Techno-economic Analysis of a LiBr-H_2O Solar Absorption Cooling System in Thailand

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ABSTRACT

This paper report the technical and economic performance of a 35 kW LiBr-H_2O absorption machine driven by 72 m^2 heat pipe evacuated tube collector with a gas back up system. The technical analysis is given to calculate the Coefficient of Performance (COP) and the Solar Fraction ($SOLF_{the}$). The economic analysis is performed using the Specific Life Cycle Cost Analysis (SLCCA) method, which is based on the economic factors applied to Thailand and the sensitivity analysis which varying the COP and $SOLF_{the}$. The optimize strategy is proposed to the maximum COP and $SOLF_{the}$ while the SLCCA is minimum.

Keywords: *Solar Absorption Cooling System, LiBr-H_2O, Specific Life Cycle Cost Analysis*

1. INTRODUCTION

The major consumers of electrical energy in many parts of the world today are the air-conditioning system. In Thailand, nearly 60% in the residential sector use air-conditioning systems, amounting to 50,000 GWh per year. This implies that Thailand would need a new 600 MW power plant to meet the additional peak demands [1]. There are generating negative impact on the environment not only the driven energy but also the refrigerants because of the air-conditioning that built around is the vapor compression [2]. If the alternative technologies were developed fully, we could become free from the scarcity of fossil fuels. It would be essential first to reduce the demand, and then to apply right-sized technology such as solar absorption cooling system with NH_3-H_2O and LiBr-H_2O are the major working pairs available [3]. The solar energy become an alternative solution, it is available abundantly in Thailand of about 5 $kWh.m^{-2}$ [4]. The several reports are evaluating the thermal and economic performance of solar cooling system with different methods [5, 6, 7].

This article describes the technical and economic analysis based on the measurement data of a 35 kW LiBr-H_2O absorption unit which was installed at the School of Renewable Energy Technology (SERT), Naresuan University, Phitsanulok, Thailand during January to December 2006 until 09:00 to 17:00 each day. The actual COP and $SOLF_{the}$ are analyzed in technical performance. The economic performance is using the SLCCA method to calculate the cost-optimum life cycle using per the energy useful, cooling capacity, is also given under taking the sensitivity analysis.

2. DESCRIPTION OF THE ACTUAL SYSTEM

The studied system is formed by the LiBr-H_2O absorption cycle at SERT which located at approximately 16 °N latitude and 100 °E longitude, this system is comprised of four main flow circuits, taking into account the generator, condenser, absorber and evaporator. To begin with, solar energy is absorbed by the collector and accumulated in the storage tank. The auxiliary heat supplies to boost the temperature of water inlet became the reference range when solar energy is not sufficient to heat the water to the required temperature level needed by the generator. The heat gained is supplied to the generator to boil off water vapor from a solution of LiBr-H_2O. The water vapor is cooled down in the condenser and then passed to the evaporator wherein it again gets evaporated at low pressure, thereby providing cooling to the space to be cooled and the water flow rate in the system is maintained constantly by working of pump (Fig 1). All measured quantities are converted into electric signals and elaborated through a data acquisition system, Agilent VEE Pro-Cooling K641-W6G; the software allows to visualize and to memorize all the parameters examined with the possibility to choose how often acquiring data.

