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A Review on Thermal Analysis of Single Effect Vapour Absorption System Integrated with Vapour Compression System

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Abstract-This abstract provides a concise overview of a review focused on the thermal analysis of a hybrid system integrating a single-effect vapour absorption system with a vapour compression system. This integration represents a synergistic approach to enhance overall system efficiency and performance. The review encompasses an in-depth examination of the thermal characteristics, energy transfer processes, and performance metrics associated with the hybrid system. Various configurations, control strategies, and operating parameters are scrutinized to identify key factors influencing the integrated system's thermal behavior. Additionally, the review explores the implications of this hybridization on energy savings, environmental impact, and overall sustainability. The synthesis of vapour absorption and compression technologies in a single-effect configuration presents a promising avenue for advancing the efficiency of refrigeration and air conditioning systems, making this review valuable for researchers, engineers, and practitioners seeking insights into the thermal dynamics and optimization potential of such integrated systems.

Keywords-Single effect vapour absorption system, vapour compression system, thermal analysis

I. INTRODUCTION

Cooling and refrigeration demand constitutes a substantial fraction of global energy consumption. Since mechanical vapour compression systems require high-grade energy for their operation, alternative cooling systems such as absorption and adsorption cooling systems are receiving more attention than ever. Conventional cooling systems have greater overall working performance than absorption and adsorption cooling systems [1].

Today's world is facing two most important environmental problems. They are the energy crisis and the greenhouse effect. Scientists are working on how to eradicate these problems. Most of the today's innovations are based on this fact. Lithium-Bromide and water driven absorption refrigeration cycle is a burning example of this concept, which not only helps in minimizing the fossil fuel usage, hence the reduced CO2 gas emission but also utilizes the low-grade heat from various industries and data centres. Energy, exergy and advanced exergy methods are used to analyse a milk powder production facility. The production of dairy products, such as milk powder and cheese, is a major industrial sector in India and other countries. It is also one of the most energy- intensive industries within the food sector. India has a high share of agricultural products in their overall exports, of which 20% of the agricultural exports are dairy products. Several scientific and engineering methods exist and are under continuous development, which target the determination, quantification and prioritisation of possible energy savings in complex and large-scale industrial processes. Dairy farming is one of the popular businesses these days. It is because of advancements in the dairy industry. With the advancements, all the dairy works are done with the help of milk processing plants and dairy machines.

The vapour absorption refrigeration cycle or the absorption refrigerator is a closed loop cycle that uses low grade heat (waste heat) to provide cooling or refrigeration. It is different from the conventionally used vapour compression refrigerator in the sense thatit works on chemical energy rather than electrical energy. The absorption refrigerator uses a chemical substance as the absorbent which absorbs the refrigerant in the absorber and the waste heat is being used to recover the refrigerant free absorbent and enable it to be reused. (Ammonia + water) and (Lithium-bromide + water) are the two commercially used working pairs for this kind of refrigerators with their operability limitations.

II. ABSORPTION REFRIGERATION CYCLE

Absorption refrigerator is a chemically driven refrigeration system which uses an absorbent refrigerant combination as the main working pair. In case of LiBr + water combo, LiBr solution works as absorbent whereas water works as refrigerant. The basic features that make it convenient to use this combination as working pair is as follows [2]:-

- The refrigerant should be more volatile than the absorbent in other words the boiling point of refrigerant should me less than that of absorbent. This feature is easily followed by LiBr+water working pair.
- There should be large difference in their boiling points so that it will be easier to separate them in the generator. This ensures that pure refrigerant flows through the refrigerant circuit (condenser, expansion valve and evaporator). This property is also smoothly followed by this pair as LiBr solution has a much higher boiling point than the refrigerant water.
- The LiBr solution has a strong affinity for the refrigerant water.
- LiBr+water solution is cheap, environment-friendly and non-toxic.

The above features make this working pair more user friendly and eco-friendly to use in the absorption refrigeration cycle. But there are some limiting factors that need to have a close look while using this pair otherwise it will lead to a bigger problem [5]. These are as follows, As working absorbent is an electrolyte solid in a solution form, higher concentration can lead to crystal formation which can block the pipes, hence it is needed to have a high pressure in the condenser and generator so that crystallization won't happen at the working temperatures. Anti-crystallizers are being used to overcome this problem.[4]

- As the refrigerant used here is water hence it is needed to have a vacuum condition in the evaporator to decrease the boiling point of water. To maintain this vacuum condition is also a big challenge.
- Corrosion is another big problem. As water carries dissolved oxygen, this system is prone to metallic corrosion. This can be avoided by using anti- corrosive materials for the construction of this system.

