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Case study on industrial surplus heat of steel plants for district heating in Northern China

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ABSTRACT

In China, district heating systems are facing a dilemma between rapid growth in demand owing to urbanization and environmental problems related to coal-fired boilers. The utilization of industrial surplus heat has great potential on improving the power of heating systems and reducing coal consumption of boilers. However, few industrial systems are constructed under the consideration of district heating. Some features of the surplus heat, such as the position, grade, and production schedule, are significantly different to traditional heat sources. To recover the surplus heat, retrofits of district heating systems are necessary. In this paper, according to the current situations and the future developments, a scheme is proposed to integrate the surplus heat of two steel plants into a large-scale district heating network. Three sources of surplus heat are involved: slag-flushing water, cooling water, and low-pressure steam. The scheme has been partly applied in a corresponding demonstration project. The actual performance proves the feasibility of the integrated system and implies significant benefits in terms of economic cost, CO_2 emission and pollutant emissions. Furthermore, the potential to extend the scheme in Northern China is also evaluated.

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1. Introduction

A number of industries are located in Northern China, consuming massive energy in production processes. A part of the energy turns into ISH (industrial surplus heat). They can be reused for internal processes, offsetting heating energy consumption, or converted to electricity by the Rankin cycle [1–3]. However, not all the heat can be recycled in these ways. Low-grade ISH, which has no matching internal demands and is uneconomical in cogeneration, is usually released directly into the atmosphere resulting in the wastage of energy.

To recover the low-grade heat and reuse for heating is a reasonable choice. Most of the Chinese DH (district heating) systems have return water temperatures of approximately 50 °C in primary networks and lower in secondary networks [4]. In Europe, low-temperature district heating systems are able to reduce return water temperatures to 25 °C [5]. Most of the ISH can be theoretically recycled to meet such a low-grade demand; hence, the researches on recovering the ISH for DH are popular. Some researchers designed systems and evaluated the feasibility to recover low-grade surplus heat for DH: Chen et al. recycled the latent heat of water vapor in flue gas via condensing boiler; Ajah et al. recovered the waste heat in pharmaceutical plants via chemical heat pump; Zebik et al. reused the waste heat in a gas-refinery and a metallurgical plant with optimized heat recovery diagrams [6–8]. The utilization of the ISH for DH can not only improve the energy efficiency of industries but also provide economic and environmental benefits for DH systems.

On the macroscopic aspect, ISH has been listed as a source for 4th generation DH systems, being a choice of future heat sources [9]. In many countries such as the UK and Sweden, the distribution of ISH has been investigated, while the feasibility and competitiveness of its integration with large-scale DH networks are under evaluation [10–13]. In China, ISH also attracts much attention, since the DH systems are facing a dilemma between the rapid growth in demand owing to urbanization and serious environmental problems related to coal consumption. Coal-fired boilers, which serve more than 40% of the DH area, are thought in urgent need to be replaced [14,15]. Like the other kinds of clean heat sources, ISH could also be used to extend the capacity of DH systems and reduce the coal consumption of boilers. Fang et al. estimated the heating power of ISH and found that only 38% is adequate for serving the

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total DH demands in Northern China in 2009 [16]. High heating potential doubtlessly makes ISH a competitive candidate for future sources.

However, ISH is much different to traditional heat sources like boilers and CHPs. It usually states in different medium and at different grades even in the same industrial plant; it is also released depending on the factory production situations rather than the heat demands of users; hence ISH is unsafe and inefficient to be traditionally treated as an independent heat source. Fang et al. indicated some systematic issues that should be solved to integrate ISH and proposed three key solutions: 1) optimize the heat recovery procedure; 2) reduce the return water temperature; 3) equip peak shaving sources to control heat supply [17]. With the three solutions, more industrial heat could be recovered and better heating quality could be achieved.

In this paper, the theoretical solutions are applied in a case study to recover ISH from steel industry to urban DH network. Different from some existing projects that only recover the single heat sources, three types of ISH of steel plants are combined [18,19]. They are the heat in slag-flushing water of BF (blast furnace), cooling water of BF, and low-pressure mixed saturated steam produced in processes of steel-making and steel-rolling. A scheme is designed and applied in a demonstration project. The actual heating performance proves the feasibility to integrate ISH into a large scale network and the economic and environmental benefits are evaluated. Furthermore, the energy-saving potential to extend the scheme to the possible steel plants in Northern China will be estimated.