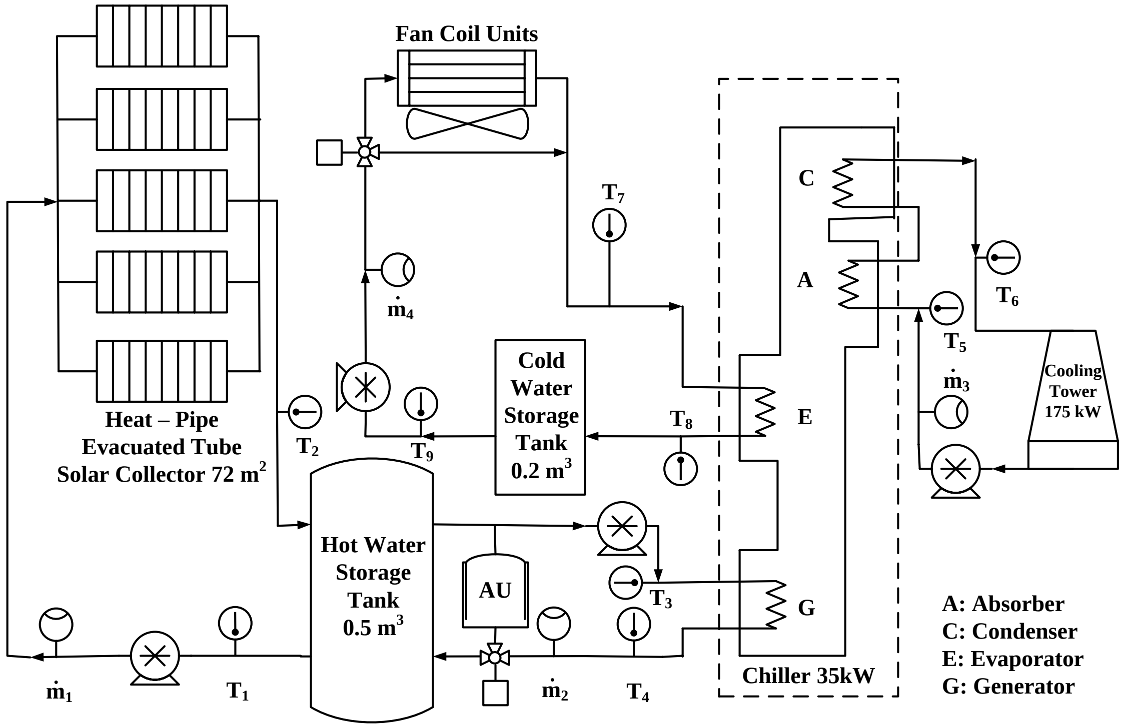

Fig. 1 Schematic of Solar Cooling at SERT, Thailand

3. TECHNICAL PERFORMANCE ANALYSIS

From the thermally driven technologies, a basic figure to describe the quality of the conversion of heat into cold is the thermal coefficient of performance, COP, defined as the useful cold, Q_{cold} ,per unit of invested driving heat, Q_{heat} [8].

$$COP = \frac{Q_{cold}}{Q_{heat}} \quad (1)$$

So

$$Q_{cold} = C_1(T_7 - T_8) \quad (2)$$

$$Q_{heat} = C_2(T_3 - T_4) \quad (3)$$

In this case C_1 = 8.03 kJ.s $^{-1}$K^{-1} and C_2 = 12.09 kJ.s $^{-1}$K^{-1}

The annual useful solar is expressed [9].

$$Q_{solar} = Q_{heat} - Q_{auxiliary} \quad (4)$$

An auxiliary heater at the exit of the storage tank boosts the temperature of the hot water from the storage tank temperature to the allowable reference temperature. The auxiliary heater capacity is calculated as follows.

$$Q_{auxiliary} = C_3(T_{ref} - T_S^*) \tag{5}$$

In this case we assume that T_{ref} = 348 K (75 °C) and C_3 = 3.97 kJ.s $^{-1}$K^{-1}.

The fraction of the solar energy met by the total energy input can be expressed as [10].

$$SOLF_{the} = \frac{Q_{solar}}{Q_{solar} + Q_{auxiliary}} \tag{6}$$

$$Q_{solar} = C_3(T_2 - T_1) \tag{7}$$

4. ECONOMIC PERFORMANCE ANALYSIS

4.1 The Present Worth Cost (PWC)

The present worth value of a cash flow over time is its value today. The present worth comparisons are made only between co-terminated proposals, to ensure equivalent outcomes. Co-termination means that the lives of the systems involved end at the same time, which is not the case in this work. When the alternative shave unequal lives, the time horizon for analysis can be set by a common multiple of system lives or by a study period that ends with the disposal of all systems. Consequently, the common-multiple method has been proposed to accommodate the present worth value for the unequal-life systems. The total present worth value for any analysis is determined by summing the present worth value so fall individual items under consideration, both future single payment (i.e., replacement cost) items and series of equal future payments (i.e., annual operating cost). The cost or the value of money is a function of the available interest rate and inflation rate, i [11].

