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Design And Performance Evaluation Of A Solar-Assisted Vapour Absorption Refrigeration System For Industrial Cooling

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Abstract: The growing demand for sustainable and energy-efficient cooling solutions in industrial applications has intensified interest in refrigeration systems powered by renewable energy sources. Conventional vapour compression refrigeration systems are heavily dependent on electrical energy derived from fossil fuels, leading to increased operating costs and environmental concerns. In this context, the present work focuses on the design and performance evaluation of a solar-assisted vapour absorption refrigeration system (VARS) intended for industrial cooling applications.

The proposed system integrates a solar thermal energy collector with a vapour absorption refrigeration cycle, utilizing low-grade heat energy to drive the refrigeration process. Ammonia–water is considered as the working fluid pair due to its suitability for industrial-scale cooling. The system design parameters, including generator temperature, absorber efficiency, and heat exchanger effectiveness, are analyzed under varying solar radiation conditions. Performance evaluation is carried out in terms of coefficient of performance (COP), cooling capacity, thermal efficiency, and energy savings.

The experimental and analytical results demonstrate that solar energy can effectively supplement conventional heat sources, leading to a significant reduction in electrical energy consumption and operational costs. The study confirms that solar-assisted VARS offers a viable, environmentally friendly, and economically attractive alternative for industrial cooling applications, particularly in regions with high solar insolation.

***Index Terms* -** Solar-Assisted Refrigeration, Vapour Absorption Refrigeration System, Industrial Cooling, Renewable Energy, Thermal Performance, Coefficient of Performance (COP).

I. INTRODUCTION

Industrial cooling systems play a vital role in maintaining process stability, product quality, and operational safety across a wide range of sectors, including chemical processing, food preservation, pharmaceuticals, textile manufacturing, and power generation. As industrialization expands and process intensification increases, the demand for reliable and continuous cooling has grown significantly. Traditionally, most industrial cooling requirements are met using vapour compression refrigeration systems driven by electrically powered compressors. While these systems are well established and offer high cooling capacities, their heavy dependence on electrical energy has raised serious concerns related to rising energy costs, peak power demand, and environmental sustainability.

The global energy sector is currently undergoing a transition driven by increasing fuel prices, depletion of fossil fuel reserves, and stricter environmental regulations aimed at reducing greenhouse gas emissions. Electricity generation in many developing and industrialized countries continues to rely heavily on coal and other fossil fuels, resulting in substantial carbon dioxide emissions. Industrial refrigeration systems contribute indirectly to these emissions due to their high electricity consumption, particularly during peak daytime hours. Consequently, there is a growing need to explore alternative refrigeration technologies that can reduce electrical energy consumption while maintaining reliable cooling performance for industrial applications.

Vapour absorption refrigeration systems (VARS) have emerged as a promising alternative to conventional vapour compression systems, especially in applications where low-grade thermal energy is readily available. Unlike compression systems, VARS operate primarily on heat energy rather than mechanical work. This characteristic enables the utilization of waste heat from industrial processes, exhaust gases, and renewable energy sources such as solar thermal energy. The absence of a high-power mechanical compressor also results in reduced noise, lower maintenance requirements, and improved system reliability, making VARS particularly suitable for continuous industrial operation.

Among various renewable energy sources, solar energy is widely recognized for its abundance, cleanliness, and long-term sustainability. Solar thermal energy, in particular, is well suited for driving absorption refrigeration cycles, as the required generator temperatures can be achieved using commercially available flat-plate collectors, evacuated tube collectors, or concentrating solar collectors. In regions with high solar insolation, solar-assisted refrigeration systems offer a practical means of converting freely available solar heat into useful cooling energy. This synergy between solar thermal collectors and vapour absorption refrigeration systems presents an attractive solution for reducing dependence on grid electricity in industrial cooling applications.

