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Hybrid Vapor Absorption and Compression System -A Thermodynamic Environmental and Economic Analysis – A Review

Bodhisatwa Chowdhury [a*]

[a]*Mechanical Engineering Department, National Institute of Technology, Tiruchirappalli, Tamil Nadu, India.*
[*]*Corresponding Author Email: 211321007@nitt.edu,*
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ABSTRACT

The purpose of reducing cost and energy and gaining a better Coefficient of Performance (COP) leads to the study for the improvement of designing and innovating different refrigeration cycles and their combinations. Researches are carried out on a hybrid cycle based on the VCR-VAR system. Different types of refrigerants are analyzed to get maximum performance keeping the environment in mind. Different designs are made to improve the waste heat recovery to gain a sustainable system. Also, hybrid systems coupled with power cycles can reduce the external power demand have been studied. According to the studies, improvement in terms of COP, costs, energy-saving and environmental friendliness is gained. In this study, summaries of various studies regarding the thermo-economic analysis of the VCR-VAR system are provided, keeping the environmental aspects in mind.

Keywords: Vapor compression-absorption refrigeration system, Thermo-economic analysis, environmental aspects, hybrid refrigeration system.

1. INTRODUCTION

Building consumption of electricity comprises 40% of the worldwide usage of electricity. Many buildings in the Tropical region do not have air conditioning systems yet, so there is a rising demand for refrigeration and cooling systems.VCR system generally consumes a large amount of fossil fuels. VAR is an alternative to the VCR system, which uses waste heat or renewable energy sources and consumes 5% less electricity and less greenhouse gas production. However, it has less COP. So they are combined in a hybrid cycle in different combinations to obtain the benefits of both the cycles.

Cascade or series mode of VCR-VAR cycle generally employs a heat exchanger to integrate the evaporator of VAR and the condenser of VCR. The parallel combination is done when cooled fluid exits from the VAR evaporator used to evaporate VCR working fluid for further cooling. The combined parallel and series comprise the cooled fluid of VAR to

evaporation of working fluid of VCR in parallel thereafter cascaded condenser where VAR fluid cools the VCR condenser. In subcooling, the VCR, placed between the expansion valve and condenser, is subcooled by the cycle fluid of VAR.

Generally, all thermodynamic modeling is done based on the 4E analysis, i.e., exergy, energy, environmental and economic evaluation with a combination of optimization and type of heat sources such as Solar, wind, biomass, fossil fuels and waste heat.

2. PREVIOUS INVESTIGATIONS ON HYBRID ABSORPTION-COMPRESSION REFRIGERATION SYSTEM

Chen et al. [1] experimented by coupling the evaporator of absorption subsystem to the VCR condenser which is placed in the gap of the subsystem's condenser. Electric heaters simulate the solar collectors and the temperature is controlled by a PID controller for the hot and chilled water tank. In addition to Payback time, the economic analysis is also done by Levelized Cost of Cooling. The electrical COP of the hybrid VCR-VAR increases with hot water temperature. Subcooling lowers the heat consumption, gives better exergic efficiency and Primary energy efficiency (PEE) than independent VCR. COP of the cascade system increases but heat consumption increases, PEE is lower than in the subcooling system.

Peng et al. [2] proposed a hybrid system that shows an increase in energy of heat source of small-scale low grade by employing parallel subcoolers and recoolers. Cascade subcooler and recooler are connected parallelly to save energy and reduce the fall in exit temperature of high-pressure compressor of VCR system.

Patel et al. [3] showed that the proposed system with solar absorption and Rankine cycle for power to the compressor of VCR produces effective low temperature colling and heating off-grade applications like process industries and is ideal for isolated and decentralized heating and cooling demands.

Razmi et al. [4] introduced a hybrid system for retail buildings employing energy storage of compressed air and wind turbine. A vapor compression system is employed in between condenser and generator to boost the performance and efficiency is seen to be improved. Elimination of pollutant refrigerants and employing wind turbines with inclusion of high temperature energy storage made it environment friendly. Employing the compressed air storage and vapor compressor made the system consume less energy.

Song et al. [5] proposed a double compression with solar absorption hybrid refrigeration (SADC-HR) design to effectively utilize the high temperature colling capacity. The cooling capacity of chilled water from single-effect solar absorption refrigeration (SSAR) subsystem

is used for a sensible load of AC system and then removal of condensation heat from VCR. At smaller solar intensities, this SADC-HR system attains better performance in economic terms than SSAR system and solar VCR-VAR cascade system and environmental impact by consuming less power and emitting less CO_2.

