Current Journal of Applied Science and Technology

Volume 42, Issue 42, Page 10-18, 2023; Article no.CJAST.101434
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

An Overview of a Two-stage Vapour Compression Cascade Refrigeration System for Low-temperature Applications

Thomas Olarewaju Oginni [a*], Bolaji Bukola Olalekan [b], Oyelaran Olatunde Ajani [b], Bello Kazeem Aderemi [b], Fadiji Ezekiel Adegoke [a] and Borokini Francis Olusesi [c]

[a] *Department of Mechanical Engineering, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria.*
[b] *Department of Mechanical Engineering, Federal University Oye-Ekiti, Nigeria.*
[c] *Department of Mechanical Engineering, Yaba College of Technology, Lagos, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2023/v42i424269

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/101434

Review Article

Received: 01/09/2023
Accepted: 05/11/2023
Published: 15/11/2023

ABSTRACT

A cascade refrigeration cycle is a multistage refrigeration system for ultra-low freezing application utilizing two stage vapour compression refrigeration system. Many refrigeration applications require low temperature for quick freezing medical items, production of ice, petroleum vapour liquefaction, pharmaceutical products preservation and storage, and manufacturing cooling processes. The two-stage cascade refrigeration system is the simplest, energy efficient and low operating cost for

**Corresponding author: E-mail: oginniolathomas@gmail.com, Oginni.olarewaju@bouesti.edu.ng;*

providing deep-freezing and maintaining extremely low temperature stability. The paper presents the overview of two-stage cascade refrigeration system for ultra-low temperature application and considered vapour compression cycle the most viable and suitable technique of attaining designed and desired temperature application. System modification using different techniques such as pre cool, flash intercooler, dedicated mechanical subcooling cycle, and novel ternary mixture of refrigerants were method adopted. The results revealed that the different techniques provide low energy consumption, high system performance and reduction in the thermal stress on the compressors as a result of reducing discharge temperature. The theoretical and experimental performance analysis outcomes showed the possibility and feasibility of achieving a low temperature of -80 ^{0}C. Vapour compression cascade refrigeration system is a promising technology in meeting the global needs for solving heat sensitive temperature-controlled products and useful in energy-deficient nations for storage and chain-distribution.

Keywords: Cascade; ultra-low temperature; heat sensitive; techniques; controlled storage; energy-deficient.

1. INTRODUCTION

“Refrigeration system is a process of removing heat from a substance or space under controlled conditions below that of the immediate surroundings. Refrigeration cycle operates vapour compression cycle, vapour absorption cycle, gas cycle, thermoelectric and magnetic refrigeration. However, the generally used cycle is vapour compression cycle due to its advantages and high coefficient efficiency. The desired low temperature is achieved by employing a working fluid called refrigerants” [1]. The additional values given by cascade refrigeration system include energy conservation, stable ultra-low-temperature operation, easy repair and low running cost [2-4].

Many refrigeration applications require low temperature for quick freezing medical items, production of dry ice, petroleum vapour liquefaction, pharmaceutical products preservation and storage [5]. The paper is aimed at simplifying the two-stage cascade refrigeration system for design and construction in solving the challenges in the existing commercial machines. The scope of the work is limited to the overviewing a two-stage cascade refrigeration system with an expected outcome of easy construction of an energy efficient machine for rapid homogeneous freezing and storage of products in energy deficient societies to increase their shelf-life for use in case of emergency.

2. CLASSIFICATION OF CASCADE REFRIGERATION SYSTEM

The cascade refrigeration system mainly includes four different systems namely the two - stage compression cascade refrigeration system (CCRS) that comprised of two Single-stage compression refrigeration systems, two - stage cascade absorption refrigeration system (CARS), compression–absorption cascade refrigeration system (CACRS) and auto-cascade refrigeration system (ACRS).