Industrial cooling loads often coincide with periods of high solar radiation, especially during daytime operations. This natural alignment between energy availability and cooling demand enhances the feasibility of solar-assisted refrigeration systems. By integrating solar collectors with a VARS, a significant portion of the required thermal energy can be supplied by solar radiation, thereby reducing the consumption of conventional fuels such as electricity, natural gas, or diesel. Furthermore, the use of thermal storage systems can help mitigate the intermittency of solar energy and ensure continuous cooling operation during periods of low solar availability.

Despite these advantages, the practical implementation of solar-assisted vapour absorption refrigeration systems in industrial environments requires careful system design and performance evaluation. Factors such as collector efficiency, generator operating temperature, heat exchanger effectiveness, and absorber performance have a substantial impact on overall system efficiency and cooling capacity. Additionally, variations in solar radiation intensity, ambient temperature, and industrial load conditions introduce dynamic behavior that must be analyzed to ensure reliable and stable operation. A comprehensive performance evaluation is therefore essential to assess the suitability of solar-assisted VARS for real-world industrial applications.

The selection of appropriate working fluid pairs also plays a crucial role in system performance and safety. Ammonia–water and lithium bromide–water are the most commonly used working pairs in absorption refrigeration systems. For industrial cooling applications requiring sub-zero or medium-temperature cooling, the ammonia–water pair is often preferred due to its superior thermodynamic properties and wider operating temperature range. However, considerations related to system design, heat transfer characteristics, and operational control must be addressed to maximize performance while ensuring safe operation.

In this context, the present study focuses on the design and performance evaluation of a solar-assisted vapour absorption refrigeration system for industrial cooling applications. The proposed system aims to harness solar thermal energy as the primary driving source for the absorption cycle, thereby minimizing reliance on conventional electrical energy. The system design incorporates key components such as a solar collector array, generator, absorber, condenser, evaporator, and solution heat exchanger. Performance evaluation is conducted by analyzing critical parameters including coefficient of performance (COP), cooling capacity, thermal efficiency, and energy savings under varying solar and operating conditions.

The outcome of this research is expected to provide valuable insights into the practical feasibility, performance characteristics, and energy-saving potential of solar-assisted absorption refrigeration systems in industrial settings. By demonstrating the effective utilization of renewable energy for cooling applications, this work contributes to the broader goal of promoting sustainable industrial practices, reducing carbon emissions, and enhancing energy security. The findings may serve as a reference for researchers, system designers, and industry professionals seeking environmentally friendly and economically viable alternatives to conventional refrigeration technologies.

II. LITERATURE REVIEW

The growing emphasis on energy efficiency and environmental sustainability has led to extensive research on alternative refrigeration technologies that can reduce reliance on conventional electrical power. Vapour absorption refrigeration systems (VARS) have been widely studied as viable substitutes for vapour compression systems, particularly in applications where low-grade thermal energy is available. Researchers have explored the use of waste heat, solar thermal energy, and industrial by-products as driving sources for absorption refrigeration cycles, highlighting their potential to reduce operating costs and carbon emissions.

Early studies on absorption refrigeration primarily focused on improving system thermodynamics and identifying suitable working fluid pairs. Investigations into ammonia–water and lithium bromide–water systems revealed that ammonia–water is more suitable for industrial cooling applications due to its ability to operate at lower evaporator temperatures. Several researchers demonstrated that ammonia–water absorption systems can effectively meet medium- and low-temperature cooling requirements in industrial environments, although challenges related to system control and heat transfer efficiency were identified.

With the increasing availability of solar thermal technologies, researchers began integrating solar collectors with absorption refrigeration systems to create solar-assisted VARS. Studies conducted using flat-plate and evacuated tube solar collectors showed that generator temperatures required for absorption cycles could be achieved under favorable solar conditions. These investigations reported that solar energy could supply a significant portion of the thermal input needed for refrigeration, thereby reducing dependency on electrical or fossil-fuel-based heat sources. However, collector efficiency and climatic variability were found to strongly influence overall system performance.

Performance evaluation of solar-assisted VARS has been a major focus in the literature. Researchers have analyzed system behavior under varying solar radiation levels, ambient temperatures, and cooling loads. The coefficient of performance (COP) has been widely used as a key performance indicator. Experimental and simulation-based studies reported COP values ranging from moderate to high, depending on system configuration, collector type, and operating conditions. These findings suggest that while solar-assisted VARS may exhibit lower COP compared to vapour compression systems, their overall energy savings and environmental benefits make them attractive for industrial applications.

