Design, Analysis & Performance Investigation of H2O/LiBr VAR Type Car AC System

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Abstract— The environmental rules and regulations have forced the refrigeration-based industries to direct the research trend in search of alternative refigerants and alternative technologies. Absorption technology appers to be a promising alternative to vapour-compression system as it uses zero ozone depletion potential fluids and zero global warming potential fluids. Vapour absorption refrigeration techniques through use of waste heat from I.C engine can contribute to the solution of the world's energy problem because; refrigeration machinery absorbs a small but significant part of the primary energy. There are two source of waste heat energy in I.C engine one is radiator and second is exhaust gases. Our aim, to describe and check the feasibility of I.C engine waste heat operated vapour absorption refrigeration system in the range of 70 to 95°C with the help of H_2O/LiBr working fluid pair to fulfill the three objectives of research: ENERGY, ECOLOGY and ECONOMY.

Keywords: - Absorption system; Water/lithium bromide; I.C engine waste heat

I. INTRODUCTION

The environment is threatened by our massive energy production and agricultural activities. Much is being said about the pollution of our biosphere, air, soil and water, depletion of the ozone layer and long term climate effects of the steadily increasing CO_2 concentration. The environmental rules and regulations have forced the refrigeration-based industries to direct the research trend in search of alternative refigerants and technologies[1-2]. New sources like the breeder fission and fusion reactors or solar radiation or use of waste heat energy are capable of providing all the energy which may conceivably be required for a very long future. The concept of the absorption refrigeration system was first studied by Faraday early in 1824. A I.C engine waste heat operated refrigeration system consists elements of heat source radiator, condenser evaporator, expansion valve and absorber.

II. HISTORICAL PERSPECTIVE - EARLY STEPS

Ghaddar NK et al.1997 [3] presented the modeling and simulation of a solar absorption system for Beirut. The results showed that for each ton of refrigeration it is required to have a minimum collector area of 23.3 m^2 with an optimum water storage capacity ranging from 1000 to 1500 l when the system operates solely on solar energy for about 7 h per day. It is the success story of use of non conventional source of energy for small capacity. Grossman 2002[4] concluded that the total system cost would be dominated by the solar part of the system. Meanwhile, Sumathy 2002 et al.[5] also developed a new model of two-stage H_2O-LiBr absorption chiller. Compared to the single-stage chiller, the two-stage chiller could achieve roughly the same total COP as of the conventional system with a cost reduction of about 50%.

Figure 1 compares the performances of the single, double and triple effect LiBr/Water cycles. Gerson 2002[6] mentions multi-effect absorption systems require higher heat supply temperatures, which may be obtained from higher-cost. For a double effect system if the supplied waste heat temperature drops below 100°C system performance drops below that of single effect system. The state of art for commercially available chillers is the working pairs LiBr/Water with single-effect and double-effect cycles. Triple-effect chillers are just about to enter the market.

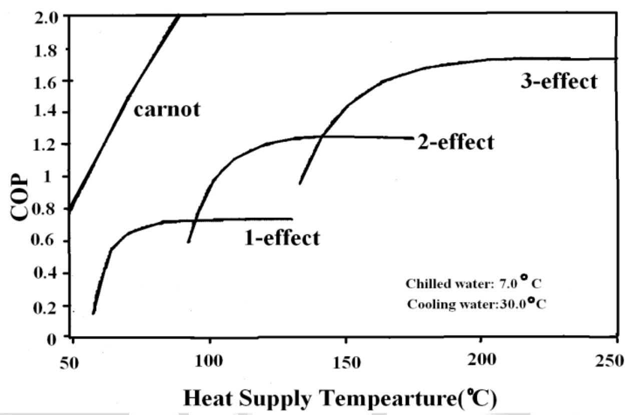


Fig. 1: COP vs. solar heat supply temperature for H_2O-LiBr absorption chillers.

I.C. Engine Waste Heat Energy Recovery - A Perfect Solution of 3 E's: Energy, Ecology and Economy for Refrigeration

I.C. engine waste heat energy - a perfect solution of 3 Es : Energy, Ecology and Economy is shown in Fig. 2.

A. Energy:

It could be saved directly and indirectly as shown in Fig. 2. So, overall thermal efficiency of the engine improved by saving of precious fuel energy which is depleting in nature.

B. Ecology:

Waste heat recovered as well as to fulfill the function of car AC VARS operated instead of VCRS so less burning of fuel and ultimately less pollution of environment. This is highly desirable to save the ecology.

