Simulation Of Aqua-Ammonia Refrigeration System Using The Cape-Open To Cape-Open (COCO) Simulator

Janavi Gohil, Sarthak Doshi, Dhairya Chheda, Arvind Prasad

ABSTRACT: In this paper we have simulated a flow sheet of aqua ammonia refrigeration system using Cape Open simulator. The main aim of writing this paper is to compare the results obtained from thermodynamic simulation of aqua ammonia refrigeration system and the results obtained from the flow sheet simulation in Cape-Open to Cape-Open (COCO) simulator. The corresponding COP values obtained from both the sources are calculated and compared. With the error being very minute; the calculations using simulator prove to be more efficient and timesaving when compared to the results obtained by calculations done using tedious thermodynamic simulations and constant mass balance for different process conditions.

Keywords: absorption refrigeration, ammonia-water, simulator, process conditions, thermodynamic simulation.

1. INTRODUCTION:

Refrigeration is an art of producing and maintaining the temperature is space below atmospheric temperature. American Society of Refrigeration Engineer defines refrigeration as “The science of providing and maintaining temperature below that of surrounding atmosphere”[1]. The equipment employed to maintain the system at low temperature is termed as refrigeration system[2]. Aqua Ammonia refrigeration system being one of the oldest systems was invented by Ferdinand Carre in 1860 [3]. In this work, simulation of Aqua Ammonia refrigeration system is carried out using the Cape-Open to Cape-Open simulator (COCO). It was found that the results are in agreement with those published in the work done by Satyabhama and Ashok Babu [4]. Raghuvanshi and Maheshwari presented empirical relations for evaluating the characteristics and performance of a single stage Ammonia Water (NH3-H2O) vapour absorption system along with the simulation and examination of varying thermodynamic parameters using MATLAB 7.0.1 [5]. Alvares and Trepp using 13 Aqua Ammonia refrigeration (AAR) cycles, performed analysis on an Aqua-Ammonia refrigeration cycle coupled with solar water heating systems using Compound Parabolic Concentrator (CPC) [5].

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Bangotra and Mahajan designed a 3TR system and calculated COP using first and second law of thermodynamics. The enthalpies were calculated using enthalpy concentration diagram of Aqua-Ammonia system [2]. Satyabhama and Ashok Babu carried out a thermodynamic simulation for investigating the the effects of different operating variables on the performance analysis of vapour absorption cycle [4]. Sun , Liuli proposed an improved configuration based on connected power and absorption cooling cogeneration using Aspen plus where in the correlations were solved using Peng Robinson equation [6]. Selim and Elsayed presented a mathematical model of a packed bed absorber for Aqua-Ammonia absorption refrigeration system by developing a computer program wherein the governing equations were solved using Runge - Kutta integration method and Nachtschiem-swigert iteration technique [7]. Martinez , David , Bruno carried out the development and application of the data reconciliation technique to analyse the performance of absorption chiller using FINCON – a MATLAB solver [8]. Zavaleta and Simoes , using Ponchon Savarit method , presented analysis of a segmented weir sieve-tray distillation column of A 5TR Aqua-Ammonia absorption refrigeration cycle [9]. Cai, Sen and Paolucci developed a dynamic model of a single effect absorption cycle using Redlich – Kwong equation of state [10]. Modelling and Thermodynamic simulation of an ammonia water double effect-double generator absorption chiller was carried out by Ezzine , Mejbri and Barhoumi using CONLES which is available as a FORTRAN code [11]. White and O’Neil proposed a new Ammonia-Water absorption refrigeration cycle, wherein the evaporator blowdown stream is recycled to the rectification section of the distillation column to provide reflux. This was done using PROCESS computer simulation package and the equations were solved using the model proposed by Ziegler and Trepp [12]. In this work we have simulated aqua ammonia refrigeration system using an Open source (GPL) simulator i.e Cape-Open to Cape-Open (COCO) simulator [13]. We validated the simulator and found the COP of 1TR system.

