DESIGN AND ANALYSIS OF ABSORPTION REFRIGERATION SYSTEM USING

[EMIM [OTF] +H_2O]

A PROJECT REPORT SUBMITTED IN THE PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology
in
Chemical Engineering
By
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CERTIFICATE

This is to certify that the thesis entitled **“DESIGN AND ANALYSIS OF ABSORPTION REFRIGERATION SYSTEM USING EMIM [OTF] + H_2O”** submitted by Sidhant Dash in the partial fulfilment of the requirement for awarding the degree of **BACHELOR OF TECHNOLOGY** in **Chemical Engineering** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Date:

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And I would like to convey my appreciation to all those who directly or indirectly supported me in carrying out this thesis work successfully.

Date: Sidhant Dash

ABSTRACT

With rapid economic expansion and persistently increasing energy consumption, human kind is going to face a growing degradation of environment, if the activities continues as usual. For this reason, utilization of low grade energy has become one of the most attractive solution to heating and cooling problem encountered with industrial and residential applications. It is viable to recover the low grade heat lost in industries to use it absorption refrigeration cycle to increase their efficiency and reducing the negative impact on the environment. Since the inception of absorption cycle, the working pair properties have been a challenging issue which determine the performance of refrigeration cycle. Thus, the search for the more beneficial working pair with excellent thermal stability, non-corrosive and non-crystallization has been a subject of research in recent years. The coefficient of performance (COP) is simply defined as the cooling capacity divided by the energy input to the absorption refrigeration cycle and it can also be used to gauge the potential success of ionic Liquid and water systems. This research provides the necessary thermodynamic measurements and/or predictive modelling of the mixture properties, COP calculation and cost estimation in order to evaluate the (IL + water) working pair based absorption refrigeration (ARS) systems for future use in absorption refrigeration. The calculations have shown that the (IL + water) based ARS have higher COPs' than the conventional working pair based systems

KEY WORDS: Ionic liquids, Coefficient of performance, Absorption refrigeration cycle.

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ABBREVIATIONS

EMIM [OTF] → 1-Ethyl-3-methylimidazolium trifluoromethanesulfonate.

BMIM [DEP] → 1- butyl -3-Methylimidazolium diethyl phosphate

BMIM [DBP] → 1- Butyl -3-Methylimidazolium dibutyl phosphate

Q_g → Heat duty of the Generator in kW

Q_e →Heat duty of the evaporator in kW.

Q_c → Heat duty of the condenser in kW

Q_a →Heat duty of the absorber in kW

M_s → Mass flow rate of weak solution in Kg/ sec

M_r → mass flow rate of water in Kg/ sec

$M_s – M_r$ → mass flow rate of weak solution in Kg/ sec

H →Enthalpy in KJ/Kg

T_a →Temperature at the absorber in ˚C

T_e →Temperature at the evaporator in ˚C

T_c → Temperature at the condenser in ˚C

T_g → Temperature at the generator in ˚C

P_a → Pressure at the absorber in kPa

P_e → Pressure at the evaporator in kPa

P_c →Pressure at the condenser in kPa

P_g → Pressure at the generator in kPa

F → flow ratio.

COP →Coefficient of performance

η →Heat ratio.

W_p →Work done by pump in kW.

CHAPTER 1

Introduction and Literature Review

1.1 Introduction

Global warming and climate change, human activities and other harmful natural events lead to an increasing in average global temperatures. This is caused primarily due to increase in “greenhouse” gases such as Carbon Dioxide (CO_2). In conventional vapour compression refrigeration process, the compressor consumes electrical energy which is obtained from the combustion of fossil fuels. Thus, in order to mitigate the imminent threat, we need to restrict the use of vapour-compression refrigeration process by some alternative refrigeration process. Absorption refrigeration system utilizes low-grade heat or waste heat for refrigeration instead of electrically driven compressor

1.2 Literature survey

Vapour compression refrigeration systems are used primarily in refrigeration systems from many years. In a vapour compression refrigeration system, refrigeration is achieved as the refrigerant evaporates at low temperatures. The input to the system is in the form of mechanical energy required in order to function the compressor. Therefore, these systems are also termed as mechanical refrigeration systems **[1, 2].** A wide variety of refrigerants can also be used in these systems to match different applications, capacities, etc. At many international Energy conferences, concerned authorities relentlessly trying to mitigate the excessive consumption of electrical energy, one has to reconsider the commonly used compression refrigeration system. Due to the persistent problem, Absorption refrigeration systems are used over vapour compression systems to overcome the shortcomings of the later **[3]**.

Various researchers stated few factors on which the Vapour compression refrigeration system and absorption refrigeration system are compared.

Power requirement:

In compressor systems, there is a huge requirement of power by the compressor while minimum power is required for the pump in absorption system to run the system.

Type of energy required:

The vapour absorption system runs particularly on the waste or the extra heat in the plant. The waste heat from the diesel engine, hot water from the solar water heater, etc. can also be used. For the vapour compression refrigeration system, the compressor can be run by electric power supply only, which is obtained from heavy combustion of fossil fuels.

Capacity control of the system

In the vapour compression cycle, the capacity control of the system is done from the compressor and in all cases stepwise capacity control is achieved. In case of the absorption refrigeration system, it is possible to obtain zero capacity when there is no load on the system. Though these days compressors with stepwise capacity control are available, but they will surely consume lots of power even if there is zero load on the refrigeration system. In the absorption system, when there is zero load the power consumption is almost zero.

Considering the above analysis between absorption cycle and compression cycle, clearly we came to approve the absorption systems because of some major advantages over the conventional vapour compression cycles.

In absorption refrigeration process, conventional fluids like ($LiBr+H_2O$) and $NH_3 + H_2O$ are commonly used working pairs. Apparently, further analysing the relative disadvantages like: $LiBr + H_2O$ (It is corrosive in nature) $NH_3 + H_2O$ (It is poisonous in nature).

These few disadvantages forced us to look beyond theses conventional pairs. We look out for ionic liquids for the absorption process. After analysing both systems, the performance of the absorption refrigeration cycle using ionic liquids is distinctively higher than that of conventional working pairs. Moreover, Ionic Liquids have many positive characteristics. Most promisingly, they have a very low vapour pressure under normal operating conditions and, therefore, do not contribute to air pollution. This is also an advantage in terms of a solvent replacement for industrial processes as it will not be lost due to evaporation **[4]**.

Literature showed us the following parameters to select ionic liquids as a working pair. Such as:

Viscosity: Higher Viscosity of Ionic liquids cause an increase pressure drop in the compression loop which would result in large pumping power and hence decreases the COP.

[EMIM] < [BMIM] < [HMIM].

Length of Cation alkyl chain: Ionic liquids with longer cation alkyl chain length pose a larger solubility but lower dependence of solubility on temperature. Thus, Ionic liquids ([BMIM] > [HMIM]) due to more sensitive dependence of solubility in temperature.

Vapour pressure lowering: The effect of Ionic liquids on the Vapour pressure of solvent follows the Order:

[MMIM] [DMP] > [EMIM] [DEP] > [BMIM] [DBP] for water

[BMIM] [DBP] > [EMIM] [DEP] > [MMIM] [DMP] for Organic solvents like methanol and ethanol.

After going through rigorous research on calculating the value of COP, we found the value range in between 0.68 and 0.72. While, COP value for EMIM [OTF] as working pair in absorption refrigeration system showed 0.82 **[5]**.

Another important objective was to estimate the cost and the possible profit that can be attained in the process. Further, analysis the cost of working pairs. We got a range of possibility in choosing a pair for the refrigeration. According to Ionic liquids today, Market cost of Conc > 98% EMIM [OTF] is around 1, 12,134 rupees, which is way too high than that of other non-Ionic pairs **[6]**. Despite having incurred a loss of around 12,000 rupees a year, we still recommend putting forth this new age working pairs for refrigeration systems because of its eco- friendly nature.

1.3 Absorption refrigeration system using IL + H_2O pairs

The involvement of an ionic liquid as a working fluid to an absorption refrigeration system has the ability to overcome some of the safety and environmental impacts of the current conventional working fluids. Current conventional absorption refrigeration systems use LiBr/water or water/ammonia. The problems like corrosion, solidification, poisonous, and odour nuisance are associated with the current systems which could probably be avoided if they were replaced with ionic liquids/water, Ionic liquid/CO_2, or Ionic liquid/hydrofluorocarbon system. Numerous ILs are completely miscible with water. When using water as the refrigerant, the cycle is limited to refrigeration temperatures above the freezing point of water. However, absorption refrigeration should be taken up whenever there is an abundant availability of waste heat.

1.4 Objectives and scope

Objective:

- ✓ Utilization of low grade heat using (IL+ water) based absorption refrigeration system.

Scope:

- ➢ Design and analysis of (EMIM [OTF] +H_2O) based absorption refrigeration system.
- ➢ Study of economic feasibility of (EMIM [OTF] +H_2O) based absorption refrigeration system.

