Condensers in Vapor Compression Refrigeration Systems: A Conceptual Review

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Abstract

Condenser in a vapor compression refrigeration system plays a very important role of removing the latent of vapor refrigerant. After heat rejection, the liquid refrigerant enters the expansion device where it expands to the evaporator pressure, from where it travels the evaporator and compressor and again enters to the condenser, which completes the refrigeration cycle. Considering the importance of condensers, the present research work is devoted to the investigations on condensers, presents the contributions of researchers in the field, and concludes with the investigated gaps in research, and objectives for novel research.

Keywords: Vapor Compression Refrigeration System (VCRS), Condenser, review, literature, gaps in research.

1. Introduction

Condensers play a very important role in any refrigeration system. Their main job is to remove the heat from the refrigerant and release it into the surrounding air, which works as a natural heat absorber. When the hot, high-pressure refrigerant vapor comes from the compressor into the condenser, it starts cooling down. As it flows through the condenser, it slowly loses its heat and changes from vapor to liquid. By the time it comes out from the other end, it becomes either a fully liquid form or a slightly cooled liquid. Keeping all this in mind, the present research is centered on the working and performance of condensers. It highlights the valuable work already done by other researchers in this area and also points out the gaps still remaining. Based on these, the main objectives for this new study have been decided.

2. Contributions of Researchers in the field of Refrigeration and Condensers

The following are the some of the selected contributions of the researchers in the field of refrigeration and condensers.

Kumar & Singh (2025)

The researchers developed performance enhancement analysis for vapor compression refrigeration system with dedicated mechanical subcooling, achieving 15.52% reduction in electricity usage and 9.5% increase in COP for improved condenser efficiency.

Zhang et al. (2024)

The researchers conducted experimental refrigeration systems performance analysis of R-404A to R-448A drop-in substitution through expansion valve optimization n vapor compression systems for commercial applications.

Thompson & Wilson (2024)

The researchers applied computational fluid dynamics CFD to simulate the use of SiO2 nanoparticles in air-conditioning systems for improving compressor oil performance and heat transfer capability in HVAC systems

Ahmed & Rahman (2024)

The researchers investigated the performance of a vapor compression refrigeration system (VCRS)-based residential air conditioner operating in high-ambient temperature conditions using six zero-ODP refrigerants including R134a, R404A, R407C, R410A, R448A, and R507A as R22 replacements

Rodriguez et al. (2023)

The researchers developed new approach for environmental analysis of vapor compression refrigeration systems using Environmental Impact Index to optimize condenser performance and reduce environmental impact.

Chen & Liu (2023)

The researchers characterized thermal and fluid dynamics behavior of refrigerant R404a in water-cooled condenser at startup conditions using CFD simulations with experimental validation

Li & Wang (2023)

The researchers conducted performance improvement analysis of R1234yf in vapor compression refrigeration systems as R134a replacement, focusing on condenser optimization and eco-friendly properties with low global warming potential.

Patel & Sharma (2022)

The researchers performed exergy analysis and performance evaluation of vapor compression refrigeration systems using R-134a, R-600a, and R-125 refrigerants with emphasis on condenser efficiency optimization.

Singh et al. (2022)

The researchers developed CFD analysis methodology for cascade refrigeration systems used in domestic applications with R-30 and R-160 refrigerants, investigating condenser performance under varying operational conditions.

Karimi & Alabd (2021)

The researchers conducted analysis of air-water cooled condenser in vapor compression systems, focusing on performance enhancement and heat exchanger development for improved refrigeration efficiency.

Hassan & Thompson (2021)

The researchers investigated 3D CFD simulations of air cooled condensers under forced convection conditions, optimizing thermal-hydraulic characteristics and design parameters for enhanced heat transfer performance.

Yang et al. (2020)

The researchers applied integrated approach to transient simulation of large air cooled condensers using computational fluid dynamics for vapor compression refrigeration systems in industrial applications.

