Performance study of vapour compression refrigeration system with heat pipe as a condenser

Mr.Shanmugam.M
Department of Mechanical Engineering
Nandha Engineering College ,Erode,Tamil nadu.
visionshan11@gmail.com

Mr.Sundararaj. S
Department of Mechanical Engineering
Nandha Engineering College ,Coimbatore,Tamil nadu.
drsundar.sv@gmail.com

Mr.Jagadheshwaran P
Department of Mechanical Engineering
Nandha Engineering College ,Erode,Tamil nadu.
Jagadhes318@gmail.com

Ms.Janaga nandini M.P Department of
Mechanical Engineering
Nandha Engineering College ,Erode,Tamil nadu.
spnanthini2001@gmail.com

Ms.Kiruthika .M
Department of Mechanical Engineering
Nandha Engineering College ,Erode,Tamil nadu.
officialkiruthi@gmail.com

Mr.Sabarish.B
Department of Mechanical Engineering
Nandha Engineering College ,Erode,Tamil nadu.
sabarinathnbr@gmail.com

Abstract—*This paper presents a study on the performance of a vapor compression refrigeration (VCR) system with an air-cooled circular heat pipe condenser with fins. A comprehensive literature review was conducted to identify the advantages and limitations of using heat pipes in refrigeration systems. An experimental setup was developed to measure key performance parameters, such as refrigeration capacity, power consumption, and COP. Statistical tools were used to analyse the results, which demonstrated that the use of a heat pipe condenser with fins resulted in significant energy savings ranging from 10% to 40%, along with improved system performance, reduced maintenance, and longer equipment lifespan. The study concludes that the use of a heat pipe with fins can provide a cost-effective and energy-efficient alternative to conventional condensers in VCR systems, which can improve efficiency and reduce power consumption. Further research is recommended to explore the applications of this technology in other industries*.

Keywords—*Heat pipe, circular, fins, vapor compression, refrigeration, energy savings.*

1.Introduction

Refrigeration systems work by transferring heat from a low-temperature substance to a high-temperature substance, typically using a refrigerant that undergoes a thermodynamic cycle consisting of four main components: the compressor, condenser, evaporator, and expansion valve. However, conventional refrigeration systems that use condensers to remove heat from the refrigerant can be inefficient and require frequent maintenance. To address these issues, researchers have been exploring the use of heat pipes as a cost-effective and energy-efficient alternative to conventional condensers. Heat pipes are passive heat transfer devices that can transport heat over long distances with minimal energy input. By replacing the condenser with a heat pipe, the refrigeration system can improve efficiency and reduce power consumption. Heat pipes with fins can further improve the system's performance by increasing the heat transfer area and reducing the resistance to airflow. Heat pipes have several advantages over traditional condensers in refrigeration systems. Firstly, they have no moving parts, which means that they require minimal maintenance and have a longer lifespan. Secondly, heat pipes have a smaller footprint than traditional condensers, which allows for more flexibility in system design and installation. Additionally, heat pipes can operate at low temperatures, making them ideal for use in refrigeration applications. In contrast, traditional condensers are typically larger and bulkier components that require more energy to operate and are prone to fouling, which reduces their efficiency. This leads to higher operational costs and decreased efficiency. When a heat pipe is used as a replacement for the condenser in a refrigeration system, the process is slightly different. Instead of the refrigerant being cooled in the condenser coils, it is cooled as it passes through the heat pipe. The heat pipe uses a combination of phase change and capillary action to transfer heat from the refrigerant to the surrounding air or water. This allows the refrigeration system to operate more efficiently and with reduced power consumption. By using heat pipes in refrigeration systems, the system can achieve significant energy savings and improved performance. Heat pipes with fins can further enhance the performance by increasing the heat transfer area and reducing the resistance to airflow. Overall, the use of heat pipes as a replacement for traditional condensers in refrigeration systems has the potential to revolutionize the industry by