The present value P_0 of a series of uniform end-of-period payments A_0 (the annual operating cost) is calculated using Eq. (10). The present worth value of a single payment in the future after period n, P_{Re} (future replacement cost), is calculated using Eq. (11). The uniform series present worth factor and the single payment present worth factor can be expressed as in Eqs. (8) and (9), respectively [12]:

$$P_0 = A_0(P/A, i\%, n) \tag{8}$$

$$P_{\text{Re}} = F_{\text{Re}}(P/F, i\%, n) \tag{9}$$

$$P_0 = A_0\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{10}$$

$$P_{\text{Re}} = F_{\text{Re}}\left[\frac{1}{(1+i)^n}\right] \tag{11}$$

The present worth method is normally used to evaluate and compare the life-cycle costs of HVAC systems [13]. What distinguishes this work is that it utilizes the present worth cost (PWC) to evaluate the cost of this system.

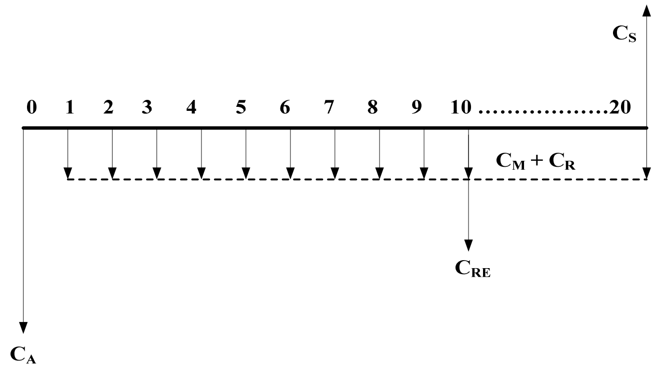

Fig. 2 Cash flow diagram for Solar Cooling System at SERT, Thailand (PWC)

4.2 The Specific Life Cycle Costs Analysis

The cost of any energy delivery process includes all of the items of hardware and labor that are involved in installing the equipment plus the operating expenses. The object of the economic analysis can be viewed as the determination of the least cost method of meeting the system life cycle costs to install cooling capacities was calculated as the SLCCA [13].

$$SLCCA = \frac{LCCA}{Q_{cold}} \tag{12}$$

The LCCA was the measurement of the total cost of a system through out its life time [14].

$$LCCA = C_A + AC_M + AC_R + BC_{RE} - BC_S \tag{13}$$

In this case $A = \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$ and $B = \left[\frac{1}{(1+i)^n}\right]$

In the economic performance, the sensitivity analysis is the study of how the variation in the output of the SLCCA can be apportioned, quantitatively, and useful for the variation of the coefficient of performance (COP) is 0.2 - 0.7 and the solar fraction ($SOLF_{the}$) is 0.5 – 1. The capital costs came to a total of 2,974,846 Baht (85,000 U.S. Dollar) with the calculated detail shown on Table 1. The analysis used SLCCA method base on assumption of the life time is 20 year, the operation period is 8 hour per day that follows on Table 2.

Table 1 The Capital Costs for SERT Energy Park Cooling System

Components	**Estimated Specific Cost**	**Life Time (Year)** [15]
Absorption Chiller	40,000 Baht. kW^{-1}	20
Solar Collector Array	13,000 Baht. m^{-2}	20
Auxiliary Heater	-	10
Heat Storage Unit	-	20
Cool Storage Unit	-	20
Cooling Tower	180 Baht.kW^{-1}	20
Fan Coil (4Units)	1,200 Baht.kW^{-1}	10
Pump (4 Units)	20,000 Baht.kW^{-1}	20
Labor/ Transportation	-	-

1 U.S. Dollar = 35 Baht [16]

Table 2 The Calculated Extent for Economic Performance Analysis [14]

Description							
Capital Cost (C_A)	2,974,846 Baht						
Annual Maintenance Cost	1	% of C_A					
Annual Running Cost (C_R)							
- Electric Cost							
COP = 0.2	2.10	Baht.kWh^{-1}					
COP = 0.3	1.40	Baht.kWh^{-1}					
COP = 0.4	1.05	Baht.kWh^{-1}					
COP = 0.5	0.84	Baht.kWh^{-1}					
COP = 0.6	0.70	Baht.kWh^{-1}					
COP = 0.7	0.60	Baht.kWh^{-1}					
- LPG Cost	COP = 0.2	COP = 0.3	COP = 0.4	COP = 0.5	COP = 0.6	COP = 0.7	
$SOLF_{the}$ = 0.4	1.39	0.93	0.70	0.56	0.46	0.40	Baht.kWh^{-1}
$SOLF_{the}$ = 0.5	1.16	0.78	0.58	0.47	0.39	0.33	Baht.kWh^{-1}
$SOLF_{the}$ = 0.6	0.93	0.62	0.46	0.37	0.31	0.26	Baht.kWh^{-1}
$SOLF_{the}$ = 0.7	0.69	0.46	0.35	0.28	0.23	0.20	Baht.kWh^{-1}
$SOLF_{the}$ = 0.8	0.46	0.31	0.23	0.19	0.15	0.13	Baht.kWh^{-1}
$SOLF_{the}$ = 0.9	0.23	0.15	0.12	0.09	0.08	0.07	Baht.kWh^{-1}
Replacement Cost (C_{RE}) in the last 10 year							
-Auxiliary Heater	0.15	Baht.kWh^{-1}					
-Fan Coil (4Units)	0.05	Baht.kWh^{-1}					
Salvage Cost (C_S)	5	% of C_A					
Discount Rate (i)	6	%					
Life Time (n)	20	Year					

