Innovative approach and Performance analysis using LabVIEW in Solar assisted vapour absorption cooling system

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Abstract: **This paper reviews the past efforts of solar assisted-single effect vapour absorption cooling system for buildings. Besides the review of the past theoretical and experimental investigations of solar absorption cooling systems, some new ideas were introduced to reduce heat transfer loss to generator and thus to increase COP to get effective cooling. An experimental setup of vapour absorption cooling system was designed, developed and constructed. In order to monitor and analyze the performance of the cooling system it is necessary to collect the operation parameters of the system. In this regard the technique of visual instruments and the characteristics of cooling system is combined using national instrument product LabVIEW.**

Keywords: **Solar Absorption cooling system (SACS), DAQ system, LabVIEW**

I.INTRODUCTION

Cold production through absorption cycles has been traditionally considered one of the most desirable applications. The CFCs and HCFCs gases, which are used by the conventional vapor compression cooling system have high global warming potential and also high ozone depleting potential [1]. These effects can be remedied by choosing the environmental friendly cooling system like H_2O/LiBr absorption system. An absorbent and a refrigerant in an absorption cycle form a working pair. The most common working pairs in absorption cooling system are lithium bromide-water and water-ammonia. For cooling purposes, the LiBr-H_2O system is the cheapest, while the cost of H_2O-NH_3 is high. The optimum generator temperatures in the LiBr-H_2O system for cooling purposes are around 75 to 92°C and evaporation temperatures about 5-10^{0}C [2]. The advantages of absorption method over conventional method is that they consume little electricity, they can be run by low thermal energy source, they have very few moving parts leading to low noise and vibration levels, and they do not emit ozone depleting substances[3].

1.1 Working principle of lithium bromide-water vapour absorption cycle:

The basic working principle of lithium bromide-water absorption cycle is depicted in Figure.1, which is the simplest and most commonly used design. In the absorption cycle, compressing refrigerant vapour is achieved by the absorber, the solution pump and the generator. Water evaporated from evaporator (which outputs a cooling effect) is absorbed into a strong lithium bromide solution in the absorber, and the absorption process need to release heat of absorption to the ambient. After absorbing the water vapour, the lithium bromide solution becomes a weak solution, which is then pumped to the generator. As heat is added to the generator, water will be desorbed from the solution in a vapour form. The vapour then flows to the condenser, where it is condensed and condensing heat is rejected to the ambient. The condensed water flows through an expansion device, where the pressure is reduced. The strong solution from the generator flows back to the absorber to absorb water vapour again, a heat exchanger could be used between the strong solution and weak solution lines. The entire cycle operates below atmospheric pressure, since water is used as the refrigerant [4].

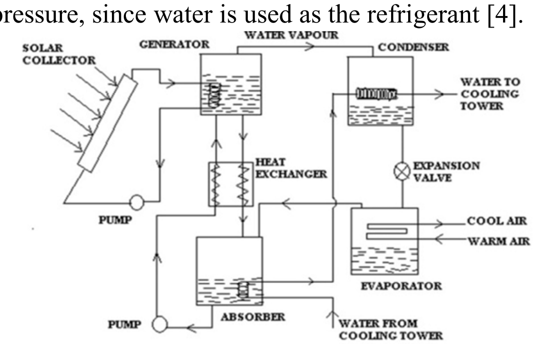

Fig: 1. Schematic representation of solar assisted single effect LiBr-H_2O absorption cycle

II. NI LABVIEW TECHNOLOGY

LabVIEW is a powerful and versatile graphical programming environment which was developed primarily to facilitate instrumentation control and data acquisition and analysis. Applications created with LabVIEW are referred to as virtual instruments (VI). VI source code is created using the graphical programming language G in a window called the block diagram. Input and output interfacing with the VI is performed in another window called the front panel. The graphical icon-based source code and interfacing creates very user-friendly applications and eliminates typing in lengthy character-based code [5]. LabVIEW itself was a graphical development environment for creating flexible and scalable test, measurement, and control applications rapidly and at minimal cost. The virtual instrument technology can make full use of computer resource, generalizing instrument hardware. It can not only improve test efficiency and precision, but also promote the development process of absorption cooling system equipments [6]. LabVIEW implements a dataflow paradigm in which the code is not written, but rather drawn or represented graphically similar to a flowchart diagram. These include simple network communication, turnkey implementation of common communication protocols (RS232, GPIB,etc), powerful toolsets for process control and data fitting, fast and easy user interface construction and an efficient code execution environment. This paper explains the performance analysis of solar assisted absorption cooling system unit based on LabVIEW.