1.5 Outline of chapters

Chapter 1: Introduction and literature survey.

Chapter 2: Presents the theory involves in the absorption refrigeration cycle .Additionally, there is a brief discussion about the COP calculation and the nuanced analysis.

Chapter 3: Presents simulation and analysis of absorption refrigeration cycle.

Chapter 4: Presents the analysis, design and economic feasibility of the system.

Chapter 5: Conclusions and future recommendations.

CHAPTER 2

Theoretical Postulates in Absorption Refrigeration Cycle using

(EMIM [OTF]+H_2O)

2.1. Introduction to absorption refrigeration cycle

As we know there are two types of refrigeration cycle such as **vapour compression refrigeration cycle** and **vapour absorption refrigeration cycle.** Vapour compression cycle is the conventional one, which indeed consumes a lot of electrical energy in which CFC's and other harmful greenhouse gases are used as refrigerants. For large quantity of electrical energy, a large amount of fossil fuels have to be burnt and thus, it will lead to more CO_2 emissions. Secondly, the working pairs used are toxic and corrosive in nature and also a leading cause which depletes the ozone layer. These factors raise more concern for environmental and energy issues and with fast economic growth, human beings have to face more and more significant environmental and energy issues. The ways to solve these problems are developing and utilizing renewable energy resources, enhancing energy utilization efficiency and so on. Absorption chillers or absorption heat pumps are both pertinent energy saving devices which can be driven by a lot of low-grade thermal energy, such as solar energy and industrial waste heat from industrial process, so the devices will play an important role in improving energy utilization efficiency and reducing environmental pollution and carbon dioxide emissions. The absorption refrigeration technology, which went through more than 120 years, has attracted much attention throughout the world, for the reason that it is environmental friendly and could make use of the low-grade energy, which refers to the ignored energy embedded in the exhaust steam of low pressure and low temperature. The absorption refrigeration is widely used in many fields, such as military, air conditioning, electric power, steelmaking process, chemical industry, drugs manufacture and so on. Although, vapour compression cycle has taken over most of air-conditioning and refrigerating applications, the well-known refrigerant–absorber systems (H_2O/LiBr and NH_3/H_2O) are still being known for certain applications, particularly in the field of industrial applications or large-scale water chiller systems. Recently, more attention has been directed towards the recovery of waste heat using the Ammonia water system.

As, we now have the idea about the superiority of vapour absorption cycle over conventional vapour compression cycle, let us now explore the working pairs for the absorption refrigeration cycle. Before that let us have a clear idea about the differences between vapour absorption cycle and vapour compression cycle, which are discussed in the following section.

2.2. Differences between absorption refrigeration system and compression refrigeration system

1. The most notable difference between these cycles is the way in which the compression work is done. In, vapour compression cycle, compression is done by using a compressor, which consumes a lot of electrical energies. Whereas in vapour absorption cycle,

compression is done by using a generator-absorber solution circuit, which comprises of generator, absorber, heat exchanger and pump.

2. Vapour compression cycle uses toxic and corrosive refrigerants where as in vapour absorption cycle we can use H_2O and ionic liquid based working pairs, which are eco-friendly in nature.

3. In vapour absorption cycle, work input is low as pumping involves liquid whereas, in vapour compression cycle, work for compression is very high.

4. Even though there are more equipment in vapour absorption cycle than vapour compression cycle, vapour absorption cycle is economically justifiable as it uses low grade source of heat like solar energy, geothermal energy and other industrial sources of heat.

5. Vapour compression cycle can be made to work at low pressure using certain working pairs whereas high pressure needs to be maintained for vapour compression cycle.

2.3. Definition of low grade energy

Low grade heat energy refers to the energy derived from the renewable sources like solar energy or geothermal energy and the ignored energy from the industries, embedded in the exhaust steam of low pressure and low temperature, which cannot be used to do any work. It plays an important role in improving energy utilization efficiency and reducing environmental pollution and carbon dioxide emissions. The use of low grade thermal energy reduces the consumption of electrical energy to a large extent.

2.4. Working pairs

The cycle performance of many refrigeration cycles depends not only on their configuration, but also on thermodynamic properties of working pairs generally composed of refrigerant and absorbent. The primarily used working pairs in absorption cycles are aqueous solutions of either ($LiBr + H_2O$) or ($NH_3 + H_2O$). However, corrosion, crystallization, high working pressure, and toxicity are their major disadvantages in industrial applications. Therefore, seeking more advantageous working pairs with good thermal stability, and with minimum corrosion has become the research focus in the past two decades. To comply with the above properties, we look forward to ionic liquids(ILs) such as (EMIM +H_2O) that have attracted significant attention due to their unique properties, such as negligible vapour pressure, non-flammability, thermal stability, good solubility, low melting points, and staying in the liquid state over a wide temperature range from room temperature to about 300°C. The above mentioned favourable properties of ionic liquids have motivated us to carry out our research on absorption refrigeration cycle using ionic liquid- based working pairs in which water is used as refrigerant and Ionic Liquid is used as an absorbent.

Requirements of working fluids of absorption cycles are as follows:-

i) The difference in boiling point between the pure refrigerant and the absorber solution at the same pressure should be as large as possible.

ii) Refrigerant should have a high heat of vaporization and high concentration within the absorbent in order to maintain low circulation ratio between the generator and the absorber per unit of cooling capacity.

iii) Both refrigerant and absorbent should be noncorrosive, environmentally friendly, and of low cost.

2.5 Ionic liquid

An ionic liquid is a salt in which the ions are loosely coordinated, that results in these solvents being liquid below 95 Degrees, or even at room temperature. At least one ion has a delocalized charge and one component is organic, which prohibits the formation of a stable crystal lattice Properties, like melting point, viscosity, and solubility of starting materials and few other solvents, are determined by the substituents on the organic component and by the counter ion.”.

Generally, there are three categories in Ionic liquids such as 1st category (completely soluble in Water, 2nd category (partially soluble in water) and 3rd category (chemically complex with water). In our research, we considered 1st category ionic liquids for the operation. Few examples of ionic liquids regularly used are:

Table 2.1 Various Ionic liquids

Ionic liquid	Chemical formula
1-ethyl – 3 – methylimadazolium tetraflouroacetate	EMIM TFA
1-Ethyl-3-methylimidazolium trifluoromethanesulfonate	EMIM OTF
1-Ethyl-3-methylimidazolium trifluoromethanesulfonate	EMIM $ETSO_4$
1-ethyl-3-methylimidazolium tetrafluoride borate	EMIM BF_4

2.6 Working principle of absorption refrigeration cycle.

A schematic diagram for a simple vapour-absorption refrigeration cycle used in the Present study is shown in Fig.2.1.

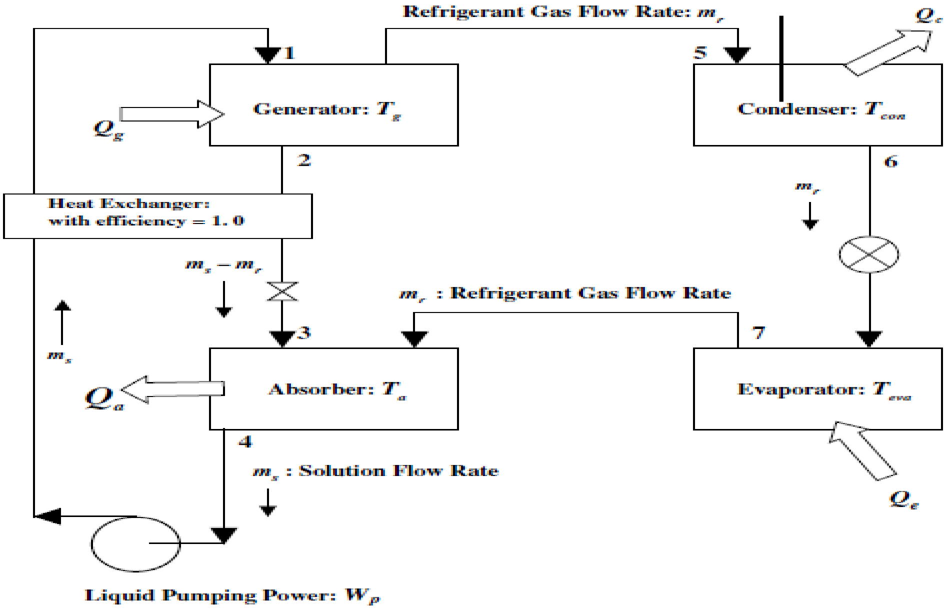


Figure 2.1 Absorption Refrigeration Cycle

Like vapour compression cycle, it also four steps that completes the thermodynamic cycle, which are as follows :

i) Isothermal heat addition in the evaporator.
ii) Chemical compression in the assembly of generator, absorber and pump.
iii) Isothermal heat rejection of generated refrigerant in the condenser.
iv) Adiabatic expansion of the condensed refrigerant in the expansion valve.

