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THERMODYNAMIC PERFORMANCE ANALYSIS OF SOLAR DRIVEN LIBR H_2O ABSORPTION REFRIGERATION SYSTEM FOR SUSTAINABLE COOLING APPLICATIONS

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ABSTRACT

The rapid growth in global cooling demand has resulted in a significant increase in electricity consumption and environmental concerns associated with conventional refrigeration technologies. Vapor compression refrigeration systems are widely used in residential and industrial applications; however, these systems require substantial electrical energy and utilize refrigerants that contribute to global warming and environmental pollution. Consequently, the development of sustainable and energy-efficient refrigeration technologies has become an important research focus in recent years.

Solar driven absorption refrigeration systems have emerged as promising alternatives because they can operate using renewable thermal energy instead of mechanical compression. These systems utilize solar thermal collectors to supply heat energy to the generator of the absorption refrigeration cycle, thereby reducing dependence on conventional electricity-based cooling technologies.

In this study, a thermodynamic performance analysis of a solar driven absorption refrigeration system using lithium bromide–water (LiBr–H_2O) as the working fluid pair is presented. A mathematical model of the system is developed using mass and energy balance equations applied to different components of the absorption refrigeration cycle. The system performance is evaluated using key parameters including coefficient of performance (COP), refrigeration effect, heat input to the generator, and solar collector efficiency.

Parametric analysis is carried out to investigate the influence of operating parameters such as generator temperature, evaporator temperature, condenser temperature, and solar radiation intensity on system performance. The results indicate that the coefficient of performance increases with increasing generator temperature and evaporator temperature, while higher condenser temperatures reduce overall system efficiency.

The findings of this study demonstrate that solar driven absorption refrigeration systems possess significant potential for sustainable cooling applications by utilizing renewable solar energy and reducing environmental impact.

KEYWORDS: Solar Absorption Refrigeration, Solar Thermal Energy, LiBr–H_2O Working Pair, Thermodynamic Analysis, Renewable Energy Cooling, Coefficient of Performance (COP).

1. INTRODUCTION

The demand for refrigeration and air-conditioning systems has increased significantly in recent decades due to rapid urbanization, industrial development, and rising living standards. Cooling technologies are widely used in residential buildings, commercial facilities, industrial processes, food preservation, and medical storage applications. Conventional refrigeration systems mainly operate based on the vapor compression refrigeration cycle, which requires mechanical energy to compress the refrigerant and circulate it through the cooling cycle [1].

Although vapor compression refrigeration systems are widely used due to their high efficiency and reliable operation, they consume a large amount of electrical energy. Studies indicate that refrigeration and air-conditioning systems account for a significant portion of global electricity consumption worldwide [2]. This increasing demand for cooling has raised serious concerns regarding energy sustainability and environmental impact.

Another major issue associated with conventional refrigeration technologies is the use of refrigerants with high global warming potential. Leakage of such refrigerants into the atmosphere contributes to greenhouse gas emissions and climate change. As a result, researchers have been focusing on developing alternative refrigeration technologies that utilize renewable energy sources and environmentally friendly working fluids [3].

Among various alternative cooling technologies, absorption refrigeration systems have gained considerable attention because they can operate using thermal energy instead of mechanical compression. Absorption refrigeration systems utilize a refrigerant–absorbent pair to produce cooling through absorption and desorption processes [4].

Solar energy is considered one of the most promising renewable energy sources for refrigeration applications because of its abundance and environmental benefits. Solar driven absorption refrigeration systems integrate solar thermal collectors with absorption refrigeration cycles to utilize solar thermal energy as the heat source for the generator [5].

