

Design and Analysis of a Solar-Powered Vapour Absorption Refrigeration System using E₂₀ Software

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The utilization of solar energy as future energy source is drawing attention of industrialist and researchers worldwide. The Concentrating Solar Power (CSP) and Solar Photovoltaic Power (SPP) is second largest installed renewable energy source. Solar energy finds potential application in refrigeration system, electricity generation, desalinate water, heat generation etc. The solar powered refrigeration system is more sustainable and environmentally friendly compared to conventional refrigeration systems. In order to explore the applications of solar powered refrigeration system, this study presents the quantitative simulation and performance maximization of a 2 TR solar-powered Vapour Absorption Refrigeration System (VARS) using E20 software motivated by its relevance for medium-scale applications such as commercial cooling and food processing. The integration of solar energy into VARS is an established field of research, with significant contributions. While fundamental principles of solar-driven ammonia-water VARS have been well documented, the application of E20 software would enhance system efficiency through simulation-based optimization. Despite E20 being a commercial tool frequently used in HVAC applications, this study applies it to a specific use case of VARS optimization, offering an improvement in methodology rather than an entirely new concept. This work presents the refining of existing designs using accessible simulation technology for performance optimization. Further, the aim is to bridge the gap between academic studies and practical implementations by demonstrating the feasibility of E20 in VAR system simulation. The performance of the system evaluated yielding a COP of 0.514, which aligns with previously established efficiency ranges.

Keywords: Absorber, Coefficient of performance, R717 (Ammonia), Refrigeration effect, Storage

Introduction

A refrigeration system is a device that may lower a substance's temperature or heat under carefully regulated circumstances. Heat, magnetism, electricity, lasers, and other forces can also be used to drive heat transfer, which is how it has historically been done. Cryogenics, air conditioning, domestic refrigerators, and commercial freezers are just a few of the various uses for refrigeration. Refrigeration is vital across numerous sectors—not only for food preservation and human comfort, but also for vaccine storage, chemical manufacturing, and climate control in industrial environments air conditioning system and

refrigeration have evolved as a subject because humans have required food and comfort for decades. Our daily lives now depend on refrigeration and air conditioning, which use 18% of the electrical energy used worldwide. In the modern day, engineers must find effective ways to conserve energy and employ renewable energy sources.¹ The utilization of solar energy and waste heat to power refrigeration systems has received more attention in recent years. Due to the rising need for refrigeration and the availability of sunlight over the last two decades, solar-powered refrigeration has become increasingly appealing. Several different energy sources may be utilized to provide refrigeration, however solar energy is advantageous and can be employed as an alternative energy source. The most dependable and abundant

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source of energy, solar energy is readily available in huge quantities.²

Cooling effect generation is one of the most efficient uses of solar refrigeration. The primary issue of the vapour compression refrigeration system lies in the fact that it uses an excessive amount of refrigerant vapour during operation, which necessitates a lot of mechanical power to run. The weight of the device and the electricity needed for it to operate would both be significantly reduced if various techniques were utilized to lower this volume before compression.³

The use of solar energy for building cooling and heating is one of the various uses being researched. Several studies are being done for this aim, particularly in nations like India where solar energy is widely available. In the summer, when there is no demand for heating but rather for cooling, solar energy is abundant.⁴ The benefit of solar air conditioning is that it may be used when both the sun's availability and the requirement for refrigeration are at their peak. In light of this, solar air conditioning is a particularly appealing use for solar energy.⁵ Heat energy can be utilized instead of work energy to produce refrigeration since it provides a high Coefficient of Performance (COP) of a system when the machine is powered by a source of work energy.⁶ The absorption system varies essentially from the 'vapour compression system' only in the way of compressing the refrigerant. The compressor in the vapour absorption refrigeration system is substituted by an absorber, a generator, and a pump.⁷ The design

of solar-powered intermittent absorption refrigeration (Fig. 1), proved advantageous in producing a substantial refrigeration effect. Because solar energy is only accessible during the day, it must be combined with a two-phase system that operates both during the day and at night in order to fulfill the continual refrigeration effect produced by solar energy.⁸

