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Influence of power source type on energy effectiveness and environmental impact of cooling system with adsorption refrigerator

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ABSTRACT

In the paper the method for energy and ecological evaluation of refrigeration system based on the adsorption machine is presented. The energy effectiveness is calculated on the level of the primary energy consumption. The method for ecological evaluation is also discussed. In the ecological evaluation the influence on greenhouse gasses (GHG) is taken into account and the ecological effects are expressed as equivalent CO_2 emission. The authors compare the effectiveness of a refrigerator existing in an example Polish food factory supplied with heat from a boiler house fired with natural gas, a cogeneration system and solar collectors. In the last case the climatic conditions and detailed solar radiation data for Poland have been used. The authors demonstrated that the application of cogeneration or renewable energy sources (RES) for the cooling system can lead to energy savings and ecological benefits. To measure the energy effects the authors introduced the following indices: (PES) – Primary Energy Savings and (GHGS) – Greenhouse Gasses Savings. The results of the mentioned indices for different configuration of heating systems are calculated and presented in the paper.

1. Introduction

Adsorption refrigerators can be applied in many technological processes where the demand for chilled water appears, especially in food industry. The basic advantage of such a solution is the wide range of heat sources that can be used as the driving power for the cooling system. Particularly the source of heat can be the boiler house, the cogeneration system, as well as the renewable energy sources (RES). In the group of RES solar collectors seem to be a solution, both as the basic and auxiliary power source for the adsorption refrigerator. Using the different power sources the energy and environmental impact can be quite different. The applications of adsorption refrigerators including ice making, air conditioning and dehumidification by desiccant systems are presented [1]. In that work the utilization of adsorption refrigerators powered by waste heat or solar energy in cooling, heating and power systems, hospitals, buildings and grain depots are also discussed. A design of adsorption cooling system supplied by solar energy which can be switched between a system with heat storage and a system without heat storage is presented e.g. in [2]. In the presented system with heat storage, a heat storage water tank is introduced as the link between the solar collector circulation and the hot water circulation for the adsorption refrigerators. The researchers report that the system with heat storage operated stably because of the regulating effect by the heat storage water tank. However, under otherwise similar conditions, the cooling effect of the system without heat storage was similar to that of the system with heat storage. In [3] the model to determine the effects of the hot water tank capacity, the cycle time and the initial hot water temperature on the performance of the silica gel–water adsorption refrigerator driven by solar energy were analyzed when the refrigerator was driven by a stable heat source and solar energy respectively. The authors of the work [4] inform that in the climate conditions typical for Poland, it is possible to effectively use the adsorption cooling system to keep a constant level of thermal comfort inside a room during all months in which there is a demand for cooling, that is approximately between April and October. Growing energy demand and global climate change are compelling reasons to look for effective utilization of waste thermal energy and renewable energy resources. Fifteen percent of the electricity produced in the whole world is employed for refrigeration and air-conditioning processes of various kinds [5]. As one kind of environmentally friendly refrigeration, the adsorption refrigeration has attracted many attentions in recent decades [6], but simultaneously poor heat and mass transfer problem of adsorption processes, is a restriction to prevent the improvements of the adsorption refrigeration technique.

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Nomenclature

B	exergy (kW)
COP	coefficient of performance
GHGS	Greenhouse Gasses Savings (kg CO_2/a)
F	area (m^2)
E	energy (kWh)
I_β	global solar radiation reaching collector with inclination angle β (W/m^2)
PES	primary energy savings (kWh/a)
ΔPES	relative primary energy savings (%)
t	temperature (°C)
T	temperature (K)
$\dot{Q}$	heat (cold) rate (kW)
$\dot{E}$	energy (kW)

Greek symbols

α	the ratio of chemical exergy of fuel per unit of lower heating value
τ	time (h)
η	efficiency
μ_{CO2}	CO_2 emission conversion factor (kgCO_2/GJ)
x	cogeneration ratio

