Analysis and Enhancement of Commercial Refrigeration Cycles Using The Natural Refrigerant CO_2

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Abstract- *In this study, Analysis and Improvement of Commercial Refrigeration Cycles Utilizing the Natural Refrigerant CO2 with Multi-Ejector and Exclusive Mechanical Subcooling. In response to the increased GWP (Global Warming Potential) of HydroFluoroCarbons (HFCs), several supermarket owners are searching for alternative refrigerants. The aims of this project are to evaluate the practicability, environmental advantages, and economic feasibility of a CO2only transcritical refrigeration system suited for small supermarkets. Although the environmental advantages of utilising CO2 as a refrigerant are obvious, there is a dearth of practical and technical information on the design and operation of these systems. In this work, simulation models of a modified Transcritical 'booster' CO2 refrigeration system with ejector was built so that its performance was compared to that of a Transcritical CO2 system. To test the efficacy of the CO2 refrigeration system in the field, energy simulations was use energy data from a real supermarket utilising an HFC refrigeration system. The findings was show that the yearly energy usage of the CO2 refrigeration system in an Indian supermarket would be comparable to that of a standard HFC refrigeration system.*

Keywords- Refrigeration System, Refrigerant, Booster, HFC, CO2 Performance, Enhancement, Simulation.

I. INTRODUCTION

1.1 Background of the study

In recent years, mechanical subcooling systems, both dedicated and integrated, have received a great deal of interest due to their tremendous potential for enhancing Transcritical CO2 refrigeration systems. (Nebot-Andrés et al., 2022) This project intends to make a substantial contribution to the worldwide design, exploration, and development of Transcritical CO2 systems. Numerous CO2 installations have happened to far, mostly in major supermarkets where the added expense of the devices is more readily justifiable. However, many smaller stores have yet to implement a cost-effective and practical solution. Other research in this subject have explored the high heat transfer coefficient of CO2 at poor vapour quality, as well as the utilisation of a single circuit as opposed to numerous circuits in a CO2 evaporator. In order to prevent refrigerant maldistribution, optimising the evaporator circuitry and design for CO2 might boost heat transfer, simplify the evaporator, and reduce material consumption and expenses. The observed high heat transfer of CO2 at low vapour quality might be used to boost heat transfer by directly feeding a poor vapour quality to the evaporator. To date, supermarkets have used ordinary HFC evaporators that are not CO2 optimised. (Bellos &Tzivanidis, 2019).

1.2 Scope of Project in broad sense

The majority of traditional refrigeration systems use chlorofluorocarbons (CFCs). Due to the usage of CFCs and other dangerous compounds, the ozone layer in the stratosphere, which shields life on earth from the sun's damaging UV radiation, is depleting. The issue concerns not just humans but also the plant and animal kingdoms on the surface of the planet. In light of this worrisome dilemma, it is imperative that CFCs be replaced with environmentally benign refrigerants. Carbon dioxide, the old refrigerant in its new form, looks to be a potential future alternative refrigerant in light of the elimination of CFCs and the exploitation of waste gases. (Shan, 2020) As a natural refrigerant, CO2 has a Global Warming Potential of one and an Ozone Depletion Potential of zero. It has excellent environmental performance and may decrease ozone layer damage. It is a suitable replacement refrigerant for CFC. Therefore, CO2 refrigeration technology has substantial growth potential. This research focuses primarily on the NH3/CO2 cascade refrigeration system, the CO2 secondary refrigerant refrigeration system, and the CO2 Transcritical refrigeration system, all of which are widely used in the refrigeration and refrigeration sector. (Yang et al., 2022)

Improving the overall performance of a Carbon Dioxide (CO2) refrigeration system in trans-critical cycle needs adjustment. This change was come more prevalent when it is used in tropical places such as India. There are several alterations that may be made to the basic cycles to increase performance and adapt the circumstances to specific needs and applications.

1.3 Purpose of Study

Analysis and Improvement of Commercial Refrigeration Cycles Using the Natural Refrigerant Co2 with Multi-Ejector and Exclusive Mechanical Subcooling is the objective of this study. In this work, simulation models of a modified Transcritical 'booster' CO2 refrigeration system with ejector was built so that its performance can be compared to that of a trans critical CO2 booster system. To test the efficacy of the CO2 refrigeration system in the field, energy simulations was use energy data from a real supermarket utilising an HFC refrigeration system.