The concentrating collector captures enough heat from the sun to power the refrigeration cycle by recirculating refrigerant. Since ammonia has a relatively low boiling point, it can evaporate from aqueous solution and flow throughout the cycle.⁹ The growing energy consumption as well as the need to maintain the ozone layer and reduce global warming cleared the way for thinking about sustainable refrigeration. A sustainable system is one that produces more without negatively impacting the environment or the energy sector. As a result, solar refrigeration became increasingly important.¹⁰ Solar energy is being used directly as a significant source of energy appealing from a sustainability standpoint due to its universal availability, little environmental effect, and cheap or no recurring fuel expense. The power collected by the earth from the sun is around 1.8×10^{11} MW, which is considerably higher than the present global rate of consumption of all economical energy sources. Solar energy could theoretically fulfill the entire world's current and potential energy needs indefinitely.¹¹

Several studies have examined solar-powered refrigeration systems, particularly those utilizing

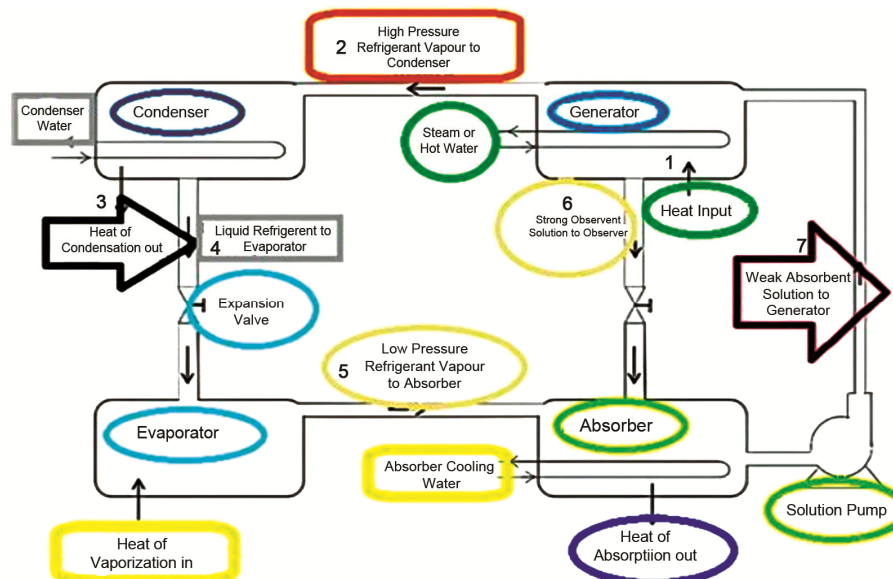


Fig. 1 — Single effects vapour absorption system showing pressure change¹²

vapour absorption cycles. Karamangil *et al.* (2010) conducted a comparative analysis of VAR systems using conventional and alternative working fluids, though the focus remained on thermodynamic assessments rather than system-level optimization or software-based validation. Bajpai (2012) designed a solar-powered VARS prototype but did not integrate any advanced simulation tools for performance prediction.

This study introduces a unique approach by applying E20 software commonly used for HVAC system simulations to a 2 TR solar-powered VARS. This capacity was selected due to its practical utility in small commercial and industrial cooling applications, making the findings directly applicable to real-world deployments. Recent developments have explored hybrid solar cooling systems and component-level improvements, yet a clear research gap remains in the use of commercial simulation tools for integrated VARS design. Although E20 software is widely employed for HVAC load calculation and system planning, its application to vapour absorption refrigeration systems—especially in conjunction with solar energy—has seen limited coverage in the literature. This lack of integration between practical design tools and VARS modeling hinders the implement ability of such systems in real-world applications. Moreover, most studies focus on either very small-scale systems (e.g., portable vaccine coolers) or large-scale industrial setups, overlooking medium-scale configurations like the 2 TR capacity considered in this study.

Solar energy stands out as an advantageous energy source for refrigeration systems compared to conventional methods due to its environmental friendliness, cost-effectiveness, Sustainability, Peak alignment. The present research addresses these gaps by applying a structured optimization framework using E20 software, demonstrating feasibility for medium-scale; solar-driven refrigeration and providing validated system performance metrics that align with theoretical expectations. This study thereby contributes to narrowing the gap between theoretical modeling and deployable solar VARS solutions.

Design Methodology

Vapour Absorption Refrigeration System (VARS)

The simulation of the 2 TR solar-powered VARS was conducted using E20 software, which facilitated performance assessment under various operational conditions. The calculations adhered to the first and

second laws of thermodynamics, ensuring accurate representation of system efficiency. While prior studies have explored similar methodologies, this paper contributes by offering a structured, detailed execution plan that maximizes system performance within practical limits.

