A Computational Study on Comparison of Refrigerants R410A and R404A for Use in Low Temperature Applications

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Abstract- Investigating the performance traits of R410A and R404A refrigerants at different air outlet temperatures is the aim of this study. Performance characteristics include a wide range of thermodynamic factors, including mass flow rate, heat rejection, power consumption, maximum discharge pressure, and coefficient of performance. Thermodynamic characteristics of all refrigerants typically decrease when temperature is lowered. Although R410A is currently a commonly used refrigerant, experimental results show that R404A has the highest mass flow rate and reaches the desired temperature faster than R410A. Additionally, there is a slight difference in the thermodynamic properties of the two refrigerants. R404A and R410A are refrigerants with different applications. R404A is ideal for faster cooling, while R410A is ideal for precise temperature control.

Index Terms- Refrigeration, R-404a, R-410a, Heat Transfer, Heat Transfer Coefficient.

I. INTRODUCTION

Refrigerant is the term used to describe a substance or mixture, frequently a fluid, used in the refrigeration cycle and heat pump. In the majority of cycles, it goes through phase transitions, going from a liquid to a gas and back. William Cullen of Glasgow University showed the earliest known application of refrigeration in 1748. Following that, Michael Faraday succeeded in compressing ammonia vapour into a liquid in the beginning of the 1800s, which was followed by the creation of the first refrigerator. Environmental effects have grown in importance during the 20th century with the development of climate control technology. Of course, the primary driving force was the ability of hydro- and chlorofluorocarbons (HCFCs) commonly used in refrigeration to deplete the ozone layer. 2010 saw the phase-out of HCFCs, including R-22, even as contemporary hydrofluoro carbons (HFCs) replaced early CFCs as the primary refrigerant. Since the HFCs have almost no ozone depletion potential (ODP), they are approved. Thus, the need for functional, ecologically acceptable refrigerants led to the development of R-410A, which Honeywell first released in 1991. Since then, research has been done on R410A performance in a number of applications. R-404A is an additional HFC refrigerant that is similar to R-410A. To replace CFC R-502 and HCFC R-22, refrigerant R-404A was created. A device that lowers the temperature of a place relative to its surroundings is called a window air conditioner. Heat from an air conditioner needs to be expelled from the confined area and dispersed outside. Heat, however, moves towards a cooler location from a region with a high temperature.

A material known as refrigerant moves through four phases in a continuous cycle. The refrigerant absorbs heat in the first stage, known as evaporation, to chill the enclosed environment. In the compression stage that follows, the temperature rises above ambient due to an increase in refrigerant pressure. The natural direction of heat flow permits energy to be released into the surrounding air when this heated refrigerant passes through the next stage, condensation. In the last stage of the expansion phase, the adiabatic expansion process lowers the refrigerant temperature and pressure.

More heat is removed from the enclosed space as a result of this cold refrigerant starting the evaporation step again. The diagram in the picture illustrates a typical window air conditioner that operates based on the previously described mechanism. The physical, thermodynamic, and chemical characteristics of a refrigerant, together with a number of other practical considerations, determine whether it is suitable for a certain application. No single refrigerant is suitable for every kind of application. A refrigerant may have certain advantages in a particular application, but it may also have some disadvantages. Consequently, a refrigerant with more advantages and fewer disadvantages is chosen.

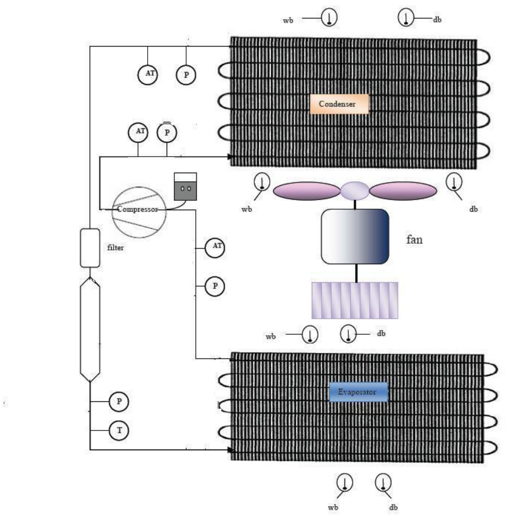

Fig. 1 Diagram schematic for the window air conditioning unit

In a window air conditioning system, Ashok Chakravarthy et al., conducted an experimental study of a substitute refrigerant for R22. For the testing using three different kinds of refrigerant, a window-type air conditioner is chosen. R-22 is being circulated by these air conditioning machines, which are widely used in many applications. Because of their superior thermal qualities and suitable pressure and temperature ranges, two zeotrope blend refrigerants R-407C (a mixture of R-32/125/134a) and R-407A (a mixture of R-32/125/134a) were chosen for use in this project's window-type air conditioner system. It was also suggested that R407C and R407A perform almost equally well in comparison to R22.