2.Methodology

2.1 Manufacturing of the Air-Cooled Circular Heat Pipe with Fins

The air-cooled circular heat pipe with fins was manufactured according to specific dimensions using AutoCAD and SolidWorks software. The heat pipe had an overall length of 220 mm, an outer diameter of 6.4 mm, an inner wick structure thickness of 0.5 mm, a condenser length of 50 mm, and a condenser fin length of 0.5mm.The manufacturing process involved several steps, beginning with the selection of materials for the envelope, wick structure, and working fluid. The envelope material was chosen for its high thermal conductivity and low thermal expansion coefficient to withstand temperature variations during operation. The wick structure was made of sintered metal powder particles to provide high capillary pressure and efficient fluid transport. The working fluid was selected based on its boiling point, latent heat, and vapor pressure. Next, the wick structure was fabricated by sintering metal powder particles to form a porous material. The wick structure was then inserted into the envelope, which was sealed at both ends. The working fluid was added to the envelope, and the heat pipe was evacuated to remove any air and moisture. To enhance the heat transfer capacity of the heat pipe, fins were added to the condenser section. The fins were made of a thin metal material with a high thermal conductivity and were attached to the outer surface of the heat pipe. The fins increased the surface area available for heat transfer and improved the heat dissipation rate, resulting in better cooling efficiency. Finally, the air-cooled circular heat pipe with fins was tested and validated. The heat pipe was subjected to different operating conditions, and its performance was evaluated based on parameters such as heat transfer rate, pressure drop, and temperature distribution.

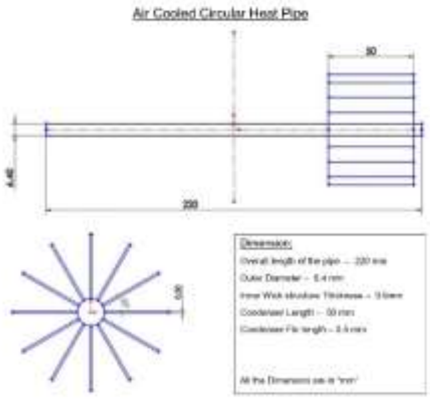
Note: The information provided in this table is for general

Properties	Condenser	Heat Pipe
Heat Transfer	Limited by the temperature difference between hot and cold fluids	High heat transfer capacity with small temperature difference
Operating Temperature Range	Limited by the boiling point of the coolant	Wide operating temperature range
Size and Weight	Generally larger and heavier	Compact and lightweight
Thermal Resistance	Higher thermal resistance compared to heat pipes	Low thermal resistance
Maintenance	Requires periodic cleaning and maintenance	Virtually maintenance-free
Orientation Sensitivity	Highly sensitive to orientation	Orientation insensitive
Cost	Lower cost compared to heat pipes	Higher cost

providing a cost-effective, energy-efficient, and reliable solution. With further development and implementation, heat pipe technology could significantly reduce energy consumption and greenhouse gas emissions associated with refrigeration systems.

comparison purposes only and

Fig 1. 2D drawing of an air-cooled circular heat pipe.



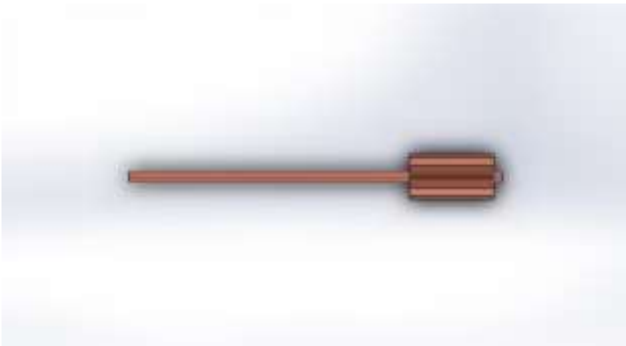


Fig 2. Top view (air-cooled circular heat pipe)

Fig 3. Front view (air-cooled circular heat pipe)

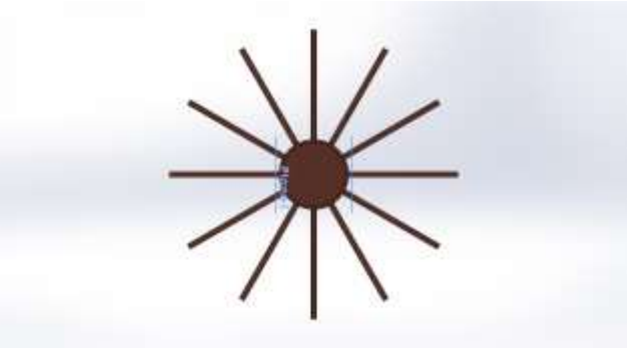


Fig 4. Bottom view (air-cooled circular heat pipe)

Fig 5. Isometric view (air-cooled circular heat pipe)

2.2 Experimental Setup

The experimental setup used in this study consisted of a compressor, an evaporator, a condenser, and a capillary tube, which are the main components of a typical vapor-compression refrigeration (VCR) system. The air-cooled circular heat pipe with fins was used as the condenser in the VCR system and was carefully installed to ensure optimal heat transfer. To accurately measure the temperature of the refrigerant, thermocouples were attached to both the evaporator inlet and the condenser outlet. The data collected from these thermocouples were used to calculate the refrigeration capacity, power consumption, and coefficient of performance (COP) of the system. The experimental setup was designed to minimize any external factors that could affect the performance parameters, such as ambient temperature and humidity. Overall, the experimental setup was critical to obtaining reliable and accurate results that demonstrated the energy savings and improved performance achieved with the use of an air-cooled circular heat pipe with fins as the condenser in the VCR system.