Basic Refrigeration Cycle

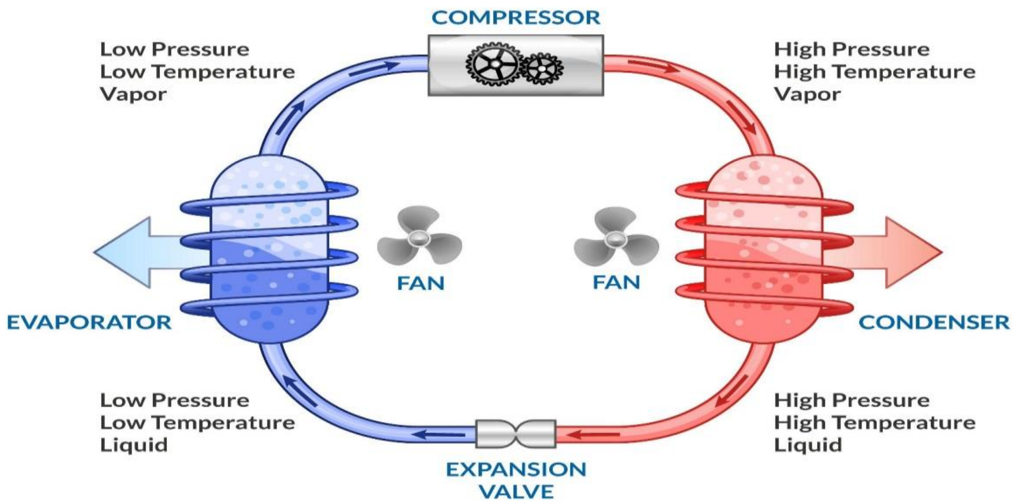


Figure 1.1 Basic refrigeration cycle showing compressor, condenser, expansion valve, and evaporator.

The basic refrigeration cycle consists of four main components: compressor, condenser, expansion valve, and evaporator. In this cycle, the refrigerant absorbs heat from the refrigerated space in the evaporator and releases heat to the surroundings in the condenser. The compressor increases the pressure and temperature of the refrigerant, while the expansion valve reduces the pressure before the refrigerant enters the evaporator again [6].

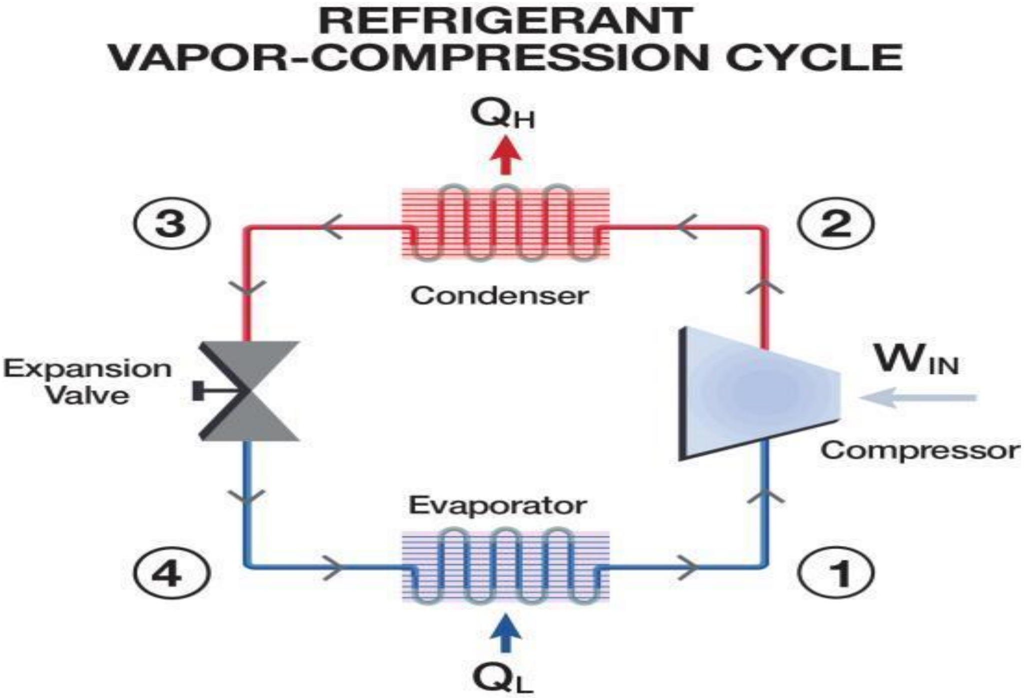


Figure 1.2 Schematic diagram of vapor compression refrigeration system .

