Predicting the Performance of Chemical Heat Pump with Various Metallic-Salts Drying System

A. S. HUSSEIN[1], M. IBRAHIM[1], AZAMI ZAHARIM[2] AND K. SOPIAN[3]
[1]Solar Energy Research Institute,
[2]Head for Renewable Energy Resources and Social Impact Research Group
Solar Energy Research Institute, and
Head Centre for Engineering Education Research
Faculty of Engineering and Built Environment,
[3]Director of Solar Energy Research Institute,
Universiti Kebangsaan Malaysia
43600, Bangi, Selangor
MALAYSIA
Ahmed_i1974@yahoo.com, Mustafa@vlsi.eng.ukm.my, azaminelli@gmail.com

Abstract: - This paper presents the performance prediction of chemical heat pump for various metallic- salts for drying purpose. A simulation has been developed to simulate the effect of various operating conditions on the performance of the chemical heat pump. Three types of metallic salts ($CaCl_2$, $SrCl_2$, *and* $MnCl_2$) have been studied as a working pairs of chemical heat pump. The performance of these three types against various generator, evaporator and condenser temperatures is compared. The results showed that $CaCl_2$ is better performance than $SrCl_2$ and $MnCl_2$. increasing condenser temperatures cause a decrease in chemical heat pump performance for each type while the performance of chemical heat pump increase with increasing evaporator temperatures for each types. The energy density also has been studied for the three types which the result show that $CaCl_2$ is higher than $SrCl_2$ and $MnCl_2$ Considering that the 25 KW is acceptable of power for drying system.

Keywords: - ($CaCl_2$, $SrCl_2$, $MnCl_2$,) – NH_3 chemical heat pump, energy density, coefficient of performance, drying.

1 Introduction

Chemical Heat Pump (CHP) are those systems that utilize the reversible chemical reaction to change the temperature level of the thermal energy which stored by chemical substances. These chemical substances play an important role in absorbing and releasing heat. The advantages of thermochemical energy storage, such as high storage capacity, long term storage of both reactants and products lower of heat loss, suggests that CHP could be an option for energy upgrading of low temperature heat as well as storage. A chemical heat pump (CHP) is proposed as one of the potentially significant technologies for effective energy utilization in drying. The CHP can store thermal energy such as the waste heat from dryer exhaust, solar energy, geothermal energy, etc. in the form of chemical energy, and release the energy at various temperature levels during the heat-demand period [1]. Benefits of chemical thermal energy storage are higher energy density compared with physical change - Compact storage, Long-term storage as reactants with small thermal loss, and Operation temperatures of storage and output are variable by choice of reaction conditions [2].The importance of chemical heat pump has increased due to the research on the development of a heat exchange system besides utilization of waste heat released from many industries [3]. Moreover, Chemical adsorption or chemisorption, a kind of reversible gas–solid reaction, is widely used in CHPs; it depends on many factors such as the thermophysical properties of the reacting bed, operating pressure, and temperature. [4]. This paper presents the study of energy density and performance of chemical heat pump for various metallic salts- ammonia for drying purpose.

2 System Description

The schematic diagram of chemical heat pump is shown in figure 1. The CHP consists of four components a cylindrical reactor, evaporator, absorber, and condenser. In this study three pairs of salts were selected. In the solid-gas chemical heat pump a reactor coupled with a condenser or an evaporator. The reactor is shell-and-tube type include finned tubes. The salt is located between the fins of the heat exchanger. The salt has a uniform axial temperature distribution for all the reactions. The reactor and the evaporator/condenser are vacuumed to the appropriate pressures.

The joint valve connecting the reactor and the evaporator/condenser is opened for the absorption reaction or as a heat-releasing step. A set of condenser and evaporator to provide or absorb gas reacting with salt, which has been oversized to maintain the system at relatively constant pressure [5]. In the condenser component the inlet air enter at low temperature and exit in high temperature due to heat exchange with ammonia gas, the hot air which is exit from condenser is used for drying process (6). The absorber receives a low pressure of ammonia in mixture state (it comes from evaporator) so as to pump to the reactor as a strong solution at high pressure.