Gado et al. [6] showed the feasibility of complete hybrid renewable energy systems where biomass operates the absorption cycle and electric power of photovoltaic/thermal (PVT) propels the compression cycle. Wind energy is also used with PVT but it is less cost-effective. With biomass and PVT cells, the annual cost is less and is environmentally friendly than the conventional system.

Wei et al. [7] proposed an idea to utilize the high temperature gradient between the exhaust gas and operating working fluid by providing a power cycle between them to compensate for the power required to run the hybrid cycle. Single effect Compression-absorption refrigeration (CAR) cycle with bmim (ionic fluid) Zn_2Cl_5/NH_3 used as working fluid in CAR. It shows that performance characteristics are better when evaporation temperature is below -5ºC.

Wang et al.[8] showed a comparative study to reduce the condenser's potential heat loss in the environment. He compared the results of a dual-effect VAR system and a hybrid VAR-VCR recovering condensation heat of generation (RCHG-ARS). He found out energy efficiency is higher while generation heat input is lower for RCHS-ARS and evaporator temperature dropped meaning that it can be operated at a lower temperature.

Higa et al. [9] showed a technique to recuperate condensation heat by implementing a single-stage VCR-VAR system. He proposed a system having dual evaporators and generators operating at different pressures and temperatures. The condensation heat of NH_3, that was wasted before, now provided to the low Pressure-temperature generator from high pressure and temperature one. The study shows a reduction in external heat source and power demand than VCR even at different pressures.

Agarwal et al.[10] analyzed the series flow triple effect H_2O-LiBr VAR for higher temperature section and R1234yf refrigerant in VCR for lower temperature providing a temperature range of 223.15-263.15K for small-scale industries with less running cost using the gas/steam turbine exhaust reducing the overall high-grade electricity consumption.

Jose et al. [11] analyzed 16 different pairs of refrigerants, ionic liquids and Hydrofluoroolefins as absorbers which are having smaller Global Warming Potential . They studied performance in single-effect VAR and compression assisted VAR based on COP, thermal and electrical COP, solution circulation factor. The isochronism method is used to

determine the absorption of R1234ze. Solubility of R1234ze, similar to R32, is more than other HFOs and also, its R1234yf isomer but lower working pressure than R32 reduces the compressor work.

Kadam et al. [12] made a systematic evaluation by comparing seven different VCR-VAR configurations with novel Acet/DMF VAR working fluid, R-134a as VCR working fluid and NH_3-H_2O VAR fluid in different combinations viz parallel, series and combined and took operating data from District cooling (DC) Qatar Plant with 252% improvement in COP. At the same time, the total equivalent global warming effect and mass flow rate of refrigerant and Operational cost are lower for cascade system than standalone VCR system. The study also shows that the utilization factor based upon electrical energy for Acet/DMF is less than NH_3-H_2O.

Jain et al. [13] provided an integrated vapor compression-absorption system where work is obtained at a lower generator temperature of 60ºC. Though the electrical energy required for system is more than cascade system, it is energy efficient due to lower generator temperature. The performance is improved by using Coefficient Structural Bond (CSB) method and the optimal cost is lower due to the use of Low pressure generator.

Jain and Colorado [14] proposed a structure of a trans-critical integrated vapor compression-absorption system and compared it with trans-critical vapor compression system. The paper evaluated that at optimum condenser pressure and temperature of generator, the overall COP and exergectic efficiency increase significantly. The requirement for external cooling water is less and can be operated in low temperature applications and warm climate environments. It also has a lower payback period, shorter breakeven point and less annualized cost.

Ustaoglu [15] studied the advanced exergic analysis of hybrid cycle with wet, azeotropic and isentropic type refrigerants by utilizing waste heat from industrial process. Paper showed that maximum exergy is destroyed at the generator and R152a/NH_3-H_2O has the lowest irreversibility. It also provided an idea that there is a scope of utilizing more than 50% of this destruction of exergy.

3. CONCLUSION

As a result, from the literature review discussed above the different areas covered in this study are as follows.

- The hybrid system is useful for district cooling in gulf areas because of having locally produced fossil fuels and water shortage and management problems. Also, possibilities for using renewable sources are there with the hybrid system.

- Complete dependency on renewable hybrid systems will be cost-effective and environment-friendly.
- The overall COP, Electrical-COP, and energy efficiency also increase using hybrid system. Major avoidable exergic destruction occurs at the generator which can be minimized by increasing the temperature of generator and reducing pressure of condenser.
- The overall demand for external cooling water can also be reduced.
- There is a chance of improving performance by selecting various azeotropes, organic refrigerants and ionic solvents.
- The hybrid system can be implemented with power cycles running on organic working fluid, minimizing electricity consumption.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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