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Review

A review of thermally activated cooling technologies for combined cooling, heating and power systems

J. Deng [a,b], R.Z. Wang [a,*], G.Y. Han [b]

[a] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Department of Aerial Four Stations, Xuzhou Air Force College, Xuzhou 221006, China

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ABSTRACT

The state of the art of research in thermally activated cooling technologies for combined cooling, heating and power (CCHP) systems are presented here in detail, mainly including absorption and adsorption refrigeration, and desiccant cooling. A basic description of thermally activated cooling is given first. Next, according to the diverse categories of thermally activated cooling, the working principles, products markets available or under development, diverse combinations of thermally activated technologies in CCHP applications or experimental units, and existing problems are listed and discussed through a comprehensive review of the literature. Furthermore, more recent advanced research of thermally activated cooling in innovative concept, material and technologies are included. Finally, detailed summary and suggestions are proposed for proper utilization of thermally activated cooling technologies, and the future development roadmap and preferred strategies are also outlined. The review will demonstrate that thermally activated cooling technologies are attractive alternatives that not only serve the need for air-conditioning, refrigeration, dehumidification, and augmenting prime movers, but also can meet the demand for energy conservation and environmental protection.

Contents

* Corresponding author. Tel./fax: +86 21 34206548.
E-mail address: rzwang@sjtu.edu.cn (R.Z. Wang).

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1. Introduction

The increasing scarcity of energy resources, global warming and blackouts resulting from weather conditions have stimulated the search for more efficient methods of energy conservation, reducing greenhouse gas emissions and ensuring power supplies. Meanwhile, increasing demand for cooling and heating power in buildings calls for resurveying traditional energy production. One method for sustainable development is to adopt the technology of combined cooling, heating, and power (CCHP), which is also known as trigeneration, building cooling heating and power (BCHP) for application in a building, or integrated energy system (IES) [1–3]. CCHP is the simultaneous production of mechanical power (often converted to electricity), heating and/or cooling from one primary fuel, and is an extension of CHP (combined heat and power, also defined as cogeneration) by coupling with thermally activated cooling technologies that take the waste heat from CHP for producing cooling [3–5]. While CHP profits from more than 100 years of experience and is a well established technology, the development of CCHP is quite slow and mostly limited to combine absorption chillers with large-scale power generation systems until the mid 1980s. The fast development of thermally activated cooling technologies together with reduction of their market price, and the commercial success of distributed energy resources (below 1 MW) technologies in the last two decades, have contributed to strengthen and spread the on-site application of CCHP technology. CCHP is a promising technology that is becoming economically feasible for the local production of cooling, heating and power [6–9]. Many authors have shown that CCHP systems possess energy saving potential, enhanced high-efficiency and low emission characteristics [9–13].

Thermally activated cooling utilized for CCHP systems primarily refers to sorption refrigeration, i.e. it employs waste heat produced in the process of power generation as the driving force to power a sorption refrigeration device. Some energy demand for refrigeration is thus shifted from electrical to thermal energy, and primary energy consumption is also reduced. The main potential application of sorption refrigeration for CCHP systems is in public buildings, such as hospitals, hotels, office buildings and food stores. It is also a reasonable alternative for district heating and cooling systems.

A typical CCHP system is shown in Fig. 1. It is comprised of a gas turbine, generator, heat recovery steam generator (HRSG), and an absorption chiller. The gas turbine is driven by natural gas and the mechanical work is further converted into electric power by the generator. At the same time, the absorption chiller, which is driven by the recovered heat from HRSG in the form of steam or hot water, generates cooling power in summer and heat in winter. Thus, the energy demand for cooling, heating and electric power in a building—or a district—can simultaneously be met by this system.

The early development of an absorption cycle dates back to the year 1777, when water–sulfuric acid was the working fluid. By the early 1900s, water–ammonia sorption refrigeration was a frequently adopted technology [14]. Later, with the development of cheap and reliable electricity-driven vapour compression equipment, sorption refrigeration became a niche technology [15]. However, over the last few decades, environmental concerns about global warming and ozone depletion by chlorofluocarbon (CFC), and hydrochlorofluorocarbon (HCFC), refrigerants have led to a resurgence of interest in sorption refrigeration systems which are largely market-driven by low-grade heat from CHP systems or solar energy. Although the most cited drawbacks for sorption refrigeration systems are the high initial cost, heavy weight, large size, and possible need for backup cooling systems, the benefits are nonetheless obvious. In addition to the benefit of using recovered heat to save energy, sorption systems are environmentally benign: they do not use ozone-depleting CFCs (due to the use of water, ammonia, and other natural refrigerants); they are noise and vibration free, long lasting.

In this paper, we review the status quo of thermally activated cooling technologies for CCHP systems, including feasibility,

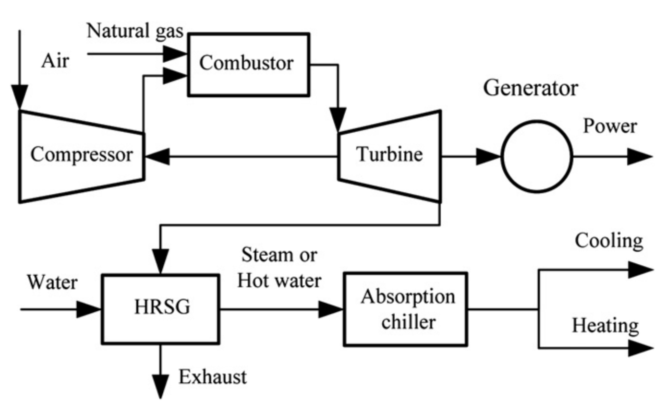

Fig. 1. Schematic diagram of a typical CCHP system.