2.6.1. Vapour absorption refrigeration cycle

A schematic diagram for a simple vapour absorption refrigeration cycle used in the present study is shown in Figure 2.1. The system is composed of condenser and evaporator units with an expansion valve similar to an ordinary vapour compression cycle, but the compressor unit is here replaced by an absorber – generator solution circuit, which has a vapour absorber, a gas generator, a heat exchanger, an expansion valve and a solution liquid – pump.

Theoretical cycle performances are calculated in the following way. The overall energy balance gives the following equation.

$$Q_a + Q_c = Q_g + Q_e + W_P \tag{2.1}$$

From the material balance in the absorber or generator, we have

$$m_s X_a = (m_s - m_r) X_g \tag{2.2}$$

Where x gives the mass fraction of absorbent in the solution, and the subscripts $_a$ and $_g$ stand for the generator and absorber solutions, and m_r and m_s are mass flow rates of gaseous refrigerant and the absorber-exit solution (or solution pumping rate), respectively.

Mass flow ratio is an important parameter for determining the system performance, which is calculated as follows

.

$$\text{Mass flow ratio, } f = \frac{m_s}{m_r} = \frac{X_g}{X_{g-X_a}} \tag{2.3}$$

Now, coming to energy balance around the generator, absorber, condenser and evaporator, we have the following equations:

$$Q_g = (m_s - m_r) H_2 + m_r H_5 - m_s H_1 \tag{2.4}$$

From the assumption of unity of heat transfer efficiency, the heat exchanger, we have

$$(H_2 - H_3)(m_s - m_r) = (H_1 - H_4)(m_s) - W_p. \tag{2.5}$$

$$(H_9 - H_{10})(1 - 1/f) = H_3 - H_2 - W_p/m_s \tag{2.6}$$

Rearranging the above equation, we get

$$H_1 = (H_2 - H_3)(1 - 1/f) + H_4 + W_P/m_s. \tag{2.7}$$

Putting the value of H_3 in the (2.5), we get

$$Q_g = m_r H_5 - H_4 m_s + H_3 (m_s - m_r) - W_p. \tag{2.8}$$

So,

$$Q_g / m_r = H_5 - H_4 f + H_3 (f - 1) - W_p/m_r. \tag{2.9}$$

Similarly, heat rejection at the absorber Q_a, is given by

$$Q_a / m_r = H_3 (f-1) + H_7 - H_4 f. \tag{2.10}$$

Condensers and evaporators heats per unit mass flow are:

$$\frac{Q_c}{m_r} = H_5 - H_6. \tag{2.11}$$

$$\frac{Q_e}{m_r} = H_7 - H_6 \tag{2.12}$$

The system performance is defined by the heat ratio, η, which is defined as

$$\eta = Q_e / Q_g + W_p. \tag{2.13}$$

However, the solution pumping-power, W_p, is usually much smaller than Qg, and it is customary to use a COP (coefficient of performance) defined as

$$\text{COP} = \frac{Q_e}{Q_g + W_p} \tag{2.14}$$

2.7 Sample calculation:

Working pair: H_2O + [EMIM] [OTF].

Triflate [OTF]: Triflouromethane sulphonate Anion
I have used Figure 3.5 as a reference for my calculation.
Basis:
100 ton of refrigeration, then Q_e = 351.7kW
Consider: T_e= 5˚C, T_a= 10˚C, T_C= 50˚C, T_g= 105 ˚C.
Required Information: - C_p of water = 4.187kJ/kg-K, C_p of [EMIM] [OTF] = 1.55kJ/kg-K
From the given operating conditions,
To obtain the pressure of absorber and generator, we need to get the saturation temperature of water at 5˚C and 50˚C using Antoine equation.
The result obtained as;
P_a=P_e= Saturated Vapour pressure at 50˚C = 0.87 kPa.

P_g=P_e = 12.34 kPa

Q_e = 351.7 kW =>m_r (H_7-H_6)
As, H_7=Enthalpy of saturated vapour at 5 ˚C = 2511 kJ/kg and H_6 = 21 KJ/kg
We obtained m_r = 0.143 Kg / sec.

Now, we have to find out the composition of absorber solution with the tabulated data given in the Appendix. From the table we have to find out X_f at 0.87 kPa and 10˚C.
By interpolation,

X_f = 0.161.
X_a = 0.839.

Similarly, at generator,
T_g = 105 ˚C.

Here, we obtained the mass fraction of water in generator using interpolation.

X_f= 0.010083
X_g= 0.9899

Now, calculating the flow ratio of the solution.
$F = \frac{X_g}{X_{g-X_a}} = 6.55$
m_s = 0.143 * 6.55 = 0.93 Kg/ sec
m_s - m_r = 0.787 Kg/ sec (Strong solution flow rate)

Now, Heat duty for the generator,
$Q_g = (m_s - m_r)\, H_9 + m_r H_5 - m_s H_1$
H_2= 155.77 KJ/kg (Enthalpy of Superheated water at 105 ˚C)
H_5= 2696.73 KJ/kg (Enthalpy of superheated water at 105 ˚C)
H_1 = 114.70 KJ/ Kg (Enthalpy of weak solution at 40 ˚C)

Putting the above values in the equation (2.8), we get
Q_g = 401.549 kW.
Putting the above values in the equation (2.10), we get
Q_a = 455.036 kW.
Pump work,
$W_p = m_s\ (\Delta H)/\rho$ (2.15)

Density of the weak solution = ((0.161*1) + (0.839 * 1.312)) * 10^3
W_p = 0.93* (12.34 – 0.87) / 1.261 *10^3
W_p = 8.45 * 10^{-3} kW

So, work done by the pump is negligible compared to heat duty of the generator. Thus, we can neglect this very value.

So, COP = Q_e / Q_g = 0.82.

CHAPTER 3

Simulation and Analysis of Absorption Refrigeration System

3.1 Introduction to Aspen Plus

Aspen ONE is Aspen-Tech's comprehensive set of software solutions and professional services specifically crafted to help process companies achieve their operational excellence objectives. It favours the value of simulation models to help process companies increase operational efficiency and profitability across their global enterprise. Aspen-one cover four major field as shown in Figure 3.1

