed to fine-tune the capillary length and refrigerant mass, with the refrigerator door kept closed under no-load conditions until a steady-state temperature was achieved. Thermocouples were used to track the compressor and evaporator temperatures, determining the pull-down time at steady-state conditions and under NO LOAD.

For R600a

1. After completing all experiments on R134a, the system was vacuumed to remove any trapped gases from the components.
2.Similarly Under controlled conditions, the system was charged with 30g, 40g, and 50g of R600a refrigerant, and the same testing procedure was followed to measure the pull-down time. Continuous tests were conducted under these conditions, with an ambient temperature of 30°C. Observations were recorded every 5 minutes for time-based conditions and every 1 minute for temperature-based conditions

Formulae used

To assess the mass flow rate and coefficient of performance (COP) of R134a and R600a, and varying the refrigerant mass charge in the refrigerator. Analyzing different charge masses allows to understand the refrigerators overall performance[3].

The following formulas have been used for the calculating performance of the refrigerator

$$m = \frac{\pi D^2}{4}\left\{\frac{2}{C_1}\left(\frac{D^{1+C_2}}{L}\right)\left(\frac{p_r}{v_r \mu_{in}^{C_2}}\right)\left[\frac{p_{in}}{p_r} - 1 + \frac{1+\beta(\ln\beta - 1)}{(1-\beta)}\right]\right\}^{1/(2-C_2)} \quad (1)$$

Where, $\beta = \frac{(1.63*10^5/pf^{0.72})Pf}{1+(1.63*10^5/pf^{0.72})(Pf-Pr)}$ (2)

COP= (Refrigeration Effect)/ (Compressor work)

Refrigeration Effect= h_1-h_4 (3)

h_4= Enthalpy at evaporator inlet in kJ/kg

h_1= Enthalpy at evaporator outlet in kJ/kg

Compressor Work= h_2-h_1 (4)

h_1= Enthalpy at compressor inlet kJ/kg

h_2= Enthalpy at compressor outlet kJ/kg

III. RESULTS AND DISCUSSION

Pull Down Time (PDT): The time taken to reach specific temperatures, measured in minutes, is recorded as the Pull-Down Time (PDT). For every 5°C decrease in temperature, the time is noted until the temperature reaches 0°C. Beyond 0°C, measurements are taken for each 1°C change until the temperature reaches -3°C.

Pull Down Time (PDT-R134a

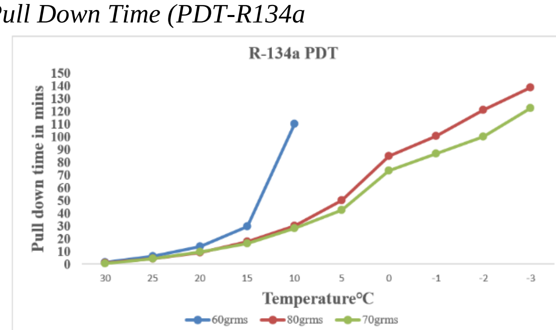

Fig.7: PDT vs Temperature of R134a

The refrigerant charge significantly affects the Pull-Down Time (PDT), as illustrated in Fig.7. Using a constant capillary tube length of 3 meters and varying the refrigerant mass (60g, 70g, and 80g) of R-134a, the temperature was lowered from an ambient temperature of 30°C during continuous operation. It was observed that the minimum pull-down time of 122 minutes was achieved with a 70g charge of R-134a, compared to the other mass charges.

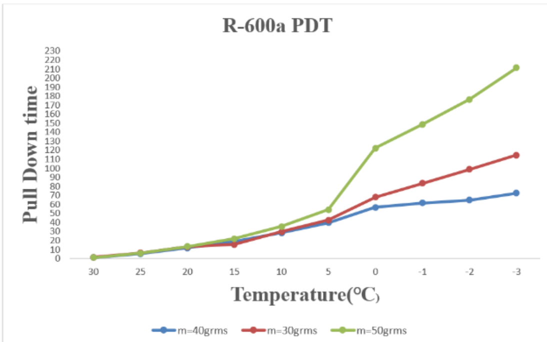

Fig.8: PDT vs Temperature of R600a

Fig.6 demonstrates that the R600a system achieved a pull-down time of 73 minutes, outperforming both higher and lower refrigerant charges. This indicates that an accurate refrigerant charge is vital for optimizing pull-down performance. The observed inverse relationship between temperature and pull-down time is a typical feature of refrigeration systems. Thus, selecting the correct refrigerant charge is crucial for balancing pull-down time and overall system efficiency.