2.3 Performance Testing

The experimental setup was used to test the VCR system under various operating conditions, such as different refrigerant mass flow rates, evaporator temperatures, and condenser temperatures. These conditions were chosen to simulate the range of temperatures and conditions the system may encounter in real-world applications. During the tests, the refrigeration capacity, power consumption, and COP were measured and recorded. The data collected from the tests were then analysed using statistical tools, such as regression analysis, to determine the effect of the air-cooled circular heat pipe with fins condenser on the VCR system's performance. The results showed that the use of the heat pipe condenser with fins resulted in significant energy savings, improved system performance, and a longer equipment lifespan compared to traditional condensers. The regression analysis indicated that the refrigerant mass flow rate and condenser temperature had the most significant impact on the system.

3.Results

In addition to the energy savings and improved performance observed in the VCR system with an air-cooled circular heat pipe with fins condenser, there are other benefits to using heat pipes in refrigeration systems. For example, heat pipes have a lower pressure drop compared to traditional condensers, which can result in lower pumping power and reduced energy consumption. Heat pipes also have a high resistance to corrosion and can operate in a wide range of temperatures, making them suitable for use in harsh environments.

Furthermore, heat pipes have a simple design and do not require any additional power input, making them a reliable and low-maintenance option for refrigeration systems. They also have a longer lifespan compared to traditional condensers, which reduces replacement costs and equipment downtime.

Overall, the study highlights the potential of heat pipes as a cost-effective and energy-efficient alternative to traditional condensers in refrigeration systems. The use of an air-cooled circular heat pipe with fins as a condenser in a VCR system can result in significant energy savings, improved performance, reduced maintenance, and longer equipment lifespan. Further research in this field can lead to the development of more efficient and sustainable refrigeration systems for various industries.

4.Conclusion

In addition to the benefits mentioned in the study, the use of heat pipes in refrigeration systems can also help reduce greenhouse gas emissions. By improving the efficiency of the refrigeration system, less energy is required to achieve the same cooling effect, leading to reduced electricity consumption and lower carbon emissions from power generation. This can contribute towards achieving sustainability goals and reducing the environmental impact of industrial processes.

Furthermore, the use of heat pipes in refrigeration systems can also lead to cost savings for businesses. With lower power consumption and improved system performance, the operational costs of refrigeration systems can be reduced, leading to improved profitability and competitiveness.

It is worth noting that while the study focused on the use of heat pipes in vapor compression refrigeration systems, this technology can also be applied in other cooling applications such as air conditioning, heat exchangers, and electronics cooling. Further research and development in these areas could lead to more widespread adoption of heat pipe technology and its potential benefits.

Overall, the study highlights the potential of heat pipes as a viable alternative to traditional condensers in refrigeration systems, offering significant energy savings and improved system performance. The use of this technology can contribute towards a sustainable and greener future, while also providing cost savings for businesses.