III. EXPERIMENTAL INVESTIGATIONS

Usually, the cooling capacity and COP of solar cooling systems were tested under practical operating conditions. Rosiek and Batlles [7] reported the flat-plate solar collectors with the area of 160 m^2 and a single-effect absorption chiller with the cooling capacity of 70 kW were used to meet the energy demands for cooling in summer. The performance of the solar-powered cooling system was monitored and controlled by a control and data acquisition system. The average values of COP and the cooling capacity were calculated of the order of 0.6 and 40 kW, respectively. Mammoli et al. [8] carried out the experiments of a solar cooling system for a 7000m^2 educational building using 124 m^2 of flat-plate collectors and 108m^2 of vacuum tubular collectors. A 70 kW absorption chiller was designed to work with hot water supply temperatures in the range from 70 to 95^{0}C. The cold water produced by the absorption chiller is stored in seven 50 m^3 cold water tanks and supplied to the cooling coils. According to the experimental results, in the peak of summer, the solar cooling system could supply approximately 18% of the total cooling load. Syed et al. [9] investigated a solar cooling system consisting of a 35 kW LiBr/H_2O absorption machine energized by 49.9 m^2 of flat-plate collectors. Thermal energy was stored in a 2m^3 stratified hot water storage tank. The generator design of the machine allowed the use of hot water in the temperature range of 65–90^{0}C. The measured maximum instantaneous, daily average and period average COP were 0.60 (at maximum capacity), 0.42 and 0.34, respectively. Li and Sumathy [10] studied the performance of a solar-powered absorption air conditioning system with a partitioned hot water storage tank. The system employed a flat-plate collector array with the surface area of 38 m^2 to drive a LiBr/H_2O absorption chiller of 4.7 kW cooling capacity. The system was provided with a storage tank (2.75 m^3) which was partitioned into two parts. The upper part had a volume of about one-fourth of the entire tank. The study revealed that the solar cooling effect could be realized nearly 2 hrs earlier for the system operating in partitioned mode. In this system a solar COP of about 0.07, which was about 15% higher than with traditional whole-tank mode, was attained. Agyenim et al. [11] developed a domestic-scale prototype experimental solar cooling system, which consisted of a 12 m^2 vacuum tubular solar collector, a 4.5 kW LiBr/H_2O absorption chiller, a 1000 l cold storage tank and a 6 kW fan coil. The average COP of the system was 0.58. M.Izquierdo [12] conducted trials to determine the performance of a commercial 4.5-kW air-cooled, single effect LiBr/H_2O absorption chiller for residential use. Measurements were recorded over a 20-day period. The hot water inlet temperature in the generator varied throughout the day from 80 to 107^{0}C. The results for the period as a whole showed that cooling power tended to decline with rising outdoor dry bulb temperatures. At outdoor temperatures from 35 to 41.3^{0}C the chilled water outlet temperature in the evaporator climbed to over 15^{0}C. The total energy supplied to the generator came to 1085.5 kWh and the heat removed in the evaporator to 534.5 kWh. The average COP for the period as a whole was 0.49.

