System Science: A Case Study of Solar Drying System

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Abstract: System science is an interdisciplinary field of science that studies the nature of complex systems in nature, society and science. The aim of this study is to present a case study on the experimental performance of solar pump dryer. The results for typical sunny day were presented. The drying curves are formed by the measurement of the material moisture content as a function of time under constant drying air conditions. The temperature 55^{o}c and two air drying speed (1m/s, and 3m/s) has been investigated. The weight was recorded on personal computer at 5 minutes intervals, and about 65g of fresh lemongrass was used in each run. The lemongrass was dried from average initial moisture content of 85% wb to an average final moisture content of 13% wb. The maximum value of solar fraction of 0.713 and the maximum value of coefficient of performance of chemical heat pump (cop^{h}) of 2 were obtained from experiment at sunny day. The total system energy output from the experiment at sunny day was 51 kwh. The results show that any reduction of energy at condenser as a result of a decrease in solar radiation will decrease the coefficient of performance as well as decrease the efficiency of drying.

Keywords:- system science, heat pump, drying curves, solar

1 Introduction

Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment [1]. 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. Neslihan and Arif [2] classified the HPD application under three main topics, air source heat-pump drying systems, ground source heat-pump drying systems, and chemical heat-pump drying systems.

A chemical heat pump (CHP) is proposed as one of the potentially significant technologies for effective energy utilization in drying. Ogura et. al. [3] 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 consumption [4-5]. CHPs are those systems that utilize the reversible chemical reaction to change the temperature level of the thermal energy which stored by chemical substances [6]. These chemical substances play an important role in absorbing and releasing heat [7]. 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 [8].

The aim of this paper to evaluate the system performance and to investigate the drying characteristics of lemongrass in a solar assisted chemical heat pump dryer under Malaysian climatic conditions for typical sunny day. Lemongrass is widely used as an herb in Asian (particularly Khmer, Thai, Lao, Sri Lankan, and Vietnamese) and Caribbean cooking. It is commonly used in teas, soups and curries. It is also suitable for poultry, fish and seafood. It is often used as a tea in African countries (Togo).

2 System Description

A solar-assisted chemical heat-pump dryer has been designed and built, as shown in Figure 1. The system is located on the roof top of a three-storey building at the National University of Malaysia (Universiti Kebangsaan Malaysia). Figure 2 show the photograph of the experimental set-up. 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 consists of reactor, evaporator and condenser. In the chemical heat pump a solid gas reactor is coupled with a condenser or an evaporator. The reaction used in this study is:

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

The drying chamber contains multiple trays to hold the drying material and expose it to the air flow. The chemical heat pump operates in heat pump mode. The overall operation of chemical heat pump occurs in two stages: adsorption and desorption. 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. 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. The system components, specifications and characteristics are shown in Table 1.

