Journal of Southeast University (English Edition) Vol. 26, No. 2, pp. 324 – 326 June 2010 ISSN 1003—7985

Feasibility analysis of urban sewage source heat pump system with freezing latent heat collection

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Abstract: Aiming to resolve the problem that conventional sewage source heat pump systems cannot satisfy heat peak loads of buildings, a new idea that the freezing latent heat is exacted as the auxiliary heat source at the peak heat load is proposed. First, on the basis of sewage characteristics, a freezing latent heat exchanger is developed to safely eliminate ice, continuously extract heat and remove sewage soft-dirt. A reasonable form of the urban sewage source heat pump system with freezing latent heat collection is presented. Then, the feasibility of the system is theoretically analyzed. The calculation results under typical operating conditions show that the heating ability of the new system is higher than that of the conventional one and the ratio of these two highest heating rates is between 4. 5 and 8. 7, which proves that the new system has great application potential in cold regions.

Key words: urban sewage; freezing latent heat; heat pump; feasibility

Urban sewage, widely distributed in each city, is one of the best heat or cold sources of heat pumps with excellent temperature conditions[1−2]. With the development of the urban sewage source heat pump technology, the characteristics on energy saving and environmental protection are exhibited in some buildings[1,3]. Sewage flux is an important design parameter excepting temperature, and it changes relatively greatly, which is closely related to the local climate, industry production and patterns of life. Two cases in China we tested respectively show that the ratio of the maximum flux to the minimum one reaches 2 : 1 in Harbin (in the spring of 2005) and 5 : 1 in Qingdao (in the winter of 2006). So the design flux in the heat pump system is chosen as the minimum flux. Thus, the heating ability of the urban sewage source heat pump system (USSHPS) is often insufficient with the limited sensible thermal energy from sewage[4−5]. The disadvantage of the conventional sewage source heat pumps is the insufficiency of the sewage flux, which limits the heating ability[6]. Moreover, the huge sewage freezing latent heat is not extracted. So we propose a new idea that at the peak heat load, the freezing latent heat can be provided as the low-temperature heat source of the heat pump unit as well as the sensible heat. And the new system is named as the urban sewage source heat pump system with freezing latent heat collection (USSHPSFLHC).

Received 2009-11-15.

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Foundation items: The National Key Technology R&D Program of China during the 11th Five-Year Plan Period (No. 2008BAJ12B05-05), the Research Foundation of Education Bureau of Heilongjiang Province, China (No. 11551114), the China Postdoctoral Science Foundation (No. 20100471438).

Citation: Qian Jianfeng, Zhang Jili. Feasibility analysis of urban sewage source heat pump system with freezing latent heat collection[J]. Journal of Southeast University (English Edition), 2010, 26(2): 324 – 326.

1 Key Equipment and System Form

1. 1 Freezing latent heat exchanger

Because urban sewage contains a lot of large-scale filth, a counter-washing device is needed to prevent the plugging of pipes or some heat transfer equipment. At the peak heat load, how to deice and extract heat in the new system (USSHPSFLHC) becomes the key point. Herein, a piece of heat exchanger equipment, named as a freezing latent heat exchanger, is designed and it consists of tubes, spiral ice scrapers and drivers (see Fig. 1). The drivers include motor-driven devices, deceleration devices, gears and driveshafts. The sewage flows inside the tubes with a low-temperature glycol antifreeze solution outside the tubes. When the adhering ice in the pipe wall is scratched off and gets away from the heat exchanger, heat transfers to the heat pump unit indirectly. In addition, the freezing latent heat exchanger can play a role in removing soft dirt and, thus, enhance the convection heat transfer.

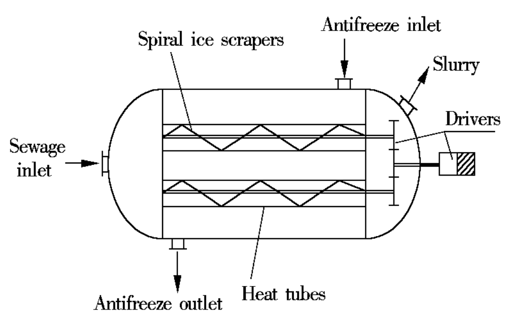
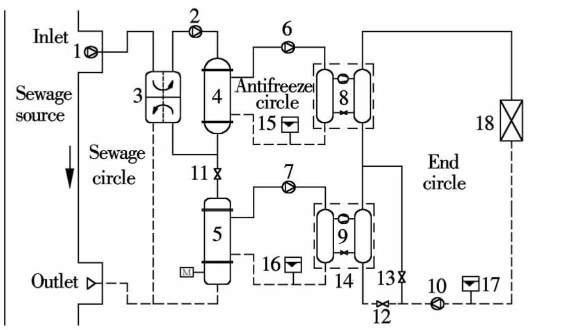


