LARGE-SCALE APPLICATION OF MUNICIPAL RECLAIMED WATER SOURCE HEAT PUMPS TO A DHC SYSTEM IN THE BEIJING OLYMPIC VILLAGE

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Abstract: The Olympic Village District Heating & Cooling (DHC), which located in the Beijing Qing River area, introduced the municipal reclaimed water source heat-pump system based on the promise of “Green Olympics” adopted by 2008 Beijing Olympic Games. This DHC system is the largest-scale use of municipal reclaimed water as heat source and sink in heat-pump system so far in China. The system feasibility was verified by two years field experiments and continued commissioning over the winter 2007.The full load operation will start in June 2008. In this paper, the outline and feature of the DHC system were described. The fouling problem and its mitigation were discussed. The energy consumption and environment effects of this system were evaluated. The evaluation results showed that the Olympic Village DHC system could reduce primary energy consumption and greenhouse gas emissions by 40% in comparison with the district heating by boiler plant.

Key Words: ***municipal reclaimed water, heat pump, plate heat exchanger, large-scale, district heating &cooling, Beijing Olympic Village***

1 INTRODUCTION

In P.R China, the municipal reclaimed water source heat-pump system (MRWSHP) becomes more and more attractive to government and energy consumers. During the last ten years, several small-scale heat-pump systems using municipal reclaimed water as heat source and sink have been built and operated in Beijing and Tianjin.

According to the statistics, the total amount of wastewater discharge would increase to 1.1 billion tons in Beijing in 2008, among which domestic discharge accounts for about 90%. Up to the beginning of 2008, fourteen wastewater treatment plants (WWTP) located in the urban and suburb of Beijing have been operated so that the rate of wastewater treatment in this city could reach 90%. The large-scale municipal wastewater treatment plants in Beijing are shown in Table 1.

Based on the abundant reclaimed water resources, the municipal reclaimed water source heat-pump system is introduced into the Beijing Olympic Village District Heating & Cooling (DHC) with the aim of reducing energy consumption and greenhouse gas emissions. This DHC system is the largest-scale use of municipal reclaimed water as heat source and sink in heat-pump system so far in China. The successful operation of the Olympic Village DHC system will play an extremely important role to not only spread the concept of “Green Olympics” adopted by 2008 Beijing Olympic Games, but also extend the utilization of large amounts of thermal energy contained in municipal sewage.

Table 1: Large-scale wastewater treatment plants in Beijing

Name of the WWTP	Treatment capacity per day (ten thousand cubic meter)	Location
Gaobeidian WWTP	100	Eastern part of Beijing, near by Tonghui river
Jiuxianqiao WWTP	40	Eastern part of Beijing, near by Ba river
Qinghe WWTP	40	Northern part of Beijing Near by Qing river
Xiaohongmen WWTP	60	Southern part of Beijing, near by Liangshui River

2 OUTLINE OF THE OLYMPIC VILLAGE DHC

Beijing Olympic Village, constructed for 2008 Beijing Olympic Games, is an exclusive accommodation for athletes and accompanying officials during the Games, as well as a commercial and residential accommodation after the Games. There are two kinds of supply area in the Olympic Village: the one is apartment buildings consisting of four parts; the other is two public buildings. The view of supply area is shown in Fig.1. All buildings in Olympic Village have excellent thermal insulation performance for energy saving.

In Olympic Village, the municipal reclaimed water source heat-pump system is used to meet the requirement of heating and cooling. The outline of this DHC is displayed in Table 2.