5. RESULTS AND DISCUSSION

The results showing the monthly techno-economic analysis during 2006 are given in Table 3. The solar cooling system provides the daily average useful cold, Q_{cold} , is 132.32 kWh with the daily average driving heat, Q_{heat} , is 370.64 kWh in which a half of thermal supplied by solar energy, $SOLF_{the}$=0.59. The daily average COP is 0.34 while the daily average ambient temperature, T_a , high water temperature inlet chiller, T_3 , and cooled water temperature outlet evaporator, T_8 , is 32, 72 and 15 C°, respectively. The calculation of SLCCA is about 8 Baht.kWh^{-1} or 64.24 Baht per day (1.84 U.S. Dollar per day) for this available system. The rating supplied by the manufacturer show a COP at nominal conditions equal to 0.70, the measurement values of the daily average actual COP is 0.34. The poor performance of this cooling system not only generating a negative effect on the thermal performance but also decreasing the economic performance as the sensitivity analysis, so that the optimize strategy is proposed to the highest COP and $SOLF_{the}$ while the SLCCA is getting low.

Table 3 Techno-economic analysis of 35 kW solar cooling system during 2006, Thailand

Month	$\overline{G}_{\beta}$ (kWh.m^{-2})	T_3 (C°)	T_8 (C°)	T_a (C°)	Q_{heat} (kWh)	Q_{cold} (kWh)	$Q_{auxiliary}$ (kWh)	COP	$SOLF_{the}$	$SLCCA$ (Baht.kWh^{-1})
Jan	5.10	73	11	21	412.64	200.00	211.68	0.48	0.49	4.18
Feb	4.90	70	16	30	336.40	161.04	108.72	0.47	0.68	4.13
Mar	4.90	71	18	34	421.76	125.60	114.40	0.30	0.73	6.79
Apr	5.55	75	19	34	450.80	110.24	186.48	0.24	0.81	10.05
May	5.40	74	15	34	380.08	110.64	186.48	0.29	0.51	10.45
Jun	5.20	70	17	33	308.00	83.44	152.00	0.27	0.51	10.45
Jul	5.10	73	14	33	337.36	126.64	148.16	0.38	0.56	6.97
Aug	4.30	63	20	32	347.36	89.20	160.96	0.26	0.54	10.45
Sep	5.45	69	17	34	399.60	101.44	186.48	0.25	0.53	10.45
Oct	5.20	74	13	34	422.32	195.68	150.64	0.46	0.64	5.16
Nov	5.00	74	15	34	500.56	187.36	170.64	0.37	0.65	6.88
Dec	4.65	74	18	31	419.12	96.88	211.28	0.23	0.50	10.45
$\overline{X}$	**5.10**	**72**	**15**	**32**	**394.64**	**132.32**	**157.20**	**0.34**	**0.59**	**8.03**

1 U.S. Dollar = 35 Baht [14]

Table 4 The Economic Performance Analysis with Sensitivity Factor

List	Specific Life Cycle Cost Analysis (Baht. kWh^{-1})					
	$SOLF_{the}$ 0.5	$SOLF_{the}$ 0.6	$SOLF_{the}$ 0.7	$SOLF_{the}$ 0.8	$SOLF_{the}$ 0.9	$SOLF_{the}$ 1.0
COP = 0.2	10.45	10.32	10.18	10.05	9.92	9.78
COP = 0.3	6.97	6.88	6.79	6.70	6.61	6.52
COP = 0.4	5.23	5.16	5.09	5.02	4.96	4.89
COP = 0.5	4.18	4.13	4.07	4.02	3.97	3.91
COP = 0.6	3.48	3.44	3.39	3.35	3.31	3.26
COP = 0.7	2.99	2.95	2.91	2.87	2.83	2.80

