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# A Review On Vortex Tube Refrigiration System With Solar Energy

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**Abstract :** The Vortex Tube Refrigeration System is an eco-friendly cooling technology using compressed air, not electricity. High-pressure air is injected tangentially into a cylindrical chamber, creating a vortex that separates it into hot and cold streams. With no moving parts, it's reliable, low-maintenance, and sustainable. Ideal for industrial spot cooling, portable refrigeration, and emergency systems, it offers a viable alternative to traditional refrigeration in energy-scarce environments.

**Keywords:** Input air pressure, Nozzle geometry and tube dimensions are optimized to enhance cooling efficiency.

## 1. Introduction

The vortex tube is a device that separates compressed air into hot and cold streams without any moving parts. This system does not require electricity, making it highly suitable for off-grid and remote applications. The basic working fluid is compressed air, which enters the tube tangentially to create a vortex. Inside the tube, the air spins rapidly, creating temperature separation due to centrifugal force and energy transfer. The cold air exits from one end of the tube (center), and the hot air exits from the other end (periphery). Common materials for building vortex tubes include aluminum, stainless steel, or plastic. The device has no moving mechanical parts, so it is low-maintenance and durable. It is environmentally friendly, as it uses no refrigerants or chemicals. The efficiency depends on the inlet pressure, nozzle design, and geometry of the vortex chamber.

## 2. LITERATURE REVIEW :

1. The Ranque–Hilsch vortex tube (RHVT), introduced by Hilsch (1947), separates compressed air into hot and cold streams without moving parts. Performance depends on nozzle design, cold-end orifice, hot-end valve, and operating pressure. Studies highlight cold-mass fraction as a key factor influencing temperature drop and flow rate. Two-stage tubes improve cooling, while nozzle number, fluid type, and optimal orifice size enhance efficiency. CFD analyses link length-to-diameter ratios (8–35) with effective energy separation. Despite low COP compared to conventional systems, RHVTs are valued for simplicity, durability, and niche uses in spot cooling and hazardous environments.

2. Solar adsorption refrigeration has attracted extensive research due to its energy-saving and eco-friendly potential. Studies have examined solar-powered adsorption, absorption, and ejector-based systems to enhance efficiency and applicability. Nguyen investigated variable-geometry ejectors, while Arazazmeh et al. analyzed multi-effect systems. Samson et al. modeled adsorption cycles, and Zhao et al. integrated parabolic concentrators for improved heat collection. Ding et al. explored semiconductor-based devices, while Elakhdar et al. studied hybrid refrigeration–power systems. Research highlights challenges such as low efficiency, complex designs, and vacuum stability. Overall, solar adsorption refrigeration shows promise for sustainable cooling, especially in energy-scarce and environmentally sensitive regions.

3. Research on expansion devices in vapor compression systems highlights throttling losses in conventional valves and explores work-recovery alternatives. Robinson and Groll (1998) demonstrated efficiency gains using expanders, while ejector-based studies (Lawrence & Elbel, 2012) showed partial recovery potential. The Ranque–Hilsch vortex tube, discovered by Ranque (1930) and explained by Hilsch (1947), emerged as a robust device achieving temperature separation without moving parts. Experiments with air (Stephan et al., 1983) and refrigerants like R-22 and R134a (Wu et al., 2012) confirmed cooling potential, though efficiencies remain limited. Recent studies propose novel vortex tube cycles to enhance COP in HVAC&R applications

4. Vortex tube refrigeration has been widely studied for its simple design and temperature separation capability without moving parts. Aljuwayhel et al. (2005) applied CFD to analyze energy separation, highlighting effects of tube length and diameter. Wu et al. (2007) improved performance using modified nozzles and diffusers. Shamsoddini and Nezhad (2010) showed nozzle number affects cooling power, while Aydın and Baki (2006) optimized length, nozzle size, and valve angle. Nimbalkar and Müller (2009) identified optimal cold-orifice diameter, and Saidi & Yazdi (1999) used exergy analysis for efficiency. Overall, studies confirm inlet pressure, geometry, and cold fraction significantly influence performance.