The vapor compression refrigeration system is the most widely used refrigeration technology. It operates by circulating refrigerant through a closed thermodynamic cycle consisting of compression, condensation, expansion, and evaporation processes. Despite its high efficiency, the system requires significant electrical energy for compressor operation and contributes to environmental concerns due to refrigerant leakage [7].

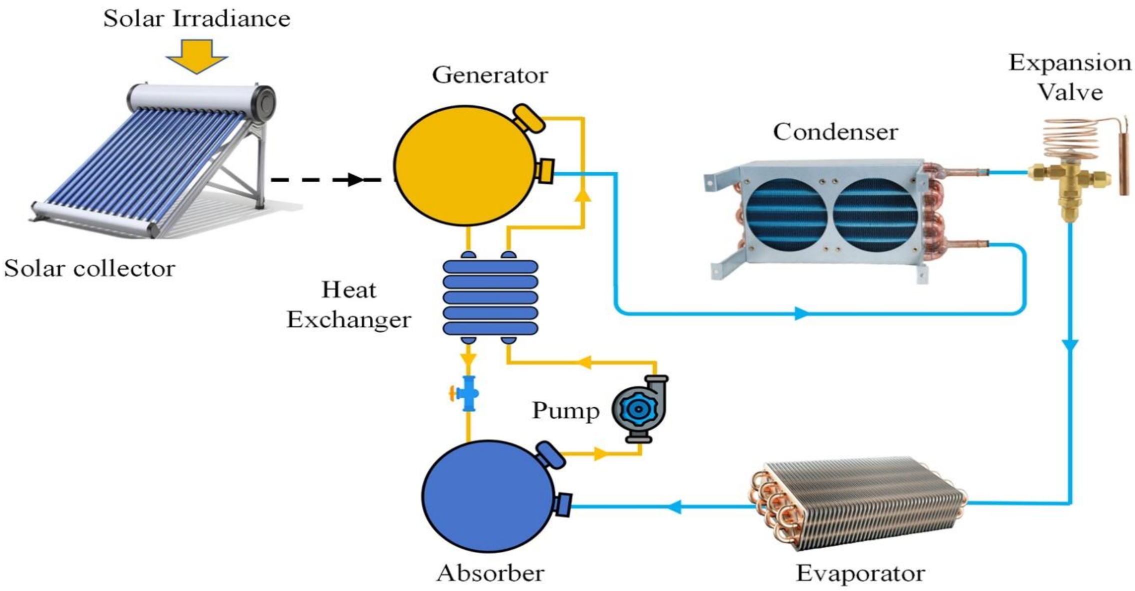


Figure 1.3 Solar driven absorption refrigeration system integrating solar collector with absorption refrigeration cycle.

A solar driven absorption refrigeration system uses solar thermal energy to operate the absorption refrigeration cycle. In this system, solar collectors capture solar radiation and convert it into thermal energy. This thermal energy is supplied to the generator of the absorption refrigeration system to separate refrigerant vapor from the absorbent solution.

The main components of the system include generator, condenser, evaporator, absorber, expansion valve, and solution pump. Solar absorption refrigeration systems are considered environmentally friendly because they utilize renewable solar energy instead of conventional electricity-driven compressors [8].

2. LITERATURE REVIEW

In recent years, significant research has been carried out on solar driven absorption refrigeration systems due to their potential for sustainable and energy-efficient cooling applications. These systems utilize low-grade thermal energy, particularly solar energy, to operate refrigeration cycles, thereby reducing dependence on conventional electricity-driven vapor compression systems.

Wang et al. (2022) analyzed the thermodynamic performance of LiBr–H_2O absorption refrigeration systems and reported that generator temperature plays a crucial role in determining system efficiency. Their study indicated that higher generator temperatures enhance refrigerant separation, leading to an increase in the coefficient of performance (COP).

Chen et al. (2023) conducted a detailed study on solar absorption refrigeration systems integrated with flat plate and evacuated tube collectors. The results showed that solar collector efficiency significantly influences the heat input to the generator and overall system performance. The study emphasized the importance of optimizing collector design for improved efficiency.