1.4 Refrigeration Cycles Using the Natural Refrigerant Co2

CO2 is a high-pressure refrigerant when efficient operation requires high operating pressures. During a standstill, the ambient temperature and pressure may approach and surpass their respective critical values.
(Joneydi Shariatzadeh et al., 2016)

When liquid CO2 is accurately delivered into a system and the pressure is substantially reduced, such as at the nozzle of a spray cannon or the cooling injector tube on a temperature chamber or thermal platform (cold plate), the liquid rapidly transforms into solid-state CO2. CO2 is a working fluid with significant benefits over hydrofluorocarbons, including greater thermal conductivity, density, latent heat, specific heat capacity, and reduced dynamic viscosity (HFCs). Its low toxicity, combustibility, and global warming potential (GWP) are further benefits. It might be good to note that a common working fluid, R404a, has a GWP of 3,700 whereas CO2's GWP is 1(Lizarte et al., 2017).

However, systems using CO2 have a usually lower coefficient of performance (COP) than HFC-based refrigeration cycles. In order for CO2 systems to be competitive with other systems from an energy perspective, a significant amount of research has been devoted to boosting their performance. Literature has investigated several concepts, and some of them have been popularised. However, further research is required to determine the most effective layouts for CO2 refrigeration systems. The use of an internal heat exchanger for subcooling, the use of subcooling with an external mechanical compression system, multistage compression, parallel compression, and cascade designs are investigated.
Equation which shows CO2 behaves as an acid:

$$CO2 + H2O \rightarrow H2CO3 \rightarrow H+(aq) + HCO3-(aq)$$

The reaction is reversible in nature.

•Reaction with alkali to give carbonates and bicarbonates.

$$CO2 + NaOH \rightarrow NaHCO3$$
$$NaHCO3 + NaOH \Rightarrow Na2CO3 + H2O$$

Now, let us know about some uses of CO2 gas.

1.5. Transcritical Vapour Compression

Refrigeration using CO2

When the compressor discharge pressure exceeds the critical pressure and the refrigerant cannot be condensed, transcritical cycles occur. There is no phase shift throughout the cooling process. Due to the need for high pressures (about 95 bar) to exchange heat with the environment in the gas cooler, these systems commonly use the trans critical cycle to operate with high compressor discharge temperatures.

There is no phase shift throughout the cooling process. Due to the necessity to attain high pressures (about 95 bar) in the gas cooler in order to exchange heat with the surrounding environment, these systems usually use high compressor pressures. discharge temperatures.(Joneydi Shariatzadeh et al., 2016)

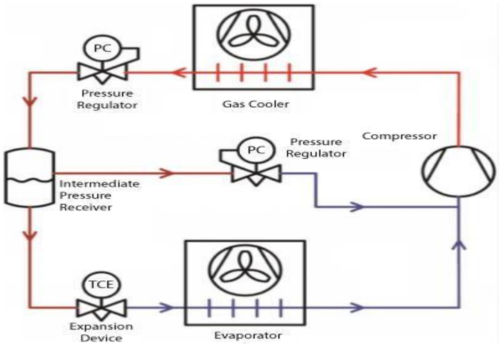


Fig1.1. Transcritical Vapour Compression Refrigeration using CO2

1.9. Booster Refrigeration System Cooling systems are intended to work within a broad range of operating parameters relating to both the needed cold and the changing ambient temperature. (Liu et al., 2021) It is nonsensical to build a system to work in extreme circumstances, i.e., with the lowest evaporation temperature and the greatest condensation temperature, given that these situations are rare. Such instances imply noncompliance with the specified technology if they are ignored. Therefore, it is necessary to take additional steps to guarantee the system's smooth functioning. Here are few instances: Switch the compressor cylinders to achieve two-step compression.

1.10. Aim and Objectives

Aim: Analysis and Enhancement of Commercial Refrigeration Cycles Using the Natural Refrigerant Co2.

Objectives:

- The goal of this research was to look into the feasibility, economic viability, and environmental benefits of developing a CO2 Transcritical cycle that avoids the use of the cascade cycle and HFCs and is suitable for small supermarkets.
- Research and analyze all ejector

Transcritical cycles to find the best one.