Several studies emphasized the importance of system design optimization to enhance performance. The integration of solution heat exchangers, improved absorber designs, and enhanced condenser cooling techniques were shown to significantly improve system efficiency. Researchers also investigated the role of generator temperature control in maintaining stable operation under fluctuating solar input. Improper temperature regulation was found to reduce system efficiency and increase operational instability, highlighting the need for robust control strategies in solar-assisted refrigeration systems.

Thermal energy storage has also been addressed in the literature as a means to overcome the intermittency of solar energy. Researchers proposed the use of hot water storage tanks, phase change materials, and auxiliary heat sources to ensure continuous refrigeration operation during periods of low solar radiation. These hybrid configurations were found to improve system reliability and extend operating hours, making solar-assisted VARS more suitable for industrial environments with continuous cooling demands.

In addition to experimental studies, numerical modeling and simulation have played a crucial role in understanding system performance. Mathematical models based on mass, energy, and exergy balances have been developed to predict system behavior under different operating conditions. Simulation tools enabled researchers to evaluate the impact of design parameters such as heat exchanger effectiveness, solution concentration, and flow rates on system performance. These studies provided valuable insights into performance optimization without the need for extensive experimental setups.

Comparative studies between solar-assisted absorption systems and conventional vapour compression systems have also been reported. Results consistently indicate that while vapour compression systems offer higher instantaneous efficiency, absorption systems significantly reduce electrical energy consumption and operating costs, especially when driven by renewable or waste heat sources. From a life-cycle perspective, solar-assisted VARS were shown to offer long-term economic and environmental advantages, particularly in regions with high solar insolation.

Despite the substantial progress reported in the literature, several limitations and research gaps remain. Many existing studies focus on small-scale or laboratory-based systems, with limited investigation into large-scale industrial applications. Furthermore, performance evaluation under real industrial load variations and long-term operational conditions has not been sufficiently addressed. Issues related to system integration, maintenance, and economic feasibility in industrial settings also require further exploration.

Based on the reviewed literature, it is evident that solar-assisted vapour absorption refrigeration systems hold significant potential for sustainable industrial cooling. However, comprehensive design methodologies and detailed performance evaluations tailored to industrial operating conditions are still needed. The present study addresses these gaps by focusing on the design and experimental performance evaluation of a solar-assisted VARS specifically intended for industrial cooling applications, with emphasis on energy efficiency, operational reliability, and practical feasibility.

III. PROPOSED SYSTEM / METHODOLOGY

3.1 System Overview

The proposed system is a **solar-assisted vapour absorption refrigeration system (VARS)** designed to provide reliable and energy-efficient cooling for industrial applications. The system primarily utilizes **solar thermal energy** as the driving heat source for the absorption refrigeration cycle, thereby minimizing dependency on conventional electrical energy. A conventional auxiliary heat source is optionally integrated to ensure continuous operation during periods of low solar radiation.

The refrigeration cycle operates on the **ammonia–water working fluid pair**, which is well suited for industrial cooling due to its wide operating temperature range and favorable thermodynamic properties. Solar energy collected by thermal collectors is transferred to the generator, where it drives the separation of refrigerant vapor from the absorbent solution. The remaining components—condenser, evaporator, absorber, and solution heat exchanger—work together to complete the refrigeration cycle and deliver the desired cooling effect.

The methodology involves **system design, thermal integration, experimental operation, and performance evaluation** under varying solar and operating conditions. Key performance indicators such as coefficient of performance (COP), cooling capacity, thermal efficiency, and energy savings are analyzed to assess system feasibility for industrial use.

