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SEWAGE HEAT SOURCE PUMP SYSTEM'S APPLICATION EXAMPLES AND PROSPECT ANALYSIS IN CHINA

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ABSTRACT

Sewage is a kind of ideal low-temperature heat sources. Sewage heat source pump system uses heat energy in sewage, and it is a method of utilizing sewage resources. In this article we analyze sewage's characteristics and sewage source heat pump system; introduce its practical applications in sewage treatment plants in China, analyze its technical and economic characteristics, and discuss its application potentiality and the problems that need solving when we promote its use in China. Through the analysis above, we can draw the following conclusion: sewage heat source pump system is feasible and advanced in technology, and can save the investment and operation expense evidently. We should promote its application range in the municipal sewage treatment plants in China.

Keywords: sewage, heat pump, example, application prospect, problem

1. INTRODUCTION

1.1 Sewage's Characteristics as Heat Source

Municipal sewage is a kind of ideal low-temperature heat sources. It has the characteristics as follow:

(1) There are a large number of sewages produced in the cities every year, and they nearly keep an invariable flow in the whole year；

(2) Sewage temperature is lower than outdoor temperature in summer, higher than outdoor temperature in winter. In a whole heating and cooling season, sewage's temperature fluctuates very little. Sewage temperature is related with the amount of sewage, region, sewage source and season, etc. In North China sewage temperature is no lower than 10℃ in winter, and does not exceed 30℃ in summer generally [3]. According to the data measured by Beijing Gaobeidian sewage treatment plant chronically, the sewage temperature is 13.5 to 16.5 ℃ in winter, which is about 20℃ higher than outdoor temperature; the sewage temperature is 22 to 25℃ in summer, which is 10℃lower than outdoor temperature [4]. And according to the data measured, sewage temperature is about 14 to 15℃ in Harbin Majiagou main intercepting channel in winter [6].

(3) Sewage contains a large amount of heat energy. For example, there is 40% waste heat produced by urban communities included in the sewage according to estimation [1].

These make it an ideal heat source for district heating and cooling system that sewage is used with heat pump together.

1.2 Sewage Heat Source Pump System

Sewage heat source pump system is a kind of system that utilizes energy in sewage, and uses sewage as heat source. According to the treatment states of sewage, it can be divided into sewage heat source pump system that uses untreated sewage as heat source and sewage heat source pump system that uses treated sewage as heat source. According to the location of the heat pump equipment room, it can divide into central, semi-central and disperse sewage heat source pump system.

Using untreated sewage as heat source, we can utilize municipal sewage in the pumping station nearby, transfer the heat energy in the untreated sewage to heat pump system, and transport it to the users nearby. Thus we can increase the range that sewages are used in district heating and cooling remarkably. But because untreated sewage contains a large amount of impurity, water treatment equipment and heat transfer equipment are relatively more complicated.

Using treated sewage as heat source, for example, secondary effluent (sewage through biological treatment) or normal water, because their water quality is better, treating process is simpler than that of untreated sewage. The system may only need 1-stage filter, or may not need the filter at all sometimes. But sewage treatment plant always lies in the edge of the city that is relatively far from heat users, if equipment room is set in the sewage treatment plant and heat pump retrieves heat energy from sewage, the pipeline for heating and cooling is relatively longer and the expenses are relatively larger then. If there are normal water systems, we can use normal water pipeline to send heat energy to the users, and adopt semi-central district heating and cooling system. When we finish utilizing heat energy from sewage, normal water can continue to be used. In this case, because it doesn't need complicated process system, the system is similar to general water-source heat pump system.

1.3 Sewage Heat Source Pump System in China

Sewage heat source pump system is applied much in the world, and the technology of that has become already ripe. Especially it is widely used in Japan, Sweden, Norway and etc. In addition, other countries, such as U.S.A., Germany, etc. have studied it a lot.

The application of sewage heat source pump system in China just starts at present. Some companies have had some helpful try in this field, and the operation result is good, for example, Beijing Gaobeidian sewage treatment plant (Heating and cooling area is about 900 m^2), Beijing Beixiaohe sewage treatment plant (Heating and cooling area is about 6000 m^2), Hebei Qinhuangdao sewage treatment plant (Heating and cooling area is about 3500 m^2), Harbin Majiagou main intercepting channel project (Heating and cooling area is about 600 m^2) and etc. [3,4,7] But the area applying sewage for heating and cooling is still smaller at present. That is also not proportional compared with enormous heat energy contained in sewage yet, but it also means that the utilization of heat energy in sewage still has great potentialities to develop.