- The goal of this research is to help supermarket operators and design engineers replace HFCs as refrigerants in supermarkets.
- To create a numerical model that predicts annual electricity consumption as well as other operational parameters of a CO2 refrigeration system such as pressures, temperatures, and refrigerant flow rates. The results of each model was compared and discussed, including annual electricity consumption and direct and indirect CO2 emissions.
- To Develop a numerical model to predict the performance using ANSYS Simulation tool.
- To conduct controlled tests on a CO2 refrigeration system that is being used as an experiment. Use the results of the experimental tests to validate and improve the numerical model of the CO2 refrigeration system.

II. REVIEW OF LITERATURE

Mojtaba Purjam et.al (2021) conducted study on “Thermodynamic modeling of an improved transcritical carbon dioxide cycle with ejector:

Aiming low-temperature refrigeration”. This article suggests a novel structure for low-temperature refrigeration and thermodynamic research on the effects of altering pressures before and after the ejection by adding a compressor, gas cooler, and turboexpander to the usual configuration of the transcritical CO2 ejector cycle. For evaporation at 45 C, a performance coefficient (COP) of around 1.4 was determined. The cycle was optimised and subjected to parametric analysis, and the impacts of component efficiencies on COP were studied. Included is a straightforward and exhaustive second Law analysis of the suggested system, and the performance of the proposed setup was briefly compared to that of comparable low-temperature refrigeration cycles. This suggested single-refrigerant cycle not only has a good performance for deep-freezing applications, but it also has a 10% lower compression ratio than R744 alternatives.

Evangelos Bellos et.al (2019) conducted study on A comparative study of CO2 refrigeration systems. The purpose of this study is to evaluate several transcritical CO2 refrigeration systems and identify the most viable configurations. The analysed systems generate refrigeration at a single temperature level and are evaluated for a number of operational situations. The refrigeration temperature is measured between 35 °C and +5 °C, whereas the condenser temperature (or gas cooler output temperature) is measured between 35 °C and 50 °C. The analysis is done using custom-built Engineering Equation Solver models (EES). According to the findings, all of the studied systems are more effective than the reference system in every situation that was evaluated. With a mean coefficient of performance increase of 75.8% and 49.0%, respectively, the system with mechanical subcooling and the two-stage compression system are shown to be the most efficient options.

Yitai Ma et.al (2013) conducted study on A review of transcritical carbon dioxide heat pump and notably transcritical refrigeration cycles used in heat pump and refrigeration systems. This study provides an overview of carbon dioxide heat pump and refrigeration systems that are transcritical. The article begins with an overview of the history and primary use of carbon dioxide as a refrigerant. Second, the characteristics of supercritical pure carbon dioxide and supercritical carbon dioxide with polyalkylene glycol (PAG) lubricants are examined and compared. In Section 3, the study started with an investigation of several unique aspects of the fundamental carbon dioxide transcritical cycle, such as the optimal system high pressure, followed by a performance analysis and comparison of a number of innovative transcritical cycles. The report concludes with an overview of research on transcritical carbon dioxide heat pump systems, including the most important components and research hotspots, including heat transmission and expander.

Tao Bai et.al (2017) studied on article Performance evolution on a dual-temperature CO2 transcritical refrigeration cycle with two cascade ejectors. This Two cascade ejectors are used to improve the performance of a dual-temperature refrigeration system in a research proposing a modified dualtemperature CO2 transcritical refrigeration cycle. Compared to the single ejector refrigeration cycle under the specified operating circumstances, the suggested system enhances the COP and exergy efficiency by 5.26–25.5% and 9.0–28.7%, respectively, and the pressure lift ratio of the two cascade ejectors may be enhanced by 6.0%–12.2%. The proposed cycle's biggest exergy destruction happens in the gas cooler, followed by the ejectors, which account for 28.9% of the system's exergy destruction rate. The performance parameters of the twin ejector cycle reveal its potential benefits in CO2 transcritical dual-temperature refrigeration systems. **Matheus Henrique Cavalheiro Garros (2021)** conducted study on Eration Cycle Performance Using Co2 (R744) Blends To Other Natural Refrigerants. This article examines the performance of R744 blends with various natural refrigerants in order to assess performance improvements. The study was conducted using the open-source programme DWSIM, and R717, R600a, and R290 were utilised in the mixes. R134a was the reference synthetic fluid used to examine the findings. The key results are that all mixes are capable of increasing the COP, and R717 can attain almost the same levels as R134a.