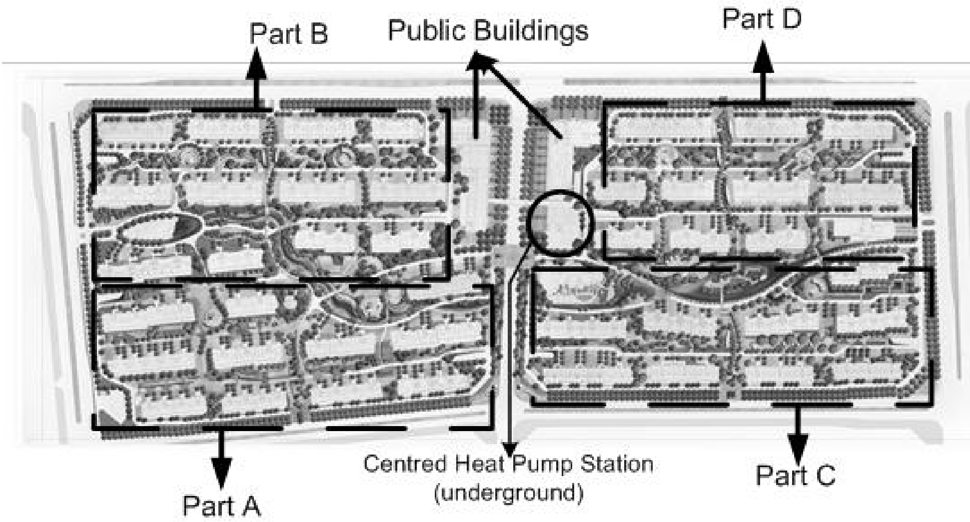

Figure 1: The view of supply area of Olympic Village

Table 2: The outline of Olympic Village DHC

Time of completion and commissioning	Winter, 2007
Full load service start-up	June, 2008
Supply floor area (apartment buildings)	413,250 m^2 (380,000 m^2)
Maximum cooling capacity (only for apartment buildings)	19,048kW (14,524kW)
Maximum heating capacity (only for apartment buildings)	20,937kW (15,960kW)
Cooling supply/return temperature	7/12°C
Heating supply/return temperature	44/38°C
Heating terminal device	Low temperature radiant floor heating
Air-conditioning terminal device	Fan-coil unit (without fresh air)

There are two important projects in Olympic Village DHC: 1) the project of heat exchange station near by Qinghe WWTP for waste heat recovery from municipal reclaimed water and transmission of recycled water; 2) the project of centred heat pump station located in Olympic Village for production and transmission of cool/hot water.

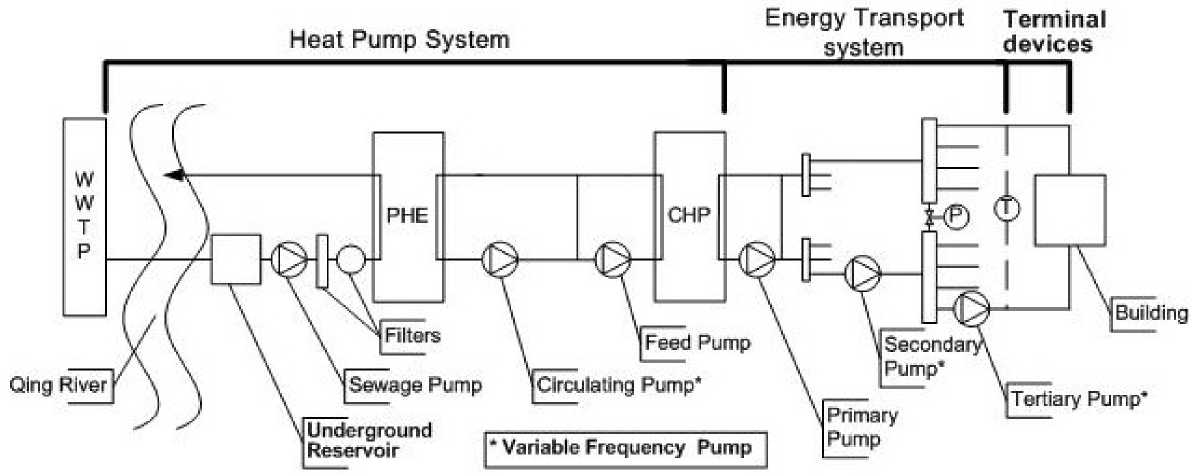

Figure 2: The flowchart of Olympic Village DHC system

As shown in Fig.2, the Olympic Village DHC system is divided into three units: 1) heat pump system; 2) energy transport system; 3) heating/air conditioning terminal devices. The outline of the facilities in heat pump system is shown in Table 3.

In winter, the low-grade waste thermal energy contained in the reclaimed water is recovered by plate heat exchangers (PHE), and then the moderately-high grade thermal energy generated by centrifugal heat pump (CHP) is supplied for residential heating. In summer, the municipal reclaimed water served as cooling medium absorbs heat rejected by the condenser of heat-pump system.

