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Technical-Economic Analysis of Steam Double Effect Absorption Chiller-Heaters Equipped with Solar Heat Pipe System

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Abstract:
The aim of this research is to indicate a steam double effect chiller-heater equipped with solar heat pipe in a certain space with the area of 975 m^2 located in Tehran, which is currently equipped with a direct-fired single effect absorption chiller-heater. Thereafter , the most obvious differences of the two chiller-heater systems are compared: the solar cooling system increases coefficient of performance as high as 0.54, decreases CO_2 dissemination by 829 tons in each year, and reduces energy consumption by 1552.42 MWh/Yr. Economic analysis of the two systems using break-even-point showed that the use of solar system is attractive in applications that have excess thermal energy, and the conversion of this energy to higher value energy markets is to be more profitable than absorption gas-fired system from 13th year on.

1. Introduction

Today, due to environmental pollution caused by gas emissions, such as carbon dioxide and sulfur dioxide, selection of an optimum technology to reduce fuel costs and use of its advantage draw attention to the value of renewable energies particularly solar energy . Amount of solar radiation in some countries like Iran as a result of being in solar belt region is very strong [1].

Located between 251 and 401 north latitude, Iran is in a favorable position with respect to the potential amount of solar energy received. Solar radiation in Iran is estimated at about 1800 to 2200kWh/m2 per year, which is higher than the global average. An annual average of more than 280 sunny days is reportedly recorded over more than 90% of Iran's territorial land, which yields a highly significant potential source of energy [2].

Lithium bromide‑water absorption equipment is currently used to produce chilled water for space cooling and can also be used to produce hot water for space heating and process heating. Absorption chiller is a popular alternative for conventional compression chillers when electricity is unreliable, costly, or unavailable [3].The low level energy operating systems begin to function better therefore, they can use renewable energy and reduce fuel consumption and pollution of environment too [4]. A solar cooling system that has been designed for Malaysia climate and similar tropical regions using evacuated tube solar collectors and LiBr/H2O absorption unit has been introduced [5]. The modeling and simulation of the absorption solar cooling system is carried out with TRNSYS program. The typical meteorological year file containing the weather parameters for Malaysia is used to simulate the system. The results showed that the system is in phase with the weather, i.e. the cooling demand is large during periods that the solar radiation is high. It was shown that, in order to achieve continuous operation and increase the reliability of the system, a 0.8m^3 hot water storage tank is essential [6]. Ref [7], designed and installed a 35.17 kW cooling (10-RT) solar-driven absorption cooling system in Thailand in 2005. The system has a 0.4 m^3 hot water storage tank and 72 m^2 evacuated tube solar collectors that delivered a yearly average solar heating fraction of 81% [8].Ref [9] conducted a comparative study among four different systems with a collector of 230m^2 and concluded that the double-effect chiller with a trough collector had the highest potential savings (86%) among the four systems to handle the demand for a 50 kW load. Qu et al. [10] implemented a double-effect absorption system with LiBr/water chillers of 16 kW. They also used a parabolic solar-collector of 52 m^2 with a heat-exchanger and pumps for circulation of the working fluids. There was also a natural gas-burner used to supply heat in the absence of solar energy [11].

There is no available reports of Technical-Economic Analysis of solar-assisted, Steam Double Effect Absorption Chiller-Heaters in the literature.

In this research a steam double effect chiller-heater equipped with solar heat pipe in a sample space with the area of 975 m^2 located in Tehran was used. The system is currently equipped with a gas-fired single effect absorption chiller-heater. technical and economic analysis to determine advantages of the system in the sample space was carried out and discussed.

2.Design of solar air conditioning building

2.1.description

The space under study is an office located in Narmak division of Tehran. Effective area of the space for air conditioning is 975 m^2. Office regular hours is 8 am to 4 pm.In Table 1 is Current system of the office is a direct-fire single effect absorption chiller-heater with the following specifications. (working 2376 hours a year):

Table(1)- The specifications of direct-fire single effect absorption chiller-heater for this research

Cooling capacity of the chiller	105.48 KW
Heating capacity of the chiller	146.2 KW
Temperature of child water of the chiller	7 °C
Temperature of hot water of the chiller	55 °C
Fluid flow for evaporator	16.5 m3/hr
Water flow for cooling Tower	55 m3/hr
Natural gas consumption of the chiller	15 Nm3/hr with the heat value of 9000 kcal/hr
Electricity consumption of the chiller	310 W

2.2. Heating and cooling load system

In order to increase the energy efficiency of the process , its heating and cooling load was calculated with 10% accuracy using h a software and architectural plans. Assumptions and results of the calculations are listed in [12].

