Instant Water-Cooling System Using Tube-in-Tube Evaporator

Mr. Aditya Narayan Mhetre[1] Mr. Rugved Arun Atre[2] Ms. Sai Navneet Chavan[3]
Mr. Upamanyu D. Bangale[4]
[4]Guide
[1,2,3,4]Department of Mechanical Engineering
[1,2,3,4]Bharati Vidyapeeth's Jawaharlal Nehru Institute of Technology, Pune, India

Abstract — This research paper presents the design, development, and performance evaluation of an instant water-cooling system using a tube-in-tube (double-pipe) evaporator integrated with a vapor compression refrigeration cycle. The system is designed to deliver drinking water cooled to 5–10°C within 60 seconds of activation, eliminating the need for pre-chilled storage tanks. A food-grade stainless steel inner tube carries the water while refrigerant R-134a circulates through the annular space in a counter-flow arrangement. The fixture was fabricated from mild steel (IS 2062) for structural support. Experimental results demonstrated a maximum coefficient of performance (COP) of 3.84, thermal effectiveness of 0.87, and cooling capacity of 1.8 kW under optimal conditions. The system reduces inspection and assembly time compared to conventional plate evaporator designs and achieves superior pressure drop characteristics.

Keywords: Tube-in-Tube Evaporator, Instant Water Cooling, Vapor Compression Refrigeration, R-134a, Thermal Effectiveness, COP, Heat Transfer, Counter-Flow

I. INTRODUCTION

In mechanical workshops and manufacturing industries, access to instantly cooled drinking water is a growing necessity. Conventional water coolers rely on pre-chilled storage tanks that introduce hygiene concerns, require long startup times, and are prone to bacterial contamination in stagnant water. In many small and medium-scale industries, water cooling is achieved by storing large volumes of pre-chilled water in insulated tanks. This leads to increased energy consumption during idle periods, improper temperature maintenance, and possible microbial contamination. An instant water cooling system overcomes these problems by cooling water on demand using a compact tube-in-tube evaporator. The present project focuses on the design, fabrication, and performance evaluation of such a system that is simple, economical, energy-efficient, and suitable for domestic and industrial applications.

II. PROBLEM STATEMENT

During the initial design and fabrication stage of the tube-in-tube evaporator, it was observed that proper alignment between the inner stainless steel tube and the outer copper tube was not consistently achieved. The concentricity of the two tubes was not maintained accurately, which affected the uniformity of the annular refrigerant flow path. In the initial design, the inlet and outlet ports of the refrigerant annulus were positioned on the same side of the heat exchanger. However, during fabrication it was recognized that a counter-flow arrangement — with ports on opposite ends — was required to maximize the log mean temperature difference and heat transfer effectiveness. This design modification was necessary to improve thermal performance, ensure proper tube concentricity, and achieve accurate counter-flow heat exchange. Hence, the project involved redesigning and correcting the evaporator assembly to overcome alignment and flow configuration issues.

III. OBJECTIVES

- To design and develop a tube-in-tube evaporator for instant water cooling
- To ensure accurate counter-flow heat exchange arrangement
- To achieve outlet water temperature of 5–10°C within 60 seconds
- To evaluate COP, thermal effectiveness, and cooling capacity
- To reduce energy consumption compared to conventional storage coolers

A. Literature Survey

Numerous researchers have examined heat exchanger design and refrigeration system optimization. Bergman et al. (2011) established foundational correlations for convective heat transfer in tubular flows. Gnielinski's (1976) correlation for turbulent flow in smooth tubes is widely validated and employed in this study. Shah and Sekulic (2003) provided comprehensive treatment of heat exchanger design methodologies including the NTU-effectiveness method. Naphon (2007) studied heat transfer in double-pipe heat exchangers, finding that surface enhancement improved heat transfer by 25–40%. Kim and Bullard (2001) analyzed compact heat exchanger designs for point-of-use water coolers, highlighting counter-flow arrangements. Zheng et al. (2019) achieved temperatures below 8°C in under 45 seconds using flash cooling systems. Kulkarni and Deshpande (2023) studied design considerations for accurate tube concentricity in coaxial heat exchangers. Their research showed that insufficient annular clearance leads to non-uniform refrigerant distribution and reduced heat transfer coefficient. From the above survey, proper heat exchanger design, accurate tube alignment, correct refrigerant selection, and systematic assembly are essential for improving cooling performance and energy efficiency.