5. Vortex tube refrigeration, discovered by Ranque (1933) and developed by Hilsch (1947), produces simultaneous hot and cold air streams using compressed gas without moving parts. Researchers have extensively studied parameters like nozzle diameter, orifice size, L/D ratio, tube length, and inlet pressure to optimize performance. Studies reveal that pressure, nozzle geometry, and cold mass fraction significantly influence temperature separation and cooling efficiency. Modified geometries such as conical tubes, diffusers, and optimized valve angles enhance results. Applications range from spot cooling in machining and welding to protective gear. Owing to its simplicity, durability, and eco-friendliness, vortex tube refrigeration shows potential as a sustainable alternative.

6. Research on capillary tubes in vapor compression systems emphasizes the influence of geometry on performance. Paliwal and Kant (2006) modeled helical coils, showing pressure drop and subcooling effects. Taib et al. (2010) analyzed domestic refrigerators, reporting COP ≈ 2.75. Park et al. (2008) simulated non-adiabatic tubes with suction-line heat exchangers, improving cycle performance. Dabas et al. (2011) highlighted transient behavior with varying tube lengths. Studies also compared refrigerants, with $NH_3$ showing highest COP (Tayde et al., 2013). Investigations on straight, helical, and serpentine tubes confirmed bore diameter, length, pitch, and coil number significantly affect mass flow rate, pressure drop, and COP.

7. The transcritical $CO_2$ refrigeration cycle has been widely studied as a sustainable alternative to HFC/HCFC systems due to its low GWP and ODP. Conventional expansion valves, however, cause high irreversible losses. Li et al. and Groll et al. proposed vortex tubes as substitutes, showing improved COP compared to throttling devices. Subsequent studies confirmed vortex tube geometry, cold mass fraction, and isentropic efficiency strongly affect performance. Liu et al. modeled a vortex tube–integrated $CO_2$ system, reporting COP improvements up to 33.7% under optimal conditions. Research highlights vortex tubes as promising for enhancing energy efficiency in $CO_2$-based refrigeration applications.

8. Research on vapor compression refrigeration (VCR) systems emphasizes efficiency improvements through alternative refrigerants and heat exchangers. R134a, a widely used refrigerant, faces phase-out due to high GWP, with R1234yf proposed as a low-GWP replacement. Studies by Akasaka (2010), Zilio (2011), and Navarro et al. (2019) compared R1234yf to R134a, showing slightly lower COP but environmental benefits. Investigations into microchannel condensers revealed enhanced heat transfer and reduced exergy losses compared to round tube designs. Recent experiments confirm that combining R1234yf with microchannel condensers improves cooling performance and exergetic efficiency, making it a promising substitute for R134a in sustainable refrigeration systems.

9. The Ranque–Hilsch vortex tube (RHVT), discovered by Ranque (1933) and later studied by Hilsch (1947), separates compressed air into hot and cold streams without moving parts. Research highlights geometry, nozzle design, and material selection as key factors influencing performance. Promvonge and Eiamsa-ard (2004) showed nozzle number enhances temperature separation, while Kargaran et al. identified optimum orifice diameter and L/D ratio. Chang et al. (2011) demonstrated improved results using divergent hot tubes. Material studies reveal PVC provides better cooling than copper, while brass and mild steel improve durability. Overall, investigations confirm that inlet pressure, nozzle geometry, and material selection significantly affect vortex tube efficiency.

10. The Ranque–Hilsch vortex tube (RHVT) has been extensively studied as a low-cost refrigeration device due to its simplicity and absence of moving parts. Researchers like Nimbalkar and Müller (2009) examined optimal orifice geometry, while Shamsoddini and Nezhad (2010) investigated nozzle effects on performance. CFD studies (Skye et al., 2006; Baghdad et al., 2011) validated flow behavior and energy separation using turbulence models, highlighting swirl velocity as a dominant factor. Curvature effects analyzed by Valipour (2011) and Bovand (2014) showed straight tubes outperform curved ones in efficiency. Overall, literature confirms that geometry, inlet pressure, and cold mass fraction strongly govern RHVT performance.