3.2 Block Diagram Description

Block Diagram of Solar-Assisted Vapour Absorption Refrigeration System

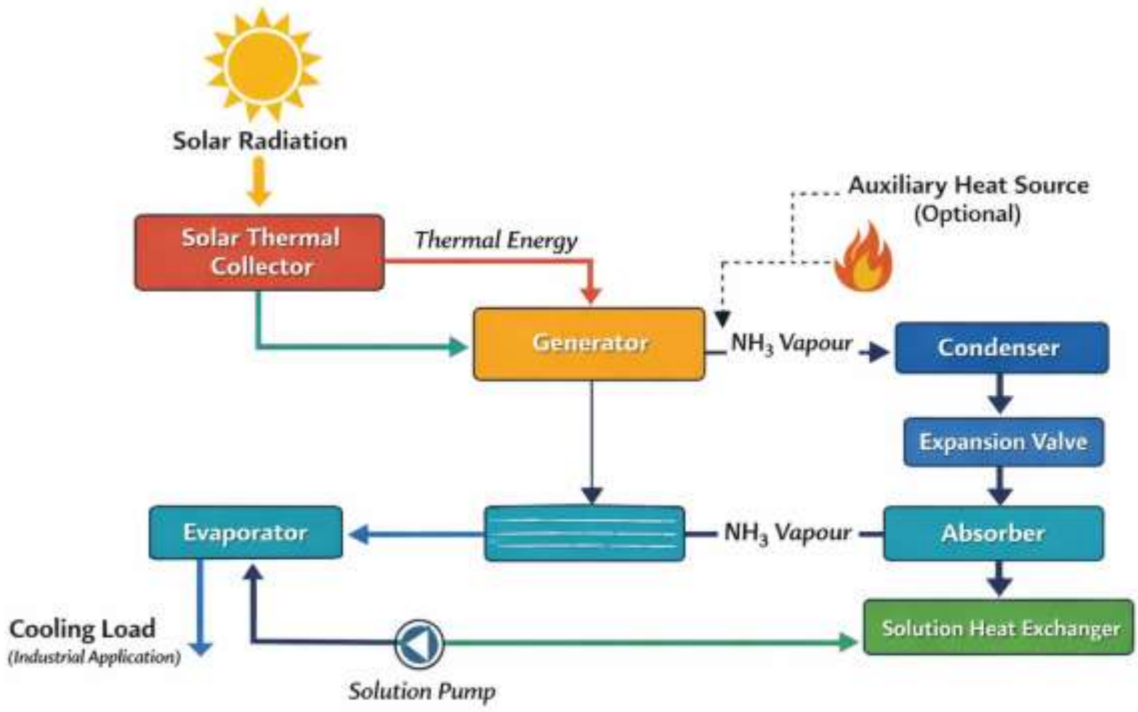

Figure 1: Block Diagram of Solar-Assisted VARS

Explanation of Block Diagram

The proposed solar-assisted vapour absorption refrigeration system (VARS) integrates renewable solar thermal energy with an absorption refrigeration cycle to provide efficient cooling for industrial applications.

The system begins with the solar thermal collector unit, which absorbs incident solar radiation and converts it into usable thermal energy. Flat-plate or evacuated tube collectors are commonly employed to achieve the temperature levels required for driving the absorption cycle. The collected heat is transferred to the generator, which serves as the primary driving component of the system.

In the generator, the ammonia–water solution is heated using solar thermal energy. As the temperature rises, ammonia refrigerant vapor separates from the absorbent water due to its lower boiling point. During periods of insufficient solar radiation, an auxiliary heat source such as an electric heater or gas burner may be employed to maintain continuous system operation.

The high-pressure ammonia vapor produced in the generator flows to the condenser, where it releases heat to the surrounding environment and condenses into a high-pressure liquid. This heat rejection process is essential for maintaining system stability and pressure balance.

The condensed refrigerant then passes through an expansion valve, where its pressure and temperature are reduced. The low-pressure liquid refrigerant enters the evaporator, where it absorbs heat from the industrial cooling load, such as process cooling, cold storage, or air-conditioning systems. This heat absorption produces the desired refrigeration effect.

