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Energy Mix Opportunity of Vapor Absorption Refrigeration System Integrated With Solar Collectors: A Case Study of Hotel Shangri-La

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Abstract

The objective of this research is modeling the absorption system with LiBr-H_2O as the working pair. The basis of this research is to implement renewable technologies in high energy consumption industry which mainly depends upon grid electricity. Based on 80 TR installed vapor compression chiller system of Hotel Shangri-La, the absorption system was analyzed with mathematical formulation in MATLAB and the model was validated with two similar models from past literature and steady state analysis of the vapor absorption system. To replace the two vapor compression chiller of the hotel each of 40 TR, a single absorption chiller of 80 TR capacity is taken into consideration. Thirty number of solar collectors each of area 3.5 m^2 when installed on the rooftop for powering the 80 TR absorption chiller, reduced the electrical load by 8.42% when fulfilling the desired cooling load. Financial analysis of the above mentioned system has been carried out. It was seen that the system was financially feasible when there is at least 50% subsidy in the capital investment since the capital investment for installation of solar assisted vapor absorption system is very high.

Keywords

Solar collectors – Vapor Absorption System – MATLAB – LiBr-H_2O refrigerant – HVAC

1. Introduction

Energy demand in Nepal has been exponentially increasing over the last few years. It has become paramount to focus on the energy saving methods, use of renewable energy sources and of reducing the green-house gases. Many of the technically feasible solutions were exploited by different segments in Nepal and still the renewable energy usage is not optimum to its full potential till date.

Deferred investment in electricity infrastructure has caused scheduled power cuts of up to 16 hours per day during dry season. As this situation is expected to worsen in future, commercial and industrial entities increasingly operate costly diesel generators. The import of petroleum products has exceeded total exports and thereby contrbutes significantly to Nepal's trade balance deficit. Hence renewble energy source has been a matter of concern for fulfilling the energy demand. A most common renewable as well as free energy is the sun. Solar energy is a very large, inexhaustble source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 10^{11} MW [1], which is much larger than the present consumption rate on the earth of all commercial energy sources. thus, in principle, solar energy could supply all the present and future energy needs of the world on the continuing basis. This makes it one of the most promising of the unconventional energy sources. In addition to its size, solar energy has two other factors in its favor. First unlike fossils and petroleum products, it is an environmental clean source of energy. Second it is free and available in adequate quantities in almost all parts of the world where people live. However, there are many problems assosciated with its use. The main problem is that it is a dilute source of energy.

Although developing countries like Nepal, the need to reduce the GHG emissions and local pollutions is not a major priority, the international consumers on the hotel industry are attracted to green hotels which utilize minimum non-renewable energy sources and to the hotels which do not disturb the natural environmental balance. This has driven the Nepalese hotel industry to focus on becoming an environmental friendly industry.

It is necessary for Nepalese hotel industry to exploit the possible scenarios to develop their own alternative energy sources and to mitigate the adverse environmental impact of using fossil fuel.

A study on the commercial sub sectors show that most of the enegy consumption almost 55.68% is found in Hotels and Restaurants. Nepal suffers the problem of grid electricity crisis and thus hotels and restaurants use other sources of energy and most of the energy is obtained from petroleum products and fuelwood which accounts for a large amount of CO_2 emissions [2].

HVAC systems utilize almost 50%-70% of electricity and balance electricity usage is for lighting and auxiliary machineries. If a practical approach on using alternate and sustainable sources for the use of HVAC can be focused, then the dependence of grid eectricity can be reduced to a significant level. If the usage of electricity for AC systems could be reduced, then the energy cost would come down, this would lead to lower overhead cost, invariably increasing the profits and thereby allowing the industry to have a sustainable growth in the country's economy.

2. Literature Review

J.R Adhikari designed a solar absorption air cooling system for an office building with LiBr-H_2O solution. He also did the performance analysis of the designed system with Engineering Equation Solver and concluded that on a long term solar cooling system is viable for reducing the high electricity consumption for refrigeration and air conditioning [3]. However, the system was designed for an office space with two rooms with the cooling load calculations based on the office building materials.