11. The literature review on vortex tube refrigeration highlights historical developments from Maxwell's 19th-century concept to Ranque's 1928 discovery and Hilsch's 1945 experiments on thermal performance. Key studies include Takamasa (1965-1981) on efficiency formulas, Kurosaka (1982) on acoustic streaming, and Stephan et al. (1983) on temperature profiles. Later works by Gutsol (1997), Frohlingsdorf and Unger (1998), and Behera et al. (2008) used CFD for energy separation analysis. Recent experiments by Sahu et al., Bornare et al., Bidwaik et al., Chatterjee et al., Karthik, and Vali et al. focus on geometrical parameters like nozzle design, spinner angles, and inlet pressure to optimize COP and temperature differences.

12. The literature review on vortex tube expansion in vapor compression refrigeration systems highlights thermodynamic analyses by Li et al. (2006), showing up to 37% COP gains in transcritical CO2 cycles, and Sarkar (2010) optimizing discharge pressure for Maurer and Keller models. Early experiments by Hooper and Ambrose (1973) replaced throttles with vortex tubes, while Han et al. (2013) tested refrigerants like R728, R744, and R134a, noting property influences on separation. Numerical studies (Table 1) from Linderstrom-Lang (1964) to Eiamsa-ard and Promvonge (2006) used k-ε, ASM, and RNG models, yielding fair to good predictions of flow and temperature fields.

13. The literature review in this paper surveys the development and application of solar collectors for vapour absorption refrigeration systems, focusing on various collector types such as flat-plate, parabolic dish, evacuated tube, parabolic trough, and Fresnel lens collectors. It summarizes research on collector design, efficiency improvements, and suitability for different temperature ranges and cycles (single or double effect). Previous studies have often evaluated collector performance in solar heating and cooling, showing that combinations of evacuated tube and parabolic collectors may offer superior results, and highlighting solar energy's potential for cost-effective and environmentally friendly refrigeration applications.

14. The literature review on vortex tube refrigeration highlights Ranque's 1932 discovery and Hilsch's 1945 experiments on thermal performance with varying pressures and geometries. Recent studies recognize its low-cost, effective cooling for electronics and food, leveraging its simplicity and reliability. Patil et al. (2019) explored a vortex tube with a thermoelectric module, enhancing efficiency. Liu and Yu (2018) reviewed its use in vapor compression cycles, noting COP improvements with refrigerants like CO2. Dhuwe and Kale (2018) investigated spinner geometry effects on COP, using CFD analysis to optimize performance.

15. The literature review on the Ranque-Hilsch Vortex Tube (RHVT) traces its origins to Ranque's 1930s discovery, with Hilsch's 1945 experiments enhancing its efficiency, achieving -50°C cold and 100°C hot temperatures. Westley, Kalvinskas, and Takahama explored flow dynamics, while Ahlborn measured velocity profiles. Haqqani and Azizuddin (2019) reviewed its cooling applications, emphasizing its simplicity and no-moving-parts design. Liu and Yu (2018) analyzed its use in vapor compression cycles, noting COP improvements with refrigerants. Dhuwe and Kale (2018) studied spinner geometry effects on COP using CFD, optimizing performance.

16. The literature review on the theoretical design of a solar-powered vapor absorption refrigeration system with latent heat energy storage highlights Raut et al.'s (2021) work, proposing a 1 kW system using an evacuated tube collector and latent heat storage for continuous operation. Yadav and Saikhedkar (2017) surveyed solar collectors like flat-plate and parabolic types for absorption systems, noting their efficiency. Liu and Yu (2018) explored vortex tube expansion in vapor compression, improving COP. Haqqani and Azizuddin (2019) reviewed RHVT applications, emphasizing its simplicity for cooling, supported by historical studies from Ranque and Hilsch.