We will introduce the application of sewage heat source pump in China by using a sewage heat source pump system in Hebei Qinhuangdao Haigang District sewage treatment plant as an example. It uses the secondary effluent as heat source.

2. APPLICATION EXAMPLE

2.1 Water Source

The amount of sewage to treat is 120,000 tons everyday on average, and sewage through disposal is up to secondary discharge standard. This project utilizes heat energy in the sewage, and adopts temperature difference of secondary effluent (Sewage in contact tank) as energy input for central air conditioning system. The amount of secondary effluent is about 5000 tons per hour. There is enough temperature difference for the sewage heat source pump system to use. The water quality of secondary effluent is as follow: Suspended solid 30mg/L, biochemical oxygen consumption 30 mg/L per 5 days, chromium measured chemical oxygen consumption 60 mg/Ls one day, ammonia and Nitrogen 25mg/L, total phosphorus 1mg/L. The temperature is not lower than 10 ℃ in winter, and it can reach about 25 ℃ in other seasons.

2.2 Cooling/Heating Load

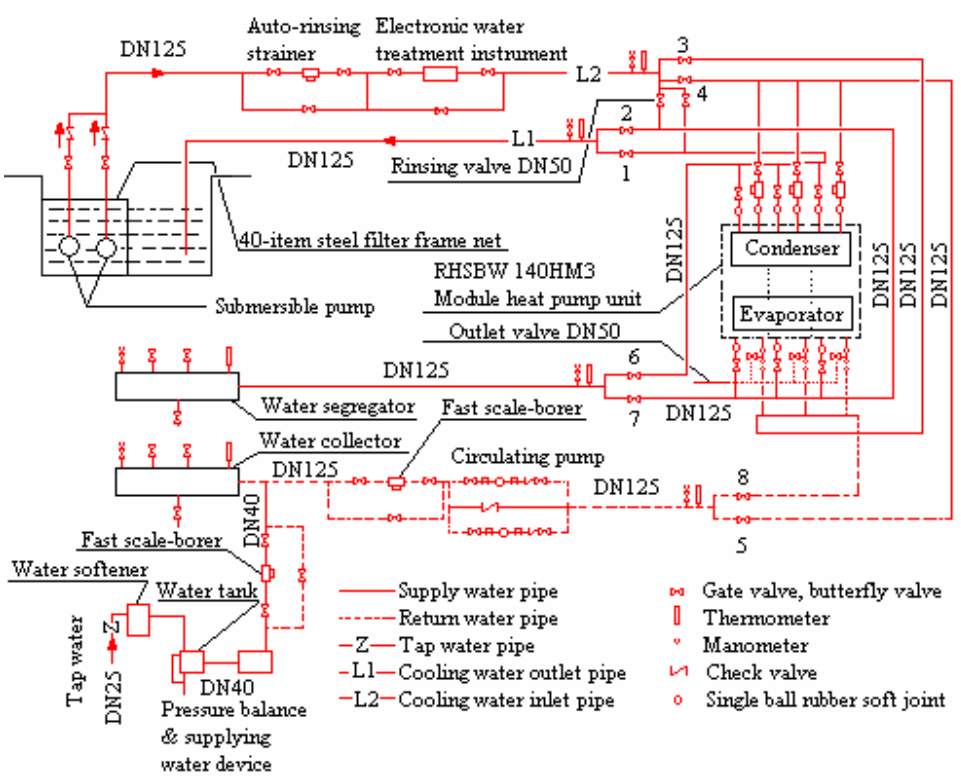
The heating period of Qinhuangdao is 152 days, and the designing outdoor temperature is -12 ℃ in winter. The total building area in the plant is 3038.78 m^2. Among it heating area is 2698.42 m^2 and cooling area is 1604.23 m^2. The total heating load is about 337.8KW, and total cooling load is about 260.6 KW.

2.3 Sewage Heat Source Pump System

Figure 1 shows systematic procedure sketch of the sewage heat source pump system that uses the secondary effluent as heat source. According to the project practice, we adopt the system that the secondary effluent enters the water-source heat pump unit's condenser directly, rather than through another heat exchanger. Here we consider the following two reasons mainly:

(1) The temperature of the secondary effluent is relatively low in winter. It will be even lower if we let the secondary effluent through another heat exchange. Thus the heat pump unit's evaporator may be frozen because the inlet water does not meet the heat pump's requirement;

(2) Through water quality analysis to secondary effluent, there is no problem for treated secondary effluent to enter the unit's plate heat exchanger. In addition, we set up a 40-item filter frame net around the submersible pump (pumping water area), do the first filtration to suspended solid, and do the second filtration by another 60-item filter before water entering the heat pump unit. Thus we can totally guarantee that the heat pump unit is not affected by suspended solid, and operates safely and effectively.