The refrigeration system that uses vapour absorption runs on heat. It resembles a vapour compression system quite a bit. Evaporator and condenser are present in both systems. In order to produce refrigeration in both situations, the refrigerant goes through two separate pressure levels of evaporation and condensation.¹³ The two processes for refrigeration's evaporation and condensation are distinct according to the technique used to establish the distinct levels of pressure in the system. These examples had distinct refrigerant circulation patterns (Fig. 2). The "absorber" and "generator" combination in the absorption system replaces the compressor in the 'vapour compression system'. The vapour absorption refrigeration system operates on heat energy, substituting the compressor of traditional vapour compression systems with an absorber, generator, and pump. The evaporator cools the fluid by facilitating ammonia's heat absorption, while the condenser releases heat from refrigerant vapors, allowing condensation. The generator supplies refrigerant vapor through heat extraction, absorber absorbs refrigerant vapor into the solution. Solar collector is flat-plate collectors provide the necessary heat input.

The Function of VARS System Components

The evaporator's function is to chill the flowing water. The system fluid to be cooled or chilled is transported through a collection of tubes inside the evaporator. Reduced to evaporator pressure is high

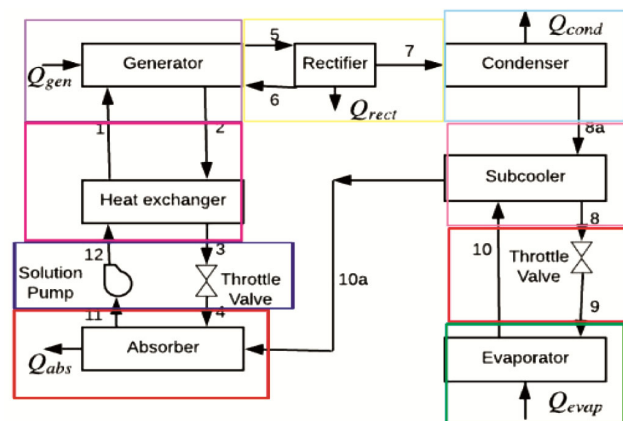


Fig. 2 — A block layout of an $\text{NH}_3\text{-H}_2\text{O}$ VAR system¹⁴

pressure liquid distillate (refrigerant). The ammonia absorbs heat from moving water and evaporates at this low pressure. The resulting formation of refrigerant vapours tends to raise the vessel's pressure. As a result, the boiling temperature will rise, negating the intended cooling effect. Thus, the reduced pressure absorber must be used to transfer the refrigerated vapours from the vessel. The evaporator as well as the absorber is physically housed within the same casing, allow ammonia vapours produced within the evaporator to travel constantly to the absorber. The minimum temperature that must be kept in the evaporator enclosure will determine how much pressure is in the evaporator. The minimal temperature reached is not a functional requirement for our system °C because we simply need to chill water to drink. The evaporator's pressure must be kept relatively close to ambient pressure as feasible since retaining a greater pressure is more difficult is challenging and expensive. Moreover, there are leakage issues, thus the device requires to be hermetically sealed. To guarantee design economy, under ambient pressure, the overall evaporator pressure is remained constant (1.1 bar). Ammonia vapours in the evaporator reach a saturation temperature of -23°C as a result.

Evaporator Temperature (T_E): -23°C

Evaporator Pressure (P_E): 1.1 bar

The condenser condenses the refrigerant vapours. Cooling water runs via tubes within the condenser, while heated ammonia vapour fills the nearby area. The ammonia condenses also on tube side as heat is transferred from the water to the refrigerant vapour. Before moving to the expansion device, the condensed liquid ammonia gathers only at bottom of the condenser. Typically, the evaporative cooling system is interconnected with the refrigeration cycle. The condenser and generator are often housed inside of the similar casing. The necessary condenser pressure to convert ammonia vapours to ammonia liquid is determined by the kind of condensing media employed and its temperature. Water serves as the condensing medium in this system. Water is accessible to a temperature approximately 25°C . $T_c=25^{\circ}\text{C}$, i.e. condensing temperature. The relevant pressure necessary for condensing ammonia vapours at 25°C may be found in the ammonia refrigeration table (R-717). As a result, the condensing pressure is set at $P_c = 10.1$ bar.

