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Modelling and Analysing the Effect of Absorbent and its Additives in Vapour Absorption System using ASPEN Plus

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In India, during summer season, the temperature and pressure of the refrigerating systems are considerably increased, which results in decrease in cooling capacity of systems followed by increase in power consumption. In this work, simulating investigation has been carried out to improve the coefficient of performance (COP) of the system. ASPEN Plus simulating software has been used to model and analyse the effect of different absorbents and their additives on COP of the systems and sensitivity analysis is conducted. For this purpose, several ranges of mass flow rate, concentration of absorbents and desorber temperature are considered tested. The amount of mass flow rate, concentration of absorbents and desorber temperature varied with respect to the COP of the system. The results indicate that the increase in concentration of absorbents (0.56 to 0.60) causes decrease of COP by (11.07 %). Similarly, increase in desorber temperature (75.8 to 86.5) ℃ causes increase in COP by (10.35 %). The increase in mass flow rate causes decreases in COP by about (13.6%), However, LiBr with 1-ethyl-3-methylimidazolium acetate (EMIM Ac) has been found superior among all other absorbents for improving cooling capacity of system.

Keywords: Single effect vapor absorption; Sensitivity Analysis; NRTL; ASPEN; EMIM Ac

I. INTRODUCTION

The single-effect vapour absorption cycle shown in Figure 1 consists of condenser, pressure-reducing valve, evaporator, absorber, solution pump, solution heat exchanger, generator, and other accessories. The details of these components are as follows: At low pressure, liquid refrigerant enters the evaporator by point '3' in cool vapour form and liquid in which, due to heat, liquid refrigerant evaporates and makes the surrounding area cool (Kaita, 2001). As the partial pressure is low in evaporator, temperature needed for evaporation is also low. The vapour form of refrigerant by point '4' entered and is absorbed in absorber by another liquid/ absorbent. (e.g., a salt solution). The importance of the absorber is to maintain the pressure in the evaporator by absorbing refrigerant vapour formed in the evaporator. The mixture of refrigerant and absorbent moves further by point '5' towards the pump. The solution pump by point '6' pumps the mixture of refrigerant and absorbent to the generator at high pressure through solution heat exchanger by point '7'.

In generator, the refrigerant-absorbent mixture liquid is heated through an external source (i.e., waste heat) causing the refrigerant to evaporate, which is further collected by condenser by point '1' where evaporated vapour condenses into liquid form due to transfer of heat to an external source of cooling water flowing across tubes (Sun *et al.*, 2012). The condensed refrigerant in liquid form is passed by point '2' through an expansion valve, which drops the pressure from high to low (i.e., high condenser pressure to low evaporator pressure) by point '3' into the evaporator unit. At low pressure in the evaporator, liquid refrigerant evaporates by taking the heat from the enclosed space and providing the desired cooling completes the refrigeration cycle as saturated vapour is again absorbed by absorbent in the absorber. The absorbent liberated from the generator as a strong solution

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by point '8' is passed through solution heat exchanger and exchange the heat with weak solution by point '9' passes through expansion valve and reaches absorber by point '10' (Amakiri *et al.*, 2022). With the above complete working effect, the system shows its performance based on which it is decided that the following process is commercially viable or not. Coefficient of performance (COP) is defined as ratio of effective heating or cooling supplied to equivalent energy required. The increased value of COP shows increased efficiency, lower power utilisation and low operational costs.

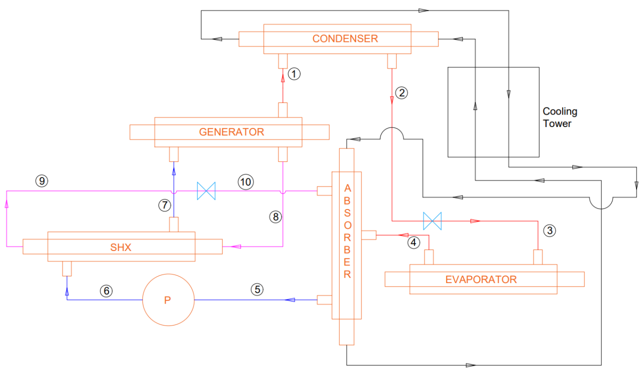

Figure 1. Single effect vapour absorption cycle

Nomenclature		*Subscript*
P	Pressure (kPa)	a - absorber
Q	Heat Transfer Rate (kW)	e - evaporator
T	Temperature (^{0}K)	g – generator (desorber)
X	LiBr Mass fraction (%)	c - condenser
s	Specific Entropy (kJ/kg^{0}K)	i - inlet
h	Specific Enthalpy (kJ/kg)	e - exit
m	Mass flow rate (kg/sec)	1, 2, 3, 4 ..... states points in Fig:1 & Fig:2
COP	Coefficient of Performance	ε - effectiveness

The COP of VAR system defines the ratio of heat capacity or heat duty of the evaporator to the energy supplied to the generator and solution pump but since energy supplied to the generator is too high as compared to energy supplied to the solution pump, Qp is neglected (Khan *et al.*, 2022a).

