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Analysis of integrated compression–absorption refrigeration systems powered by a microturbine

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ABSTRACT

This paper analyses various configurations of integrated refrigeration system consists of a compression chiller and an absorption chiller that powered by a microturbine to generate cooling at low temperatures. The compression chiller is operated directly by the microturbine at the low temperature stage and the waste heat from the microturbine is used to drive the absorption chiller that operates at the high temperature stage and helps to the compression chiller performance. The thermodynamic system is analyzed, based on the mass and energy equations. From the results obtained, it is concluded that the use of these configurations of integrated refrigeration system is more efficient and mostly less energy consuming than the system without absorption chiller. The best configuration to save energy is the system that uses two stage compression chiller with an intercooler between two compressors and a subcooler at condenser outlet.

Analyse des systèmes frigorifiques intégrés à compression à absorption fonctionnant à l'aide d'une microturbine

Mots clés : Système de cogénération ; Intégré système frigorifique ; Compression ; Absorption ; Efficacité énergétique

1. Introduction

Combined heat and power (CHP) is the simultaneous generation of heat and power in a single process. The significant benefit of CHP is its overall efficiency, which can be as much as 85–90%. The basic element of CHP system is prime mover (reciprocating engine, microturbine, Stirling engine and fuel cells) and much of the waste heat from prime mover is recovered. One of the most promising targets in the application of CHP lies in energy production for buildings. Also steam and heat produced by these systems can be utilized in industrial processes (Alanne and Saari, 2004; Hinnells, 2008).

The use of CHP systems in refrigeration application would bring several advantages such as enhancement power since the

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Nomenclature

CHP	Combined heat and power
COP	Coefficient of performance
$COP_{Improvement}$	Improvement of the COP over the base system
EES	Engineering Equation Solver
EUF	Energy Utilization Factor
$EUF_{Improvement}$	Improvement of the EUF over the base system
MGT	Micro gas turbine
PR	Pressure ratio at compressor
P_{hig}	Condenser pressure
P_{Low}	Evaporator pressure
T_{amb}	Ambient temperature
η_{ise}	Compressor isentropic efficiency
η_{MGT}	Microturbine efficiency

system can be operated independent of the grid and saving energy. The production of cooling power at low temperatures is required in some applications such as frozen process and iced storage systems. Conventional compression systems can be applied to this type of applications, but these systems need to consume a great amount of electricity. Fernández-Seara et al. (2006) analyzed an alternative refrigeration system that could reduce the electricity consumption in those applications. This system consists of a compression system at low temperature stage and an absorption system at high temperature stage. Also they studied the possibility of powering this system by means of a cogeneration system. Cogeneration is synonyms with CHP. In hybrid refrigeration systems CHP can supply simultaneously the power to the compression system and the heat to the absorption system. An integrated refrigeration system (IRS) with a gas engine, a vapor-compression chiller and an absorption chiller has been set up and tested by Sun (2008). He has shown that this system saves running costs as compared to the conventional refrigeration system by using the waste heat. Hwang (2004) has presented and analyzed the performance potential of a refrigeration system that is integrated with a microturbine and an absorption chiller. This system with subcooler, with subcooler and microturbine intake air precooler, and with condenser air precooler can reduce the annual energy consumption by 12, 19, and 3%, respectively, as compared to a refrigeration system operating without any waste heat utilization from the microturbine. Ho et al. (2004) have presented a microturbine cogeneration system that providing electrical power and space cooling to a laboratory space. They studied the performance of the cogeneration system under varying heat load in the cooling space and longer microturbine operating period. Liao et al. (2004) have discussed the feasibility of air-cooled absorption in CHP systems, where the control strategies based on the application can avoid the occurrence of crystallization. Bruno et al. (2005) have studied the performance of gas microturbines of different power capacities directly coupled to double effect water/LiBr absorption chillers. In these systems post-combustion natural gas have used to increase the cooling capacity of the system. Also Bruno et al. (2009) have analyzed various integrated configurations of several types of commercially available absorption cooling chillers and MGT cogeneration systems driven by biogas. MGTs are fueled with biogas and their waste heat is used to drive absorption chillers and other thermal energy users. They compared these configurations with conventional configurations using operational data from an existing sewage treatment plant. A novel cascaded absorption/vapor-compression cycle with a high temperature lift for a naval ship application has been conceptualized and analyzed by Garimella et al. (2011). Also they compared the performance of this system with an equivalent two-stage vapor-compression cycle. Hybrid refrigeration cycles which combine a mechanical compressor and an absorption cycle in such way that they share a single evaporator have analyzed by Herold et al. (1991). They have shown that the cycle have significant potential from a thermodynamic viewpoint.

In this paper, several configurations of a refrigeration system that integrated with a microturbine and an absorption chiller to generate cooling at low temperatures were analyzed. The electricity produced by the microturbine used to drive the compression chiller and the heat recovered from the microturbine is used in the absorption chiller. Overall efficiencies of these configurations were compared to a system that operating without any waste heat utilization and consisting of a microturbine and a compression chiller.

2. Description and modeling of the main subsystems

The main parts of proposed system are micro gas turbine, vapor- compression chiller and water/LiBr absorption chiller. The complete integrated system was modeled using the software package Engineering Equation Solver (EES) (Klein, 2003). The advantage of this software is that users can easily build their own model equations and use the built-in thermodynamic properties for the most common substances, including water/LiBr properties.

2.1. *Micro gas turbine*

Microturbines are small, compact high-speed turbo-generators of between 28 and 200 kWe, which consist of a centrifugal compressor, a radial turbine and a permanent magnet-alternator rotor operating as a Brayton cycle. The main advantages that MGTs have over other technologies are the fuel flexibility, low emissions, quiet operation and low maintenance (Bruno et al., 2005, 2009). The electrical efficiency of the current regenerative MGTs is in the range of 25–30% depending on the MGT size (Bruno et al., 2005). However the microturbine efficiency depends on the ambient temperature. As the ambient temperature increases, the efficiency and the power of microturbine both decrease (Fig. 1). This is mainly because the air density at high air temperature is lower and, for the same inlet volume of air, a lower mass of fluid circulates the system (Bruno et al., 2005). The electrical efficiency change depending upon the ambient temperature in this