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Thermodynamic Evaluation of Cooling with Process Heat in Cogeneration Process for Industrial Applications in India

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ABSTRACT

In this paper the thermodynamic evaluation of cooling with process heat for industrial application in India has been investigated to identify the effects of various operating parameters. In this system simultaneous production of vapor absorption refrigeration (VAR) cooling and process heat from different heat sources with higher energy efficiency take place. This is one of the solutions to fulfill energy requirements from solar energy and also helps in the reduction of carbon dioxide emissions. The VAR cooling system operates using the heat taken from parabolic trough collector and condenser heat of the VAR cooling system is used in process heat for various applications as per demand requirement. Though the production of cooling effect decreases due to extraction of heat from condenser for process heat application i.e. specifically in dairy industry, the complete cycle meets the energy requirements in industrial sector & also increases the overall efficiency. The different parametric study is also carried out to simulate the results of various useful outputs by varying various input points.

I. Introduction

India is having good potential in solar energy for thermal power generation in industrial sector from renewable energy. About 5,000 trillion of kWh per year energy is incident over India's land area with most of the parts receiving Direct Normal Irradiance (DNI) of 4-6.5 kWh per sq. m per day. Around 200-250 sunny days are available in a year for operating Concentrating Solar Power (CSP) for both producing heat and electricity [1]. The total installed capacity of renewable energy system in India is 45,743 MW (including small hydro power only) as on November 2016. This includes, 61.39% (28,082) from wind power, 17.79% (8,138) from SPV power, 10.92% (4,997) from bio-power, 9.45% (4,323) from small hydro power & 0.44% (203) from concentrated solar thermal power as shown in Figure 1.2 [2]. The launching of the Jawaharlal Nehru National Solar Mission (JNNSM) symbolizes both and indeed encapsulates the vision and ambition for the future of solar energy. The cost of power produced from Concentrated Solar Power (CSP) is becoming competitive with conventional energy sources with the development of technologies [3].

Many industries use their electricity for their own requirements, like cooling, process heat for different applications (preheating or feed water heating) to fulfil the energy demand. According to Ministry of Petroleum and Natural Gas, nearly 42 % of refined crude is used for process heat for industrial and commercial applications. These include boiler make-up water and feed-water heating, steam generation, cooling using vapor absorption refrigeration. Over 15 million tons of fuel oil has been estimated to be consumed in industries for those applications.

Today,they either buy power from the State Electricity Boards,or generate their own power largely.In other way solar concentrating collectors are specially designed for such operating temperature ranges for cooling system.Solar thermal heat can give the solution to overcome these huge amount of electricity for different industrial applications.To reduce energy demand and provides two such outputs like cooling,process heat, a new concept of Co-generation is being introduced in solar vapor absorption refrigeration cooling for continuous production of cooling and process heat, which can meet the captive requirement and helps in significant savings. The term of “Cogeneration” is giving a generalized idea on heat management for combined production of cooling and process heat as per their load requirement.Cogeneration process reduces the installation cost of each system and improves the overall efficiency, reliability and economical aspects for energy conversion applications.A new cogeneration process through renewable sources has been developed by Sterling engine and fluidized bed combustor separately.The Sterling engine is operated by solar energy and Biomass combustion is operated by fluidized bed combustor. The drawback of the system was the high investment cost & smaller size [4].Waste heat from ORC is utilized for heating through heat exchanger and remaining part of heat is utilized in generator of single effect absorption chiller.Three case studies have been considered on solar power generation,cooling-cogeneration & heating-cogeneration.The three outputs from single heat source increase the efficiency [5] and the efficiency of energy production can be increased from current levels that range from 35% to 55%, to over 80% [6].

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Cogeneration system is a cost-effective at smaller and smaller scales, meaning that cooling and process heat can be produced for individual sites. The cogeneration-based district energy model was developed and used to examine a range of scenarios by several authors [7–15]. The current study is a direct extension of two previous articles by the authors [16, 17] in which a design and thermodynamic analysis has been investigated for cogeneration-based district heating and cooling [18]. Several authors are investigated on cogeneration for combined power, cooling and district heating, but cooling with process heat using waste heat from cooling system are missing in the literature survey. In the vapor absorption refrigeration system (Single Effect; LiBr-H2O) the condenser heat can be used for another such outputs like process heat.

II. System Description

The VAR cooling system has been designed such that the heat of condenser and HE-2 can be used to heat the supplied raw water (State points 12-14-15). The condensate from the HE-2 is supplied (State point 9) to the evaporator through throttle valve (State point 10). Water vapor formed from the evaporator is absorbed (State point 11) by the strong LiBr salt sprayed in the absorber maintaining low pressure in the evaporator. As LiBr salt solution absorbs water vapor, it becomes weak solution (LiBr-water) and then pumped to the generator through HE-1 (State points 1-2-3). In generator the solution (LiBr-water) splits into LiBr and water vapors and the heated water vapor at super-heated condition is supplied to the condenser whereas LiBr salt returns back to the absorber through HE-1 and EV-1.The raw water heated through HE-2 and condenser and supplied to the storage tank (State point 15) at temperature of 85-90 ^{0}C as shown in Fig.1.

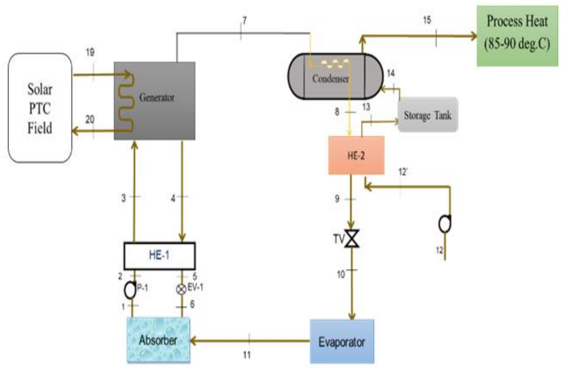

Figure 1. Schematic diagram of cooling & process heat for Industrial applications.

