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Application of a heat pump system using untreated urban sewage as a heat source

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HIGHLIGHTS

- The block problems caused by suspended solids in USSHP system is presented.
- The block problems in USSHP system is overcome by auto-avoiding-clogging equipment.
- The characteristic parameters of USSHP system are tested.
- The influence factors of USSHP system were analysed by the test results.

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ABSTRACT

Untreated urban sewage contains large amounts of thermal energy; and its temperature is suitable as a heat source in heat pumps for the heating and cooling of buildings. However, it is not widely used in heat pump systems due to the problem of filth. This paper presents an untreated sewage source heat pump (USSHP) system in which auto-avoiding-clogging equipment is used to continuously capture suspended solids in the sewage. Thus, the block problems caused by filtration and fouling in the heat exchanger tubes can be efficiently resolved in this system. In an actual engineering application, the characteristic parameters of USSHP system are tested under typical operating conditions for heating status. Based on the test results, the performances of the USSHP system are examined. The results indicate that the thermal resistance of the convective heat transfer and fouling on the sewage side in the sewage exchanger is 80% of its total thermal resistance. The COP of the heat pump unit and the COP of the USSHP system are 4.3 and 3.6, respectively.

1. Introduction

With the rapid development of the urbanisation process in China, the majority of primary energy is consumed by the heating and air conditioning of buildings and domestic hot water. A series of critical environmental problems, such as pollution, energy shortage and climate change, will inevitably be caused by the utilisation of fossil fuels. In China, energy consumption in non-industrial buildings is approximately 27.8% of primary energy [1]. Thus, using renewable energy instead of fossil fuel is increasingly important to energy conservation and environmental protection. Currently, heat pumps comprise an energy-saving and environmentally friendly technology that is widely applied in the heating and air conditioning in buildings. A low-grade heat source, such as air, ground, groundwater and untreated urban sewage, is required to operate a heat pump system. The selection of a low-grade heat source is dependent on local meteorological and hydrogeological conditions. For instance, conventional air-source heat pumps cannot operate efficiently and steadily during the winter in cold regions due to lower ambient design temperatures [2]. Among these low-grade heat sources, untreated urban sewage, which is referred to as original sewage in municipal drainage pipelines without any physical and chemical treatments, is a promising heat source as its temperature is highly suitable for a heat pump system during the winter and summer and its flow rate is immense and steady throughout the year [3]. An untreated sewage source heat pump system has a superior coefficient of performance in heating/cooling systems. For an urban sewage source heat pump system in Tokyo, the coefficient of heating performance has increased by 60% compared with the coefficient of heating performance for an air source heat pump, whereas it exhibits 20% electric energy savings compared with an air source heat pump system [4]. According to the simulation results, a USSHP system can reduce energy consumption by 34%, lower CO_2 emissions by 68% and lower NO_x

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emission by 75% compared with a conventional air source heat pump system [5]. Therefore, a USSHP system has more energy-saving potential and competitive advantages for the heating and cooling of buildings.

