Economic Analysis of Solar Assisted Chemical Heat Pump Dryer

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Abstract :- The economic analysis of solar energy systems is carried out in order to determine the least cost of meeting the energy needs, considering both solar and non-solar alternatives. This paper presents the evaluation of the economical benefits of using solar assisted chemical heat pump dryer system for agricultural products. The economic analysis of solar assisted chemical heat pump dryer was performed to obtain the life cycle savings (lcs) and payback period (pbp). The life cycle savings is expressed in generalized form in terms of two economic parameters, p1 and p2 which relate all life cycle cost considerations to the first year fuel cost or the initial solar system investment cost. The typical meteorological year file containing the weather parameters for malaysia is used to calculate the monthly average daily radiation and solar fraction. The initial cost of the solar assisted chemical heat pump dryer was usd5068 with average annual savings of usd1224.50 and payback period was 3.9 years.

Keywords :- solar energy system, non-solar alternatives, economical benefits, life cycles, economic analysis

1 Introduction

Solar processes are generally characterized by high initial cost and low operating costs [1-3]. The basic economic problem is of comparing an initial known investment with estimated future operating costs [4]. Most solar energy processes require an auxiliary (conventional) energy source, so that, the system includes both solar and conventional equipments, and the annual loads are met by a combination of these sources. In essence, solar equipment is bought today to reduce tomorrow's fuel bill [1].

Different terms and methods can be used to evaluate different figures of merit to study the economic feasibility of a solar system. Some of these are the life cycle cost [2]; net present value, internal rate of return [4-5]; pay back period [6], utility-expense rate, equivalency of annual income [7]; life cycle savings [1].

In order to evaluate the economic viability of the system, the interest is in calculating the savings which will be accrued annually and on along term basis because of installing the solar system [6]. The solar system would help in saving conventional energy in the form of fuel or electricity. Life cycle savings (LCS) method takes into account the time value of money and allows detailed consideration of the complete range of cost.

Payback period is a term used frequently for judging the economical viability of a solar system. The most common definition is the time needed for the cumulative fuel savings to equal the total initial investment [1, 6]. When a value of payback period is quoted, it is necessary to ascertain which definition has been used and whether the value has been determined by using actual savings from year to year or by using the discounted value of money [6].

In this paper the economic analysis of solar assisted chemical heat pump dryer was performed to obtain the life cycle savings (LCS) and payback period (PBP). The life cycle savings (LCS) is expressed in a generalized form in terms of two economic parameters, P_1 and P_2, which relate all life cycle cost considerations to the first year fuel cost or the initial solar system investment cost.

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).

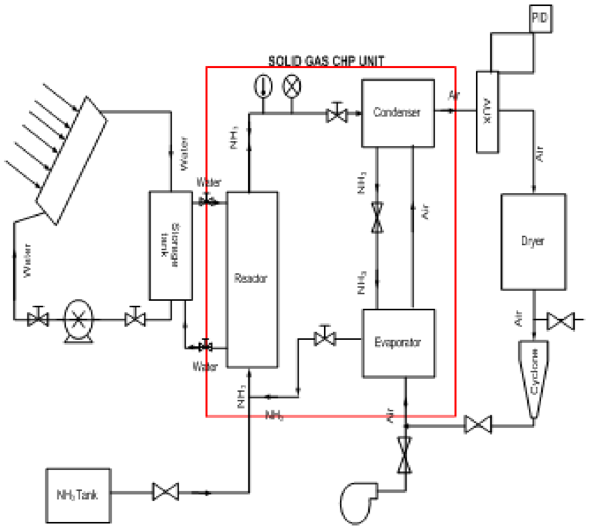

Fig.1 Schematic diagram of solar assisted chemical heat pump dryer

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. 2 Photograph of the experimental set-up

3 Life Cycle Savings (LCS)

The life cycle savings (LCS) is defined as the difference between the life cycle costs (LCC) of the conventional fuel-only system and solar plus auxiliary energy system (Duffie & Beckman 1991), and given by:

$$LCS = P_1.C_F.L.SF - P_2.C_S \qquad (2)$$

Where

LCS is the life cycle savings, \$
C_F is the unit cost of delivered conventional energy for the first year of analysis, \$-GJ^{-1}
L is the annual load, GJ

SF is the annual fraction of load supplied by solar energy equipment, $

C_S is the total cost of installed solar energy equipment, $

P_1 is the factor relating life cycle fuel cost savings to first year fuel cost savings

P_2 is the factor relating life cycle expenditures incurred by additional capital investment to the initial investment

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

The total cost (C_s) of a solar system is calculated as follows:

$$C_S = C_A A_C + C_E \quad (3)$$

Where

C_A is the area dependent costs include such items as the purchase and installation of the collector and a portion of storage cost, $-m^{-2}

A_C is the collector area, m^2

C_E is the solar energy system investment costs which are independent of collector area, $

Here, P_1 accounts for fuel escalation and the discounting of future payments, and is calculated by:

$$P_1 = [(1+d)/(d-i)][1-((1+i)/(1+d))^N] \quad (4)$$

Where

d	discount rate
i	inflation rate
N	period of economic analysis, year

The factor P_2 accounts for investment related expenses which can be calculated by:

$$P_2 = 1 + P_1 M_s - R_v(1+d_f)^{-N} \quad (5)$$

Where

M_S	solar system performance degrade
R_v	resale value of solar system, $

4 Pay Back Period (PBP)

The most common definition of pay back time is the time needed for the cumulative fuel savings to equal the total initial investment, that is, how long it takes to get an investment back by savings in fuel. The pay back period (BPP) can be given as (with discounting):

$$PBP = \ln\left[1-\left(P_2 C_S / C_F L F\right)(d-i)/(1+d)\right] / \ln\left[(1+i)/(1+d)\right]$$

(6)

5 Results And Discussions

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.

