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Review

Heat exchanger applications in wastewater source heat pumps for buildings: A key review

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ABSTRACT

Wastewater heat recovery applications are becoming widespread in energy saving applications. A sustainable and low emissions operation in air conditioning and heating processes is achieved by harvesting the otherwise wasted energy in wastewater through specially designed heat exchangers, lying at the core of heat pumps. This combined system is called wastewater source heat pump. In this study, a review of wastewater heat exchangers in wastewater source heat pump applications is presented, and wastewater heat exchangers are classified in detail based on multiple features, including utilization and construction methodology. Also, the potential of wastewater, types of wastewater source heat pumps, and their applications are briefly discussed.

Contents

Abbreviations: WW, wastewater; WWHEX, wastewater heat exchanger; WWSHP, wastewater source heat pump; WWTP, wastewater treatment plant; GFX, gravity-film heat exchanger; HP, heat pump; COP, coefficient of performance; PER, primary energy ratio; PV, photovoltaic; CFD, computational fluid dynamics.

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1. Introduction

The urban sewage and domestic/industrial used water heat pump (HP) technology has attracted interest in recent years [1]. This recovery application aims to reduce energy consumption of buildings, and provides a new energy source through a HP application using wastewater (WW) because space heating and cooling, and domestic hot water supply represent the biggest share in energy consumed by residential buildings [2]. WW in urban sewage and buildings retains a significant portion of its energy, and recycling the energy in these heat sinks is the essential phenomenon in developing wastewater heat exchangers (WWHEX) [3]. Swiss researches reported that more than 15% thermal energy supplied to buildings was lost through the sewer system [4]. To recover this energy, various types of heat exchangers (HEX) can be developed according to the area of use like domestic, sewage, filtered sewage, etc. In recent years, an increasing amount of research has been pursued for heat recovery using WWHEXs. In the present study, various types of HEXs used in both large scale WWHEX facility and scientific studies are reviewed to provide a general understanding of the developments in this field.

WW is a safe and locally available energy source. It is also a good heat sink because the temperature level in the wastewater is approximately 9–14 °C in winter period, and 28–29 °C in summer period [5,6]. The wastewater temperature in United Kingdom varies between 10 °C in February and 24 °C in July and the measured data from three different locations show that the temperature difference between two points changes from 0.1 to 4 K per km length of sewage channel [5,6]. If a cooling capacity is needed in summer, especially in countries with high outdoor temperatures, WW can be used as a heat sink with a WWHEX combined with a HP system. Another application of WW is the recovery of waste heat in WW for preheating circulation fluid [7].

Efficient utilization of the energy content of the WW depends on an appropriate design and/or selection of WWHEX for the HP system. In the literature, such special WWHEX designs, which are either tested on lab-scale or commercial use, have been reported. In this review study, WWHEXs are described in detail, classified, and some examples of commercial applications are given.

2. Description of wastewater source heat pump (WWSHP) systems

HP is a device that transfers heat from a low-grade heat source (cold side) (e.g. ground water, surface water, soil, outdoor air, WW, etc.) to a working fluid, and by the application of a higher grade form of energy (e.g. mechanical energy), raises the temperature or increases the heat content of the working fluid before releasing its heat for utilization (hot side). The main components of a vapor compression cycle HP are: compressor, condenser, evaporator, and expansion valve.

HP systems have both cooling and heating modes [8]. Fig. 1 indicates a classification of HP systems according to their operation modes. Monovalent HP heating system (HP heating system without supplemental heating) is a system, in which the HP alone supplies heat during the heating season.

Bivalent HP heating system (hybrid HP heating system, HP heating system with supplemental heating) is a system, in which the HP may be supplemented by other heating equipment (supplemental heating), which serves, for example, to meet or assist in meeting heating demand on unusually cold days or when the HP is not in operation. The term “bivalent” is employed because as a rule the supplemental heating is based on a different supply of energy from that used to operate the HP. Multivalent HP system can be used in tandem with a cogeneration (CHP) system in larger buildings [10].

The performance of a WWSHP system varies system by system according to operation conditions such as sewage temperature, clean water temperature, HP equipment. COP of the WWSHP system is directly related to the temperature of Weijie et al. [11] reported that the COP value of a WWSHP is almost kept constant because the variation of the WW temperature is not very large. The COP values of WWSHP systems are in the range of 1.77–10.63 for the winter season in the heating mode while they are between 2.23 and 5.35 in the summer season for the cooling purposes [5]. Also when a WWSHP system is compared to a gas based heater system, the WWSHP system is more economic and directly decreases the gas consumption for heating and hot water supply [12].

Industrial WW has a temperature range between 30 and 40 °C, and the COP value of the HP systems in this case is at least 7–8. But these systems may contain highly corrosive components and require special handling, while the amount of flow is not large compared to urban sewage [13].

The economic viability of a WWSHP system depends on the price of current traditional energy sources, the size of the WWSHP system (required heating power), and the heat recovered from sewage in relation to piping length [4]

Fig. 2 shows the utilization of WWHEX and HP in a WWSHP system as a whole. The basic operation can be summarized as follows:

(I) The HEX recovers the waste heat in WW, and transfers it to the circulating HEX medium (secondary cycle, water, or the water–glycol mixture). In this step WW cools by transferring its heat to the HEX medium (1).
(II) The HEX medium transfers its heat to the HP working medium (refrigerant with a low boiling temperature) in the evaporator (2) to form vapor. (HEX power = evaporator power). With the help of a compressor (3), vapor is compressed to increase its heat. The compressor is driven externally. The other units of

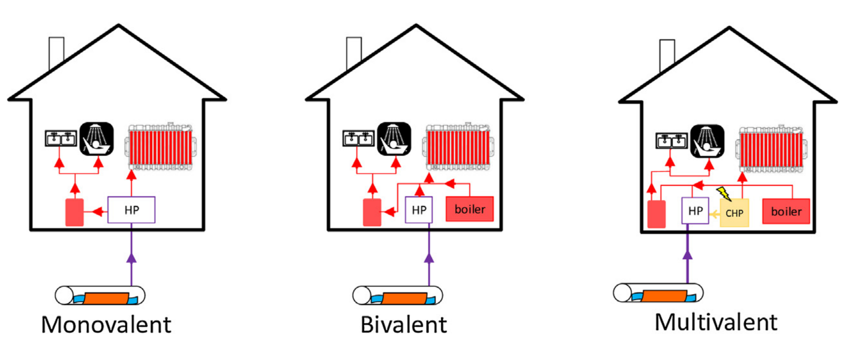

Fig. 1. Heat pump operation modes.

Adapted from Ref. [9].