C. Economy:

AC operated by saving of precious fuel and cost highly reduced and profit increased. So, it can compensate the initial cost of system installations. With an attractive payback, it provides a compelling case for return on investment. It is a fixed cost that is hedged against increasing energy costs.

Ultimately, I.C. engine waste heat energy recovery for air conditioning approach is Effective (Do the right thing) and Efficient (Do the right thing with right way).

Car Vars – Effective & Efficient Approach

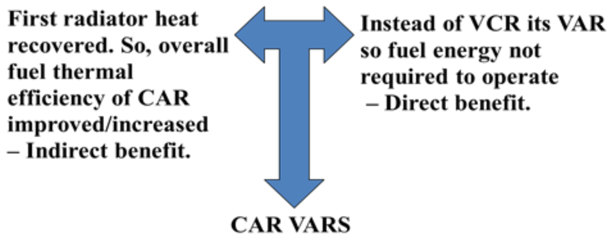


Fig. 2: A perfect solution of 3 E's : Energy, Ecology and Economy.

III. Design, Analysis And Performance Investigation Of Single Effect Vars

Following assumptions are required to be made:

- The system is in steady state.
- The system is perfectly insulated, so the heat exchange with the surrounding is only through the specified equipments.
- The refrigerant states leaving the condenser and evaporator are assumed to be saturated.
- Pressure losses in all the heat exchangers and the pipelines are negligible.
- The reference environmental state for the system is 25ºC environment temperature (T_0) and 1 atmospheric pressure (p_0).
- Cooling water first enters the absorber at 32ºC, then passes through the condenser and finally it is rejected from the system at 32.2ºC.
- The water to be chilled enters the evaporator at 12ºC and leaves at 7ºC.
- The H_2O/LiBr weak solution concentration 58.1%, strong solution concentration 63.6% is taken for evaluated systems.
- The energy required for running the cooling tower and the associated water pumps and cooling fans is not considered in the analysis.

The properties like enthalpy, entropy, density of water-lithium bromide solution is taken from References [7-12]. The properties of water like specific heat of enthalpy, entropy, water; steam etc. is used from the [7, 13-14]. The performance evaluated range in present work majority data can be achieved from the paper published by H.T.Chua et al., [7] in the International Journal of Refrigeration in year 2000. The aqueous water – lithium bromide chart is used for property from ASHRAE [15].

Figure 3 shows the H_2O/LiBr type single effect vapour absorption refrigeration system operated with the hot water working fluid. Total seventeen state points are mentioned to explore the system well.

A. Design Input Data

- Refrigeration capacity of chilling plant: 1 TR (3.5 kW).
- Weak solution concentration: 58.1%.
- Strong solution concentration: 63.6%.
- High temperature generator (HTG): 90°C.
- Hot source, working fluid water inlet temperature to HTG: 95°C and outlet temperature from HTG: 90°C.
- Evaporator temperature: 4.1°C.
- Inlet temperature of chilling water into evaporator: 12°C.
- Outlet temperature of chilling water from evaporator: 7°C.
- Inlet temperature of cooling water into absorber: 32°C.
- Outlet temperature of cooling water from condenser: 32.20°C.
- Heat exchanger effectiveness for HX1: 80%.
- Efficiency of pump: 75%.
- Efficiency of motor to drive the pump: 90%.
- Reference temperature of environment for exergy analysis: 25°C.

Figure 4 shows the PTX behavior of design system. The colour lines in PTX behavior are mentioned with identical colour in Fig. 3. PTX diagram is drawn with scale to show the real operating conditions in system.

IV. Results And Discussion

Figure 5 shows the theoretical, actual, exergetic, carnot and relative coefficient of performance (COP) of evaluated system. In which, without consideration of pump work theoretical COP is calculated.

Actual COP is obtained with the consideration of pump work. Through literature survey it is found that past researcher's have neglect the small amount of pump work that is required for pumping the solution from absorber to heat exchanger. Generally past researchers have considered assumptions zero pump work required or they have neglected the pump work in their energy and exergy analysis. But in present work, researchers have considered the small amount of pump work to get the higher accuracy in energy and exergy analysis and to observe the effect of pump work. The effect of pump work on COP is very small on overall performance of the system, still energy point of view its effect is important because it consumed high grade energy. Relative COP is the ratio of actual COP to the carnot COP of the system.