In the work Analysing Alternative Refrigerants to R22 for Air-Conditioning Applications at Various Evaporating Temperatures, S. Venkataiah et al. demonstrate a 1.5 tonne room air conditioning system using a few chosen refrigerants that have been assessed for their suitability as substitutes for R22 in air conditioning applications. Some studies indicate that R22 operates better than all other refrigerants.

Two hydro-fluorocarbon (HFC) refrigerant combinations that are friendly to the ozone layer, R410A and R419A, were the subjects of a computational thermodynamic investigation in this work. In a vapour compression air conditioning system, the results were compared to the performance of R22, the baseline refrigerant. Bolaji et al. conducted this computational analysis. In every operating situation and performance feature that was taken into consideration, R410A's performance was quite similar to that of R22. R410A performs somewhat better than R22 in terms of discharge pressure and refrigerating impact. The majority of small refrigeration and air conditioning systems use capillary tubes as expansion devices due to their affordability and ease of use, according to the findings of Yadav et al.

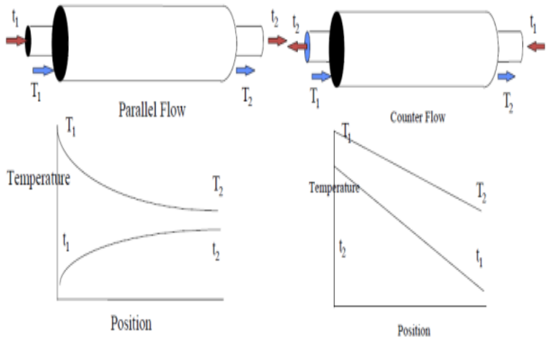

Fig. 2 Basic flow arrangements for tubular heat exchangers.

A study comparing R22 and R410A split air conditioning systems under high ambient temperature conditions was carried out by Vance Payne et al. The systems were tested and compared at outside temperatures ranging from 27.8 °C to 54.4 °C. With a modified compressor, the R410A system tests were conducted at an ambient temperature of 68.3 °C (155.0 °F). Both systems' capacity and efficiency declined linearly as the outside temperature rose; Nevertheless, compared to the R22 system, the R410A system's performance decreased more quickly. All tests, including the ones where the specially designed compressor extended to an external temperature of 68.3 °C and created a supercritical situation at the condenser input, showed steady operation of the R410A system. There were no discernible modifications to the system's functionality or noise level.

Instead of using air cooling, Balaji N. et al. examined a single split cooling air conditioning system that used fluid-based cooling. The heat exchanger's coolant, pure ethylene glycol, and its analysis of the experimental results It is evident that the modified system takes 25.69% longer to cool than the existing split cool air conditioning system.

Joseph Stalin et al. state that in order to use heat energy through waste heat recovery, a significant and consistent effort must be made. The majority of our condo is involved in the fictitious study of boiling water production and LPG reduction for our comfort. S.H. Noie-Baghban et al. examined the design and heat transmission constraints of single heat pipes for three distinct wick types and three working liquids using computer modelling. The heat transfer rate obtained via PC replication is quite close to the experimental data for heat absorption in the course section.

According to Awad et al.'s study, air-cooled condensers perform better when it comes to convection outside the condenser cylinders than when it comes to condensation within, with the convection side experiencing the most improvement. Although they have the ability to improve the air side, aluminium ejected microchannel-level cylinders increase the condensation exhibition more than traditional round tubes. Joseph Stalin and colleagues used the waste heat from the refrigeration condenser to study the analytical analysis of boiling water and the decrease of LPG gas. In a study conducted by P. Sathiamurthi et al., the three types of heat pipes that carry wick and are evaluated using CFD simulation are compared.

Seshaiah et al. examined how a refrigeration unit functioned at various flow rates using a cascade model in CATIA and ANSYS software. They discovered that while greater refrigerant mixture flow rates led to better heat transfer rates, they also increased work consumption, which had an impact on the coefficient of performance. As a well-refrigerated unit should require less labour to operate, this is not advised. The study also employed CFD analysis to calculate the velocity, pressure drop, mass flow rate, and heat transfer coefficient at various mass flow rates (1, 1.5, and 2 kg/s).