2.1 Single Refrigeration System

“A cascade system consists of two independently operated single–stage refrigeration systems in series: a lower system that maintains a lower evaporating temperature and produces a refrigeration effect and a higher system that operates at a higher evaporating temperature” [6]. “These two separate systems are connected by a cascade condenser in which the heat released by the condenser in the lower system is extracted by the evaporator in the higher system. Cascade cycle is used where a very wide range of temperature between low and high temperatures are required. Cascade improves the coefficient of performance (COP) of a refrigeration cycle. Moreover, the refrigerants with progressively lower boiling points can be selected to have reasonable evaporator and condenser pressures in the two or more temperature ranges” [7]. The schematic diagram of a two-stage cascade refrigeration system is shown in Fig. 1.

The feasibility study of building a cascade refrigeration system using commercially available “off the shelf” components was reported [8]. “A small business with common and less expensive refrigerants and components was used. The study gave detailed of cascade refrigeration system, refrigerants behaviour and natural gas behaviour for designing and building the system.

The first and second stages of the system were integrated. The equipment is built with all off the shelf componentry which can be easily obtained at any HVAC warehouse" [8].
"The presentation of a combined refrigeration system consisting of two compression refrigeration cycles linked by a heat exchanger that reduces the work of the compressor but increases the amount of heat absorbed by the refrigerated space as a result of the cascade stages and improves the COP of a refrigeration system. The waste heat generated was found useful in absorption refrigeration systems" [9].

In an attempt to enhance the system performance, [10] "a study provides the advantages of vapour compression refrigeration and summaries various techniques used in cascade refrigeration system to include operating parameters such as Condensing, Sub Cooling, Evaporating and Super heating temperatures in high temperature circuit and temperature differ heat exchanger Evaporating, Superheating, condensing and Sub-cooling in the low temperature circuit".

2.2 Multistage Refrigeration Cycle

"Multistage refrigeration system is used for many refrigeration applications and fields. It is a suitable choice to solve many problems that appears in single stage system and set to obtain a high volumetric efficiency and reaching an ultra-low temperature that is suitable for storing blood plasma and biological tissues" [9]. Fig. 2 shows the schematic diagrams of multistage of vapour compression refrigeration cycles [11].