Note: 1. When the system operates in summer, valves 1, 4, 7 and 8 open, but Valves 2, 3, 5 and 6 close;
2. When the system operates in winter, Valves 2, 3, 5 and 6 open, but valves 1, 4, 7 and 8 close.

Figure 1: Heat pump equipment room's systematic procedure sketch

2.3.1 Chiller: According to the cooling/heating load and the need of the project, we adopt 3 semi-hermetic screw modular chillers (Heat pumps). For every heat pump, the rated cooling and heating capacities are 141KW and 161 KW respectively, and motor power is 30.1 KW. They adopt high-powered semi-hermetic compressors and stainless steel brazed welding plate heat exchangers. Three units are divided into a main unit and two sub units. They can operate together, and can operate independently too. Thus we can balance the running time of 3 units, guarantee the same running time, the same wearing and tearing, and lengthen units' life.

2.3.2 Water-source side's system: Sewage's water quality is the main factor influencing heat pumps' cooling and heating performance. Sewage's water quality influences not only heat exchange efficiency, but also the equipments' service life.

(1) Water-source pump

Water-source side's circulating water flow is about 60 m^3/h in summer, about 50 m^3/h in winter. Secondary effluent's amount can meet the demands completely. We adopt 2 submersible pumps as water-source pumps. The technical parameters are as Table 1 shows.

Because the water-source pump is set in the secondary effluent of the contact tank, we adopt submersible pumps. But because the water quality of the secondary effluent is good, we do not adopt submersible sewage pumps. In order to prevent bigger suspended solid in the secondary effluent from entering and jamming the water-source pumps' inlets, we set up a 40-item stainless steel filter frame net around the pumps' inlets, and install an auto-rinsing strainer and an electronic water treatment instrument on the pipes behind the water-source pumps in the project.

Table 1: Water-source pumps' technical parameters

Model	Flow (m^3/h)	Lift (Mh_2O)	Motor power (KW)	Rotating speed (rpm)	Electrical source (V/ HZ)
SP46-4	50	30	7.5	2900	3*380/50

(2) Auto-rinsing strainer

Because filtering technology is the key problem to implement the sewage heat source pump system, it is very important for us to select the right filtering equipment. We adopt an auto-rinsing strainer (Flow 100 m^3/h, filtering precision 60-item/0.23mm, model ZG100-L) in this project. Table 2 shows its technical parameters.

Table 2: Auto-rinsing strainer's technical parameters

Model	ZG100-L	Flow (m^3/h)	100	Filtering precision	60-item/0.23mm
Material			Body carbon, steel; filtering components, axes, blowdown pipes and manual blowdown valve, stainless steel.		
Pendulum decelerator			Installation mode, vertical; twice deceleration.		
Pressure differential controller			Rated pressure difference modulating scope: 0.02-0.1MP; allowable pressure maximum: 2MP		

Figure 2 shows the auto-rinsing strainer's figure and operation principle.

Auto-rinsing strainer has following characteristics: supplying water continuously, auto-rinsing, high accurate and reliable filtration, and large filtering area.

Figure 2: Auto-rinsing strainer's figure and operation principle

2.3.3 User system: The user system is almost the same as that of routine air conditioning system. It includes cold/hot water circulating pump, water collector, water segregator, pressure balance & supplying water device and air conditioning equipment. Supply/return water temperatures are 7/12 ℃ in summer, and 50/40 ℃ in winter.

2.4 System Control

(1) Cold/hot water system's operation control

The sewage heat source pump system realizes the operation modes of heating/cooling through switching the valves on the pipes in this project. The control method is the same as general water-source heat pump system, and we will not introduce it in detail here.

(2) Water-source side's system operation control

The rinsing pressure that the auto-rinsing strainer needs is no less than 0.2Mpa, but when the strainer runs normally its pressure loss is only 0.01-0.02Mpa. The pressure difference needed when rinsing is much larger than that needed in normal operation. So an adjusting valve is set in the water source side's system in order to match the rinsing pressure requirement.

(3)Heat pumps and other equipments' operation control

According to the load and circulating water flow's change, the system will regulate the parameters and number of the equipments such as heat pumps and water pumps. The equipments can be operated alone, and they can open or close in order automatically too.