Also, the efficiency of the second law decreases, with the hydrocarbons, particularly R600a, having nearzero efficiencies at evaporation temperatures close to 0°C. Reducing mass flow rate and operating pressures is a significant accomplishment, given the R744 cycle has high operational pressures. The current study demonstrates improvements in R744 transcritical cycles in terms of COP, refrigerant charge, and operating pressures.

III. METHODOLOGY

Components and behaviour of a refrigeration system are simulated using numerical simulation models. The simulation models used to investigate the performance of a supermarket-appropriate CO2 refrigeration system. All systems were evaluated at varying evaporation temperatures and heat rejection temperatures. Inlet and outlet temperature is 30, 35, 40, 42 and 67degee. The investigation is done using a numerical model generated in ANSYS. Two distinct refrigeration models were simulated using ANSYS. The objective was to reduce the environmental effect of a small supermarket refrigeration system by minimising the equivalent direct and indirect CO2 emissions by analysing and comparing the simulation results of both models and to calculate the COP of both models.

Research Gap

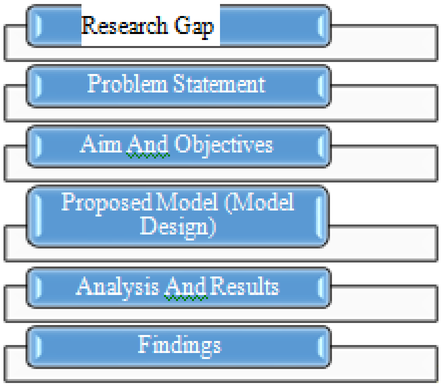


Fig.3.1. Methodology

3.1 Proposed Ejector Solution The suggested system is a Transcritical booster system with an ejector; in this system, it is planned to run a line from the main compressor's suction line to the ejector. In addition, we feed in the high-pressure line from the gas cooler. The model has an ejector mechanism that is parallel. The Parallel ejector system is comprised of a total of six different ejectors. Determine the model's impact and coefficient of performance (COP) by utilising the recommended system in order to lessen the model's negative effects on the environment and boost its overall efficiency.

3.2 Problem Statement

Regarding refrigerants and system type, it is now difficult for commercial refrigeration decision makers to make a definite selection. In the last decade, several refrigerant choices and system topologies have developed on paper and in reality. In recent years, the industry has been under the environmental microscope, especially after leakage investigations have exposed the full consequences of HFC emissions in centralised systems. Significant emission reductions are undoubtedly attainable, but they need modifications. As laws on the usage of hydrofluorocarbons (HFCs) become more stringent owing to their high global warming potential (GWP), many shop owners are seeking alternatives (Global Warming Potential). CO2 refrigeration systems seem to be viable solutions for designing environmentally friendly refrigeration systems. CO2 is known as a "Natural Refrigerant" since it occurs naturally. Consequently, we was evaluate and enhance CO2based commercial refrigeration cycles.

Analysis and Enhancement of Commercial Refrigeration Cycles Using the Natural Refrigerant Co2 Using

Multi-Ejector and Exclusive Mechanical Subcooling was investigated in this study. **3.3**

Flowchart

The development of this ANSYS computer software follows particular techniques and stages dependent on the application's characteristics. Design is followed by a series of sequential procedures leading to the analysis of the findings.