V.K Bajpai designed solar powered refrigeration system of unit capacity with NH_3-H_2O solution and concluded that a solar water heating unit can be usefully employed for water cooling purposes. In the month of summers, when the solar heating unit is closed and even the solar potential is quite high, the unit can be used for refrigeration [4].

2.1 Vapor Absorption System

A vapor absorption system consists of five basic components; an absorber, a generator, a condenser, an evaporator and a solution heat exchanger.

A solution heat exchanger, placed between the absorber and generator, makes the process more efficient. Low pressure water vapor is absorbed in the absorber by the solution. The heat generated during the absorption is removed by cooling water.

A pump circulates the weak solution, with a part of it being sent to the generator through the solution heat exchanger. In the generator, the weak solution which comes from the solution heat exchanger is heated to boil and release the water vapor.

The strong solution with LiBr is returned to the solution heat exchanger and absorber. The water vapor is condensed to liquid and condenser, and then it is passed via an expansion valve to the evaporator.

2.2 Single Effect Solar Absorption System

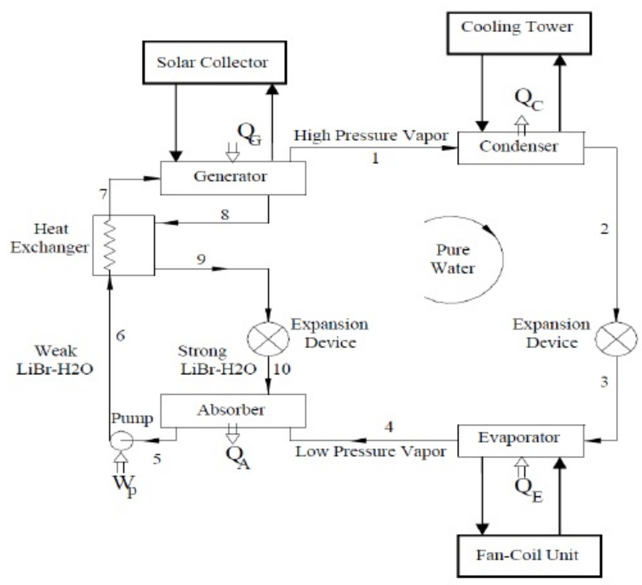

Figure 1: Single Effect Solar Absorption System

As shown in figure 1, the solar energy is gained through the solar collector. The hot water from hot storage tank is supplied to the generator to boil off water vapor from the solution of LiBr-H_2O. The water vapor is cooled down in the condenser and then passed to the evporator where it is again evaporated at lower pressure and temperature.

The strong solution leaving the generator and flowing to the absorber passes the solution heat exchanger to preheat the weak solution entering the generator. In the absorber, the strong solution absorbs the water vapor leaving the evaporator.

An auxiliary heater is required to drive the generator when the temperature of the hot water is not sufficient.

3. Methodology

3.1 Sample Selection

Hotel Shangri-La has installed two chiller plant 40 TR capacity each for producing chilled water to fulfil the HVAC requirements of the hotel. The COP of the installed system, on average is 2.1 and it uses R22 as a refrigerant. The problem formulation is based on the present condition of energy use in Hotel Shangri-La. Almost 59% of the total electricity consumption is used for HVAC. So, a vapor absorption system is modelled in MATLAB, based on the installed vapor compression system capacity. The input values and parameter values for the system is based on the Thermax Cogenie LT Z518 absorption chiller of 80 TR Capacity which is to replace the existing two compression chillers of capacity 40 TR each. The designed vapor absorption system is to be powered by solar energy.

3.2 Numerical Equations for Vapor Absorption System

Based on the existing 80 TR vapor compression chiller system of the Hotel and the inlet temperature of the external streams, the absorption system is designed. The cooling water for the absorber and the condenser is provided from the cooling tower that is used in existing compression system. Therefore, the cooling water temperature incoming has the temperature of about 12-15°C.