The vapour absorption cycle is one of the important refrigeration systems. (Kaita, 2001; Khan *et al.*, 2022a; Sun *et al.*, 2012) whose application in renewable energy has gained attention by the researcher and has advantage over energy-intensive vapour compression refrigeration systems (Gkouletsos *et al.*, 2019; Herrera-Romero & Colorado-Garrido, 2020). The absorption cycle avoids the use of fossil-based electricity to reduce the emission of greenhouse gas as compared to vapour compression refrigeration cycle (Kadam *et al.*, 2022). It uses low-temperature heat sources for required cooling and fraction of energy for pumping of liquid in the system as compared to VCR (Papadopoulos *et al.*, 2019).

VAR systems deals with number of working fluids such as Propane/Water, Trifluoroethanol (TFE)/ Pyrrolidone (PYR), Acetaldehyde/Water, R134a/Dimethylformamide (DMF), Lithium Bromide (LiBr)/water, Ammonia (NH_3)/water, Acetaldehyde/Ethyl ether, Propane/Acetone, Potassium formate/water, etc., out of which LiBr - water and NH_3 - water are widely used for commercial applications due to their low cost and viable coefficient of performance (COP) (Papadopoulos *et al.*, 2020). The extensively used working fluids has following limitation: NH_3 – water needs rectifier due to low boiling point difference resulting into system complexity whereas in LiBr – water pair, mass fraction of the salt LiBr exceeds the solubility limit faces crystallisation problem and addition to it, each fluid (i.e. NH_3 – water, LiBr – water) has issue of corrosion phenomena due to electrolytic nature of components. (Abdulateef *et al.*, 2008; Bellos *et al.*, 2017) LiBr - water absorption cycles are most suitable for solar applications because of its low cost, which can be helpful in energy generation machine but due to its size they are not readily available at residential size (Florides *et al.*, 2003). Lithium bromide is considered as an exceptional absorbent as it meets the required characteristics of absorption refrigeration systems like stability in aqueous solution and low vapour pressure at absorber conditions (De Lucas *et al.*, 2007).

Potassium formate solution also finds its application as an absorbent because of its inherent advantages such as physical properties, absorption – desorption rates, biodegradable, low vapour pressure and lesser toxicity in nature. At the same concentration and similar vapour pressure, its mass transfer behaviour is much better as compared to other fluid absorbent (Riffat *et al.*, 1998). The use of potassium formate (KCOOH) solution provides better corrosion resistance and results in reduction of overall investment cost for VAR cycle

(Kumar *et al.*, 2023). Potassium formate - water (KCOOH/H_2O) absorption refrigeration system has higher temperature working range along with higher heat retrieval rate at expense of lower COP (Bicui *et al.*, 2023).

The application of additives helped in inhibiting the corrosion, regulating pH, creating protective coating at internal surfaces resulting in increase in efficiency, decrease in crystallisation temperature, improved corrosion resistance and increase in COP (Herold *et al.*, 2016; Zhang & Hu, 2012). The sodium lactate used as an additive in LiBr /Water with mass fraction of 2:1 improves the COP of the system as well it shows anticorrosive properties towards absorbent (Donate *et al.*, 2006). The addition of additives to LiBr/water solution has resulted in decrease of crystallisation properties (Iyoki & Uemura, 1989; Zhang *et al.*, 2018). The ionic liquid-based additives at low pressure benefits the dehumidification in the process and releases latent heat for a given absorption cycle (Zhang *et al.*, 2018).

