Solar Chemical Heat Pump Drying System for Tropical Region

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Abstract: - Solar assisted chemical heat pump drying system for tropical region has been studied. A simulation has been done under the meteorological conditions of Malaysia. The system consists of four mean components, solar collector (evacuated tubes type), storage tank, chemical heat pump units and dryer chamber. The monthly efficiency for evacuated tube solar collector has been predicted to be between the range (59 – 64%) with the deference between mean collector temperature and ambient temperature 20 ºC. The solar fraction as a function of solar collector area has been studied. It was found that as the collector area increases the loss increases and hence the solar fraction increases. A monthly coefficient of performance for heating (COP^h) for chemical heat pump has been predicted and the maximum value of 1.8 as function for solar collector area 10 m^2 and storage tank size 0.2 m^3 were found. Any reduction of energy at condenser as a result of the decrease in solar radiation which in the final decrease the coefficient of performance as well as decrease the efficiency of drying.

Key-Words: - evacuated tube collector efficiency, solar fraction, collector area, chemical heat pump, coefficient of performance, drying.

1 Introduction

In recent years, considerable importance has been placed on the rational use of energy resources. The depletion of conventional energy resources and its adverse impact on environment have created renewed interest for the use of renewable energy resources. As a result, considerable research and development activities have taken place to identify reliable and economically feasible alternate clean energy sources. The choices for the alternate energy sources are: energy from sun, wave, wind and geothermal etc. Among these sources, solar energy, which is an energy source for heating and cooling applications [1-3], is a highly popular source due to the following facts: direct and easy usability, renewable and continuity, maintaining the same quality, being safe, being free, being environment friendly and not being under the monopoly of anyone Along with this, other solutions like waste energy recovery using heat pump have found significant attention in recent years. As far as the economical aspect is concerned, the importance of this heat recovery cannot be under stated, as the resulting energy efficiency is considerably high [4]. In order to reduce the energy consumption, it is necessary to select an efficient heating system, the heat pump presents an efficient and environmentally friendly technology due to its low energy consumption [5]. Heat pump dryers have been known to be energy efficient when used in conjunction with drying operations. The principal advantages of heat pump dryers energy from the ability of the heat pumps to recover energy from the exhaust gas as well as their ability to control the drying gas temperature and humidity. Heat pumps have been extensively used by industry for many years, although their application to process drying and, in particular, to drying textile products is relatively lower. The studies on HPDs can be classified in three groups. The first group includes studies in which the performance analysis of these systems has been investigated [6-11], while the second group covers studies on developing simulation models [12-16]. The investigations on the application of HPDs to drying systems for industrial use belong to the last group [17-21]. In most of these studies, food products and agricultural materials were dried in various types of HPDs. 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. CHP are those systems that utilize the reversible chemical reaction to change the temperature level of the thermal energy which stored by chemical substances [22]. These chemical substances play an important role in absorbing and releasing heat [23]. 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 [24].

Figure 1 shows the general classification of CHP. Systems involving chemical reaction and requiring only one state variable (e.g. pressure) to be specified are mono variant systems, and these induce volume changes, while those that require both the temperature and pressure to be specified are di variant systems [25]. The most critical component of CHPs is the reactor, where heat and mass transfer, chemical, adsorption and absorption occur. Many researchers have developed models to simulate the dynamic behavior of the reactor [26-31]. Stitou and Crozat [32] classified models into three categories: local, global and analytical models.