For developing the analytical model for simulating LiBr-H_2O absorption system, each component of the absorption system is treated as a control volume with its own inputs and outputs. The mathematical model is described by mass balances, energy balances and heat transfer equations between internal and external streams for each component. Following assumptions were made:

- Steady State and Steady Flow.
- Changes in potential and kinetic energies across each component is negligible.
- No pressure drops due to friction
- Only pure refrigerant boils in the generator.
- Mass accumulation in the system components is neglected

A schematic diagram of the designed system's flow diagram is shown in figure 2.

The model was validated with two other models from the previous research. Wonchala et al [6], who did the analysis for a 10 kW vapor absorption system and Patel et al. [7] who designed and fabricated a vapor absorption system of 140 kW. The comparison between the models is as shown:

Table 1: Comparison with Wonchalal et al. 10 kW

Data	Results from	
	Wonchala et al	MATLAB Model
Heat Capacity of Generator (kW)	14.2	13.87
Heat Capacity of Condenser (kW)	10.69	10.60
Heat Capacity of Absorber (kW)	13.51	14.32
Coefficient of Performance	0.71	0.721

Table 2: Comparison with Patel et al. 140 kW

Data	Results from	
	Patel et al	MATLAB Model
Heat Capacity of Generator (kW)	200.8	197.18
Heat Capacity of Condenser (kW)	148.02	147.13
Heat Capacity of Absorber (kW)	181.57	184.23
Coefficient of Performance	0.75	0.702