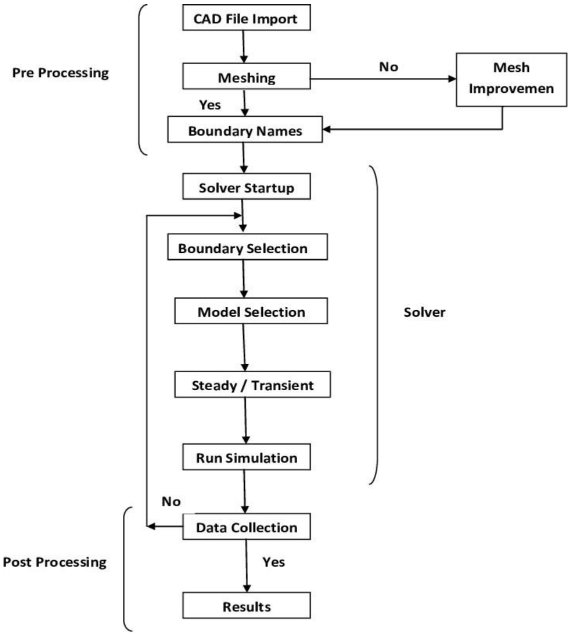


Fig.3.2. Flowchart

3.4Scope of The Study To research and evaluate CO2 refrigeration technologies. To investigate the "booster" Transcritical CO2 refrigeration system. To investigate a transcritical "booster" CO2 refrigeration system with an ejector. Design and develop the mathematical model for the 'booster' Transcritical CO2 refrigeration system. Design and Develop the Transcritical 'booster' CO2 refrigeration system with ejector numerical mathematical model. Using ANSYS Software, create the simulation model. The study was done using an ANSYS-developed numerical model.

IV. MODELLING AND ANALYSIS

4.1 Modelling

The model was created using Catia V5 software and analysed with Ansys Workbench 16. Design The following are the components of the model: There are two variations. The first type is a transcritical booster parallel compression system with multiple ejectors and exclusive mechanical subcooling, while the second is a transcritical booster System.

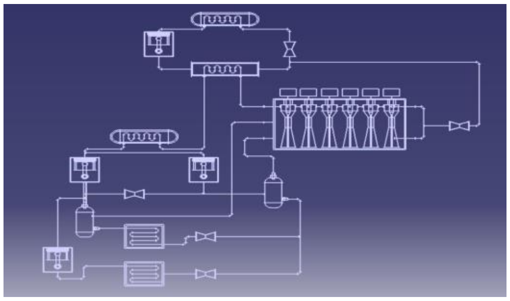


Fig.4.1. (a) Isometric view (b) fornt view of Transcritical booster parallel compression system with multi ejector and exclusive mechanical subcooling

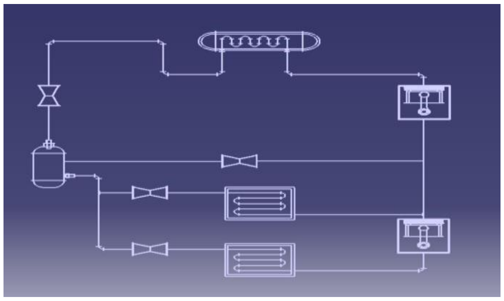


Fig.4.2. (a) Isometric view of Transcritical booster System (b) Front view of Transcritical booster System

4.2 Analysis

Analysis on Transcritical booster parallel compression system with multi ejector and exclusive mechanical subcooling.