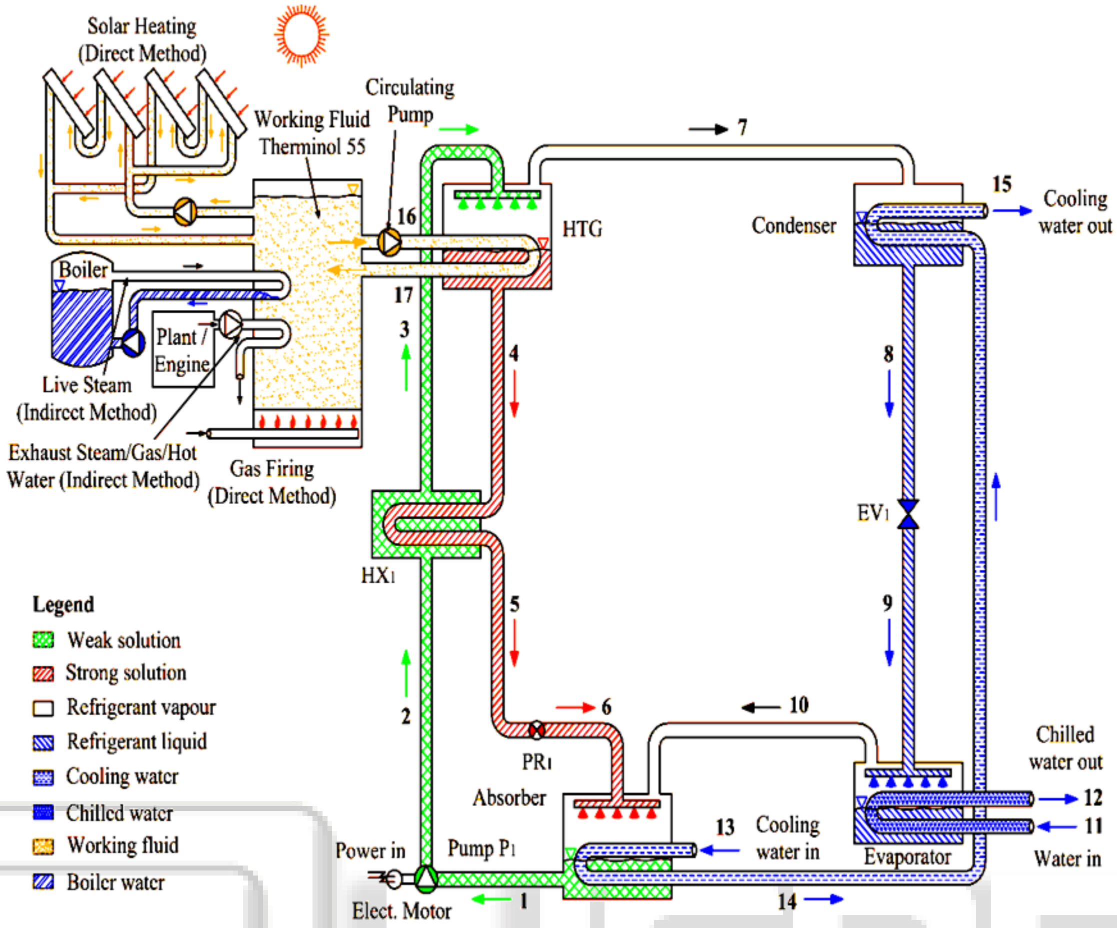


Fig. 3: Single effect vapour absorption refrigeration system (SEVARS).