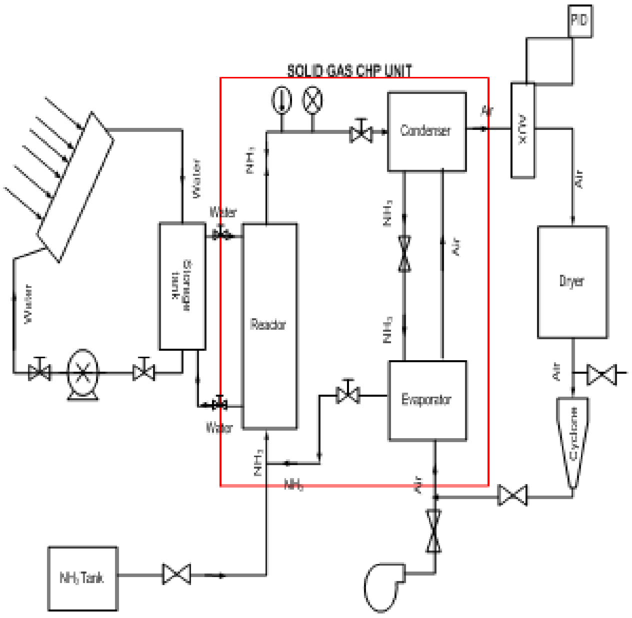

Fig.1 Schematic diagram of solar assisted chemical heat pump dryer

Fig. 2 Photograph of the experimental set-up

Table 1 Component specification and characteristics of the system parameters

No.	System/components	Specifications
1	*Solar Collector*	
	(Type Evacuated tubes)	
	Number of tubes	30
	Size	(2210 x 2040 x 161) mm
2	*Storage Tank*	
	Material	mild steel
	Size	(1040 x 430) mm
3	*Chemical heat pump unit*	
	- Reactor	
	Material	SS 316
	Size	(900 x 180) mm
	- Condenser and Evaporator	
	Material	SS 316
	Size	(700 x 160) mm
4	*Drying Chamber*	
	Material	mild steel
	Size	(620 x 620 x 620) mm
5	*Blower*	
	Type	Venz, Hp: 1-2
	Capacity	200 L/min
6	*Auxiliary heater*	
	Capacity	12 kW

3 Mathematical Model

3.1 Chemical heat pump coefficient of performance

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:

$$COA = \frac{Q_c + Q_r}{Q_r} = \frac{\Delta H_c + \Delta H_r}{\Delta H_r} \tag{2}$$

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

$$COP^h = \frac{Q_c + Q_r}{(Q_u - Q_s) + Q_r} \tag{3}$$

3.2 Solar fraction

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

$$SF = \frac{[Q_u - Q_s]}{Q_c} \tag{4}$$

In the solar collector the useful energy gain of collector surface area is given by the following equation:

$$Q_u = \eta A_C I \tag{5}$$

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 (9):

$$\eta_{eva} = 0.84 - 2.02(T_m - T_a)/I - 0.0046[(T_m - T_a)/I]^2$$
(6)

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:

$$Q_s = (UA)_{strg}(T_l - T_a) \tag{7}$$

Where Q_s is the heat loss from the storage tank, T_l is the water temperature in the tank and $(UA)_{strg}$ is the loss coefficient of storage tank and calculated using the following equation [10]:

$$(UA)_{strg} = \frac{A_s}{\frac{k}{d} + \frac{1}{h}} \tag{8}$$

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.

3.3 Moisture ratio

The moisture ratio (MR) is the ratio of the moisture content at any given time to the initial moisture content (both relative to the equilibrium moisture content). It can be calculated for each time interval using the following formula:

$$MR = \frac{M - M_e}{M_o - M_e} \tag{9}$$

4 Results and Observations

The performance of the system has been investigated experimentally under different Malaysian climate conditions. The results for sunny day conditions are presented. Figure 3 shows the hourly average values of solar radiation and ambient temperature for typical sunny day in December for Malaysia. Figure 4 shows the experimental of solar fraction against the time. As seen from the figure the maximum value was 0.713 and the solar fraction of system decrease as a solar radiation decrease.

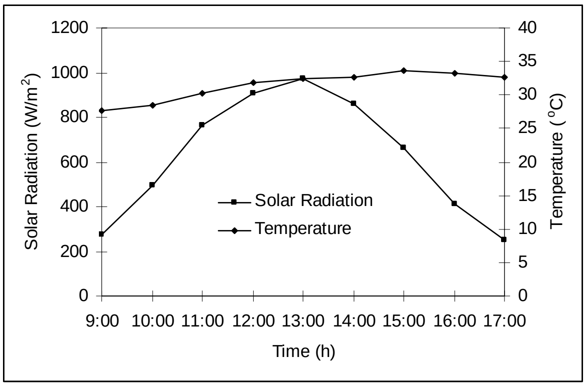

Fig. 3 Average hourly radiation and ambient temperature in Malaysia for typical sunny day