The generator's purpose is to distribute refrigerant for the system as a whole. This is achieved by extracting the liquid (refrigerant) from ammonia as well as water solution. Steam or hot water, which are the two most common high-temperature energy sources used in generators, pass through tubes submerged in a diluted mix of absorbent and refrigerant. The hotter steam or water absorbs the heat from the solution, leading the refrigerant to evaporate (vaporize) and separates from an absorbent medium. The absorbent solution gets stronger when the refrigerant is removed by boiling. The concentrate absorbent solution flows back to the absorber, while vaporized refrigerant passes to the condenser. The refrigerant vapour is absorbed by the ammonia liquid medium within the absorber. The heat gained in the evaporator is released as the refrigerated vapour condenses from the vapour to a fluid as it is absorbed. The absorption process results in a decrease in pressure inside the absorber. Because of the decreased pressure and the absorbents' attraction for water, the evaporator produces a constant flow of refrigerant vapour. Moreover, an absorption process condenses all refrigerated vapours and emits the heat that the refrigerant removed from the evaporator. The heat emitted by the condensation of ammonia vapours and their absorbed in the solution is transferred to the cooling water pumped through absorber tube bundle. The concentrated solution's absorption capacity declines as it absorb more and more refrigerant. The generator then receives the weaker absorbent solution and utilizes heat to propel the refrigerant away. The heated refrigerant vapours produced by the generator make their way to the condenser. The cooling tower water moving through the condenser condenses the refrigerant vapours and gathers up condensation heat, which it sends to the cooling tower. The cycle is completed when the liquid refrigerant returned to the evaporator. Pumps use energy to produce mechanical power by moving fluid and are powered by some mechanism (usually reciprocating or rotational). Pumps employ a variety of sources of energy, including manual labour, electricity, motors, or utilize renewable power and vary greatly in size from tiny for medical uses to enormous industrial pumps. A strong solution of 'refrigerant absorbent' is created when the absorbent absorb the refrigerant. The pump uses high pressure to drive this solution towards the generator. Consequently, the pump enhances the solution's pressure. The liquid refrigerant passes through an expansion valve from the condenser to the

evaporator. The expansion device regulates the pressure differential between the refrigeration unit's high pressure (condenser) and low pressure (evaporator) sides by forming a liquid seal between the two sides of the cycle. The pressure drop caused by the 'liquid refrigerant' flows at high pressure through the expansion unit decreases the refrigerant temperature relative to the evaporator. A little percentage of the 'liquid refrigerant' boils off as a result of the pressure drop, reducing the residual refrigerant temperature to the evaporator temperature. The refrigerated vapour and liquid refrigerant mixture is then fed into the evaporator.

A flat-plate collector's construction is demonstrated. The three essential components are an insulated box, a full-aperture absorber, and transparent cover sheets. The absorber is often a sheet of metal with a high heat conductivity that has tubes or ducts attached to it or integrated into it. The surface is Painted or coated to increase the absorption of radiant energy and, in some situations, to reduce the emission of radiant energy. The glazing or cover sheets, prevent chilly air from entering the area above the absorber while still allowing sunlight to reach the absorber. The insulated box gives the collector support, acts as a seal, and minimizes energy loss from the sides or rear. A "flat plate collector" is a weather-resistant, enclosed structure with one or even more transparent coverings enclosing a dark absorber plate. It must be constructed of tempered glass with the low iron level that ranges in thickness from 3.2 to 6.4 mm. When this kind of glass is utilized, the collector has an 85% transmittance Copper is used to make the absorber plate due to its high conductivity. Moreover, it resists rusting, using 0.05 mm-thick copper plates and 1.25 cm tubes. With 15 cm between tubes, 97% efficiency is achieved. Moreover, copper plate is painted with black paint that has emittance values of 0.08–0.12 and absorptance values of 0.85–0.9. Steel, aluminium, or fiber glass is used in its construction. A lot of people utilize fiber glass.

Calculations

The working pressures at which the system operates must be established before proceeding with additional calculations. Given the condenser pressure (P_c) and evaporator pressure (P_e) is determined; the corresponding values may be calculated.

Now;

$$h_{ge} = 1625 \text{ kJ/kg}$$

$$h_{fe} = 470 \text{ kJ/kg}$$

$$h_{ge} = 1550 \text{ kJ/kg}$$

$$h_{fe} = 205 \text{ kJ/kg}$$

Points 1, 2, 3, and 4 on the "pressure enthalpy" chart represent the condenser and evaporator pressures (Fig. 3).

With the concentration $C = 1$ and condenser pressure (P_c), point 1 indicates a pure ammonia saturated vapour.

At P_c and $C = 1$, point 2 indicates pure NH_3 saturated liquid. This place is indicated in the liquid area.