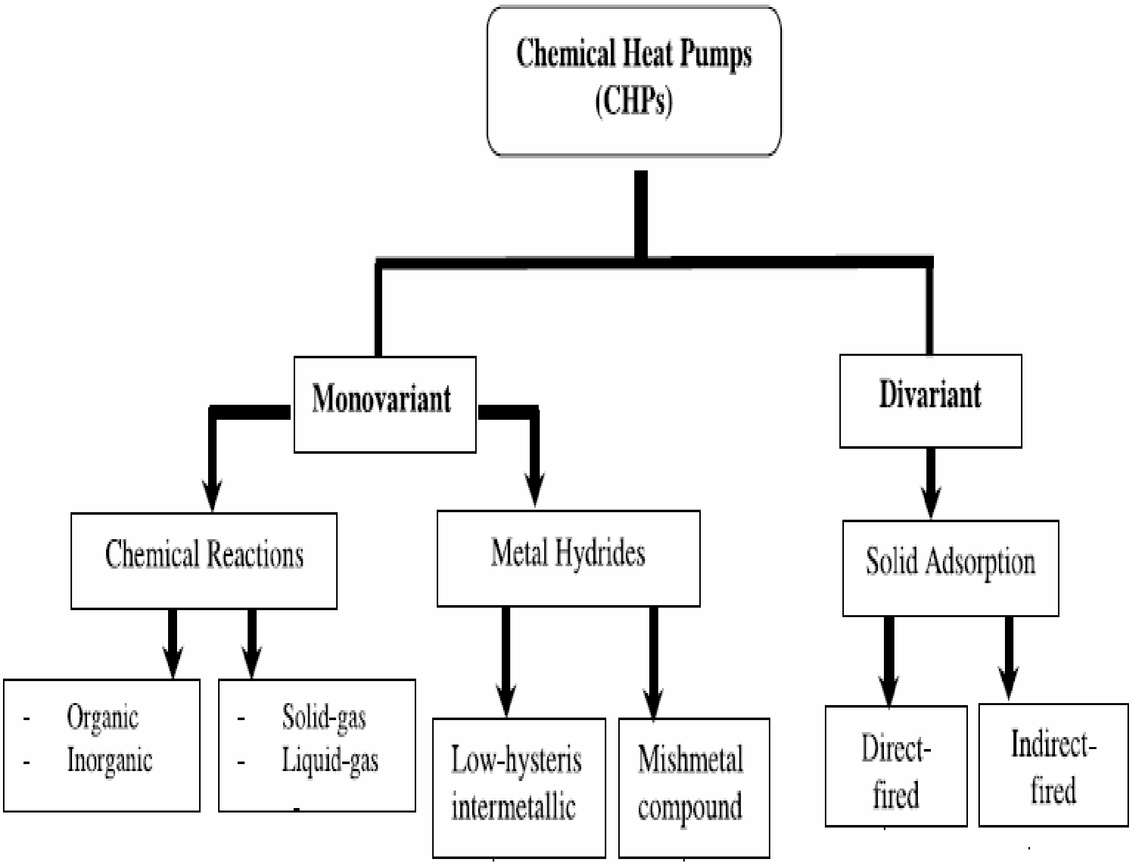

Fig. 1 Classification of CHP [25]

Ogura et. al. [33] studied the CHP and proposed a chemical heat pump dryer (CHPD) system for ecologically friendly effective utilization of thermal energy in drying. The CHPD has been discussed from the view point of coupling the CHP and direct dryer, the efficiencies of various types of CHPD systems were evaluated on the bases of energy and energy consumption [21, 34].

In this study the simulation has been conducted to predict the performance of solar assisted chemical heat pump drying system under the meteorological conditions of Malaysia

2 System Description

The schematic of the solar chemical heat pump dryer system with integrated storage tank system is shown in Figure 2. The system consists of four mean components solar collector (evacuated tubes type), storage tank, chemical heat pump unit and dryer chamber. In this study, a cylindrical tank is selected as a storage tank. The chemical heat pump unit contains of reactor, evaporator and condenser. Depending on the phase of working substance, CHP could be categorized into two types, solid-gas and liquid gas. In the solid-gas chemical heat pump a reactor coupled with a condenser or an evaporator