Subscripts and superscripts

a	ambient
AD	adsorption refrigerator
B	boiler house
CT	cooling tower
CW	cooling water
CHP	cogeneration heat power plant
ChW	chilled water
d	delivery
E	energy
EL	electricity
F	fuel
FT	food technology
gr	gird
in	inlet
HT	hot water tank
HW	hot water
LCP	liquid chilling package
out	outlet
SC	solar collectors
Q	heat
CW	cooling water

The energy and environmental impact of cooling systems is considered in relation to the primary energy consumption. The energy and environmental impact of cooling systems is considered in relation to the primary energy consumption. In the [7] a primary energy reduction for the cogeneration systems and a vapor compression refrigerating system connected with building for a primary energy operational strategy is analyzed. The trigeneration primary energy saving indicator for the primary energy savings from different trigeneration system is introduced [8]. The primary energy ratio depends on operation modes of domestic or industrial technical installations, for example, the combined cooling heating and power system for a commercial building [9], the desiccant cooling systems powered by solar air collectors [10] and the combined mechanical cryogenic refrigeration system cooperated with the cooling room [11] are discussed. The primary energy may be also used as one assessment level to estimate energy consumption from the source to the final user on the European heating and cooling market [12]. For example, the primary energy consumption factor (PEC) is used for the systems of combined cold, heat and electricity generation [13] and also to evaluate the primary energy consumption on the national level [14], as well as a Primary Energy Savings (PES) for solar systems for the production of cold or heat [15]. The primary energy savings for the operational strategy of trigeneration system powered by natural gas is also analyzed [16]. In addition, the evaluation of the impact of the cooling systems operation on the environment can also be performed by analyzing the amount of CO_2 emission for using variable speed drives in chillers [17], based upon the thermal or electricity demand management operation mode of combined cooling, heating, and power system for a building [18], using an optimal energy dispatch algorithm for a trigeneration system [19], or based on the concept of trigeneration CO_2 emission reduction indicator to assess the emission reduction of CO_2 other greenhouse gases into the environment [20].

2. Cooling systems with adsorption refrigerator

This paper examines two cooling systems whose primary aim is to produce the required amount of cold for the technological processes (FT) in a food factory. The first system uses a renewable energy source to drive the adsorption refrigerator (AD), while the second system uses the heat from the cogeneration system to drive the adsorption refrigerator.

Fig. 1 shows a layout of the cooling system for the production of cold in the form of chilled water whose temperature is 7/12 °C with the application of AD and liquid chilling package (LCP). In this system (SCAD), the adsorption refrigerator is powered from a renewable energy source through a system of solar collectors (SC) which heat the water in the tank (HT). Taking into account the range of ambient temperatures in Polish conditions glycol has been applied as the intermediate working fluid in the solar collector. The hot water from the tank is used to power the adsorption refrigerator. When a solar system cannot heat the water to a minimum temperature required to power the AD, it is switched off. At the same time the electricity-powered (EL) liquid chilling package is switched on. The AD and the LCP are cooled with the use of cooling water which transfers the heat to the environment through the cooling towers (CT).

Fig. 2 shows a layout of the cooling system (CHPAD) for the production of cold in the form of a chilled water whose temperature is 7/12 °C, using only AD, where the heat source to power the AD is hot water heated in the tank (HT) by the heat obtained from the cogeneration system (CHP). At the same time the CHP system produces electricity (EL). Consequently, it is a trigeneration system for the simultaneous production of cold, heat and electrical energy. In

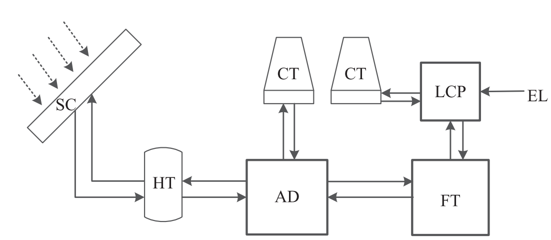

Fig. 1. A layout of the system (SCAD) with the adsorption refrigerator powered by the heat from the solar energy source: SC – solar collectors, HT – hot water tank, AD – adsorption refrigerator, FT – food technology, CT – cooling tower, LCP – liquid chilling package, EL – electricity.