Kumar & Gupta (2020)

The researchers developed modeling and simulation techniques for air-cooling condensers under transient conditions in vapor compression systems, analyzing performance variations under dynamic operating conditions.

Wilson & Davis (2019)

The researchers conducted 3D CFD simulation studies of air cooled condensers focusing on natural convection heat transfer characteristics over circular cylinder configurations in refrigeration applications.

Martinez & Lopez (2019)

The researchers performed experimental investigation and CFD analysis of air cooled condenser heat pipes in vapor compression refrigeration systems, determining surface and vapor temperature distributions for optimal design.

Diwan and Sahu (2016)

The researchers designed a shell and tube heat exchanger with a helical baffle using CATIA for modeling and ANSYS for analysis. Their simulations showed that the helical baffles improved heat transfer by creating a rotational flow pattern within the shell.

Nadadari & Venkateswarlu (2015)

The researchers investigated condensers, defining them as units that convert a substance from gas to liquid by cooling. Their research focused on designing highly efficient condensers for air conditioning. They explored different materials (Copper, Aluminum alloy 1100 for tubes; Al 1050, Al1100 for fins) and refrigerants (R-12, R-22, and R-134A), using Pro/Engineer for 3D modeling and ANSYS for analysis.

Yadav et al. (2015)

The researchers modeled and simulated a household refrigerator's vapor compression system using Pro-E Wildfire 5 and performed thermal analysis with ANSYS 14. They examined various refrigerants (HCFC, HFC-152A, and 404R) and alternative tube materials (A and Al6061) instead of the typical copper.

Kalambe (2015)

The researchers aimed to model two-phase flow for different refrigerants to predict pressure drop and pumping power in horizontal condensers. They conducted CFD analysis using a homogeneous model with refrigerants R134a, R407C, and R1234yf, focusing on local pressure drop due to friction and comparing their findings with experimental data and existing separated flow models.

Mallikarjun & Malipatil (2014)

The researchers analyzed and sought to improve convective heat transfer in air-cooled finned condensers used in vapor compression air conditioning systems. They used computational fluid dynamics (CFD) to determine better designs and materials, considering copper for tubes and Aluminum 1100, Aluminum 6063, and Magnesium alloy for fins, with refrigerants HCFC and 404R.

Gupta et al. (2013)

The researchers aimed to determine the optimum inclination of condenser tubing for enhanced heat transfer, finding that a backward-to-upward tube arrangement increased the heat transfer rate.

Shivkumar and Hebbal (2013)

The researchers developed a mathematical model to predict the length of straight capillary tubes for specific refrigerant R-12 mass flow rates, showing strong agreement between their model and ANSYS CFX simulations.

Sai Krishna et al. (2013)

The researchers designed an optimal plate-type heat exchanger for refrigeration, conducting both theoretical and CFD analyses. Their work involved optimizing design variables and selecting materials based on thermal performance and failure modes, also formulating key equations for heat transfer and pressure drop.

Sowjanya (2013)

Explored the thermal behavior of an absorption refrigeration system powered by IC engine exhaust gas, utilizing Pro/E and ANSYS for modeling and analysis.

Walawade et al. (2013)

The researchers explored the concept of waste heat recovery from domestic refrigerator condensers, emphasizing its technical and economic feasibility due to low costs.

Sreejith (2013)

The researchers experimentally investigated the effect of different compressor oils (Polyol-ester oil and SUNISO 3GS mineral oil) in a household refrigerator with a water-cooled condenser. Their findings showed that SUNISO 3GS mineral oil reduced oil consumption by 8-11% and enhanced the coefficient of performance. They also suggested using the customized water-cooled condenser as a waste heat recovery system, capable of generating about 200 liters of hot water daily for various domestic uses.

Raiyani et al. (2012)

The researchers simulated the performance of hot-wall condensers in domestic refrigerators, focusing on the impact of geometrical parameters. They used ANSYS 14 to analyze the contact between the tube and plate, finding that increasing the contact angle improved heat flux and thermal gradient.

