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Absorption Refrigeration Systems Powered by Waste Heat Engine and Renewable Energy: A Review

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Abstract

Conventional Refrigeration Systems (VCRS) are the most commonly used in industrial buildings and facilities. Conventional refrigeration systems are among the most energy-consuming sources in addition to causing more environmental problems and gas emissions, such as hydrocarbons (HCs) and hydrochlorofluorocarbons (HCFCs), are known to contribute to global warming and ozone depletion. Absorption Refrigeration Systems (VARS) are a good alternative to conventional refrigeration systems because they use low-grade heat sources and operate with environmentally friendly liquids. The most important of these heat sources is the heat wasted from engines, industrial processes and many other sources. The global objective of the study is a literature review on the different ways to operate the absorption refrigeration system using waste heat in engines that include exhaust gases and engine cooling water as well as renewable energy that includes solar energy. Reviews of the literature have demonstrated how the absorption refrigeration system can be used and operated using a variety of thermal sources. This study also supports the usage of ecologically friendly chillers to provide air conditioning and refrigeration, as it shows these systems have a lower performance coefficient when compared to conventional refrigeration systems.

1. Introduction

Compression refrigeration systems consume approximately one-fifth of the world's electricity generation, as per the Worldwide Institute of Refrigeration (IIR). It is anticipated that the rate of consumption will increase to nearly half that of residential and commercial buildings in the years ahead [1]. The significant increase in energy consumption associated with these applications has placed a significant burden on conventional energy sources, indicating that fossil fuel reserves may soon be depleted unless immediate action is taken. Furthermore, it is more crucial than ever to boost the supply of energy by either finding new sources or preserving the ones that already exist by reducing the pace at which energy is consumed, as costs have increased as a result of the growing demand for energy. In order to power refrigeration systems, there has been a rise in interest in recent years in renewable energies that are plentiful and sustainable, such as waste heat from industrial processes, wind, and solar energy. [2-5].

An illustration of an energy balance for a contemporary car engine can be found in Fig. 1. Heat rejected in exhaust gas 30% and heat transmitted to coolants 25-30%. and 35% for power, with radiation releasing a little portion of the energy 5% [6]. The examination of heat fluxes initially reveals that there are two engine waste heat streams that may be recovered, namely cooling water 80-100°C and exhaust gas 300-600°C. The enormous amounts of energy required to drive the large amounts of greenhouse gas emissions are produced by the compressors in standard (VCRSs), which exacerbate a number of environmental problems. Moreover, it's well known that common (VCRS) refrigerants such hydrocarbons (HCs) and hydrochlorofluorocarbons (HCFCs) contribute to ozone depletion and global warming. Through the ratification of two significant agreements in 1987 (Montreal) and 1997 (Kyoto), the international community has made significant progress towards protecting the ozone layer and the environment. The use of hydrocarbons and chlorofluorocarbons (CFCs) is restricted as part of these agreements (HCFCs). NASA reports that in spite of these attempts, the ozone hole has gotten worse, rising from around 24,000,000 km^2 in 1994 to about 28,300,000 km^2 [7]. A resolution requiring the outlawing of all (HCFCs) by the year 2015 was passed by the European Commission (EC) in October 2000 [8-9]. An institute studying climate change said that, since the beginning of the century, the average global temperature has increased by 0.6 °K. If the current trend continues, it is expected to rise by 1.4-4.5 °K by 2100 [10].

Innovative refrigeration systems are the outcome of research into the use of waste heat and renewable energy sources. These techniques conserve alternative energy sources in addition to lowering greenhouse gas emissions. An overview of absorption refrigeration systems, their operation from waste heat from engine exhaust in general, renewable energies, and other sources, as well as techniques to enhance their performance, are covered in this paper. This study promotes resource efficiency to improve system performance and the use of environmentally friendly refrigerants to provide air conditioning and refrigeration without harming the environment.

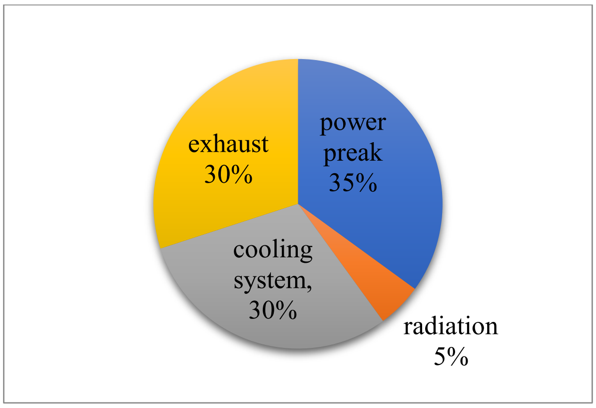


Fig. 1 Total percentage of waste energy in engine.

2. Absorption refrigeration system

Figure 2 illustrates the seven main parts of the absorption refrigeration cycle: the condenser, evaporator, two expansion valves, generator, absorber, compressor, and heat exchanger. The absorber and the refrigerant are the two main fluids that the system is filled with. a weak absorber-refrigerant mixture that is moved via a pump and heat exchanger from the low-pressure absorber to the high-pressure generator. A few other heat sources that can be added to the generator are waste heat, geothermal energy, and sunlight. For the refrigerant and absorbent to separate evaporatively, the heat source's temperature needs to be between 80 and 120 °C [11].

Subsequently, the high-pressure vapour condenses into a saturated liquid within the condenser. The high-pressure saturated liquid begins to expand after passing through an expansion valve, which ultimately reduces its temperature and pressure. The saturated low-pressure liquid refrigerant is converted to a low-pressure vapour upon entering the evaporator [12]. The vapour is subsequently absorbed by the absorbent. The generator's potent absorber, which remains within, returns to its original position upon separation from the refrigerant. Consequently, an expansion valve is employed to reduce the pressure of the stronger absorber to the absorber pressure level. Reviews of literature on the absorption refrigeration system's operation will clarify how the system operates using renewable energy and other sources, as well as the heat lost from the engines.

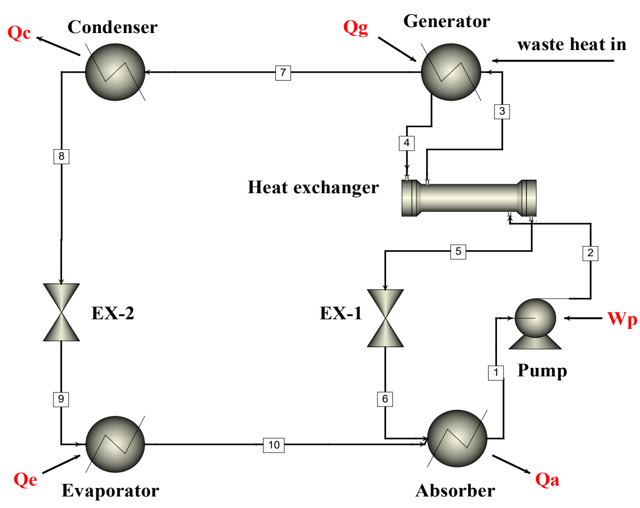


Fig. 2 single-effect absorption refrigeration cycle.