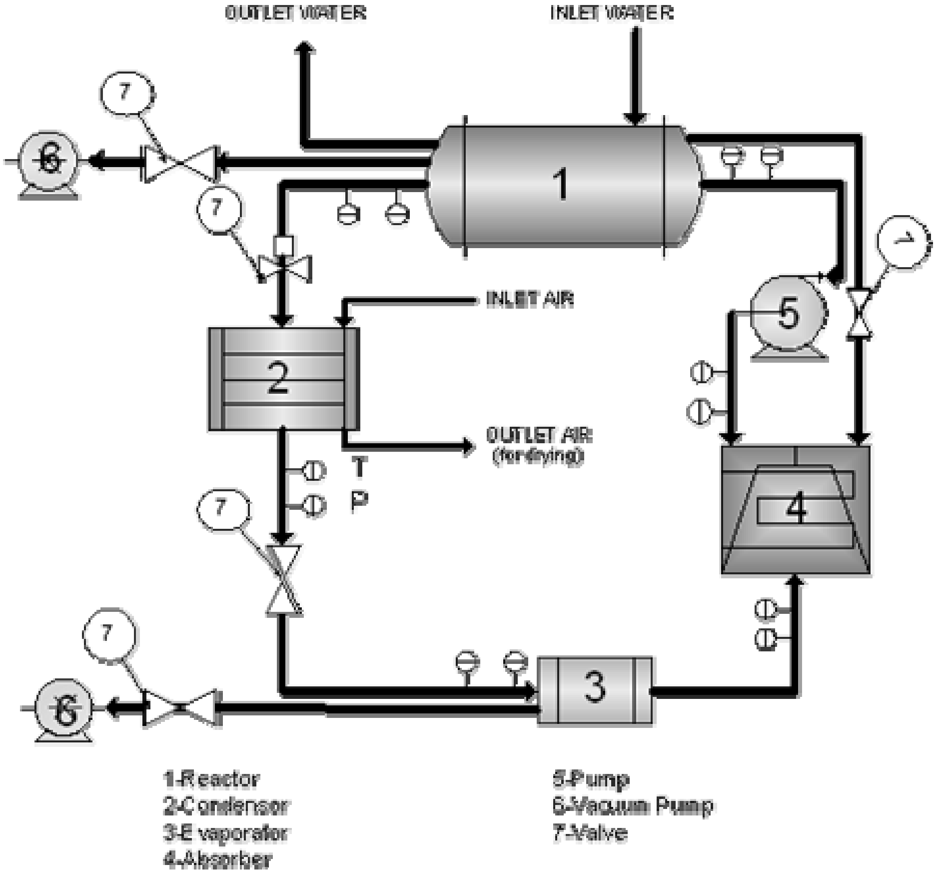

Fig. 1. The schematic diagram of the chemical heat pump system.

3 Methodology

In the solid-gas chemical heat pump, the reactor contains a salt which reacts with the gas. The ammonia-metal chloride systems are considered to be monovariant, only one variable (temperature or pressure) is normally specified to define the equilibrium state of the system. The overall reaction can be expressed as,

$$S.\ p\ G + q\ G \leftrightarrow S\ (p + q)\ G + q\ \Delta H_r \qquad (1)$$

Where S is metallic salt and G ammonia gas, the ΔH_r representing the Enthalpy change of reaction per mole of ammonia gas, and the *q* represents change in stoichiometric coefficient of the metallic salt, it has range from 1 to 8 [7].The operation of the chemical heat pump used in this work is based on the variables chemical reactions between the ammonia and the following salts:

$$CaCl_2.2NH_3 + 6NH_3 \rightleftarrows CaCl_2.8NH_3 + 6\Delta Hr \qquad (2)$$

$$SrCl_2.NH_3 + 7NH_3 \rightleftarrows SrCl_2.8NH_3 + 7\Delta Hr \qquad (3)$$

$$MnCl_2.2NH_3 + 4NH_3 \rightleftarrows MnCl_2.6NH_3 + 4\Delta Hr \qquad (4)$$

The two main criteria of performance of the thermochemical process are the energy density of the reactor (i.e. the quantity of stored energy relative to the volume of the reactor) De_R and the cooling or heating power ($Q_{e,c}$) which the evaporator or the condenser can deliver. The relationship between $Q_{e,c}$ and reaction power (Q_r) can be calculated by:

$$Q_{e,c} = \frac{\Delta h_g}{\Delta h_r} . Q_r \tag{5}$$

Where Δh_g is the enthalpy of gas phase. The energy density for the reactor De_R can be conducted as:

$$De_R = Q_r / V_R \tag{6}$$

Where the V_R is the volume of the reactor and Q_r is the heat storage capacity for CHP only for the latent heat of the reaction and neglect sensible heats of the reagents, and for ($CaCl_2/NH_3$) is 36 kWh [8], ($SrCl_2/NH_3$) is 38 kWh [4], and ($MnCl_2/NH_3$) is 44 kWh [9]. For a given energy density of the reaction or reactive composite (De_r), can be express as:

$$De_r = De_R . \left(\frac{V_R}{V_{\Sigma M}}\right) . \left(1 + \frac{Z_e + 2Z_d}{2Z_r}\right) \tag{7}$$

The thicknesses of the exchanger plates and the diffusers in this study are shown in figure 2 and the values for these thicknesses as follows:

$$Z_e = 1 \, x \, 10^{-3} \, m \qquad Z_d = 2 \, x \, 10^{-3} \, m$$
$$V_R = 0.0135 \, m^3$$

The ratio of (volume of reagent V_r/volume of reactorV_R) as high as much but remaining necessarily lower than 1), the difference (V_R-$V_{\Sigma M}$) and the thickness $Z_r$of the reactive layers are suitable to the criterion of energy densityDe_R and the criterion of power Q_r, respectively, [10].