Fig. 1 Sketch of freezing latent heat exchanger

1. 2 System form

A reasonable form of the heat pump system is put forward, as shown in Fig. 2. At the peak heat load, the sewage heat exchanger and the freezing latent heat exchanger run in series with two sets of heat pump units (first-stage and second-stage heat pump units). Under the cooling condition, the sewage heat exchanger and the first-stage heat pump unit run; valves 11, 12 and pump 8 are closed; valve 13 and pumps 1, 3, 6, 10 are open. Under the heating condition, the system runs the same as the cooling condition at the low heat load. But at the peak heat load, the end water cycle is heated by successive heat pump units; valves 11, 12 and all the pumps are open; valve 13 is closed.



1,2—Sewage pump; 3—Counter-washing device; 4—Sewage heat exchanger; 5—Freezing latent heat exchanger; 6,7—Antifreeze solution pump; 8—First-stage heat pump unit; 9—Second-stage heat pump unit; 10—End pump; 11 to 14—Valves; 15 to 17—Expansion tank; 18—Fan-coil

Fig. 2 System chart of USSHPSFLHC

2 Feasibility of System

At the peak heat load, ice-water slurry flows in the freezing latent heat exchanger, so the system design process needs to avoid the risk of plugging pipes by slurries. The safe parameters are that the average ice packing factor (IPF) is less than 30% [7] and the flow rate is higher than 0.05 m/s[8]. The second constraint condition on the flow rate is almost tenable on all the real occasions. The chart of the design parameters is shown in Fig. 3, and

$$I_s = (1-\beta) I = \frac{Q_F - c(1-\beta) G_1 (T_2 - T_3)}{L G_1} < 30\% \quad (1)$$

where I_s and I are the ice packing factors for the system and the freezing latent heat exchanger, respectively, %; G_1 is the total sewage flux, kg/s; Q_F is the heat transfer quantity of the freezing latent heat exchanger, kW; T_2 and T_3 are the first-stage and the second-stage outlet temperatures of the sewage, ℃; c is the specific heat of water, kJ/(kg·℃); L is the freezing latent heat of water, kJ/kg; β is the flux parameter of the counter-washing device.

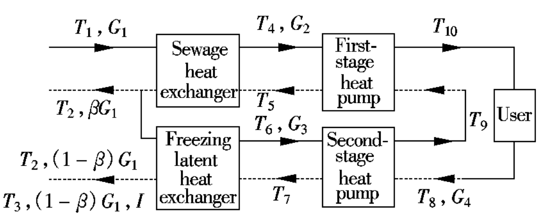


Fig. 3 Chart of work parameters in new system

It is equivalent to add a freezing latent heat exchanger and a second-stage heat pump unit on the conventional USSHPS, but the heating performance is worse than that on the conventional USSHPS. That is, it has poor performance and a high initial investment. The new system is only adopted when the conventional one is not appropriate for heat users. The work parameters of the new system are shown in Fig. 3.

In the conventional USSHPS, the index of the heating quantity can be obtained by

$$\frac{Q}{G_1} = 1.163 (T_1 - T_2) \frac{\varepsilon_1}{\varepsilon_1 - 1} \quad (2)$$

where Q is the end heat load, kW; T_1 is the sewage temperature in the sewage heat exchanger, ℃; $\varepsilon_1 = f(T_{10}, T_5)$ is the heating coefficient of the performance of the first-stage heat pump unit. Here, T_{10} is the supply temperature in the end circle, ℃; $T_5 = T_2 - \Delta t_h$ is the antifreeze outlet temperature in the sewage heat exchanger, ℃; Δt_h is the outlet temperature difference between the sewage and the antifreeze, ℃.