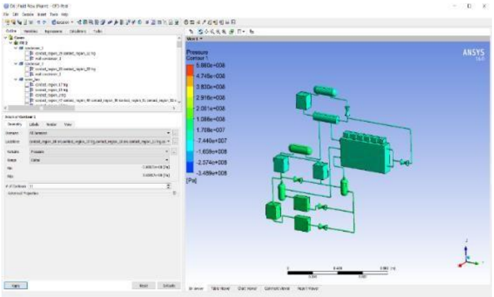


Fig.4.3. Pressure

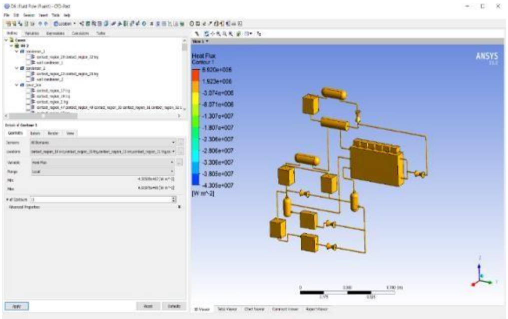


Fig.4.4. Heat Flux

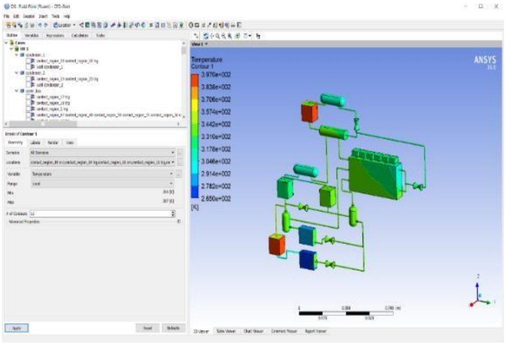


Fig.4.5. Temperature

Analysis on Transcritical booster System

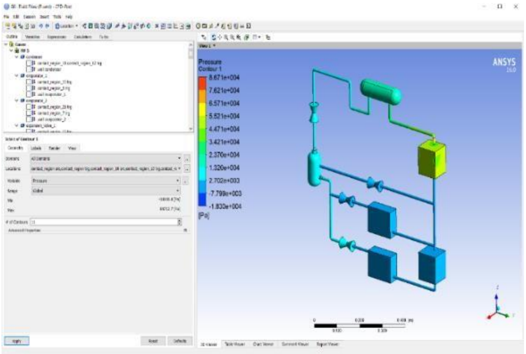


Fig.4.6. Temperature

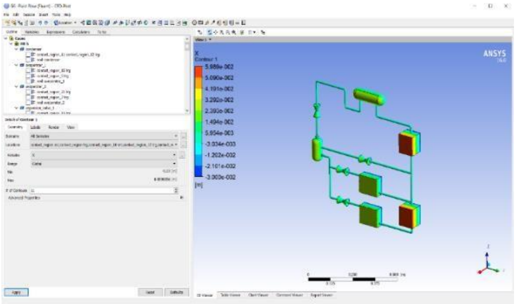


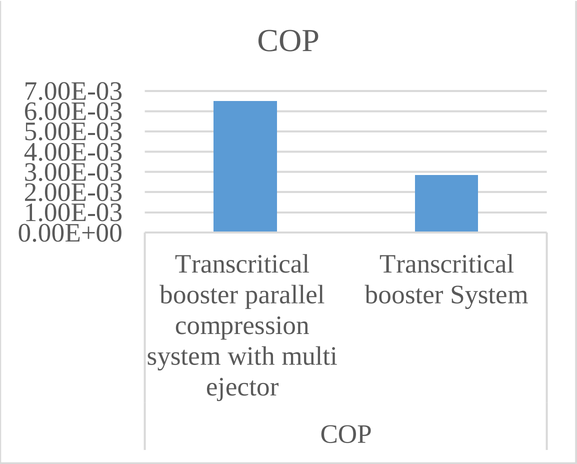
Fig.4.7. Heat Flux

V. RESULTS

Transcritical booster parallel compression system with multi ejector and exclusive mechanical subcooling and Transcritical booster System were compared. Analytical results were used to compute the outcomes.

Results on Transcritical booster parallel compression system with multi ejector and exclusive mechanical subcooling

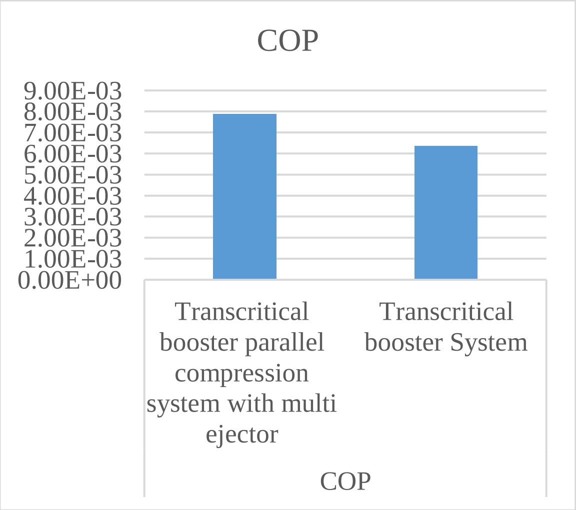
Inlet temperature and outlet temperature are is (67^{0}c)



Graph.5. 1 COP at Inlet temperature and outlet temperature are is (67^{0}c)

In the above graph results shows related to COP. COP is maximum for Transcritical booster parallel compression system with multi ejector and minimum COP is for Transcritical booster System. There is a difference of 56.23% in the COP between the two models.

