Energy Policy 62 (2013) 236–246

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Industrial waste heat utilization for low temperature district heating

Hao Fang [a,*], Jianjun Xia [a], Kan Zhu [a], Yingbo Su [b], Yi Jiang [a]

[a] *Department of Building Science, Tsinghua University, Beijing 100084, China*
[b] *Heran Energy Management Company, Chifeng 024005, Inner Mongolia, China*

HIGHLIGHTS

- We review situation of industrial waste heat recovery with a global perspective.
- We present a way to analyze the potential to utilize industrial waste heat for DH.
- Northern China has huge potential for using low-grade industrial waste heat for DH.
- A demonstration project is introduced using the universal approach we propose.
- It proves huge benefits for factories, heat-supply companies and the society.

ARTICLE INFO

Article history:
Received 9 December 2012
Accepted 23 June 2013
Available online 19 Jul 2013

Keywords:
Industrial waste heat
Low temperature district heating
Benefits evaluation

ABSTRACT

Large quantities of low grade waste heat are discharged into the environment, mostly via water evaporation, during industrial processes. Putting this industrial waste heat to productive use can reduce fossil fuel usage as well as CO_2 emissions and water dissipation. The purpose of this paper is to propose a holistic approach to the integrated and efficient utilization of low-grade industrial waste heat. Recovering industrial waste heat for use in district heating (DH) can increase the efficiency of the industrial sector and the DH system, in a cost-efficient way defined by the index of investment vs. carbon reduction (ICR). Furthermore, low temperature DH network greatly benefits the recovery rate of industrial waste heat. Based on data analysis and in-situ investigations, this paper discusses the potential for the implementation of such an approach in northern China, where conventional heat sources for DH are insufficient. The universal design approach to industrial-waste-heat based DH is proposed. Through a demonstration project, this approach is introduced in detail. This study finds three advantages to this approach: (1) improvement of the thermal energy efficiency of industrial factories; (2) more cost-efficient than the traditional heating mode; and (3) CO_2 and pollutant emission reduction as well as water conservation.

1. Introduction

Large quantities of low grade waste heat are discharged into the environment during industrial processes (Zhang and Akiyama, 2009), mostly via water evaporation. Sources of the waste heat consist of variety of gaseous exhaust, waste process liquids, cooling media, and chemical waste (Skop and Chudnovsky, 2006).

Studies show that the energy lost in industrial waste heat is huge. Johnson et al. (2008) found that as much as 20–50% of energy is lost as waste heat in metal and non-metallic mineral manufacturing in United States. Sogut et al. (2010) found that 51% of the overall heat of the process is wasted in a cement plant in Turkey. McKenna and Norman (2010) established a model to estimate the industrial heat loads and technical recovery potentials for energy-intensive industries in the UK, and concluded that about 10% of the heat load is technically recoverable.

By recovering industrial waste heat, energy efficiency can be increased, greenhouse gases emissions can be reduced (Patil et al., 2009), the cost of waste disposal can be lowered (Kiang, 1981) and large amounts of water can be saved, which would otherwise evaporate during the cooling process.

There have been a number of studies focused on waste heat recovery for reuse in industrial sector. In some cases, the recovered waste heat can be used internally to increase the efficiency level of industrial processes themselves, e.g. combustion air preheating (Tipton and Hughes, 1978; Truedsson, 2000). In other cases, the recovered waste heat can be used externally across different industrial uses, e.g. water desalination (Bailie, 1982; Gitterman and Zwickler, 1966) and waste-heat power generation (Cunningham and Chambers, 2009;

* Corresponding author. Tel.: +86 10 62775553; fax: +86 10 62770544.
E-mail addresses: fangh10@mails.tsinghua.edu.cn, fhcaesar1111@gmail.com (H. Fang).