When the antifreeze outlet temperature is at a minimum, the value of the heating quantity of the USSHPS reaches the upper limit. Here, considering $T_5 = 1$ ℃, $\Delta t_h = 2$ ℃, $T_{10} = 45$ ℃ and $\varepsilon_1 = 4.2$, we can see that the maximum value of Q/G_1 for the USSHPS, or the minimum value for the USSHPSFLHC, is

$$\frac{Q}{G_1} \geqslant 1.53 T_1 - 4.59 \quad (3)$$

At the same time, the safety conditions regarding ice discharge for the USSHPSFLHC must be satisfied. Then,

$$\frac{Q}{G_1} = 1.163 (T_1 - T_2) \frac{\varepsilon_1}{\varepsilon_1 - 1} + (1-\beta) \frac{\varepsilon_2}{\varepsilon_2 - 1} \cdot [93.06 I + 1.163 (T_2 - T_3)] \quad (4)$$

where $\varepsilon_2 = f(T_9, T_7)$ is the heating coefficient of the performance of the second-stage heat pump unit; T_7 and T_9 are the antifreeze inlet temperature in the freezing latent heat exchanger and the outlet supply temperature of the condenser side of the second-stage heat pump unit, respectively, ℃.

When the index of Q/G_w in the USSHPSFLHC reaches the theoretical maximum value, the following conditions can be satisfied: 1) The antifreeze outlet temperature of the first-stage heat pump unit is minimum; here, it is taken as 1 ℃; 2) The outlet IPF of the freezing latent heat exchanger is maximum; that is $I < 0.3/(1-\beta)$; 3) $T_2 = T_5$ and $T_3 = 0$ ℃; 4) The average of ε_2 is higher than that of ε_0. When considering the heat load factor, ε_2 can be considered as 2.0. Then,

$$\frac{Q}{G_1} \leqslant 1.53 T_1 - 2.33\beta + 55.11 \quad (5)$$

So the applicability condition is

$$1.53 T_1 - 4.59 \leqslant \frac{Q}{G_1} \leqslant 1.53 T_1 - 2.33\beta + 55.11 \quad (6)$$

3 Results and Discussion

From Eq. (6), we can see that the sewage inlet temperature in winter plays an important role in the heating system's applicability. For example, when $T_1 = 10$℃ and $\beta = 0.5$, the USSHPS only can be used under the condition of $Q/G_1 \leqslant 10.7$ while the USSHPSFLHC can be used when $10.7 < Q/G_1 \leqslant 69.3$

Tab. 1 shows the comparison of the heating ability of the USSHPS and the USSHPSFLHC. The design heat load is 1 MW and β is 0.5. Here, the highest heating rate means the ratio of the greatest heating ability to the design heat load. From Tab. 1, we can see that the heating ability of the USSHPSFLHC is much higher than that of the USSHPS, and the ratio of the two highest heating rates is between 4.5 and 8.7.

Tab. 1 Comparison of heating ability of two systems

Sewage inlet temperature/℃	Sewage flux/ (t·h⁻¹)	$\frac{Q}{G_1}$/ (kW·t⁻¹·h⁻¹)	Largest heating rate/%	
			USSHPS	USSHPSFLHC
8	20	50.0	15	132
8	40	25.0	31	265
8	60	16.7	46	397
8	80	12.5	61	529
8	100	10.0	77	662
10	20	50.0	21	138
10	40	25.0	43	277
10	60	16.7	64	415
10	80	12.5	86	554
12	20	50.0	28	145
12	40	25.0	55	289
12	60	16.7	83	434
14	20	50.0	34	151
14	40	25.0	67	301

4 Conclusion

This paper puts forward a new heat pump system for buildings in the cold areas with low sewage flux. A special freezing latent heat exchanger and a heat pump system form are introduced. Through theoretical analysis, the applicability and potential of the system is discussed. The results show that the heating ability of the USSHPSFLHC is much higher than that of the conventional USSHPS.

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污水源采集凝固热热泵系统的可行性分析

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摘要:针对常规污水源热泵系统出力常无法满足建筑最大负荷的问题,提出了在高峰负荷下提取污水凝固潜热作为补充热源的新思路. 首先,结合污水特征设计了一种集除冰、取热、除垢于一体的凝固换热器,并给出了城市污水源采集凝固热热泵的合理形式. 然后,从理论上分析探讨了新系统的供热潜力. 典型的工况计算结果表明,采集凝固热热泵系统的供热能力大于常规城市污水源热泵系统,两者的最大供热率之比在 4.5 ~ 8.7 之间,说明该污水源采集凝固热热泵系统在寒冷地区的应用潜力较大.

关键词:城市污水;凝固热;热泵;可行性

中图分类号:TU831.6