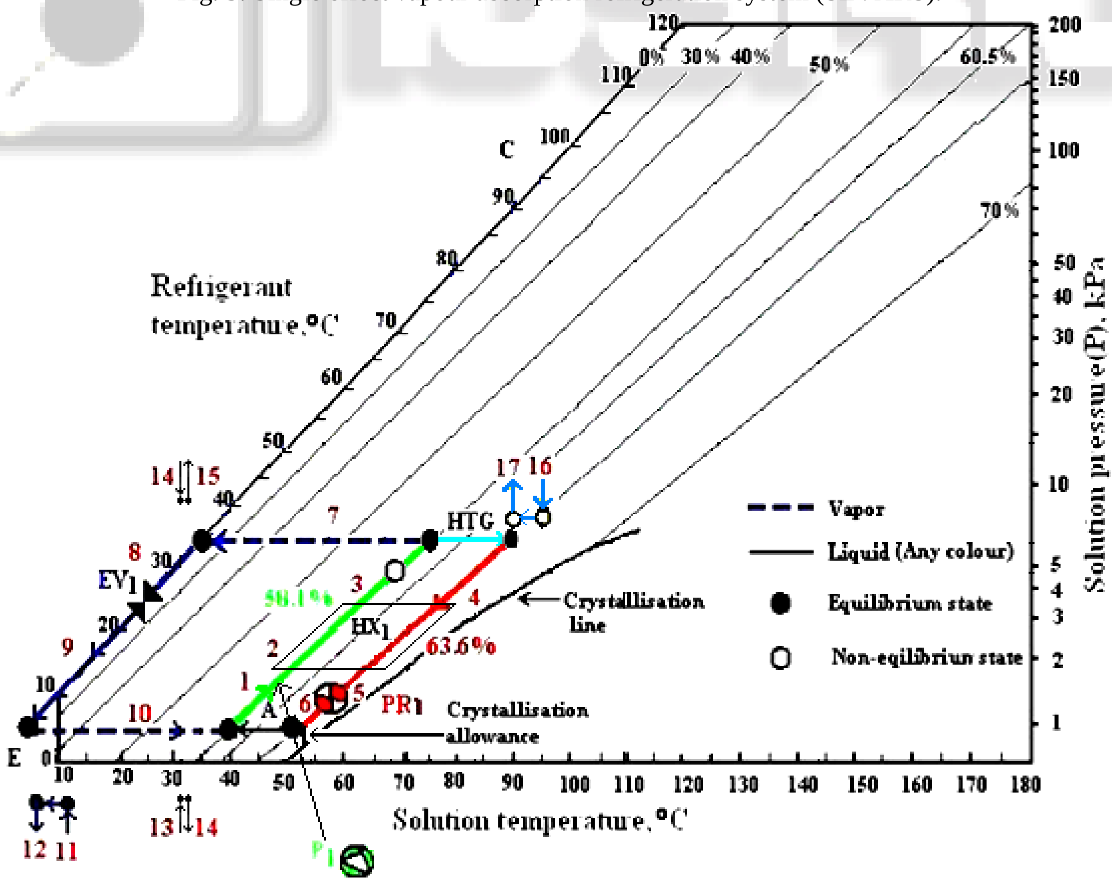


Fig. 4: PTX Behavior of single effect vapour absorption refrigeration system.

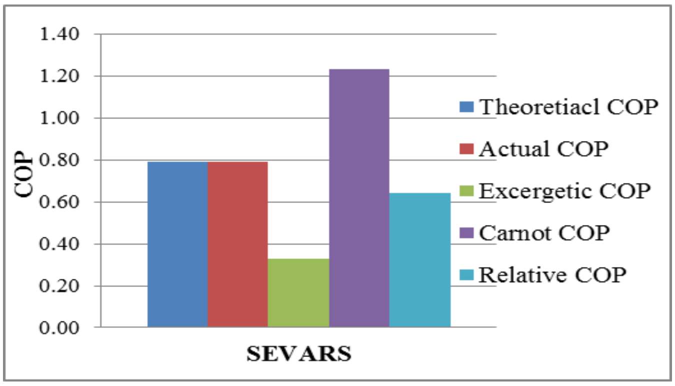


Figure 6 shows the effectiveness of major components of the various types of designed systems. If the effectiveness of heat rejection components like absorber and condenser are compared, in that case it is seen that absorber effectiveness is higher. Also, it is desired because it is one of the critical components of the vapour absorption refrigeration system. Through higher performance of absorber, system performance is improved and overall total cost of the system reduced.

