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Energy Analysis of Water-Lithium Chloride (LiCl-H_2O) operated Absorption Refrigeration System using ANN Approach.

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Abstract: ***The objective of this work is to exploit artificial intelligence for performing energy analysis of absorption refrigeration system (ARS) with water-lithium chloride as working fluid. Energy analysis of water-lithium chloride operated vapour absorption refrigeration system is a very intricate process due to limited thermodynamic property data points and analytical functions required for estimating the thermodynamic properties of untraditional working fluid pairs. These equations usually involve the higher order complex partial differential equations and cannot be solved using simple mathematics and are time consuming too. With the help of ANN, authors have formulated new mathematical equations for estimating thermodynamic properties of each salient state of the ARS cycle. Heat load in major component of the ARS and first law based performance indexes are calculated in this analysis. The maximum difference between the predicted results and experimental data of thermodynamic properties are less than 1%. Value of the coefficient of multiple determinations is 1 for test data set and can be considered satisfactorily for using ANN in vapour absorption refrigeration system.***

Keywords- Energy Analysis, ANN, ARS, Water-Lithium Chloride, COP.

I. INTRODUCTION

Absorption refrigeration system attracts the waste heat utilization researchers because it can be driven by waste heat sources, solar heat and geothermal energy. It's operational cost is very less compare to compression refrigeration system [1-3]. Besides, ARS's working fluids do not deplete ozone layer and contribute in global warming. Hence, these are environment friendly [4-5]. Performance of the ARS is majorly depends on the selection of working fluid. Hence, many researchers have proposed new working fluid after great investigation for enhancing the performance of ARS [6-7]. G.S.Grover et.al [8] and more recently Arzu Sencan et.al [9] have carried out performance analysis of lithium chloride – water (LiCl-H_2O) based vapour absorption refrigeration system. In their published work, both the researchers have not done the first law based (energy) analysis of the proposed ARS. Thermodynamic properties of proposed working fluid pair are available in the past published work as complex partial differential equations or limited data points [10].

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Artificial neural network is used to solve many engineering non linear problems and this methodology is capable to solve of complex physical phenomenon such as in the mechanical engineering [11-13]. In last decades, number of researchers is applied ANN modeling in energy systems [14-16]. In this present work, authors have derived an expressions for estimating the thermodynamic properties of the working fluid at all the thermodynamic states by using ANN .The results have been compared with those obtained by Arzu Sencan et.al [9]. By the use of above thermodynamic properties, heat load in each major component in the absorption refrigeration cycle and performance parameters like circulation ratio (f) and coefficient of performance (COP) are also calculated.

II. SYSTEM DESCRIPTION

A schematic water-lithium chloride ARS is shown in Figure 1. After the evaporator, Water vapour flows to the absorber, where it mixed into hydroscopic solution of absorbent lithium chloride and converted into liquid working solution. The weak solution is pumped to the generator through solution heat exchanger using pumping work where it gets heated. A high temperature heat source supply heat in the generator for converting water into steam. The strong solution is returned to the absorber through the solution heat exchanger and pressure reducing valve.

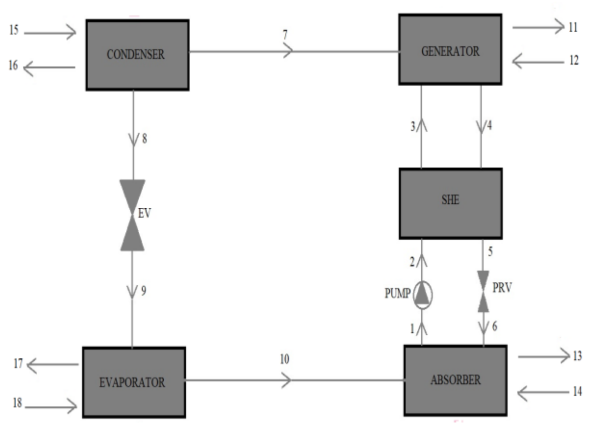

Figure 1: Single effect proposed ARS in this study.