IV. THEORETICAL ANALYSIS AND SIMULATION

The main components of a solar absorption cooling system are the solar field, the absorption cooling system and the heat storage water tank. Many research works were carried out by theoretical analysis and simulation with the aid of Simulation softwares. Balghouthi et al. [13] presented the feasibility of solar-powered absorption cooling technology using TRNSYS and EES programs with a meteorological year data file containing the weather parameters of Tunisia. The optimized system for a typical building of $150m^2$ was composed of a $LiBr/H_2O$ absorption chiller of a capacity of 11 kW, a 30 m^2 flat-plate solar collector area tilted 35^0 from the horizontal and a 0.8 m^3 hot water storage tank. Florides et al. [14] designed a $LiBr/H_2O$ absorption unit with the cooling capacity of 11 kW in Cyprus. The optimum system as obtained from the complete system simulations consisted of 15 m^2 compound parabolic collectors tilted at 30^0 from horizontal and a 600 l hot water storage tank. Assilzadeh et al. [15] reported a solar cooling system using evacuated tubular solar collectors and a $LiBr/H_2O$ absorption unit. It was shown that a 0.8 m^3 hot water storage tank was essential in order to achieve continuous operation and increase the reliability of the system. The optimum system for Malaysia's climate for a 3.5 kW system consisted of 35 m^2 evacuated tubular solar collector sloped at 20^0. Atmaca and Yigit [165] simulated a solar cooling system based on a 10.5 kW constant cooling load. A modular computer program was developed for the absorption system to simulate various cycle configurations and solar energy parameters for Antalya, Turkey. It was shown that the solar collector area of 50 m^2, a 3750 kg storage tank mass seemed to be the best choice. Joudi and Abdul-Ghafour [17] developed an integrated program for the complete simulation of a solar cooling system with a $LiBr/H_2O$ absorption chiller. The results obtained from the simulation were used to develop a general design procedure for solar cooling systems, presented in a graphical form called the cooling fchart. Using this design chart could simplify the designer's task for predicting the long term cooling energy supplied from a solar collector array serving an absorption chilled water system. Jian Sun [18] made a mathematical model of a single effect, LiBr–H2O absorption heat pump operated at steady conditions. He took into consideration of crosscurrent flow of fluids for heat and mass exchangers, two-dimensional distribution of temperature and concentration fields, local values of heat and mass transfer coefficients, thermal parameter dependent physical properties of working fluids and operation limits due to the danger of the LiBr aqueous solution hydrates and crystallization.Xiaohong Liao [19] focused on the crystallization issues and control strategies in $LiBr-H_2O$ air-cooled absorption chillers. He specified six causes which may trigger crystallization: (1) high ambient temperature; (2) low ambient temperature with full load; (3) air leak into the machine or non-absorbable gases produced during corrosion; (4) too much heat input to the desorber; (5) failed dilution after shutdown; and (6) chilled water supply temperature is set too low when the weather and/or exhaust are too hot.

V. INNOVATIVE APPROACH OF SOLAR ABSORPTION COOLING SYSTEM

The schematic diagram as per innovative design is shown in Figure.2. As per the new design, three major electrical components are required to run the system. A fan in the air cooled condenser, a blower in the evaporator and a solution pump to pump weak solution from the absorber to the generator. In this new design the generator is placed inside the insulated hot water storage tank. The separate insulation cost for the generator gets avoided. If the storage tank and generator are separate units then the hot water has to be circulated from the tank and heat transfer loss will occur. From the new design the heat transfer loss is minimized. Thermo siphon principle is used to transfer heat from the solar collector to the storage tank.

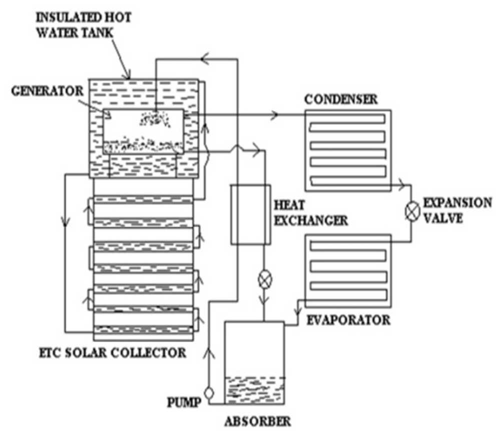

Fig.2 SACS with Generator placed inside hot water tank

This avoids the usage of pump to circulate the water from collector to tank. The two main circuits: 1. Hot water circuit (solar collector – hot water storage tank – solar collector). 2. Refrigerant circuit (generator – condenser – evaporator – absorber – solution pump – generator) is evacuated and the vacuum pressure can be raised to reduce the boiling point of water. This helps to run the absorption cooling system even in low solar thermal intensity. The refrigerant vapour and the strong solution from the generator are passed to the absorber by siphon principle and the components of the cooling system are placed at proper altitudes so that both fluids will flow in the required pressure. The components used in conventional cooling system like condenser and evaporator are used to get better performance and reduce cost.