Point 3 shows the pure NH_3 (wet) state when pressure (P_e) and $C = 1$. Points 2 and 3 are congruent because 2-3 is a 'throttling process' for which enthalpy remains unchanged.

Point 4 shows the state of pure ammonia at pressure P_e ; they are saturated vapour that collect heat in the evaporator and transform from moist to saturated vapour. This site is indicated in the vapour area.

The chart (Fig. 3), indicates the enthalpies at points 1, 2, 3, and 4.

$$h_1 = 1625 \text{ kJ/kg}$$

$$h_2 = h_3 = 470 \text{ kJ/kg}$$

$$h_4 = 1550 \text{ kJ/kg}$$

Refrigeration capacity of the unit: 2 TR

The refrigeration effect or heat absorption by ammonia in the evaporator's refrigerant is

$$Q_E = m_r(h_4 - h_3) \text{ kJ/Kg}$$

where, Q_E = total heat absorbed by the evaporator,

m_r = mass of refrigerant in kg/min

h_3 = enthalpy at the evaporator inlet

h_4 = enthalpy at the evaporator exit

If the volumetric flow rate of ammonia in the evaporator is m_r .

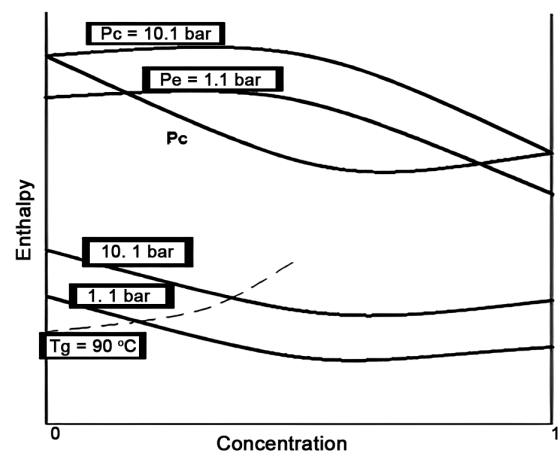


Fig. 3 — The concentration-enthalpy graph indicating the condenser and evaporator pressure at various points¹⁵

$$Q_E = m_r (h_4 - h_3)$$

$$= m_r (1550 - 470)$$

$$m_r \times 1080 = 2 \times 3.5 \text{ kW.}$$

$$m_r = 0.38 \text{ kg/min.}$$

The equation for the heat dissipated from the condenser by circulating cooling water is:

$$Q_C = m_r (h_1 - h_2) = 0.38 (1625 - 470)$$

where, Q_E = total heat released by the condenser,
 m_r = mass of refrigerant in kg/min
 h_1 = enthalpy at the condenser inlet
 h_2 = enthalpy at the condenser exit

As a result, heat dissipated;

$$Q_C = 438.9 \text{ kJ/min}$$

In the case of a solar water heater:

Energy input (energy received by the 'collector plate') is provided by

$$Q_u = K \times S \times A$$

where, K = effectiveness of a collector plate (assuming $k=0.85$)

S = usual amount of solar heat that strikes the surface of the earth

$$= 6 \text{ kWhr/m}^2/\text{day} = 250 \text{ W/m}^2$$

A = Collector plate area

Let $K = 0.85$, $S = 250 \text{ W/m}^2$ be assumed.

As a result, four collection plates with size of 4×4 sq m can be used.

One plate has an area of $4 \times 4 = 16 \text{ m}^2$.

Thus the area of four plates is $= 4 \times 16$

Total Collector Plate Area = 64 m^2

Hence, the area of four plates is $= 4 \times 16 = 64 \text{ m}^2$

$A = 64 \text{ m}^2$

$$Q_u = 0.85 \times 250 \times 64 = 13,600 \text{ Watts} = 13.6 \text{ kW}$$

Heat requirement in the generator, $Q_g = 816 \text{ kJ/min}$.

The energy received by the collector contributes to the heating of the fluid flow through the collecting plates' tubes.

$$Q = m \times C_p \times (T_o - T_i)$$

For Plate Collector:

Let the flow rate of water through the conduits be $m = 0.035 \text{ kg/s} = 2.1 \text{ kg/min}$.