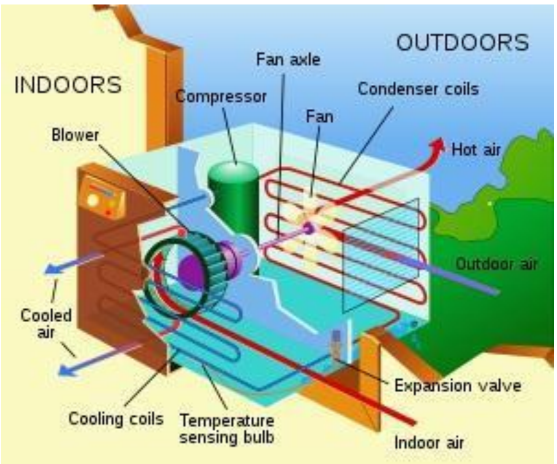

Fig. 3 Typical diagram of window air conditioner

There is no refrigerant that performs optimally across the board, according to research by Nagaraju et al. that compared the capabilities of three distinct refrigerants. R404A is the recommended choice for short-term temperature regulation because of its significance in the industrial and medical domains. R410A is recommended for household use since its specifications are comparable to those of R22.

These studies revealed that the majority of research is conducted using R22 as a baseline refrigerant. R22 is a common refrigerant used in air conditioners, but because of its significant ozone depletion potential, research is currently being done to replace it. Refrigerants must be chosen based on specific requirements, as there isn't one that can meet all performance standards. To improve performance, some studies involve changing out the system's components or adding further parts to the system altogether. Many refrigerants exist, but none can meet all human performance requirements. The majority of studies concentrate on C.O.P., however for companies and the medical field, the amount of time it takes to attain the appropriate temperature is critical. The study examines the performance of R410A and R404A, two refrigerants that have been suggested as potential replacements for R22 in most studies.

II. COMPUTATIONAL FLUID DYNAMIC ANALYSIS

A simulation model was created to forecast how long it would take for water to cool down after being kept in a commercial freezer. To accomplish this, CFD simulations were carried out while taking into account two distinct refrigerant materials in the system. A simulation tool was thought to be ANSYS FLUENT.

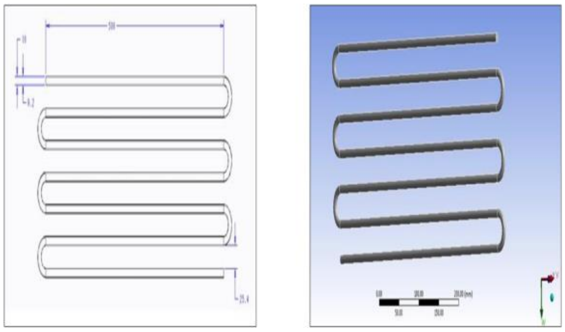

Fig. 4 Cascade refrigeration system models that have been dimensioned (on the left) and meshed (on the right).

Table. 1 Material properties of Refrigerants

Properties	Units	R-404a	R-410a
Liquid density	(kg/m^3)	1023.1	1040
Vapour density	(kg/m^3)	74.210	3
Critical temperature	C	72.07	72.8
Gas heat capacity	(kJ/kg C)	1.6065	0.84
Liquid heat capacity	(kJ/kg C)	1.1574	1.8
Freezing point	C	-117.5	-155
Boiling point	C	-46.45	-48.5

III. RESULTS AND DISCUSSION

In this CFD study, the refrigerants R410a and R404a utilized in the cascade refrigeration system are employed. The pressure, velocity, and heat transfer rate findings are calculated and displayed in Figs. 5 and 6 as well as Table 2. The constant mass flow input is maintained at 1 kg/s.

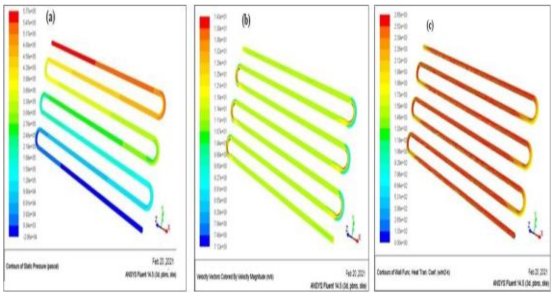

Figure 3 R410A refrigerant base fluid at 1 kg/s mass flow input: a) pressure, b) velocity, c) rate of heat transfer.