To perform the energy analysis of a lithium chloride – water absorption system, following assumptions are taken-

(i) Thermodynamic system operates in steady state.

(ii) There are no pressure drops except through pump.

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(iii) In the condenser & evaporator, the refrigerant interacts with latent heat exchange phenomenon.
(iv) There are no jacket heat losses.

III. THERMODYNAMIC ANALYSIS

This energy analysis involves mass and solution balance equations which can be written as:

$$m_w = m_s + m_R \quad (1)$$

$$m_w x_w = m_s x_s \quad (2)$$

Mathematically, circulation ratio (f) can be written as

$$f = \frac{m_w}{m_s} \quad (3)$$

Combining Equation (1) and Equation (2) with Equation (3), one can write as

$$f = \frac{x_s}{x_s - x_w} \quad (4)$$

On applying energy balance for all the components of the proposed vapour absorption system, one can write-

$$Q_{AB} = m_R \left[h_{10} + (f-1) h_6 - f\, h_1 \right] \quad (5)$$

$$Q_{CO} = m_R (h_7 - h_8) \quad (6)$$

$$Q_{GE} = m_R \left[h_7 + (f-1) h_4 - f h_3 \right] \quad (7)$$

$$Q_{EV} = m_R \left[h_{10} - h_9 \right] \quad (8)$$

$$Q_{SHE} = m_R (f-1)(h_{10} - h_{11}) \quad (9)$$

$$W_P = m_R f (h_8 - h_7) \quad (10)$$

3.1 Fluid Properties

The architecture of the proposed neural network is shown in Figure 2 for predicting the specific enthalpy of lithium chloride-water. The most popular feed forward back propagation learning algorithm is used in the modeling of artificial neural network for the proposed network. It consists of an input layer, hidden layer, bias and an output layer. The input layer accepts the two inputs, temperature and solution (LiCl) – concentration, while output layer predicts the specific enthalpy for the given inputs. There are 2 neurons in input layer, 10 neurons in hidden layer and 1 neuron in the output layer respectively. Input range for temperature is between 0 0C to 120 0C and concentration is from 0% to 50%.

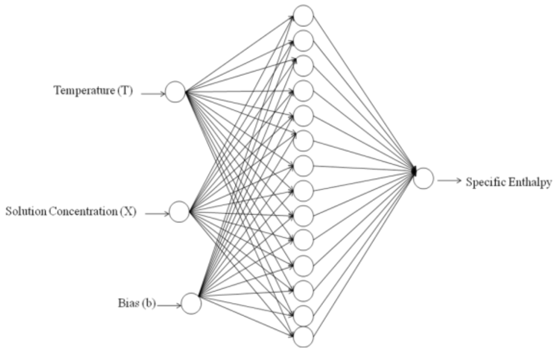

Figure 2: Architecture of neural network used in this analysis.

The algorithm uses Logistic Sigmoidal Transfer function as an activation function for hidden layer and purelin Transfer function for output layer as:

$$f(y) = \frac{1}{1+e^{-y}} \quad (12)$$

Where, y is the sum of all weight used in modeling of the neural network. Authors trained the network with all available training functions and achieved the best results by the Levenberg-Marquard (trainlm) training function. In this analysis, authors have used 80 percent data [10] for training and remaining for testing the neural network which give the validation to the network. Authors have normalized input and output data due to asymptotic nature of the sigmoidal and tansigmoidal transfer functions. As to proposed work, for satisfactory training, mean square error should be least and the same is presented in Figure 3. The range of normalized input and output pairs is between (0-1).

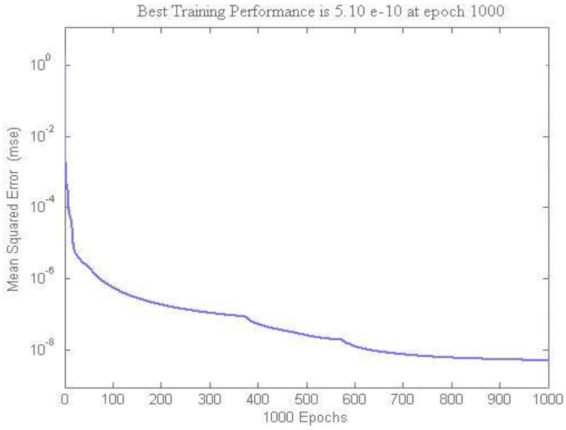

Figure 3: Pattern of mean square error based on 2-14-1 neural network architecture

Figure 4 shows the regression analysis of the test data values to the actual values [10] which is another basis parameter for validating the network [11-16]. In the evaluation of R2, authors have used the unknown data set which is not used in training session of the neural network.