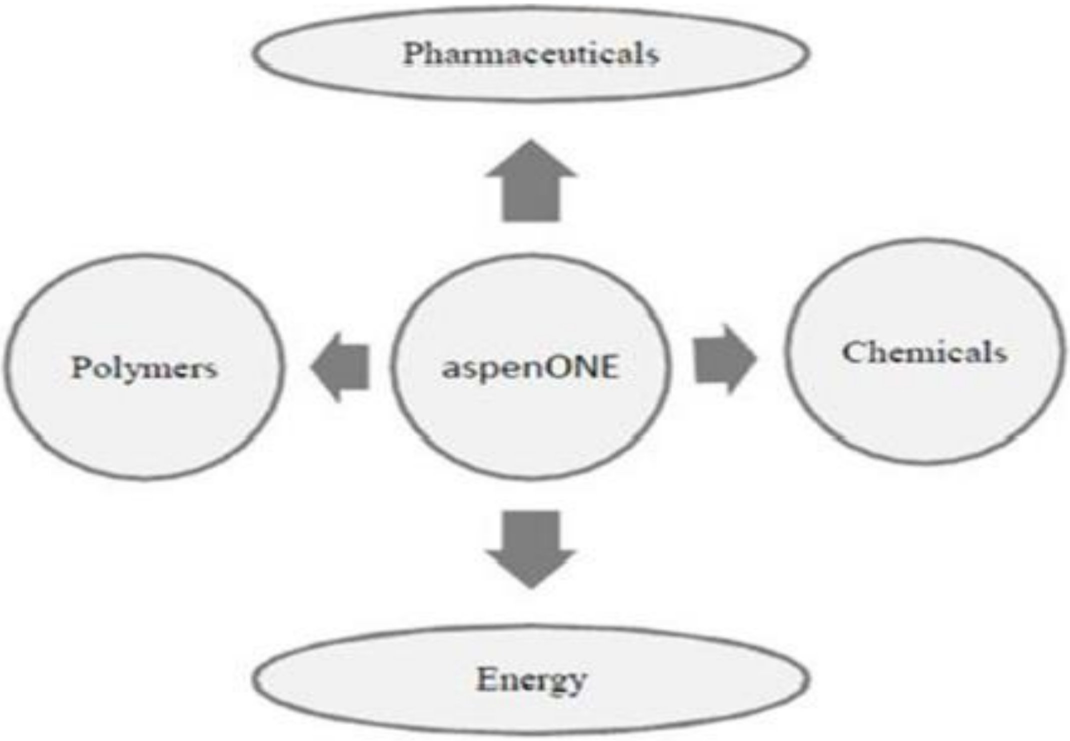


Figure 3.1 Aspen ONE engineering classification

3.2 Aspen one engineering

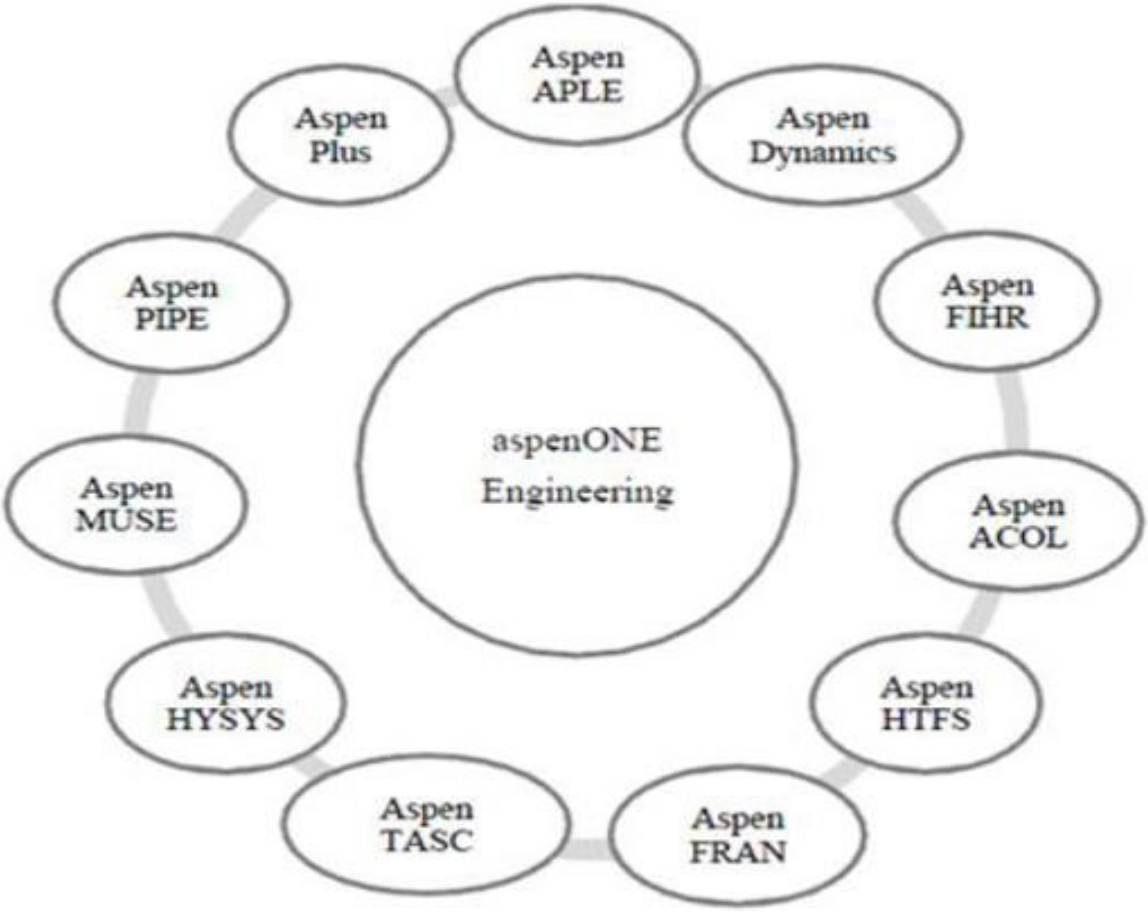


Figure 3.2 Aspen ONE engineering classification

3.2.1. Aspen Plus

Aspen Plus is a market-leading methodology demonstrating instrument for theoretical configuration, optimization, and execution checking for the chemical, polymer, specialty chemical, metals and minerals, and coal power commercial ventures. Aspen plus is a software package designed to allow a user to build a process model and then simulate the model without tedious calculations.

3.3 Equation of state

In physics and thermodynamics, an equation of state is a relation between intensive and extensive state of the system.

3.3.1. Guidelines for choosing a property method for polar non – electrolyte systems

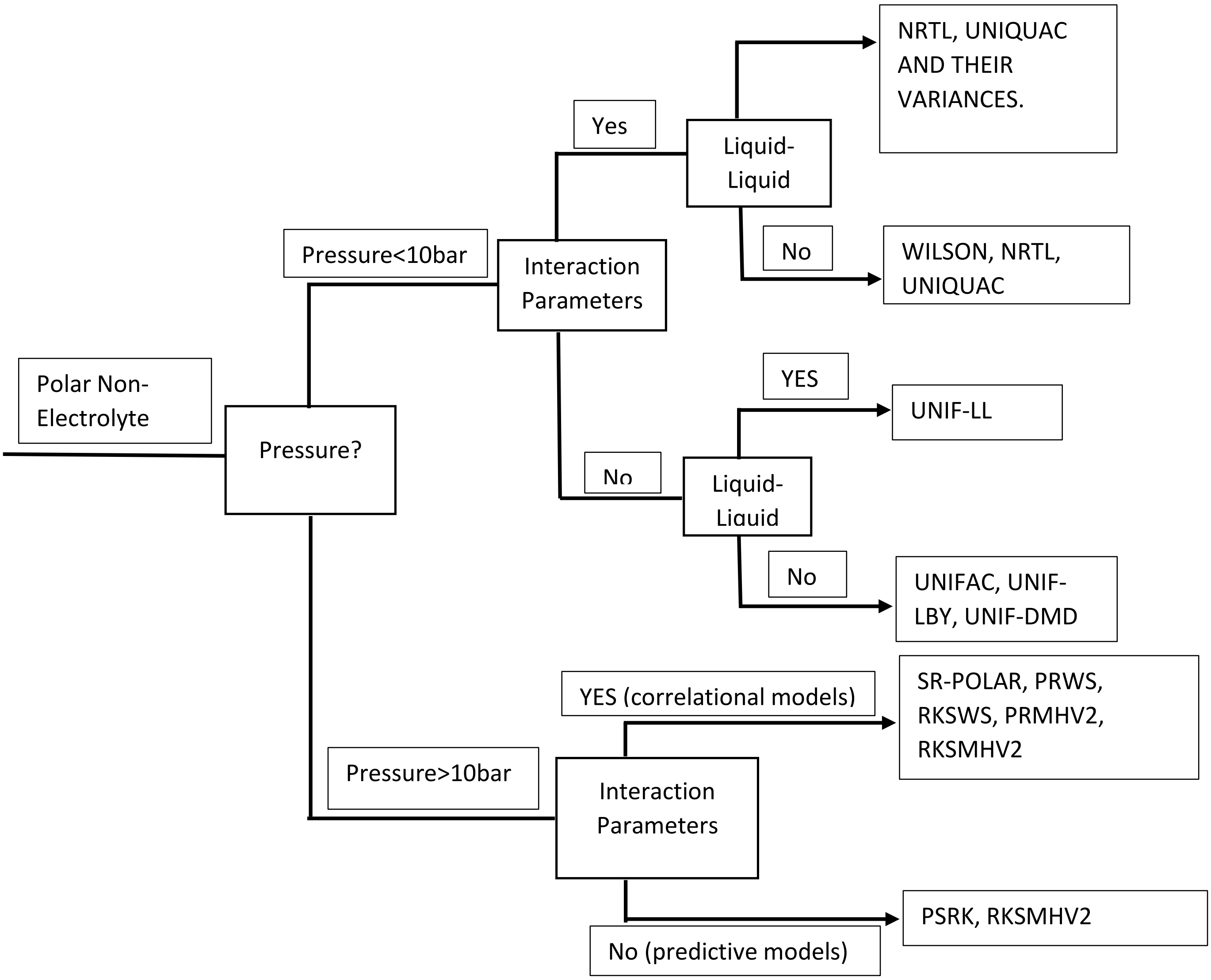


Figure 3.3 Guidelines for choosing property methods

Aspen plus contains various property methods, but for Ionic liquid like EMIM [OTF], we have choose NRTL property method because of the above mentioned criteria.