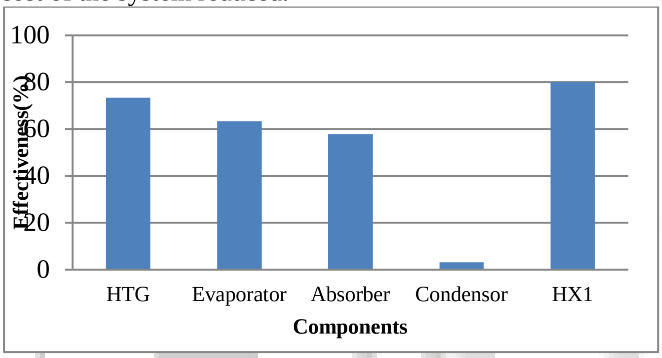
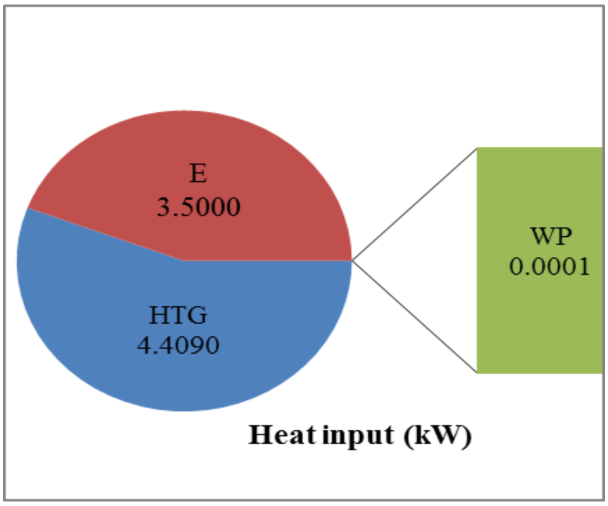


Fig. 6: Major components effectiveness for SEVARS

A. First Law-Energy Comparisons

Figure 7shows the first law of SEVARS. The total of the heat input components like evaporator, high temperature generator and pump is equal to the heat output components like absorber and condenser. From the Fig. 7 it is concluded that for the requirement of the same cooling capacity of 4.41kW the heat required in HTG of SEVARS is highest. Major part of heat output can be possible through the absorber. So, design and selection of absorber should be carried out with great care to improve the system overall performance.



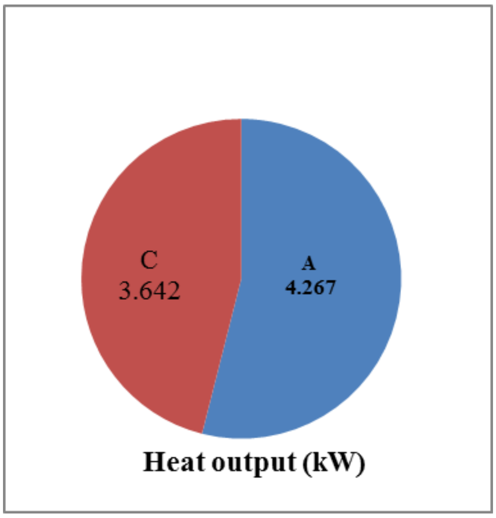


Fig. 7: First law - energy analysis for SEVARS

B. Second Law - Exergy Comparisons

Figure 8 shows the exergy change, heat transfer and internal irreversibility comparison of HTG. Figure 9 and 10 show the exergy change, heat transfer and internal irreversibility comparison of the evaporator, absorber and condenser components. With the help of Fig. 9 it is found that for the evaporator chilled water exergy changed for designed system the values of exergy change, heat transfer and internal irreversibility of absorber component are higher. Figure10 shows that condenser cooling water exergy change and heat transfer irreversibility values in SEVARS. The irreversibility occurred at the remaining components like heat exchanger, expansion valve and pressure reducing valve of system are mentioned in Figure 11.

C. System Exergetic Cooling Efficiency and Total Exergy Loss

The very important parameter to judge the system performance is the exergetic cooling efficiency and the total exergy loss of the system that described in the Fig. 12. The second law efficiency of the absorption cooling system is measured by the exergetic efficiency for cooling. This is defined as the ratio of the useful exergy gained from a system to that supplied to the system. Therefore, the exergetic efficiency of the absorption system for cooling is the ratio of the chilled water exergy at the evaporator to the exergy of the heat source at the generator.

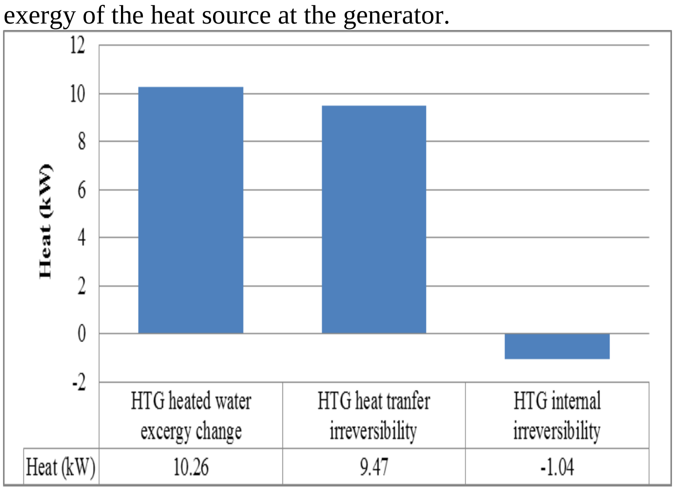


Fig. 8: Exergy comparison of HTG component for SEVARS.