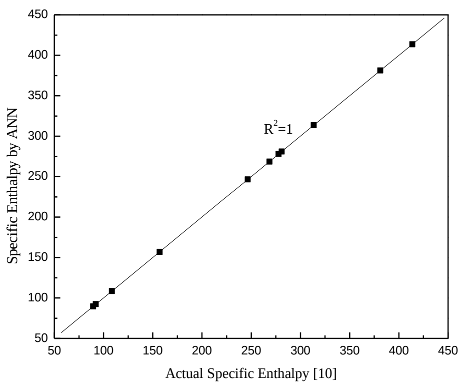

Figure 4: Comparison between test data values from [10] and derived by ANN on the basis of R2Following equations are derived by using ANN for estimating the specific enthalpy of water-LiCl solution.

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$$X = \frac{x}{51}$$

$$T = \frac{t}{121}$$

$$F1 = -9.42037X + 12.23251T + 4.106476$$

$$E1 = \frac{1}{1+e^{-F1}}$$

$$F2 = 13.29882X + 3.106821T - 16.2691$$

$$E2 = \frac{1}{1+e^{-F2}}$$

$$F3 = 14.71955X + 11.13208T - 0.45784$$

$$E3 = \frac{1}{1+e^{-F3}}$$

$$F4 = 17.60042X + 6.724249T - 19.1971$$

$$E4 = \frac{1}{1+e^{-F4}}$$

$$F5 = 10.79811X - 1.61482T - 8.7348 \quad (22)$$

$$E5 = \frac{1}{1+e^{-F5}} \quad (23)$$

$$F11 = -38.0378X - 0.87892T - 3.10053 \quad (34)$$

$$E11 = \frac{1}{1+e^{-F11}} \quad (35)$$

$$F12 = 5.908709X - 5.56906T + 5.027964 \quad (36)$$

$$F13 = 9.784646X + 1.359426T + 2.171037 \quad (38)$$

$$E13 = \frac{1}{1+e^{-F13}} \quad (39)$$

$$F14 = -13.6499X + 13.72829T - 13.655 \quad (40)$$

$$E14 = \frac{1}{1+e^{-F14}} \quad (41)$$

$$F6 = 0.593741X - 0.4367T + 1.445378 \quad (12)$$

$$E6 = \frac{1}{1+e^{-F6}} \quad (13)$$

$$F7 = 0.535939X - 5.53929T + 1.382563 \quad (14)$$

$$E7 = \frac{1}{1+e^{-F7}} \quad (15)$$

$$F8 = -3.99248X + 0.014939T + 3.882795 \quad (16)$$

$$E8 = \frac{1}{1+e^{-F8}} \quad (17)$$

$$F9 = 0.779896X + 1.762168T - 0.25162 \quad (18)$$

$$E9 = \frac{1}{1+e^{-F9}} \quad (19)$$

$$F10 = -17.6628X - 5.90391T + 4.824947 \quad (20)$$

$$E10 = \frac{1}{1+e^{-F10}} \quad (21)$$

$$E12 = \frac{1}{1+e^{-F12}}$$

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$$\text{Specific Enthalpy} = -0.00248E1 - 0.03344E2 - 0.01095E3 - 0.00245E4 + 0.037595E5 - 8.18274E6 + 0.020474E7 - 1.28658E8 + 0.708895E9 - 0.0032E10 + 4.142937E11 - 0.03474E12 + 2.81736E13 + 0.008468E14 + 4.893278 \quad (42)$$

On combining Equations 12-42, one can calculate the enthalpy of -18 the solution. Enthalpies at thermodynamic states 7-18 are obtained from correlations found in Popiel et.al and Arora C.P [17].