(4)Central control room

The central control room carries out long-distance monitor to the sewage heat source pump system, and reflects the change of every unit's parameter such as the water-source's inlet/outlet water temperatures and circulating water's inlet/outlet water temperatures, etc in time. The equipment can run without any operator in the equipment room, only need itinerant inspection regularly.

3. TECHNICAL & ECONOMIC ANALYSIS

The water-source heat pump heating system's COP can reach 3.5-4.5 in the whole winter. It is much higher than that of the central heating system using regional boiler house as heat source. We use the sewage heat source pump system in Qinhuangdao Haigang District sewage treatment plant as an example, and carry out its technical & economic analysis. Because the project is operated totally according to municipal public service's BOT model, the project investor cares more for the investment and operation expenses of the project. We compare the investment and operation expenses of the sewage heat source pump system with those of the system using electric chillers and oil boiler as follows.

3.1 Investment's Compare

Because the user part of the sewage heat source pump system is the same as that of general air conditioning system, we only compare the investment of the equipment room part. Table 3 and 4 show the two systems' expenses.

Table 3: Investment estimate of the sewage heat source pump system

No.	Name	Model	Number	Price (RMB yuan)	Total price (RMB yuan)
1	Water-source heat pump unit	RHSBW140HM	3	180,000	540,000
2	Cold/hot water circulating pump	KQL80-160	2	3,100	6,200
3	Water-source pump	200QJ50-26/2	2	5,000	10,000
4	Auto-rinsing strainer	ZG100-L	1	36,000	36,000
5	Accessorial equipment		1	63,680	63,680
6	Material expense				79,800
7	Installing and debugging expense				69,000
	Total				804,680

Table 4: Investment estimate of the system using electric chillers and oil boiler

No.	Name	Model	Number	Price (RMB yuan)	Total price (RMB yuan)
1	Chiller	KLSW-040S	3	160,000	480,000
2	Oil boiler	DSJ30	1	85,000	85,000
3	Cold water pump	KQL80-160	2	3,100	6,200
4	Cooling water pump	KQL80-160	2	3,100	6,200
5	Cooling stack	LBCM-50	1	50,000	50,000
6	Accessorial equipment		1	63,680	63,680
13	Material expense				85,000
14	Installing and debugging expense				75,000
	Total				851,080

3.2 Operation Expense's Compare

As the reason mentioned above, we only compare the operation expenses of the equipment room part here. Because the operation expenses of the air conditioning system are reflected by energy consumption to a great extent, we compare the operation expenses caused by energy consumption in this article.

(1) Energy consumption

Table 5 shows the energy consumption of the air conditioning systems.

Table 5: Energy consumption of the air conditioning systems

	Sewage heat source pump system		System using electric chillers and oil boiler	
Summer	Water-source heat pump unit	30.1KW×2	Chiller	30.0KW×2
	Cold/hot water circulating pump	7.5KW×1	Cold water pump	7.5KW×1
	Water-source pump	5.5KW×1	Cooling water pump	7.5KW×1
	Supplying water pump	2.0KW×2	Supplying water pump	2.0KW×2
	Auto-rinsing strainer	1.5KW×1		
	Total	78.7KW	Total	79.0KW
Winter	Water-source heat pump unit	39.7KW×2	Oil boiler	0.75KW×1
	Cold/hot water circulating pump	7.5KW×1	Diesel oil	32.7kg/h
	Water-source pump	5.5KW×1	Cold water pump	7.5KW×1
	Supplying water pump	2.0KW×2	Cooling water pump	7.5KW×1
	Auto-rinsing strainer	1.5KW×1	Supplying water pump	2.0KW×2
	Total	97.9KW	Total	19.75KW Diesel oil 32.7kg/h

Note: The energy consumption not indicated in the table is all electricity consumption.

(2) Operation expense

Table 6: Operation expenses of the air conditioning systems

	Sewage heat source pump system		System using electric chillers and oil boiler	
Summer	0.4 RMB yuan/KWhr × 78.7 KW × 10 hr/d × 120d = 37776 RMB yuan		0.4 RMB yuan/KWhr × 79.0 KW × 10 hr/d × 120 d = 37920 RMB yuan	
	Total	37776 RMB yuan	Total	37920 RMB yuan
Winter	0.4 RMB yuan/KWhr × 97.9 KW × 20 hr/d × 150 d = 117480 RMB yuan		Electricity: 0.4 RMB yuan/KWhr × 19.75 KW × 20 hr/d × 150 d = 23700 RMB yuan Diesel oil: 3.6 RMB yuan/kg × 32.7 kg/hr × 20 hr/d × 150 d = 353160 RMB yuan	
	Total	117480 RMB yuan	Total	353160 RMB yuan

In Qinhuangdao, the cooling time is about 120 days, and operation time is about 10 hours per day in summer. The heating time is about 150 days, and operation time is about 20 hours per day. We calculate operation expense by 0.4 yuan (RMB)/KWhr for electricity and 3.6 yuan (RMB)/kg for diesel oil. Table 6 shows the operation expenses both in summer and in winter.

