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Mapping potentials of low-grade industrial waste heat in Northern China

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ABSTRACT

Low-grade industrial waste heat has drawn great attention in China. A new regulation concerning low-grade industrial waste heat (IWH) use has been issued by the NDRC (National Development and Reform Commission) and the Ministry of Housing and Urban-Rural Development. Among the four major tasks mentioned, the most important is investigating IWH. However, there is little official data on the amount of waste heat in China. This paper presents a three-level method of IWH investigation. Meanwhile, the information needed at each level is summed up and heating area in northern China is taken as a case. A series of means are adopted, such as official statistics analysis, literature investigation, field test and so on. Results reveal the drastic situation of energy waste, and the great potential for energy conservation through the use of IWH. Approximately, 100 Mtce (2.93 EJ) potential of waste heat in industry can be recovered during heating season in whole northern China with 3.04 billion m^3 of water saving. Questionnaire inquiry covers 11 cities in Hebei, a typical industrial province. The feasibility and benefit of waste heat to district heating (DH) were verified in a case in Qianxi county. But usually waste heat doesn't distribute according to residential heat demand, as details are necessary when we regard it as potential heat source in any level. Moreover, it is recommended that policy makers should attach importance to data statistics, technology evaluation and stimulating market mechanism for proposed aim on waste heat.

1. Introduction

In China, the world's largest industrial producer, energy consumed by industrial sectors accounts for nearly 2/3 of the total energy consumption (National Bureau of Statics (NBS), 2010; National Bureau of Statics (NBS), 2011). The average annual emissions from 1996 to 2012 show that industrial sectors contribute to 70% of China's energy-related CO_2 emissions (Liu et al., 2015). In present industrial processes, a huge amount of energy is continually discarded into the environment, mostly by cooling towers and cooling fans. The process of waste heat dissipation leads to huge water and electricity consumption in industrial sectors. In the winter in North China, massive combustion of fossil fuels for industrial production and domestic heating has brought about a long-lasting toxic haze, which raises concerns for public health and pressures all levels of government to take action.

The total urban area with heating in northern China reached 12 billion m^2 in 2013 with a rapid 10% growth rate in the last decade (Tsinghua University Building Energy Research Center (THUBERC), 2015). Owing to the deep process of rapid urbanization, the heat demand is still increasing (Zhang et al., 2016). District heating (DH) in Northern China consumed 181 million ton standard coal equivalents (Mtce, 5.30 EJ) in 2013, accounting for one quarter of China's building energy consumption. The urban DH system in China was responsible for 4.4% of total CO_2 emissions in 2010, with an average increase of 10.3% in the past decade (Chen et al., 2013). Coal burning boilers, the most common and widespread DH system in northern China, are also suspected as a leading cause of the frequent haze-fog pollution during heating periods in recently years. Study indicate that a major contributory factor to urban PM 2.5 air pollution in Beijing is coal boilers, which typically have low thermal efficiency and are only equipped with coarse filters (Lin et al., 2011).

Industrial energy saving and clean heating are two aspects of energy conservation and environmental protection. Clearly, it is beneficial to match the huge energy demand for residential heating with the surplus heating supply from industry. Utilizing industrial waste heat (IWH) for DH in this way can therefore solve multiple problems.

1.1. Industrial energy saving & waste heat policies in China

In the 11th Five-Year Plan period, the Chinese government launched a series of policies to promote industrial energy saving such as the Top-1000 Enterprise Program and the Ten Key Energy-Saving projects (Zhao

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et al., 2014; Zhou et al., 2010). The Top-1000 Enterprise Program was carried out in 2006 to achieve energy savings of 100 Mtce (2.93 EJ) by 2010 (National Development and Reform Commission (NDRC), 2006). This target was accomplished and eventually reached 150 Mtce (4.40 EJ) in total (National Development and Reform Commission (NDRC), 2011). As part of the Ten Key Energy-Saving projects, the government provided massive sums of money as financial incentives for energy conservation projects. Waste heat and pressure utilization is one of the most significant measures accessed by the subsidy (Ministry of Finance and the National Development and Reform Commission (MOF and NDRC), 2007).

Based on past practices and stringent energy-saving demands, an implementation plan known as "Warming Program by Waste Heat" was issued in 2015 by the NDRC and the Ministry of Housing and Urban-Rural Development (National Development and Reform Commission (NDRC), 2015). The target was that 2 billion m^2 of heating demand should be satisfied by low-grade industrial waste heat (IWH) rather than coal by 2020, resulting in 50 Mtce (1.47 EJ) conserved for heating purposes each year. Four main tasks of the implementation plan involved urging local governments to carry out effective and efficient recycling of low-grade IWH, which included adjusting measures to local conditions and establishing application techniques and operation mechanism systems. Of these tasks, investigating low-grade IWH is the most vital. Therefore, designing a methodology for this investigation is the key issue of the Warming Program.