In table 1, authors have presented the comparison of the values of enthalpy derived from the above derived equations to values estimated by the S.K.Chaudhary et.al [10] and calculated by Arzu et.al [9].

Table 1: Comparative analysis between the values between the actual enthalpy [10], past work to the present work.

x (%)	**t (^{0}C)**	**Actual Enthalpy [10] (kJ/kg)**	**Enthalpy from published work of Arzu et al.[9] (kJ/kg)**	**Enthalpy from present authors work (kJ/kg)**	**Absolute Relative Error in published work of Arzu et al.[10]**	**Absolute Relative Error in present authors work**
5	30	92.2	92.39	92.25	0.19	0.05
10	90	313.6	313.6	313.56	0	0.04
15	50	157	157.01	157.03	0.01	0.03
20	90	277.9	277.32	277.96	0.58	0.06
25	90	268.5	265.84	268.55	2.66	0.05
30	30	89.4	95.02	89.44	5.62	0.04
35	30	108.5	107.63	108.46	0.87	0.04
40	70	246.5	246.42	246.58	0.08	0.08
45	70	281	281.93	281.05	0.93	0.05
45	110	381.2	381.5	381.14	0.3	0.06
50	110	413.7	408.2	413.64	5.5	0.06

IV. RESULTS AND DISCUSSION

In this simulation, calculations were performed for mass of refrigerant equal to 0.005 kg/s and the parameters taken as T_{EV}=7°C, T_{CO}=40°C, T_{AB}= 40°C, T_{GE}=80°C. Table 2 shows the evaluation of ARS cycle using specific enthalpy at respective thermodynamic state as per the chemical composition & temperature the working fluids with mass flow rate.

Table 2. Thermodynamic properties at various states of vapour absorption refrigeration cycle.

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State	Temperature (^{0}C)	X (Concentration) (% LiCl)	m (mass flow rate) (kg/s)	Specific Enthalpy (kJ/kg)
1	40	41.68	0.5	178.7174
2	40	41.68	0.5	178.7174
3	45	41.68	0.5	191.8352
4	80	50.82	0.495	349.3161
5	52	50.82	0.495	283.8133
6	52	50.82	0.495	283.8133
7	80	-	0.005	2643.23
8	40	-	0.005	167.5051
9	7	-	0.005	167.5051
10	7	-	0.005	2513.583
11	100	-	0.7	419.0723
12	91.5	-	0.7	383.2614
13	27	-	0.75	113.1767
14	34.8	-	0.75	145.7771
15	27	-	0.75	113.1767
16	30.8	-	0.75	129.0611
17	16	-	0.45	67.15145
18	9	-	0.45	37.80562

Table 3 shows the energy analysis and performance index of the proposed absorption refrigeration system. The sum of heat load in generator & evaporator is equal to the heat rejection load at the condenser & absorber. The ratio of the heat load in evaporator to the generator will be recognized as the coefficient of performance (COP) for the ARS. It can easily observe from the table 3, highest heat load observed in the generator and the lowest in solution pump and the contribution pump work is negligible in total heat input.

Table 3. Heat load in major components and performance parameters of the proposed system.

Thermodynamic Quantity	Symbol	Energy Flow (kW)
Heat Load in Evaporator	Q_E	11.73
Heat Load in Absorber	Q_{AB}	14.07
Heat Load in Generator	Q_{GE}	14.75

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Heat Load in Condenser	Q_{CO}	12.37
Heat Load in SHE	Q_{SHE}	26.20
Pump Work	W_P	0.063
Coefficient of Performance	COP	0.795 (Dimensionless)
Circulation Ratio	f	5.57 (Dimensionless)

Figure 5 shows the effect of the generator temperature on the coefficient of performance and circulation ratio with at different values of T_{AB} for the given evaporator and condenser temperature.