The location and weather conditions are:

Latitude: 35.5 degrees north

Longitude: 51.4 degrees east

Altitude: 1219 m

Dry temperature in summer: 37 ‘C

Humid temperature in summer: 23 ‘C

Annual relative humidity: 40.1%

2.3. Design

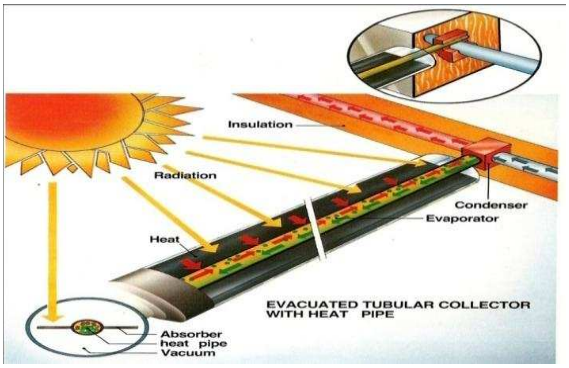
The possible reason of steam double effect absorption chiller-heaters that 140°C steam with the minimum pressure of 6 bars limited application. It is required for operation of their generators. Supplying expensive high pressure and temperature is not reasonable. Therefore, the application of these systems in houses has been limited. In this research these systems was combined with solar heat pipes to provide steam required in generator of the chiller.

Table(2)-Report of cooling and heating load with software[12]

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1800 COOLING OA DB / WB 35.7 °C / 23.1 °C			HEATING DATA AT DES HTG HEATING OA DB / WB -6.7 °C / -8.8 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	15 m²	1290	-	15 m²	-	-
Wall Transmission	420 m²	5385	-	420 m²	15389	-
Roof Transmission	975 m²	71512	-	975 m²	66700	-
Window Transmission	30 m²	1470	-	30 m²	3870	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	35 m²	624	-	35 m²	2015	-
Floor Transmission	0 m²	0	-	0 m²	0	-
Partitions	526 m²	0	-	526 m²	0	-
Ceiling	0 m²	0	-	0 m²	0	-
Overhead Lighting	2423 W	2423	-	0	0	-
Task Lighting	4292 W	4292	-	0	0	-
Electric Equipment	1800 W	1800	-	0	0	-
People	45	3231	2704	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	10% / 0%	9202	0	0%	0	0
>> Total Zone Loads	-	101230	2704	-	87974	0

Since heating and cooling loads of the building are 8797 W and 101230 W(According to Table2), respectively, the following steam double effect absorption chiller-heater was selected:
Cooling capacity of the chiller: 105.48 kW
Heating capacity of the chiller: 76000 kcal/hr
Temperature of cold water of the chiller: 7°C
Temperature of hot water of the chiller: 65°C
Fluid flow for evaporator: 18 m3/hr
Water flow for cooling Tower: 22 m3/hr
Steam flow of the generator: 3 m3/hr
Electricity consumption of the chiller: 2000 W

It should be noted that the chiller does not need natural gas for operation. Solar heat pipe is a recent type of solar collectors that is cheaper than solar parabolic systems. The idea of heat pipes was first presented by Grever in 1964. The system was then used for transferring heat from one place to another in applications like space rockets or portable computers. In recent years the system has become a solar collector with the capacity of transferring heat up to 200 degrees Celsius with the minimum losses [13].
An individual heat pipe is made up of three basic components :evaporator, adiabatic and condenser. Transferring heat takes place through successive evaporation and condensation of working fluid of the heat pipe. It is surprising that electrical or mechanical devices are not used in these systems and heat loss through vacuum covers is not significant [14]. In order to prevent disorder in simultaneous evaporation and condensation inside the pipe, a fuse is utilized. Using the fuse, heat pipe can be installed even vertically as a result of capillary effect. Figure 1 shows typical structure of solar heat pipes and Figure 2 shows Solar heat pipe system in 3th Khordad building in Tehran.