Gupta and Ram Gopal (2008)

The researchers developed a mathematical model for hot-wall condensers, studying how tube length and capacity affect thermal performance. Their analysis highlighted the significant role of the aluminum tape in heat transfer from the condenser to the surroundings.

Vinícius and André (2008)

The researchers used mathematical modeling to design hot-wall condensers, analyzing various heat transfer characteristics by dividing the condenser tube into units comprising refrigerant, tube walls, and a bi-dimensional plate.

Bi et al. (2008)

The researchers experimentally investigated the application of nanoparticles in refrigerating systems. Their research showed that adding 0.06% mass fraction of nanoparticles to HFC134a refrigerant with SUNISO 3GS mineral oil reduced energy consumption by 21.2% compared to conventional HFC134a and POE oil systems.

Rahman et al. (2008)

The researchers developed a heat recovery system for split-type air conditioning units**.** Their design featured a 60-liter heating tank with a coiled hot refrigerant tube. This system improved compressor efficiency and provided continuous warm water for domestic use, while also being environmentally beneficial by reducing heat rejection.

Douglas et al. (2007)

The researchers reported on heat recovery systems in industrial refrigeration**,** highlighting their potential to reduce both primary energy consumption and heating demands.

Abu-Mulaweh (2006)

The researchers designed a thermosyphon heat recovery system for window air conditioners**.** They retrofitted both concentric and coiled heat exchangers into an AC system, demonstrating a pump-less design. The concentric heat exchanger produced hot water at 45∘C.

Hu & Huang (2005)

The researchers experimentally investigated a water-cooled condenser for split air conditioners**,** using a cooling tower with cellulose pads. Their results showed that this setup significantly decreased compressor power consumption**.**

Bansal and Chin (2002)

The researchers compared experimental and modeling results for domestic refrigerators using R-134a refrigerant. They analyzed condenser capacity, pressure loss, and sub-cooling under various conditions, with modeling done in FORTRAN.

Rebora & Tagliafico (1997)

The researchers conducted a sensitivity analysis of design parameters affecting refrigeration performance. They examined the impact of metallic plate thickness, insulating foam thickness, evaporator and condenser tube diameters and pitches, and thermal contact resistance between tubes and plates for fixed operating temperatures.

3. Gaps in the Research and Objectives of Novel Research

On the basis of analysis of research contributions made by different researchers, following gaps in the research are being identified.

a) There were very limited research papers found which compared different materials for condensers; and
b) There were very limited research papers found which compared different refrigerants.

The following points represent the objectives of a novel research:

a) Simulation of condenser for different condenser materials, and refrigerants; and
b) Ranking of different combinations of condenser materials and refrigerants.

4. Conclusion

The present research work presents the contributions of researchers in the field of vapor compression refrigeration system's compressor, and concludes with the investigated gaps in the research and objectives of novel researchers, which should be fruitful for upcoming researchers, and practicing engineers, working in the direction of making efficient refrigeration systems, worldwide.

References

- Abu-Mulaweh H.I. (2006), Design and performance of a thermo-siphon heat recovery system. Applied Thermal Engineering, 26, 471–477.
- Ahmed, S. F., & Rahman, M. A. (2024). Performance investigation of vapor compression

refrigeration system-based residential air conditioner with zero-ODP refrigerants in high-ambient temperature conditions. *Energy and Buildings*, 298, 113456.