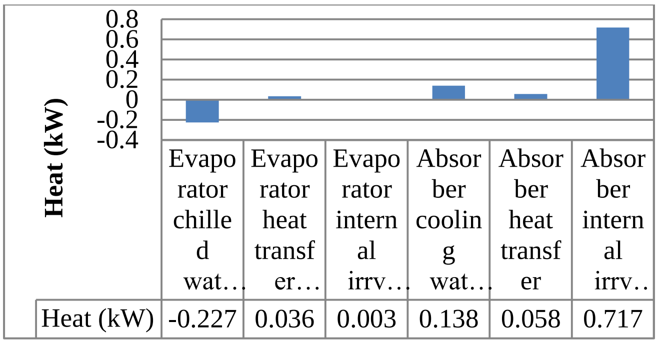


Fig. 9: Exergy comparison of evaporator and absorber for SEVARS

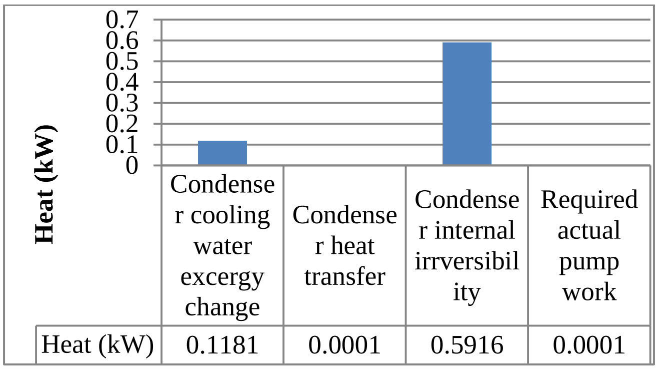


Fig. 10: Exergy comparison of condenser and pump work for SEVARS.

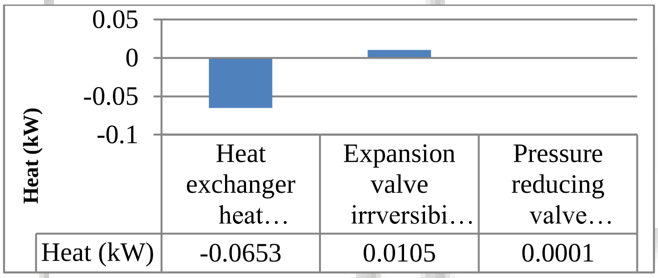


Fig. 11: Exergy comparison of heat exchanger, expansion valve and pressure reducing valve for SEVARS

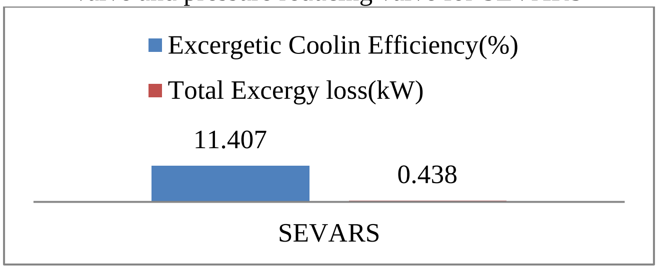


Fig. 12: Exergetic cooling efficiency for and total exergy loss of SEVARS.

D. Energy- Utilization Diagrams

Figures 13 show the energy-utilization diagrams of SEVARS. In the diagram, there are two lines of different energy level-the higher one for energy donor and the lower one for energy acceptor. The line A (= $1 - T_0/T$) indicating the temperature change is also drawn, where T_0 is chosen as 298.15 K (25°C). On the X axis the change in ΔH value of that particular component is taken as base to plot the diagrams.

The following findings are made from the EUDs.