III. LIBR + WATER BASED ABSORPTION REFRIGERATION SYSTEM

The use of LiBr + Water for absorption refrigeration system started around 1930s. The outstanding features of LiBr+water system is the non-volatility of the absorbent i.e. LiBr. This eliminates the use of rectifier as used in Ammonia+ water-based absorption refrigeration system. Another advantage is the high heat of vaporization of refrigerant i.e. water. But the use of water as refrigerant also restricts the use in low temperature applications. The COP of these kinds of refrigeration system is higher than the ammonia + water-based refrigeration system. The thermodynamic analysis of the system involves finding important parameters like enthalpy, mass flow rates, coefficient of performance (COP), heat and mass transfer and crystallization in LiBr + Water system [2]. The thermodynamic analysis is carried out with the following assumptions: -

1) Steady state and steady flow
2) No pressure drops due to friction

3) Pure refrigerant comes out from the generator through the refrigerator circuit in form of vapour.

Refrigerant absorbent systems should possess some desirable properties for vapour absorption cycle. These are as follows-

- The refrigerant should be more volatile than the absorbent in other words the boiling point of refrigerant should me less than that of absorbent.
- There should be large difference in their boiling points so that it will be easier to separate them in the generator. This ensures that pure refrigerant flows through the refrigerant circuit (condenser, expansion valve and evaporator).
- The refrigerant should exhibit high solubility with solution in the absorber.
- The absorbent should have strong affinity for the refrigerant, this will minimize the amount of refrigerant to be circulated.
- Operation pressure should be low so that the pipe walls need not to be strong.
- It should not undergo crystallization otherwise; it will block the pipes and flowrates will be changed
- The mixture should be chemically stable, safe and inexpensive.

Fig.1.1 presents the working principle of vapour-absorption refrigeration cycle. As its name indicates, the vapour absorption refrigerator contains an absorber and a generator instead of a compressor (which is an integral part in vapour compression system). Different parts of a vapour absorption refrigerator are as follows:-

1) Evaporator
2) Absorber
3) Generator
4) Condenser

Water enters the evaporator at low temperature and pressure. Here water is in vapour – liquid state. This water refrigerant absorbs heat from the substance to be chilled and gets fully evaporated. As the boiling point of the refrigerant is high, process is being carried out in a low pressure or almost vacuum condition. This low pressure or vacuum condition helps in reducing the boiling point temperature of the refrigerant. A temperature around 3-4 ˚C can vaporise the water refrigerant. Then this water vapour enters the absorber section at constant pressure. Concentrated LiBr solution is present in absorber. Since water is highly soluble in LiBr solution, water vapour is absorbed through this concentrated solution making it dilute. At this point, it can be stated that, the power consumed by the compressor, is saved by this chemical absorption process which makes this system more energy saving and eco-friendly. From this absorber, dilute solution of LiBr + water is carried to the generator through a pump. Generator is the section where the refrigerant and absorbent are separated. Here heat is supplied to the solution. This heat is generally the waste heat coming out from data centres, steam power plants, hotels or big apartments. Water vaporises from the solution and moves to the condenser and the dilute LiBr + water solution becomes concentrated again and moves to the absorber. Condenser block is used as a device to condense the water vapour to liquid water. This can be done by passing normal cooling water or air flow. Generally, a valve is used to reduce the pressure that is required in the evaporator.

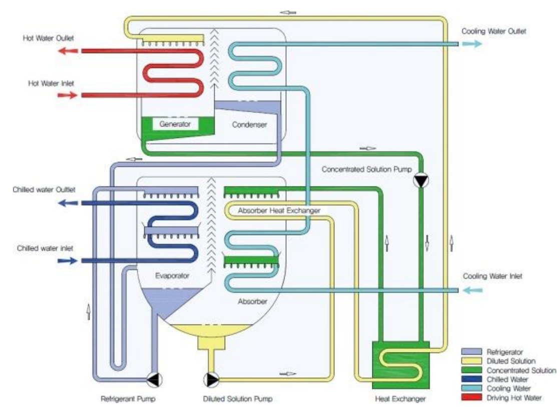

Fig. 1: Vapour absorption refrigeration system [3]

In recent years, the lithium bromide/water absorption system has become prominent in refrigeration air conditioning. It possesses several advantages over the other types of absorption system, such as:

1) It has the highest coefficient of performance (COP) compared to other single-stage absorption units at the same cycle temperatures
2) It is compared to simplifier components since it can work efficiently without the need of rectification columns. A basic generator is

sufficient due to the nonvolatility of the absorbent (LiBr), allowing only water vapour to be driven off the generator.