Mass flow rate(m)

The mass flow rate of R134a and R600a refrigerant flowing through refrigerator of different mass charges is calculated by the equation of 1. The data required for R134a is taken from[4] & R600a from[5].

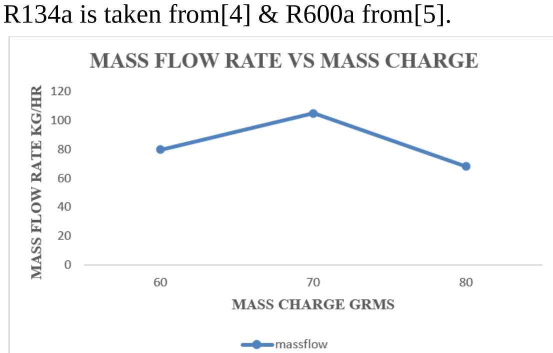

Fig.9: Mass flow rate vs Mass charge of R134a

The graph of mass charge versus mass flow rate illustrates that the mass flow rate increases initially, starting at a charge of 60 grams, reaching an optimum level at 70 grams. Beyond this optimal charge, at 80 grams, the mass flow rate begins to decline, indicating a peak efficiency at 70 grams before decreasing with higher charges.

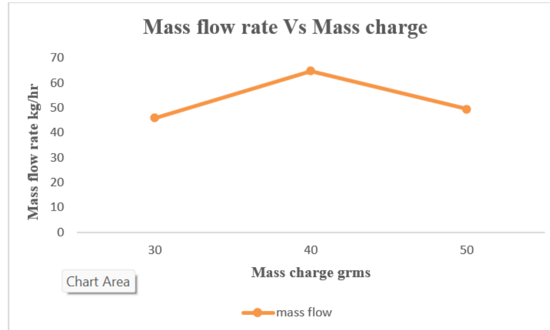

Fig.10:Mass flow rate vs Mass charge of R600a

The graph shows the relationship between mass charge and mass flow rate for R600a refrigerant at charges of 30, 40, and 50 grams. It illustrates that the mass flow rate increases up to the optimal charge, but decreases beyond this point due to the compressor's increased power consumption, which leads to potential inefficiency in the system.

Coefficient of Performance (COP)

COP of the refrigerator is calculated using Equation (3) and (4), which consists of enthalpies of the refrigerants at different temperatures and phases.

All the values taken from ASHRAE Hand book [6]

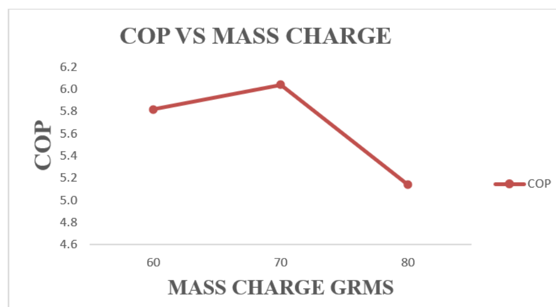

Fig.11: Mass charge vs COP of R134a

The figure demonstrates the COP for various mass charges of R-134a at 60, 70, and 80 grams. Notably, the optimal charge of 70 grams achieves the highest COP, highlighting its superior efficiency compared to the other charges.

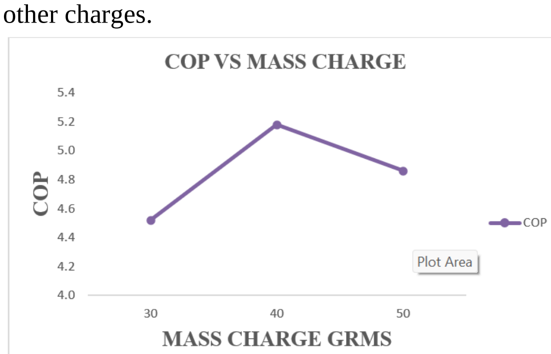

Fig.12: Mass charge vs COP

The Fig.12: illustrates the COP of R600a at 30g, 40g, and 50g. The highest COP is achieved at the optimal charge of 40g. As the refrigerant charge increases, the COP improves until it reaches this optimal point, but exceeding the optimal charge leads to a decline in COP.