In the chemical heat pump a solid gas-reactor, coupled with a condenser or an evaporator. The reactor contains a salt which reacts with the gas, in the chemical heat pump heat is supplied to the reactor at high temperature to regenerate ammonia which will then be condensed in the condenser at medium temperature, the heat required to evaporator at low temperature is supplied to vaporize ammonia, which reacts with salt and release heat at medium temperature. The heating performance for chemical heat pump could be defined as (6):

$$COP^h = \frac{Q_C + Q_r}{Q_r} = \frac{\Delta H_C + \Delta H_r}{\Delta H_r} \tag{8}$$

Where Q_C is the condenser hest rejection, t and ΔH_c is the enthalpy of condensing.

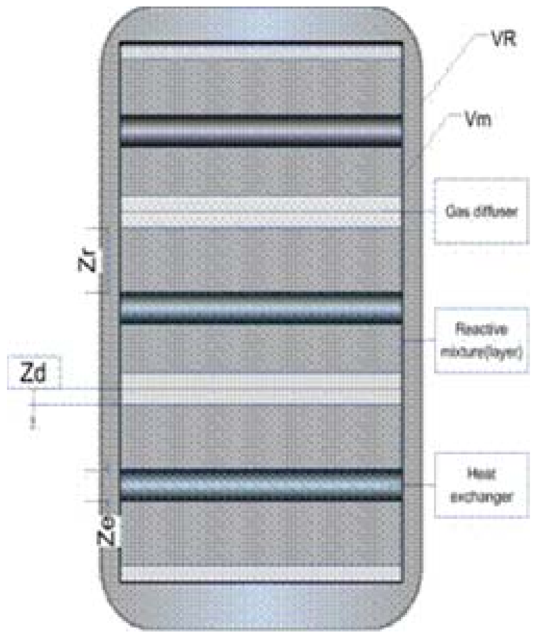

Fig. 2. Cross-section of a reactor for the thicknesses of the exchanger plates, diffusers, and the reactive mixtures.

4 Results and Observations

Figure 3 shows the heating power vs. the effect of thickness of the reactive composite (Z_r).The increasing of thickness of reactive composite (Z_r) leads to decrease in heating power for all working pairs used in this paper. The ($MnCl_2/NH_3$) has lowest Q_c , ($SrCl_2/NH_3$) in the middle, and ($CaCl_2/NH_3$) is the highest,. As a result of this study with this simulation, it seems that the lowest thickness of the reactive composite is the best solution for the maximum power (in the same volume and storage capacity of the reactor).considering the 25 KW is acceptable of power for drying system and the (Z_r) that is opposite this value for each working pair are ($CaCl_2$ is 38mm,, $SrCl_2$ is 21mm,.and $MnCl_2$ is 7mm) approximately.

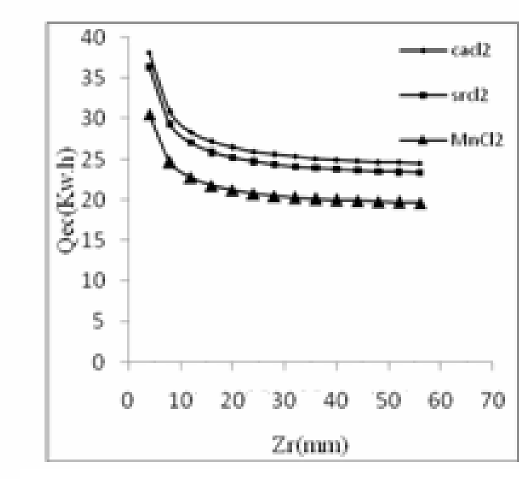

Fig.3. The effect of thickness Z_r of the reactive composite on the cooling and heating powers