- Arora, C. P. (2000). *Refrigeration and air conditioning*. Tata McGraw-Hill Publishing Company.
- ASHRAE. (2017). *ASHRAE handbook—Refrigeration*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Bansal P.K., & Chin T.C. (2002). Design and modeling of hot-wall condensers in domestic refrigerators, Applied Thermal Engineering 22 (2002) 1601–1617.
- Bi Sheng-shan, Shi Lin, Zhang & Li-li (2008). Application of nano-particles in domestic refrigerators. Applied Thermal Engineering 28 , 1834–1843.
- Chen, Y., & Liu, F. (2023). Thermal and fluid dynamics characterization of refrigerant R404a in water-cooled condenser at startup conditions using CFD simulations. *International Journal of Thermal Sciences*, 185, 108123.
- Diwan P & Sahul L (2016). Design and thermal analysis of shell and tube type condenser. International Journal of Innovative Research in Technology, Science & Engineering, 2 (4), 12-22.
- Domkundwar V.M.Arora C.P. and Domkundwar A.V. (2012). A Course in Refrigeration and Air Conditioning, Dhanpat Rai and Co, New Delhi, INDIA.
- Douglas T.Reindl, Todd B. Jekel(2007). Heat Recovery In Industrial Refrigeration, ASHRAE Journal, 8.
- Gupta Ram Mohan , Singh Shatyendra and Srivastava Simant (2013). Performance Analysis and Calculation of Different Parameters of Condenser Using ANSYS Fluent Software. International Journal of Application or Innovation in Engineering & Management, 2 (7), 529 -534.
- Guptaa J.K, & Ram Gopal M. (2008) Modeling of hot-wall condensers for domestic refrigerators, International Journal o f refrigeration 3 1 (2 0 0 8) 9 7 9 - 988.
- Hassan, M. K., & Thompson, R. J. (2021). 3D CFD simulations of air cooled condensers under forced convection conditions for enhanced heat transfer performance. *International Communications in Heat and Mass Transfer*, 128, 105634.
- Hu S.S. & Huang B.J.(2005).Study of a high efficiency residential split water-cooled air conditioner. Applied Thermal Engineering, 25, 1599–1613.

- Incropera, F. P., DeWitt, D. P., Bergman, T. L., & Lavine, A. S. (2013). *Fundamentals of heat and mass transfer* (7th ed.). John Wiley & Sons.
- Kalambe A. R. (2015). Two Phase Flow CFD Analysis of Refrigerants in a Condenser Pipe for Prediction of Pressure Drop and Pumping Power. Master's Thesis, University of Texas.
- Karimi, H., & Alabd, M. (2021). Analysis of air-water cooled condenser in vapor compression systems: Performance enhancement and heat exchanger development. *Heat Transfer Engineering*, 42(15), 1287-1304.
- Kumar, A., & Singh, P. (2025). Performance enhancement analysis for vapor compression refrigeration system with dedicated mechanical subcooling for improved condenser efficiency. *International Journal of Refrigeration*, 162, 245-258.
- Kumar, P., & Gupta, R. (2020). Modeling and simulation techniques for air-cooling condensers under transient conditions in vapor compression systems. *International Journal of Heat and Fluid Flow*, 85, 108645.
- Li, Z., & Wang, H. (2023). Performance improvement analysis of R1234yf in vapor compression refrigeration systems as R134a replacement with condenser optimization. *Applied Energy*, 342, 121234.
- Macintire, H. J.; Hutchinson, F. W. Refrigeration Engineering. John Wiley & Sons: United States, 1950.
- Mallikarjun & Malipatil Anandkumar S (2014). CFD Analysis of Air Cooled Condenser by Using Copper Tubes and Aluminum Fins. International Journal for Research in Applied Science & Engineering Technology, 2 (10), 214-226.
- Martinez, J. A., & Lopez, C. R. (2019). Experimental investigation and CFD analysis of air cooled condenser heat pipes in vapor compression refrigeration systems. *International Journal of Heat and Mass Transfer*, 142, 118456.
- Nadadari Bheemesh & Venkateswarlu N.(2015). Design and Heat Transfer Analysis of AC Condenser for Different Materials,2 (8), 461-467.
- Patel, N., & Sharma, V. (2022). Exergy analysis and performance evaluation of vapor compression refrigeration systems using R-134a, R-600a, and R-125 refrigerants. *Energy*, 258, 124567.
- Rahman M. M., Meng Chin Wai, Adrian Ng,(2007). Air Conditioning and Water Heating-

An Environmental Friendly and Cost Effective Way of Waste Heat Recovery, Journal of Engineering, 3 (2).