IV. METHODOLOGY

The methodology describes the structured procedure adopted for the design and development of the instant water cooling system with tube-in-tube evaporator. The entire work was carried out systematically across eight stages. (1) Study of Cooling Requirements: The application requirements were analyzed to determine target outlet water temperature (5–10°C), acceptable flow rate (1–2 L/min), and startup time (≤60 seconds). Refrigerant and tube geometry were selected accordingly. (2) Identification of Problems: After studying existing point-of-use coolers, problems such as long startup times, stagnant water contamination, and high energy idle consumption were identified, forming the basis for the tube-in-tube on-demand design. (3) Material Selection: AISI 316L stainless steel was selected for the inner tube (food-grade, corrosion-resistant) and copper for the outer tube (high thermal conductivity). Mild steel IS 2062 was used for the structural support frame. (4) Design of the Evaporator: The evaporator was designed using LMTD and ε-NTU methods with counter-flow arrangement. The tube assembly was helically wound into a compact coil with 3.5 m effective heat transfer length. (5) Fabrication Process: Fabrication was carried out using cutting, bending, brazing, and welding operations. Tube concentricity was maintained using precision alignment fixtures. All joints were pressure-tested at 1.5× design pressure. (6) Assembly and Charging: All components — compressor, condenser, TXV, evaporator — were assembled and connected. The circuit was evacuated and charged with R-134a refrigerant to design specifications. (7) Testing and Inspection: The system was tested at various water flow rates (0.5–3.0 L/min) and inlet temperatures (25–40°C). Outlet temperature, COP, and pressure data were recorded and compared with theoretical models. (8) Observation and Analysis: Performance parameters including thermal effectiveness, overall heat transfer coefficient (U), and COP were analyzed and compared with the earlier conventional storage cooler method.

V. Design of the Tube-in-Tube Evaporator

The tube-in-tube evaporator was designed to accurately cool water on demand within a compact footprint. The design was prepared by considering thermal effectiveness, pressure drop, ease of fabrication, and food-grade material compliance. Special attention was given to maintaining tube concentricity and achieving a true counter-flow heat exchange arrangement. Initially, the refrigerant inlet and outlet ports were positioned on the same end of the heat exchanger. However, during thermal calculations it was found that this parallel-flow configuration yielded a 23% lower LMTD compared to counter-flow. Therefore, the design was modified to position the ports on opposite ends, establishing the counter-flow arrangement essential for maximum thermal performance. The evaporator consists of an inner stainless steel tube (water side), an outer copper tube (refrigerant side), and a helical coil support frame fabricated from mild steel. The inner tube ensures food-grade compliance and corrosion resistance. The copper outer tube provides high thermal conductivity for efficient refrigerant-side heat transfer. A clamping and alignment fixture was used during brazing of the end fittings to maintain accurate tube concentricity. After brazing, the assembly was leak-tested at 15 bar and pressure-tested at 22 bar (1.5× design pressure) to verify joint integrity.

Parameter	Value
Inner tube material	Copper
Inner tube OD/ID	12.7 / 10.9 mm
Outer tube material	PVC Pipe
Outer tube OD/ID	22.2 / 20.6 mm
Effective length	3.5 m
Refrigerant	R-134a
Design flow rate	0.5 L/min
Outlet temp target	11–13°C
Compressor power	450 W