2. ABSORPTION REFRIGERATION SYSTEM:

A Vapour Absorption refrigeration (VAR) system is similar to a Vapour compression refrigeration (VCR) system. In both the systems the required refrigeration is provided by refrigerants vapourizing in the evaporator. In a vapour compression system the refrigerant coming from the evaporator is compressed and sent to the condenser. In a vapour absorption system the vapours from the evaporator are absorbed in a solvent. This mixture is sent to a rectifier for separation of the refrigerant from the solvent. The refrigerant from the rectifier is condensed in the condenser. The functions of a compressor in a vapour compression system are replaced by an absorber, generator and a pump in a vapour absorption system. While designing a VAR, it is of utmost importance to choose ideal refrigerant - absorbent mixture [2]. The most commonly refrigerant – solvent mixtures are Ammonia-Water and Lithium Chloride + Lithium Bromide- Water. When compared with Lithium Bromide-Ammonia system, Ammonia-Water combination preferred because there are no limitations caused by high freezing temperature of refrigerant and low crystallization temperature of the solution. Also this combination is less corrosive as compared to Ammonia-Sodium thiocyanate system. Aqua Ammonia system has a drawback due to the volatile nature of water. But this problem can be solved by designing an effective rectifying section[4].

3. CAPE OPEN SIMULATOR:

Most engineering simulations entail mathematical modelling and computer assisted investigation. Process simulators do a rigorous mass and energy balance of a given flowsheet. Process simulators do a rigorous mass and energy balance for given process parameters. The unit operations in simulator are mathematical models. These models are solved to complete the mass and energy balance. A simulator is an invaluable tool to verify the process parameters. It also gives us a valuable insight of the size of equipments. This also assists in verifying the design of equipments and gives valuable insights in sizing. Simulation of refrigeration cycle in process simulator gives the refrigerant flows, power and utility requirements. Different simulators are available for use in various process and optimization problems. The open source (GPL) and commercial simulators are given in table1 below.

Name	License
Aspen Plus	Commercial
Aspen HYSYS	Commercial
Apros	Commercial
BATCHES	Commercial
ProSim Plus	Commercial
Usim Pac	Commercial
CHEMCAD	Commercial
DWSIM	Open source (GPL)
CHEMSEP	Open source (GPL)
COCO simulator	Open source (GPL)

Table 1: *Different simulators available.*

In this work the Ammonia absorbtion refrigeration system was simulated on Cape-Open to Cape-Open (COCO) simulator. This simulator is free for academic use. This simulator has easy to use interface. The learning curve is steep. The simulator results have been validated independently [13].

4. FLOWSHEET DEVELOPMENT:

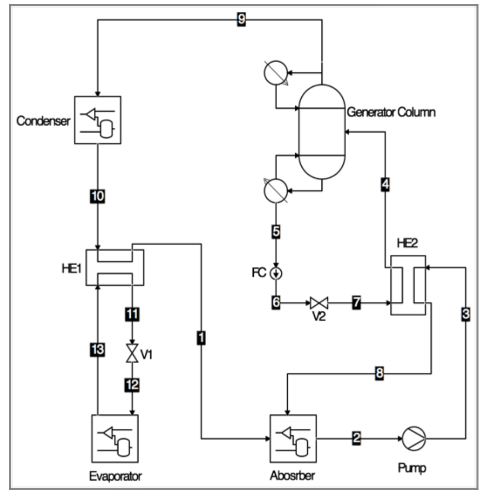

Figure 1: *Aqua ammonia refrigeration system flowsheet*

Saturated Ammonia vapours leave the evaporator through stream 13. It is superheated in heat exchanger (HE-1). It leaves the exchanger through stream 1 and enters the absorber. In the absorber the superheated Ammonia vapours are absorbed in weak ammonia solution coming from stream 8. Mixing of weak solution with vapours generates heat. This heat (**Qa)** is removed in the absorber by cooling water. The strong solution in the absorber is pumped out (stream 2) using a pump. The discharge of the pump (stream 3) passes through the heat exchanger (HE-2). Here it heats up and leaves the exchanger through stream 4. The strong solution in stream 4 is near saturation. This stream enters the rectification column. Here it is separated into a weak solution (stream 5) and pure Ammonia vapours (stream 9). As far as various energy flows out of the system are concerned, heat is supplied to the system at generator and evaporator, heat rejection takes place at absorber and condenser and a small amount of work is supplied to the solution pump[14]. The COCO simulator can be used to design process equipments by using unit operations. The absorption, evaporation and condensation systems were developed using the unit operations as stated below.