The modelling of VAR cycles for different refrigerants by using software tools like ASPEN Plus, Engineering Equation Solver (EES), Absorption Simulation (ABSIM), Computational Fluid Dynamics (CFD - ANSYS) helps in analysing and improving its performance. Kim *et al.* discussed the absorption cycle in which the flow of refrigerant as well as static condition of refrigerant is considered for evaluating new working fluids. The modelling of VAR to be efficient reduced the governing equation from cubic to quadratic form, which resulted in an error in solution temperature of about 1K (Kim & Infante Ferreira, 2008). (Kohlenbach & Ziegler, 2008a) focused on developing a model on single effect VAR system using LiBr water pair, where enthalpy is balanced by considering steady state for each major component. The dynamic behaviour of the system for each component and its delay time during cycle was studied through modelling (Kohlenbach & Ziegler, 2008b, 2008a). Momentary behaviour of the absorption cycle using software has been reported for the process generation model by (Matsushima *et al.*, 2010). ASPEN, a process modelling software package uses mathematical models for prediction of the performance of simple & complex processes using a large database of varied parameters. It is compatible for user design and allows steady-state process modelling using predefined inputs. The shortcomings faced by other software like process simulation capabilities, library of unit operations and models (such as reactors, separators, heat exchangers), integration with other tools, etc., are handled by ASPEN Plus hence, it is promising and used in our present work.

The objective of this study is to simulate the model and compare the working fluids for a single effect refrigerant absorbent pair such as water/LiBr, water/KCOOH, water/LiBr along with additive (1-ethyl-3-methylimidazolium acetate) and water/KCOOH along with additive (1-ethyl-3-methylimidazolium acetate) for vapour absorption cycles in ASPEN Plus. The simulated model should be able to integrate a larger process model and only requires data from the user, such as temperature, pressure, quantity of heat, etc., to provide useful results such as COP, mass flow rate, concentration of different absorbents, etc. The comparison of different working fluids will result in effective analysis for the researchers to choose the better combination for desired VAR cycle, it will also help in optimising the process (Khan *et al.*, 2022b; Kolapkar & Sathyabhama, 2022; Zhang *et al.*, 2024)

II. MATERIAL AND METHODS

The working fluids considered in this work are LiBr/Water, KCOOH/Water, LiBr/ Water with additive (1-ethyl-3-methylimidazolium acetate) and KCOOH/Water with additive (1-ethyl-3-methylimidazolium acetate). The reason for choosing this fluid was their corresponding data is not much available in published literature for the stated capacity (1kW) within the range of concentration (56% -60%) with respect to mixture of organic and ionic liquids as an absorbent and additives.

Figure 2 represents the single effect model implemented in ASPEN which is based on breaking the components into a block. The process of modelling in which the whole cycle of a complex process is divided into multiple simple components based on their levels of involvement and instant modelling decisions are highlighted wherever required. The pumps, valves, etc., are modelled just by selecting the block provided in ASPEN and if components don't have exact models, they are required to make some further assumptions for building a model. ASPEN Plus solves the data in a sequential pattern therefore it is compulsory to model a "break" for providing inputs in a closed cycle (Somers *et al.*, 2011).

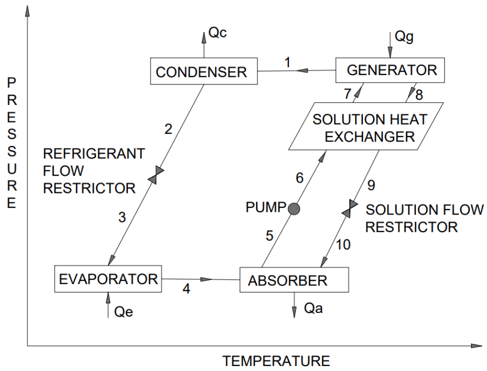

Figure 2. Single effect vapour absorption cycle operating principle

Table 1. Specifications of Absorbents and additive

Material	Lithium Bromide	Potassium Formate	EMIM Ac
CAS No	7550-35-8	590-29-4	143314-17-4
Formula	BrLi	$CHKO_2$	$C_8H_{14}N_2O_2$
Physical State	Solid	Solid	Liquid
Molecular Mass	86.85 g/mol	84.12 g/mol	170.1 g/mol
Density	3.460 g/cm³ at 20 °C	1.91 g/cm³	1,027 g/cm³ at 25 °C
Thermal conductivity	0.69 W/(m·K) at 25°C	0.56 W/(m·K) at 25°C	0.2137 W/(m·K) at 25°C
Specific Heat Capacity	0.815 J/(g·K)	2.55 J/(g·K).	1.348 J/(g·K)
Supplier	Thomas Baker	Sigma Aldrich	Sigma Aldrich

Table 2. System Components and their Aspen Block Models with Input Values.