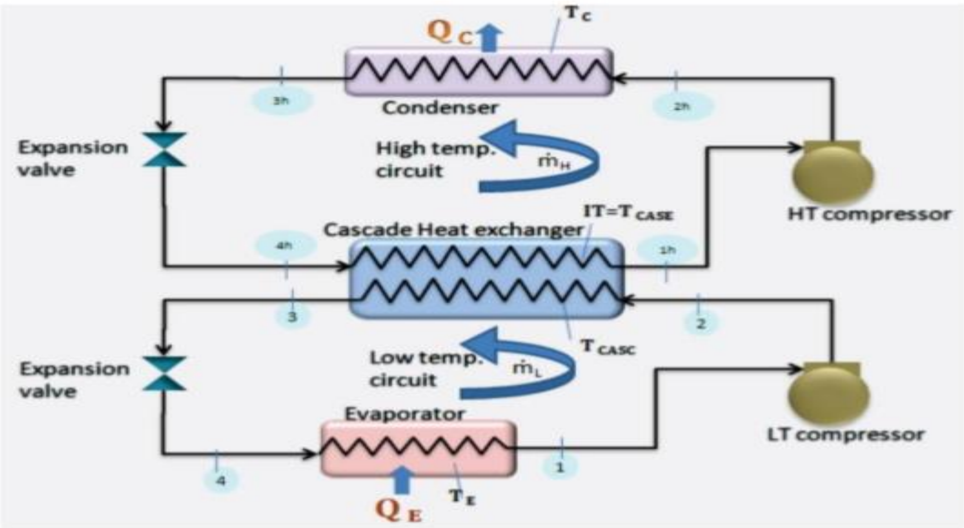


Fig. 1. Schematic diagram cascade refrigeration system

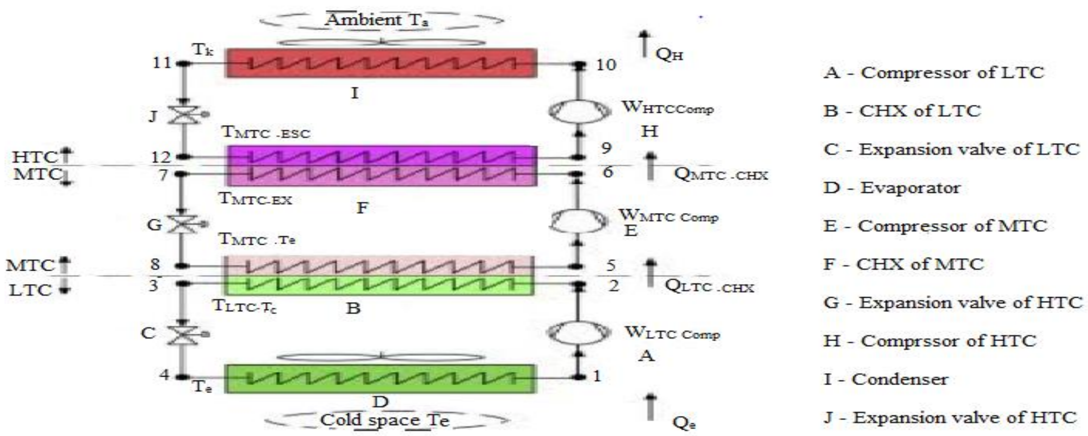


Fig. 2. Multistage vapour compression refrigeration systems

The available multistage system to achieve low temperature are stated below:

i. Two Compressors and Two Evaporators
ii. One Compressor and Two Evaporators
iii. Two Stage Compression with Intercooler
iv. Three Stage Compression with Multiple Expansion Valves and Flash Intercooler.

"However, multistage system suffers from oil wandering problem, high change in specific volume at low temperature in the evaporator, return of oil from the evaporator since the mass flow rate of the refrigerant is reduced, the condenser is designed for pull down load which is maximum, thermostatic expansion valve demands more superheat for the same setting of spring force and the multistage system is very expensive and therefore requires special design" [11].

3. REVIEW ON CASCADE REFRIGERATION SYSTEM

"Cascade is a freezing system that uses two dissimilar refrigerants having different boiling points, which run through its own independent freezing cycle and are thermally joined for production of ultra-low temperature refrigeration" [7]. The refrigerants can be selected to have reasonable evaporator and condenser pressures in the two or more temperature ranges. The two cycles are connected through the heat exchanger in the middle, which serves as evaporator in cycle 1 and condenser cycle 2 as illustrated in Fig. 1.

3.1 Two-Stage Cascade Refrigeration System

"A design and construction of a two-stage cascade refrigeration system using R404 and R22 as refrigerants for the high temperature and low temperature was presented" [6]. "There was an introduction of a heat exchanger to bring the inlet of compressor and throttling device in physical contact in order to superheat the refrigerant entering the compressor and pre cool it before introducing to the throttling device was done. This helped to achieve a better coefficient of performance (COP) and long durability of the system" [6].

In a two-stage vapour compression refrigeration system (VCRS) where two reciprocating single stage compressors were used. The Low Temperature Circuit (LTC) used low boiling refrigerant R23 and High Temperature Circuit (HTC) employed high boiling point refrigerant R12. The result revealed ultra-low temperature with higher efficiency of system or COP, reduce Global Warming Potential (GWP) risk and reduce the power consumption for getting same lower temperature. The series of single stage vapor compression system were thermally coupled with the evaporator of HTC and condenser of LTC known as cascade condenser. This system is developed to achieve temperature up to -20°C for applications such as cold storage in malls and stores and in blood banks. The working fluid in the system are R22 (LTC) and R134a (HTC), carefully chosen due to their suitable difference in boiling points and critical point for the desirable temperature. These fluids are harmless to environment, and GWP and ODP are negligible. The system theoretical COP was found to be 2.61 while the actual COP of 0.71 was obtained.

The necessities for simulating the system parameter data for effective analysis aroused [7] where other study was based on the simulation of the two-stage cascade refrigeration system model, validation and evaluation of the model with experiment data. The research was preceded by a design for the two-stage cascade refrigeration system R22/R32 followed by experiment to obtain operational parameters which would be validated and evaluated of the components of this cascade refrigeration system. The design of the two-stage cascade refrigeration system was aimed at obtaining the appropriate temperature and pressure for simulation. The experiment results obtained was the COP value 1.018 at the temperature evaporator -40 ^{0}C. Based on the analysis, the performance evaluation of the actual two-stage cascade refrigeration system is lower than the design due to the ineffective heat exchange process in the cascade heat exchanger.