Patel et al. (2023) investigated the environmental impact of conventional and renewable refrigeration technologies. Their findings highlighted that absorption refrigeration systems using renewable energy sources such as solar energy can significantly reduce greenhouse gas emissions and environmental pollution compared to traditional systems.

Kumar et al. (2024) evaluated the performance characteristics of solar driven absorption refrigeration systems under varying operating conditions. The study demonstrated that the coefficient of performance increases with increasing evaporator temperature, while excessive condenser temperatures negatively affect system efficiency.

Singh et al. (2025) focused on solar thermal driven refrigeration systems and analyzed the influence of condenser temperature on system performance. The results indicated that higher condenser temperatures increase system pressure and reduce heat rejection efficiency, thereby decreasing COP.

Kaushik et al. (2024) presented a thermodynamic analysis of absorption refrigeration systems and highlighted the importance of working fluid selection. The LiBr–H_2O pair was found to be highly suitable for air-conditioning and cooling applications due to its favorable thermodynamic properties and environmental compatibility.

Oubourhim et al. (2025) reviewed recent advancements in solar assisted absorption refrigeration systems and concluded that integrating thermal energy storage systems can improve system reliability during periods of low solar radiation.

Despite the extensive research available in this field, there is still a need for comprehensive thermodynamic analysis considering multiple operating parameters simultaneously. Most of the existing studies focus on individual parameters, whereas a combined parametric analysis can provide better insights into system optimization.

Therefore, the present study aims to perform a detailed thermodynamic performance analysis of a solar driven LiBr–H_2O absorption refrigeration system by evaluating the effects of generator temperature, evaporator temperature, condenser temperature, and solar radiation intensity on system performance.

3. METHODOLOGY

The present study focuses on the thermodynamic performance analysis of a solar driven absorption refrigeration system using mathematical modeling and parametric analysis. The objective of this research is to evaluate the performance of the system under different operating conditions and identify optimal parameters for improving system efficiency.

The proposed system integrates a solar thermal collector with an absorption refrigeration cycle. Solar radiation is captured by the solar collector and converted into thermal energy. This thermal energy is supplied to the generator of the absorption refrigeration system to separate refrigerant vapor from the absorbent solution.

The thermodynamic behavior of the system is analyzed using mass balance and energy balance equations applied to different components of the absorption refrigeration cycle including the generator, condenser, evaporator, and absorber.

The performance of the system is evaluated using key parameters such as coefficient of performance (COP), refrigeration effect, generator heat input, and solar collector efficiency.