Water specific heat $C_p = 4200 \text{ J/kg/k}$

Water intake temperature at collector plate (T_i) = 25

As a result, $0.035 \times 4200 \times (T_o - 25) = 13,600$

Water outlet temperature at collector plate (T_o) = 92.5°C

The temperature (T_o) should correspond to the generator's input temperature, assuming that water loses heat while passing through the tubes. In addition, the generator's efficiency as a 'heat exchanger' is lower than 100%. As a result, gross heat in the generator may be estimated to occur at 90.

Assumption Losses: $T_o = 90^\circ$. The temperature at the generator is 90° .

This is the overall heat; the process receives that is designed as a 2 TR refrigeration unit. The pump's effect to increasing the pressure is insignificant and is thus ignored.

The C.O.P of a Conventional System

The following expression can be applied to estimate the C.O.P. of the refrigeration unit:

C.O.P = Refrigeration effect/heat input (generator)

Therefore,

$$\text{C. O. P} = \frac{2 \times 210}{816} = 0.514$$

Now Solar assisted VARS calculations are given below

Given

Refrigeration Capacity (Q_e) = 2 TR = $2 \times 3.5 = 7 \text{ kW}$

The required generator heat input (Q_g) must be 763.6 kJ/min

$$\text{C. O. P} = \frac{Q_e}{Q_g} = \frac{7}{763.6} = 0.55$$

Solar Collector Requirement

Assuming:

- Collector effectiveness $K=0.85$
- Solar intensity $S=250 \text{ W/m}^2$

$$Q_u = K \cdot S \cdot A \Rightarrow A = \frac{Q_u}{K \cdot S} = \frac{12.727}{0.85 \times 0.25} \approx 59.9$$

A solar collector area of $\sim 60 \text{ m}^2$ is sufficient to provide the heat input required for 2 TR operation at COP = 0.55.

• C.O.P of the entire process (involving the solar water heater):

$$\text{C. O. P} = \frac{\text{Net refrigeration effect produced}}{\text{Heat input (Solar collector)}}$$

Heat input (solar collector) = Area \times Solar Constant

$$= 250 \times 64$$

$$\text{C. O. P} = \frac{2 \times 210 \times 1000}{250 \times 64 \times 60} = 0.4375$$

As a result, the estimated C.O.P of the entire system is 0.4375.

Technologies Related

The absorption system looks to be one of the more promising options for cooling (Fig. 4). Solar collectors can be used to supply energy for Rankine-vapour compression cycles, desiccant cooling, and absorption cooling, among other configurations or cycles. Hybrid solar cooling systems also have the possibility.

Although there is a large market for this technology, owing to their high startup prices, solar cooling systems now in use cannot compete with electricity- or gas-fired air conditioning systems. The price of solar cooling may be decreased by lowering component costs and enhancing their performance. The expenses for solar components will decrease as a result of improvements such decreased collector area, greater system performance, and decreased collector cost. Several solar-powered refrigeration systems, including liquid/vapor, solid/vapor, adsorption, vapour compression, and photovoltaic vapour compression systems have been suggested and are under development. The majority of the aforementioned techniques have not been proven to be profitable. Solar-powered refrigeration systems find potential applications in Food processing industries, Jute industries, Industrial chemical operations like distillation, steam power plants, and other heat-exchange devices etc.

Cost Optimization of Solar VARS compared to Conventional VARS are discussed in the following points-

- The operational cost of solar VARS is significantly lower than that of conventional vapour compression systems. In Fig. 5, the COP

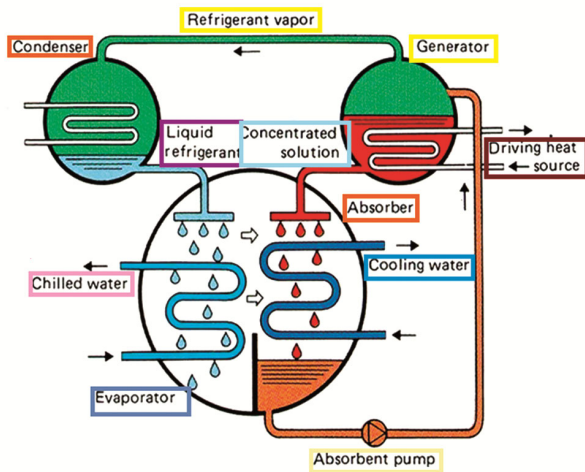


Fig. 4 — Simplified VARS operating concept¹⁶

of solar assisted VARS is higher than the conventional VARS, which means solar assisted VARS power consumption is also low which directly proportional to operational cost. (As solar energy is freely available and the system consumes minimal electrical power).