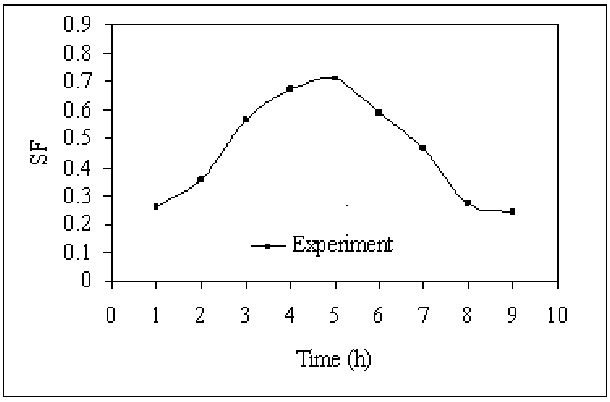

Fig. 4 Experimental SFs for sunny day

Figure 5 show the experimental values of coefficient of performance of chemical heat pump (COP^h) for sunny day. The operating conditions were high pressure condenser 12 bar, low pressure evaporator 3 bar, and (3) kg of $CaCl_2$ salt has been used. As seen in the Figure a maximum value COP^h of 2 was obtained for sunny day. Any reduction of energy at condenser as a result of a decrease in solar radiation will decrease the coefficient of performance.

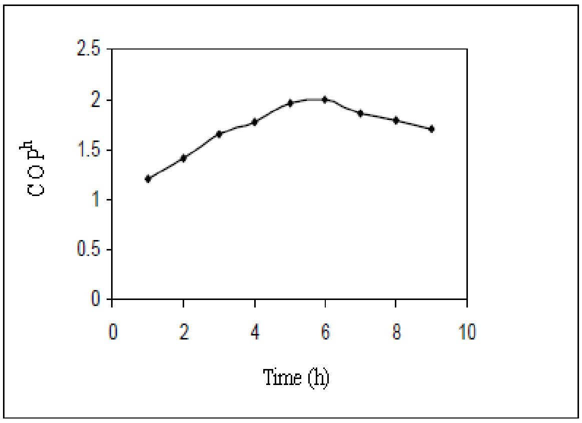

Fig. 5 Coefficient of performance experimental curve against time for sunny day

Figure 6 shows the relation between the COP^h and the solar radiation. As seen from this figure that any increasing in solar radiation will increase the COP^h.

Drying characteristics of lemongrass in solar assisted chemical heat pump dryer has been investigated for typical sunny day. The drying curves are formed by the measurement of the material moisture content as a function of time under constant drying air conditions. The temperature 55 °C and two air drying speeds (1m/s, and 3m/s) has been investigated, the weight was recorded on personal computer at 5 minutes intervals, and about 65g of fresh lemongrass was used in each run. The lemongrass was dried from average initial moisture content of 85% wb to an average final moisture content of 13% wb. Figure 7 present the plotting of the experimental and predicted moisture contents, expressed as dimensionless moisture ratio (MR) against the drying time at constant temperature 55 °C and constant air speed 1 m/s for sunny day. It was obvious, from the figure that the logarithmic model predicted well the drying curve of lemongrass, as the lines of the observed moisture contents (MRobser) and predicted moisture contents (MRpred) data were identical for the most of the drying time.