System Components	ASPEN Block Models	Input data
Condenser	Counter flow HX	Temperature: 85°C - 90°C, Pressure: 4 kPa - 10kPa
Evaporator	Counter flow HX	Temperature: 5°C - 6°C, Pressure: 0.5 kPa - 2kPa
Absorber	Counter flow HX	Refrigerant = 6°C - 7°C, Absorbent = 40°C - 50°C, 0.5 kPa - 2kPa
SHX	Counter flow HX	Weak Solution = 30°C - 40°C, Strong Solution = 85°C - 90°C
Valve 1	B9	Temperature: 40°C - 30°C
Valve 2	B10	Temperature: 55°C - 40°C
Desorber	B6, B7	Temperature: 70°C - 90°C, Pressure: 4 kPa - 10kPa

Table 3. Simulating conditions used in the cycle.

Parameter	Details
Low Temperature	5°C
High Pressure	10kPa
Solution flow rate	10 kg/h
Solution heat exchanger effectiveness	0.75
Strong solution concentration	0.56 and 0.6

A. Experimental Procedure

The single effect vapour absorption refrigeration system for LiBr/water pair is modelled in ASPEN Plus V12.1 for which properties of a given mixed pair is represented carefully. The procedure of the study is detailed below: In the modelling process; an important point is to precisely model the refrigerant absorbent mixture properties for the VAR system. The two ways for modelling the thermodynamic properties of any mixtures are activity coefficient methods and equation of state out of which activity coefficient methods are well known for better representation of non-ideal liquid mixtures at low point pressure. The pressure at which LiBr/Water fluid mixture operates is sub-atmospheric hence, the activity coefficient method is considered (AspenTech, 2010). The activity coefficient method mainly consists of the Redlich–Kwong equation of state and non-random two liquid (NRTL) model in which the first one is used for all properties of vapor phase and the second is used for different properties of liquid solution (H. & J.M., 1968). In ASPEN (ELECNRTL), activity coefficient property method is considered for LiBr/water solution as its operating properties and fluid mixtures are in the form of electrolytes and for different states such as pure water and steam, steam tables can be used.

Table 4. Assumption for single effect VAR cycle

Points	Flow From	Flow to	Assumption
1.	Generator (Desorber)	Condenser	Saturated vapour: Mass flow rate ratio can be obtained from waste heat temperature
2.	Condenser	Valve	Vapour quality of 0
3.	Valve	Evaporator	Determined by the refrigerant pump model
4.	Evaporator	Absorber	Vapour quality of 1
5.	Absorber	Pump	Vapour quality of 0

6.	Pump	SHX	Determined by the solution pump model
7.	SHX	Generator (Desorber)	Determined by the SHX model
8.	Generator (Desorber)	SHX	Saturated liquid: Mass flow rate ratio can be obtained from waste heat temperature
9.	SHX	Valve	Determined by the SHX model
10.	Valve	Absorber	Determined by the solution valve model

For single-effect vapour absorption cycle, the break was introduced at 'stream 1' (S1M), which is the exit of the absorber (Stream 14M), and inlet of pump is not connected as shown in Figure 3. If the following fluid streams provide the same result as it is expected in the same state, then it shows that the process is well formulated thermodynamically which is verified by the modelling process and found consistent. The break in stream 1 allows the inputs to be provided to the inlet of the pump where it is at low side pressure and quality of vapour is zero, temperature, mass flow rate and concentration of mixed fluids as stated above. The pump used between stream 1 (S1M) and stream 2 (S2M) for all types of stated fluids needs input such as exit pressure, efficiency of pump, etc. The pump efficiency is to be taken 100% by default due to low sensitivity prediction to overall cycle efficiency. The pump work is very small in magnitude as compared to heat duties of all other components. Hence, it is assumed to be neglected. In the single-effect vapour absorption cycle, one refrigerant and one mixed solution valve is present, the pressure-changing devices are modelled as valves in Figure 3. The model of the valve is easy to understand hence, they are needed to provide exit pressure.