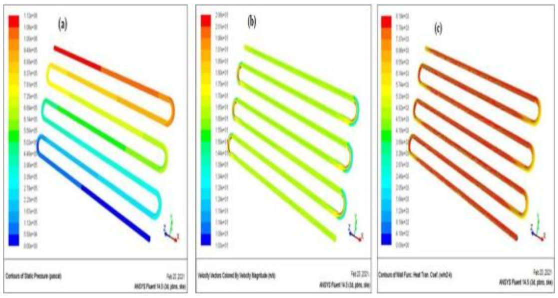

Fig. 4 R404A refrigerant base fluid at 1 kg/s mass flow input: a) pressure, b) velocity, c) rate of heat transfer.

Table. 2 Results of mass flow rate at 1 kg/s as determined by CFD analysis.

Fluid	Pressure (Pa)	Velocity (m/s)	Heat Transfer Coefficient (w/m^2-k)	Mass Flow Rate (kg/s)	Heat Transfer Rate (W)
R-410a	2250000.00	28.60	4970.00	0.01	144.34
R-404a	3330000.00	41.20	15100.00	0.01	311.95

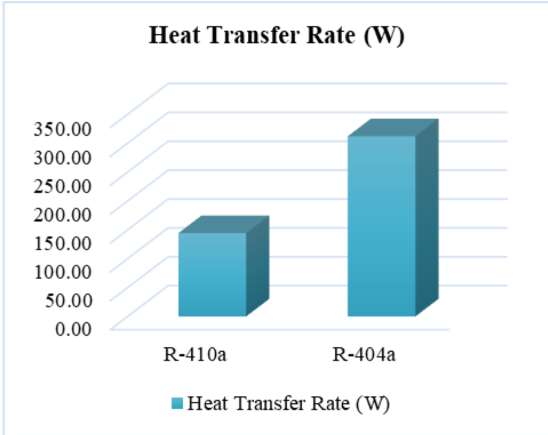

Fig. 5 Overall heat transfer rate results for R-410a and R-404a

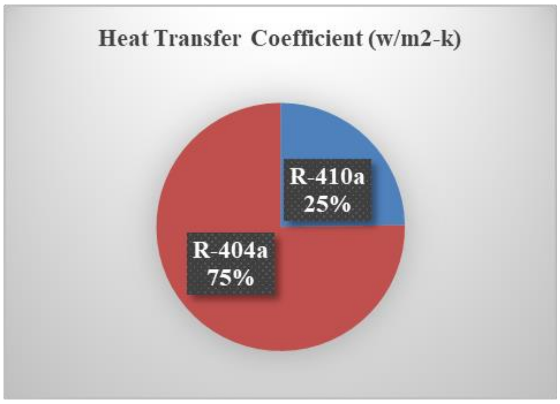

Fig. 6 Overall heat transfer coefficient results for R-410a and R-404a

The overall heat transfer coefficient and total heat transfer rate findings for both refrigerant types are shown in Figures 5 and 6. Refrigerant R404a consistently has a greater overall heat transfer rate than refrigerant R410a. In a similar vein, it has been discovered that in both situations, refrigerant R404a's total heat transfer coefficient is higher than that of R410a. The R-410a refrigeration system's high and low points operate in a vacuum. Because of the very large vapour volume under suction settings, R-410a can only be used with radial or rotating blowers. This refrigerant was widely used for office building cooling as well as theatre and auditorium cooling.

R-404a, in contrast, demonstrated a favourable outcome for the rises in C.O.P. attained under the recommended circumstances. Mainly responsible for the improvement in corrosion characteristics inside the tubing used inside the cascade and condenser devices is the refrigerant, with higher concentrations of R404a.

CONCLUSION

We keep the remaining input values fixed and generate the azeotropic collection of R410a and R404a. The refrigerant unit's coefficient of performance will be impacted by the increased labour consumption that comes with higher refrigerant mixture flow rates, according to the analysis. The heat transfer coefficient, pressure drop, velocity, and mass flow rate at different mass flow rates may all be found via CFD analysis.