17. The literature review on vortex tube applications in refrigeration cycles traces Nellis and Klein's (2002) exploration of vortex tubes as alternatives to throttling valves, noting efficiency gains in Joule-Thomson cycles but limited impact on vapor compression systems. Liu and Yu (2018) reviewed vortex tube expansion in vapor compression, highlighting COP improvements with refrigerants like CO2. Dhuwe and

Kale (2018) investigated spinner geometry effects on COP using CFD. Haqqani and Azizuddin (2019) emphasized RHVT's simplicity for cooling, while Ranque's 1930s discovery and Hilsch's 1945 experiments laid foundational insights.

18. The literature review on vortex tube refrigeration systems highlights Giri’s (2018) review, noting Aljuwayhel et al.’s (2005) CFD study on energy separation via viscous shear, with optimal tube length enhancing performance. Nellis and Klein (2002) explored vortex tubes in refrigeration cycles, finding limited gains in vapor compression but potential in Joule-Thomson systems. Liu and Yu (2018) reviewed vortex tube expansion in vapor compression, improving COP with refrigerants like CO2. Dhuwe and Kale (2018) used CFD to study spinner geometry effects on COP, while Haqqani and Azizuddin (2019) emphasized RHVT’s industrial cooling applications.

19. The paper "A Kind of Refrigerant System Design Combined with Knudsen Compressor and Vortex Tube" by Xiang Wang et al. (2018) explores a novel refrigeration system leveraging the Knudsen compressor's boost effect and the vortex tube's cooling capability. Building on Knudsen's thermal transpiration principle (1909) and Gupta's advancements in micro-machined pumps (2012-2014), the study proposes an energy-efficient system driven by low-grade waste heat. It cites Reynolds (1879) for gas flow theory and Vargo et al. (1999) for Knudsen compressor applications. The literature highlights the system's potential for industrial cooling, supported by prior research on micro-scale gas dynamics and energy separation.

20. The paper "An Experimental Performance Study of Vortex Tube Refrigeration System" by Sankar Ram T. and Anish Raj K. (2013) investigates the Ranque-Hilsch effect, building on Ranque’s (1933) and Hilsch’s (1947) foundational work on vortex tube cooling. It references Soni and Thomson (1975) for optimal design parameters and Behera et al. (2005) for CFD analysis. The study explores temperature separation influenced by mass flow rates, nozzle design, and tube geometry, supported by experimental data. Earlier works by Kurosaka (1982) and Takahama (1981) on acoustic streaming and energy separation further contextualize the research.

21. The paper "Numerical Simulations of Cryogenic Hydrogen Cooling in Vortex Tubes with Smooth Transitions" by Matveev and Leachman (2021) builds on Ranque’s (1933) and Hilsch’s (1947) vortex tube discoveries, advancing cryogenic hydrogen cooling efficiency. It cites prior work on parametric optimization [8], complex systems [9,10], and air-based vortex tubes [12-18], noting small efficiency gains. CFD studies [19-24] inform the use of the Redlich-Kwong model for hydrogen at 70 K, enhancing accuracy. The study extends prior conference findings [25], focusing on smooth transitions to improve cooling performance.

22. The paper "Modeling and thermal analysis of a solar thermoelectric generator with vortex tube for hybrid vehicle" by Mtopi Fotso et al. (2019) builds on solar thermoelectric energy conversion research [1], emphasizing automotive applications [2,3]. It leverages vortex tube cooling, rooted in Ranque-Hilsch effect studies, and integrates thermoelectric generator (TEG) technology for hybrid vehicles. The work draws on prior TEG efficiency studies and vortex tube performance analyses, enhancing energy recovery from solar flux and vehicle heat, supported by thermodynamic modeling and experimental data.

23. The paper "Multifaceted analytical and computational fluid dynamics investigations of vortex tube technology for the optimization of seawater desalination efficiency" by Mina A. Saad et al. (2025) builds on

Ranque's (1933) and Hilsch's (1947) vortex tube research, advancing its application in desalination. It draws on computational studies [1-4, 7-9] and experimental work by Syed et al. (2011) and Chen et al. (2012) on hydrogen separation, enhancing energy efficiency. The study integrates single-effect evaporation technology, leveraging vortex tubes for pre-cooling, supported by CFD analysis using ANSYS Fluent.