Research Methodology Flowchart

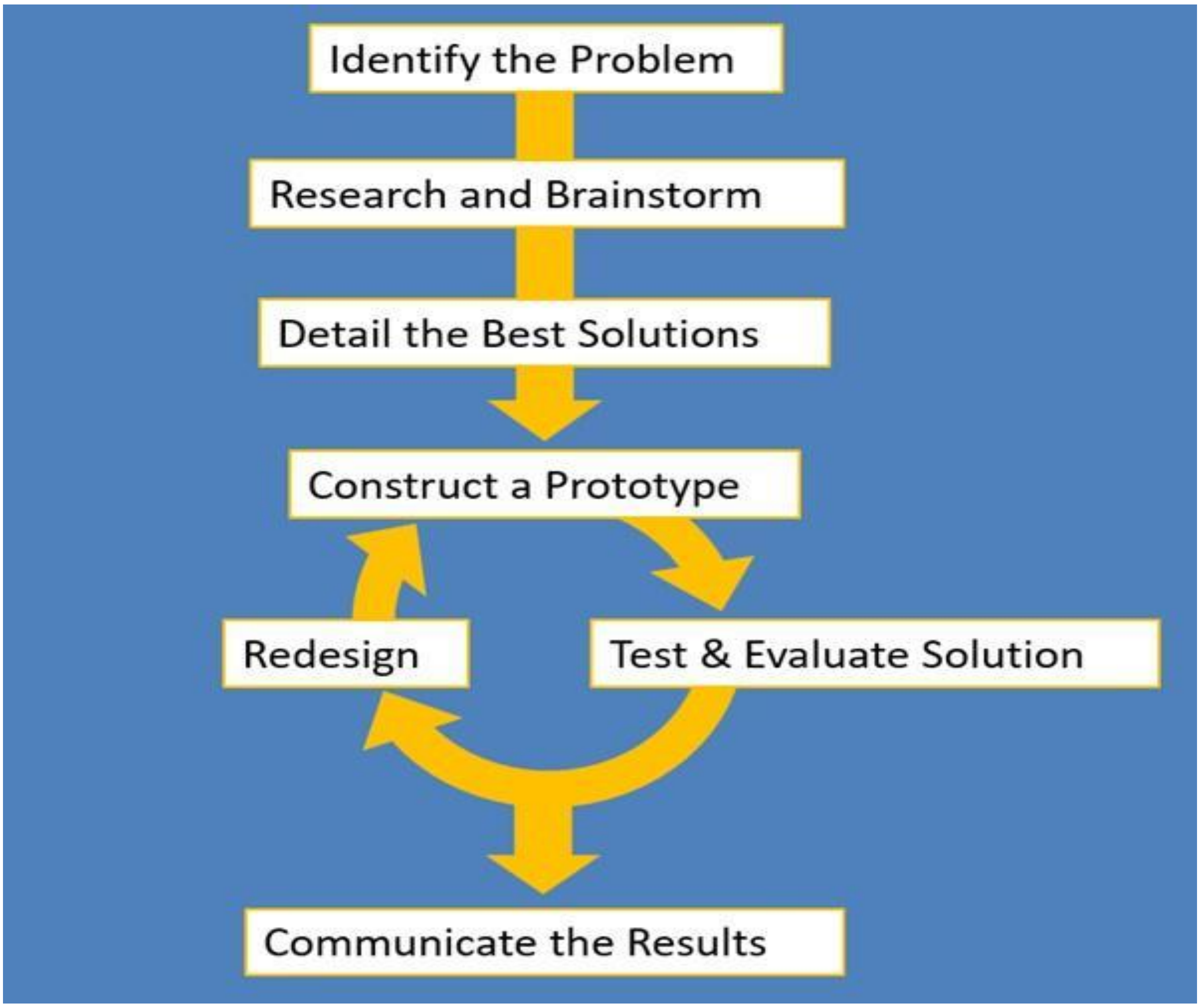


Figure 3.1 Research methodology flowchart showing the sequence of steps used in thermodynamic modeling and performance analysis [17].

The research methodology consists of the following steps:

1. Literature review of solar absorption refrigeration systems
2. Selection of working fluid pair (LiBr–H_2O)
3. Development of system configuration
4. Thermodynamic modeling using mass and energy balance equations
5. Parametric analysis of operating conditions
6. Evaluation of system performance parameters
7. Optimization of operating parameters

4. Mathematical Modeling

The thermodynamic performance of the solar driven absorption refrigeration system is evaluated using mathematical modeling based on the first law of thermodynamics.

Mass balance and energy balance equations are applied to each component of the refrigeration cycle in order to determine system performance.

Mass Balance Equation

The mass balance equation ensures conservation of mass within the refrigeration cycle.

$$\sum m_{in} = \sum m_{out}$$

Where

m = mass flow rate of the working fluid.

Energy Balance Equation

The energy balance equation is based on the first law of thermodynamics and represents the conservation of energy within the system.

$$Q + \sum mh_{in} = \sum mh_{out}$$

where

Q = heat transfer rate

h = specific enthalpy of the working fluid.

Refrigeration Effect

The refrigeration effect represents the amount of heat removed from the refrigerated space by the evaporator.

$$Q_e = m_r(h_1 - h_4)$$

where

Q_e= refrigeration effect

m_r= mass flow rate of refrigerant.

Heat Supplied to Generator

The heat supplied to the generator is the thermal energy required to separate refrigerant vapor from the absorbent solution.

$$Q_g = m_s(h_7 - h_6)$$

where

Q_g = heat input to generator

m_s = mass flow rate of solution.