1. Absorber: consists of COCO models mixer and flash. The vapours leaving the evaporator and the weak solution from the generator are mixed and flashed to form a strong solution that enters the generator.
2. Condensor: consists of COCO models flash and mixer. Pure ammonia vapours from the top of the generator are flashed. The vapour fraction in the flash column is fixed as 0.0000001 in order to get liquid Ammonia that enters the evaporator. We design a condenser using mixer and flash column since the direct use of cooler was not possible. This was because if the cooler is used directly, the Ammonia vapours are not completely liquefied thus affecting the desired liquid fraction.
3. Evaporator: consists of COCO models flash and mixer. Liquid Ammonia is flashed and the resultant mixture enters the absorber.

5. SIMULATOR THERMODYNAMICS PACKAGE AND VALIDATION :

The Aqua Ammonia systems are highly non ideal. Ammonia and water are polar compounds, hence the non ideality. Correlations have been proposed to calculate various thermodynamic and physical properties of Aqua Ammonia solution [4]. The Peng Robinson equation of state was used as the thermodynamic model on the basis of successful results obtained by Sun,Liuli [6]. The validation of the thermodynamic model was done by comparing the equilibrium flash temperatures and vapour concentrations with values published in Perry's handbook [15].

Conc (liq)	Pressure (bars)	Conc (vap) graph	Conc (vap) Simulator	Temp(K) simulator	Temp (K) graph
0.1	8	0.558	0.553	415.25	415.15
0.2	10	0.795	0.819	396.18	395.15
0.3	30	0.840	0.853	428.00	428.15
0.4	0.2	0.996	0.99	243.59	250.15
0.1	6	0.590	0.58	403.03	403.15
0.1	0.2	0.801	0.86	299.18	303.15

Table 2. *Reading the enthalpy concentration graph for aqua ammonia refrigeration system*

Table 2 shows the comparisons. The values obtained by the graph were in good agreement with the values obtained by the simulator. The vapour and the liquid enthalpies from the simulator were validated by comparing the heat loads for isobaric heating of aqua ammonia solutions. The heat calculated by simulators were in close agreement with that predicted from enthalpy concentration diagram [15]. The percentage error is shown in Table 3.

Pressure (bars)	T_{in} (K)	T_{out} (K)	$Q_{calculated}$ (KW)	$Q_{simulator}$ (KW)	% ERROR
0.2	235.15	283.15	917.87	905.88	1.306
6	376.15	403.15	484.97	502.3	3.573
8	327.15	363.15	630.44	608.57	3.47
10	335.15	373.15	634.3	619.93	2.265

Table 3. *Validation of simulator thermodynamics (heat load)*

6. SIMULATION OF FLOWSHEET:

The flowsheet was simulated for a refrigeration load of 1TR. The thermodynamic package used was Peng Robinson Equation of State. The pressure of the operation in the evaporator was 3.51 bars and in the condenser was11.621 bars. The flow of weak solution was given as 0.00888 kg/s. The number of transfer units (NTU) was taken as 10 in HE1 and HE2. The number of stages in the generator was taken as 4 and the reflux was taken as 2 [9]. The absorber and condenser temperatures were fixed to 303K.

7. RESULTS AND DISCUSSION:

The output given by the simulator is tabulated in Table 4 column 3. It was found that the output of the simulator was in close agreement with mass flows, heat loads and power requirements published in work done by Satyabhama and Ashok Babu [4].

PROCESS PARAMETER	RESULT (1)	RESULT (2)	% ERROR
Condensor pressure	1.172 MPa	1.16213 MPa	0.8
Evaporator pressure	0.3581 MPa	0.351 MPa	1.98
Weak solution concentration	0.3495	0.3501	0.171
Rich solution concentration	0.5049	0.5048	0.019
Vapour concentration after generator	0.9859	1	1.43
Mass flow of refrigerant	0.00279 kg/s	0.00277 kg/s	0.71
Rich solution flowrate	0.01167 kg/s	0.011167 kg/s	4.310
Weak solution flowrate	0.00888 kg/s	0.00888 kg/s	0
Circulation ratio	4.18	4.03	3.5
Heat input to generator Q_g	5.301 kJ	11.430 kJ	115.61
Heat rejected in the absorber Q_a	5.1 kJ	4.933 kJ	3.27
Heat rejected in the condenser Q_c	3.328 kJ	3.295 kJ	0.99
Heat rejected in the evaporatorQ_e	3.5 kJ	3.376 kJ	3.5
COP	0.656	0.2953	54.98

Table 4. *Results and comparisons.*

RESULT(1), from work done by Satyabhama and Ashok Babu [4].