In energy transport system, the application of PST (Primary-Secondary-Tertiary Pumping System) and frequency control technology could sharply reduce the energy consumption of water pump system.

Table 3: Outline of facilities in heat pump system

Kind of Facility	Name of Facility	Specification	Number
Heat Exchange Facility	Plate Heat Exchanger (PHE)	Design capacity of Heat transfer Cooling: 5,725kW Heating: 4,200kW	4
		MRW* Temperature inlet/outlet Cooling: 12.5 /7.5 °C Heating: 26 /35 °C	
		LMTD Cooling: 2.05°C Heating: 2 °C	
Heating/Cooling Facility	Centrifugal Heat Pump (CHP)	Refrigerant: R134a	4
		Design cooling capacity: 5,400kW Design heating capacity: 5,247kW	
		Design supply/return temperature Cooling: 5/12 °C Heating: 44.5/38.5 °C	

* MRW: Municipal Reclaimed Water

* LMTD: Log Mean Temperature Difference

3 FEATURES OF OLYMPIC VILLAGE DHC

3.1 Municipal reclaimed water and its filtration

The reclaimed water with secondary treatment is obtained from a large-scale municipal WWTP which located in 3km away from the Olympic Village. The changes of temperature and discharge of the municipal reclaimed water were continuously monitored from August 2005 to January 2008. The daily highest and lowest temperatures were 26.4 ^{o}C in August and 12.5 ^{o}C in January. The daily average discharge is 16,667m^3/h. The lowest discharge is 7500 m^3/h happening at around 6:00am.

For the Olympic Village DHC system, the total requirement of municipal reclaimed water is 3,500m^3/h. In order to make sure the system safety and performance, an underground reservoir of 3000m^3 was built to relieve the contradiction of reclaimed water supply and requirement. Before flowing into the heat exchanger, the reclaimed water is continuously filtered by thick grid and auto self-cleaning strainer in order to remove the suspended solid and fibrous materials. After the process of heat exchange, the municipal reclaimed water is directly discharged into Qing River.

3.2 Plate heat exchanger

In Olympic Village DHC system, the high-efficiency indirect mode is used for waste energy recovery. As shown in Fig.2, the heat exchange process between the municipal reclaimed water and the intermediate heat-transfer medium is efficiently carried out through plate heat exchanger outside the heat pump unit.

The field experimental results indicated that the wastewater secondary treatment by WWTP has a weak effect to decrease the corrosivity of the sewage. Thus, AISI316 was used as the material of plate heat exchanger. To prevent clogging by suspended solid and fouling, a wide space (larger than 3mm) between the removable plates was selected. Under the design conditions, the heat transfer coefficient of the plate heat exchanger could reach 5000~6000W/ (m^{2}*K).

In the design process, we made a detailed comparison between the direct mode and the high-efficiency indirect mode. The analysis results proved that the high-efficiency indirect mode could bring more benefits to not only reduce the first cost, but also increase the operational efficiency. There are three main reasons: firstly, the conventional centrifugal heat pump could be used without preservation treatment in evaporator and condenser; secondly, the high cost for rubber ball cleaning system could be saved; finally, the low-grade thermal energy contained in the municipal reclaimed water could be efficiently recovered by plate heat exchanger. The feasibility of plate heat exchanger using municipal reclaimed water as heat-transfer medium has been verified by two years field simulated experiments and continued commissioning during the winter 2007.

3.3 Fouling and its mitigation

It is no doubt that the water quality of sewage will be greatly improved by secondary treatment in WWTP, which makes people ignore the problems caused by fouling during waste energy recovery from municipal reclaimed water.

Actually, the fouling growing faster than most people think has a strong effect on the heat transfer performance of municipal reclaimed water. A field simulated experiment system for plate heat exchanger has been operated for two years in Qinghe WWTP. The filed and laboratory experimental results show that the fouling formatted by municipal reclaimed water is a composite substance mainly consisting of microbe and extracellular products. The composite fouling could sharply reduce by 50 % of the heat transfer coefficient of plate heat exchanger during 20 days in cooling season.