- In any systems there are three major parts: one is separation part, in which generator and condenser are considered. Second is mixing part, in which evaporator and absorber are considered and third one is the heat exchanger part.
- The shaded area between the energy donor and energy acceptor mentioned the exergy loss.
- The distance between lines of the energy donor and acceptor A^{ed}-A^{ea} indicates the driving force to make the process proceed. It must have some positive value to do so.
- Exergy loss does not give any information about ways to improve the system. However, EUDs clearly indicate the main reason for yielding the exergy loss. Hence, we can concentrate our attention on the part yielding large exergy loss and able to put positive efforts to reduce the exergy loss.

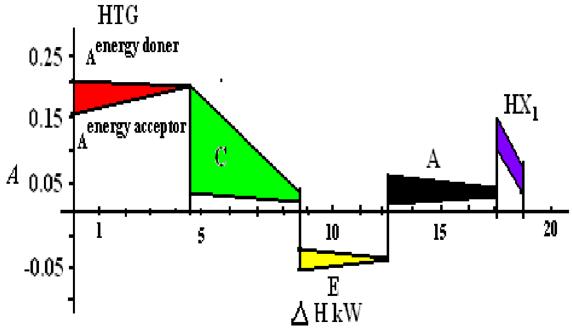


Fig. 13: Energy-utilization diagram for SEVARS.

V. CONCLUSIONS

Following major conclusions are made.

- Vapour absorption refrigeration systems maintained harmony with the environment and minimize the use of energy from the grid. The lots of benefits of vapour absorption refrigeration system over vapour compression systems attract human being to use VAR technology since long time. For one ton of refrigeration effect, VAR system saves 0.65kW electricity compared with conventional vapour compression system. Application of vapour absorption systems are strongly recommended where industrial waste and I.C. Engine waste heat is available at temperature between 90-120°C.
- Among the various working fluids, lithium bromide water solution has been the most prevalent. In I.C. Engine waste heat and solar applications the H_2O/LiBr system is superior to the NH_3/H_2O system for several reasons.
- I.C. engine exhaust heat from radiator or from the exhaust gases to operate SEVARS is advisable to save 3E'S: ENERGY, ECOLOGY & ECONOMY. It is EFFECTIVE & EFFICIENT approach to recover the waste heat.
- For the developing country like India the importance of waste heat as energy source is very high. However, waste heat recovered systems are not widely used because they are costlier. With the help of continuous research in the field of waste heat recovery to operate VARS, system cost is reduced and it is feasible to install. To make these systems cost effective and competitive to the conventional systems, there is a need to optimize them.

- Thermodynamics first law – energy analysis and second law – exergy analysis are important effective tools for system optimization.
- The required pump work is very small but it should not be underestimated because it consumed the high grade energy.
- If energy and exergy point of view system is well balanced then the associated irreversibilities with the system reduced and system performed better and actual COP less deviated from ideal COP.
- It shows that exergetic efficiency of the system is improved and system performed better if it is operated with multi-effects at higher source temperature.
- Absorber is one of the critical components of the vapour absorption refrigeration system. Through higher performance of absorber, system overall performance is improved and overall cost of the system reduced.
- Generally the associated irreversibility is higher in HTG as heat input component and absorber as heat output.
- The very important parameter to judge the system overall performance is the exergetic cooling efficiency and the total exergy loss of the system. The second law efficiency of the absorption cooling system is measured by the exergetic efficiency for cooling.
- Second law analysis results of VARS were presented in a novel graphical form named EUDs. All exergy changes and irreversibilities in the system to be viewed in single energy utilization diagram. With the help of energy utilization diagrams component should be identified where associated exergy losses are higher. Hence, we can concentrate our attention on the part yielding large exergy loss and able to put positive efforts to reduce the exergy loss.
- The principle of exergy destructions in a process leading to increase losses are due to: dissipation (friction), heat transfer under temperature difference and unrestricted expansion.
- Energy and exergy point of view the relative importance each and every system components with each others can be seen from the system total energy changed and exergy changed percentage figures. It is clearly seen that absorber, generators, condenser, evaporator, heat exchanger are key components to improve the system performance. The role of solution pump, pressure reducing valve and expansion valve is minor on system performance.
- There is only negligible change in overall performance of system in terms of COP variation if pump efficiency varied but its effects more in case of change of effectiveness of heat exchangers.

A. Concluding Remarks

Concerns regarding the Global Warming Potential and the more recently defined Thermal Equivalent Warming Impact (TEWI) are an opportunity to further explore the applications of absorption refrigeration. Finally, the adoption of waste heat energy from I.C.Engine and solar energy to power absorption chillers, even with marginal economic benefits, should not be underestimated for next generation point of view.

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