1.2. Industrial waste heat (IWH) studies

Previous studies estimate the volume of waste heat in different ways, especially when involving the new low temperature heat source for the European 4th DH system. The gross potential for industrial waste heat delivery in Sweden in 2009 was estimated as 9 TWh/a (32.4 PJ/a) by a top-down investigation (Broberg et al., 2012) and the recovery rate of primary energy supply from industry to DH may reach 3.13% in 2008 (Persson and Werner, 2012). And waste heat contributed to approximately 7% of supplied energy in Swedish DH systems in 2012 (Ivner and Broberg Viklund, 2015). Assuming technology in China could reach the same level (approximately 4% due to technological development), a new heat strategy with industrial excess heat recovery for DH of 731.2 TWh (amounting to 89.8 Mtce or 2.64 EJ) was considered in a heat roadmap of China for 2030 (Xiong et al., 2015).

(Miró et al., 2015) researched industrial waste heat from 33 countries (excluding China) and 6 sub regions of different countries using a literature investigation and energy data published by national or international official agencies. Similarly, (Lund and Persson, 2016) also mapped potential heat sources in Denmark, studying the distribution of 8 heat sources for heat pumps and the DH network through geographical information systems (GIS). However, these resources were mostly close to scattered inhabited areas and included lakes, ground water, and waste water treatment. The potential volume of low-temperature heat in Denmark was estimated as 3.4 TWh/a (12.24 PJ/a).

As well as case studies estimating the total potential waste heat for a country, Broberg et al. (2012) identified a total regional waste heat in Oster Gotland and Orebro of 21 TWh/a (75.60 PJ/a) using questionnaires of the 85 largest companies. They also set 4 different scenarios to analyze how DH market conditions affect the realization of waste heat potential.

The estimation and application prospects of excess heat in the industrial sector have also been discussed in some studies. (Persson et al., 2014) estimated 11.27 EJ/a of excess heat, of which 2.92 EJ/a came specifically from industrial sectors, based on carbon dioxide emission data. They introduced the concept of an excess heat ratio to infer to the European energy policy that the DH system should make full use of wasted energy to establish heat synergy regions. (Zhang et al., 2013) applied a MEFA (material/energy flow analysis) approach in their investigation of a Chinese iron/steel plant in Shandong province. It revealed a waste heat potential of 4.87 GJ/ton steel in the plant, equivalent to 26% of total consumption. (McKenna and Norman, 2010) investigated the waste heat resources in steel, chemical, nonferrous metal, and nonmetal manufacturing industries in the United Kingdom. They used maps to represent the potential and grade of industrial waste heat, as well as location information. The economic and CO_2 reduction analysis of conversion from industrial process to DH were analyzed in three Swedish counties with data of 83 companies (Djuric Ilic and Trygg, 2014). How to compare DH with IWH to DH with CHP (Combined Heat and Power generation) on environmental implication was discussed as well (Olsson et al., 2015).

Previous literature rarely includes a general methodology that covers most energy-intensive industrial sectors and that fits different requirements from macro policy making to energy planning to preparation for a real project. Studies focused on the specific situation of China, the largest energy consumer and industrial producer in the world, were even fewer. This paper provides a three-level methodology for low-grade industrial waste heat investigation for three different purposes: rough estimations based on macro data for regional macro policy-making, careful calculations using a mixed method including field surveys and questionnaires for district energy or heating supply planning, and delicate in-situ investigations as preparation for a real project. To illustrate this methodology in detail, different sized regions in northern China are used as examples.

2. Three-level methodology for studying low-grade industrial waste heat (IWH)

This study is a statistical analysis of low-grade IWH in northern China. This section presents the scientific method, divided into 3 levels which meet different requirements.

2.1. Different motivations for low-grade industrial waste heat (IWH) investigation

Due to different regional scales, there are three main motivations for IWH investigation that apply to nationwide policy or project guidance.

The first is to help local administrators decide whether IWH is worth utilizing as a strategic resource. Given the amount of waste heat and local heating demand, policy makers can perform a simple calculation and determine if they should build new pipelines to connect low-grade IWH to existing heating networks. After they take full account of all factors such as the energy security, environmental and social benefits, and economic efficiency.

The second purpose is to provide concrete data about low-grade IWH to support local energy or heating supply planning. In this scenario, not only the total amount of waste heat should be collected, but also the industrial type, grade, and regional distribution of the waste heat. Using this information, planners can make a judgment as to the type of district heating that should use the waste heat. For instance, high-grade heat sources such as electricity and steam should be introduced in regions where low-grade waste heat of 30–50 °C dominates, whereas extra high-grade heat sources are of little use in regions where waste heat of 50–100 °C is the majority. Furthermore, in a region with several cities in close proximity, some of them might possess plenty of waste heat but have small heating demands, while some of them may have huge heating demands but be short of waste heat. In such a case, the imbalance between supply and demand can be solved by taking these cities as a whole and building pipelines between them. So that waste heat in one city can be delivered to one in greater need.

The third objective is to support the complex design of a real project involving low-grade IWH utilization. The key factor of energy symbiosis network design like DH using waste heat is quality and available quantity of heat sources (Dou et al., 2016). Every detail, particularly the feasibility of each waste heat source, should be investigated, including production scheduling, stability of the waste heat source, available