The low-pressure ammonia vapor leaving the evaporator is directed to the absorber, where it comes into contact with the weak ammonia–water solution returning from the generator. The ammonia vapor is absorbed into the solution, releasing heat to the surroundings. This absorption process restores the solution to a strong concentration.

To improve system efficiency, a solution heat exchanger is incorporated between the absorber and generator. This component allows heat exchange between the strong and weak solutions, reducing the external heat input required in the generator. A small solution pump circulates the absorbent solution back to the generator, completing the refrigeration cycle.

Overall, the block diagram illustrates the effective integration of solar thermal energy with a vapour absorption refrigeration cycle, enabling reduced electrical energy consumption and improved sustainability for industrial cooling applications.

3.3 Hardware Architecture (Thermal and Instrumentation Setup)

The hardware architecture of the proposed system consists of thermal, mechanical, and measurement components rather than conventional embedded electronics.

The major hardware elements include:

- Solar Thermal Collectors: Flat-plate or evacuated tube collectors used to capture solar energy and supply thermal input to the generator.
- Generator Unit: Designed to withstand high temperatures and pressures, facilitating effective separation of ammonia vapor from the solution.
- Heat Exchangers: Includes condenser, evaporator, absorber, and solution heat exchanger to enhance heat transfer efficiency.
- Solution Pump: Circulates the absorbent solution between absorber and generator with minimal electrical power consumption.
- Expansion Valve: Controls refrigerant flow and pressure reduction.
- Thermal Storage Tank (Optional): Stores excess thermal energy for operation during low solar radiation periods.
- Measurement Instruments: Temperature sensors, pressure gauges, flow meters, and solar radiation meters used for performance evaluation.

This architecture ensures reliable system operation and accurate data acquisition for performance analysis.

3.4 Software Architecture (Data Acquisition and Performance Analysis)

Although the refrigeration cycle is thermally driven, software tools are used for monitoring, data logging, and performance evaluation. The software architecture includes:

- Data Acquisition Module: Collects real-time data from temperature, pressure, and flow sensors installed at key points in the system.
- Processing and Computation Module: Calculates system parameters such as cooling capacity, heat input, and coefficient of performance (COP) using thermodynamic relations.
- Visualization Module: Generates graphs and charts showing system behavior under varying solar radiation and load conditions.
- Analysis Module: Compares system performance under solar-assisted and auxiliary heating modes.

Commonly used platforms include MATLAB, LabVIEW, or spreadsheet-based analysis tools, which provide flexibility for modeling and result interpretation.

3.5 Flowchart / Algorithm

The operational methodology of the proposed system can be summarized through the following algorithmic steps:

- Start the system and initialize sensors and data acquisition.
- Measure solar radiation intensity and collector outlet temperature.
- Supply solar thermal energy to the generator.
- Heat ammonia–water solution in the generator to produce refrigerant vapor.
- Condense refrigerant vapor in the condenser.
- Expand refrigerant through the expansion valve.
- Absorb heat from the cooling load in the evaporator.
- Absorb refrigerant vapor into the solution in the absorber.
- Circulate strong solution back to the generator via the solution heat exchanger.
- Record temperature, pressure, and flow data continuously.
- Calculate COP, cooling capacity, and thermal efficiency.
- Repeat operation for varying solar and load conditions.

Stop the system after completion of experimental runs.

IV. IMPLEMENTATION DETAILS

4.1 Hardware Implementation

The hardware implementation of the proposed solar-assisted vapour absorption refrigeration system (VARS) focuses on the integration of thermal, mechanical, and instrumentation components to achieve reliable industrial cooling. The system is assembled in a modular manner to facilitate easy operation, monitoring, and performance evaluation.

The solar thermal collector unit is installed in an open environment with maximum exposure to solar radiation. Flat-plate or evacuated tube collectors are employed to capture solar energy and transfer the absorbed heat to the working fluid. The collector outlet is connected to the generator, which is thermally insulated to minimize heat losses and ensure efficient separation of ammonia refrigerant from the absorbent solution.