3. VARS powered by engine waste heat

3.1. Exhaust gas

The literature survey uses of exhaust gas produced during engine combustion in order to power the absorption cooling system.

Koehler et al. [13] The exhaust gas-heated absorption refrigeration system prototype was evaluated and refined using a 420 horsepower diesel engine, as illustrated in Fig. 3. The authors demonstrated that the exhaust emissions were insufficient to power a 5 kW absorption refrigeration system for 20%, 40%, and 80% of its operational duration, respectively.

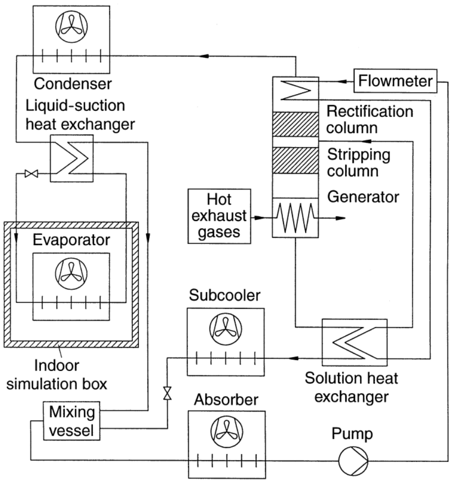


Fig. 3 The important components of the transport refrigeration air-cooled absorption prototype.

Jiangzhou et al. [14] Adsorption air conditioning systems (ARCS) were implemented in the compartments of locomotives powered by internal combustion engines as seen in Fig. 4. In a zeolite-water system, an adsorbent and cold storage evaporator are operated using residual heat from engine exhaust gas. The average refrigeration capacity of the prototype apparatus was 5 kW, while the chilled air temperature was maintained at 18 °C. The authors stated that the system for locomotive driver cabin air conditioning was straightforward, dependable, and uncomplicated to operate.

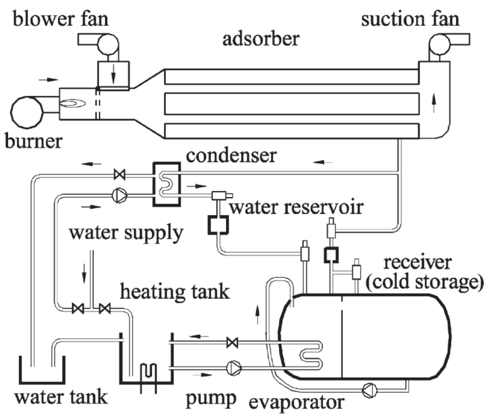


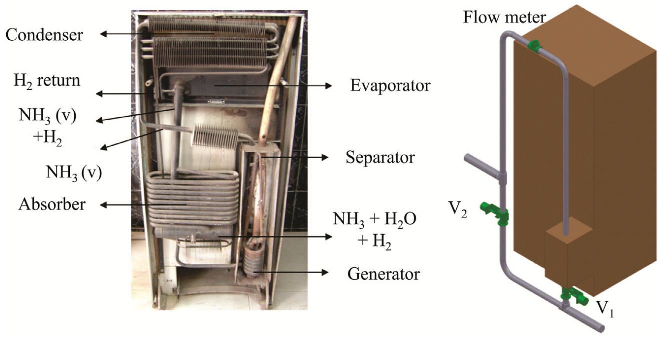
Fig. 4 Schematic diagram of experimental system.

Lin et al. [15] It was discovered that waste heat from the exhaust was insufficient to power a commercial diffusion absorption refrigerator (DAR) when the engine capacity exceeded 50% when coupled with diesel engine exhaust. The locator-petter T series air-cooled diesel engine produced 9.5

kW. A relatively low system COP of 0.034 was observed. Not for use in an automobile, the configuration was intended to test DAR operation and connection with engine exhaust. Ramanathan and Gunasekaran [16] examined the air-cooling application using H_2O-LiBr working pair (VARS) technology. Reference data for idling was their focus. This information was essential for the VARS to replace the VCS. They used engine experiment data from another study. Their simulations showed that the evaporator capacity was 3.7 kW at 1300 rpm and 11 kW at 2000 rpm.

Vicatos et al. [17] considered a Nissan 1400 compact truck's engine-exhaust-driven air conditioning system (ACS). Experimental work on a lab prototype supported the researchers' theoretical findings. Since their coefficient of performance (COP) values were low, 0.08, they concluded that their design needed considerable improvements. VARS units use NH3-H_2O working pairs. The toxicity of NH_3 prevented the use of a direct expansion evaporator. Rather, the passenger compartment was cooled with a mixture of water and glycol. For the selected automobile, the 2 kW cooling load of the system at 0 ℃ was acceptable.

Manzela et al. [18] An internal combustion engine-driven ammonia-water absorption refrigeration system's exhaust was investigated. Throttle valve positions of 25%, 50%, 75%, and wide-open were used to evaluate the engine. After three hours, the refrigerator reached a steady state temperature of between 4 and 13 ℃, depending on whether the engine throttle valve was opened. The computed energy availability of exhaust gas shows that a specialised system can significantly increase its cooling capacity. Mohapatra et al. [19] A 2.8-liter V6 diesel engine was suggested as a potential power source for a 10.55-kilowatt absorption chiller. Further investigation is warranted regarding the dependability of the system, regulatory concerns pertaining to ammonia or lithium bromide, and the cost-benefit analysis of the increased weight, they noted. Additionally, automobile absorption refrigeration systems may be powered by engine exhaust emissions. Rêgo et al. [20] experimentally investigated ammonia-water absorption cooling. In order to evaluate the heat-supplied capacity of the absorption chiller, exhaust gas from an internal combustion engine was attached. As seen in Fig. 5 a microcontroller-controlled exhaust gas flow. The exhaust stream had enough heat to power the absorption system between 1500 and 4300 rpm, except at 1000 rpm. Evaporation temperature decreased more between 1500 and 2500 rpm than at higher engine speeds. Control system activity increased when engine speed and torque were varied to imitate actual scenarios. The generator's wide temperature range allowed the system to drop to slightly over 0 °C.



(a) (b)

Fig. 5 schematic of the absorption refrigeration system (a) (b) prominence of V1, V2, and the flow meter.