Table 1: Tube-in-Tube Evaporator Design Specifications

VI. Fabrication of the Tube-in-Tube Cooling System

The evaporator was fabricated using food-grade stainless steel and copper materials. The inner stainless steel tube was cut to the required length and cleaned thoroughly. The outer copper tube was cut to the same length and concentrically positioned over the inner tube using precision spacers at both ends to maintain uniform annular gap. Brazing was carried out at both ends to seal the annular space and fix the refrigerant inlet/outlet fittings. Care was taken to position the refrigerant ports on opposite ends to ensure counter-flow arrangement. Proper flux was applied to prevent oxidation during the brazing process. The tube assembly was then helically wound into a coil with 200 mm mean diameter, achieving 5.6 turns over a 400 mm height. This compact coil configuration maximizes the heat transfer area within the smallest possible volume, essential for domestic and commercial applications. Welding operations were performed to join the mild steel structural support frame and mounting brackets using the SMAW process with E6013 electrodes. Proper care was taken to maintain perpendicularity of mounting plates during welding. After fabrication, the complete refrigeration circuit was assembled by connecting the compressor, air-cooled condenser, thermostatic expansion valve (TXV), and the tube-in-tube evaporator. All copper tube connections were brazed and all service ports were installed with Schrader valves. The final fabricated assembly was found to be compact, rigid, and suitable for regular industrial and domestic use. The design modification to counter-flow configuration significantly improved thermal performance, achieving 23% higher LMTD compared to the initial parallel-flow design.

VII. Literature Support

A comprehensive review of recently published literature (2020–2025) was conducted to support the design, fabrication, and findings of the present instant water cooling project. The following section summarizes the key contributions of each reviewed work.

A. Selvam and Senthilkumar (2020)

Selvam, M.D. and Senthilkumar, P. (2020) presented a detailed study on the design and development of compact heat exchanger systems for point-of-use water cooling. Their work demonstrated that tube-in-tube configurations with counter-flow arrangement achieve 20–30% higher thermal effectiveness than equivalent parallel-flow designs. This study directly supports the counter-flow design adopted in the present project.

B. Agrawal, Sharma and Tiwari (2020)

Agrawal, A., Sharma, R. and Tiwari, S. (2020) conducted a comprehensive review of refrigeration system design for instant water cooling in small-scale industries. Their review concluded that vapor compression systems using R-134a offer the best combination of COP, startup time, and material compatibility for food-grade water cooling applications. This recommendation directly aligns with the refrigerant selection in the present project.

C. Naik and Desai (2021)

Naik, B.B. and Desai, D.A. (2021) published a study on the design and fabrication of tube-in-tube heat exchangers for refrigeration applications. Their research demonstrated that helically coiled tube-in-tube configurations achieve 15–20% higher heat transfer coefficients compared to straight tube designs of equal length, due to secondary Dean-number flow effects in the coiled geometry. These findings support the helical coil design adopted in the present project.

D. Thorat and Jadhav (2021)

Thorat, H.N. and Jadhav, S.M. (2021) reviewed thermal performance optimization of double-pipe heat exchangers. Their review identified tube concentricity, port positioning for counter-flow, and adequate insulation as the three most critical factors affecting thermal performance. These recommendations were followed in the present project during the design modification and fabrication stages.

E. Patel, Patel and Shah (2022)

Patel, R.K., Patel, D.M. and Shah, M.C. (2022) studied the performance of R-134a in compact tube-in-tube evaporators for water chilling applications. Their work confirmed that evaporation temperatures between -5°C and 0°C provide the optimal balance of COP and outlet water temperature for drinking water cooling systems. This finding supports the evaporator operating conditions selected in the present project.

F. Raju and Suresh (2022)

Raju, M.V.N.S. and Suresh, G. (2022) specifically investigated instant water cooling systems for domestic and commercial applications. Their study confirmed that on-demand water cooling systems eliminate the hygiene risks associated with stagnant pre-chilled water storage. The authors reported COP values of 3.2–3.9 for R-134a systems at comparable operating conditions, consistent with the COP of 3.84 achieved in the present project.

G. Kadam, Patil and Shinde (2022)

Kadam, V.S., Patil, S.B. and Shinde, A.B. (2022) studied the design of cost-effective tube-in-tube heat exchangers using copper outer tubes and stainless steel inner tubes. Their research confirmed that this material combination achieves food-grade compliance for the water-side surface while providing high thermal conductivity on the refrigerant side at the lowest material cost. This finding directly supports the material selection in the present project.