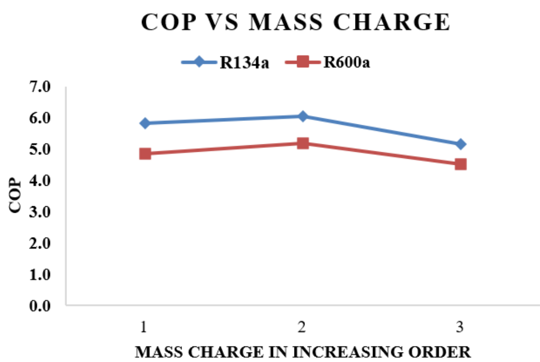

Fig.13: Mass charge in increasing order vs COP

The figure illustrates that the maximum COP was achieved by R134a (60, 70, 80 grams) compared to R600a (30, 40, 50 grams) under different mass charges. The higher COP of R134a can be attributed to its greater cooling capacity, lower specific heat, and favorable operating conditions, all of which contribute to its superior performance in refrigeration systems.

Obtained values are tabulated in Table 2 for both refrigerants

Table 2

Mass charge	R134a								
	Temp at Evaporator inlet	Temp at discharge	Temp at suction	Enthalpy, KJ/KG			Ref effect	Comp work	COP
	T1	T2	T3	h1	h2	h3	R	W	
60	-10.7	49.3	5.5	184.9	447	402.3	260.2	44.7	5.82
70	-11.5	48.3	5.1	184.6	445	401.5	262.6	43.5	6.04
80	-2.0	51.9	9.4	197.3	454	404.1	256.7	49.9	5.14

Mass charge	R600a								
	Temp at Evaporator inlet	Temp at discharge	Temp at suction	Enthalpy, KJ/KG			Ref effect	Comp work	COP
	T1	T2	T3	h1	h2	h3	R	W	
50	-10.0	66.2	1.6	177.08	585	669	407.9	84	4.86
40	-15.4	63.9	0.4	164.8	584	665	419.2	81	5.18
30	-11.6	69.2	2.2	172	588	680	416.0	92	4.52

Validation

The obtained values were validated with Mario et al.[7] conducted experiment by using the R134a & R600a. and found the highest COP at the optimum charge, specifically 1350g with a COP of 1.8. In this study, the experimental findings similarly revealed the highest COP at the optimum charge, with R134a achieving a COP of 5.18 at 60g and R600a reaching a COP of 5.18 at 40g.

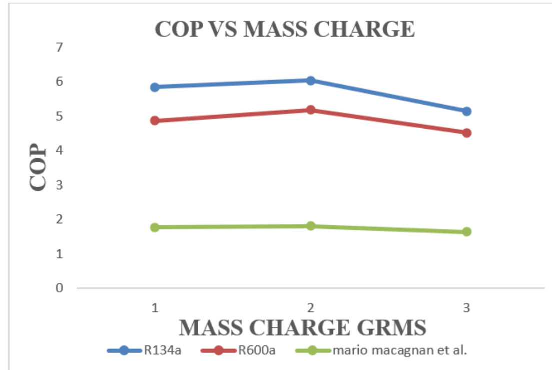

Fig.14: COP vs Mass charge

Table.3: shows the mass charges of R134a, R600a and compared mass charge

Mass charge in grams	R134a	R600a	Mario Macagnan et al.
1	60	30	1150
2	70	40	1350
3	80	50	1550

Table.4: shows the COP of R134a& R600a with Mario Macagnan et al

COP VS MASS CHARGE			
Mass charge	R134a	R600a	Mario Macagnan et al.
1	5.84	4.86	1.77
2	6.04	5.18	1.8
3	5.14	4.52	1.64

IV. CONCLUSIONS

R-134a:

- For the chosen R134a (Tetra-Fluoro-Ethane) is a hydrofluorocarbon (HFC) refrigerant it is favored for its non-ozone-depleting properties, replacing older refrigerants like R12.