Hilali et al. [21] built engine exhaust-powered LiBr-H_2O VARS. With a 1.3 L engine and VARS, it could produce 2.5 kW. VARS performance is described with engine performance. The investigation's maximum COP was 0.78 at 11°C evaporator. The VARS' cooling capacity improves with engine revolutions per minute (rpm) because exhaust gas discharge rate increases, allowing for higher heat recovery. We collected 3 kW of heat during engine idling and 18 kW at maximum load. The (VARS) performed best with exhaust heat recovered less than 9 kW. Even at low engine speeds, the generator with the lowest pressure drop and maximum efficiency increased cooling capacity. Aly et al. [22] Fig. 6 shows a diesel engine exhaust heat-powered diffusion absorption refrigeration (DAR) system's thermal performance. DAR heat exchanger exhaust gas flow was manually controlled via two valves. Experimental results showed that the (DAR) system could regulate exhaust gas passage across engine loads. The refrigerated cabin reached 10-14.5 °C 3.5 hours after system activation, depending on engine load. A 30 Nm torque regulated exhaust mass flow rate achieved the best performance coefficient of 0.10 after three hours of system operation.

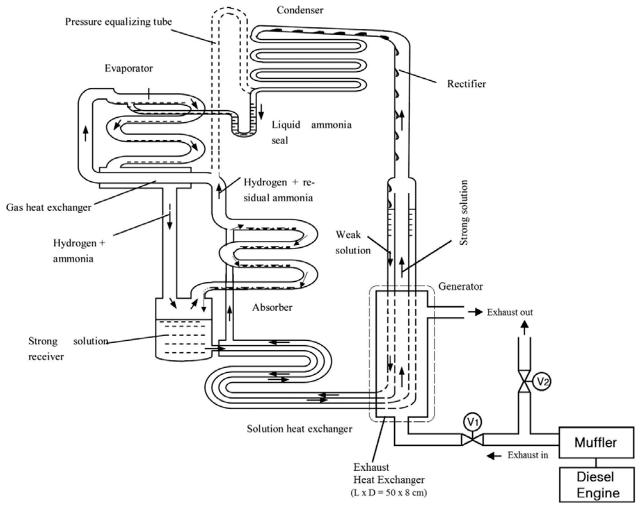
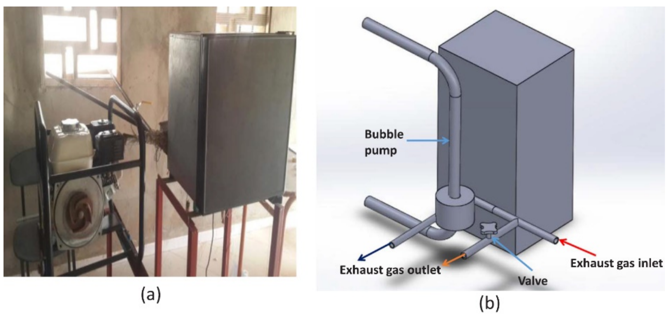


Fig. 6 A schematic diagram of the experimental setup.

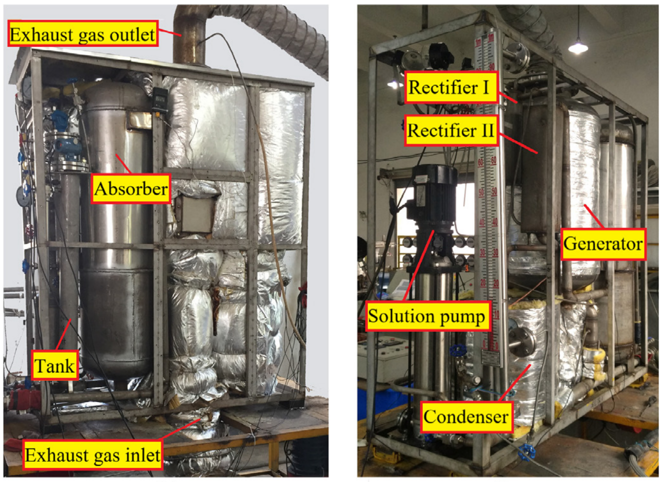
Adjibade et al. [23] The experimentally (DAR) cycle used heat exchange with exhaust gas from an internal combustion engine and grid electricity as seen in Fig. 7. They understood component behavior using heat transfer analysis and thermodynamic balances. Operating temperatures for exhaust and electrical sources were 140 °C to 152 °C. They concluded that exhaust gases can power the (DAR) cycle.



(a) (b)

Fig. 7 Engine exhaust system-adapted experimental absorption refrigerator (a) and its schematic (b).

Yuan et al. [24] An experiment with an absorption refrigeration system was proposed as a way to recover heat from the exhaust fumes of marine engines. For this system, a ternary composition (NH_3-H_2O-LiBr) was used. Figure 8 shows how a prototype absorption device reduced a rectifier's heat exchange area by 16% under experimental operating conditions. The ternary system functions at a refrigeration temperature of less than -15.0 °C, in contrast to the binary system.



(a) (b)

Fig. 8 Absorption system: (a) front view (b) left rear view.

Kaewpradub et al. [25] Single-effect LiBr-H_2O-based (VARS) was tested with 4-stroke gasoline engine exhaust. Experimental apparatus schematic as seen in Fig. 9. They specified heat exchanger types for VARS components. Engine operating between 1200 and 1400 rpm is ideal for running the (VARS), according to experiments at 1000, 1200, 1400, and 1600 rpm. It was found that speeds greater than 1600 rpm promote LiBr-H_2O solution crystallization because higher effluent temperatures raise generator temperatures. The cooling load was 700 W, and the COP reached 0.275 at 1400 rpm.

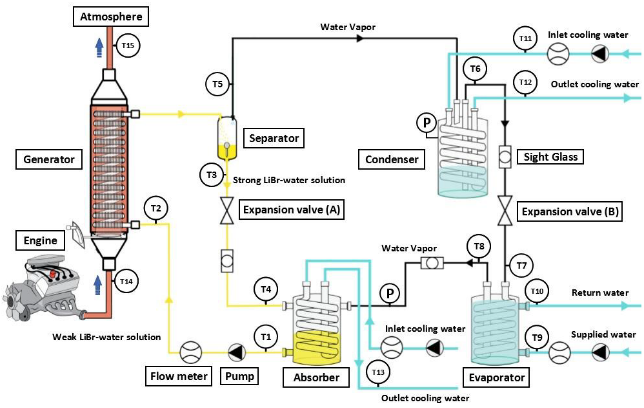


Fig. 9 Experimental apparatus schematic diagram.

Venkataraman et al. [26] transportable heat-driven absorption refrigeration/air conditioning is evaluated. The biggest obstacles to transport technology implementation. According to the study, VARS units are incompatible with cars and reduce engine efficiency and performance when coupled to engine exhaust. SoFCs, as APUs, minimize engine load and deliver a steady heat load to VARS, improving efficiency.

Bux and A. C. [27] suggested Make use of a (H_2O-LiBr) working pair to connect diesel engine exhaust to a plate heat exchanger desorber. Although the project's goal was to build a passenger automobile air conditioning system using (VARS) technology, it did not specify the cooling load or the plate heat exchanger's capacity to generate adequate refrigerant. As these researchers performed, it is not advised to directly link heated exhaust gases with the desorber because of temperature incompatibility and corrosion. Vijesh and Steffin [28] waste heat-powered vapour absorption refrigeration systems operate at a higher efficiency level. Various conditions are incorporated into the VARS system efficacy calculation. According to the results, increasing the input temperature enhances system efficacy. This system employs energy from engine exhaust to refrigerate via vapour absorption.