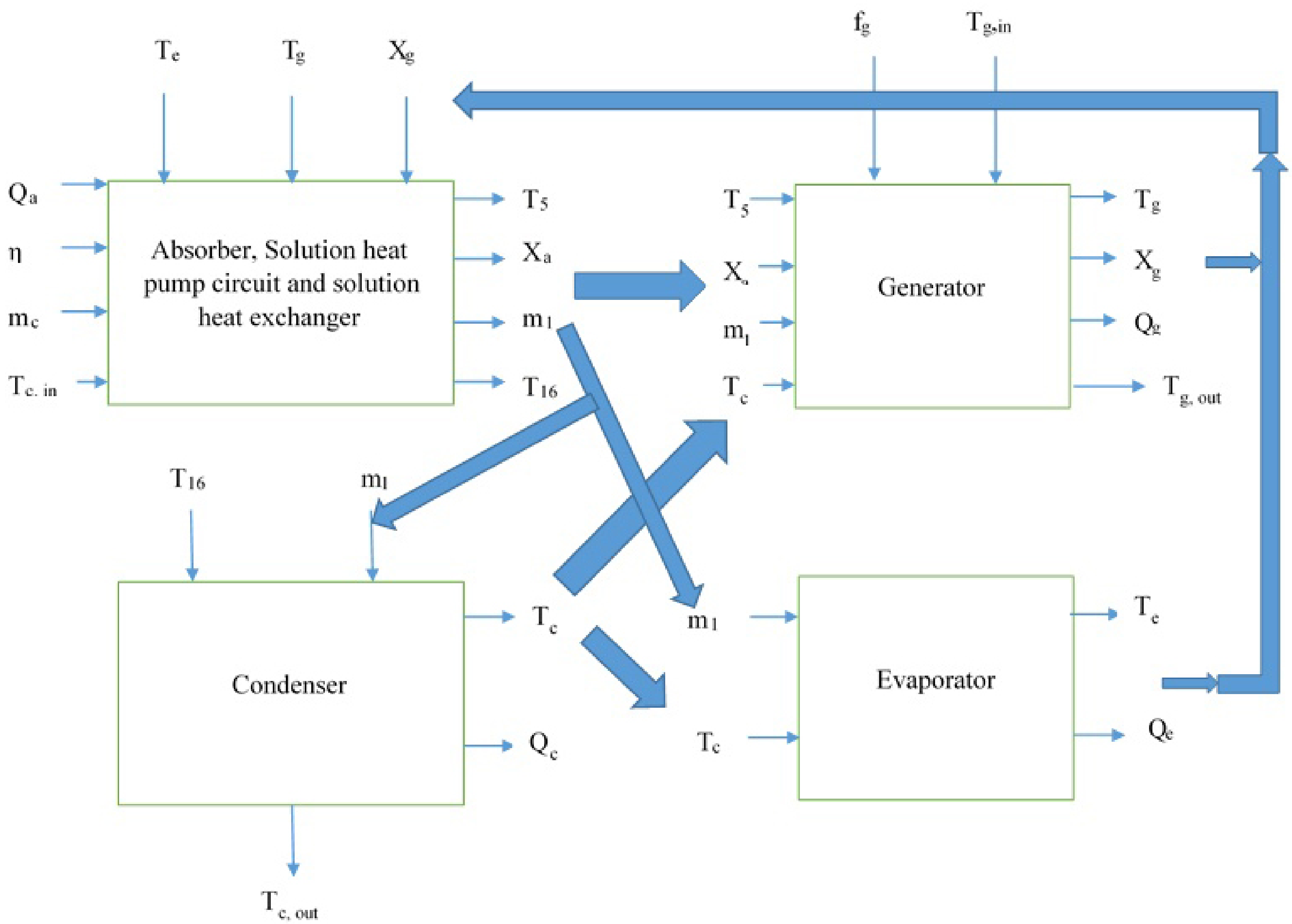

Figure 2: Flow Diagram of Absorption System [5]

4. Result And Analysis

For steady state analysis of the required 80 TR absorption system, the input parameters for modeling the absorption system in this thesis is based on the specifications of Thermax Cogenie LT absorption chiller model Z518 [8]. The result was compared with the result from MATLAB/ SIMULINk model which are as follows:

Table 3: Comparison with Steady State Analysis

Data	Results from	
	MATLAB Model	Steady State Analysis
Evaporator Heat Transfer Rate (kW)	284.10	280
Condenser Heat Transfer Rate (kW)	300.06	303.87
Generatorr Heat Transfer Rate (kW)	348.60	334.16
Absorber Heat Transfer Rate (kW)	338.85	332.036
Coefficient of Performance	0.79	0.83

4.1 Solar Collectors for Hot Water Inlet to Generator

It has been seen that on average, per month electricity consumption is 56660 kWh, out of which 33604 kWh electricity consumption is used for HVAC requirements. As calculated, the heat required in the generator is 345.6 kW. The data for solar radiation has been retrieved from NASA meteorological data. The data is based on a 22 years average data. The latitude and longitude of Hotel Shangri-La was calculated to be 27.725^{0}N, 85.322^{0}E. For 80 TR absorption chiller, the total electrical load is 345.6 kW.The average solar insolation is 7.85 kW/m^2/day and on installing 30 solar flat plate collectors each of 3.5m^2 area, the average available heat energy from solar is 29.13 kW. This results in saving of 8.42% of direct electricity consumption with an electrical energy saving of 48938.4 kWh per year.

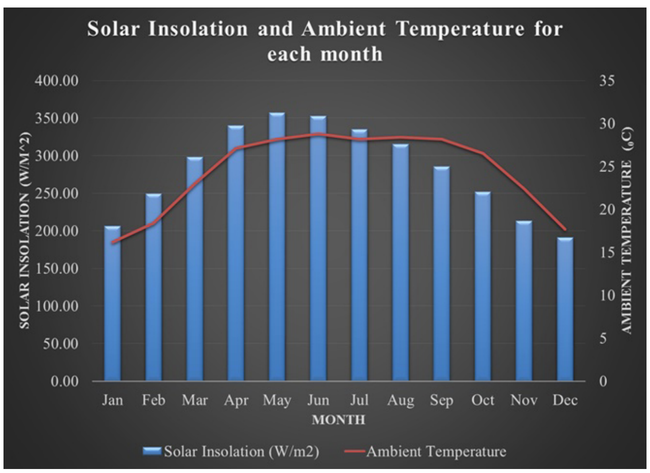

Figure 3: Solar Insolation and Ambient Temperature in Kathmandu year 2012 (Source: Nepal Statistical Data)