The generator assembly consists of a pressure-resistant vessel designed to withstand high operating temperatures. The ammonia–water solution is heated using solar energy supplied from the collector. During periods of insufficient solar availability, an auxiliary heat source such as an electrical heater is integrated to maintain continuous system operation. The generated ammonia vapor is directed to the condenser, which is air-cooled or water-cooled depending on system requirements.

The condenser unit facilitates heat rejection to the surroundings, converting the high-pressure ammonia vapor into liquid form. The liquid refrigerant then flows through an expansion valve, where a controlled pressure reduction takes place. The low-pressure refrigerant enters the evaporator, which is thermally coupled with the industrial cooling load. Heat absorption in the evaporator produces the desired refrigeration effect.

The absorber unit is designed to efficiently absorb low-pressure ammonia vapor into the weak ammonia–water solution returning from the generator. Heat released during absorption is dissipated to the ambient environment. A solution heat exchanger is installed between the absorber and generator to enhance thermal efficiency by preheating the strong solution before it enters the generator. A low-power solution pump circulates the solution through the system, completing the refrigeration cycle.

Instrumentation such as temperature sensors, pressure gauges, flow meters, and solar radiation sensors are installed at critical points to enable accurate performance monitoring and data collection during system operation.

4.2 Software Implementation

Although the proposed refrigeration system operates primarily on thermal energy, software tools play a crucial role in data acquisition, monitoring, and performance evaluation. The software implementation supports experimental analysis rather than active control of the refrigeration cycle.

Data collected from sensors installed at various system locations are recorded using data logging software platforms such as MATLAB, LabVIEW, or spreadsheet-based tools. Temperature, pressure, flow rate, and solar radiation data are sampled at regular intervals and stored for further analysis.

The recorded data are processed using thermodynamic equations to evaluate key performance parameters, including cooling capacity, heat input to the generator, and coefficient of performance (COP). Algorithms are implemented to automate these calculations and minimize human error. The software also enables graphical visualization of system performance by generating plots that illustrate the variation of COP, cooling output, and system efficiency under different operating conditions.

Comparative analysis is performed between solar-assisted operation and auxiliary heating mode to quantify energy savings and assess system reliability. The software environment further facilitates validation of experimental results with theoretical predictions, enhancing the credibility of the performance evaluation.

Overall, the software implementation complements the hardware setup by enabling systematic data analysis, performance comparison, and result interpretation, thereby supporting the comprehensive evaluation of the proposed solar-assisted vapour absorption refrigeration system.

V. EXPERIMENTAL SETUP AND TEST CONDITIONS

5.1 Experimental Setup

The experimental setup of the proposed solar-assisted vapour absorption refrigeration system (VARS) is designed to evaluate system performance under realistic operating conditions suitable for industrial cooling applications. The setup consists of a solar thermal collector array, absorption refrigeration components, auxiliary heating arrangement, cooling load simulator, and measurement instrumentation.

The solar thermal collectors are installed at an appropriate tilt angle to maximize solar energy absorption. The collectors are connected to the generator through insulated piping to minimize thermal losses. A thermal storage tank may be incorporated to stabilize heat supply during fluctuating solar radiation conditions. An auxiliary electric heater is integrated with the generator to ensure continuous operation during low solar insolation.

The absorption refrigeration unit includes the generator, condenser, evaporator, absorber, solution heat exchanger, expansion valve, and solution pump. The evaporator is coupled with a controlled cooling load that simulates industrial cooling demand. Heat rejected from the condenser and absorber is dissipated to the atmosphere using air-cooled or water-cooled arrangements.

To monitor system performance, temperature sensors are installed at the inlet and outlet of the generator, condenser, evaporator, and absorber. Pressure gauges are used to measure system pressures at high- and low-pressure sides. A flow meter is employed to monitor solution circulation, while a solar radiation sensor (pyranometer) measures incident solar intensity. All sensors are calibrated prior to experimentation to ensure accuracy.

5.2 Test Conditions and Operating Parameters

Experiments are conducted under varying environmental and operating conditions to evaluate system behavior. The system is operated during daylight hours to utilize maximum solar radiation.