In single-effect vapour absorption cycle, solution heat exchanger (SHX) is used where heat is transferred from hot inlet ("point S11") to cold side inlet ("point S2M") results in hot side exit ("point S12") and cold side exit ("point S3M"). The SHX is modelled using a heater block connected by a hot stream that shows heat rejection on the hotter side is added to the cooler side. The exit temperature is unknown about "point S3M" and "point S12" out of which "point S12" can be determined from the effectiveness of solution heat exchanger.

$$\varepsilon = \frac{(T_4 - T_5)}{(T_4 - T_2)} \quad (1)$$

Above equation provides T5 (point S12 - hot-side exit temperature), since T2 (S3M - cold-side exit temperature), and T4 (point S11 - hot-side inlet temperature), are known. The equation (1) was employed in ASPEN, which provided three out of four states, and the rejected heat by hotter side must be equal to heat gain by the cooler side. Hence, temperature at ("point S3M") T3 can be calculated. Being the refrigerant as pure water, for thermophysical properties steam tables were used. In a condenser, heater blocks are modelled which provides the assumption of heat to be added at constant temperature where user input requires zero vapour quality at exit. The modelling of condenser and evaporator is similar as their input vapour quality was '1' at exit. The requirement of heater on behalf of heat exchanger in the model can be applied for evaporator. The absorber was considered as a heater block in model having two inlets, one exiting from the evaporator (stream S10W) and second exiting from the solution heat exchanger via solution valve (stream S13). The vapour quality at the exit of the absorber (stream S14M) is considered as a saturated liquid in single-effect vapour absorption cycle. The requirement of heater on behalf of heat exchanger in the model can be applied for absorber as well. Generators are also known as desorbers that is well known for its application of separation of mixed fluid into vapour and fluid by the means of external heating (i.e., waste heat). The process generator includes change in pressure, addition or rejection of heat, separation of fluid mixture out of which separating the components creates a difficult task in modelling. It has single inlet and two outlets, from inlet mixed fluid (i.e. absorbent-refrigerant pair) enters (stream S3M), and out of two outlets, one outlet provides saturated vapour (i.e. pure water) (stream S6W) and another outlet provides saturated liquid (i.e. solution) (stream S11). As the working model for single effect vapour absorption cycle is made, they are needed to adapt as per designer of an VAR cycle in which input such as availability of quantity of waste heat or desired cooling load, exit temperature of evaporator, exit temperature of absorber or condenser or generator is to be considered. The above inputs define low and high pressure, concentration of strong and weak solution or the mass flow rate of a saturated vapour and liquid. The input for defining the mass flow rate will be based on availability of waste heat or cooling load at a given component through a pump at the bottom. The exit temperature of an evaporator defines low pressure, exit temperature of absorber defines concentration of weak solution, exit temperature of condenser high pressure and the exit temperature of desorber defines concentration of strong solution at the exit.

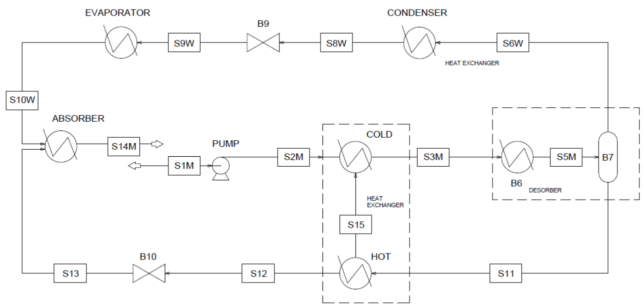

Figure 3. Single effect cycle model implemented in ASPEN

Figure 3 represents the constructed model for the single-effect vapour absorption cycle, which is modelled for experimenting all types of fluid mixtures mentioned above. (i.e., LiBr/H_2O, KCOOH/ H_2O, LiBr/H_2O with additive (1-ethyl-3-methylimidazolium acetate (EMIM Ac)) and KCOOH/H_2O with additive (1-ethyl-3-methylimidazolium acetate)).

III. RESULT AND DISCUSSION

Figure 4 shows the variation of COP with variation in concentration range (i.e., 0.56 - 0.6) for four different absorbents (i.e LiBr, KCOOH, LiBr with EMIM Ac, KCOOH with EMIM Ac). The defined range of concentration is within the limit to avoid crystallisation phenomena. There is a decrease in COP with a percentage increase in concentration. However, the rate of decrease is moderate up to 0.58 concentration followed by a higher rate of decrease with further increase in concentration.

$$COP = \frac{Q_e}{Q_g} \quad (2)$$

where, Q_e = Refrigerating capacity; Q_g = Desorber heat input

The COP of LiBr with EMIM AC is higher than any other refrigerant at any given concentration. The increase in concentration drops the circulation ratio, which results in a decrease in COP out of which refrigerant shows satisfactory value for given concentration range. EMIM AC is an ionic liquid having a property of good solubility, thermal stability, low vapour pressure and having high circulation ratio resulting in a large working temperature range (Ding *et al.*, 2021).