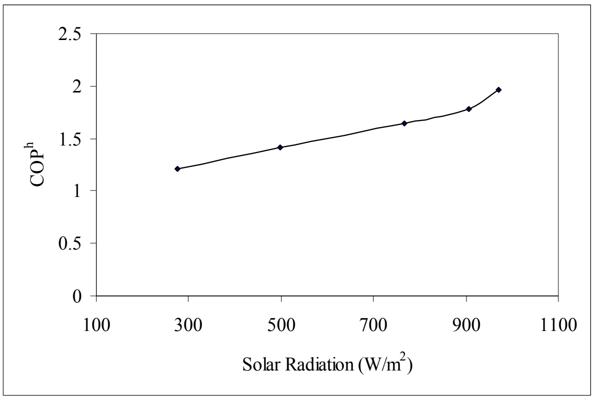

Fig. 6 The relation between COP ^{h} and solar radiation

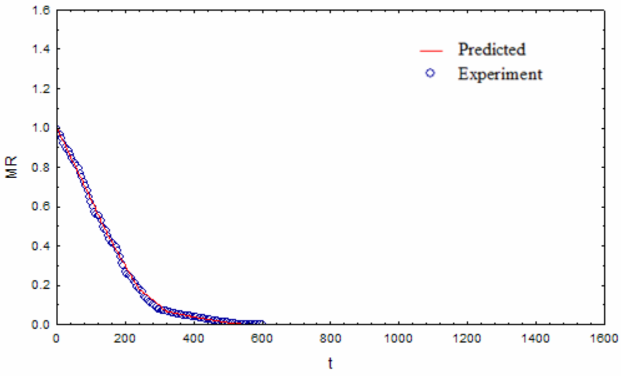

Fig. 7 Comparison between predicted and experimental moisture ratio of lemongrass for sunny day

Figure 9 illustrates the effects of changing air velocity on the drying curves of lemongrass at fixed drying temperature. It was noticeable that the effect of air velocity on the drying time was very low. Compared to the drying air temperature, changing in air velocity was not considerably accelerating the drying process, as it was observed in pervious works of several authors [11].

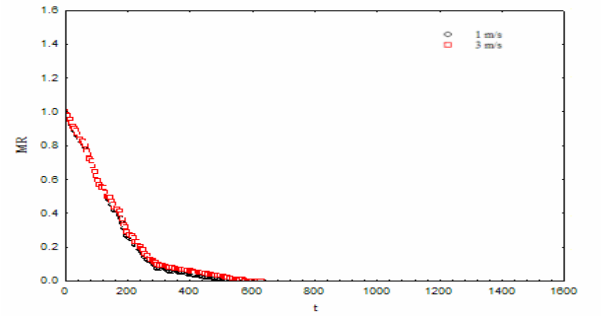

Fig. 8 MR against time at 1 and 3 m/s (55 ° C)

Figure 9 shows the system energy output over about 9 hours drying time for typical sunny day. The total energy required to maintain a drying temperature of 55 ° C is about 60 kW over nine hours drying time. At the sunny day the system contributed 51 kWh and contributed approximately 85% of the overall energy requirements.

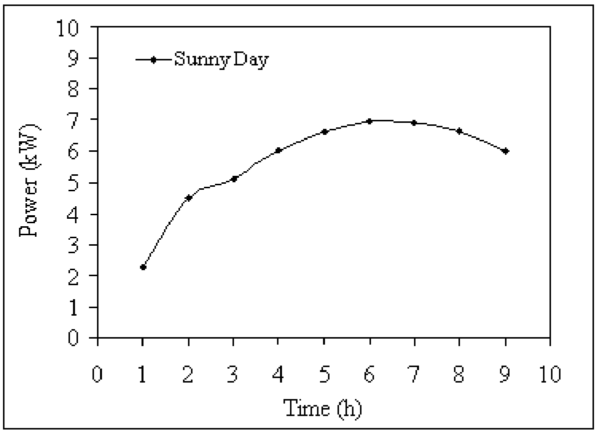

Fig. 9 System power output

5 Conclusions

A solar assisted chemical heat pump dryer has been designed, fabricated and tested. The performance of the system has been studied under the meteorological conditions of Malaysia. The results of typical sunny day were presented. The maximum value of solar fraction was 0.713, whereas the coefficient of performance of chemical heat pump (COP^{h}) maximum value 2, were obtained from experiment at sunny day. The results show that any reduction of energy in the condenser as a result of a decrease in solar radiation will decrease the coefficient of performance as well as decrease the efficiency of drying. The drying characteristics of lemongrass dried in solar assisted chemical heat pump dryer have been Investigate. The lemongrass was dried from average initial moisture content of 85% to an average final moisture content of 13 %. It was obvious that the logarithmic model predicted well the drying curves of lemongrass, as the lines of the observed moisture contents (MRobser) and predicted moisture contents (MRpred) data were identical for the most of the drying time. The model was found satisfactorily described the drying behaviour of several agricultural products. The total energy required to maintain a drying temperature of 55 °C is 60 kWh. The system contributed 51 kWh which amounts approximately 85 % of the overall energy requirement for sunny day.

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