3.4 Simulation (Aspen plus flow sheet)

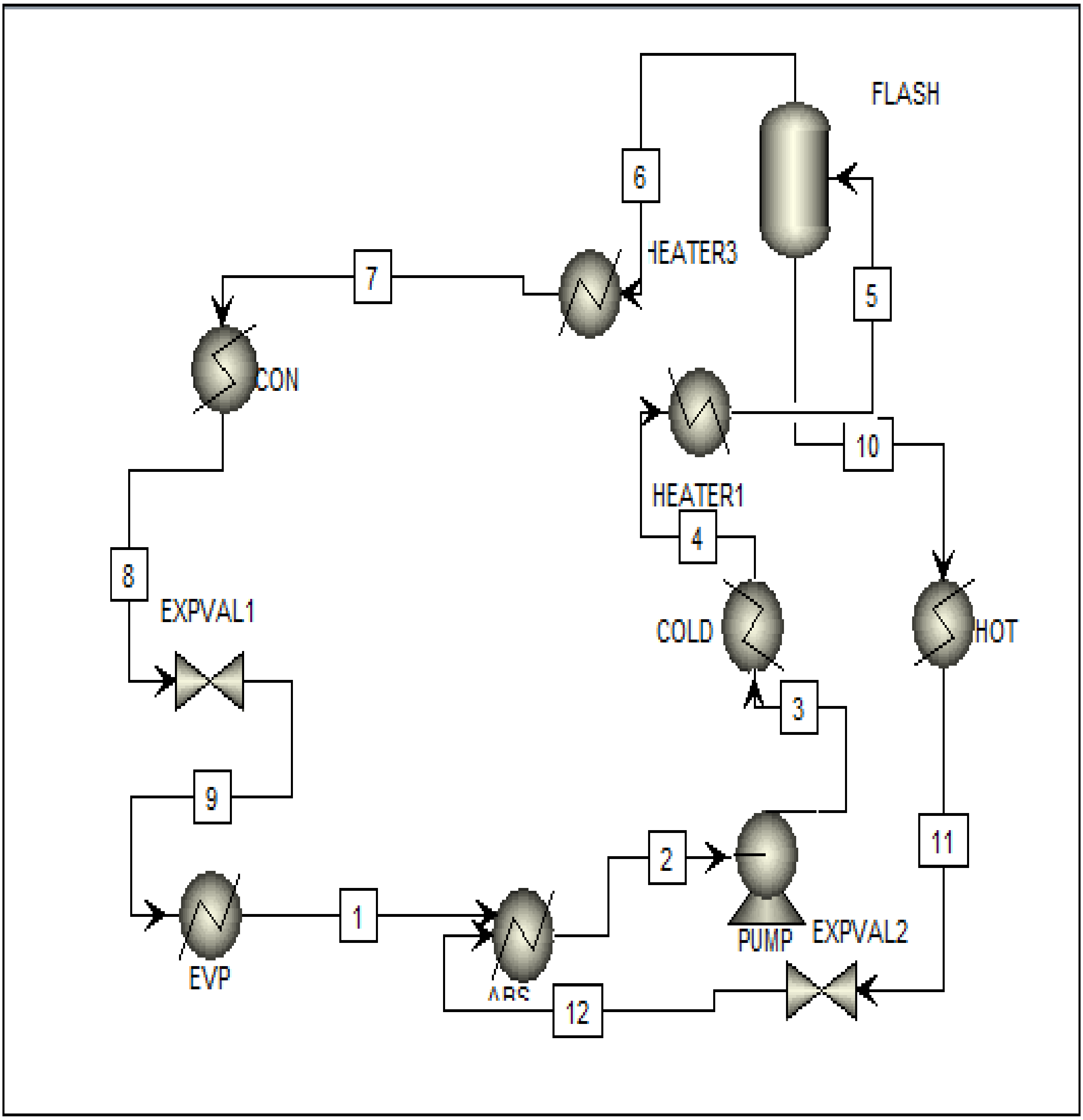


Figure 3.4 Aspen flow-sheet

3.5 Modelling in Aspen Plus

As alluded to in the introduction, modelling Aspen plus is based in taking the process and breaking down into more simple components, also known as blocks.

i) State Point 1

State point 1 refers to the saturated liquid refrigerant which is given to the evaporator.

ii) Pumps

Pumps are used in the following instances, between states 2 and 2A in both models. Pumps require only one input, the exit pressure. One could also include pump efficiency, but the default value of 100% was used because of the negligible effect on the overall cycle of picking a different efficiency (the pump work is several orders of magnitude smaller than the heat duties of other components).

iii) Valves

The other pressure change devices needed to model the cycle are valves. Particularly, for the single effect cycle there is one refrigerant and one solution valve, for the double effect cycle there are two of each. The valve model is self-explanatory; one only needs to give the exit pressure or some equivalent (i.e. pressure ratio).

iv) Solution heat exchangers

A solution heat exchanger (SHX) is used once in the single effect cycle. Heat is transferred from state 4 which is the hot side inlet to state 2 which is the cold side inlet, resulting in states 5 which is the hot side exit and 3 which is the cold side exit. This was modelled using two heater blocks, connected with a heat stream to shows that the heat rejected on the hot side was to be added to the cold side. The effectiveness of the SHX can be calculated as shown in this equation as per Figure 3.4.

$$E = \frac{T_{11} - T_{10}}{T_{11} - T_3}$$

v) Condensers

The condensers were modelled as heater blocks. Assuming no pressure drop, the only input mandatory is to specify a vapour quality of 0 at the exit. Since the refrigerant is pure water, the property method for this component, as well as any refrigerant components, should be changed to steam NBS for improved results. Modelling the condensers using the heater block model introduces new assumptions, that heat is being added at constant temperature.

vi) Evaporators

Modelling the evaporators was very similar to modelling the condensers. The evaporator was modelled as a heater block using the steamNBS property method. The inputs to the model system were zero pressure drop and with a vapour quality of 1 at the exit.

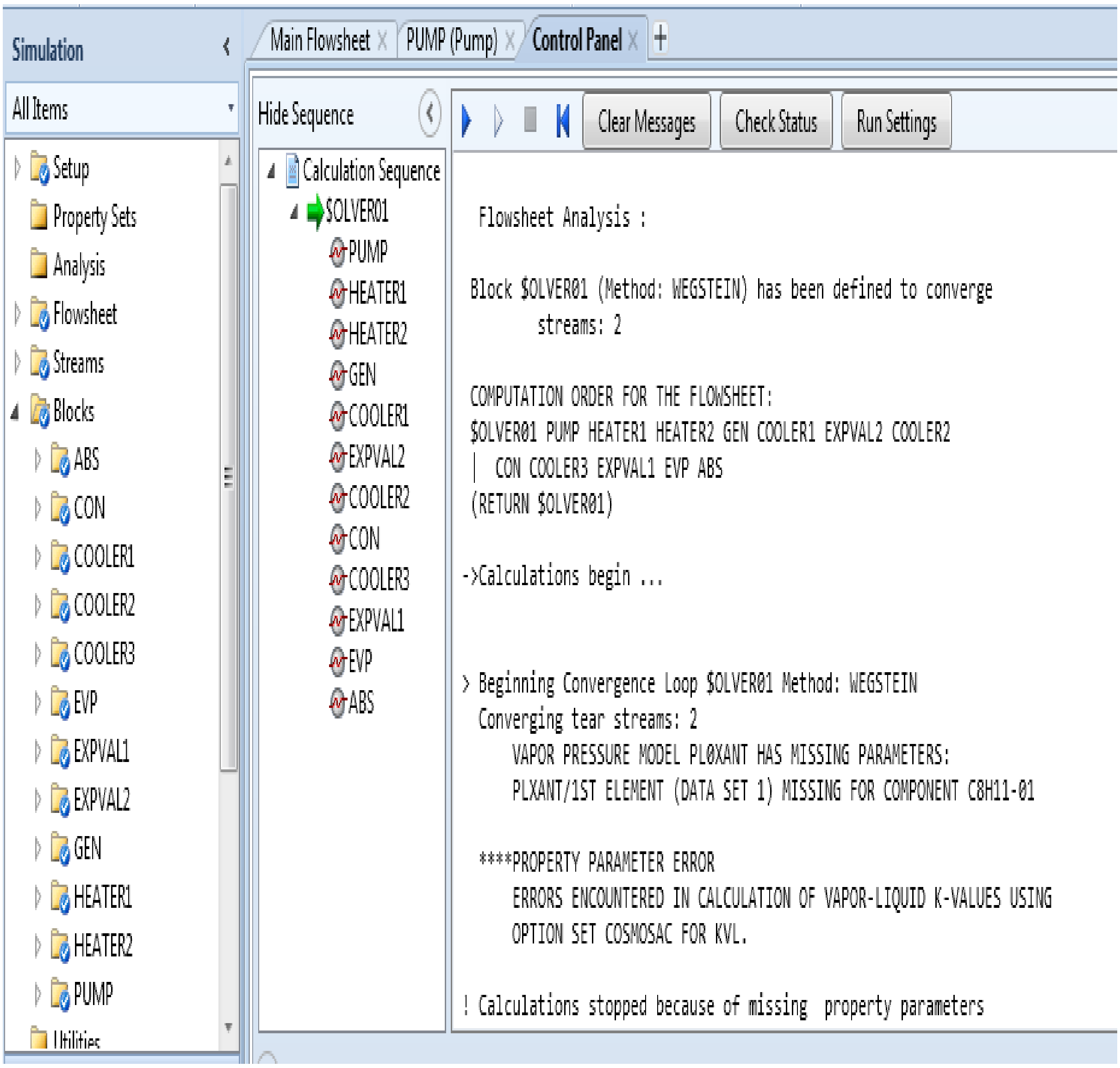
vii) Absorbers

The absorber is modelled as a heater block with two inputs, the exit of the evaporator and the exit of the solution valve. The inputs are zero pressure drop and zero vapour quality. The absorber model is used once in the single and double effect cycles. The problem about using a heater in the model rather than a heat exchanger applies for the absorber model as well.

viii) Generator:

Desorber or generator is modelled by using a flash block which separates the vapour from the liquid. Along with the flash block a heater block is used to provide the heat needed for generating the refrigerant, which is equivalent to the waste heat energy. Its inputs are zero pressure drop and outlet temperature (based on the temperature of the heat input to the cycle).