3) Less pump work is needed compared to other units due to operation at vacuum pressures. On the other hand, the lithium bromide/water absorption system has some drawbacks such as: It is limited to relatively high evaporating temperature since the refrigerant is water. This means that evaporation temperature above 00C must generally be satisfied to prevent the flow of freezing.
4) Crystallization of LiBr salt at moderate concentrations (>0.65 kg LiBr/kg solution) will tip of the cycle range of operation.
5) The systems have to be designed in hermetically sealed units since they operate at vacuum pressures. Improper operation would result if leakage of air into the system occurred.
6) Irrespective of its drawbacks, the LiBr/water unit is still considered as the most economical for this kind of refrigeration technique.
7) This study describes and analyses the computer modelling of such units. The modelling procedure is generalized to enable those concerned with use or evaluation of cycles employing this material to save considerable time and effort required for calculations. India, being a warm tropical country, most of the refrigeration and HVAC applications involves cooling of air, water, other fluids or products. Heating is used only for a very small period in winter in the northern parts of the country and in places at high altitudes.
8) Refrigeration and Air-conditioning accounts for a significant portion of the energy consumption in many manufacturing industries (like chemicals, pharmaceuticals, dairy, food etc.), agricultural & horticultural sectors (mainly cold stores) and commercial buildings (like hotels, hospitals, offices, airport, theatres, auditoria, multiplexes, data processing centers, telecom switching exchanges, etc.) Refrigeration and air conditioning and air conditioning system cover a wide variety of cooling applications, using both standard and custom- made equipment's. Some commonly used applications are process cooling by chilled water or brine, ice plants, cold stores, freeze-drying, air-conditioning systems etc.

IV. PAST STUDIES

Altun et al. (2020) investigated a solar-powered absorption cooling system modelled using the TRNSYS software. The performance of the system using dynamic modelling under the weather conditions of Mugla, Trabzon, Izmir, Konya, Canakkale and Istanbul. The external catalog data file of the absorption chiller model was created to get more realistic results. A parametric study was carried out to evaluate the selected parameters' influence on system efficiency. Various parameters such as solar collector type, area, storage tank volume, collector slope, boiler setpoint temperature, room thermostat set point temperature were investigated to see their impact on the performance of the solar- absorption system, in every city. Instead of using a constant boiler setpoint temperature, a novel control strategy is proposed. Besides, the payback period and the levelized cost of cooling of the optimized systems were studied. Results showed that, in terms of financial analysis, Izmir is the most suitable city for solar-based absorption cooling system applications with a payback period of 10.7 years. Trabzon is found to be the least suitable city due to the longest payback period, and the highest levelized cost of cooling among all locations.

Jain et al. (2020) presented a novel structure of trans critical vapor compression- absorption integrated refrigeration system (TVCAIRS) based on its thermo-economic viability. The integration of single effect vapor absorption refrigeration system (VARS) (with H_2O-LiBr fluid couple) in trans critical vapor compression refrigeration system (TVCRS) (with R744 refrigerant) provides a subcooling of 5 °C in the proposed configuration. Hence, the overall COP and exergetic efficiency of TVCAIRS is 28.6% and 26.9%, respectively higher than the equivalent standalone TVCRS with optimum gas cooler pressure and generator temperature. Besides, the requirement of external cooling water for the gas cooler, absorber and condenser cooling of TVCAIRS is 12.3% less than the equivalent TVCRS. The direction for the further process improvement of TVCAIRS is also presented. Further, the thermodynamic performance of proposed system is also investigated for low temperature refrigeration application and hot climate conditions. The comparative results showed that the present TVCAIRS is thermodynamically more efficient as compared to the equivalent TVCRS and conserves more water resources with effective recovery of waste heat for the sustainable development. The techno-economic analysis of proposed TVCAIRS shows a shorter breakeven point and payback period of 1.3 yr. and 1.8 yr., respectively with total annualized cost of INR 5,641,614 (17.8% less than the equivalent TVCRS). Further, selection diagram for TVCAIRS and equivalent TVCRS shows that TVCAIRS is more feasible as compared to the TVCRS under low temperature and hot climate conditions and its viability strongly increases, if financial incentives of reduced interest rate are offered with longer life designs and operation duty.