"The performances of cascade refrigeration systems with two-stage refrigeration systems were compared using exergy method" [12]. "The considered systems used natural refrigerants, namely carbon dioxide (R744), ammonia (R717) and propane (R290). R744 was used in the low stage and R717/ R290 in the high stage, while the two-stage system used only R717/R290. The experimental results on comparison showed that for a given refrigeration capacity, evaporator and condenser temperature and cascade-condenser temperature, the compressor of R744 in the cascade cycle is more compact than those of R290 and R717 in the two-stage cycles. While cascade system provides lower exergy efficiency for both the two blends of refrigerants R744/R290 and R744/R717" [12].

"A new concept of Two Stage Compression-Absorption Cascade Refrigeration System (TSVCACRS) was introduced for achieving low temperature Industrial Cooling" [13]. "The system comprises of Two Stage Compression System having flash intercooler integrated with single stage vapor absorption refrigeration system, thermally coupled by means of cascade con exchanger. That proposed TSVCACRS system would minimize the compressor works up to 28%, compared to existing installed TSVCACR" [13].

In view to reducing energy consumption by the CRS, Canan [14] designed a serial flow double effect thermodynamic analysis to improve the performance of absorption – vapour compression cascade cycle. The novel cycle working fluid used R-134a for vapour compression section & LiBr-H_2O for absorption section. He compared the developed cycle with single effect absorption – vapour compression cascade cycle and one stage vapour compression refrigeration cycle. The results indicate that the electrical energy consumption in the novel cycle is 73% lower than the one stage vapour compression refrigeration cycle.

3.2 Cascade Refrigeration Cycle Optimization

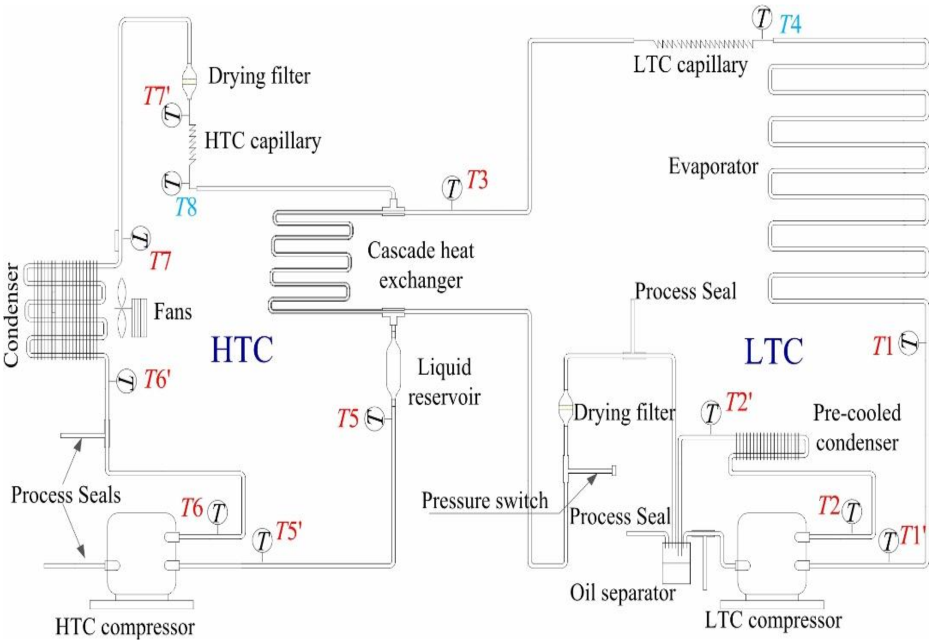
"Studies showed that, the multi-objective optimization of the system is an effective way to optimize the performance of CRS, which can achieve an optimal balance between thermodynamic efficiency and economic cost" [15]. "The study reviewed the cascade refrigeration systems based on refrigerants, various designs, research on optimization, related experiment studies, applications, and economical analysis. Moreover, an ejector–expansion CRS is suggested as another good option because of its less system complexities. The results showed that, the maximum COP of this system is improved by 7 % compared with the conventional system" [16]. "COP increases with the increasing evaporation temperature and decreasing condensation temperature. When the temperature difference in cascade heat exchanger increases, the cooling capacity almost linearly decreases and the system COP decreases more rapidly. When subcooling occurs in the both subsystems, the increase of COP in the cascade system is higher than that in the subsystems. COP of cascade slightly rises with superheating in both the high temperature and low temperature circuits" [17].