3.6 Error found:



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 Flowsheet Analysis :

Block $OLVER01 (Method: WEGSTEIN) has been defined to converge
        streams: 2

COMPUTATION ORDER FOR THE FLOWSHEET:
$OLVER01 PUMP HEATER1 HEATER2 GEN COOLER1 EXPVAL2 COOLER2
|   CON COOLER3 EXPVAL1 EVP ABS
(RETURN $OLVER01)

->Calculations begin ...


> Beginning Convergence Loop $OLVER01 Method: WEGSTEIN
 Converging tear streams: 2
     VAPOR PRESSURE MODEL PLXANT HAS MISSING PARAMETERS:
     PLXANT/1ST ELEMENT (DATA SET 1) MISSING FOR COMPONENT C8H11-01

 ****PROPERTY PARAMETER ERROR
     ERRORS ENCOUNTERED IN CALCULATION OF VAPOR-LIQUID K-VALUES USING
     OPTION SET COSMOSAC FOR KVL.

! Calculations stopped because of missing  property parameters
```

Figure 3.6 Error found in Aspen plus

As we have simulated the absorption refrigeration cycle in aspen plus, we have got an error while simulating the absorption process.

3.6.1. Plaxtant error:

The problem here is that Ionic liquid exists in the Aspen PLUS database but is missing the necessary PLXANT data. This has to be supplied by Aspen PLUS. Since it exists in both Aspen PLUS and OLI our routines do not attempt to provide any data. **This is really an Aspen Plus issue**.

3.6.2. Property parameter method error:

Due to unavailability of property parameters of Ionic liquids in Aspen plus and Hysys, We could not able to retrieve the result.

3.7 Manual simulation

As you have already seen that our simulation did not run due to severe issue with Aspen Plus, we switched over to the tedious manual simulation. In manual simulation we calculated the value of COP for the system and then we changed the state conditions to optimize the value of COP.

Reference Condition
Ionic liquid: EMIM [OTF]
Refrigerant: H_2O

$T_a = 10$ ˚C, $T_g = 105$ ˚C, $T_c = 50$ ˚C, $T_e = 5$ ˚C

Table 3.1 COP calculation table for $T_a = 10$˚C.

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
$P_e = 0.87$ kPa	$P_a = 0.87$ kPa	$P_g = 12.34$ kPa	$P_c = 12.34$ kPa		
$T_e = 5$ ˚C	$T_a = 10$ ˚C	$T_g = 105$ ˚C	$T_c = 50$ ˚C	6.55	0.82
$Q_e = 351.7$ kW	$Q_a = 407.73$ kW	$Q_g = 426.127$ kW	$Q_c = 370.097$ kW		
	$X_a = 0.839$	$X_g = 0.989$			

Table 3.2 COP calculation for T_a = 25 ˚C.

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 0.87 kPa	P_a = 0.87 kPa	P_g = 12.34 kPa	P_c= 12.34 kPa	45	0.43
T_e= 5 ˚C	T_a= 25 ˚C	T_g = 105 ˚C	T_c= 50 ˚C		
Q_e= 351.7 kW	Q_a= 770.05 kW	Q_g= 812.914 kW	Q_c= 394.56 kW		
	X_a= 0.968	X_g= 0.989			

Table 3.3 COP calculation for T_g = 120˚C.

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 0.87 kPa	P_a = 0.87 kPa	P_g = 12.34 kPa	P_c= 12.34 kPa	6.416	0.791
T_e= 5 ˚C	T_a= 10˚C	T_g = 120˚C	T_c= 50 ˚C		
Q_e= 351.7 kW	Q_a= 416.7 kW	Q_g= 444.44 kW	Q_c= 379.44 kW		
	X_a= 0.839	X_g= 0.993			

Table 3.4. COP calculation for T_g = 90 ˚C

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 0.87 kPa	P_a = 0.87 kPa	P_g = 12.34 kPa	P_c= 12.34 kPa	6.82	0.8468
T_e= 5 ˚C	T_a= 10˚C	T_g = 90˚C	T_c= 50 ˚C		
Q_e= 351.7 kW	Q_a= 389.24 kW	Q_g= 415.31 kW	Q_c= 377.77 kW		
	X_a= 0.839	X_g= 0.982			

Now, changing the evaporator temperature keeping others constant.

Table 3.5 COP calculation for T_e = 10 ˚C

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 1.22 kPa	P_a = 1.22 kPa	P_g = 12.34 kPa	P_c= 12.34 kPa	125	0.240
T_e= 10 ˚C	T_a= 40˚C	T_g = 105˚C	T_c= 50 ˚C		
Q_e= 354.31 kW	Q_a= 1524.81kW	Q_g= 1536.50 kW	Q_c= 366 kW		
	X_a= 0.982	X_g= 0.989			

T_e = 25 ˚C, and keeping other conditions while processing.

Table 3.6. COP calculation for T_e = 25 ˚C

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 3.61 kPa	P_a = 3.61 kPa	P_g = 12.34 kPa	P_c= 12.34 kPa	20.53	0.672