Recently, the use of the urban sewage source heat pump has evolved due to the solutions developed for the problems caused by the filth of urban sewage. Many researchers have conducted numerous studies on reduced fouling, heat transfer enhancement technologies and the system performance of the sewage water source heat pump. An auto-strainer was developed to cut and remove suspended fibrous solids, such as paper and plastic bag, from urban sewage. Suspended solids are periodically blown out through an automatic release valve. In addition, an automatic cleaning device was developed to remove fouling deposits that stick to the heat transfer surface inside the heat exchanger tube. This sewage source heat pump achieves COPs of 4.65 and 3.56 for cooling and heating, respectively, providing 30% savings in operating costs compared with a conventional refrigerator-and-boiler system [6]. Currently, a district heating and cooling system in Tokyo uses heat generated by untreated sewage for the district heat supply via a sewage source heat pump station, which enables considerable energy savings and significant reductions in CO_2 and NO_x emissions [4]. In this system, a rotating screen-type auto-strainer is used to remove the majority of the suspended solids from the sewage. The application and development of the urban sewage source heat pump are promoted by Sun and his co-workers in China [7]. They developed auto-avoiding-clogging equipment, whose filtration surface can continuously regenerate to remove solids in the sewage, and an indirect heat exchange system to prevent clogging and fouling in the heat exchanger tubes of the heat pump unit. It was applied to the heating and cooling system of a hotel in Harbin in 2003. An 18 MW heat pump, which utilises untreated sewage as its heat source, was placed into operation in 2006 by Viken Fjernvarme in Oslo, Norway [8]. In this system, a conveyor belt with a grating (3 mm gap) is applied to separate the solids from the sewage. Cho et al. evaluated the heating and cooling performance of a heat pump that utilises the heat energy of the raw water supplied to a water treatment facility [9]. The raw water source provides a favourable heat source compared with an ambient air source, except during the spring season. The average unit COP for the heating status is 3.3, and the average unit COP for the cooling status is 7.2. A heat pump that employs waste water discharged from saunas and public baths as a heat source was designed, and an energy analysis was performed to evaluate the efficiency of the system using TRNSYS [5]. The results indicate that the annual mean COP of the heat pump is approximately 4.8 and the heat pump can supply 100% of the hot water load except on weekends during the winter season. Based on the test results, the system performance of an urban sewage source heat pump system was investigated under actual operating conditions. A suitable method for improving the performance of a USSHP system was proposed [10]. An experimental investigation of a waste water source heat pump was performed by Kahraman [11]. The heating coefficients of performance were calculated based on the measurements. The heating coefficient of the performance of the system is 3.69 for heat source temperatures of 40 °C. To obtain reasonable design parameters for a USSHP system, such as pressure drops on the sewage side of the heat exchanger, the rheology and flow characteristics of untreated urban sewage were investigated by theoretical analysis and experimental methods. The basic equation of rheology and calculation equations of flow resistance were developed for a circular pipe [3]. The soft-dirt characteristics of the heat exchanger tubes were also examined [12]. Few reports explore the technical difficulties and suitable solutions for a USSHP system, such as ways to prevent clogging and reduce fouling and improvements in heat transfer and the operational characteristics of a USSHP system in actual engineering practice. Based on these aspects, we have attempted to obtain the characteristic parameters for the operating status of a USSHP system based on test data during the heating and cooling season and to evaluate the heating/cooling performance of a USSHP system. In this paper, a USSHP system is detailed including key facilities in the USSHP system, such as the auto-avoiding-clogging equipment and sewage heat exchanger. The fouling resistance and the system performance are analysed with test data. A comparison of the primary energy costs of a USSHP and other heating and cooling systems for buildings is provided. The results can serve as a reference for the design and operation of a USSHP system in actual engineering applications.

2. Description of a USSHP system

A USSHP system is shown in Fig. 1. Generally, a USSHP system consists of three subsystems, i.e., the sewage intake system, the heat exchange system between the filtrated sewage and the intermedium water (clear water) and the heat pump system. The main facilities include the auto-avoiding-clogging equipment, sewage heat exchanger, heat pump unit and other associated facilities, such as pumps and valves. The untreated sewage in the municipal drainage pipelines can flow freely into the sewage reservoirs through the intake pipe under the action of gravity. The main function of the sewage reservoirs is to supply sufficient sewage flow in the first-stage sewage pump for a period of approximately 2 h. A part of the larger aperture feculence is also separated from the sewage using a gravity sedimentation method in the reservoirs. The sewage stored in the sewage reservoirs is transported to the auto-avoiding-clogging equipment by the first-stage sewage pump,

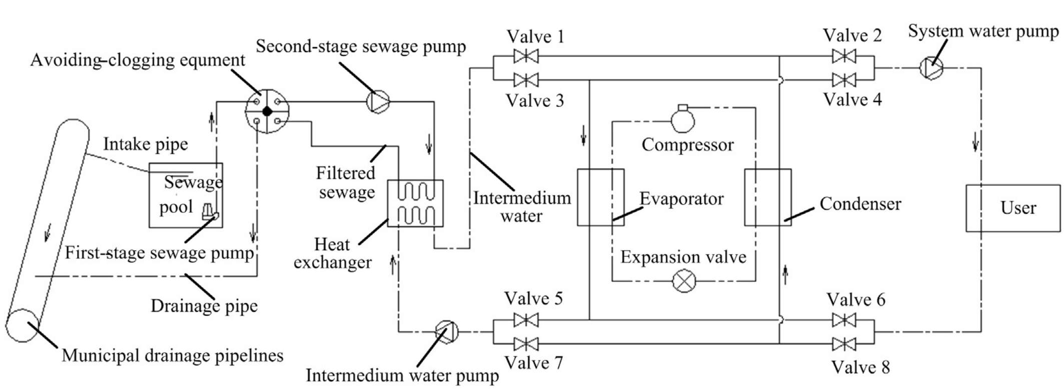

Fig. 1. Schematic flow diagram of the USSHP system.