Coefficient of Performance

The efficiency of the absorption refrigeration system is evaluated using the coefficient of performance.

$$COP = \frac{Q_e}{Q_g}$$

A higher COP indicates better system performance.

5. RESULTS AND DISCUSSION

This section presents the thermodynamic performance analysis of the solar driven absorption refrigeration system under different operating conditions. The performance of the system is evaluated using the coefficient of performance (COP), refrigeration effect, and system efficiency.

The influence of different operating parameters such as generator temperature, evaporator temperature, condenser temperature, and solar radiation intensity on system performance is analyzed.

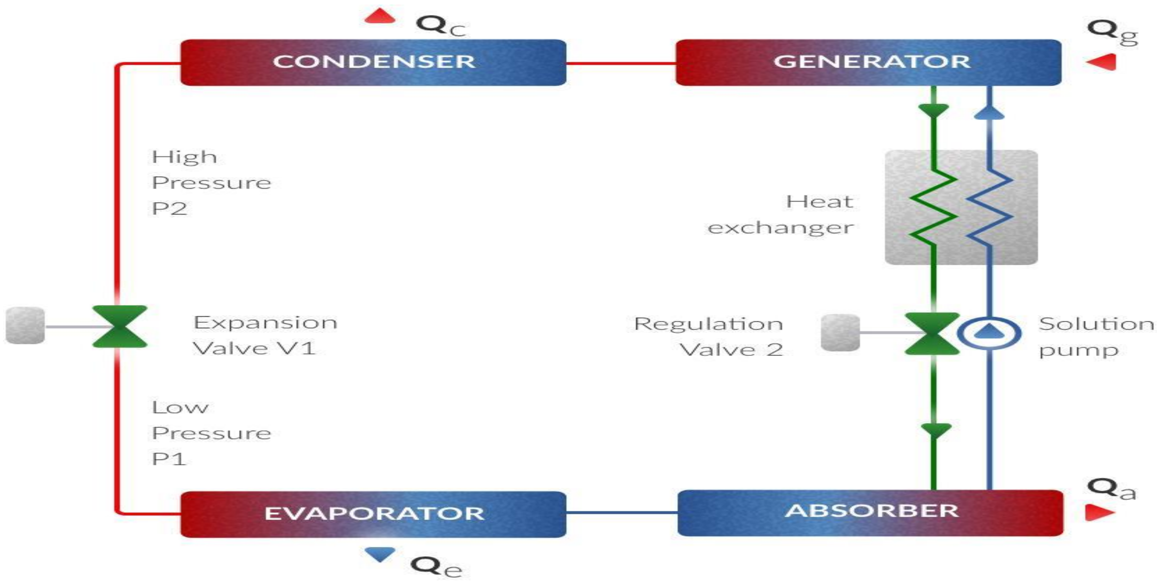
Effect of Generator Temperature on COP

Generator temperature is one of the most important parameters affecting the performance of the absorption refrigeration system. The generator receives heat energy from the solar collector and uses this heat to separate refrigerant vapor from the absorbent solution.

Table 1 Variation of COP with Generator Temperature.

Generator Temperature (°C)	COP
80	0.55
85	0.60
90	0.65
95	0.69
100	0.72
105	0.74
110	0.75

The results show that the coefficient of performance increases with increasing generator temperature because higher generator temperatures improve the separation of refrigerant vapor from the absorbent solution.