24. The paper "Design and Development of a Cooling System for a Vaccine Container by using Vortex Tube Refrigeration" by Sagar Swami et al. (2022) builds on vortex tube refrigeration research. It cites Voronchikhin and Tuev (2012) for portable thermostatic units, Sharma et al. (2010) for energy separation studies, and Nellis and Klein (2005) for throttling valve optimization. Zhai (2018) and Bidwaik and Dhavale (2015) contribute mine cooling and pressure-temperature insights, while Reddy and Govindarajulu (2017) explore vehicle air conditioning, motivating this vaccine preservation system using CFD analysis.

25. The paper "Experimental Analysis of Vortex Tube Made of Homogeneous Wood" by K. Kiran Kumar Rao et al. (2016) builds on Ranque's (1932, 1934) and Hilsch's (1945) foundational vortex tube research. It references Gulyaev (1950) for length-to-diameter ratios, Soni and Thompson (1975) for optimal L/D, and Singh et al. (2004) for nozzle design impacts. Balmer (1980) and Dincer et al. (2008) explore heat separation and valve angles, while Behera et al. (2005) link secondary flow to cold-end design. Kun Chang et al. (2011) and Nimbalkar et al. (2009) enhance performance with divergent tubes and orifice optimization.

26. The paper "Three-Dimensional CFD Simulation of Fluid Flow inside a Vortex Tube on Basis of an Experimental Model- The Optimization of Vortex Chamber Radius" by S. E. Rafiee and M. M. Sadeghiazad (2016) builds on Ranque's (1932, 1934) and Hilsch's (1945) foundational vortex tube research. It leverages CFD modeling, informed by prior studies on turbulent flow and energy separation, to optimize vortex chamber radius. The work aligns with experimental validations from earlier literature, enhancing cooling efficiency, and draws on established insights into geometrical impacts on vortex tube performance.

27. The research on vortex tube technology and its applications in refrigeration systems spans several studies, focusing on innovative designs and performance enhancements. Xiang Wang et al. (2018) proposed a refrigerant system integrating Knudsen compressors and vortex tubes, driven by waste heat, showcasing energy savings. Sankar Ram T. and Anish Raj K. (2013) experimentally studied vortex tube refrigeration, analyzing the Ranque-Hilsch effect. Matveev and Leachman (2021) used CFD to optimize cryogenic hydrogen cooling in vortex tubes with smooth transitions, improving efficiency by 7%. Mtopi Fotso et al. (2019) modeled a solar thermoelectric generator with vortex tubes for hybrid vehicles, achieving 147.3 W power. Saad et al. (2025) explored vortex tubes for seawater desalination, achieving 3.5 kg/day productivity. Swami (2022) developed a vortex tube cooling system for vaccine containers, optimizing for 276 K. Rao et al. (2016) tested wooden vortex tubes, focusing on L/D ratios. Rafiee and Sadeghiazad (2016) optimized vortex chamber radius via CFD, increasing cold temperature difference by 6.3%. Kumar et al. (2014) improved vortex tube performance with conical hot tubes, boosting COP by 25-30%. These studies collectively advance vortex tube applications in refrigeration, desalination, and energy systems, emphasizing efficiency and environmental benefits.

28. The paper "Device for separation of vortex gas-dynamic energy" by A.I. Leontiev and S.A. Burtsev (2015) proposes a hybrid device combining Ranque-Hilsch vortex tube mechanisms with gas-dynamic energy separation for supersonic flows. Building on early temperature stratification studies [1-2] and vortex tube research [9-11], it critiques the Fulton model [12] and highlights heat exchange impacts [11]. The study develops a calculation method, demonstrating a 1.3 times higher cooling depth than vortex tubes and three times that of gas-dynamic devices when using natural gas, advancing energy separation efficiency.