Meraj et al. (2020) investigated performance analyses of interconnected N number of fully covered semi-transparent photovoltaic thermal integrated concentrator collectors combined with single effect vapor absorption refrigeration system The proposed system was analyzed under the constant mass flowrate of collectors' fluid. Mathematical expressions have also been derived for generator temperature of the absorption unit as a function of both design and operating parameters. Further, simulations have been performed for a typical day of May month of New Delhi climatic conditions. Performance parameters have been evaluated such as collector exit temperature, generator inlet temperature, electrical power output, electrical efficiency, overall thermal energy gain, instantaneous thermal efficiency, overall exergy gain and coefficient of performance of the absorption system. The simulation code has been written in MATLAB. From the present analyses, the following salient conclusions have been drawn: Operating generator temperature of the absorption system is suitable for five number of photovoltaic thermal- integrated parabolic concentrator collector connected in series. The proposed system will continue operating for 5 h during May month in New Delhi climate conditions. The maximum solar coefficient of performance, refrigeration coefficient of performance, and exergy coefficient of performance are reported as 0.1551, 0.8344, and 0.2697, respectively, for the proposed novel system under given design and operating conditions. Additionally, the effects of other design parameters of this novel system have also been investigated.

Jonathan et al. (2020) used a hydrophobic membrane desorber to separate water vapor from an aqueous LiBr solution. Influencing factors, such as the H2O/LiBr solution and cooling water temperatures, were tested and analysed. With the experimental data, a solar collector system was simulated on a larger scale, considering a 1 m2 membrane. The membrane desorber evaluation shows that the desorption rate of water vapor increased as the LiBr solution temperature increased and the cooling water temperature decreased. Based on the experimental data from the membrane desorber/condenser, a theoretical heat load was calculated to size a solar system. Meteorological data from Emiliano Zapata in Mexico were considered. According to the numerical result, nine solar collectors with a total area of 37.4 m2 provide a solar fraction of 0.797. The membrane desorber/condenser coupled to the solar system can provide an average of 16.8 kg/day of refrigerant fluid that can be used to produce a cooling effect in an absorption refrigerant system.

Kanti et al. (2020) presented a comparative performance assessment of a single-effect and a double-effect vapor absorption system for the operation of a cold storage facility. The proposed cold storage is powered through a combination of a grid-interactive solar photovoltaic system and parabolic trough collectors. A thermal model of the VAR systems is developed based on the first law and the second law of thermodynamics. An economic model has also been developed to compute the payback period. The maximum coefficient of performance of the double-effect VAR system (for the present case) for a calendar year is found to be 1.32, which is about 80% higher than that of the corresponding single-effect system. Also, the exergy efficiency of the double-effect VAR system is estimated to be about 16% higher than that of the single-effect system. The payback period of the double-effect VAR system-based multi-commodity cold storage powered through the solar thermal-PV system is found to be about six months lesser than the corresponding single-effect system. Thus, the double-effect VAR system is a more feasible option to operate a cold storage facility from the energy, exergy, and the economic point of view.

Venkataraman et al. (2020) presented an up-to-date review of the heat driven absorption refrigeration/air conditioning systems specifically meant for transport applications. This is followed by a discussion on the major challenges involved in implementing such a technology for the transport sector, the ways in which such a technology can be developed further and why using heat driven refrigeration/air conditioning systems could be a game changer in the automotive industry. From the study carried out two things are apparent – there is currently no VARS unit that can readily be used on-board vehicles and linking VARS units with engine exhaust leads to drop in engine efficiency and thus overall vehicle performance. Fuel cells (SOFCs in particular), if used as APUs can reduce the load on the engine and also supply a constant heat load to the VARS and thus be more effective.