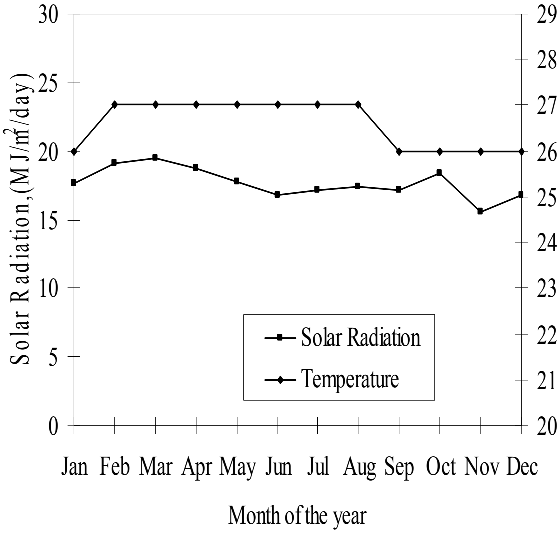

Fig.3 Monthly weather data for Sepang in Malaysia

Figure 4 shows the monthly predicted solar fraction as a function of solar collector area. In Figure 4 the monthly solar fraction increases 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. In this study the collector area 10m^2 has been installed on the roof top of a three-storey building at the National University of Malaysia (Universiti Kebangsaan Malaysia), and the economic analysis (saving and pay back period) will be consider this collector area. The average annum solar fraction as a function of solar area collector 10 m^2 was 0.335 as seen from the Figure 4.

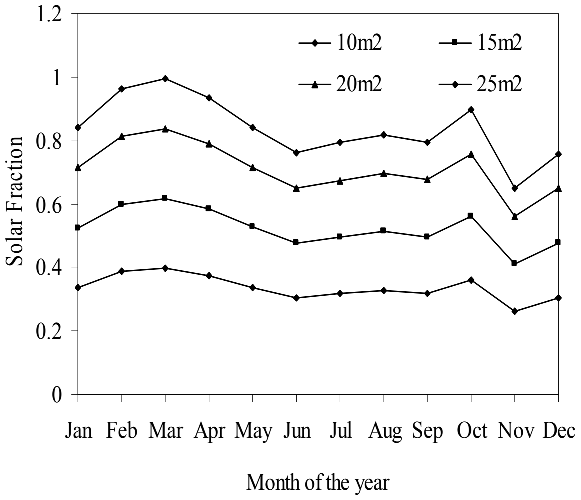

Fig. 4 Monthly solar fraction predicted curve as function of solar collector area

The actual cost of the solar assisted chemical heat pump dryer is shown in Table 2. It is obvious that the main cost of the solar assisted chemical heat pump dryer is from the solar collectors.

Table 2 Costing of solar assisted chemical heat pump dryer

Item	Cost (USD)
Evacuated tubes collector	2500
Water storage tank	375
Reactor	281
Condenser	218
Evaporator	218
Dryer	469
Blower	157
Pumps	300
Auxiliary heater	150
Piping and fitting	100
Instrumentations	300
Total	5068

In order to calculate the payback period, the solar assisted chemical heat pump dryer is assumed to be maintenance free. To work out the present worth of the electricity that is to be used for pay back years into the future, the discount d and inflation rates i have to be factored in.

Table 3 Parameters used in the calculation of the life cycle saving and pay back period

Parameter	Remarks
Inflation rate i (%)	3
Discount rate d (%)	10
$C_{unit.\ elect}$ ($)	0.07
Daily electricity consumption (kWh)	60
Cost of electricity per annum ($)	1533
Ratio of resale value at end of period of analysis to intial investment, Rv (%)	30
Solar system performance degrade (%)	1
Cost of solar assisted chemical heat pump dryer ($)	5068
Annually solar fraction, SF	0.335
Solar saving, LCS($)	1224.5
Pay back period, PBP (years)	3.9

With reasonable values of the parameters given in Table 3, the initial cost of the solar assisted chemical heat pump dryer was USD5068 with average annual savings of USD1224.5 and payback period was 3.9 years.

6 Conclusion

The economic analysis of solar assisted chemical heat pump dryer was performed to obtain the life cycle savings (LCS) and payback period (PBP). The life cycle savings (LCS) is expressed in a generalized form in terms of two economic parameters, P_1 and P_2, which relate all life cycle cost considerations to the first year fuel cost or the initial solar system investment cost. The initial cost of the solar assisted chemical heat pump dryer was USD 5068 with average annual savings of USD 1224.5 and pay back period was 3.9 years.

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