Ahmad et al. [29] in a variety of climates, a single-effect vapour absorption refrigeration system was tested with lithium chloride (LiCl-H_2O) and lithium bromide (LiBr-H_2O) water. The optimal generator operating temperature, performance coefficient (COP), solution concentration, and component heat burden were assessed for two systems. The equipment has a capacity of 300 kW. The maximal COP for the LiBr-H_2O system ranges from 0.741 to 0.902, while the LiCl-H_2O system ranges from 0.809 to 0.926. LiCl-H_2O requires 370.787 kW, while LiBr-H_2O requires 382.573 kW. Compared to LiBr-H_2O, the LiCl-H_2O system has a greater COP and a lower generator burden.

3.2. Engine cooling water

Some previous researchers used the heat waste from the water from the cooling of the engines to power the absorption refrigeration system.

Sharma et al. [30] employed a hot water-driven, single-stage lithium bromide water solution absorption refrigeration system to assess and explore the impact of multiple variables on the coefficient of performance (COP). findings demonstrate that while an increase in condenser pressure lowers the COP, an increase in evaporator pressure raises the COP. The COP rises as the concentration of the LiBr solution input to the absorber falls. Táboas et al. [31] utilized a variety of absorbents and NH_3 as the refrigerant to assess the absorption refrigeration cycle that is fueled by jacket water in diesel fishing vessel engines. According to simulations, the COP values of NH_3 / ($LiNO_3$ + H_2O) and NH_3/$LiNO_3$ fluid mixtures are higher than those of NH_3/H_2O. At 25 °C, the potential evaporation temperatures of the working fluid cycles of NH_3/$LiNO_3$ and NH_3 / ($LiNO_3$ + H_2O) were the lowest, at -18.8 °C, -17.5 °C, and -13.7 °C, respectively.

Palomba et al. [32] the proposed onboard absorption device is to be tested using a 195 kW marine engine. Reduced fuel consumption of about 1600 kg annually and reduced CO_2 emissions by three tonnes are possible for a cooling load typical of an Italian fishing vessel. Larger vessels with 10 kW cooling capacity could save seven times as much fuel.

Kanase [33] suggested using an absorption cooling system rather than a compression cooling system, which is more stressful on engines and worse for the environment as seen in Fig. 10. Cooling water and wasted engine exhaust gas were utilized. Because absorption cooling uses waste heat from the engine, it was a successful substitute for air conditioning in cars.

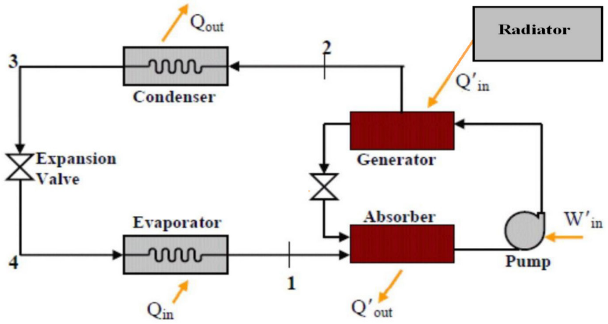


Fig. 10 Flow chart of the system proposed.

3.3. waste heat generated by engine-coupled exhaust gases and cooling water

Some researchers have investigated the potential of utilizing the waste heat of engines, which encompasses exhaust heat and engine cooling water heat, in the absorption refrigeration system.

Cao et al. [34] for the refrigeration and chilling requirements of a cargo ship, a cascaded absorption-compression cycle was suggested as a solution. The recommended waste heat-powered system substantially reduces CO_2 emissions by 11% and petroleum usage by 38% in comparison to the conventional system, as demonstrated by the simulation results. Salmi et al. [35] a steady-state thermodynamic model for ship applications was developed, which employs NH_3-H_2O and H_2O-LiBr for absorption refrigeration cycles. The energy sources are scavenged air, jacket water, and exhaust gases, as illustrated in Fig. 11. The generator and evaporator's performance coefficients were evaluated at both tropical and ISO temperatures. The results indicated a potential reduction of 70% in the ISO electricity required by the accommodation compressor when combined with case ship data. An estimated 47 to 95 tonnes of fuel are conserved annually.

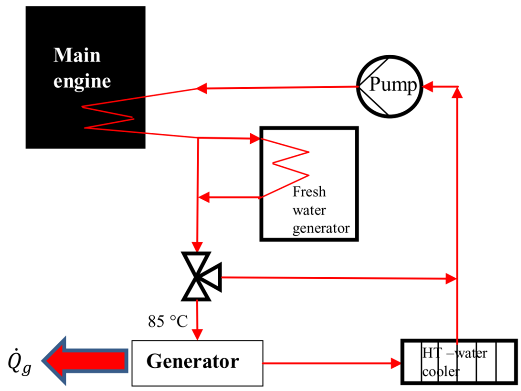


Fig. 11 An illustration of the jacket water-based ME cooling and generator heating process.

Ammar and Seddiek [36] examined the absorption refrigeration cycle using jacket cooling solutions and shipboard diesel engine exhaust gases from a thermos-economic and environmental perspective as seen in Fig. 12. LiBr-H_2O combinations were used as its solvents. In comparison to the primary engine during a cruise, the absorption refrigeration cycle decreased annual fuel consumption by 156 tonnes and exhaust gas emissions by 6.3%. In practice, this application has the potential to decrease emissions of CO_2, NOx, and SOx by 0.08, 13.18, and 4.99 USD/kg, respectively.

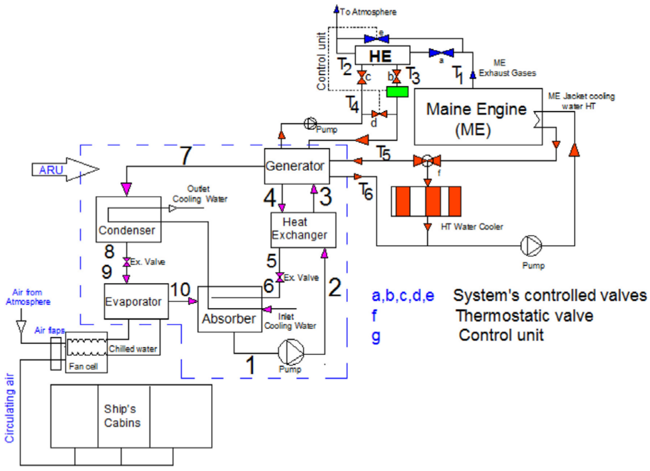


Fig. 12 The principal elements of an absorption refrigeration system on a passenger ship.

4. VARS driven by renewable energy

Previous research has discussed the feasibility of operating absorption cooling systems using renewable energy, the most important of which is solar energy.