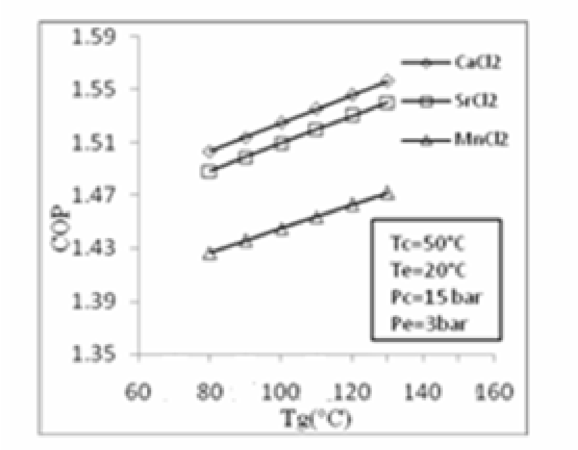

Fig.4.The effect of variation generator temperature on the COP

Figure 4 shows the COP vs. generator temperatures (*Tg)*, for variables chemical reactions cycle at *T*c=50, *T*e =20, and *Tg* vary from 80 to 130°C. The COP values for this cycle increase with generator temperatures. The COP values from higher to lower are ($CaCl_2/NH_3$), ($SrCl_2/NH_3$) and ($MnCl_2/NH_3$). Figure 5 shows the COP vs. condenser temperatures (*Tc)* at Te =20, *Tg=100,* and *T*c range is 35-60°C.The COP values for this cycle decrease with condenser temperatures increase. Figure 6 shows the COP vs. evaporator temperatures (*Te)*, at *Tg=100, T*c=50, and *T*e =15-40°c.

The COP values for all salt types increase with evaporator temperatures increase,

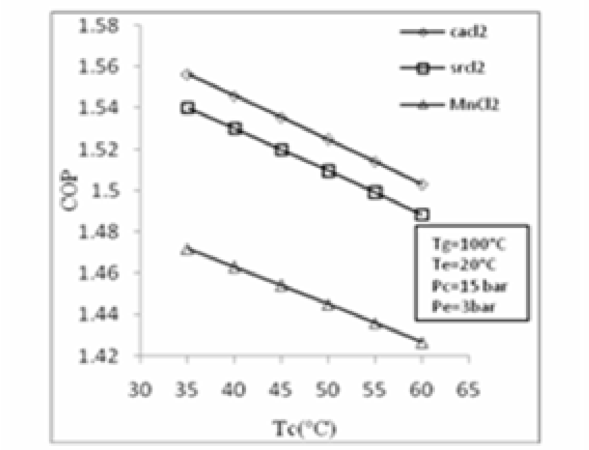

Fig.5 The effect of variation condenser temperature on the COP values.

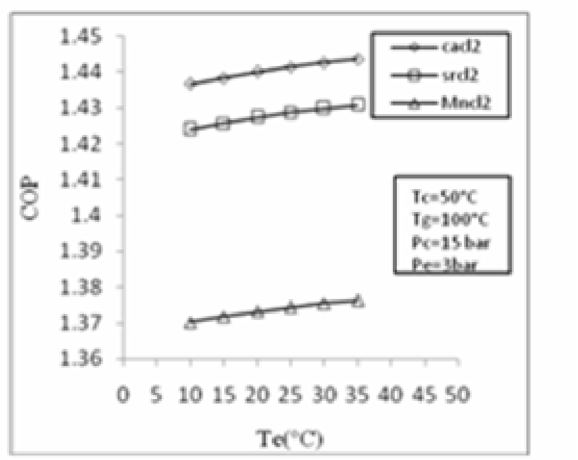

Fig.6 .The effect of variation evaporator temperature on the COP values.

5 Conclusion

This paper presents the study of the energy density and the coefficient of performance of the chemical heat pump for drying purpose. Three types of metallic salts have been discussed for this study. The results show that the best cooling and heating power depends on the effect thickness of the reactive composite(Z_r), considering that the 25 KW is acceptable of power for drying system and the (Z_r) that is opposite for this value for each working pair are ($CaCl_2$ is 38 mm, $SrCl_2$ is 21mm, and $MnCl_2$ is 7mm) approximately.

Based on the results of this study of the performance of chemical heat pump for three working pair's, the $CaCl_2$ was higher heating as compared with other working pairs, and it showed the effect increased of (Z_r) on heating power. and the ability to allow storage, with a high energy density for future heating , and the coefficient of performance COP at the same conditions apply to three chlorides was increased with Tg, Te, and decreased with Tc .

Nomenclatures

COP	coefficient of performance
De	energy density (kW h m^{-1})
Q_c	condenser heat(KJ/Kg)
Q_{ec}	cooling or heating power (kW)
Q_e	evaporator heat(KJ/Kg)
Q_r	reaction heat(KJ/Kg)
T	temperature (°C)
V	volume (m^3)
Z_d, Z_e, Z_r	thickness of gas diffuser, heat exchanger plate, reactive composite (m)

Greek letters

ΔHr	enthalpy of reaction ($Jmol^{-1}$)
Δh	variation of enthalpy ($Jmol^{-1}$)

Subscripts

C	*cooling*
ec	evaporator/condenser
g	gas phase
G	gas
h	heating
R	reactor
r	reaction or reactive composite
S	solid
Σm	total volume of the modules

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