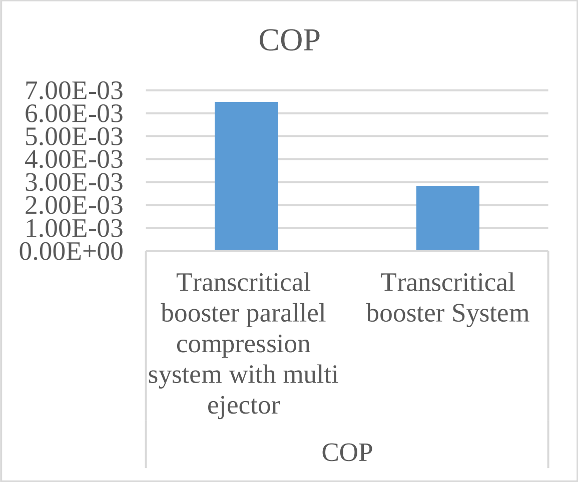
Inlet temperature and outlet temperature are is (42^{0}c)



Graph.5. 2 COP at Inlet temperature and outlet temperature are is (42^{0}c)

In the above graph results shows related to COP. COP is maximum for Transcritical booster parallel compression system with multi ejector and minimum COP is for Transcritical booster System. There is a difference of 19.42% in the COP between the two models.

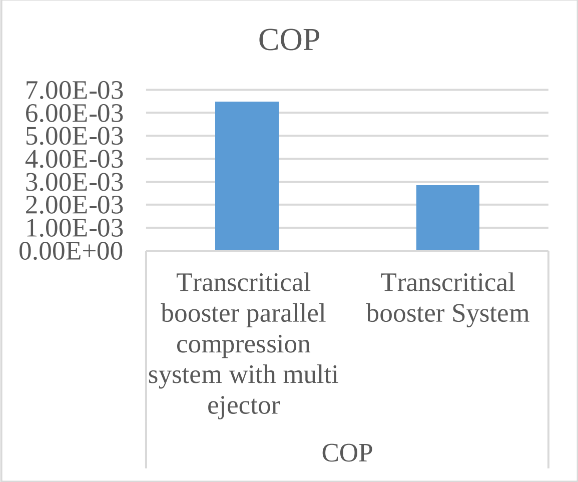
Inlet temperature and outlet temperature is 313k (40^{0}c)



Graph.5. 3 COP at Inlet temperature and outlet temperature are is (40^0c)

In the above graph results shows related to COP. COP is maximum for Transcritical booster parallel compression system with multi ejector and minimum COP is for Transcritical booster System. There is a difference of 56.23% in the COP between the two models.

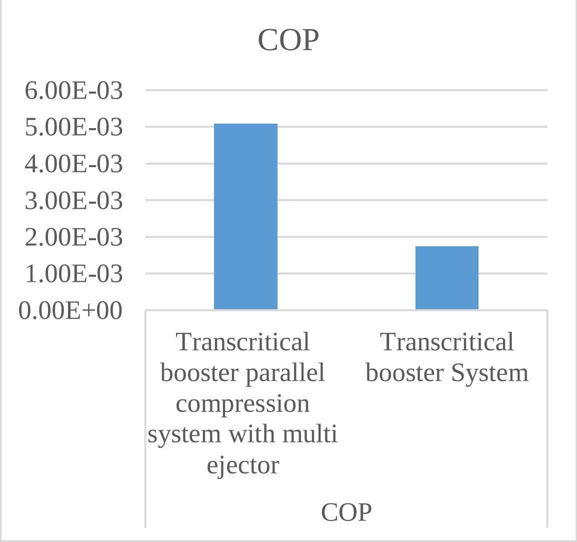
Inlet temperature and outlet temperature is 313k (35^0c)



Graph.5. 4 COP at Inlet temperature and outlet temperature are is (35^0c)

In the above graph results shows related to COP. COP is maximum for Transcritical booster parallel compression system with multi ejector and minimum COP is for Transcritical booster System. There is a difference of 56.23% in the COP between the two models.

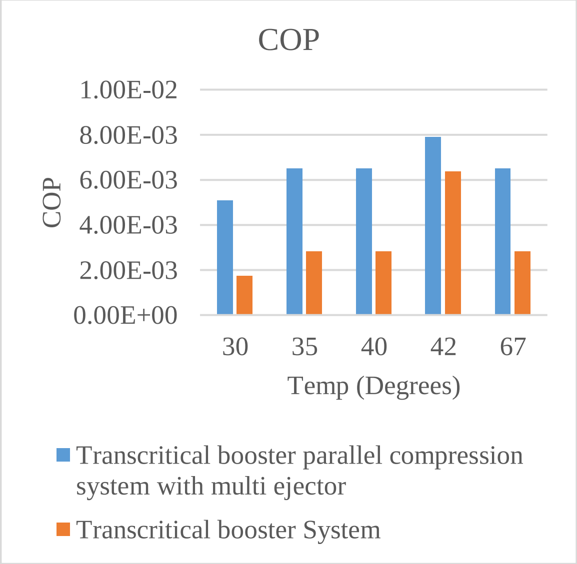
Inlet temperature and outlet temperature is 313k (30^0c)



Graph.5. 5 COP at Inlet temperature and outlet temperature are is (30^0c)

In the above graph results shows related to COP. COP is maximum for Transcritical booster parallel compression system with multi ejector and minimum COP is for Transcritical booster System. There is a difference of 65.84% in the COP between the two models.