The formation process of composite fouling is strongly depended on the water quality, water temperature and velocity. On the one hand, the secondary treatment by WWTP could not make a thorough removal of the components causing fouling, such as anaerobic bacteria, biological nutrients, and silicon substance, etc; on the other hand, the working temperature and velocity of plate heat exchanger in MRWSHP system is suitable for fouling growth. In results, the fouling problem is inevitable and considerable during waste energy recovery from the municipal reclaimed water.

According to the fouling characteristics, a Clean-In-Place (CIP) method, including special cleaning agent and cleaning process, was developed by our research group for mitigating the fouling in plate heat exchanger using municipal reclaimed water as heat-transfer medium. The field experimental results demonstrated the high efficiency of fouling mitigation by this new CIP method. The cleaning effect is shown in Fig. 3.

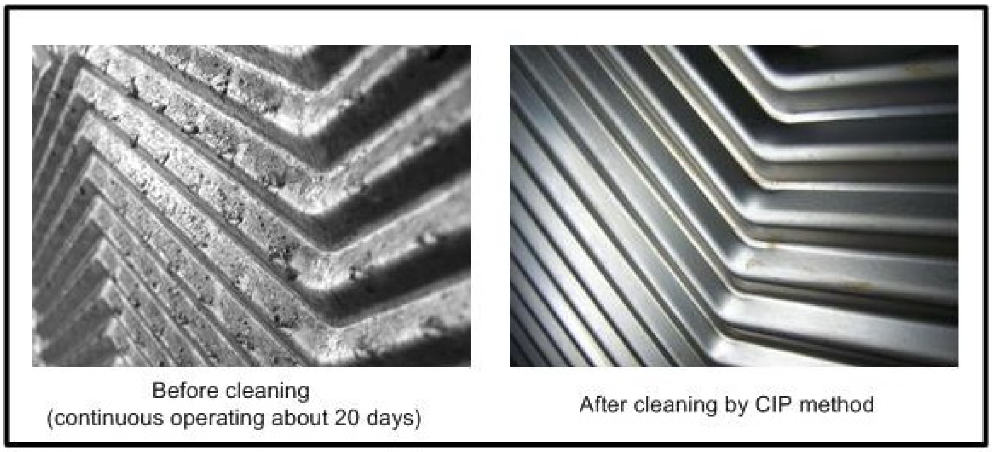

Figure 3: Cleaning effect by the new CIP method

4 SYSTEM PERFORMANCE EVALUATION

4.1 Cooling supply

During the cooling season, the municipal reclaimed water is cooler than outdoor temperature. According to the field monitoring, the average temperature of reclaimed water is 3~5 ^{o}C lower than outdoor temperature from June to September in Beijing. Therefore, the energy consumption of the reclaimed water source heat pump in Olympic Village DHC system could be reduced by 10~15%, as well as a sharp reduction of regional heat pollution, compared with the air-source system.

4.2 Heating supply

For the first time in China, the large-scale centrifugal heat pump system is used for district heating. The energy consumption of Olympic Village DHC system in heating season is calculated in comparison with three heating modes widely using in Beijing. The calculation conditions are specified in Table 4.

Table 4: Calculation conditions of the four heating modes

Total heating capacity	3.68MW
Mode 1: Municipal reclaimed water source heat pump for district heating (Olympic Village DHC)	
Average temperatures of reclaimed water	16℃ (heating season)
The average LMTD of plate heat exchanger	3.0℃ (in heating/cooling season)
Heating supply/return temperature	44/38^{o}C
Seasonal coefficient of performance*	3.85
Mode 2: Boiler plant for district heating	
Boiler efficiency	80.0%
Heat value of standard coal	29308kJ/kg
Mode 3: Gas boil for household heating	
Gas boiler efficiency	87.3%
Heat value of natural gas	36400kJ/Nm^3
Mode 4: Air source heat pump for micro-district heating**	
Seasonal coefficient of performance*	2.82

*The energy consumption for heat transportation is not included.

** In the Case 4, the unit heating capacity of air source heat pump could meet the heating load requirement of one apartment building.

For this calculation, the apartment buildings are considered as the evaluation object. The heating area is of 310,000 m^2. The heating season lasts four months. The total heating capacity is simulated hourly by the DeSTII software. The equipment performances are calculated based on the performance curves presented by the manufacturers.