VI. PERFORMANCE ANALYSIS OF SACS USING LABVIEW

The thermal coefficient of performance of the vapour absorption cooling system was dependent upon the heat supplied to the generator and the cooling effect produced by the evaporator. These parameters should be measured and monitored during the operation process, and so the DAQ system based on LabVIEW 10.0 was set up which consists of both hardware and software components. The main components of the hardware configuration for the absorption cooling system consisted of USBDAQ 6210 data acquisition switch unit, a personal computer, temperature and flow sensors.

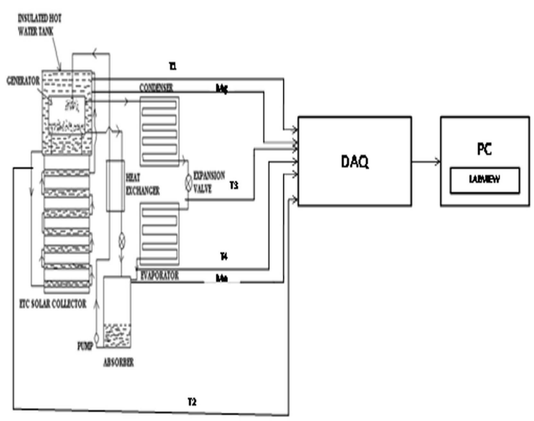

Fig.3 Data acquisition system by using LABVIEW

Figure.3 shows a schematic diagram of the DAQ system set up for this research. Temperature signal was collected by copper-constantan thermocouple (T type) sensors. There were 4 temperature measuring points, including hot water inlet (T_1) and outlet temperature (T_2) to heat the generator, evaporator inlet (T_3) and outlet chilled water temperature (T_4). Flow rate was collected by revolving style flow meter and converted to standard 4-20mA direct current signal. There were 2 flow rate measuring points, including hot water flow rate from collector to storage tank and chilled water flow rate in evaporator. All these collected signals were modulated by USBDAQ 6210 data acquisition switch unit, and then input into the PC. The software configuration was programmed by LabVIEW 10. The front panel of the LabVIEW GUI developed for this DAQ system. The other section was a block diagram, the core of the whole software, where the flow chart-style code was created with these functional blocks (VIs). DAQ was simply the process of measuring a real-world signal, such as a voltage, and bringing that information into the computer for processing, analysis, storage, or other data manipulation. Figure.4 shows the program block diagram of the DAQ modular in this DAQ system. For further analysis and research on the performance of the solar absorption cooling system, all these collected data should be logged to files. The block diagram extended the functionality of our previously created code to gain the direct readings of each parameter and log those values to a spreadsheet file compatible with Excel. The thermocouple measurements are noted in digital form and stored in table. The mass flow rate of water inside the hot water storage tank (m_1) and also inside the evaporator (m_2) is measured and stored in the table. The values of T_1, T_2, T_3, T_4, m_1 and m_2 are given inside the for-loop and the respective formula node where formula is specified for calculating the heat supplied to generator (Qg), cooling effect produced in the evaporator (Qe).

$$Q_g = m_1 C_{pw} (T_1\text{-}T_2) \quad (1)$$

$$Q_e = m_2 C_{pw} (T_4\text{-} T_3) \quad (2)$$

$$COP = Q_e / Q_g \quad (3)$$

The case selector is used to select the appropriate case to which the formula is specified. Then the thermal coefficient of performance (COP) was calculated. These values are given to the execute table control where the table is build for all these values and as the program executes the values are tabulated in these table. These values are given to the waveform chart where graph is plotted to monitor and analyse the performance of the solar absorption cooling system.

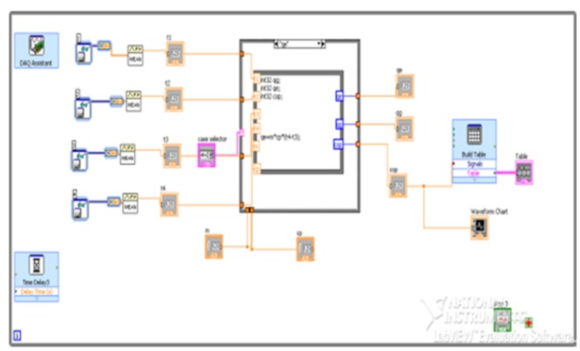

Fig .4 The block diagram

VII. RESULTS AND DISCUSSION

The specific heat capacity of water is taken as C_{pw}= 4178 J/Kg^{o}C. The mass flow rate of hot water in generator is m_1=0.05 kg/s and that of in evaporator is m_2=0.04 kg/s. The experiment was conducted on a typical hot day and readings were noted from 9 a.m to 5 p.m to find the thermal coefficient of performance of the experimental setup. The maximum generator temperature reached was 85^{0}C and the corresponding findings are discussed below.