"In 2020, Wang experimentally investigated the pull-down performance of a −80 ^{0}C ultra-low temperature freezer. The study concluded that the volumetric efficiency of high temperature cycle compressor deteriorated more obviously during the pull-down process, and had higher potential for performance improvement compared with that of low temperature cycle" [18]. "In order to optimize the performance of a vapour compression cascade refrigeration cycle by considering the statistical analysis methods, Taguchi and ANOVA approaches. They concluded that the coefficient of performance and exergy efficiency within the range of the operating parameters in the evaluation were found to be 3.274% and 37.63%" [19]. "In a further study to optimize the performance of cascade refrigeration system, a novel ternary mixture of R600a/R23/R14 was proposed for ARC systems for −83˚C applications. The results demonstrated the feasibility of the proposed R600a/R23/R14 ternary mixture as an environmental benign alternative for Auto-Refrigeration cascade systems" [20]. In a similar work, Roy and Mandal [21] "numerically investigated energetic, exegetic, economic and environmental performances of a 50-kW cooling capacity cascade refrigeration system using four different refrigerant pairs, namely R41/R404A, R170/R404A, R41/R161 and R170/R161. The result showed that the coefficient of performance and exergetic efficiency of the system to be maximum with R41/R161 refrigerant pair followed by R170/R161 for the same operating conditions".

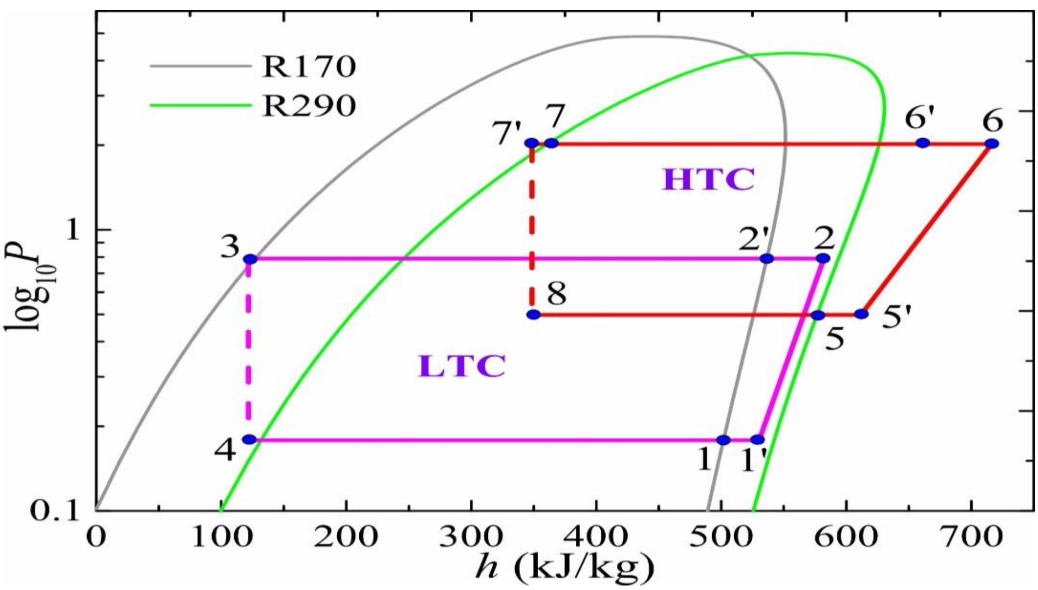
The design of a CRS utilized to improve the performance of a ULT freezer is illustrated by the refrigeration system in Fig. 3(a) [22]. The HTC is made up of a high-temperature compressor, an air-cooled condenser, and a high-temperature capillary, whereas the LTC is made up of a low-temperature compressor, a pre-cooled condenser, a low-temperature capillary, and an evaporator linked with a heat exchanger. The refrigeration system also includes related components, including liquid reservoirs, drying filters, process seals, and oil separators.