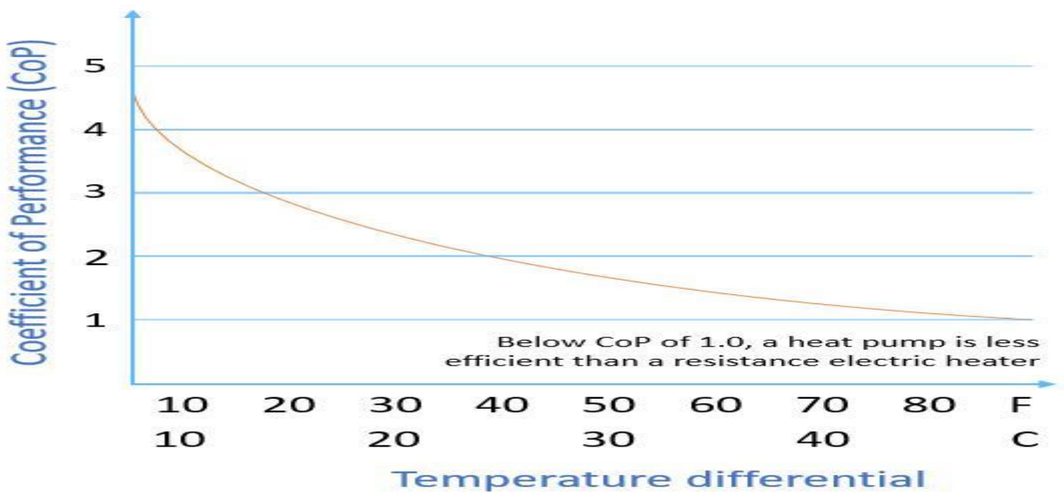


Figure 4.1 Variation of coefficient of performance (COP) with generator temperature .

The graph indicates that COP increases gradually as generator temperature increases due to improved refrigerant vapor generation in the generator.

Effect of Evaporator Temperature on COP

The evaporator temperature influences the refrigeration effect and overall system efficiency.

Table 2 Variation of COP with Evaporator Temperature.

Evaporator Temperature (°C)	COP
4	0.60
6	0.63
8	0.66
10	0.69
12	0.72
14	0.74

The results indicate that COP increases with increasing evaporator temperature because higher evaporator temperature improves the refrigeration effect.

Effect of Condenser Temperature on COP

Condenser temperature affects the heat rejection process of the refrigeration system.

Table 3 Variation of COP with Condenser Temperature.

Condenser Temperature (°C)	COP
30	0.75
32	0.73
34	0.71
36	0.69
38	0.67
40	0.65

The results show that COP decreases as condenser temperature increases. Higher condenser temperatures increase system pressure and reduce the efficiency of heat rejection.

Effect of Solar Radiation on System Efficiency

Solar radiation intensity directly affects the heat energy supplied to the generator.

Table 4 Variation of System Efficiency with Solar Radiation

Solar Radiation (W/m^2)	Efficiency
400	0.52
500	0.56
600	0.60
700	0.63
800	0.66
900	0.68

The results indicate that system efficiency increases with increasing solar radiation intensity because higher solar radiation provides more thermal energy to the generator.

Comparison with Literature

Table 5 Comparison of Present Results with Previous Studies.

Study	COP Range	Remarks
Wang et al. (2024)	0.70–0.76	Similar trend observed
Kumar et al. (2024)	0.68–0.74	System efficiency improved
Patel et al. (2023)	0.72–0.78	Collector efficiency important
Present Study	0.55–0.75	Comparable results

The comparison shows that the results obtained in the present study are consistent with previously reported research findings.

6. CONCLUSION

This study presents the thermodynamic performance analysis of a solar driven absorption refrigeration system using solar thermal energy as the heat source. The results indicate that generator temperature, evaporator temperature, condenser temperature, and solar radiation intensity significantly influence system performance.

The coefficient of performance increases with generator temperature and evaporator temperature, while higher condenser temperatures reduce system efficiency. Solar radiation intensity improves system efficiency by increasing the heat supplied to the generator.

The results demonstrate that solar driven absorption refrigeration systems have significant potential for sustainable cooling applications by utilizing renewable energy and reducing electricity consumption.

7. Future Scope

Future research can focus on improving the efficiency of solar driven absorption refrigeration systems by using advanced solar collectors such as evacuated tube collectors and parabolic collectors. The integration of thermal energy storage systems can also improve system reliability during periods of low solar radiation.

Further studies may investigate hybrid solar cooling systems and advanced optimization techniques to enhance system performance and expand the practical applications of solar refrigeration technologies.

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