Figure(1) - Typical structure of solar heat pipes

Figure (2) – Solar heat pipe system in 3th Khordad building in Tehran.

Different factors are important in determining surface area of solar collectors, among which are intensity and amount of solar radiation, optimal angle of collector slope and required steam discharge.

According to simulations performed by TRNSYS software, amount of solar radiation in each unit of area in Tehran and temperature in 8760 hours of year are listed in figure 3.

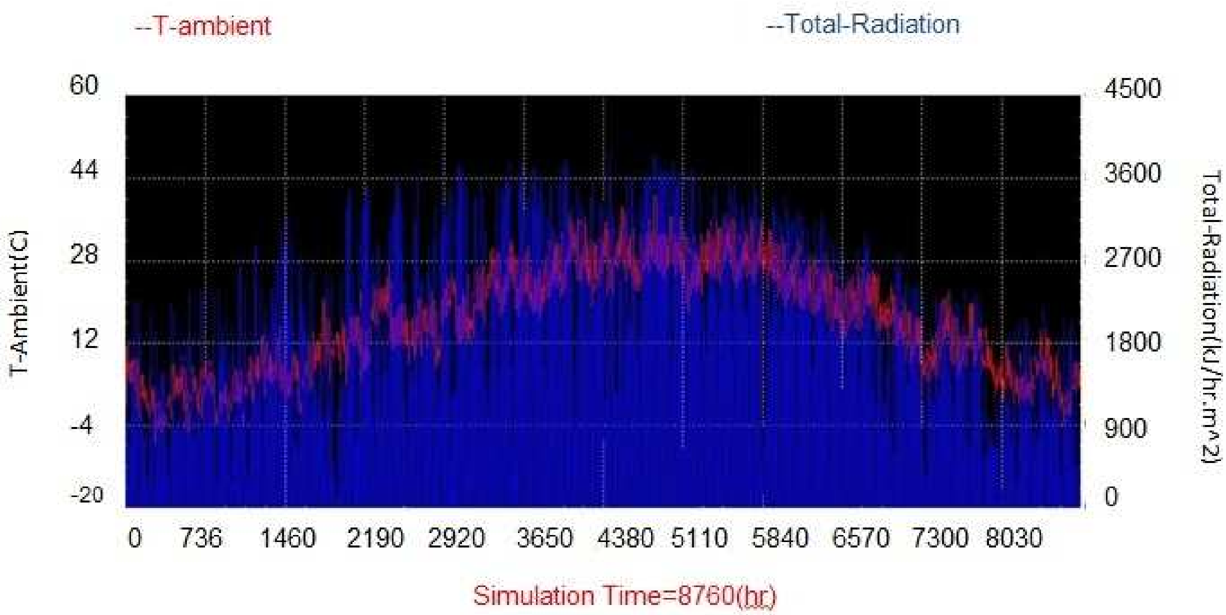


Figure (3)- Amount of solar radiation in each unit of area in Tehran

Heating degree day and cooling degree day could be obtained by entering climatic information into RetScreen software. The results are shown in figure 4.