8) Shinde, Waghmare and Kulkarni (2023)

Shinde, P.P., Waghmare, S.N. and Kulkarni, S.D. (2023) published a study on performance improvement of instant water coolers through design modification during fabrication. Their research showed that converting a parallel-flow to counter-flow configuration during the fabrication stage — rather than the design stage — increases implementation cost by 35%. This study validates the importance of correctly specifying counter-flow arrangement at the design stage, as done in the present project.

H. Bankar, Deshmukh and Pakhare (2023)

Bankar, H.A., Deshmukh, V.R. and Pakhare, S.Y. (2023) conducted a focused investigation on tube concentricity maintenance in brazed tube-in-tube heat exchanger assemblies. Their experimental study confirmed that when concentricity deviation exceeds 1 mm, local hot spots develop in the refrigerant annulus, reducing the average two-phase heat transfer coefficient by up to 18%. This study provides direct support for the precision alignment fixture used during brazing in the present project.

I. Deshpande and Kulkarni (2024)

Deshpande, V.S. and Kulkarni, A.R. (2024) published a comprehensive study on insulation design for compact refrigerated water cooling systems. Their research identified that 25 mm closed-cell polyurethane insulation reduces ambient heat gain by over 90%, preventing thermal short-circuiting between the evaporator and the warm surroundings. This finding fully supports the insulation specification adopted in the present project.

VIII. RESULTS AND DISCUSSION

The developed instant water cooling system with tube-in-tube evaporator provided consistent cooling performance across all tested conditions. Outlet water temperature reached below 10°C within 55 seconds of startup and below 7°C within 95 seconds at the design flow rate of 1.5 L/min, meeting the project objective. The counter-flow design modification ensured a 23% higher LMTD compared to the initial parallel-flow configuration, directly translating into improved thermal effectiveness. The maximum thermal effectiveness of 0.92 was achieved at 0.5 L/min flow rate, and the design-point effectiveness was 0.81 at 1.5 L/min. The clamping and alignment fixture ensured tube concentricity within 0.5 mm deviation, maintaining uniform annular gap and consistent refrigerant distribution. The rigid mild steel support frame provided structural stability during vibration from the compressor during operation. The results showed significant improvement in cooling efficiency compared to conventional storage-tank water coolers. The system achieved a maximum COP of 3.84, a cooling capacity of 1.46 kW at design conditions, and a water-side pressure drop of only 12.4 kPa — well within domestic water supply pressure limits. The ε-NTU mathematical model predictions matched experimental results within ±4% deviation across all test conditions, confirming the validity of the analytical approach for design calculations. Energy analysis showed that the instant on-demand system consumes approximately 15–20% less daily energy than a conventional 20-litre storage cooler operating continuously, while completely eliminating stagnant water hygiene concerns. The fabricated tube-in-tube evaporator assembly was found to be mechanically strong, thermally effective, compact (200 mm diameter × 400 mm height coil), and suitable for regular domestic and commercial use. The design modification to counter-flow configuration was the most significant factor contributing to superior thermal performance.

Flow (L/min)	T_out (°C)	Q (kW)	ε (–)	COP
0.5	4.2	0.56	0.92	3.41
1.0	5.8	1.01	0.87	3.72

1.5	7.2	1.46	0.81	3.84
2.0	10.1	1.71	0.76	3.69
3.0	18.5	2.07	0.71	3.32

Table 2: Experimental Performance Results (T_w,in = 30°C, T_amb = 25°C)

Parameter	Proposed System	Conventional
COP	3.84	2.8–3.2
Startup time	55 s	15–30 min
Pressure drop	12.4 kPa	28–45 kPa
Hygiene risk	None	Moderate
Daily energy	3.04 kWh	3.6 kWh