Kaynakli and Kilic [37] studied the thermodynamics of water and lithium bromide. They discovered that as absorber and condenser temperatures fall, evaporator and generator temperatures increase (COPc) and (COP). As a result, the solution heat exchanger (SHE) had a greater influence on the parameters than the refrigerant heat exchanger. With the SHE, COP rises by 44%, while with the RHE, it rises by 2.8%. Gutiérrez-Urueta et al. [38] Novel single-effect LiBr-H_2O adiabatic absorption chiller components were investigated as seen in Fig. 13. The construction makes use of plate heat exchangers. Constructed and evaluated liquid sheets and droplets as adiabatic absorbers, with an emphasis on evaporator limitations and performance characteristics. The conductance and heat and mass transfer efficacy of the absorber have been assessed. Both instances demonstrate the effects of recirculation ratio. The droplet configuration has fewer evaluation parameters than the liquid sheet configuration, 50% reduction in absorber size relative to drips.

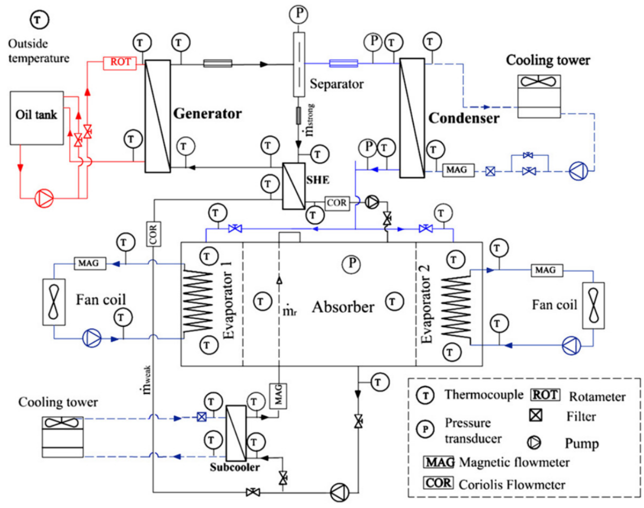


Fig. 13 Flow diagram of the test rig.

Abdulrahim and Darwish [39] an eight-effects MED was utilized to examine the theoretical relationship between thermal solar energy and LiBr/H_2O absorption as shown in the Fig. 14. The COP of a 2148 kW absorption refrigeration unit was 0.74, whereas the MED controlled desalination while producing 459 m^3 of water per day at a constant FR of 5.7.

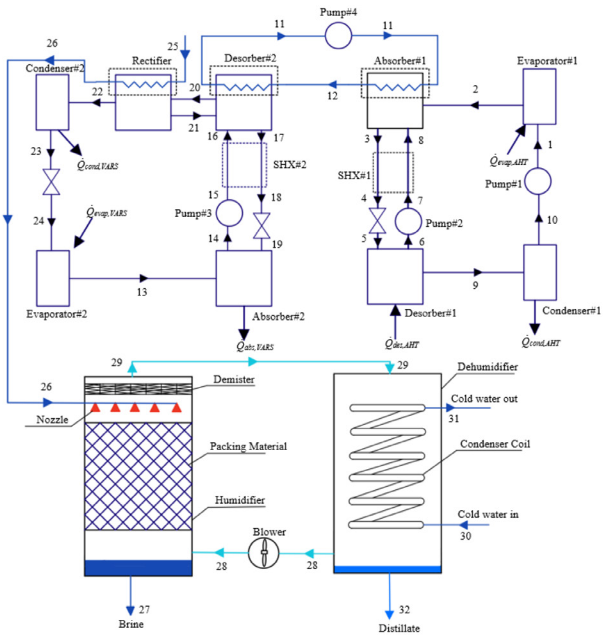


Fig. 14 Schematic of the proposed novel cycle.

Gutiérrez-Urueta et al. [40] investigated exergy and energy in a water-LiBr absorption plant with a singular effect as shown in the Fig. 15. Chilling and heating are both necessary for this operation. Temperature has an impact on performance coefficients and exergy efficiency. The findings imply effects on an adiabatic absorption system's exergy efficiency. As the component of the system with the lowest exergy efficacy, the absorber should be calibrated first. A new metric for adiabatic absorbers is the recirculation ratio. The heat exchanger can be optimized for the solution.

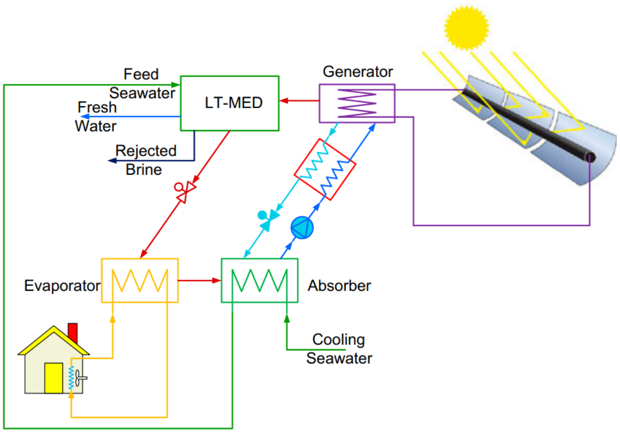


Fig. 15 show the heat pump-assisted desalination system.

Omar and Micallef [41] A LiBr/water absorption refrigeration system was mathematically modelled utilizing an adiabatic absorber as shown in the Fig. 16. A higher or lower absorber or generator temperature increases or decreases the coefficient of performance, respectively. The recommended temperatures for the generator and adiabatic absorber in an absorption refrigeration system were ascertained through this analysis to be 80°C and 40°C, correspondingly A solar collector enables the device to produce electricity at a low generating temperature of 80 °C, resulting in a high COP value.

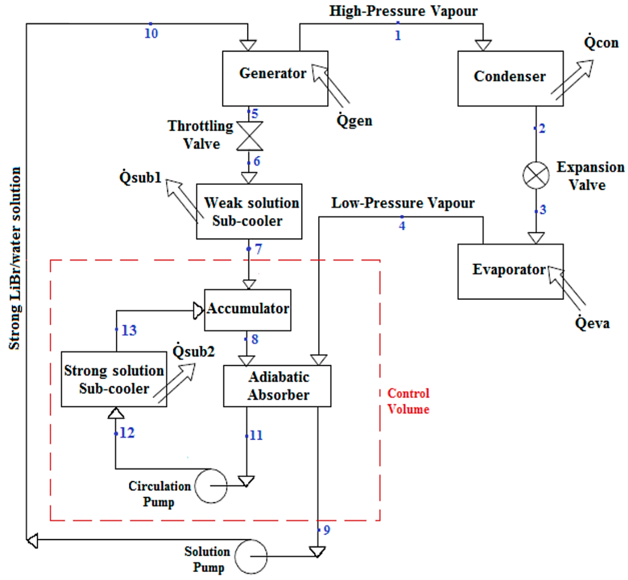


Fig. 16 Diagram illustrating the water/LiBr system with an adiabatic absorber connected.