1.1. Background of the case study

Qianxi is a county of Tangshan city (China), located around 150 km to the east of Beijing. The population is approximately 390,000. The DH network is mainly constructed in recent 10 years and serves 3.2 million m^2 space heating area in 2015. The heat is provided by small coal-fired boilers in two existing heating stations (L and F).

Two steel plants (J and W) are considered to be the new heat sources of the Qianxi DH network. They separately have 6.5 million and 2 million tons of steel production, and locate around 11.5 km and 7.5 km to downtown. The plants purchase Iron ore as raw material and produce steel products in four major processes: sintering, iron-making, steel-making, and steel-rolling (Fig. 1).

1.1.1. Heating potential of ISH

Slag-flushing water of BF, cooling water of BF and cooling water of cogeneration are three main untapped low-grade ISH. Firstly, as for the slag-flushing water, its heat is transferred from hot BF slag during its cooling process from 1450 °C to approximately 100 °C. The temperature of the slag-flushing water is lower than 100 °C and its heating potential could be estimated as the heat released from BF slag. Secondly, the cooling water of BF is responsible for cooling the BF and the other associated equipment such as the hot-blast stove and top-pressure recovery turbine plant. Its temperatures are measured between 35 °C and 45 °C. Finally, the heat in cooling water of cogeneration is from the exhaust gas when it condenses at approximately 50 °C. The generator is driven by the 0.4 MPa mixed saturated steam produced by gas of basic oxygen furnaces and flue gas of rolling heating furnaces. It has no more than 18% energy of the steam converted into electricity and the rest 82% is released in condenser. Recovering the steam directly can prevent the release of low-grade heat after power generating.

Table 1
Heating potential of ISH in steel plants J and W.

Heat sources	Temperature (°C)	Quantity (MW)		
		J	W	Total
BF cooling water	35–45	116.8	39.9	156.7
BF slag-flushing water	<100	140.7	47.7	188.4
Low-pressure steam	143	44.0	8.0	52.0
Total		301.5	95.6	397.1

The heating potentials of three types of surplus heat are listed in Table 1. The maximum theoretical heating power is approximately 397.1 MW (megawatt).

1.1.2. Heat demands

The accessible heat demands include two parts: Buildings in urban area (District heating) and buildings in factory area (Factory heating). Both the district heating and factory heating are taken into consideration. The total heat demands are shown in Table 2.

DH system in the downtown serves both residential buildings and commercial buildings, whose current peak heat density is approximately 45 W/m^2 in average. The heating area is expected to increase at a fast rate, which will be 6.8 million m^2 in 2020 and 10.8 million m^2 in 2030. The. Even if the peak heat density does not reduce as energy-saving technologies possibly applied, the local DH demand will still increase from 144 MW to 308 MW in 2020 and 486 MW in 2030.

Factory heating includes heating for production workshops, office buildings, and employee residences served by a small part of the slag-flushing water. The current factory heating demands of steel plants of J and W are approximately 8 MW and 7 MW, respectively. In the future, according to the plans of the plants, they are expected to be separately 12 MW and 8 MW, which is more stable than the DH demand.

Table 2
Heat demands (unit: MW).

	Local DH	Factory heating	Total demands
2015	144	15	159
2020	308	17	325
2030	486	20	506

2. Methodology

Fig. 2 shows the connecting structure proposed for ISH, in which heat sources and users are indirectly connected via two parts: primary network and secondary network. Heat will be distributed to substations via the primary network and then delivered to users through the secondary network. For the integration of ISH, a

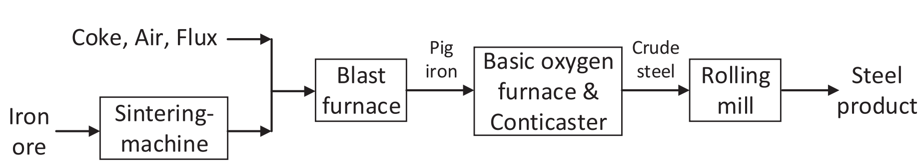

Fig. 1. Process of production of the two steel plants.

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