29. The paper "Numerical Study on the Effect of Geometrical Parameters on the Performance of Vortex Tube Cooling Device Using SIMFLOW" by Mohd Hazwan bin Yusof et al. (2016) investigates the impact of cold outlet diameter (4-5 mm) and hot tube length (175-194 mm) on a 10 mm inner diameter vortex tube using SIMFLOW 2.1. Building on Ranque's (1933, 1934) and Hilsch's (1947) foundational work, it draws from Saidi et al. (2005) on exergy analysis, Dutta et al. (2005) on CFD energy separation, and Behera et al. (2005) on CFD simulations. The study identifies 4 mm cold outlet diameter and 175 mm hot tube length as optimal, enhancing cooling efficiency.

30. The paper "An Experimental Study of the Effect of Pressure Inlet Gas on a Counter-Flow Vortex Tube" by Mahyar Kargaran and Mahmood Farzaneh-Gord (2013) investigates the impact of inlet pressure and tube length on vortex tube performance using air as a working fluid. Building on Ranque's (1932, 1934) and Hilsch's (1947) foundational work, it draws from Nimbalkar and Muller (2009) on cold-end orifice optimization, Dincer et al. (2009) on plug design, Stephan et al. (1983) on length effects, and Saidi and Valipour (2003) on parameter classification. The study aims to enhance thermal efficiency for industrial cooling applications.

31. The paper "An Investigation of the Effect of the Hot End Plugs on the Efficiency of the Ranque-Hilsch Vortex Tube" by Maziar Arjomandi and Yunpeng Xue (2007) examines how hot-end plug design impacts vortex tube efficiency. Building on Ranque's (1932, 1934) and Hilsch's (1947) foundational work, it explores temperature separation optimization. The study tests various plug configurations experimentally, enhancing energy separation and cooling performance. It draws on prior research by Lay (1959) and Gao (2005) on flow dynamics, contributing to improved vortex tube applications in refrigeration and industrial cooling systems.

32. The paper "Effect of Orifice and Pressure of Counter Flow Vortex Tube" by J. Prabakaran and S. Vaidyanathan (2010) investigates the impact of orifice diameter (5-7 mm) and inlet pressure (4-7 bar) on the performance of a counter-flow vortex tube with a 12 mm diameter and 240 mm length. Building on Ranque's (1933) and Hilsch's (1947) foundational work, it draws from Lay (1959), Soni and Thomson (1975), Hartnet and Eckert (1957), Gao (2005), Behera et al. (2005), Arjomandi and Yenpeng (2007), and Kirmaci (2009) to optimize vortex tube design for enhanced cooling efficiency in spot cooling applications.

33. The paper "CFD investigation of a vortex tube: Effect of the cold end orifice in the temperature separation mechanism" by Ons Tlili et al. (2011) uses computational fluid dynamics to study the impact of cold-end orifice design on vortex tube performance. Building on Ranque's (1933) and Hilsch's (1947) pioneering work, it draws from prior CFD analyses by Behera et al. (2005) and experimental studies by Nimbalkar and Muller (2009) on orifice geometry. The research explores how orifice size influences

temperature separation, contributing to optimizing vortex tube efficiency for refrigeration and industrial cooling applications.

34. The paper "Design & Analysis Vortex Tube Refrigeration System" by Abhinav Giri and Dr. Piyush Jaiswal (2020) investigates the impact of variable hot-end geometries, specifically inline conical valve angle and tip diameter, on vortex tube performance. Building on Ranque's (1933) and Hilsch's (1947) foundational work, it draws from studies like Arjomandi and Xue (2007) on hot-end plug design and Behera et al. (2005) on CFD simulations. Three vortex tubes were designed and tested experimentally to maximize temperature drop, focusing on geometrical parameters to enhance energy separation efficiency for cooling and heating applications.

35. The paper "An Experimental Investigation of the Optimum Geometry for Energy Separation of the Ranque-Hilsch Vortex Tube" by Abdellah Ahmed (2014) explores optimal geometrical parameters for enhancing energy separation in vortex tubes. Building on Ranque's (1933, 1934) and Hilsch's (1947) foundational work, it draws from studies like Soni and Thomson (1975) on design expressions, Behera et al. (2005) on CFD simulations, and Arjomandi and Xue (2007) on hot-end plug optimization. The experimental study focuses on parameters like tube length, diameter, and orifice size to maximize temperature separation, contributing to improved vortex tube efficiency for industrial cooling applications.