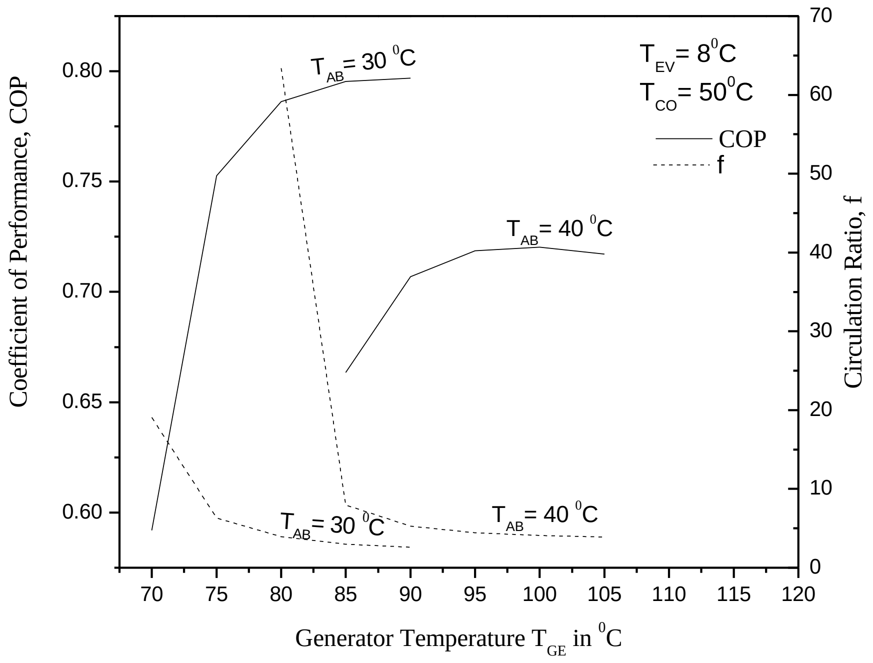

Figure 5: Variations of COP and f with the Generation Temperature TGE (0C)

As can be seen from the figure 5, COP initially increases rapidly but after that it attains a limiting value at certain higher generator temperatures. It is also observed that the COP is achieved higher at lower absorber temperatures. The (f) decreases as the generator temperature is increased while it's deceasing rate is much higher at higher T_{AB}. Figure 6 shows effect of the evaporator temperature on the COP and f (circulation ratio) at different values of T_{AB} (absorber temperature) for the given generator & condenser temperature. It can be noticed from the figure 6 that the COP of the ARS increases while circulation ratio (f) of the absorption system decreases when T_{ev} (evaporator temperature) increases. It is found that the COP is higher at lower absorber temperatures.

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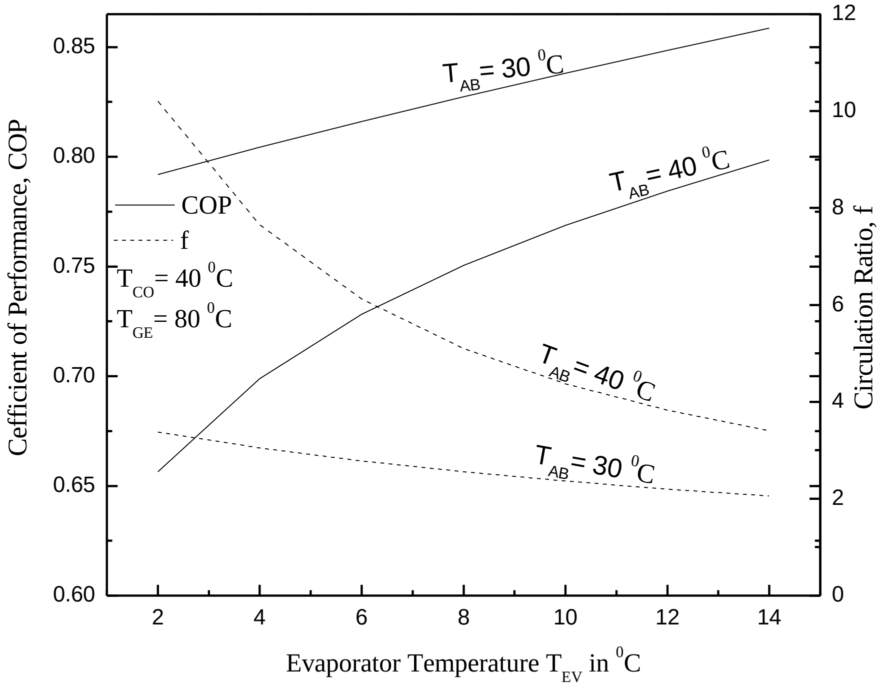

Figure 6: Variations of COP and f with the T_{EV} at different T_{AB}.