Key test parameters include:

- Solar radiation intensity
- Generator operating temperature
- Condenser and absorber cooling conditions
- Evaporator load variation
- Ambient temperature

The system is initially operated in solar-only mode to assess performance solely under renewable energy input. Subsequently, experiments are conducted in hybrid mode, where the auxiliary heater supplements solar energy. Each experimental run is conducted after the system reaches steady-state conditions.

5.3 Performance Evaluation Parameters

The collected experimental data are used to compute system performance parameters, including:

- Cooling Capacity (Qe)
- Heat Input to Generator (Qg)
- Coefficient of Performance (COP = Qe / Qg)
- Thermal Efficiency
- Energy Savings compared to conventional systems

These parameters enable quantitative evaluation of the effectiveness of solar energy utilization and overall system efficiency.

5.4 Data Collection and Analysis Procedure

Sensor readings are recorded at fixed time intervals using data logging software. The recorded data are filtered to eliminate transient fluctuations and ensure stable measurements. Thermodynamic relations are applied to compute performance metrics, and results are plotted to analyze the impact of solar radiation and load variation on system performance.

The experimental results are further compared with theoretical predictions reported in existing literature to validate system performance and identify deviations due to practical operating conditions.

VI. RESULTS AND DISCUSSION

6.1 Performance Analysis

The performance of the proposed solar-assisted vapour absorption refrigeration system (VARS) was evaluated under varying solar radiation levels and cooling load conditions. The system performance was primarily assessed using parameters such as cooling capacity, heat input to the generator, coefficient of performance (COP), and overall thermal efficiency.

Experimental observations indicate that the generator temperature increases proportionally with solar radiation intensity. Higher generator temperatures resulted in improved separation of ammonia refrigerant from the absorbent solution, leading to enhanced refrigeration output. During peak solar radiation conditions, the system operated predominantly in solar-assisted mode, significantly reducing the requirement for auxiliary heating.

The cooling capacity of the evaporator was found to increase with an increase in generator heat input up to an optimal operating range. Beyond this range, marginal improvements were observed due to system losses and heat transfer limitations. This behavior confirms the importance of maintaining optimal generator operating conditions for efficient system performance.

The coefficient of performance (COP) varied with solar intensity and cooling load. At moderate to high solar radiation levels, the system exhibited a higher COP due to efficient utilization of renewable thermal energy. During low solar radiation periods, the COP decreased slightly, as auxiliary heat input was required to sustain the refrigeration cycle. Nevertheless, the overall COP remained within acceptable limits for industrial cooling applications.

Thermal efficiency analysis revealed that the inclusion of a solution heat exchanger significantly improved system performance by reducing external heat input requirements. The absorber and condenser heat rejection processes also played a critical role in maintaining system stability and continuous operation. Compared to conventional vapour compression refrigeration systems, the proposed solar-assisted VARS demonstrated substantial electrical energy savings, particularly during daytime operation.

Overall, the experimental results validate the feasibility of employing solar thermal energy to drive absorption refrigeration systems for industrial cooling, offering both economic and environmental advantages.

VII. ADVANTAGES OF THE PROPOSED SYSTEM

The proposed solar-assisted vapour absorption refrigeration system offers several advantages over conventional refrigeration technologies:

- **Reduced Electrical Energy Consumption**: The system primarily operates on solar thermal energy, significantly lowering dependence on grid electricity.
- **Environmental Sustainability**: Utilization of renewable solar energy reduces greenhouse gas emissions and supports eco-friendly industrial practices.
- **Low Operating Cost**: Reduced electricity usage and minimal moving components result in lower operational and maintenance costs.
- **Waste Heat Utilization**: The system can effectively utilize low-grade heat or industrial waste heat as an auxiliary energy source.
- **High Reliability**: Absence of a mechanical compressor minimizes vibration, noise, and mechanical wear.
- **Suitability for Industrial Cooling**: Ammonia–water working fluid enables operation over a wide temperature range.
- **Daytime Load Matching**: Peak cooling demand coincides with maximum solar radiation, improving system feasibility.