- **Comparative COP**



Graph.5. 6 Comparative COP

In the above graph results shows related to Comparative COP by applying different temperatures. COP is maximum for Transcritical booster parallel compression system with multi ejector and minimum COP is for Transcritical booster System. By applying 42^0c temperature COP is maximum and as compared to other temperature 42^0c is efficient for the system.

VI. CONCLUSION

Existing HFCs leaked from supermarket refrigeration systems have a detrimental effect on the environment due to their high GWP.

This research examines the overview and different systems using CO2 as a refrigerant. CO2 is a natural refrigerant since it occurs naturally in the atmosphere. The primary benefits of CO2 are that it is nonexplosive, non-toxic, readily accessible, environmentally acceptable, and has great thermophysical qualities. Being a natural substance, CO2 poses no unanticipated environmental risks, has no ODP, and has a GWP value of 1. It is inexpensive and has high safety properties, making it an almost perfect refrigerant for use in somewhat large refrigeration systems. CO2 technologies are thus an appropriate choice for India. With a growing emphasis on reducing greenhouse gas emissions, tight limitations have been imposed on the usage of CFC and HCFC refrigerants. The thesis examines several methods for enhancing the performance of CO2 systems. In particular, subcooling technologies, such as dedicated mechanical subcooling and integrated mechanical subcooling, have been used to improve CO2 performance. The advantages of subcooling include the lowering of the ideal working pressure, and therefore the specific compression work, and the enhancement of the specific cooling capacity.

This study adds to the general objective of minimising this environmental effect by examining the applicability, economic feasibility, and environmental advantages of using the low global warming potential (GWP) refrigerant CO2 to small supermarket refrigeration systems. To study this, numerical models was constructed, experimentally verified, utilised to reproduce the operating characteristics of a real system, and used to compute and analyse the energy performance of refrigeration systems.

Transcritical booster parallel compression system with multiple ejectors and exclusive mechanical subcooling is superior than Transcritical booster System, according to research. Benefits of the transcritical booster parallel compression system with multi ejector and proprietary mechanical subcooling include: Cost Savings Less expensive than parallel compression transcritical CO2 racks because the swept volume of the compressors is less. (i.e., smaller compressors or a lesser quantity of compressors) Energy saving Reduced energy consumption is the consequence of a higher COP, increased operating of parallel compressors, and a smaller swept volume for the MT compressors. As stated in this thesis, the COP of CO2 systems was enhanced provided that the COP of the Transcritical booster parallel compression system with multi ejector and exclusive mechanical subcooling efficient cycle is more than the COP of the Transcritical booster System cycle.

According to the findings, the system with the highest coefficient of performance (COP) is the Transcritical booster parallel compression system with multi ejector. The system with the lowest COP is the Transcritical booster system. A higher Coefficient of Performance was necessary for a model or system to function properly. There is a difference of 56.23% in the COP between the two models while operating at a temperature of 340 kelvin (670 degrees Celsius). There is a discrepancy of 19.42% in the Heat Flux between the two models at the temperature of 315 kelvin (420 degrees Celsius). There is a difference of 56.23% in the COP between the two models when comparing them at a temperature of 313k (400c). The coefficient of performance (COP) of the two models differs by 56.23 percent when applied at a temperature of 308 kelvin (350 degrees Celsius). There is a difference of 65.84% in the COP between the two models when comparing them to 303 kelvin (300 degrees Celsius). The coefficient of performance (COP) is maximized at a temperature of 420 degrees Celsius, which, in comparison to other temperatures, is excellent for the system. According to the findings, the most efficient model or system is a Transcritical booster parallel compression system with multi ejector. This research concludes that a future-efficient Transcritical booster parallel compression system with multiple ejectors and exclusive mechanical subcooling exists.

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