For Apricus solar collectors of 3.5m^2 area ech, the inlet temperature to the collector is 18^{0}C and the outlet temperature is 80 ^{0}C. For available solar energy of 29.13 kW, the mass flow rate of cold water to the collector is 0.112 kg/s and hence, a pump with the capacity to recover the head loss in the collector is required. Furthermore, for every square meter of the flat plate collectors manufactured by the Apricus company, 53.8 liters of storage tank is required. This results into 5.65 m^3 of storage tank when thirty number of solar collectors of 3.5 m^2 is installed. Taking into consideration that the temperature of hot water from the storage tank is 70^{0}C and the temperature of hot water in the generator is 85^{0}C, the mass flow rate of hot water from storge tank to generator is 0.464 kg/s and a suitable pump needs to be installed for this discharge.

4.2 Financial Analysis

The financial analysis was carried out with the quotation available from the Airtech Industries. The system life cycle was considered to be 16 years [9]. The average electricity price was taken from NEA Electricity Bill Directives, 2012.. On the basis of these and assuming the inflation rate to be 8.6%, the financial analysis was carried out. It was seen that without subsidy, the rate of return was only 1.16%. On increasing the subsidy rates in capital investment from 10% to 90%, it was seen that the project seems feasible only when there is a subsidy at 50% and more. The internal rate of return for different subsidized rates is shown in the graph below.

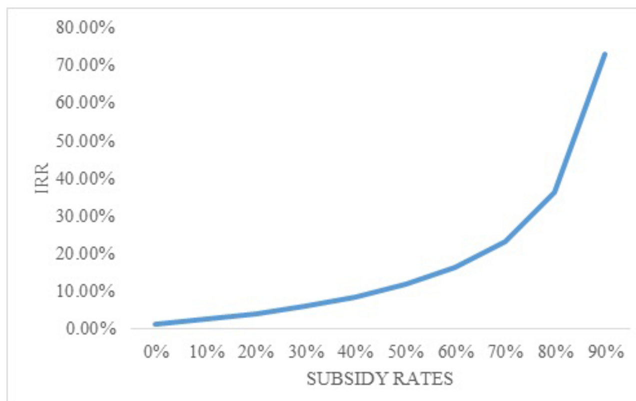

Figure 4: IRR for different subsidized rates

5. Conclusion and Recommendations

5.1 Conclusion

In this thesis, the energy consumption of a 5 star hotel (Hotel Shangri-La) building was studied and it was found that the major consumption of electricity was through the HVAC use. The installed 2 chiller plant of 40 TR each is going to be replaced in the near future and with this objective, the mathematical modeling of an absorption system was done. It was seen that most of the electricity consumption was from the use of HVAC. Almost 59% of the total electricity was used for HVAC requirements. Since absorption system is powered by heat, the consumption of electricity reduces to a larger extent. This research introduces solar technology to operate a single effect LiBr-H_2O absorption cooling system. Based on the model results, the following conclusion were drawn:

- From the simulated results of the absorption system, the evaporator heat transfer rate, condenser heat transfer rate, the generator heat transfer rate, the absorber heat transfer rate and the COP of the overall system was found to be 284.10 kW, 300.06 kW, 348.60 kW, 338.85 kW and 0.79 respectively with a deviation of 5%.
- Installing thirty number of solar flat plate collectors, it was seen that almost 8.42% of the direct electricity consumption is saved per year. When solar energy is not available, then the auxiliary heater can be powered through the electricity or the existing boiler system can be used to provide heat to the system.
- It was seen that the absorption system in financially not feasible without subsidy with the current market inflation rate of 8.6% because of its high capital cost. Hence, 50% subsidized capital cost made the absorption system feasible with an IRR of 11.91% but increasing the payback period to 14 years. However, on increasing the subsidy rates, the payback period decreased, with an increased NPV and IRR.

5.2 Recommendations for future

In this research, the mathematical modeling of different components of an absorption system has been done. However, in the future, further research can be done which are as follows:

- Research on the viability of thermal storage system for HVAC use.
- Optimization on the component design of absorption cooling system for increasing the COP.
- Building analysis with retrofitting of the system.
- Research on implying the technology for refrigeration in supermarkets.
- Research on the use of evacuated tube collectors for powering the absorption system.

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