Table 5. Concentration of different fluids with respect to COP of system

Concentration at Absorber	COP			
	LiBr	**KCOOH**	**LiBr with EMIM Ac**	**KCOOH with EMIM Ac**
0.56	0.7600	0.6737	0.7679	0.6807
0.57	0.7382	0.6484	0.7491	0.6576
0.58	0.7021	0.6321	0.7232	0.6505
0.59	0.6424	0.6100	0.7080	0.6401
0.60	0.5217	0.5896	0.6529	0.6151

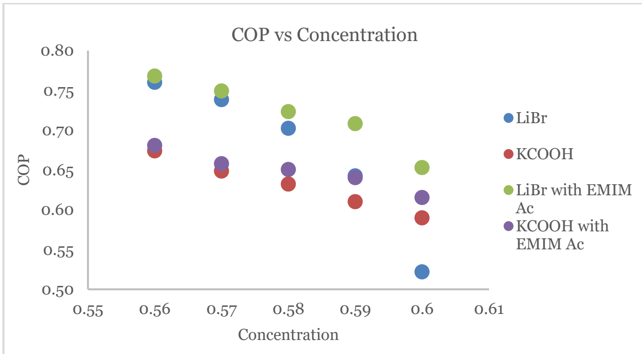

Figure 4. COP vs Concentration of different fluids (Ding *et al.*, 2021)

Table 6 shows the mass flow rate of different fluid with respect to COP of system. The selection of mass flow rate and temperature ranges is based on cooling load requirements, properties of absorbent with and without additives, Design of heat exchanger, efficiency of vapour absorption system, parts or component limitations. Table 7 shows the desorber temperature of different fluids with respect to COP of system. The Figure 5 shows the variation in COP with variation in mass flow rate of refrigerant with and without additives (EMIM Ac). There is a decrease in COP with increase in mass flow rate for LiBr with and without additives (EMIM Ac). COP remains stagnant with increase in mass flow rate for KCOOH with and without additives.

Table 6. Mass flow rate of different fluids with respect to COP of system

Mass flow rate kg/sec	**COP**			
	LiBr	**KCOOH**	**LiBr with EMIM Ac**	**KCOOH with EMIM Ac**
0.0030	0.76256	0.67300	0.81280	0.72876
0.0040	0.76257	0.66692	0.81540	0.72853
0.0045	0.76256	0.66646	0.80310	0.71688
0.0049	0.76256	0.66621	0.80250	0.71672
0.0050	0.76256	0.66618	0.80220	0.71653
0.0100	0.76256	0.66571	0.80170	0.71606
0.0200	0.76257	0.66554	0.79080	0.70120

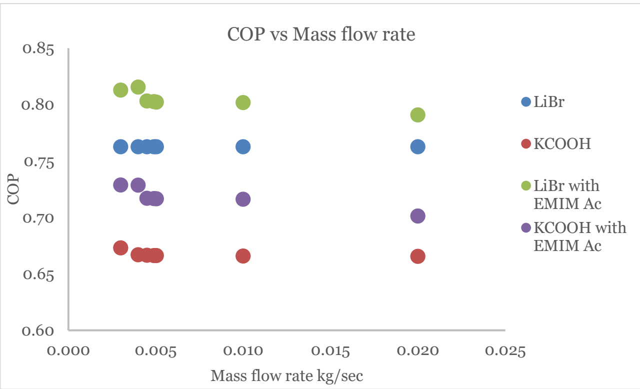

Figure 5. COP vs Mass flow rate of different fluids (Adhikari *et al.*, 2012)

The Figure 6 shows the effect of variation in desorber temperature on COP for all refrigerants (i.e LiBr, KCOOH, LiBr with EMIM Ac, KCOOH with EMIM Ac). There is an increase in COP with an increase in temperature, and the rate of increase is higher at higher temperature (Mahalle *et al.*, 2019; Osta-Omar & Micallef, 2016).