1 U.S. Dollar = 35 Baht [14]

In the economic analysis is shown on Table 4. The improvement depends on the thermal performance, COP, if the maximum COP is required for the continuous operation, COP=0.7, the payment is about 3 Baht.kWh^{-1} for each SOLF $_{the}$. In the technical analysis, the poor performance of the cooling system is partly due to the huge heat losses such as the discrepancy between the large collector array and the relatively small absorption chiller energy demand. This condition should be reduced by some improvements that have been made in past three decades on the main components of the solar absorption cooling system, such as the solar collector, absorption chiller and hot water storage tank [17]. The first idea is to create a new type of cooling machine that would be more suitable to make use of the low density, unsteady solar energy, under the local climatic conditions which can be easily provided by conventional solar hot water system [18]. The second idea is to increase the size and the height of hot water storage tank that usually be improvident storage for hot and cold water depending on the load [19]. Improving the positive of performance for the entire solar cooling by an appropriate design is the thermally stratified storage tank. This natural process creates a transition zone temperature gradient between cold and hot fluid zones, called the thermocline [20]. Thermocline storage is attractive because the working fluid can be sent to the solar collector at lower temperature. Also, the potential reduction in cost and complexity of pumping, valving, and pumping make it highly desirable to investigate at some length the characteristics and behavior of the storage system. For temperature stratified water tank is limited by the flow rate, collector flow and load flow [21].

This experiment has a limitation of water flow rate via the four main flow circuits will have significantly affect the thermal energy that is balancing the COP, whereas measurements taken by other works [22] and it indicated that the supplying water temperature effects on the actual COP by varying the flow rate, as measurements taken by other author [5, 23, 24]. On the other hand, increasing the frequency of cleaning the solar collector and cooling tower (which is an effect of operating conditions) [25] is just as important as the frequency of examining and repairing the pipe’s joint in order to reduce the heat losses in the water circuit and improve the efficiency of the components too [26].

6. CONCLUSION

There is no reason to turn this cooling system into a minimum COP since this would increase the reliability and decrease the cost of the operated system. This measurement is not operating under optimized both technical and economic conditions as it is experiencing some energy and money losses. In the future development of this study, the research will focus on the optimization of COP by adjusting the water flow rate for energy balancing to attain the highest COP of the chiller. Reducing the heat losses also has the added advantage of reducing the consumption of auxiliary heat (i.e. LPG) and this can be both economically and environmentally beneficial.

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Nomenclature

A	the capital recovery factor of the annual payment
A_0	the annual operating cost, Baht
B	the capital recovery factor of the once payment
COP	coefficient of performance
C_A	the capital cost, Baht
C_{AUX}	the auxiliary energy cost, Baht
C_E	the electrical energy cost, Baht
C_M	the maintenance costs, Baht
C_R	the running cost, Baht
C_{RE}	the replacement cost, Baht
C_S	the salvage cost, Baht
C_1	the constant value, kJ.s $^{-1}$K^{-1}
C_2	the constant value, kJ.s $^{-1}$K^{-1}
C_3	the constant value, kJ.s $^{-1}$K^{-1}
G_β	solar radiation incident on the collector , W m^{-2}
G	solar radiation incident on the horizontal , W m^{-2}
i	discount rate, %
$LCCA$	the life cycle costs analysis, Baht
n	period of analysis, years
P_0	the present value, Baht
P_{Re}	the future replacement cost, Baht
$Q_{auxiliary}$	auxiliary heat, kWh
Q_{cold}	the useful cold at evaporator , kWh
Q_{heat}	the driving heat at generator , kWh
Q_{solar}	the solar energy input, kWh
$SLCCA$	the specific system life cycle costs, Baht kwh^{-1}
$SOLF_{the}$	the solar thermal energy fraction

T_a	ambient temperature, K
T_{ref}	reference temperature , K
T_S^*	the average temperature at storage tank , K
T_1	water temperature inlet collector , K
T_2	high water temperature supplied by collector , K
T_3	high water temperature inlet chiller , K
T_4	water temperature outlet chiller , K
T_7	warmed water temperature inlet evaporator , K
T_8	cooled water temperature outlet evaporator , K

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