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Thermodynamic analysis of a trigeneration system consisting of a micro gas turbine and a double effect absorption chiller

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ABSTRACT

Combining heating and power systems represent an option to improve the efficiency of energy usage and to reduce thermal pollution toward environment. Microturbines generate electrical power and usable residual heat which can be partially used to activate a thermally driven chiller. The purpose of this paper is to analyze theoretically the thermodynamic performance of a trigeneration system formed by a microturbine and a double-effect water/LiBr absorption chiller.

The heat data supplied to the generator of the double effect air conditioning system was acquired from experimental data of a 28 kW_E microturbine, obtained at CREVER facilities. A thermodynamic simulator was developed at Centro de Investigación en Energía in the Universidad Nacional Autónoma de México by using a MATLAB programming language. Mass and energy balances of the main components of the cooling system were obtained with water–lithium bromide solution as working fluid. The trigeneration system was evaluated at different operating conditions: ambient temperatures, generation temperatures and microturbine fuel mass flow rate. The results demonstrated that this system represents an attractive technological alternative to use the energy from the microturbine exhaust gases for electric power generation, cooling and heating produced simultaneously.

1. Introduction

Cogeneration systems represent one of the strategic technologies to increase the efficiency of energy usage and distributed power generation. Among the ways of achieving cogeneration, also called combined heating and power (CHP), the use of microturbines is considered a very attractive option. The microturbines (MTs) are small size combustion turbines, with powers ranging between 28 and 200 kW_E. Among other advantages and from the environmental point of view, the use of MTs is of special interest nowadays for the reason that the level of CO_2 and NO_X emissions of MTs are significantly lower than that of reciprocating engines of similar capacity, as well as fuel flexibility [1]. One application of cogeneration systems is the coupling of an MT with absorption systems, both for single and double effect. The residual heat of the MT is used to activate the refrigeration system. In this case, the term trigeneration is applied since an additional benefit, cooling, is obtained. The interest in double effect systems for this application stems from the higher coefficient of performance compared to those of single effects, besides the commercial availability. Some works in this field have been found in the literature:

Bruno et al. [1] studied the integration of several types of commercially available absorption systems with MTs driven by biogas. It was analyzed a case study for a sewage treatment plant, finding the best configuration that completed the demands for such plant. The study developed in Ref. [2] deals with the coupling of four MTs with various power capacities with a double effect water–LiBr absorption system, focusing mainly on the effect of post-combustion natural gas on the system gas to raise the cooling capacity. Hwang [3] performed a theoretical study to show the potential of the coupled refrigeration systems with an MT and an absorption chiller, considering several applications of the cooling capacity of the chiller. The energy saving of the coupling was presented and its economical feasibility was also verified. Ho et al. [4] presented a cogeneration study using a single effect commercial absorption chiller in their experiments, showing the overall system efficiency under variable operating loads. Saito et al. [5] developed a simulation of a "micro cogeneration system" composed of a solid oxide fuel cell, an MT and a water–LiBr absorption refrigerator, considering both single and double effect. Their results show a fuel

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consumption reduction in the areas where the system was applied, giving the optimal operating conditions.

More recent works include the study developed in Ge et al. [6], which simulated and tested a trigeneration system using a single stage ammonia–water commercial absorption system to satisfy the energy demand of a supermarket. The system model was validated with the experimental results showing the effect of some parameters on the system performance. Arteconi et al. [7] also studied a trigeneration system for a supermarket, adding the suggestion of combining such system with photovoltaic systems and a technical and economical analysis. They used both water–LiBr and ammonia–water absorption units in the study as well as MTs. Velumani et al. [8] presented a hybrid cogeneration system consisting on a solid oxide fuel cell, an MT and a single effect absorption cycle to satisfy the demand of a building. The proposed system would have a thermal efficiency around 70%. Some works focuses on the evaluation of combined cooling, heating and power (CCHP) in terms of primary energy and economical analysis. Keil et al. [9] showed three examples of installation in Germany in their study, being one of them a CCHP system which uses a double effect absorption system. A cogeneration engine supplies the heat to activate this system. For this particular case, the application obtained good results in terms of energetic efficiency. A very recent work presented by Schicktanz et al. [10] analyzed the primary energy consumption and economic viability of a CCHP, based also on German data, indicating the most influential parameters of each study. The importance of electric efficiency of the CHP unit is highlighted. On the other hand, various researchers focus on the simulation of single and double effect absorption chillers [11–14]. These works present in detail the calculation methods and results with respect to the system performance or exergy analysis as a functions of operating parameters, without the integration of other systems.