36. The paper "An experimental study on the effect of geometrical parameters on the performance of a vortex tube" by Mahyar Kargaran and Mahmood Farzaneh-Gord (2013) investigates the impact of geometrical parameters, specifically cold orifice diameter to inlet diameter (d/D) and length to inlet diameter (L/D) ratios, on vortex tube performance using air as the working fluid. Building on Ranque's (1932, 1934) and Hilsch's (1947) foundational work, it draws from prior studies like Soni and Thomson (1975) and Behera et al. (2005) on design optimization and CFD analysis. The experimental results propose optimal d/D and L/D ratios to maximize temperature separation efficiency for industrial cooling applications.

37. The paper "Heat and Mass Transfer Between Cold and Hot Vortex Cores inside Ranque-Hilsch Vortex Tube-Optimization of Hot Tube Length" by Seyed Ehsan Rafiee and M. M. Sadeghiazad (2016) uses 3D CFD models to study the effect of hot tube length (95-125 mm) on vortex tube thermal performance. Building on Ranque's (1933) and Hilsch's (1947) work, it draws from Dutta et al. (2010) on NIST real gas models, and Baghdad et al. (2011) and Rafiee and Sadeghiazad (2015) on turbulence models. The study identifies 115 mm as the optimal hot tube length for maximum cooling and heating efficiency, validated against experimental data with less than 7% error.

38. The paper "A Review on Vortex Tube Refrigeration System" by Shrikrushna Nagane et al. (2015) synthesizes research on vortex tube performance, focusing on geometrical and operational parameters. It draws on Deepak Patel's (2013) work on maximizing COP through experimental analysis, SarathSasi's (2014) optimization of nozzle count and material (noting PVC's superior temperature difference), and Manujendra Sharma's (2014) study on counter-flow vortex tube geometry, including tube length, diameter, and nozzle variations. Building on Ranque's (1933) and Hilsch's (1947) foundational work, the review highlights vortex tubes' advantages—simplicity, no moving parts, and environmental friendliness—for industrial cooling applications.

39. The literature review of this paper highlights previous studies on vortex tubes, focusing on their geometry and flow mechanisms, especially through computational and experimental investigations. Researchers have used CFD modelling and turbulence models such as RNG k-ε to explore temperature separation and energy transfer within vortex tubes, examining geometric effects like diameter, length, nozzle number, and hot tube shape. Most studies agree that divergent hot tubes enhance cooling performance over straight or convergent designs, but detailed 3D numerical analysis for divergent and convergent tubes is limited, motivating the current investigation.

40. The literature review in this paper discusses the development and operation of vortex tube refrigeration systems as an alternative to conventional refrigeration, emphasizing their environmental advantages due to the absence of refrigerants like CFCs. It covers fundamental studies on vortex tube working principles, temperature separation mechanisms, and influencing parameters such as tube geometry, diameter, orifice size, and nozzle number. Researchers have found that increasing inlet nozzles and optimizing geometric features enhance temperature separation, and the vortex tube's application is beneficial in personal cooling systems and environmentally safe refrigeration, though its effectiveness compared to vapor compression cycles is generally limited.

## 3. CONCLUSION :

Vortex tube refrigeration systems, leveraging the Ranque-Hilsch effect, offer a simple, eco-friendly alternative for spot cooling, producing hot and cold streams without moving parts or harmful refrigerants. Their performance hinges on optimizing geometric (nozzle, tube length, orifice diameter) and operational (inlet pressure, cold mass fraction) parameters, with studies showing enhanced cooling at higher pressures and optimal cold fractions (~60–70%). Integration with solar-powered vapor absorption systems or Knudsen compressors boosts sustainability, achieving COPs up to 0.875. Despite low standalone efficiency, advancements in materials, CFD modeling, and hybrid systems promise broader applications in industrial and cryogenic cooling.

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