"An anti-condensation loop is inserted in the door seal, and a pre-cooled condenser is positioned in the LTC to improve the performance of the CRS and reduce the cooling temperature in the freezer. Running high-temperature discharge gas through the anti-condensation loop can stop water vapor from condensing at the freezer door. R290 and R170, two natural refrigerants, are used to create the high-temperature fluid in the HTC and the low-temperature fluid in the LTC. Temperatures were recorded at several locations in order to trace the temperature fluctuation of two refrigerants" [23].

The P-h diagram of the CRS is shown in Fig. 3(b) [24]. The ecologically friendly refrigerants R170 for a ULT freezer and R290 for high-temperature applications are combined to form a CRS. Experimental assessments of the ULT freezer's performance indicate that a temperature of -60ºC is easily achievable with the right modifications to cut down on cold loss and spray foam insulation.



(a) Schematic diagram of CRS



(b) P-h diagram of CRS

Fig. 3. Schematic diagram and P-h diagram of the CRS freezer [23, 24]

3.3 Factors that Increase Coefficient of Performance in Two Stage VCRS

The coefficient of performance of vapour compression refrigeration system using dedicated mechanical subcooling cycle is enhanced by the reduction in the pressure ratio across each stage, reduction in the compressor work, an increase in evaporator temperature and decrease in exergy loss as reported [25].

4. FIELD APPLICATIONS OF CASCADE REFRIGERATION SYSTEM

Cascade refrigeration system plays a vital role in preservation and storage of short shelf-life products and others that require limited and monitoring temperature–controlled space in our daily needs, medical profession, pharmaceutical company, food industry, hospital, Aero plane, Satellite components testing [26,27]. Some essential medicines and vaccines need unbroken cold chain to maintain its integrity (from the time of manufactured until the moment of vaccination). Storing vaccines at low temperature lessens the need for other preservatives and the risk of bacterial growth within the vaccine for effectiveness [27]. “Delivering vaccines to all corners of the world is a complex undertaking. It takes a chain of precisely coordinated events in temperature-controlled environments to store, manage and transport these life-saving products” [28]. Cascade cycle is used where a very wide range of temperature between low and high temperatures are required for safe vaccine handling and other short shelf-life products as desired. This technology enhances the coefficient of performance of a refrigeration cycle as well designed purposely to solve the various identified challenges associated with an ultra-low temperature products management. Cascade cycle is used where a very wide range of temperature between low and high temperatures are required [27].

i. Medical/Pharmaceutical field: Storage of blood banks, plasma, bone banks, drugs preservation such as vaccines, glaucoma eye drops, aerosol spray against asthma, insulin for diabetes are kept refrigerated at all times since even the tiniest temperature change can cause them to lose their potency.
ii. Industrial field: It is used in alloy production, liquefaction of gases, etc.
iii. Biological field: It is used in the preservation of human tissue, fluid storages such as blood and plasma, semen, virginal secretions, plants, etc.
iv. Transportation field: It is used in storing aviation materials in good and safe conditions such as Avgas at -100 ^{0}C and Jet fuel at (-40 ^{0}C of Jet A to -47 ^{0}C of Jet A-1), refrigerated trucks (chiller) to transport foods and drinks.
v. Food’s packaging: It is used in food processing and packaging such as fish, meat, fruits, vegetables, etc. The refrigerator storage is used to extend the shelf life of items rather than trashing them and to retain its quality of fresh [29].