Figure 7 shows the effect of the condenser temperature on the COP and f (circulation ratio) with T_{ev} at different values for the given generator and T_{AB}(absorber temperature). It can be easily observed from the figure 7 that the coefficient of performance of the ARS increases while f of the absorption system decreases when evaporator temperature increases. It is also observed that the coefficient of performance is higher at lower condenser temperatures.

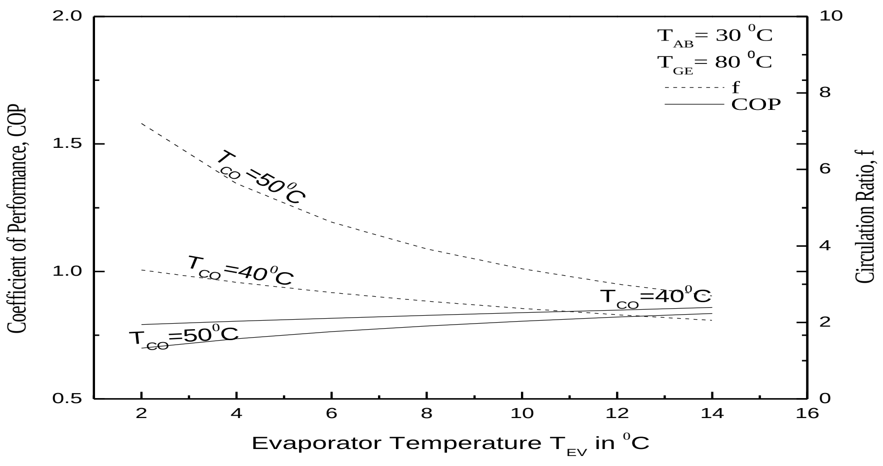

Figure 7: Variations of COP and f with the T_{EV} at different condenser temperature T_{CO}.

V. CONCLUSION

The aim of this paper is to show the possible use of artificial neural networks for energy analysis of untraditional working fluid (LiCl-H_2O) operated vapor-absorption refrigeration system. Mathematical formulations are derived by using the above new approach for calculating the specific enthalpy values of the solution at all the thermodynamic states. The values so obtained were found to compare well with the earlier published work. The analysis shows that the generator and absorber heat loads are higher than condenser and evaporator. Circulation ratio is used to calculate energy analysis and its higher value increase irreversibility at the absorber and generator. Energy analysis shows that in order to obtain high COP, it is essential to maintain the low value of *f* (circulation ratio) which implies higher value of T_{GE} and lower value of T_{CO} & T_{AB}.

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This work shows that ANN modeling is another alternative to estimate the thermodynamic properties of water-lithium chloride working fluid. Equations derived by using ANN approach gives much faster and simpler solutions in comparison with the complex and slender ., data provided in earlier past published work. Thus, the ARS design procedure can be simplified.

NOMENCLATURE

P	Pressure (kPa)
t	temperature (^{0}C)
x	Solution Concentration(%)
Q	Heat Load (kW)
f	Circulation Ratio
$\dot{m}$	Mass Flow Rate(kg/s)
h	Enthalpy(kJ/kg)
SHE	Solution Heat Exchanger
X	Normalised value of solution concentration
T	Normalised value of temperature
COP	Coefficient of Performance
ANN	Artificial Neural Network

Subscript

w	Weak Solution
s	Strong Solution
R	Refrigerant
EV	Evaporator
AB	Absorber
CO	Condenser
GE	Generator

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