RESULT (2), from CAPE OPEN SIMULATOR.

The only values that differ to a greater extent are heat load of the generator and coefficient of performance (COP). We fixed the value of reflux ratio on the basis of explanation provided by Zavaleta and simoes [9]. Absence of the explanation for reflux ratio used for calculation in the work done by Satyabhama and Ashok Babu resulted in large %error for the generator load in Table 4. Higher the value of the heat load, lower is the value of the COP. Also the COP value obtained by us is less than the COP value obtained in work done by Satyabhama and Ashok Babu [4] because in distillation column more heat is required to boil the feed as well as the reflux. Also, a distillation column is preferred over a dephlegmator because excellent purity of ammonia is obtained at the top of the distillation column. This prevents water accumulation in the system.

8. Conclusion:

The results obtained in this work using the COCO simulator are in good agreement with Satyabhama and Ashok Babu [4]. This shows that Open source simulators are equally efficient and accurate when compared to commercial simulators.

REFERENCES:

[1] "Intro on Refrigeration." [Online]. Available: https://www.scribd.com/doc/67294460/Applied-Thermodynamics-3rd-Edition.

[2] A. M. Arun Bangotra, "Design Analysis Of 3 TR Aqua Ammoniavapour Absorption Refrigeration System," Int. J. Eng. Res. Technol., vol. 1, no. 8, pp. 1–6, 2012.

[3] M.E. Kharagpur, "Refrigerator," Hist. Cool. Devices Am. Eur. Asia., vol. 3, pp. 1–271, 2010.

[4] S. T.P.Ashok Babu, "THERMODYNAMIC SIMULATION OF AMMONIA-WATER," vol. 12, no. 3, pp. 45–53, 2008.

[5] S. G. Alvares and C. Trepp, "Simulation of a solar driven aqua-ammonia absorption refrigeration system Part 1: mathematical description and system optimization," Int. J. Refrig., 1987.

[6] L. Sun, "Imece2013-62879," pp. 1–10, 2013.

[7] A. M. Selim and M. M. Elsayed, "Performance of a packed bed absorber for aqua ammonia absorption refrigeration system," Int. J. Refrig., vol. 22, no. 4, pp. 283–292, 1999.

[8] D. E. Martinez, J. C. Bruno, M. J. Bagajewicz, and A. Coronas, "Performance Analysis of Absorption Chillers Using Data Reconciliation," ASME 2010 10th Bienn. Conf. Eng. Syst. Des. Anal. Vol. 1, vol. 1, pp. 41–50, 2010.

[9] E. W. Zavaleta-Aguilar and J. R. Simões-Moreira, "Thermal design of a tray-type distillation column of an ammonia/water absorption refrigeration cycle," Appl. Therm. Eng., vol. 41, pp. 52–60, 2012.

[10] W. Cai, M. Sen, and S. Paolucci, "Dynamic Simulation of an Ammonia À water Absorption Refrigeration System," pp. 2070–2076, 2012.

[11] N. Ben Ezzine and A. Bellagi, "Thermodynamic Simulation of Ammonia-Water Double Effect Absorption Chiller," pp. 1–8, 2004.

[12] S. D. White and B. K. O'Neill, "Analysis of an improved aqua-ammonia absorption refrigeration cycle employing evaporator blowdown to provide rectifier reflux," Appl. Energy, vol. 50, no. 4, pp. 323–337, 1995.

[13] "Open source Cape-Open to Cape-Open simulator." [Online]. Available: http://www.cocosimulator.org/index_download.html.

[14] V. A. R. S. B. O. A.-W. P. 1, Kharagpur, "Water Pair," pp. 1–16, 2010.

[15] D. W. Perry, R.H. and Green, Perry's Chemical Engineers' Handbook, Eighth Edition. McGraw-Hill, 2007.