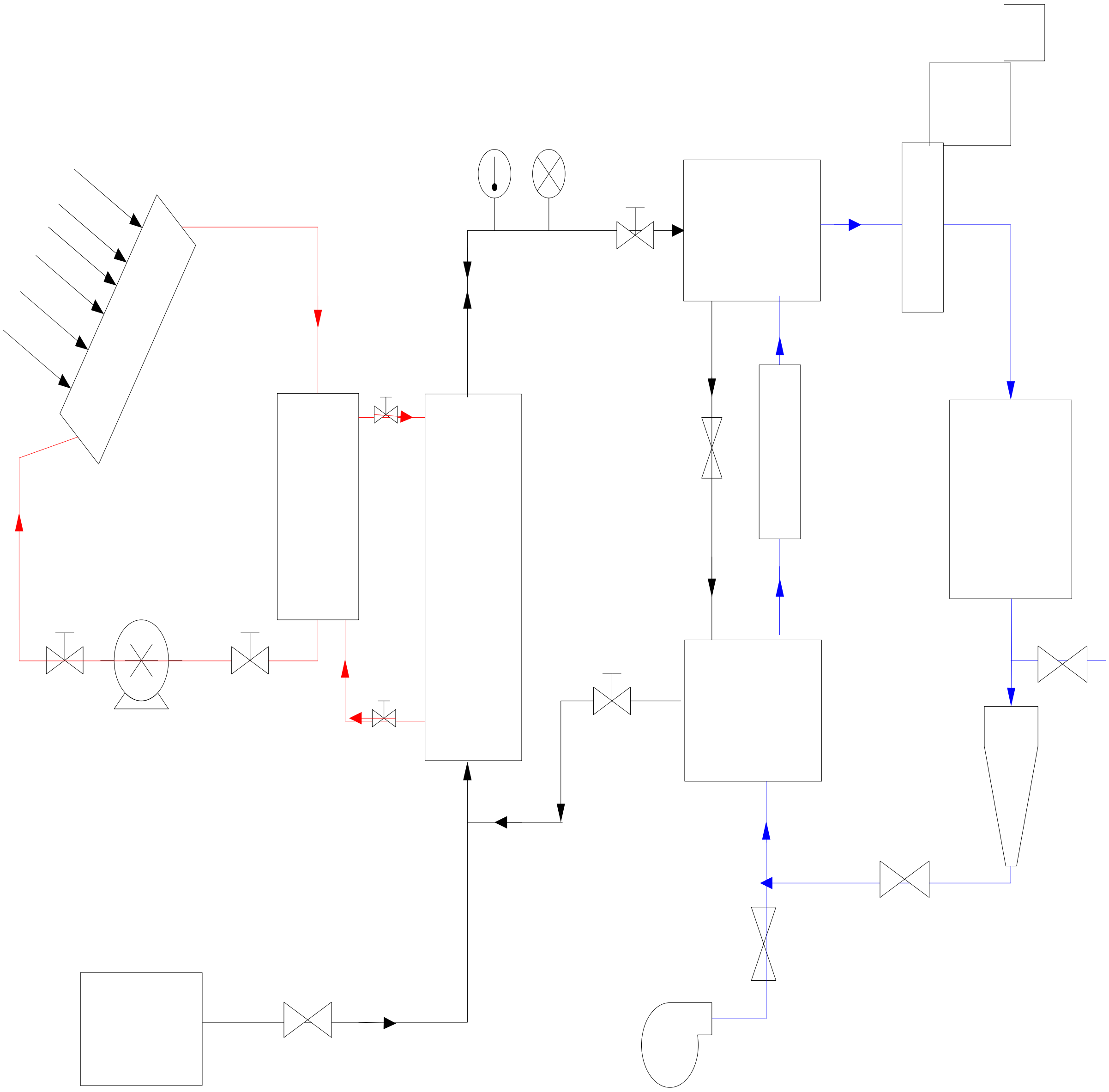

Fig.2 Schematic diagram of solar assis

while liquid-gas systems consist of at least two reactors endothermic and exothermic reactors. Besides, other components such as the condensers and, separators and heat exchanger are also usually required [35]. In the solid-gas chemical heat pump, the reactor contains a salt which reacts with the gas. The reactions used in this study is:

$$CaCl_2.2NH_3+6NH_3 \rightarrow CaCl_2.8NH_3+6\Delta H_r \qquad (1)$$

Where ΔH_r is the enthalpy of chemical reaction for chemical heat pump.