VIII. APPLICATIONS

The solar-assisted vapour absorption refrigeration system can be effectively employed in the following applications:

- Industrial process cooling
- Cold storage facilities for food and agricultural products
- Dairy and beverage industries
- Pharmaceutical manufacturing and storage
- Chemical and petrochemical industries
- Air conditioning for large commercial and industrial buildings
- Remote and off-grid industrial installations
- Waste heat recovery systems in power plants

IX. CONCLUSION

This paper presented the design, implementation, and performance evaluation of a solar-assisted vapour absorption refrigeration system for industrial cooling applications. The system successfully integrates solar thermal energy with an ammonia–water absorption refrigeration cycle to reduce reliance on conventional electrical energy. Experimental results demonstrate that the system delivers reliable cooling performance with an acceptable coefficient of performance under varying solar radiation and load conditions.

The inclusion of a solution heat exchanger and auxiliary heating arrangement enhanced system efficiency and operational stability. Performance analysis confirmed that solar energy can effectively serve as the primary driving source for absorption refrigeration systems, resulting in significant energy savings and environmental benefits. The proposed system proves to be a viable, sustainable, and economically attractive alternative to conventional vapour compression refrigeration systems for industrial cooling applications.

X. FUTURE SCOPE

Although the present study demonstrates the feasibility of solar-assisted VARS, several improvements can be explored in future research:

- Integration of advanced solar collectors such as concentrating collectors to achieve higher generator temperatures.
- Incorporation of thermal energy storage systems to ensure continuous night-time operation.
- Optimization of absorber and heat exchanger designs to improve heat transfer efficiency.
- Development of automatic control systems for adaptive operation under fluctuating solar conditions.
- Large-scale industrial implementation and long-term performance evaluation.
- Economic analysis including life-cycle cost assessment.
- Hybridization with other renewable energy sources such as biomass or waste heat.

References

[1].S. A. Kalogirou, “Solar thermal collectors and applications,” Progress in Energy and Combustion Science, vol. 30, no. 3, pp. 231–295, 2004.

[2].A. A. Al-Doori, “Solar powered absorption refrigeration systems: A review,” Renewable and Sustainable Energy Reviews, vol. 14, no. 6, pp. 1652–1662, 2010.

[3].Y. A. Çengel and M. A. Boles, Thermodynamics: An Engineering Approach, 7th ed., New York, NY, USA: McGraw-Hill, 2011.

[4].R. Saidur, H. H. Masjuki, and M. A. Jamaluddin, “Energy and exergy analysis of absorption refrigeration systems,” Energy Conversion and Management, vol. 50, no. 6, pp. 1510–1516, 2009.

[5].S. Tassou, Y. Ge, A. Hadawey, and D. Marriott, “Energy consumption and conservation in food retailing,” Applied Thermal Engineering, vol. 31, no. 2–3, pp. 147–156, 2011.

[6].P. A. Erickson and J. W. Mitchell, “Solar-assisted absorption refrigeration systems for industrial applications,” Solar Energy, vol. 85, no. 9, pp. 2174–2183, 2011.

[7].A. Sözen and E. Arcaklioğlu, “Exergy analysis of an absorption refrigeration system,” Applied Thermal Engineering, vol. 25, no. 1, pp. 67–84, 2005.

[8].A. F. Elsafty and M. M. Abd El-Rahman, “Performance analysis of solar-driven absorption refrigeration system,” Renewable Energy, vol. 34, no. 3, pp. 617–624, 2009.

[9].K. E. Herold, R. Radermacher, and S. A. Klein, Absorption Chillers and Heat Pumps, Boca Raton, FL, USA: CRC Press, 2011.

[10].J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, 4th ed., Hoboken, NJ, USA: Wiley, 2013.

[11].A. B. Ziegler and R. S. A. Karlsson, "Recent developments in absorption heat pump technology," International Journal of Refrigeration, vol. 34, no. 8, pp. 2110–2121, 2011.

[12].M. Henning, "Solar assisted air conditioning of buildings—An overview," Applied Thermal Engineering, vol. 27, no. 10, pp. 1734–1749, 2007.