As shown in Table 5, the primary energy utilization coefficients of the four heating modes were calculated. Benefited from the high efficient recovery of waste energy contained in the municipal reclaimed water, the Mode1 has the best energy-saving performance. Moreover, the total primary energy consumption of Olympic Village district heating system could be reduced by 40% in comparison with the district heating by boiler plant.

Table 5: Comparison of energy consumption over a heating season

	Energy consumption for heat production*		Energy consumption for heat transportation**		Primary energy consumption (GJ)	Primary energy utilization coefficient***
Mode 1	Electric energy	2,774,886 (kWh)	Electric energy	765,532 (kWh)	34447	1.116
Mode 2	Standard coal	1,722 (t)	Electric energy	765,532 (kWh)	57915	0.664
Mode 3	Natural Gas	1,209,999 (Nm^3)	——	≈0	44044	0.873
Mode 4	Electric energy	3,792,849 (kWh)	Electric energy	297,047 (kWh)	39394	0.966

* The energy consumption for fouling mitigation is neglected in Case 1.

**For Mode 1, the energy consumption of Primary-Secondary-Tertiary Pumping System is derived from the system commissioning. For Mode 2, the heat transportation system is same as Mode 1. For Mode 3, the tertiary pump system of Mode 1 is used here for micro-district heat transportation.

*** The primary energy utilization coefficient is the ratio of total heating capacity to primary energy consumption; the average generating efficiency is 37%.

Accompanying with the effective reduction in primary energy consumption, the Olympic Village district heating system brings a sharply reduction of greenhouse gas emission, as well as a considerable reduction of acid gas emission. The evaluation results of harmful substance emission are shown in Fig. 4 and Fig 5.

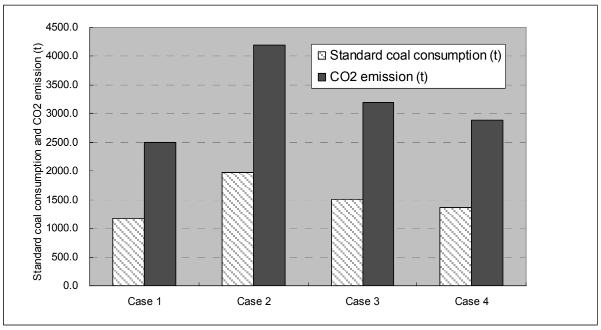

Figure 4: The standard coal consumption and CO_2 emission in a heating season

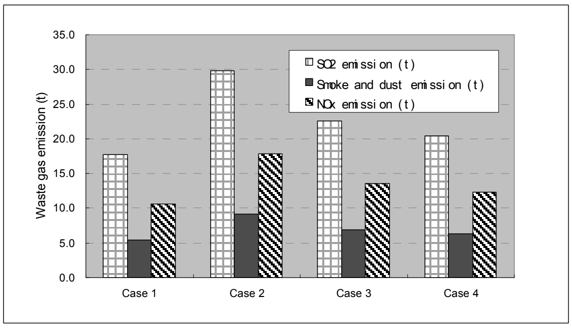

Figure 5: The waste gas emission in a heating season

5 CONCLUSIONS

The municipal reclaimed water source heat-pump system was introduced into the Olympic Village District Heating & Cooling in Beijing, which is the largest-scale use of thermal energy of municipal reclaimed water by centrifugal heat-pump system so far in China.

Although municipal reclaimed water has already been used elsewhere for heating and cooling purposes, the Olympic Village DHC system is unique in that it is the first large-scale DHC system in China using plate heat exchanger to efficiently recover the waste energy from the reclaimed water. To maintain a high performance of this DHC system, a Clean-In-Place method was developed to prevent fouling in plate heat exchanger using municipal reclaimed water as heat-transfer medium.

In order to verify the system feasibility, two years field simulated experiments and continued commissioning over the winter 2007 were carried out. Furthermore, the system performances were evaluated in the aspects of energy consumption and environmental effects. The evaluation results are shown as follow: 1) in cooling season, the energy consumption of Olympic Village district cooling system could be reduced by 10~15% compared with the air-source system; 2) in heating season, the primary energy utilization coefficient of Olympic Village district heating system is 1.116. With the high efficient recovery of waste energy contained in the municipal reclaimed water, the primary energy consumption of Olympic Village district heating system could be reduced by 40% in comparison with the district heating by boiler plant, as well as a considerable reduction of harmful gas emission.

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