- E20 software was utilized to optimize the collector area (64 m² for a 2 TR system), ensuring the most cost-effective configuration without over sizing, thereby minimizing unnecessary expenditure.
- The use of ammonia (R717), which has zero ozone depletion potential and low global warming potential, reduces environmental compliance costs in the long term.
- When evaluated over the life cycle, the solar VARS achieves better cost-efficiency due to reduced energy bills, minimal recurring operational expenses, and lower reliance on grid electricity or fossil fuels.
- The absence of compressors and the inclusion of only a minimal number of moving components further reduce both capital investment and future maintenance requirements.

Key Advantages of VARS with Solar Integration

- **Low Operational Costs:** Once installed, solar collectors provide free energy input with minimal recurring expenses.
- **Environmentally Sustainable:** The system uses ammonia (R717), which has zero ozone depletion potential (ODP) and low global warming potential (GWP).
- **Quiet and Reliable Operation:** Few moving parts (primarily the pump), resulting in low noise and reduced mechanical wear.
- **Adaptability:** Can utilize alternative heat sources (e.g., industrial waste heat) when solar radiation is unavailable.

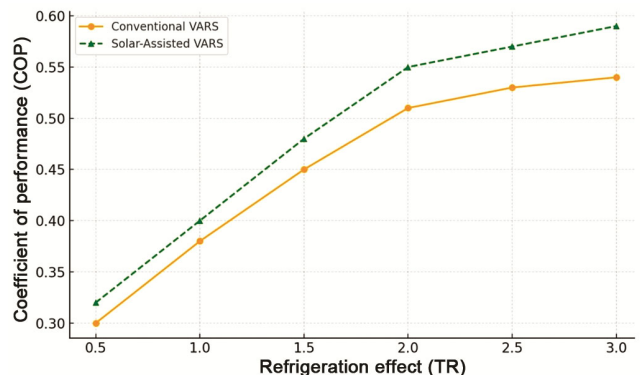


Fig. 5 — Estimation of system parameters using E20 software

- **Low Maintenance:** The absence of compressors and rotating machinery minimizes maintenance requirements.

These advantages make the system especially promising for deployment in energy-scarce or environmentally sensitive regions.

Challenges and Limitations in Vapour Absorption Refrigeration System

The proposed solar-powered VARS system has several limitations that must be considered for real-world implementation.

- **High Initial Cost:** Solar collector panels and absorption system components involve significant upfront investment.
- **Inconsistent Solar Availability:** Cooling performance may degrade during prolonged cloudy periods or at night without thermal storage.
- **Limited Commercial Familiarity:** Adoption is hampered by low awareness and lack of skilled technicians for VAR systems compared to conventional refrigeration.

Suggested Mitigations

- Incorporating thermal storage or hybridization with electric backup can stabilize performance during low solar periods.
- Research into alternative absorbent-refrigerant pairs (e.g., LiBr-H₂O, ionic liquids) may enhance efficiency and reduce corrosion.
- Designing modular, compact systems could improve system portability and ease of installation.

Results

The choice of a 2 TR capacity system was made due to its suitability for medium-scale applications, such as cooling for small commercial establishments and industrial processes. This capacity balances energy efficiency and practical application, addressing the specific needs of target use cases. The COP obtained from the study is 0.514, a value consistent with prior literature findings. This reinforces the claim that while optimization techniques are explored, the core efficiency levels remain within expected operational limits. Future work should focus on experimental validation and comparative analysis with alternative simulation tools to establish the unique benefits of the approach employed.

The heat input needed for operation of the 2 TR vapour refrigeration system under the specified operating conditions are about 816 kJ/min. The heat

in the generator is usually provided by hot water from the flat plate solar-powered water heater.

E20 Software Use is detailed in how it assists in optimizing system parameters in Fig. 5.

Designed Operating Conditions

Evaporator pressure: 1.1 bar
Condenser pressure: 10.1 bar

The area of the solar collectors employed: 64 sq m, which translates to four 4×4 metre square plates.

Heat input delivered (at generator): 816 KJ/min

COP of refrigeration unit: 0.514

The total system C.O.P is 0.4375

The system performance is summarized in the following Table 1:

An overall COP of system is 0.4375 and COP of refrigeration unit is 0.514, according to the research, indicate efficient solar energy utilization with scope for improvement. Four 4×4 m flat-plate solar collectors provide the necessary 816 kJ/min heat input. For medium-scale installations, a 64 m² collecting area is practicable and optimized for energy requirements.