Table 7. Temperature of desorber for different fluids at concentration of (X=0.6) with respect to COP of system

Temperature (Desorber) (°C)	**COP**			
	LiBr	**KCOOH**	**LiBr with EMIM Ac**	**KCOOH with EMIM Ac**
75.8	0.3126	0.2052	0.3354	0.4200
76.8	0.3750	0.2676	0.4314	0.4824
77.8	0.5284	0.4228	0.6208	0.6340
78.8	0.8598	0.7542	0.9552	0.9654
79.8	0.9162	0.8112	1.0140	1.0212
80.8	0.9810	0.8784	1.0818	1.0836
81.8	1.0554	0.9546	1.1580	1.1562
82.8	1.1424	1.0446	1.2474	1.2402
83.8	1.2444	1.1490	1.3500	1.3398
84.8	1.3662	1.2738	1.4718	1.4586
85.8	1.5156	1.4592	1.6230	1.5720
86.5	1.7004	1.6776	1.8078	1.7232

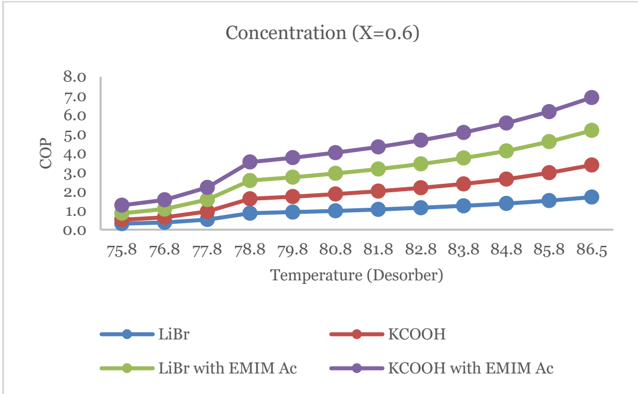

Figure 6. COP vs Temperature of desorber for different fluids at concentration of 0.6 (Anand *et al.*, 2016; Kaynakli & Kilic, 2007)

The Table 8 represents the increasing trend in COP for each fluid with an increase in temperature but in case of KCOOH with EMIM Ac a slight reversal trend is observed at temperature of 83.8°C to 84.8°C. This effect is observed due to a rise in strong solution concentration leading to a drop in circulation ratio, which affects both strong and weak solutions. However, the mass flow rate of refrigerant is affected resulting in an increase in generator temperature. The Figure 7 concludes that at higher desorber temperature, high COP can be attained (Sofyan *et al.*, 2020).

Table 8. Temperature of desorber for different fluids at concentration (X = 0.56) with respect to COP of system

Temperature (Desorber) (°C)	**COP**			
	LiBr	**KCOOH**	**LiBr with EMIM Ac**	**KCOOH with EMIM Ac**
75.8	0.2286	0.1761	0.2811	0.2199
76.8	0.2409	0.1887	0.2931	0.2412
77.8	0.2613	0.2097	0.3129	0.2606
78.8	0.2861	0.23601	0.3362	0.2613
79.8	0.3168	0.2676	0.3660	0.2676

80.8	0.3564	0.3090	0.4038	0.3090
81.8	0.4092	0.3654	0.4530	0.3990
82.8	0.4824	0.4410	0.5238	0.4488
83.8	0.5916	0.5547	0.6285	0.6069
84.8	0.7710	0.7374	0.8046	0.7875
85.8	1.1229	1.0983	1.1475	1.1457
86.5	2.1249	2.1171	2.1327	2.1585

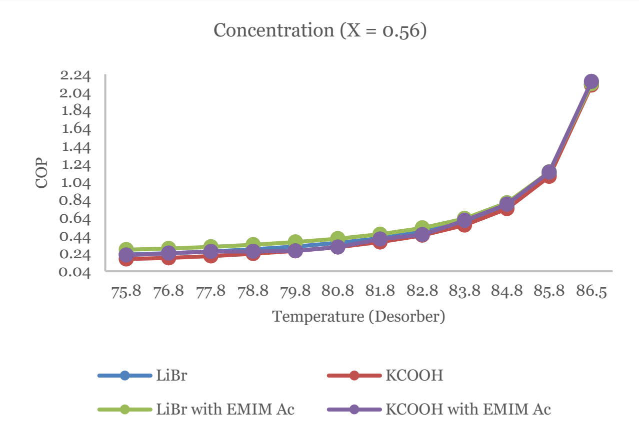

Figure 7. COP vs Temperature of desorber for different fluids at a concentration of 0.56 (Anand *et al.*, 2016; Kaynakli & Kilic, 2007)

A. *Sensitivity Analysis*

For checking the effect of temperature of generator, following assumption are considered:

- ✓ Temperature of Solution heat exchanger at exit: 53°C
- ✓ Capacity of evaporator: 1kW
- ✓ Temperature of evaporator unit: 6°C
- ✓ Percentage ratio of an absorbent in an absorber at inlet: 53%
- ✓ Percentage ratio of an absorbent at exit: 60%
- ✓ Exit temperature of absorber unit: 34°C
- ✓ Pressure in evaporator and absorber: 0.934kPa