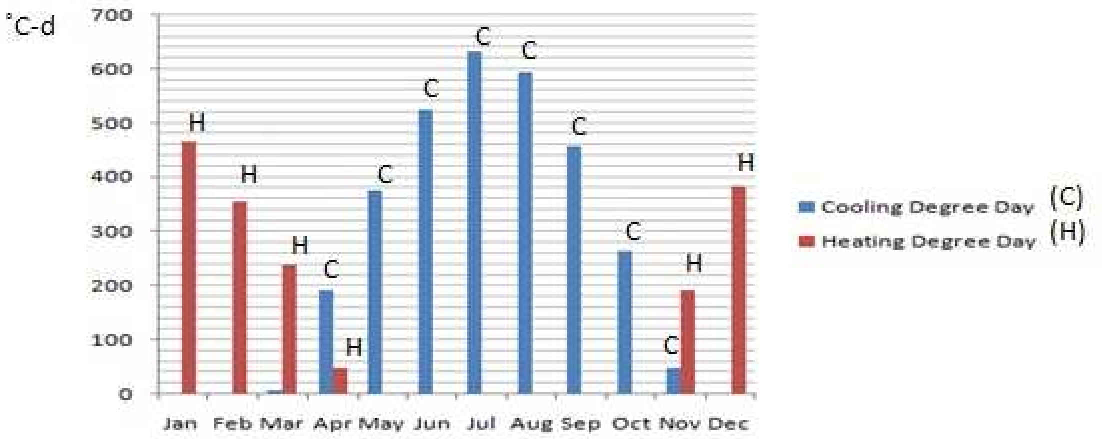


Figure (4) - Heating degree day and cooling degree day for Tehran

According to previous studies, optimal slope for installing solar collectors in Tehran is 34 degrees facing south (for simultaneous heating and cooling). However, since this slope results in overheating load in winter and optimal cooling angle is 18 degrees but Since the system is supposed to be used in simultaneous heating and cooling mode, slope of heat pipes will be equal to latitude of Tehran [15].According to the above, and using the following equation, the number of heat pipes and the absorption area can be calculated [16]:

$$N = (Q_u - \text{collector}) / m\, C_p\, (T_{out} - T_{in}) \quad (1)$$

Where, n is the number of heat pipes, m is working fluid flow rate between heat pipe and generator and Q_u is useful energy gain in unit of area that can be calculated using the following equation:

$$Q_u = F_R\, (Ta)_{ave}\, G - F_R U_L \Delta T \quad (2)$$

Where Q_u useful energy gain in unit of area (W/m^2),F_R is collector heat removal factor,$(Ta)_{ave}$ is transmittance-absorptance product(w/m^2K),U_L is collector overall loss coefficient ($w/m^2 K$) and ΔT is difference between internal temperature of collector and ambient temperature (°C).

According to the above information and using equations 1 and 2, optimal absorptive area of heat pipe will equal 135 m^2.

Adding a solar heat pipe to the effective area of 135 m^2 to chiller-heater, other equipment like water storage tank, solar station pump, and an electric heater will be required.

Based on discharge rate of hot water outflow and the distance between chiller and roof (where heat pipes are installed), discharge rate of pump equal to 26.3 m^3/hr. Furthermore, volume of water tank is approximately 37m^3. According to the results of software simulations, working hours of auxiliary system (electric heater) in cloudy days equals 270 hr/year. Therefore, capacity of this system is 30 KW.

Capabilities measurement of chiller-heater systems can be evaluated by "coefficient of performance" .In absorption systems, it is calculated as follows [17]:

$$COP_{(heating)} = (Q_c + Q_a) / (Q_g + W_p) \quad (3)$$

Where Q_c is heat transfer in condenser of the chiller, Q_a is heat transfer in absorber of the chiller, Q_g is heat transfer in generators of the chiller and W_p is required power in chiller pumps (solution and cooling pumps).Putting the quantities in equations, coefficient of performance for single effect and double effect systems are 0.63 and 1.17, respectively. It shows that double effect system is technically better than single effect one.

3. Economic analysis

Break-even-point method for Economic analysis was used for each systems. In this method each system was analyzed separately. Fixed costs of each design should be determined and then variable costs of first year can be calculated based on interest and inflation rates. In order to determine total cost in the first year, the variable cost will be added to the fixed cost. This will be repeated until nth year (effective lifespan of the research) and, therefore, total cost of the plan until nth year will be

calculated. By putting annual economic information of the two systems in a single diagram, they will be compared economically.
Table 2 shows global price of equipment and energies mentioned in the research.

Table (3)- Global price of equipment and energies mentioned in the research(2011).[18]

natural gas	**electricity**	**heater**	**pump**	**storage tank**	**solar heat pipe**	**Steam double effect chiller heater**	**Direct-fired chiller heater**
0.4 $/m^3$	0.33$/KWh	50 $/KW	11 $/W	790$/m^3$	278 $/m^2$	510$/KW	500$/KW

Energy economy calculations, difference of interest and inflation rates are considered 8% and effective lifespan of both systems is considered 30 years. It should be noted that installation and setup cost of both systems equals 12% of equipment cost and maintenance cost equals 1% of initial investment [18].
According to the numbers listed in table 3 and technical specifications of the systems, fixed costs (including equipment, installation and setup) for single effect and double effect systems are 59069 and 141630 dollars, respectively. In order to find variable costs (including energy consumption and maintenance), we use the following equation:

$$V\,C_n = (C_e + C_m)\,(1 + i)^n \qquad (4)$$

Where VC_n is variable costs in nth year, C_e is energy costs of a year, C_m is annual maintenance cost, i is the difference between interest and inflation rate for energy, and n is the given year in economic calculations.