5. CONCLUSION

An overview of two stage vapour compression cascade refrigeration system studies has been made to give a summary of the improvement of system performance for the vapour compression refrigeration systems. System modification using different techniques had been presented through deep assessment of the literature. The results revealed that the two stage vapour compression techniques using pre cool, two reciprocating single stage compressors, simulation of a two-stage cascade refrigeration system model, exergy method, flash intercooler, serial flow double effect thermodynamic analysis, dedicated mechanical subcooling cycle, statistical analysis methods, Taguchi and ANOVA approaches, and novel ternary mixture of refrigerants provide low energy consumption, high performance and reduces the thermal stress on the compressor and feasibility of achieving ultra-low temperature of -80 ^{0}C. The review is summarized as follows:

i. Pre cooled refrigerant before introducing to the throttling device helped to achieve a better coefficient of performance and long durability of the system.
ii. Two reciprocating single stage compressors produce ultra-low temperature with higher efficiency of system, reduce Global Warming Potential risk and reduce the power consumption for getting same lower temperature.
iii. Simulation of a two-stage cascade refrigeration system model produces high coefficient of performance at the temperature evaporator -40 ^{O}C.
iv. Exergy method using natural refrigerants produces lower exergy efficiency.
v. Flash intercooler system integration minimized the compressor works compared with existing system.

vi. Serial flow double effect thermodynamic analysis improves the performance of cascade cycle.
vii. Novel cycle working fluid reduces the electrical energy consumption than the one stage vapour compression refrigeration cycle.
viii. Dedicated mechanical subcooling cycle reduces system pressure ratio across each stage, reduction in the compressor work, an increase in evaporator temperature and decrease in exergy loss.
ix. statistical analysis methods, Taguchi and ANOVA approaches increase the coefficient of performance and exergy efficiency of the system over existing designs.
x. Novel ternary mixture provides the feasibility of achieving −83 ^{0}C temperature applications as an environmental benign alternative for Auto-Refrigeration cascade systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Shukla A, Dwivedi MK, Dubey N, Yadaw AK. Study of performance of a household refrigeration system with different refrigerants. International Journal of Engineering Research and Technology (IJERT). 2018;7(6):2278–0181.
2. Bingming W, Huagen W, Jianfeng L, Ziwen X. Experimental investigation on the performance of NH3/CO2 cascade refrigeration system with twin-screw compressor. International Journal of Refrigeration. 2009;32:1358-1365.
ISSN: 0140-7007
3. Dopazo JA, Fernandez SJ, Sieres J, Uhia J. Theoretical analysis of a CO2–NH3 cascade refrigeration system for cooling applications at low temperatures. Applied Thermodynamics Engineering, University of Vigo, Spain. 2012;29:1577-1583.
4. Lemboye KT, Layemi AT, Oduntan K, Akintunde MA, Dahunsi OA. Developing a two-stage cascade compressor arrangement for ice block production. Journal of Machinery Manufacturing and Automation, World Academic Co. Limited, Hong Kong. 2015;4(2):10-16.
5. Parikh K, Bavaliya S, Chauhan D, Patel M, Vadukul V. Design and fabrication of cascade refrigerator: a review. International Research Journal of Engineering and Technology (IRJET). 2020;07(05):2395-0072.
6. Ghulam R, Nilesh K, Neha P, Ashwini W, Renuka D. Cascade refrigeration system for blood storage. Dr. D. Y. Patil Institute of Technology, Pimpri,Pune / Savitribai Phule Pune University, India; 2017.
7. Darwin RB, Syaka WS, Muhammad B. Characteristics study of two-stage cascade refrigeration system design for household air blast freezing. International Journal of Mechanical Engineering and Technology (IJMET). 2019;10:1804-1813.
8. Mingli H. A study of two-stage cascade refrigeration. World Journal of Education Research, University of Denver, Denver, USA. 2017;4:290-295.
9. Jinkun Z, Shengjian L, Qin W, Dahong L. Optimization analysis on the performance of an auto-cascade absorption refrigeration system operating with mixed refrigerants. International Journal of low-carbon Technologies. 2018;13:212-217.
10. Umesh CR. A review of vapour compression cascade refrigeration system. Asian Journal of Engineering and Applied Technology. 2016;5:36-39.
11. Mishra RS. Thermal modeling of three stage vapour compression cascade refrigeration system using entropy generation principle for reducing global warming and ozone depletion using ecofriendly refrigerants for semen preservation. International Journal of Engineering and Innovation. 2017;1:22-28.
12. Ouadha A, Haddad C, En-nacer M, Imine O. Performance comparison of cascade and two-stage refrigeration cycles using natural refrigerants. International Congress of Refrigeration 2007 (conference), Beijing, upgraded; 2014.
13. Bhavesh P, Surendra SK, Bhumik M. Thermodynamic modeling & parametric study of a two stage compression absorption refrigeration system for ice cream hardening plant. International Conference on recent advancements in Air conditioning & Refrigeration, Bhubaneswar, India. 2016;10-12.
14. Canan C. Thermodynamic performance analysis of the double effect absorption compression cascade refrigeration cycle.