- There is 11% deviation in PDT for 60grms and 80grms mass charge in R134a refrigeration.
- For 80grms mass charge steady state obtained at 7℃.
- From the experimental findingscomparative to 60grms and 80grms of mass charge, 70gms of R134a mass charge gives the maximum mass flow rate and COP.
- For R134a refrigerant 70grms of mass charge gave the high COP than other mass charges i.e: COP=6.04.

R-600a:

- The selected hydrocarbon refrigerant (R600a) is an environmental friendly type with zero ozone depletion potential, miscible with mineral oil, negligible global warming potential and compatible with system materials.
- For R600a refrigerant comparative to 50grms and 30grms of mass charge 40grms gives the highest mass flow rate & COP.
- And R600a refrigerant, 50grms took 35% deviation comparative to other mass charge of 30&40grms.
- For R600a refrigerant 40grms of mass charge gave high COP than other mass charges i.e: COP=5.18
- From the Outcomes, 70grms of R134a and 40grms of R600a gives the higher mass flow compared to other mass charges because, if the refrigerator is “Overcharged” with high mass charge that may leads to elevated pressure in the condenser and evaporator, and surplus refrigerant can result inefficient heat transfer.
- Consequently, the system may not remove heat effectively, diminishing its overall efficiency and increasing energy consumption. Excess refrigerant can also cause liquid refrigerant to flow back to the compressor, which is meant to handle vapor.
- And if the refrigerated is “Undercharged” it affects the cooling capability as more refrigerant leaks out, temperatures rise because there’s no effective heat exchange between the condenser coil and outdoor air or the cooling coil and indoor air.
- This can damage the compressor and shorten its lifespan. Additionally, the system may have difficulty achieving the desired cooling temperature or maintaining consistent cooling, leading to temperature fluctuations and poor performance.
- Low refrigerant levels cause frosting and freezing at the cooling coil.

In Conclusion, optimal refrigerant charge ensures efficient heat transfer and desired cooling capacity and minimizes energy usage by maintaining efficient heat exchange and system longevity. Any deviation from the ideal charge can result in numerous operational problem and reduced efficiency.

ACKNOWLEDGMENT

The authors wish to acknowledge and thank JNTU Hyderabad for their valuable support in providing the experimental setup.

Research Funding: None declared.

Conflict of interest statement: The authors have no conflicts of interest to disclose concerning this article.

Abbreviations and units

m- Mass flow rate(Kg/hr)

COP- Coefficient Performance

PDT- Pull Down Time (minutes)

REFERENCE

[1] James M. Cales “The Next generation of refrigerants-Historical review, considerations and Outlook”, International Journal of refrigeration, Vol.: 31, 2008, pp:1123-1133.

[2] Madhu Sruthi Emani and Bijan Kumar Mandal “Development of Refrigerants:A Brief Review”, Indian Journal of Science and Research, Vol.:14(2), 2017, pp: 175-181.

[3] Li Yang, and Wen Wang, “A generalized correlation for the characteristics of adiabatic capillary tubes”, International Journal of Refrigeration,Vol.:31,2008,pp:197-203.

[4] https://www.igasusa.com/pt-charts/R134A-PT-Chart.pdf

[5] https://www.tega.de/fileadmin/Downloads_und_Bilder/kaeltemittel/Natuerliche_Kaeltemittel/Dampfdrucktabellen_EN/R_600a_pT_EN.pdf

[6] Thermophysical properties of refrigerants, ASHRAE handbook,2009.

[7] Mario Henrique Macagnan, Jacqueline Biancon Copetti, Ronaldo Bueno de Souza, Robert Krause Reichert and Martin Amaro "Analysis of the Influence of refrigerant charge and compressor duty cycle in an automotive air conditioning system", International congress of mechanical engineering, ISSN 2176-5480,2013.

[8] Austin.N "Experimental Performance Comparison of R134a and R600a refrigerants in vapor compression refrigeration system at steady state conditions", Vol.:2(3), pp:14-20.

[9] Suresh Boorneni and Satyanarayana "Improving and Comparing of performance of Domestic refrigerator by using refrigerants R134a and R60a", International Journal of Computational Engineering Research, Vol.:04, ISSN:2250-3005.

[10] Harshit Kumar Shrivastav and Kostubh Namdeo "Comparative Analysis of refrigerator using refrigerant R-134a & R600a fitted with water cooled condenser", Vol.:6, ISSN:2349-6002.