The drying chamber contains multiple trays to hold the drying material and expose it to the air flow. The general working of chemical heat pump occurs in two stages: adsorption and desorpition. The adsorption stage is the cold production stage, and this is followed by the regeneration stage, where decomposition takes place. During the production phase, the liquid-gas transformation of ammonia produces cold at low temperature in the evaporator. At the same time, chemical reaction between the gaseous ammonia and solid would release heat of reaction at higher temperature.

CHP could operate in two modes depending on the required output: “heat pump” (cold production at low temperature and heat generation at medium temperature) and “heat transform” (heat supplied at the medium temperature and heat utilization at higher temperature [25]. In the heat pump mode, in the first stage, 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 at evaporator at low temperature is supplied to vaporize ammonia which will react with chloride salt and releases heat at medium temperature. In heat transform mode, the consumption of heat is at medium temperature, while the heat rejection is at high temperature and also at low temperature.

The incoming air is heated by condensing refrigerant (ammonia) and enters the dryer inlet at the drying condition and performs drying. After the drying process, part of the moist air stream leaving the drying chamber is diverted through the evaporator, where it is cooled, and dehumidification takes place as heat is given up to the refrigerant (ammonia). The air is then passing through the condenser where it is reheated by the condensing refrigerant and then to the drying chamber.

3 Theoretical Background

The development of mathematical models for different components of the system is essential before the simulation program of the system is considered for evaluation the performance. In the solar collector the useful energy gain of collector surface area is given by the following equation [36]:

$$Q_u = \eta A_C I \qquad (2)$$

Where η is the collector efficiency, A_C is the collector area and I is the instantaneous solar radiation incident on the collector per unit area.

The collector efficiency for the evacuated tube collector is given by [37]:

$$\eta_{eva} = 0.84 - 2.02(T_m - T_a)/I - 0.0046[(T_m - T_a)/]^2 \qquad (3)$$

Where T_m is the mean collector temperature and T_a is the ambient air temperature.

In this study, a cylindrical tank is selected as a storage tank. The heat loss from the tank on ground is calculated by:

$$Q_S = (UA)_{strg}(T_{col} - T_a) \qquad (4)$$

Where Q_S is the heat loss from the storage tank, T_{col} *is* the collector temperature and $(UA)_{strg}$ is the loss coefficient of storage tank and calculated using the following equation [38]:

$$(UA)_{strg} = \frac{A_S}{\frac{k}{d}+\frac{1}{h}} + (UA)_{gnd} \qquad (5)$$

Where k and d are the thermal conductivity and thickness of insulation and h is the convective heat transfer coefficient. In this study, the conduction resistance of the tank wall is neglected because the wall thickness is very thin. A_S represents the exposed area and *(UA)* $_{gnd}$ represents heat loss through ground from the bottom of the tank and is neglected because there is no loss with the ground for this study.

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:

$$COP^h = \frac{Q_C + Q_r}{Q_r} = \frac{\Delta H_C + \Delta H_r}{\Delta H_r} \tag{6}$$

Where Q_C is the condenser hest rejection, Q_r is the reaction heat and ΔH_c is the enthalpy of condensing. And for the integrated heat pump with solar collector and storage tank the heating performance of chemical heat pump could be:

$$COP^h = \frac{Q_C + Q_r}{(Q_u - Q_S) + Q_r} \tag{7}$$

The Solar Fraction (*SF*) is defined as the utilized solar heat divided by the total heat demand and calculated from the following relationship:

$$SF = \sum [Q_u - Q_S] / Q_C \tag{8}$$

4 Results and Observations

Simulations were performed for Sepang location in Malaysia, which is at latitudes 3.1N. The data for the monthly average solar radiation on a horizontal surface and the monthly average outside air temperature of this location are shown in Figure 3.