López-Zavala et al. [42] designed and implemented a solar-powered LiBr-H_2O absorption cooling and desalination system. The system is cooled using three saltwater pressures. The cycle was designed to improve cooling and desalination as shown in the Fig. 17. Efficiency increased by 19.4% over a single-effect absorption system.

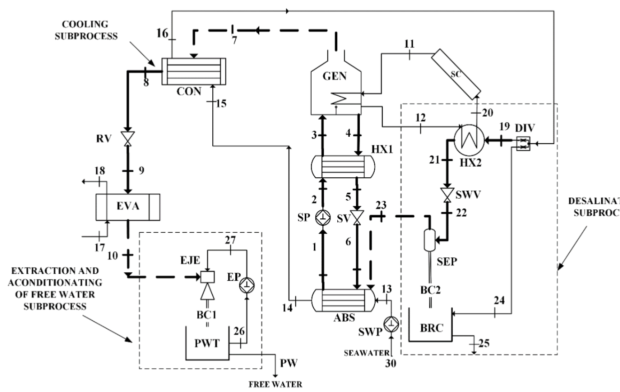


Fig. 17 Diagram of the desalination and cooling system for LiBr/H_2O absorption.

Marashli et al. [43] a Solar Absorption Cooling system (SESAC) has been developed using evacuated tube collectors and a working fluid consisting of lithium bromide-water (LiBr-H_2O). The refrigeration system cycle's fluctuating temperature had an impact on both the coefficient of performance (COP) and the crystallization of LiBr-H_2O, 120 kW provides modest refrigeration, and the evacuated tube solar collectors cover 243.3 m^2. The most substantial influence on system efficacy was identified as generator temperature. At a generation temperature of 110 degrees Celsius, the maximum (COP) value was 0.74, excluding crystallization.

Aljuhani and Dayem [44] a solar absorption cooling-chilled water system simulation, as illustrated in Fig. 18, was examined. The tent necessitates 70 kW to maintain the zone air temperature at 24 degrees Celsius during the summer, with a cooling demand of 8850 kWh over a seven-day period, as reported by the results. Furthermore, the potential impact of cold-water storage on the efficiency of the system was examined. By utilizing a 500 m^3 refrigerated water reservoir, the capacity of an absorption chiller is decreased from 20 to 4.7 tonnes. In addition, a PV system with a 70% performance ratio was built to supply the electrical demand of the absorption system.

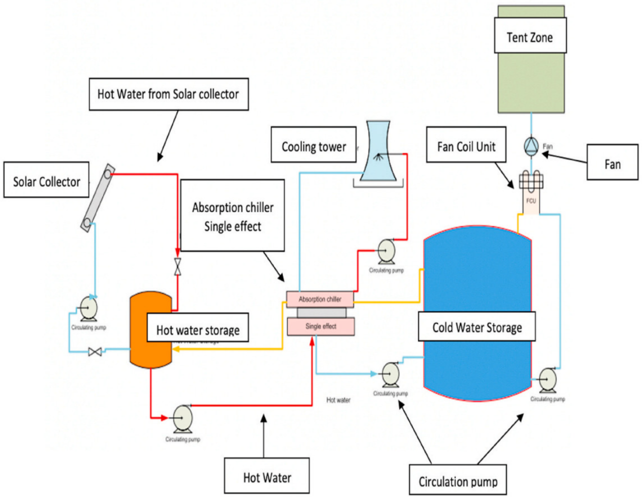


Fig. 18 Solar cooling system components.

Jiménez-García and Rivera [45] the experimental ammonia-water absorption refrigeration system, as illustrated in Fig. 19, was examined using second-law analysis under a variety of conditions. This study used chemical and physical energy to determine the irreversibility of absorption systems. The refrigeration and heating of water are temperature-dependent with respect to the exergy coefficient of performance (ECOP) or second-law efficiency. The absorption system's maximum ECOP was 14.4%. Hassan et al. [46] theoretical investigations were conducted on ABC-ADC systems. The proposed combined ABD-ADC system offers 7.13 percent more cooling capacity than the ABC-ADC system. The COP of the proposed ABD-ADC system was 2.73 percent greater than that of the ABC-ADC alone. The cooling capacity and COP of the single-stage ADC system are 27.07% and 58.34% lower, respectively, than those of the ABD-ADC configuration.

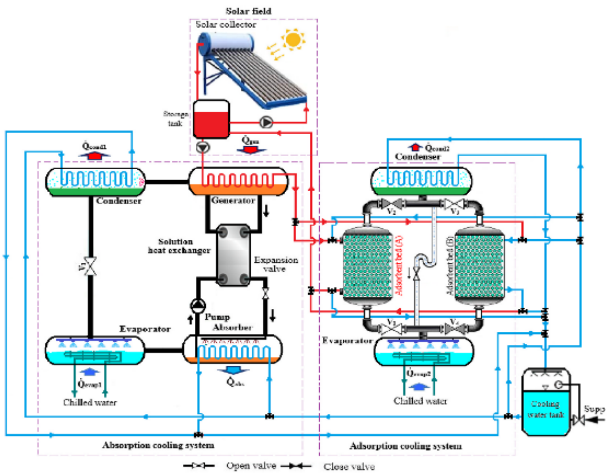


Fig. 19 Combined separated ABC-ADC setup schematic diagram.

Sharma et al. [47] analyzed a thermal energy storage-equipped solar-powered vapour absorption machine (VAM) utilized for pumping milk as shown in the Fig. 20. Summertime cooling energy production by the system amounts to 2356 kWh per month, whereas winter and monsoon only generate 620 kWh. With an average value of 0.41-0.46 during the summer and 0.34-0.39 during the monsoon and winter, the optimal performance coefficient (VAM) is 0.55. The system has an average energy efficiency ratio (EER) of 4.55, with a range of 2.5 to 6.5 when compared to traditional vapour compression refrigeration systems.

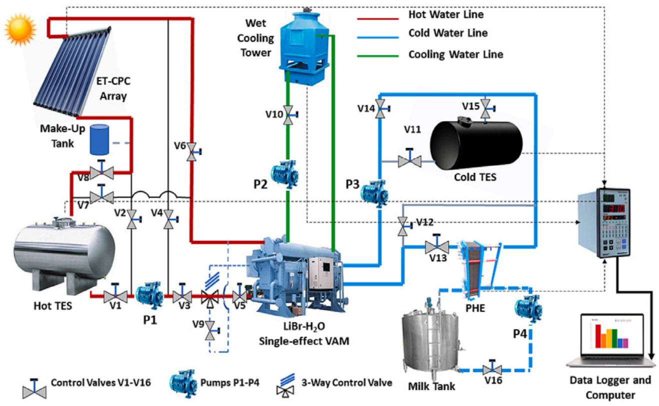


Fig. 20 Layout of a solar-powered absorption cooling system.