Alhamid et al. (2020) presented a solar-gas fired absorption cooling installed and tested in a real environment at the University of Indonesia, Depok, Indonesia. The cooling system provides chilled water to the building of the Mechanical Research Center of the university. This system has a unique single/double-effect water/Lithium Bromide absorption chiller with a nominal cooling capacity of 239 kW. In addition, the system consists of evacuated tube solar collectors (~181 m2 total aperture area) and fan coil units installed in the building. The absorption chiller is driven by (i) hot water (75 – 90 °C) produced by the solar collectors which supply heat to the single-effect generator and (ii) by a direct gas-fired burner at the double-effect high-temperature generator when it is needed. The driving heat supply from the gas-burner is 113.2 kW and 93.3 kW (at 90 °C) from the solar collector field. This study focuses on the control strategy of the solar-gas fired absorption chiller system based on operational data obtained from the field test carried out in an Asian tropical climate, particularly Indonesia. The proposed and implemented control strategy consists of the control of both external and internal operation variables. The external control strategy includes the control of three water flow loops (hot water, cooling water, and chilled water) that are controlled according to the cooling load of the building and weather conditions (i.e., solar irradiation and ambient temperature). The internal operation variable (total solution flow rate) and gas flow rate are adjusted according to the required cooling capacity. The field tests of thermal and electrical COP are around 0.9–1.1 and 4.5–5.5, respectively. The field test results demonstrate the feasibility of the implemented control strategy for the optimum and safe operation of the system in an Indonesian climate, with the possibility of adapting to other similar Asian tropical climates.

Liu et al. (2020) presented a LiBr/H2O absorption chiller and a Kalina integrated in cascade to achieve full utilization of low-grade waste heat. A parametric analysis has been conducted to investigate the effect of key operational parameters in terms of turbine- inlet pressure, turbine-outlet pressure, ammonia concentration, segment temperature and refrigeration temperature. The coupled system is then compared with the Kalina cycle without absorption chiller, in terms of the turbine-outlet pressure and the net power output. Moreover, the comparisons between two systems are illustrated in the temperature-entropy diagram. Results show that the optimal turbine-inlet pressures in all studied cases are obtained as 3200–3300 kPa for given conditions. System net power output decreases obviously with higher turbine-outlet pressure while increases with the increasing ammonia concentration. At refrigeration temperature of 2 ℃, the coupled system produces the maximum electricity output because the system can reach to a lower turbine-outlet pressure. The optimal thermal efficiency is 0.1678. After being integrated with an absorption chiller, the net power output of the Kalina cycle is improved by nearly

45%. This paper provides a performance-enhanced power generation system for cascade utilization of low-grade waste heat.

Azhar et al. (2019) presented exergy analyses of lithium bromide-water based single to triple effect direct and indirect fired vapour absorption systems. The analysis carried out by various investigators on exergy of the absorption cycles have been discussed. To fill the gap in the knowledge on exergy destruction rate in the absorption system, optimization of the single to triple effect direct and indirect fired absorption cycles have been conducted for a wide range of operating conditions. Hence optimum parameters in various components of the systems for maximum exergy coefficient of performance and minimum exergy destruction rate have been determined. The indirect fired systems have been optimized for different temperatures of the energy source related to the main generator temperature. While the direct fired systems have been optimized considering exergy destruction rate during the combustion process of energy sources. The energy sources selected in the present analysis are compressed natural gas and liquefied petroleum gas. Double effect cycle yields better exergy performance when the difference in temperatures of the energy source and the generator is between 6 to 37 °C, while triple effect cycle performs well when it is beyond 37 °C.

V. CONCLUSION

Both systems have their advantages and disadvantages. Vapour compression systems are more common due to their higher efficiency, but vapour absorption systems can be suitable in certain situations, especially when waste heat or other heat sources are available for the absorption process. The choice between them depends on factors like energy availability, cost, and environmental considerations. Vapour compression and vapour absorption systems are two distinct refrigeration technologies employed to achieve cooling in various applications. The vapour compression system, widely used in air conditioning and refrigeration, operates on the principles of the vapor compression cycle. The compressor raises the pressure and temperature of the refrigerant vapor, while the condenser dissipates heat, causing the refrigerant to condense. The expansion valve regulates the flow of the liquid refrigerant to the low-pressure evaporator, where it absorbs heat and evaporates, completing the cycle.

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