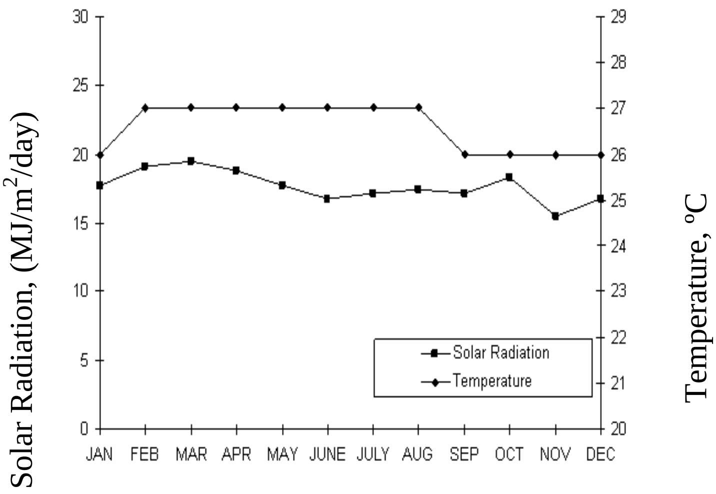

Fig. 3 Monthly weather data for Sepang

Efficiency curve for the evacuated tube collector is plotted in Fig. 4, as a function of (Tm-Ta) (°C). It can be seen that the efficiency decrease with the higher difference temperature. Figure 5 shows the monthly predicted of the efficiency of evacuated tube collector which is the maximum can get 64% as shown in the figure, and figure 6 shows the monthly predicted of useful energy with the maximum value can be getting around 1300W. Figure 7 shows the monthly predicted solar fraction as a function of solar collector area while figure 8 shows the annual solar fraction predicted curve as a function of solar collector area for different storage tank sizes. In figure 7 the monthly solar fraction increase with the collector area but at a decreasing rate. The reason for this is that the larger the collector size, will give higher losses. Moreover, the higher the collectors size the higher will be the collector inlet temperature and will decrease the collector efficiency. Figure 8 shows that the annual solar fraction increases as a result of increasing the storage tank size. Figure 9 shows predicted monthly values of coefficient of performance for chemical heat pump. As seen in the figure the maximum COP^h for chemical heat pump 1.8 as function for solar collector area 10 m^2 and storage tank size 0.2 m^3 were found. If there is a reduction in the energy available at the condenser as a result of a decrease in solar radiation as well as the decrease in latent heat contribution from the drying material as the drying progresses.

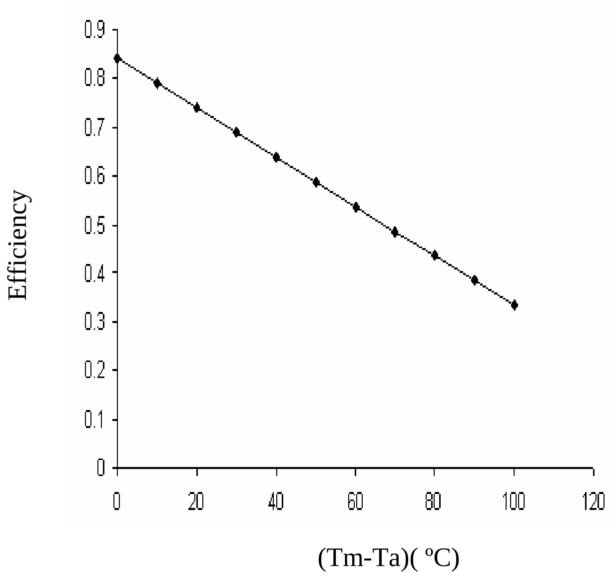

Fig. 4 Characteristics curve of vacuum tube with the temperature difference of mean collector temperature and ambient temperature