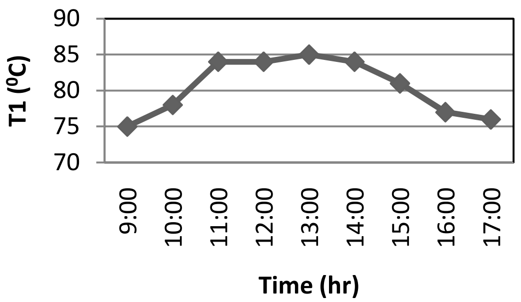

Fig.5 Hot water inlet temperature to generator

Fig.5 shows variations in the hot water inlet temperature from collector to tank throughout the experiment period. In the LabVIEW the program is made such that the temperature is noted for every minute and the average of temperature for 60 minutes is taken and plotted in the graph. Around 9 a.m the temperature in the storage tank reached 75^0C, then gradually increased and attains a maximum temperature of 85^0C around 1 p.m. Then the temperature starts decline and around 5 p.m it comes near 75^0C.

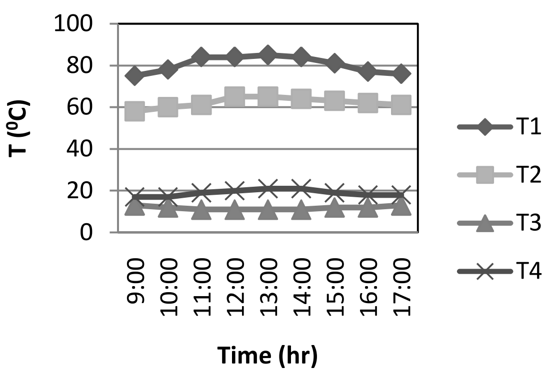

Fig.6 Inlet and outlet external fluid temperatures

Fig.6 shows the hot water inlet and outlet temperatures of the storage tank. The average difference between the inlet and outlet temperature was 18.3^0C. Also the graph shows the inlet and outlet temperatures of chilled water in the evaporator. The chilled water mean temperature difference was found to be 7.1^0C.

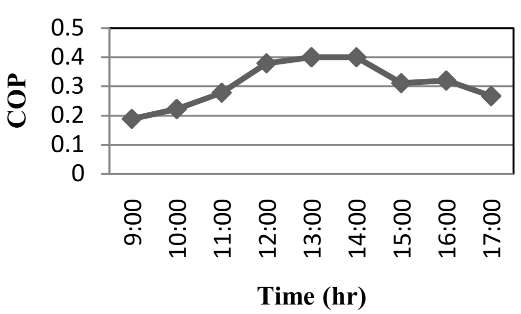

Fig.7 Change in COP during the experiment

Fig.7 shows the mean COP for every one hour throughout the experiment. The COP was calculated from the ratio between Q_e and Q_g. The maximum COP obtained was 0.4 and an average COP obtained for the entire experiment was 0.307.

VIII. CONCLUSION

It is concluded that single effect absorption cooling method using LiBr-H_2O as working fluid pair is more suitable for cooling the buildings. Flat plate and evacuated tube solar collectors are more reliable and economical for this system. According to the new idea given in this paper only three major electrical equipments are used (condenser fan, cooling coil fan and a pump). Hence the operational cost is very much minimized when compared with compression system. The data acquisition system using LabVIEW graphical programming language is a very effective way of monitoring the working of solar assisted vapour absorption cooling system. Using this, operator can easily enter the control parameters and retrieve gathered data in Excel compatible files, which are easily amenable for further analysis for energy management. The DAQ system was developed quickly and easily to store the required parameters of solar absorption cooling system and to calculate the thermal COP. Through practical data acquisition, it was proved that the performance of DAQ system was stable, the operation was reliable and each measurement precision met the testing requirement. It should be noted that we must setup the correct parameters of serial port from the LabVIEW, otherwise once the DAQ program was run, a fatal error would occur. Thus the manual work for measuring, collecting, calculating and storing the data were minimized.

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