Journal of Thermal Science and Technology. 2018;13.

15. Mingzhang P, Huan Z, Dongwu L, Yan Z, Youcai L, Guangrui B. A review of the cascade refrigeration system. Energies. 2020;13.
DOI: 10.3390/en13092254
Available:www.mdpi.com/journal/energies
16. Dokandari DA, Hagh AS, Mahmoudi SM. Thermodynamic investigation and optimization of novel ejector-expansionCO2/NH3 cascade refrigeration cycles (novelCO2/NH3 cycle). Int. J.Refrig. 2014;46:26–36.
17. Jain V, Kachhwaha SS, Sachdeva G. Thermodynamic performance analysis of a vapour compression–absorption cascaded refrigeration system. Energy Conversion. Management. 2013;75:685–700.
18. Wang H, Song Y, Cao F. Experimental Investigation on the Pull-Down Performance of a -80°C Ultra-Low Temperature Freezer. International Journal of Refrigeration. 2020;119:1-10.
Available:https://doi.org/10.1016/j.ijrefrig.2020.04.030
19. Ustaoglu A, Kursuncu B, Alptekin M, Gok MS. Performance optimization and parametric evaluation of the cascade vapor compression refrigeration cycle using taguchi and ANOVA methods. Applied Thermal Engineering. 2020;180.
Article ID:115816
Available:https://doi.org/10.1016/j.applthermaleng.2020.115816
20. Rui S, Zhang H, Zhang B, Wen D. Experimental investigation of the performance of a single-stage auto-cascade refrigerator. Heat and mass transfer. 2016;52:11-20.
Available:https://doi.org/10.1007/s00231-015-1577-4
21. Roy R, Mandal BK. Thermo-economic analysis and multi-objective optimization of vapour cascade refrigeration system using different refrigerant combinations: A comparative study. Journal of Thermal Analysis and Calorimetry. 2020;139:3247-3261.
Available:https://doi.org/10.1007/s10973-019-08710-x
22. Liu Z, Bai M, Tan H, Ling Y, Cao Z. Experimental test on the performance of a −80°C cascade refrigeration unit using refrigerants R290-R170 for COVID-19 vaccines storage. Journal of Building Engineering. 2022;63:105537.
23. Tan H, Xu L, Yang L, Bai M, Liu Z. Operation performance of an ultralow-temperature cascade refrigeration freezer with environmentally friendly refrigerants R290-R170. Environmental Science and Pollution Research. 2023;30:29790-29806.
24. Liu Z, Yuan K, Ling Y, Tan H, Yang S. Experimental study on a -86 °C cascade refrigeration unit with environmental-friendly refrigerants R290-R170. Environmental Science and Pollution Research; 2023.
DOI: 10.1007/s11356-023-29240-y
25. Mogaji TS, Awolala A, Ayodeji OZ, Mogaji PB, Philip DE. COP enhancement of vapour compression refrigeration system using dedicated mechanical subcooling cycle. Nigerian Journal of Technology (NIJOTECH). 2020;39:776–784.
26. Nasir A, Mohammed A, Adegoke AS, Abdulkarim HT. Design and performance evaluation of an ice block making machine, A R P N Journal of Science and Technology. 2013;3:332-339.
27. Kasi P, Cheralathan M. Review of cascade refrigeration systems for vaccine storage. Journal of Physics: Conference Series. 2021;2054:012041.
Available:https://doi.org/ 10.1088/1742-6596/2054/1/012041
28. WHO. Global status report on blood safety and availability 2021, Geneva: World Health Organization. Licence: CC BY-NCSA 3.0 IGO; 2022.
29. Bai T, Lu Y, Yan G, Yu J. Performance analysis of an ejector enhanced two-stage auto-cascade refrigeration cycle for low temperature freezer. Journal of Thermal Science. 2021;1-12.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/101434