- The findings on the analytical heat transfer rate at exclusive drift rates show very little meaningful variation. An ideal depiction of the heat transfer costs for various drift fees may be obtained by comparing the resulting values. Thus, for the refrigeration unit using our refrigerant, a modest flow charge of 1 kg/min is appropriate and advised.
- Since R-404a is denser than R-410a, combinations with higher concentrations of R-404a require more paint for pumping and flow, which is again not advised as it lowers the C.O.P. of the refrigeration unit. However, it has been observed that combinations with higher concentrations of R-404a do not show any particular pattern in the warmness transfer rates at specific glide rates. An increased amount of R-404a provides further proof of corrosion inside the tubing used in the cascade and condenser device.
- Therefore, evidence suggests that higher concentrations of R-410a are having more beneficial effects than higher quantities of R-404a. At that moment, R-410a and R-30 are used to observe that it provides a higher heat transfer flow rate at a lower cost and with less effort required.

REFERENCES

[1] M. Ashok Chakravarthy, M. L. S. Deva Kumar, “Experimental Investigation of an Alternate Refrigerant for R22 in Window Air Conditioning System”, IJSRP, Volume 2, Issue 10, October 2012 ISSN 2250-3153).

[2] S. Venkataiah & G. Venkata Rao, “Analysis of Alternative Refrigerants to R22 for Air-Conditioning Applications at Various Evaporating Temperatures”, IJERA, ISSN: 2248-9622, Vol. 4, Issue 3(Version 2), March 2014, pp.39-46.

[3] Bukola Olalekan Bolaji, Zhongjie Huan, “Computational Analysis of the Performance of Ozone-Friendly R22 Alternative Refrigerants in Vapour Compression Air-Conditioning Systems”, Vol. 38 2012 No. 4, DOI: 10.5277/EPE120404.

[4] G. Maruthi Prasad Yadav, P. Rajendra Prasad, G. Veeresh, “Experimental analysis of vapour compression refrigeration system with liquid line suction line heat exchanger by using R134a and R404A”, IJSRMS, ISSN: 23493771 Volume 1 Issue 12, pg: 382-395.

[5] W. Vance Payne and Piotr A. Domanski “A Comparison of an R22 and an R410A Air Conditioner Operating at High Ambient Temperatures” National institute of Standards and Technology, Thermal Machinery Group Gaithersburg, Maryland USA.

[6] S.C. Arora & Domkundwar,” Refrigeration and Air Conditioning” Dhanpatrai & Sons, 2000.

[7] S. Aphornratana, T. Sriveerakul, “Analysis of a combined Rankine–vapour–compression refrigeration cycle”, Energy Convers. Manage. 51 (2010) 2557–2564.

[8] A. Arora, S.C. Kaushik, Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A, Int. J. Refrig 31 (6) (2008) 998–1005.

[9] C. Cimsit, I.T. Ozturk, Analysis of compression absorption cascade refrigeration cycles, Appl. Therm. Eng. 40 (2008) 311–317.

[10] Jincan Chen, Chih Wu, Optimization of two-stage combined refrigeration system, energy conversion management, Vol 37, pp. 353-358, 1996.

[11] Balaji N, Suresh Mohan kumar P., Experimental Investigation of Split air Conditioning System by liquid Based Cooling System, Arabian J. Sci. Eng. volume 40, pages1681–1693(2015).

[12] M. Joseph Stalin, S. Mathana Krishnan, G. Vinoth Kumar, Efficient usage of waste heat from cascade refrigeration condenser, Int. J. Adv. Eng. Technol., 2012, 4(1), pp. 414-423.

[13] Steven Brown, Samuel F. Yana-Motta, Piotr A. Domanski, Comparative analysis of an automotive air conditioning systems operating with CO2 and R134a, Int. J. Refrigeration 25(1):19-32 (2002).

[14] M. M. Awad, H. M. Mostafa, G. I. Sultan, A. Elbooz, Performance enhancement of air-cooled condensers, Acta Polytechnica Hungarica, 4(2), 2007.

[15] S.H. Noie-Baghban, G.R. Majideian, Waste heat recovery using heat pipe heat Exchanger (HPHE) for surgery rooms in hospitals, Appl. Therm. Eng. 20 (2000) 1271–1282.

[16] P. Sathiamurthi, R. Sudhakaran. Effective utilization of waste heat in air conditioning. Int. J. Adv. Eng. Technol., 2012. IJAET ISSN:2231-1963.

[17] P. Sathiamurthi, P.S.S. Srinivasan, design and development of waste heat recovery system for air conditioner, Eur. J. Sci. Res. ISSN 1450-216X Vol.54 No.1 (2011), Pp.102-110.

[18] S.C. Kaushik, M. Singh, Feasibility and refrigeration system with a canopus heat exchanger, Heat Recovery Syst. CHP 15 (1995) 665–673.