III. Thermodynamic Eveluation

The thermodynamic evaluation of vapor absorption refrigeration cooling and process heat for combined production of cooling and process heat has been analyzed. Specifically, the thermodynamic analysis are taken to better understand the performance of the proposed system.The following energy balance equation of major components of the system are expressed as:

Generator: $Q_g = m_3 \cdot h_3 + m_7 \cdot h_7 - m_4 \cdot h_4$

Condenser: $Q_c = m_7 \cdot h_7 + m_8 \cdot h_8 - m_{13} \cdot h_{13} - m_{15} \cdot h_{15}$

Evaporator: $Q_e = m_{11} \cdot h_{11} - m_{10} \cdot h_{10}$

Pump 1: $W_{p_1} = m_2 \cdot h_2 - m_1 \cdot h_1$

HE-2: $Q_{HE-2} = m_8 \cdot h_8 + m_{12'} \cdot h_{12'} - m_9 \cdot h_9 - m_{13} \cdot h_{13}$

The coefficient of performance of the single effect VAR cooling system is expressed as

$$COP = \frac{Q_e}{\left(Q_g + W_{P1}\right)}$$

IV. Result And Discussions

The thermodynamic evaluation of vapor absorption refrigeration cooling with process heat in cogeneration process are presented. The different parametric study is carried out to simulate the results of various useful outputs by varying various input points such as DNI and generator heat of VAR system, evaporator temperature and coefficient of performance. The performance analysis of the PTC has been carried out at NISE. The characteristics curve between efficiency and (Tm-Ta/DNI) is shown in figure 2. Efficiency has reached maximum to 45 % in the month of May and minimum efficiency reached up to 25%.

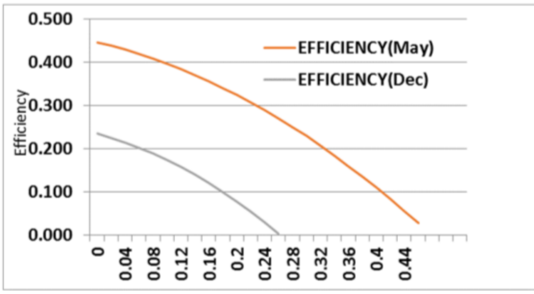

Figure 2. Characteristics graph between efficiency vs. Tm-Ta/DNI.

Figure 3, Plotted the graph between coefficient of performance and evaporator temperature at generator temperature of 180°C. It is seen that, the COP is increasing by increases of evaporator temperature from 10°C to 16°C and slowly increases from 0.539 to 0.57 at evaporator temperature of 7°C to 11°C. It is also examined that at evaporator temperature of 70°C, 10°C and 15°C the COP increasing from 0.56, 0.54 and 0.39.Figure 4 shows the graph between coefficient of performance and generator temperature.

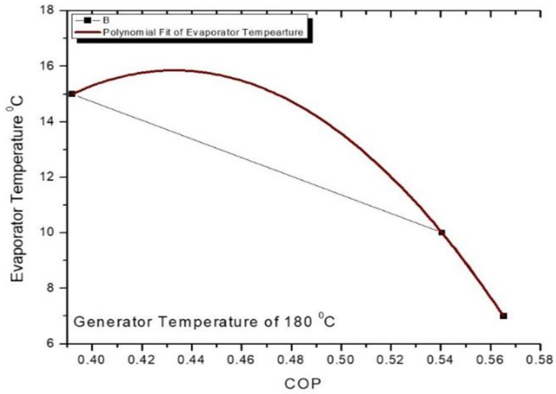

Figure 3. Evaporator Temperature vs. Coefficient of Performance at generator temperature 180 °C.

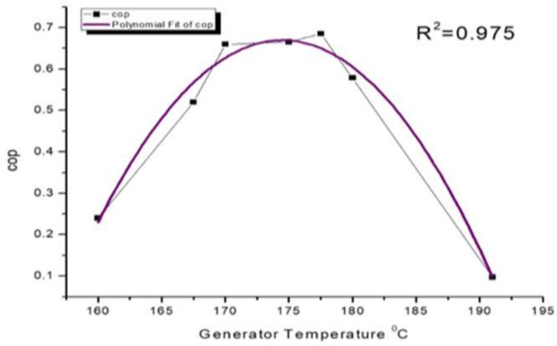

Figure 4. Generator Temperature vs. Coefficient of Performance.

It is seen that, the COP is achieved to 0.685 at a generator temperature of 177.5°C. COP increasing from 0.24 to 0.685 at a generator temperature of 160 to 177.5°C and COP drastically decreasing from 0.685 to 0.097 at generator temperature from 177.5 to 191 Figure 4 shows the graph between coefficient of performance and generator temperature. It is seen that, the COP is achieved to 0.685 at a generator temperature of 177.5 °C. COP increasing from 0.24 to 0.685 at a generator temperature of 160 to 177.5 °C and COP drastically decreasing from 0.685 to 0.097 at generator temperature from 177.5 to 191 °C.

IV. Conclusion

The VAR cooling heat of condenser and HE-2 can be utilized to heat the water from 90-100 0C for process heat applications. The system is ideal for industries specifically in dairy industry to fulfil the energy requirements for various applications i.e. cooling and process heat. The major aspect of this process is especially the developing trends of cooling and process heat form solar parabolic trough collector. It is expected that in the near future cooling with process heat in co-generation process will constitute one of the competitive options of cooling and process heat for various end use applications.

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