Detailed Analysis of Results

- **COP Values:** The refrigeration unit achieved a COP of 0.514, which is competitive compare to conventional systems, demonstrating efficient utilization of solar energy as shown in Fig. 6. The overall COP of system is 0.4375 includes losses in solar energy conversion, highlighting areas for potential improvement.
- **Energy Input:** The heat input of 816 kJ/min was supplied by four 4x4 m flat-plate solar collectors, optimized for sufficient solar energy absorption.
- **Collector Area Optimization:** The choice of a 64 m² collector area ensures the required energy input while maintaining feasibility for medium-scale applications.

Table 1 — System Performance of VARS

Parameter	Value	Explanation
Evaporator Pressure	1.1 bar	Maintains effective cooling without excessive pressure.
Condenser Pressure	10.1 bar	Ensures efficient condensation using available cooling water.
Heat Input (Generator)	816 kJ/min	Derived from solar energy to meet operational requirements
C.O.P (Refrigeration Unit)	0.514	Indicates the efficiency of the refrigeration cycle.
Overall System COP	0.4375	Accounts for energy input from solar collectors.
Solar Collector Area	64 m ²	Optimized for adequate solar energy capture.

- The solar-powered VARS achieved a Coefficient of Performance (COP) of 0.55, whereas conventional systems having Coefficient of Performance (COP) of 0.514 considering the sustainable energy source.
- A higher COP leads to more efficient heat utilization, reducing the thermal stress on system components and enhancing overall reliability.
- Unlike conventional systems that rely on mechanically driven compressors, the VARS uses an absorber, generator, and pump, resulting in fewer moving parts and, consequently, lower maintenance requirements.
- Improved COP directly reduces the frequency of system cycling and energy input demands, thereby lowering wear-and-tear and extending component life.
- Optimization of COP through simulation (using E20 software) ensures system stability, minimizes overloading, and leads to reduced operational and maintenance interventions over time.

Key findings and Future Scope

- The system achieved a refrigeration unit COP of 0.514 and an overall system COP of 0.4375, demonstrating operational efficiency under optimized conditions.
- The 2 TR capacity was chosen to align with medium-scale applications, balancing efficiency and practicality.
- Solar energy proved to be an effective heat source, with flat-plate collectors generating sufficient heat for continuous operation.

This work makes it clear that the fundamental absorption refrigeration system can be based on either lithium bromide-water (LiBr-H₂O) systems, in which liquid water serves as the refrigerant, or ammonia-water (NH₃-H₂O) systems, in which ammonia serves as the refrigerant. The subsequent studies on this subject will focus on different refrigerant combinations that are more efficient and have as their major benefit a lack of ozone depletion. Any modification that results in a general increase in the system's C.O.P, material savings, or a simpler design process can be made. The methods outlined in this paper may be utilized to build and create an appropriate system that can utilize solar electricity as effectively and efficiently as possible.

The primary constraint at the moment is the capacity to access solar energy whenever needed. For

instance, refrigeration is bad when it's too cold at night or there are long periods of gloomy weather. Improvements can be made by changing the solar collector's design to have a wide acceptance angle and creating generator tubes out of materials with greater thermal conductivity. More accomplishments made by researchers abound. Nevertheless, in order to compete with conventional refrigerated systems, solar-powered refrigeration options are being developed, more advancement needs to be made.

It is envisaged that these conclusions might be utilized to develop and selection of future absorption refrigeration systems. Creating innovative working fluid combinations and improving ideal operating conditions. To improve performance and reliability, future research should:

- Explore alternative refrigerant-absorbent pairs to enhance COP and environmental compatibility.
- Optimize solar collector designs to improve energy absorption and efficiency.
- Develop hybrid systems to address variability in solar energy availability.

Conclusions

This study refines the simulation and performance analysis of a 2 TR solar-powered VARS using E20 software, emphasizing enhanced methodological execution rather than introducing a fundamentally new concept. The results confirm expected efficiency values, aligning with existing research. The study highlights the importance of optimization strategies to substantiate the claimed benefits. The main constraint at the moment is the accessibility of solar- energy whenever it's essential; for example, during nights and lengthy overcast days, one can't achieve a high adequate temperature, and so refrigeration is inadequate. Efficiency can be improved by optimizing the solar collector angle and using high-conductivity materials in generators. While progress has been made, further advancements are needed for competitiveness. These findings aid in developing absorption refrigeration, new fluid pairs, and better working conditions.

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