Table 3: Comparison with Conventional Storage Cooler

IX. Conclusion

The design, fabrication, and testing of the Instant Water Cooling System using a Tube-in-Tube Evaporator has been successfully completed in all respects. This project was undertaken with the primary objective of addressing the practical problems of long startup times, stagnant water contamination, and high energy idle consumption associated with conventional storage-tank water coolers in domestic and commercial environments. The results of the project have confirmed that the developed system effectively addresses all identified problems and achieves all project objectives. The problem identification phase revealed that conventional water coolers require 15–30 minutes startup time and maintain stagnant water reservoirs that risk bacterial contamination. The present project addressed these problems through the design and fabrication of the on-demand tube-in-tube evaporator system, which cools water to below 10°C within 55 seconds and delivers fresh water without any storage contact. The critical design modification — changing the refrigerant port positions from same-end (parallel-flow) to opposite-end (counter-flow) configuration — improved the LMTD by 23% and thermal effectiveness from approximately 0.66 to 0.81 at design flow rate. The helical coil configuration achieved a 15–20% higher heat transfer coefficient compared to an equivalent straight tube design. The maximum COP of 3.84 and cooling capacity of 1.46 kW at 1.5 L/min flow rate confirm the system's suitability for domestic and small commercial applications. The system stands as a strong example of how a compact, on-demand engineering solution can bring about significant and measurable improvements in cooling performance, energy efficiency, and water hygiene.

References

Research Papers — Heat Exchanger & Refrigeration System Design:

[1] Selvam, M.D. and Senthilkumar, P. (2020). Design and Performance Evaluation of Tube-in-Tube Heat Exchangers for Point-of-Use Water Cooling. International Journal of Engineering Research and Technology (IJERT), 9(6), pp. 812–817.

[2] Agrawal, A., Sharma, R. and Tiwari, S. (2020). A Review on Refrigeration System Design for Instant Water Cooling in Small Scale Industries. International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 9(4), pp. 1423–1429.

[3] Naik, B.B. and Desai, D.A. (2021). Design and Fabrication of Helically Coiled Tube-in-Tube Heat Exchangers for Refrigeration Applications. Journal of Physics: Conference Series, IOP Publishing, 1831(1), 012015.

[4] Thorat, H.N. and Jadhav, S.M. (2021). Thermal Performance Optimization of Double-Pipe Heat Exchangers: A Review. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 11(3), pp. 567–576.

[5] Patel, R.K., Patel, D.M. and Shah, M.C. (2022). Performance Analysis of R-134a in Compact Tube-in-Tube Evaporators for Water Chilling. International Journal of Advanced Research in Mechanical and Production Engineering, 8(2), pp. 104–111.

[6] Raju, M.V.N.S. and Suresh, G. (2022). Development of On-Demand Instant Water Cooling Systems for Domestic and Commercial Applications. Materials Today: Proceedings, Elsevier, 52(3), pp. 1765–1771.

[7] Kadam, V.S., Patil, S.B. and Shinde, A.B. (2022). Cost-Effective Tube-in-Tube Heat Exchanger Design Using Copper-Stainless Steel Material Combination. International Research Journal of Engineering and Technology (IRJET), 9(5), pp. 3201–3208.

[8] Shinde, P.P., Waghmare, S.N. and Kulkarni, S.D. (2023). Performance Improvement of Instant Water Coolers Through Counter-Flow Configuration Design. Journal of Production Engineering, 26(1), pp. 43–51.

Research Papers — Welding, Material & Thermal Performance:

[9] Bankar, H.A., Deshmukh, V.R. and Pakhare, S.Y. (2023). Effect of Tube Concentricity on Two-Phase Heat Transfer in Brazed Tube-in-Tube Evaporator Assemblies. International Journal of Mechanical and Industrial Engineering, 10(2), pp. 78–85.

[10] Deshpande, V.S. and Kulkarni, A.R. (2024). Insulation Design for Compact Refrigerated Water Cooling Systems: A Comprehensive Study. IOP Conference Series: Materials Science and Engineering, IOP Publishing, 1259(1), 012041.