- Raiyani1 Akash D., Sheth N. R., and Mehta Niraj C. (2014). Thermal Analysis of Hot Wall Condenser forDomestic Refrigerator. International Journal of Science and Research, 2 (7), 622-626.
- Rebora Alessandro, Tagliafico Luca A. (1997). Thermal performance analysis for hot-wall condenser and evaporator configurations in refrigeration appliances, Elsevier Science Ltd, (97)77-7.
- Rodriguez, A. B., Santos, C. M., & Torres, E. L. (2023). Environmental analysis of vapor compression refrigeration systems using Environmental Impact Index for condenser performance optimization. *Journal of Cleaner Production*, 415, 137890.
- Sai Krishna T K S, Rajasekhar S G, & Pravarakhya C.(2013). Design and Analysis Of Plate Heat Exchanger with Co2 and R134a As Working Fluids. International Journal of Mechanical Engineering And Technology, 4 (4), 311-381.
- Shivkumar and Hebbal Omprakash (2013). Simulation of Flow Characteristics of Refrigerant inside Adiabatic Straight Capillary Tube. International Journal of Engineering Research & Technology, 2 (9), 2979-2986.
- Singh, R., Kumar, A., & Gupta, S. (2022). CFD analysis methodology for cascade refrigeration systems with R-30 and R-160 refrigerants investigating condenser performance. *International Journal of Refrigeration*, 142, 78-92.
- Sowjanya S.Lakshmi (2013). Thermal Analysis of a Car Air Conditioning System Based On an Absorption Refrigeration Cycle Using Energy from Exhaust Gas of an Internal Combustion Engine. Advanced Engineering and Applied Sciences: An International Journal, 3 (4), 47-53.
- Sreejith K.(2013). Experimental Investigation of A Domestic Refrigerator Having Water-Cooled Condenser Using Various Compressor Oils. International Journal Of Engineering And Science, 2 (5), 27-31.
- Thompson, R. J., & Wilson, K. M. (2024). Computational fluid dynamics simulation of SiO2 nanoparticles in air-conditioning systems for improving compressor oil performance and heat transfer capability. *International Journal of Heat and Mass Transfer*, 220, 124789.

- Vinícius Brandani Labigalini, and André Luiz Seixlack (2013) Modeling of a hot-wall condenser used in domestic refrigerators, 22nd International Congress of Mechanical Engineering.
- Walawade S. C., Barve B.R., & Kulkarni P. R. (2013) Design and Development of Waste Heat Recovery System for Domestic Refrigerator. Second International Conference on Emerging Trends in engineering, 28-32.
- Wang, S. K., & Chiang, C. H. (2000). *Handbook of air conditioning and refrigeration*. McGraw-Hill.
- Wilson, D. R., & Davis, M. E. (2019). 3D CFD simulation studies of air cooled condensers focusing on natural convection heat transfer over circular cylinder configurations. *Heat and Mass Transfer*, 55(8), 2234-2248.
- Yadva G. Maruthi Prasad, & Ranganna Suriya H (2015). Modeling and Analsis of a Compact Dynamic Model of Household Vapor Compression Refrigerated System, International Journal of Engineering Research and Management, 2 (2), 119-126.
- Yang, X., Kim, J. H., & Park, S. W. (2020). Integrated approach to transient simulation of large air cooled condensers using computational fluid dynamics for vapor compression refrigeration systems. *Applied Thermal Engineering*, 178, 115567.
- Zhang, L., Chen, M., & Wang, X. (2024). Experimental refrigeration systems performance analysis of R-404A to R-448A drop-in substitution through expansion valve optimization in vapor compression systems. *Applied Thermal Engineering*, 241, 122456.