INTERNATIONAL JOURNAL OF REFRIGERATION 62 (2016) 19–29

Available online at www.sciencedirect.com

ScienceDirect

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

Experimental study on performance of a biogas engine driven air source heat pump system powered by renewable landfill gas

Jiying Wu *, *Yimin Ma*

Mechanical and Energy Engineering College of Jimei University, No.9 Shigu Road, Jimei, Xiamen 361021, China

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form 14 August 2015
Accepted 19 August 2015
Available online 22 October 2015

Keywords:
Landfill gas
Biogas engine driven air source heat pump
Performance test
Waste heat recovery
Energy conservation

ABSTRACT

The equipment configuration of a landfill gas (LFG) fueled biogas engine driven air source heat pump system was studied. The process flow for collecting and purifying LFG was analyzed, and the LFG collection and purification method was determined. An experimental apparatus was set up, and the effect of biogas engine speed variation on LFG consumption, exhaust fume temperature of biogas engine, recovered waste heat from exhaust fume and cylinder liner, coefficient of performance (COP) of the heat pump and primary energy ratio (PER) of the system were experimentally tested. The results indicated that LFG consumption and biogas engine exhaust fume temperature increased with biogas engine speed. When the biogas engine operated in the 70%–90% rated speed range, the system heat output and exhaust fume waste heat recovery rate would be relatively higher. In addition, the maximum COP and PER reached 4.2 and 1.4 respectively.

Étude expérimentale sur la performance d'un système de pompe à chaleur aérothermique entrainé par un moteur au biogaz alimenté par un gaz de décharge renouvelable

Mots clés : Gaz de décharge ; Pompe à chaleur aérothermique entrainée par un moteur au biogaz ; Test de performance ; Récupération de chaleur perdue ; Conservation d'énergie

1. Introduction

Under the constraint of limited resources and environmental protection requirements, measures must be taken to improve energy utilization efficiency and promote energy source diversification so as to reduce the dissipation rate of resource and the cost of resources and environment. The Fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC) finalized in November 2014 pointed out that

* *Corresponding author.* Mechanical and Energy Engineering College of Jimei University, No.9 Shigu Road, Jimei, Xiamen 361021, China. Tel.: +86 592 6062816; Fax: +86 592 6183523.
E-mail address: wjyjw@jmu.edu.cn (J. Wu).
http://dx.doi.org/10.1016/j.ijrefrig.2015.08.023

Nomenclature

c	specific heat capacity [kJ kg^{-1} K^{-1}]
G	mass flow rate of gas [m^3 s^{-1}]
H	heating value of gas [kJ m^{-3}]
m	mass flow rate of water [kg s^{-1}]
P	power of compressor [kW]
Q	heat [kW]
t	temperature of water [°C]
COP	coefficient of performance [non-dimensional parameter]
PER	primary energy ratio [non-dimensional parameter]

Subscripts

con	condenser
e	shaft
LFG	land fill gas
g	exhaust fume
in	inlet
out	outlet
w	cylinder liner cooling water

water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. The report also pointed out that the global warming potential (GWP) of methane, the second important greenhouse gas, is 30% larger than that in the Fourth Assessment Report (AR4) of IPCC. That is the GWP of methane is 33 times that of carbon dioxide (Zhai and Li, 2014). According to this report, the emission of CH_4 from landfills and waste is one of the dominant anthropogenic CH_4 sources. Landfill gas, the major constituent of which is methane, is a complex mixture of different gases generated by microbial anaerobic digestion and degradation of organic substances in landfill waste. Obviously, LFG is a kind of greenhouse gas as well. However, LFG is also a renewable green energy source for the post-combustion products of it are carbon dioxide and water, which make LFG a fuel of less secondary pollution (Orhan and Berrin, 2013a, 2013b). Hence, the comprehensive management and utilization of LFG has currently become one of the energy-saving and emission-reduction problems concerned internationally. LFG can be recovered and used as fuel of biogas engine to drive air source heat pump for heating, which can be an alternative to conventional heating systems, to reduce the consumption of fossil fuel and the emission of uncontrolled greenhouse gases from landfills. The environmental and energy-saving effects of such systems should be promising.

Biogas engine driven air source heat pump is also a kind of gas engine driven heat pump, which uses a gas engine that takes the electricity motor in conventional heat pump instead to drive the heat pump compressor. Due to advantages of reclaiming waste heat from the cooling water of cylinder liner and exhaust fume of the gas engine, the PER of gas engine driven heat pump systems, compared with those of coal-fired boilers, gas-fired boilers and electrically-driven heat pumps, can be improved over 110%, 75% and 33% respectively (Ma et al., 2002). The time from the end of 1970s to the beginning of 1990s saw the culmination of gas driven heat pump research. Many prototypes of this kind of heat pump were built by researchers around the world during this period, which laid the foundation for commercial production of gas engine driven heat pumps (Kiani et al., 2004; Meneghetti et al., 2002; Slim et al., 2008; Toshihiko et al., 2005). For example, a high temperature gas engine driven heat pump, which took refrigerant R114 as the working medium and had a rated power of 75 kW, rated speed of 1100 rpm, PER of 1.2 and waste heat recovery rate of 71%, was developed by the International Research & Development Co., LTD of UK (Eustace, 1984). Howe et al. (1989) experimentally tested three residential gas engine driven heat pump systems rated 15–30 kW, and the heating season performance factor (HSPF) was 1.3–1.6. Morgan et al. (1989) conducted experimental study on a gas engine driven heat pump system located in Washington, and the results of their researches showed that the HSPF of the system was 1.25–1.54.

In China, however, under the background of the energy structure, policy adjustment and increasing environmental protection requirements, researches and applications in this field have got increasing attention ever since the end of 1980s (Ma et al., 1988). Yang et al. (2003) studied the characteristics of a gasoline/natural gas dual-fuel internal combustion engine driven heat pump system under various operating conditions. Hou et al. (2001) theoretically analyzed the effect of cold and heat source temperature on COP, PER, and the operating characteristics of this air-cooled gas engine driven heat pump experimental system were tested as well. By numerical simulation method, Ling et al. (2003) calculated and analyzed the PER of a gas engine driven heat pump. Li et al. (2008) experimentally and theoretically studied the performance parameters, partial load characteristics, and engine waste heat recovery performance of a gas engine driven heat pump experimental apparatus, which used a 6 kW water-cooled motorcycle engine to simulate the gas engine. Jiang et al. (2009) and Xu and Yang (2008) made energy consumption and numerical calculations and experimental tests for biogas engine driven air-conditioning systems. In addition, the authors of this paper have done some research work on the theoretical analysis, system configuration and experimental tests for a biogas engine driven heat pump system and a direct-fired biogas fueled absorption heat pump system (Wu, 2006; Wu and Zeng, 2007).

Although many studies have been made on the gas engine driven heat pumps, reports on the LFG fueled biogas engine driven heat pumps are still hardly found. Therefore, an LFG fueled biogas engine driven air source heat pump system was presented in this paper and the energy-saving characteristics of the system were experimentally tested.

2. Physical properties and combustion characteristics of LFG

2.1. Heating value of LFG

The major constituent of LFG is approximately 50%–60% methane and 30%–40% carbon dioxide. The remaining gases with trace amount are nitrogen, oxygen, hydrogen nitride, hydrogen sulfide, hydrogen etc. The heating value of LFG is about 19,400 kJ m^{-3}, which is a little greater than that of coal gas but