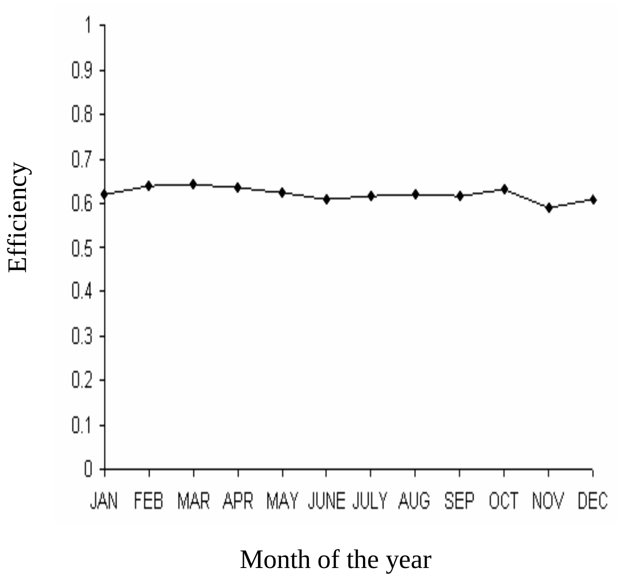

Fig. 5 Monthly efficiency predicted curve of evacuated tube

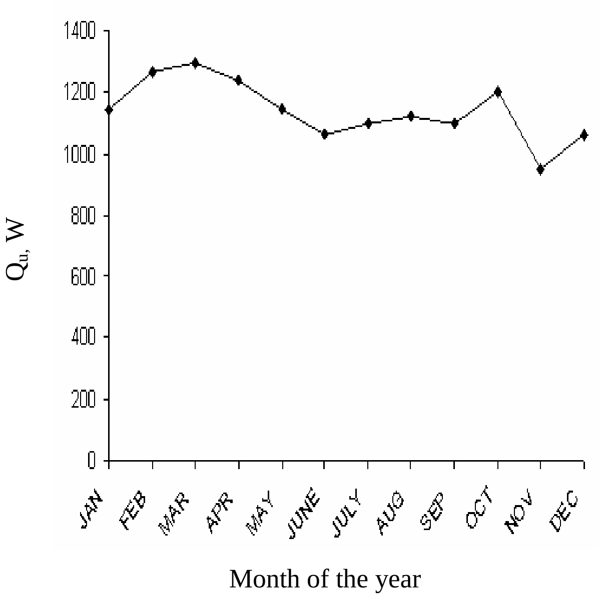

Fig. 6 Monthly useful energy predicted curve

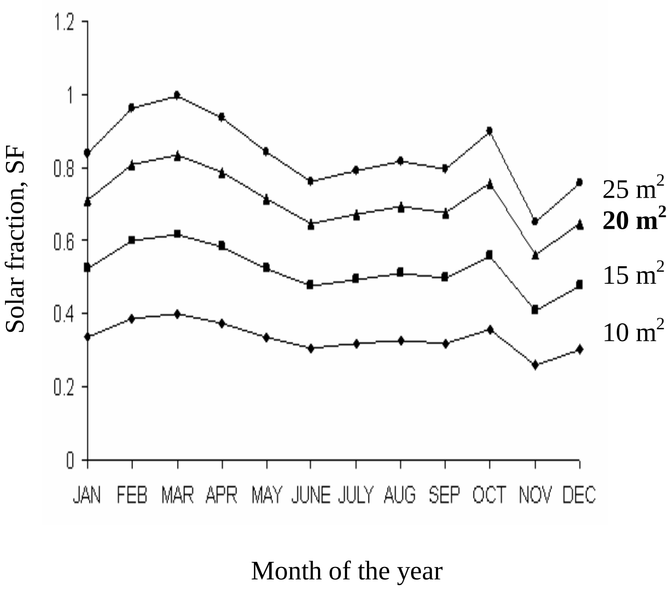

Fig. 7 Monthly solar fraction predicted curve as function of solar collector area