T_e= 25 ˚C	T_a= 40˚C	T_g = 105˚C	T_c= 50 ˚C		
Q_e= 349.24 kW	Q_a= 502.28 kW	Q_g= 519.04 kW	Q_c= 366 kW		
	X_a= 0.941	X_g= 0.989			

Table 3.7 COP calculation for T_c=40 ˚C

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 0.87 kPa	P_a = 0.87 kPa	P_g = 7.36 kPa	P_c= 7.36 kPa	6.41	0.837
T_e= 5 ˚C	T_a= 10˚C	T_g = 105˚C	T_c= 40 ˚C		
Q_e= 357.1 kW	Q_a= 399 kW	Q_g= 426.44 kW	Q_c=		
	X_a= 0.839	X_g= 0.993			

Table 3.8.COP calculations for T_c= 60 ˚C

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
P_e= 0.87 kPa	P_a = 0.87 kPa	P_g = 19.89 kPa	P_c= 19.89 kPa	6.806	0.809
T_e= 5 ˚C	T_a= 10˚C	T_g = 105˚C	T_c= 60 ˚C		
Q_e= 351.7 kW	Q_a= 462.16 kW	Q_g= 434.30 kW	Q_c= 332.54 kW		
	X_a= 0.839	X_g= 0.985			

CHAPTER 4

System Analysis and Economic Feasibility

Based on the results of the previous chapter, the following analyses have been made

4.1. System analysis

4.1.1. T_e at 5˚C, 10˚C and 25 ˚C

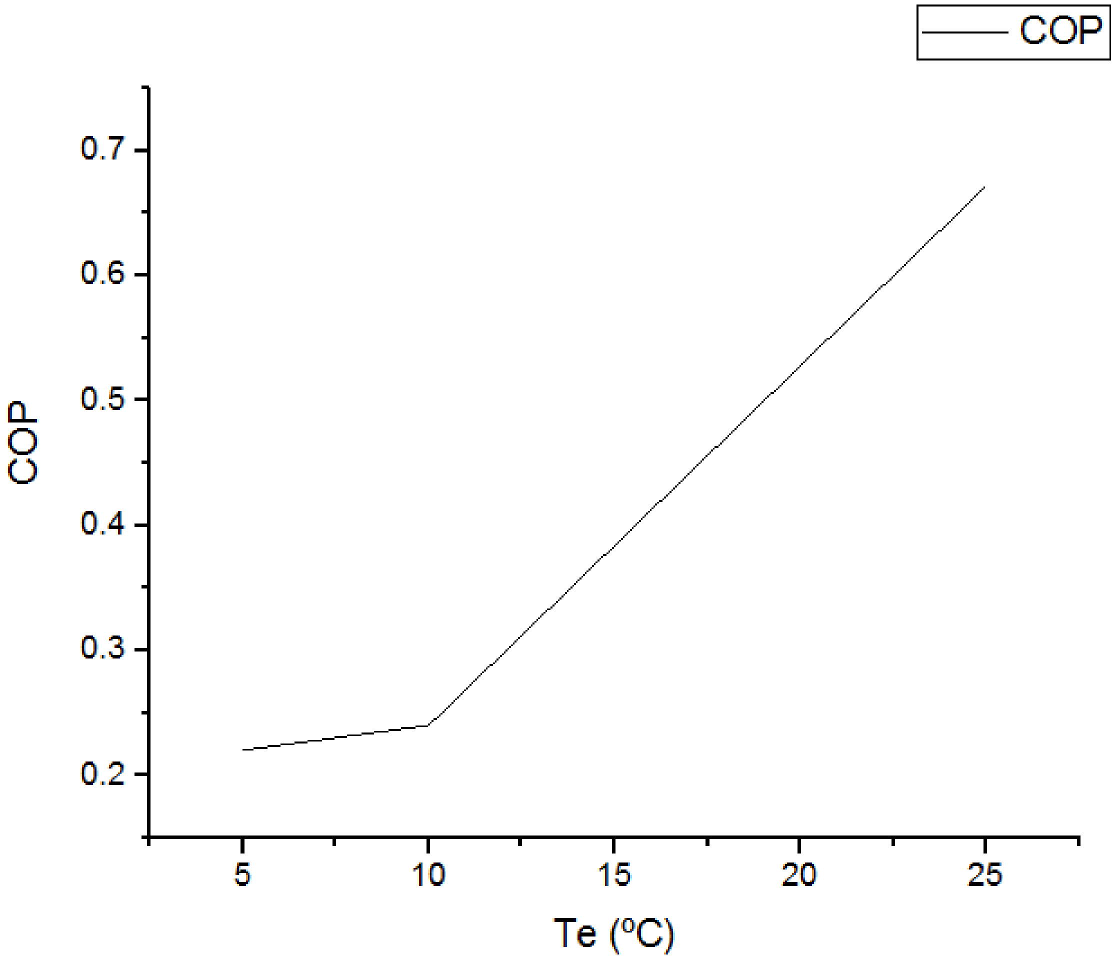

Figure 4.1 Variation of COP with T_e

Details: With increase in evaporator temperature, there is linear rise in the value of a COP (Coefficient of performance)

4.1.2. T_a at 10 °C, 25 °C and 40 °C.

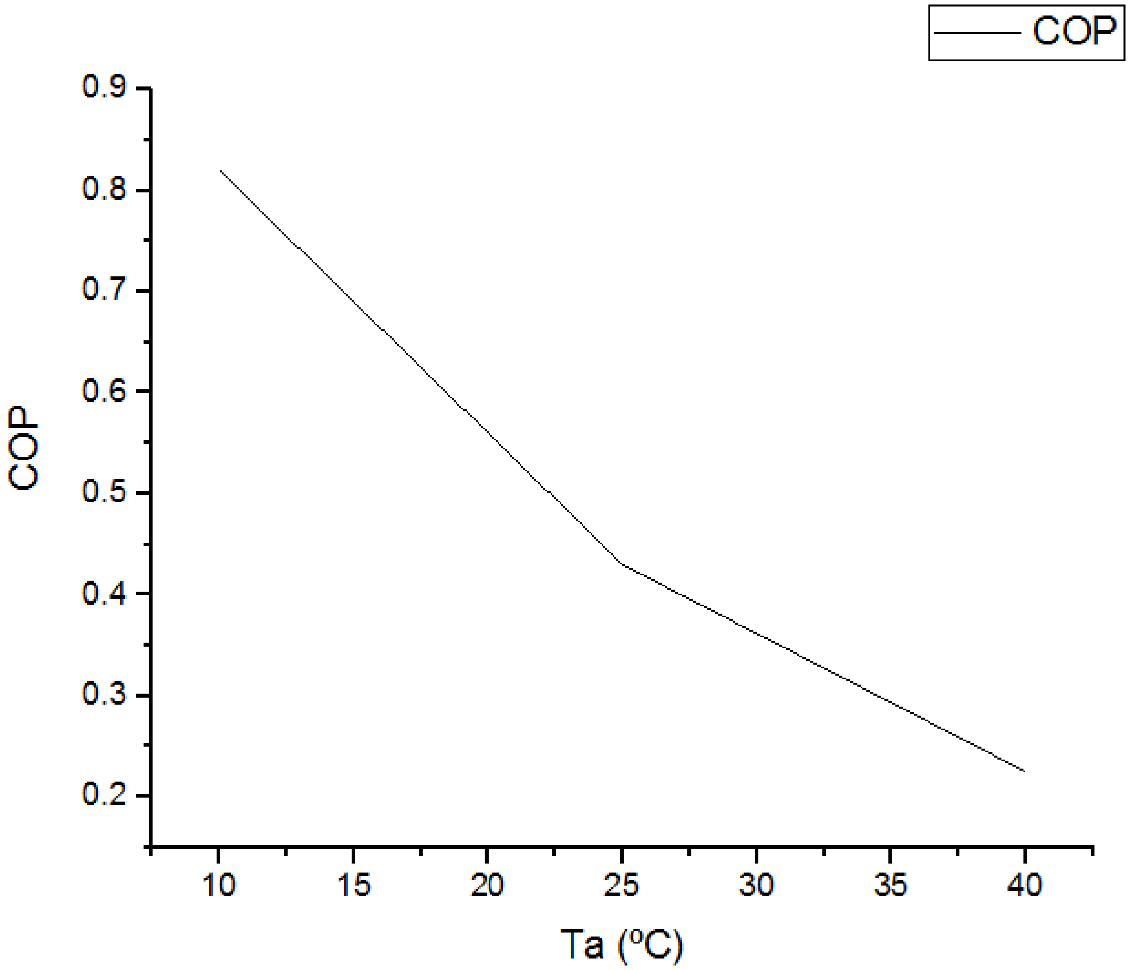

Figure 4.2 Variation of COP with T_a

Details: With increase in Absorber temperature in the system, there is a subsequent rise in the value of COP (Coefficient of performance)

4.1.3. T_g at 75 °C, 90 °C, 105 °C and 120 °C.

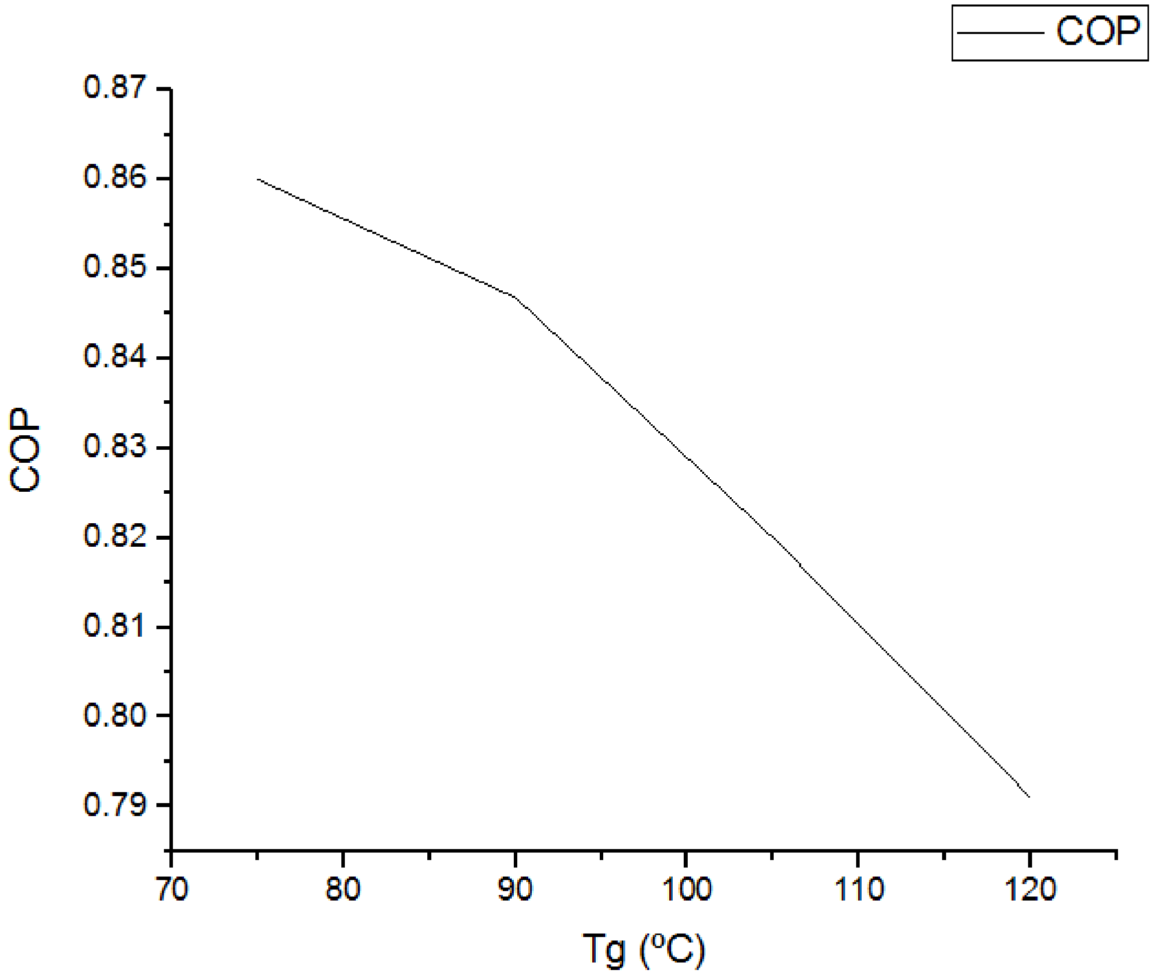

Figure 4.3 Variation of COP with T_g

Details: As obtained from the graph, the COP value decreases with increase of Temperature in Generator.

4.1.4. T_c at 40 ˚C, 50 ˚C and 60 ˚C.

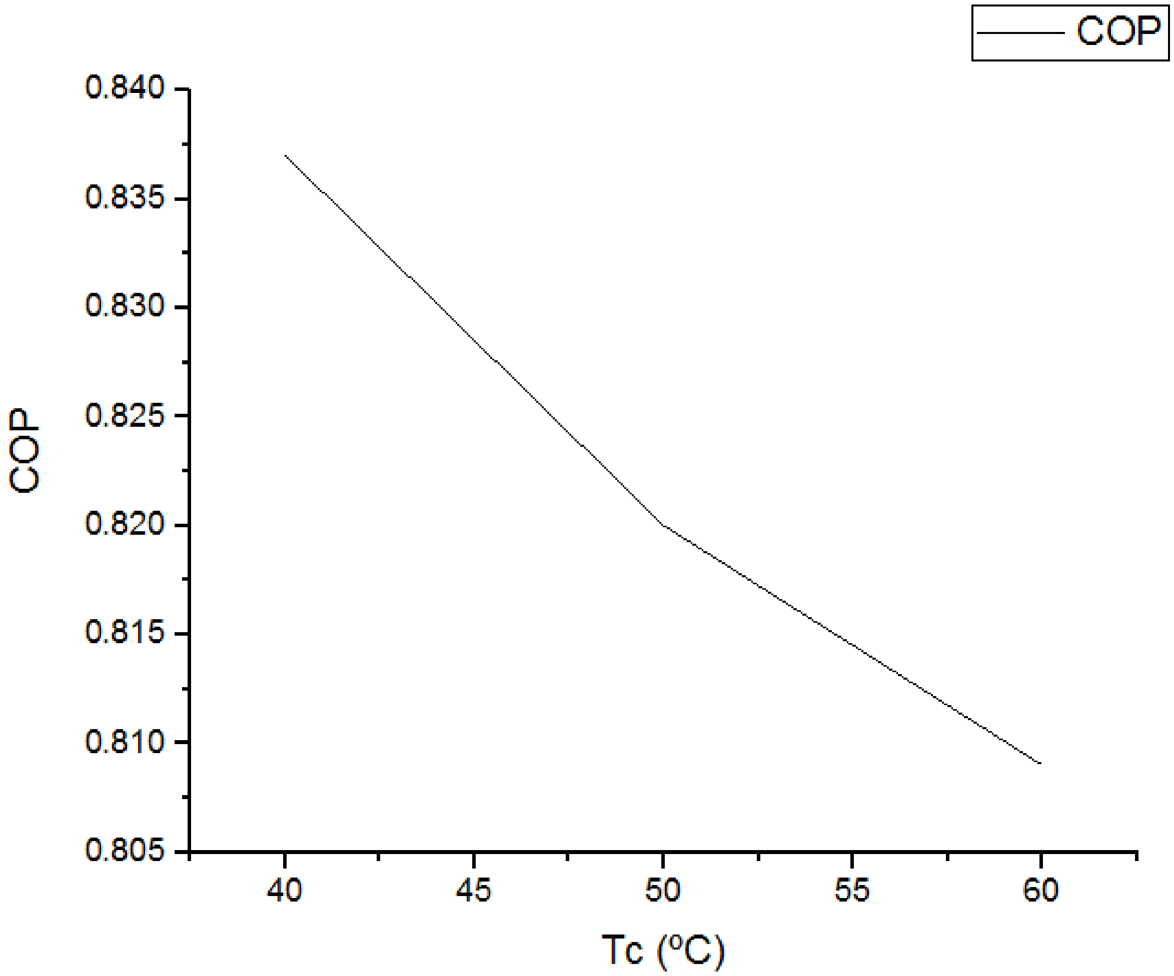

Figure 4.4 Variation of COP with T_c .

Details: The value of COP decreases with increase in Temperature of Condenser.

4.2 Cost estimation

Ionic liquid: EMIM [OTF].

Basis: Let a plant works for 8 hrs a day for about 300 days a year.

In general electricity consumption unit:

Table 4.1. Electricity Tariff

ELECTRICITY CONSUMPTION IN kWhr	COST PER UNIT IN INR
0 – 100	5.10
101 – 300	6.20
>301	6.90

Total fixed of the 1.5 tonne absorption refrigeration system using EMIM [OTF]
= 3, 25, 000 rupees

Let the estimated life time of the system → 10 years

Then annual fixed cost of the system → 32,500 Rupees

Operating cost of the equipment:

Heat duty of the evaporator → 5.27 kW

Heat duty of evaporator per year → 12661.2 kWh

Heat duty of absorber per year → 14678.28 kWh

Heat duty of generator per year → 15336 kWh

Heat duty of condenser per year → 13320 kWh

Heat duty of pump per year → negligible

Net heat duty required per year=Heat duty of (evaporator + generator + pump) = 27,977kWh

From above heat duty calculation, $Q_a + Q_c = Q_g + Q_e + W_p = 27,977$ kWh.

- ✓ If we possess 27,977 kWh of thermal energy as a low grade energy at 105^0C per year it will operate an absorption refrigeration system having 1.5 ton of refrigeration capacity on the basis of 8 hours per day for 300 days in a year.
- ✓ Moreover, in this process still lower grade energy of 14678.28 kWh at 10^0 C in the absorber and 13320 kWh at 50^0 C in the condenser will be created.

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4.2.1. Comparison with vapour compression refrigerator:

Total fixed of the 1.5 tonne vapour compression refrigeration system → 40,000rupees.

Its lifetime is approximately 1-4 years for industrial purpose.

Hence, annual fixed cost = 20,000 rupees

Heat duty of 1.5 tonne vapour compression refrigeration = 1.2 kW

For 8 hour of heat duty, Heat duty annually = 2880 kW