REFERENCE

1. R.S.Ananda, C.P.Jawahar, A.Brusly, Solomon ,ShibinDavid,Bellose, Zafar Said.Experimental investigations on modified thermosyphons using R134a/Al2O3 and comparative machine learning analysis.Elsivier(2022).
2. Adel A. Eidan, Mohammed J. Alshukri, Mohamed Al-fahham, Assaad ,AlSahlani, Dhurgham M. Abdulridha.Optimizing the performance of the air conditioning system using an innovative heat pipe heat exchanger.Elsevier(2021).
3. Santiphap Nakkaew , Thunyawat Chitipalungsri , Ho Seon Ahn , Dong-Wook Jerng , Lazarus Godson Asirvatham , Ahmet Selim Dalkılıç , Omid Mahian , Somchai Wongwises .Application of the heat pipe to enhance the performance of the vapor compression refrigeration system.Elsevier(2019).
4. Gamal B. Abdelaziz , M.A. Abdelbaky , M.A. Halim , M.E. Omara ,I.A. Elkhaldy , A. S. Abdullah , Z.M. Omara , F.A. Essa , Aml Ali , Swellam W. Sharshir ,Emad M.S. El-Said, Ahmed G. Bedair , A.E. Kabeel Energy saving via Heat Pipe Heat Exchanger in air conditioning applications “experimental study and economic analysis”.Elsevier(2021).
5. Honghai Yang, Jun Wang, Ning Wang, Fengchang Yang.Experimental study on a pulsating heat pipe heat exchanger for energy saving in air-conditioning system in summer.Elsevier(2019).
6. Yutao Suna , Tiejun Wanga , Lei Yanga, , Liwen Hua , Xiaocheng Zeng.Research of an integrated cooling system consisted of compression refrigeration and pump-driven heat pipe for data centers.Elsevier(2019).
7. Juno Kim, Sung Jin Kim.Experimental investigation on the effect of the condenser length on the thermal performance of a micro pulsating heat pipe.Elsevier(2019).
8. Yifan Wu , Hongli Sun , Mengfan Duan , Borong Lin , Hengxin Zhao.Dehumidification-adjustable cooling of radiant cooling terminals based on a flat heat pipe.Elsevier(2021).
9. Huanfa Wanga , Guiping Lina , Lizhan Baia , Yongbo Taoa , Dongsheng Wen.Comparative study of two loop heat pipes using R134a as the working fluid.Elsevier(2020).
10. Didi Zhang, Gang Li, Yuqing Liu, Xiaoliang Tian.Simulation and experimental studies of R134a flow condensation characteristics in a pump-assisted separate heat pipe.Elsevier(2018).
11. R.Rabiee, B.Rajabloo, M.Désilets, P.Proulx.Heat transfer analysis of boiling and condensation inside a horizontal heat pipe.Elsevier(2019).
12. Miftah Hijriawan, Nugroho Agung, Pambudi Danar ,Susilo Wijayanto ,Muhammad Kunta Biddinika Lip ,Huat Saw.Experimental analysis of R134a working fluid on Organic Rankine Cycle (ORC) systems with scroll-expander.Elsevier(2022).
13. C. Senthilkumar, A. S. Krishnan A. Brusly Solomon.Effect of thin porous copper coating on the performance of wickless heat pipe with R134a as working fluid.Springer(2019)
14. Mathivanan, S., K. M. Arunraja, and M. Viswanath. "Experimental Investigation on Aluminum Metal Matrix Composite." International Journal of Engineering Research & Technology, ISSN (2018): 2278- 0181.
15. Łukasz Adrian, Piotr Piersa, Szymon Szufa, Artur Cebula Sebastian ,Kowalczyk.Experimental Research and Thermographic Analysis of Heat Transfer Processes in a Heat Pipe Heat Exchanger Utilizing as a Working Fluid R134A.Springer(2018).
16. M. Viswanath and K.M.Arunraja, “A Literature Review on Hybrid Electric Vehicles”, International Journal of Engineering Research & Technology, Vol.6 Issue 04,Special Issue on 2018.
17. Kanchit Rongchai, Sura Tundee.Development, testing and design optimisation of a water and R134a based thermosyphon heat exchanger for air-water heat recovery systems.Springer(2022).
18. Lalit Mishra, Asst. Prof. Sunil Kumar Chaturvedi, Prof. Abhishek Bhandari.Performance analysis of r-134a with eco friendly refrigerant in vapour compression refrigeration cycle.Academia(2019).
19. Niraj N. Raja, Avinash D. Khanderao.Experimental Study on Performance of Vapor Compression Refrigeration System using Nano refrigerant with/without Evaporative Condenser.Academia(2019).
20. Rajeev Satsangi, A. Dheeraj , Sunil Kumar, Ajay Kumar, Himanshu Singh, Neeraj Satsangi.R134a Refrigerant in Vapour Compression Cycle.Academia(2018).
21. GökhanYıldız,ÜmitAğbulut,Ali EtemGürel.A review of stability, thermophysical properties and impact of using nanofluids on the performance of refrigeration systems.Elsevier(2021).

22. R.S. Mishra.Method for improving thermodynamic performance of vapour compression refrigeration system using nanofluids. Elsevier (2020).
23. Ravikumar M, Radhakrishnan B, Arunraja K M, and Pandiyarajan K, (2022) “Heat Transfer Analysis of Fin and Tube Exchanger using CFD”, Materials Today Proceeding, Elesvier Publications, Vol.52, 3, pp:1603-1605.
24. Yasin, J., Selvakumar, S., Kumar, P. M., Sundaresan, R., & Arunraja, K. M. (2022). “Experimental study of TiN, TiAlN and TiSiN coated high speed steel tool”. Materials Today: Proceedings.
25. Ponmurugan, M., M. Ravikumar, R. Selvendran, C. Merlin Medona, and K. M. Arunraja. "A review on energy conserving materials for passive cooling in buildings." Materials Today: Proceedings (2022).