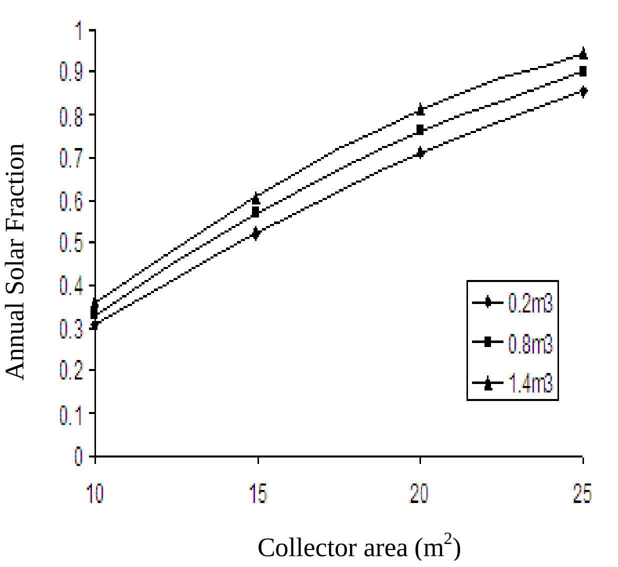

Fig. 8 Annual solar fraction predicted curve as function of solar collector area

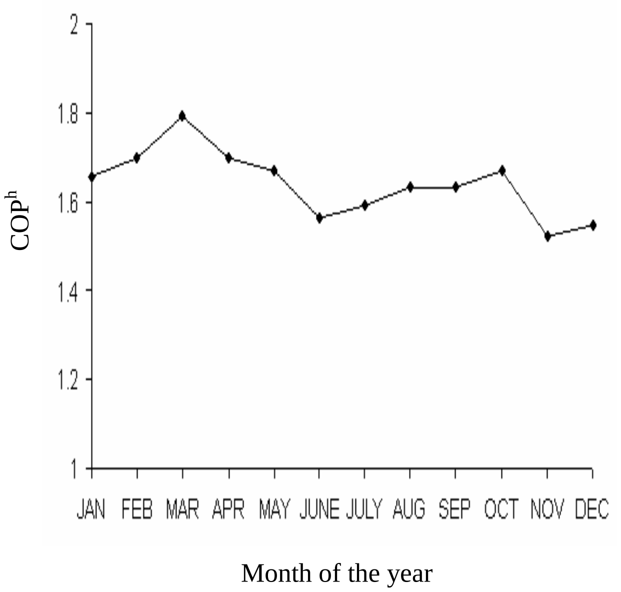

Fig. 9 Monthly coefficient of Performance predicted curve for a collector of 10 m^2 area and storage tank size of 0.2 m^3

5 Conclusion

A simulation has been developed to predict the performance of solar assisted chemical heat pump under the meteorological Malaysia condition. Values of the COP^h and SF of the system as high as 1.8 and 0.4 as function for solar collector area 10 m^2 and storage tank size 0.2 m^3 respectively. Efficiency of 64% was predicted for evacuated tubes collector. The results show that any reduction of energy at condenser as a result of a decrease in solar radiation which in the final decrease the coefficient of performance as well as decrease the efficiency of drying.

Nomenclature

ΔH_r	enthalpy of chemical reaction (J/mol)
Q_u	useful energy gain of collector (W)
η	collector efficiency
Ac	collector area (m^2)
I	solar radiation (MJ/m^2)
η_{eva}	evacuated tube collector efficiency
Tm	mean collector temperature (K)
Ta	ambient air temperature (K)
Qs	storage tank heat loss (J)
$(UA)_{str}$	storage tank loss coefficient (W/K)
$Tcol$	collector temperature (K)
K	thermal conductivity (W/m.K)
d	thickness of insulation (m)
h	convective heat transfer coefficient ($W/m^2.K$)
As	exposed area of storage tank (m^2)
$(UA)_{gnd}$	heat loss from the bottom of storage tank (W/K)
COP^h	coefficient of performance of chemical heat pump
Qc	condenser heat rejection (J)
Qr	reaction heat (J)
ΔHc	enthalpy of condensing (J/mol)
SF	solar fraction

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