Dione et al. [48] analyzed NH_3-H_2O vapour absorption using a linear Fresnel reflector. The 10 kW linear Fresnel reflector and absorption machine components were designed. The NH_3-H_2O thermodynamic model was simulated using outflow temperature. The linear Fresnel reflector contains 30 with10 m long, 0.2 m wide reflectors, 4 m tall absorber tubes, and 10 m long, 4.065 m tall trapezoidal cavity. Performance coefficient is 0.51 and heated source temperature is 169.24 °C.

Zhao et al. [49] created a mathematical model for a VARS powered by geothermal energy recovery using LiBr and LiCl solutions as working fluids as illustrated in Fig. 21. Greater cooling water flow, chilled water inlet temperature, and working fluid concentration raise the system coefficient of performance (COP), whereas greater cooling water inlet temperature decreases it. The LiBr and LiCl solution single-effect absorption refrigeration systems have the greatest COP values (0.795 and 0.785, respectively), as well as the highest ECOP values (0.694 and 0.684).

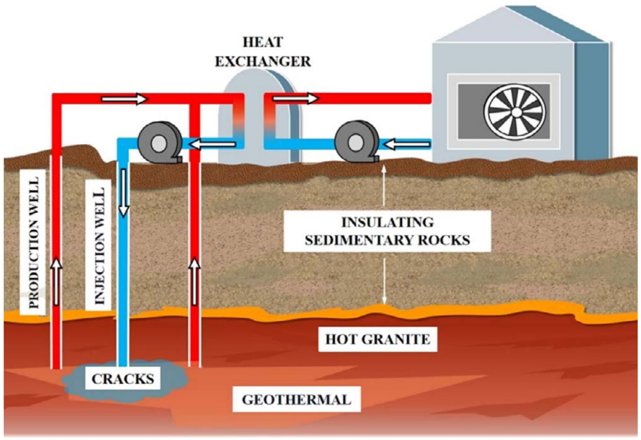


Fig. 21 Schematic diagram of geothermal energy extraction.

Verma et al. [50] performed a study of the literature on several techniques for improving the cycle layout modification and working pair selection-based COP of VARS, as these are the most promising approaches for improving VARS performance as showed in Fig. 22. This technology futuristic features include the addition of new, corrosion-resistant working pairs to the system constituent parts as well as nanoparticles that lower system costs while increasing heat transfer rate.

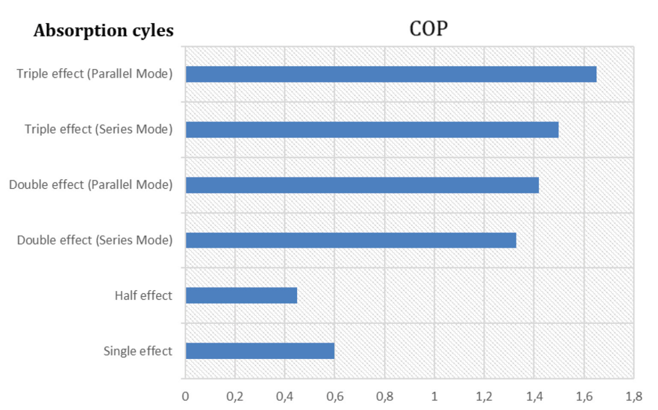


Fig. 22 COP comparison for different VARS.

5. Conclusions

The results were demonstrated through literary evaluations of absorption refrigeration systems that operate in a variety of thermal sources:

1. The possible operation of the absorption refrigeration system using renewable energy and certain other sources, as well as the heat that is squandered from engines.
2. One of the disadvantages of single-effect absorption refrigeration regulators is that they have a low performance factor and require a longer period of time to perform the entire process compared to traditional cooling systems.
3. Absorption cooling systems have a higher edge than conventional refrigeration systems in terms of reducing energy consumption and protecting the environment.
4. The results also demonstrated, by the researchers literature reviews, the feasibility of using engine cooling water and exhaust energy to run the absorption cooling system, so utilizing 30-70% of the engine total wasted energy.
5. By improving the design of the system primary components, the absorption cooling system performance coefficient was raised by 5 to 20%.
6. The efficient design of various components, particularly the generator and absorber, should be addressed, and it is advised that a heat recovery technique be implemented.
7. Currently, two solution pairs have been employed in these systems: NH_3-H_2O and LiBr-H_2O. Additional research is being conducted to identify alternative viable solution combinations that produce a comparable refrigeration effect. A few examples are ammonia sodium thiocyanate NH_3-NaSCN, ammonia lithium nitrate NH_3-$LiNO_3$, and carbon methanol, among others.

Table 1. Summery of research on coupling the VARS with different sources.

References	Type of system	Heat sources	Working fluid	Nature of work	Remarks
[13]	VARS	Exhaust gas	NH_3-H_2O	Experimental	Design of VARS components, engine exhaust coupling with VARS, and VARS performance
[14]	ARCS	Exhaust gas	zeolite-water	Experimental	Testing and the operation of the prototype machine illustrated that this novel system could meet the air conditioning needs of a locomotive's driver's accommodation.
[15]	DAR	Exhaust gas	NH_3-H_2O	Experimental	The findings indicated that the refrigerator operating on engine exhaust exhibited superior performance compared to the initial refrigerator powered by AC and DC current.
[16]	VARS	Exhaust gas	LiBr-H_2O	Simulation	The results suggest that when the desorber's working temperature varies, so does the system's performance.
[17]	VARS	Engine exhaust	NH_3-H_2O	Theoretical	Sufficient thermal energy is present in the exhaust emissions of motor vehicles to supply power to an air conditioning system.
[18]	VARS	Exhaust gas	NH_3-H_2O	Experimental	A specialised system has the potential to substantially enhance cooling capacity by utilising the expected energy availability from exhaust gas.
[19]	VARS	Exhaust gas	NH_3-H_2O or LiBr- H_2O	Experimental	According to the results, engine exhaust emissions have the potential to be employed as a power source for automotive absorption refrigeration systems.
[20]	VARS	Exhaust gas	NH_3-H_2O	Experimental	Except when the engine speed was 1000 rpm, the exhaust gas contained sufficient heat to operate the absorption system between 1500 and 4300 rpm.
[21]	VARS	Exhaust gas	LiBr-H_2O	Experimental	The investigation yielded a maximal COP of 0.78 at an evaporator temperature of 11°C.
[22]	DAR	Exhaust gas	NH_3-H_2O	Experimental	The optimal performance coefficient for a controlled exhaust mass flow rate was 0.10 at 30 Nm of torque.
[23]	DAR	Exhaust gas and electrical energy	NH_3-H_2O	Experimental	Their conclusion was that the (DAR) cycle can be powered by exhaust fumes.
[24]	VARS	Exhaust gas	binary NH_3-H_2O and ternary NH_3-H_2O- LiBr	Experimental	The ternary system exhibits a significant increase in cooling capacity, ECOP, and COP, as well as a decrease in heat loss. These results suggest that the ternary system has a higher energy conversion efficiency.