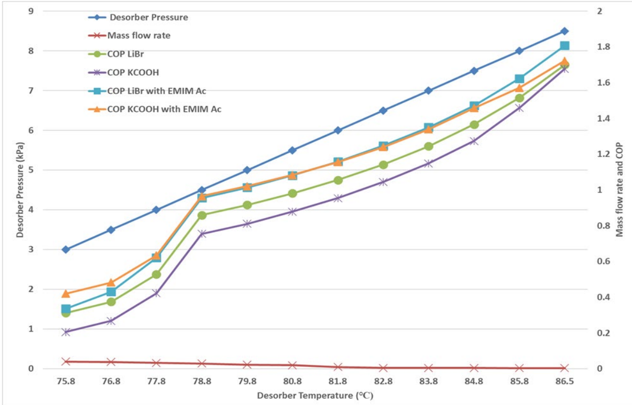

Figure 8. Effect of generator temperature (Kaynakli & Kilic, 2007)

For checking the effectiveness of solution strength, a constant difference of 4% between the absorber inlet absorbent percentage ratio and absorber outlet ratio was considered. The following conditions were assumed:

- ✓ Capacity of evaporator: 1kW
- ✓ Temperature of evaporator unit: 6°C
- ✓ Exit temperature of solution from Generator: 80°C
- ✓ Temperature of Solution heat exchanger at exit: 53°C
- ✓ Pressure in evaporator and absorber: 0.934kPa

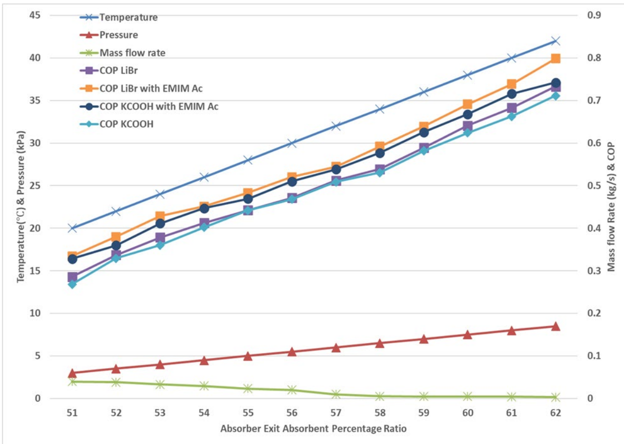

Figure 9. Effectiveness of strength of solution (Kallitsis *et al.*, 2023)

LiBr with EMIM Ac is an absorbent along with additives showing a considerate result for vapour absorption refrigeration system. The desired cooling capacity of 1kW is obtained under given input parameters with stated assumptions. The heat energy source in generator (desorber) is low-grade waste heat/ solar energy through which 90°C temperatures can be drawn. The COP obtained from the modelled system is 1.86 at the absorbent concentration of 0.6.

IV. CONCLUSION

There is a decrease in COP with increase in concentration in all absorbent with and without additives, but steep drop is observed in case of LiBr which further concludes in the form of crystallisation of the process. It also explains the increase in concentration of absorbents (0.56 to 0.60) causes a decrease of COP by (11.07 %). LiBr with EMIM Ac shows comparatively good result among all four absorbents even in increased concentration percentage resulting into high COP respectively. Figure 6 represents, increase in desorber temperature (75.8 to 86.5) °C causes increase in COP by (10.35 %). Throughout the temperature range, it was observed that KCOOH with EMIM Ac is high other than last two temperatures (i.e. 85.8 & 86.5), which shows for further increase in temperature LiBr with EMIM Ac is showing good result in accordance to COP. The increase in mass flow rate causes decreases in COP by about (13.6%). However, COP remains constant with increase in mass flow rate for KCOOH with and without additives (EMIM Ac). Generally, it is observed that COP is independent of mass flow rate in higher capacities but for very small values variation is observed. COP is maximum for refrigerants with additives indicating the ability of additives to enhance the performance of refrigerants in the VAR system.

While examining the effectiveness of strength of solution for a constant 4% difference between the absorber inlet and outlet absorbent percentage ratios, it was found that LiBr with EMIM Ac, at higher percentage ratios yielded slightly better results. An ideal temperature at the absorber outlet is around 34.8°C, which would result in an absorber outlet LiBr with EMIM Ac percentage above 59%.

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