From the technical and economic analysis above, we can see the following facts. The investment of sewage heat source pump system is about 6% lower than that of the system using electric chiller and oil boiler. Their operation expenses are almost the same in summer, but the operation expense is about 67% lower than that of the system using electric chiller and oil boiler. Totally there is a 60% saving for operation expense every year.

Certainly, the investment and operation expenses' saving proportion is affected by such factors as equipment selection, electricity price and oil price. Because this project is relatively smaller, when the project is larger, we should make a concrete analysis to the investment and operation expense's saving again.

4. APPLICATION POTENTIALITY ANALYSIS

Everyday the cities produce a large number of sewages that contain a large amount of heat. For example, the 38,000 TJ of heat energy is wasted to the sewage system annually in Tokyo Metropolitan Districts, which is equivalent to the energy consumed by 400,000 houses for heating and cooling [2].

According to the heat energy flow through the water system in February 1998, Sapporo, the temperature of tap water was 3.8 ℃, then the temperature rose to 13.1℃ after users used. The sewage treatment plant's effluent temperature was 13.8 ℃ finally. The 700MJ/s sensible heat was released to the receiving water body. The total amount of the heat energy in the effluent was about 5,500TJ/year comparable to about 26% of the annual consumption of domestic use in Sapporo [5].

For example, in an urban district with a population of 330,000, it will produce 60,000 ton/d sewage if the sewage amount produced by each person is 180 kg/d. In the condition that the proportion between industrial wastewater and domestic sewage is 1:1 in municipal sewage, we need to build a sewage treatment plant whose treatment ability is 120,000 ton /d. Its secondary effluent is 5,000 ton/hr. If we use temperature difference of 5 ℃ separately both in summer and winter, use cooling index 80 W/m^2 and heating index 60 W/m^2, then the energy in sewage can supply a cooling area of 360,000 m^2 and a heating area of 480,000 m^2 respectively.

5. CONCLUSION

From the analysis above, we can draw the conclusion that sewage heat source pump system has more advantage than the system using electric chiller and oil boiler both in technology and investment & operation expenses.

If we use sewage heat source pump system, it can realize both heating and cooling, and don't need to set up boiler house and cooling stack. It also reduce air pollution, and save investment and operation expense. There is enough water in sewage treatment plant. We can utilize low-temperature heat energy if we use sewage, secondary effluent or normal water as heat source. We should use sewage heat source pump system more in China.

Sewage heat source pump system has wide application prospect, but there are also some problems needed solving.

(1) Cleaning technology

Because there are many kinds of suspended solid and saline, cleaning technology is the key factor to retrieve energy from sewage. We must solve the problems such as blocking, corrosion, and fouling, etc.

(2) Heat pump's location

If the system is used for district heating and cooling, should we choose untreated sewage or secondary effluent/normal water? And should we choose central, semi-central or disperse sewage heat source pump system? These all need technical & economic analysis.

(3) Heat users

If we adopt general water-source heat pump, the hot water temperature it can offer is 45-50 ℃ in winter, which can meet fan coil's requirement, but can not match radiator's requirement. The hot water temperature offering to radiator should be above 70 ℃ generally.

There are three kinds of solutions:

a The system only supplies energy to the users that use fan coils, such as public facilities or office building;

b The system supplies energy to the building using floor heating;

c We can adopt 2-stage heat pump system, adding a high-temperature heat pump system behind sewage heat source pump system. It can raise outlet water temperature from 45-50 ℃ to more than 70 ℃.

(4) Sewage's temperature

Sewage temperature is related with many factors such as region, living standard, sewage water flow, composition of municipal sewage (The proportion between industrial wastewater and domestic sewage) of the city and the season, etc. But it is better that inlet water temperature for sewage heat source pump is no lower than 12℃ in winter. So we should investigate and analyze municipal sewage water temperature change in a whole year.

(5) Guaranteeing

If sewage heat source pump system is applied to district heating and cooling, we must consider whether we should set up an energy-storing tank and spare boilers.

(6) Economy

We should analyze whether it is reasonable in economy when comparing with the other ways for heating and cooling.

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