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.06.104

Nomenclature

Main symbols

a	proportion
cv	calorific value, kJ/kg
E	energy, GJ
e	energy intensity, kW/GJ(m^2 a)
Eff	energy efficiency
h	enthalpy, kJ/kg
k	conversion factor, kg(mass)/kgce
P	population
s	building area per capita, m^2
T	time duration, s
W	economic cost, million RMB yuan

Greek letters

η	ratio
Δ	difference

Indices

a	after waste heat recovery retrofitting
annual	annually
b	before waste heat recovery retrofitting
cog	waste heat co-generation
dh	district heating
dom	domestic hot water
e	energy-intensive sectors
h	heating, heating region, heating season
ind	industry, industrial sector
init	initial
life	life period
n	national
oper	operation
p	process, pollutant, population
t	thermal
th	theoretical amount
w	water
wh	waste heat

Abbreviations

AHP	absorption heat pump
ce	coal equivalent
CHP	combined heat and power
CR	carbon emission reduction
DH	district heating
EMC	energy management contract
ICR	index of investment vs. carbon reduction
NR	NO_x emission reduction
PR	pollutant emission reduction
SR	sulfur dioxide emission reduction
tce	tons of coal equivalent
THUBERC	Tsinghua University Building Energy Research Center
WC	water conservation

Ziebik, 2000). However, waste heat lower than 200 °C is difficult to use in the industrial sector, either economically or technically, due to its low exergy (Cunningham and Chambers, 2009).

Studies investigating waste heat recovery for district heating (DH) were mostly conducted either during the 1980s or from 2007 to the present; during periods of global energy crises and global warming concerns. Skole (1981) showed that with the help of government, several DH schemes using industrial waste heat were built in Sweden. Heitner and Brooks (1982) conducted evaluations of regional waste heat availability, and compared it to the residential thermal loads to find out what percentage of the residential thermal load could be served by industrial waste heat by DH networks. Konigs et al. (1982) reported on the use of industrial waste heat from a steel mill for DH in Volklingen, in Germany. Belaz (1986) described the scheme of recovering 2.4 MW of waste heat from a cement plant and reusing it in the local DH system in Switzerland. de Jong (1990) introduced an electric driven heat pump to upgrade the industrial waste heat (water) from 40 to 60 °C for DH in Bergen op Zoom, in the Netherlands. Ajah et al. (2007) conducted a study on the technical, economical, institutional and environmental feasibilities of upgrading low grade waste heat generated by a pharmaceutical plant by heat pumps for DH in Delft, in the Netherlands. Patil et al. (2009) led another study on the feasibility of combining waste heat recovery with district heating macroscopically from a multi-actor perspective. Sogut et al. (2010) designed a heat recovery unit to utilize the waste heat of a rotary kiln in a cement plant, and estimated that by harvesting this heat, the thermal loads of 678 dwellings in the vicinity could be satisfied. Chen et al. (2012) introduced a condensing boiler with a heat pump to recover both sensible and latent heat from flue gas for DH in the UK and EU. Svensson et al. (2008) presented an approach to investigate the competition between external and internal use of waste heat from a craft pulp mill, and concluded that external use, i.e. for DH, is more effective in reducing CO_2 emission. In terms of waste heat collection, most of these studies introduced electric driven heat pumps to recover a portion of the waste heat in a single factory. Through literature reviews and in-situ investigations, it could be concluded that low grade industrial waste heat temperature has a distribution mostly between 30 and 100 °C (de Jong, 1990; Ajah et al., 2007; Svensson et al., 2008; Tsinghua University Building Energy Research Center (THUBERC), 2011), with another major low thermal grade portion between 30 and 40 °C, which is useless in the summer but useful in the winter due to the difference of ambient temperature. Very few of the studies proposed an integrated method in which different types of equipment might be applied in heating seasons, to recover waste heat of different thermal grades (mainly from 30 to 100 °C) in a highly efficient way. In addition, very few of these studies presented a clear and detailed view of the full-scale implementation scenario, including system design, economic analysis, environmental impact assessment, etc.

As a new generation of DH, low temperature DH has lower return water temperature, compared to the currently-prevalent DH network of which the return water temperature is no less than 45 °C. Therefore, it can better match the low quality building heating demand (Li and Svendsen, 2012). Furthermore, low return water temperature contributes significantly to utilizing renewable and sustainable energies (e.g. geothermal heat, solar heat, biomass, etc.) as well as surplus heat (e.g. industrial waste heat), thus providing huge potential for replacing fossil fuel with much more "clean" heat sources (Chen et al., 2012; IEA DHC Annex TS1, 2012).

The purpose of this paper is to propose an approach to the integrated and efficient utilization of low-grade industrial waste heat for DH, especially low temperature DH. The method of estimation on the implementation potential of such an approach