[25]	VARS	Exhaust gas	LiBr-H_2O	Experimental	It was found that speeds above 1600 (rpm) increase the likelihood that the LiBr-H2O solution will crystallise. At 1400 rpm, a maximum COP of 0.275 and a cooling load of 700 W were achieved.
[26]	ARAS	Exhaust gas and fuel cell	LiBr-H_2O and NH_3-H_2O	Review	summarizing the advancements in absorption refrigeration and engine exhaust technologies for transportation applications
[27]	VARS	Exhaust gas	LiBr-H_2O	Experimental	It is generally not advisable to directly couple heated exhaust gases with the desorber due to temperature incompatibility and potential for corrosion.
[28]	VARS	Exhaust gas	LiBr-H_2O	Experimental	The results indicate that the system's effectiveness enhances as the temperature of the input increases.
[29]	VARS	Heat	LiBr-H_2O and LiCl-H_2O	Comparison	The maximal COP of the LiBr-H2O system was (0.741) to (0.902), as indicated by the results. Conversely, the highest COP of the LiCl-H2O system is (0.809) to (0.926).
[49]	VARS	Hot water	LiBr-H_2O	Theoretical	The engine cooling system wastes (10 kW) while the engine is idling, (68 kW) when the engine is loaded, and the engine cooling water temperature ranges from 71 to 84 °C.
[30]	VARS	Hot water	LiBr-H_2O	Investigative	The resulting graph demonstrates that the (COP) decreases as the condenser pressure increases, whereas the (COP) increases as the evaporator pressure increases. When the LiBr solution input to the absorber is at reduced concentrations, the (COP) increases.
[31]	VARS	Hot water	$NH_3/LiNO_3$, NH_3/H_2O and $NH_3/(LiNO_3$ $H_2O)$	Thermodynamic simulation	When the condensing temperature is 25 °C, the lowest evaporation temperature for the NH3/ (LiNO3 + H2O) cycle that can be reached with a heat source at 85 ~C was found to be 17.5-25.5 °C.
[32]	VARS	Hot water	NH_3-H_2O	Experimental	Fuel savings could be up to seven times higher for larger vessels that require a cooling capacity of 10 kW.
[33]	VARS	Hot water	LiBr-H_2O	Theoretical	Instead of using the standard compression cooling system inside the automobile, the technology proved to be a successful substitute for the air conditioning.
[34]	ABC	Exhaust gas and jacket water	-	Modeling	Both CO2 emissions and petroleum consumption were decreased by 11% and 38%, respectively, with the suggested waste heat-powered system.
[35]	VARS	Exhaust gas and jacket water	H_2O-LiBr and NH_3-H_2O	Thermodynamic model	Together with case ship data, the results showed that the accommodation compressor could theoretically save 70% on electricity under ISO standards.
[36]	VARS	Exhaust gas and jacket water	LiBr-H_2O	Thermodynamic analysis	With a six-year payback, both systems are financially viable for new or operational ships.
[37]	VARS	Solar	LiBr-H_2O	Thermodynamic analysis	COP increases by 44% with the SHE and 2.8% with the RHE.
[38]	ASC	Solar	LiBr-H_2O	Experimental	The evaluation parameters of the liquid sheet configuration are greater to those of the droplet's configuration. The absorber size can be reduced by 50% compared to drops.
[39]	VARS	Solar	LiBr-H_2O	Modelled, and simulated	The absorption refrigeration unit had a capacity of 2148 kW and a coefficient of performance (COP) of 0.74
[40]	VARS	Solar	LiBr-H_2O	Energy and exergy	The energy effectiveness of the absorber and solution heat exchanger increases as the absorption temperature increases; however, the latter's performance decreases as the generation temperature increases.
[41]	VARS with adiabatic absorber	Solar	LiBr-H_2O	Mathematical model	A solar collector enables the system to achieve a low generator temperature of 80 °C, leading to a high coefficient of performance (COP) rating.
[42]	VARS	Solar	LiBr-H_2O	Developed a novel of LiBr-H2O	Compared to a conventional single-effect absorption system, the results indicated that performance was 19.4% improved.
[43]	SESAC	Solar	LiBr-H_2O	Mathematical model	With no crystallization and a generating temperature of 110 °C, the maximum value of (COP) was 0.74.
[44]	SESAC	Solar	LiBr-H_2O	Simulation	According to study, the tent will require a refrigeration capacity of approximately 70 kW to maintain the zone air temperature at (24 °C) throughout the summer
[45]	ADC	Solar	NH_3-H_2O	Experimental	14.4% was the maximum ECOP obtained by the absorption system.
[46]	ABC and ADC	Solar	LiBr-H_2O for ABC and Sg- H_2O for ADC	Theoretical investigated.	The two proposed combined ABD-ADC configurations have a COP that is 2.73 percent higher than the COP of the two individual ABC-ADC setups.
[47]	VAM	Solar	LiBr-H_2O	Methodology	The optimum value of the performance coefficient of (VAM) is (0.55)
[48]	VAM	Solar	NH_3-H_2O	Thermodynamic model	Coefficient of performance reaches (0.510) at 169.24℃ heat source temperature
[49]	VARS	Geothermal	LiBr - LiCl	Mathematical model	the greatest COP values (0.795 and 0.785, respectively), as well as the highest ECOP values (0.694 and 0.684).
[50]	VARS	-	Multi working fluid	Review	study of the several techniques for improving the cycle layout modification and working pair selection-based COP of VARS

Nomenclature

Name	Description
ABC	Absorption cooling system
ACS	Air condition system
ADC	Adsorption cooling system
ARAS	Absorption refrigeration air conditioning system
ARCS	Adsorption air conditioning system
ASC	Adiabatic absorption chiller
CFcs	Chlorofluorocarbon
COP	Coefficient of performance
COPex	Exegetic coefficient
DAC	Diffusion absorption chiller
DAR	Diffusion absorption system
ECOP	Exergy coefficient of performance
EER	Energy efficiency ratio
GR	Gained solar
HCFCs	Hydrochlorofluorocarbons
HCs	Hydrocarbon
IIR	International institute of refrigeration
MED	Multi- effect distillation
RHE	Refrigerant heat exchanger
RPM	Revolution per minute
SCR	Solution circulation ratio
SESAC	Single effect solar absorption cooling system
SOFC	solid oxide fuel cell
SHE	Solution heat exchanger
UPC	Unit product cost
VAM	Vapour absorption machine
VARS	Vapour absorption refrigeration system
VCRS	Vapour compression refrigeration system
VSC	Vapour compression system

Chemical formulation	Description
CO_2	Carbon dioxide
EG	Ethylene glycol
H_2O	Water
LiBr	Lithium bromide
LiCl	Lithium chloride
LiI	Lithium iodide
$LiNO_3$	Lithium nitrate
NaSCN	Sodium thiocyanate
NH_3	Ammonia
NOx	Nitrogen oxide
Sg	Selica gel

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