Total cost for the compression refrigeration cycle = 19872 rupees

Total cost = fixed cost + operating cost = 39,872 rupees.

Total fixed of the 1.5 tonne absorption refrigeration system using EMIM [OTF] → 3, 25,000 rupees.

The heat duty of the generator is greater than the heat duty of the absorber. So, the above refrigeration system does not need any extra heat energy.

Hence,

Total annual cost = fixed cost + pump cost

= 32500 + negligible

= 32500 rupees.

(EMIM [OTF] + H_2O) working pair incurred a profit of **7,372 rupees** than that of regular vapour compression system.

CHAPTER 5

Conclusions and Future Scope

This chapter summarizes the major conclusions from this research work and presents some much needed suggestions for future work

5.1. Conclusions

- After manually simulating the refrigeration systems, we got COP of 0.82 using the system of EMIM [OTF] + H_2O.The obtained value of COP using ionic liquids is much higher than that of conventional liquids.

- The annual capital cost of the absorption refrigeration cycle using H_2O + [EMIM][TFA] is coming out to be Rs 32500 and hence, it makes a profit of Rs 7,372 per year with reference to the vapour compression cycle.

- The H_2O + [EMIM] [TFA] system of 1.5 ton refrigeration capacity is utilizing 27,138 kWh of low grade energy at 105ºC and releases the same amount of low grade energy. This system not only helps in reducing the average global temperature but also reduces the use of fossil fuels and CO_2 emissions.

- Ionic Liquids have many favourable properties which make them attractive in number of applications. Ionic liquids like EMIM [OTF] have a very low vapour pressure under normal operating conditions and have a high working temperature condition.

- Here, these novel compounds were investigated to improve the current process: absorption refrigeration. An extensive thermodynamic evaluation of Ionic liquids and water systems was performed in order to calculate the coefficient of performance, design and estimate the cost of operation of the plant. Experimental measurements of COP and heat duty were measured manually.

- For large quantity of electrical energy, a large amount of fossil fuels have to be burnt and thus, it will lead to more CO_2 emissions. Secondly, the working pairs used are toxic and corrosive in nature and also a leading cause which depletes the ozone layer. These factors raise more concern for environmental and energy issues and with fast economic growth, human beings have to face more and more serious environmental and energy issues. So, we landed on a better solution with ionic liquid as working pair.

- Major conclusion regarding the influence of evaporator, generator, absorber and condenser temperature on the value of COP were drawn. It was shown that the (water+ [EMIM [OTF]) systems have a higher coefficient of performance than that the current technology. (Water +LiBr), and the coefficient of performance increases with increasing excess enthalpy

- As we have tried to simulate the ionic liquid in Aspen plus and Aspen hysys, we remained unsuccessful. Then, we tried to analysis the system manually and carried out the manual simulation to obtain the results for the working pair as ([EMIM] OTF).

5.2. Future scope

Further research using IL+water as working pair is recommended for absorption refrigeration system, which includes,

1) Generation of thermophysical data is extensively needed for the development of such kind of application.
2) Rigorous design and economic analysis for IL+water based absorption refrigeration system is required.

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