This paper presents an analysis of the results obtained through a simulation of the thermodynamic performance of a trigeneration system integrated by a micro gas turbine, a double effect absorption cycle and a heat exchanger. The heat data supplied to the generator were acquired from experimental data of a 28 kW_E microturbine model Capstone C30, from CREVER facilities. The available experimental data were used to analyze the influence of the operating parameters of the microturbine on the specific systems performance. The results obtained will be useful to pose a scenario for this kind of trigeneration system.

2. System description

The proposed trigeneration system consists of a microturbine to produce electrical power, a double effect absorption water/LiBr chiller for air conditioning and a heat exchanger to produce hot water. A portion of the energy of the exhaust gases at high temperature of the MT are used to supply heat to the generator of the double effect absorption system. The remaining portion, with high enough temperature, is used to generate hot water in the heat exchanger. Fig. 1 shows the schematic diagram of this system with an example of values of energy obtained.

2.1. The microturbine

A microturbine consists of a centrifugal compressor, a radial turbine and alternator rotor, operating as a Brayton cycle. Its main feature is that a high speed generator is directly coupled to the turbine rotor and uses power electronics instead of a gearbox and conventional generator. A microturbine usually uses a single shaft, which has lower production costs than the double shaft and the generator can also be mounted opposite to the exhaust gases, therefore, they come out with lower pressure loss, which improve the net power and reduces the fuel consumption. Another way of decreasing the fuel consumption, is to use regenerators to preheat the inlet air, in addition, air emissions are very low at full load. The microturbine used in this analysis can be fueled with natural gas or propane. It is a 28 kW_E Capstone C30 model [15,16]. Detailed description about experimental facility used to obtain the data is found in Ref. [16].

2.2. Double effect absorption chiller

The main components of a double effect absorption system are a condenser, an evaporator, an absorber, a low pressure generator, a high pressure generator, two solution heat exchangers, a pump and throttling valves as shown in Fig. 2. A double effect absorption chiller can operate at three pressures and four temperatures levels. The heat is supplied to the high pressure generator ($\dot{Q}_{HP,GE}$) to obtain the primary steam and a concentrated working solution. The primary vapor changes to liquid phase in the low pressure generator, giving the heat of vaporization to the concentrated solution ($\dot{Q}_{LP,GE}$) to generate a secondary steam (going to the condenser) and the most concentrated solution, which goes to the absorber. In the condenser, two refrigerant lines converge to transfer heat to an external circuit ($\dot{Q}_{CO}$) and change the steam to liquid phase. The condensed water is evaporated at low pressure, removing the heat of vaporization of the area to be cooled ($\dot{Q}_{EV}$). In the absorber, the vapor contacts the concentrated solution (coming from the low pressure generator through the solution heat exchanger 1) to obtain a useful heat at low temperature ($\dot{Q}_{AB}$). The diluted working solution obtained in the absorber is sent to the high pressure generator, passing through solution heat exchangers 1 and 2, to repeat continuously the thermodynamic cycle.

2.3. Heat exchanger

A 40 kW plate heat exchanger was used in this analysis. The heat exchanger uses directly a part of exhaust gases of the MT and residual heat of the double effect absorption chiller to produce hot water.

3. Mathematical model of the double effect absorption chiller

The developed model is based on the following assumptions:

a) The analysis is made under thermodynamic equilibrium and steady state condition.

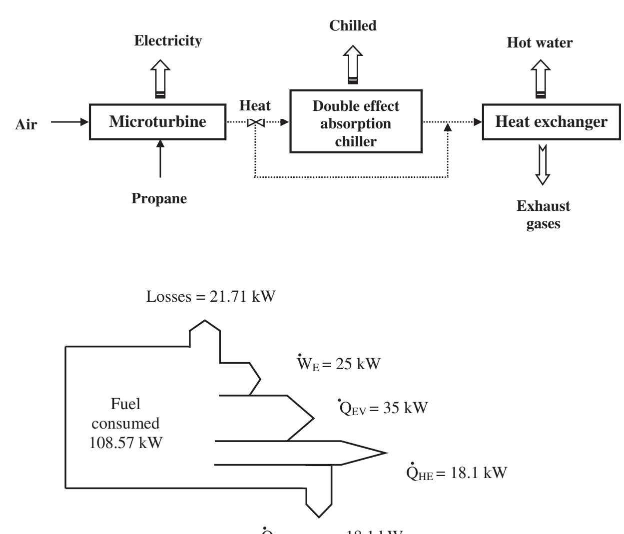

Fig. 1. Diagram of the trigeneration system.