4. Results and Discussions

Using equation 4, costs of the two designs were calculated for 30-year period. The results are shown in figure 5.

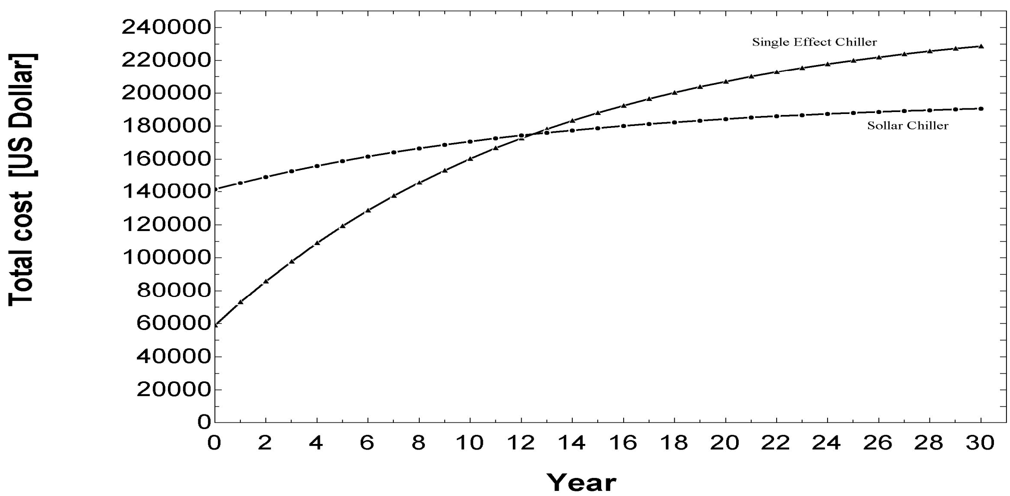


Figure 5-Economic analysis of two systems by determining break-even-point

As shown in figure 5, solar absorption system, compared with gas-fired system, requires higher initial investments due to more peripheral equipment, but its increasing slope and variable costs careless than the

other system. The reason is that absorption system uses low level of fossil energy. As a result, total cost of absorption system will be less than gas-fired system from 13th year on. Therefore, absorption system is more economical than gas-fired system after 13 years, and helps saving financial resources.
According to the statistics (RetScreen), consuming every MWh of energy in Iran Disseminates 0.543 tons of carbon dioxide in the atmosphere. Considering this fact and taking into account the amount of energy consumed in the above two systems, it can be concluded that using solar absorption chiller-heater prevents the dissemination by 829 tons a year. If, as experienced in the world, one ton reduction in Co_2 dissemination was rewarded by 15 dollars in Iran, there was 12435-dollars extra profit for the project. Considering effective 30-years lifespan of solar chiller-heaters, total reduction in CO_2 dissemination will be 24870 ton that is a significant number [19].
This shows environmental importance of the solar system and its advantage over fossil-fired systems.

5. Conclusion

In this research, a steam double effect chiller-heater equipped with solar heat pipe was used in a sample space with the area of 975 m^2 located in Tehran, which is currently equipped with a direct-fired single effect absorption chiller-heater. These two two chiller-heater systems were compared and concluded that: the solar system increases coefficient of performance by .54, decreases CO_2 dissemination by 829 tons in each year, and reduces energy consumption by 1552.42 MWh/Yr. Economic analysis of the two systems using break-even-point

showed that solar system will be more profitable than absorption gas-fired system from 13th year on.
Using chiller-heaters equipped with solar collectors not only reduces fossil fuels consumption and pollutant dissemination, but also provides economic benefit compared with fossil-fired systems. It is expected to reduce growth costs . These systems will decrease as a result of severe completion among manufacturers in upcoming years.

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