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Analysis on energy-saving effect and environmental benefit of a novel hybrid-power gas engine heat pump

Yanwei Wang [a], Liang Cai [a,*], Xiaowei Shao [b], Gaolong Jin [c], Xiaosong Zhang [a]

[a] Air Conditioning and Refrigeration Laboratory, School of Energy and Environment, Southeast University (SEU), 2 Sipailou Street, Xuanwu District, Nanjing, China

[b] Emerson Network Power Co., Ltd, 2 Sipailou Street, Xuanwu District, Nanjing, China

[c] Han Jia Design Group Co., Ltd, 2 Sipailou Street, Xuanwu District, Nanjing, China

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ABSTRACT

Taking a novel hybrid-power gas engine heat pump as an example, fuel-consumed rate, fuel-consumed flow, fuel conversion efficiency and life cycle assessment were used to analyze energy-saving effect and natural gas environmental benefits on human health, ecosystem quality and resource consumption through contrast with electric power consumption model. The test results show that the fuel conversion efficiency under different operating conditions of HPGHP is higher than conventional GHP under the same load. Besides, from the total indicator, scores on resource consumption is the highest. Gaseous product is mainly CO_2 and other carbon or sulfur oxide gases are discharged in form of negative or water body, which means the use of natural gas effectively control the pollution gas emissions. At last, concept of environmental benefit time was established; the result shows that HPGHP can embody better environmental benefits than gas heat pump when running more than 1778 h.

Analyse des économies d’énergie et des avantages vis-à-vis de l’environnement d’une nouvelle pompe à chaleur hybride à moteur à gaz

Mots clés : Efficacité de la conversion du combustible ; Évaluation du cycle de vie ; Pompe à chaleur ; Hybride ; Moteur à gaz ; Avantages vis-à-vis de l’environnement dans le temps

* *Corresponding author*. Tel./fax: +86 13951907157.
E-mail address: cailiang@seu.edu.cn (L. Cai).

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Nomenclature

EB(j)	potential score that first j kind of environmental impact type on the environment;
$EB(j)_i$	potential score that first i kind of influence indicator in the first j kind of environmental impact type on the environment;
$Q(j)_i$	emission amount that first i kind of influence indicator in the first j kind of environmental impact type;
$PF(j)_i$	potential score per unit that first i kind of influence indicator in the first j kind of environmental impact type on the environment;
NB(j)	standardized potential score that first j kind of environmental impact type on the environment;
R(j)	standard score that first j kind of environmental impact type on the environment;
t	life cycle;
T_{re}	environmental benefit time, h;
S_{plus}	effect score that hybrid-power production and operation stages damage environment, Pt;
S_{con}	positive score per hour that HPGHP benefits environment, Pt;

1. Introduction

Gas heat pump (GHP) is a kind of air conditioning system using natural gas as the main energy and the engine to drive the steam compressor, which owns many advantages: high energy using and capacity adjustment ability, low power consumption and brilliant development prospects. At present, the fuel engine mainly work on part load in the GHP system and the operation condition is changing with external load (Li et al., 2005a). Usually, it deviates from calibration work conditions. In addition, the engine often runs in poor stability, which causes lower thermal efficiency and more emission.

On the foundation of researching hybrid-power and gas heat pump technique, air conditioning and refrigeration laboratory from Southeast University Lab has developed a hybrid-power gas heat pump air conditioning system (HPGHP) through a new type of battery and gas engine common drive which can effectively overcome the defects of GHP. HPGHP is a new system combined with gas heat pump and hybrid-power technique. In this novel system, the power sources are gas engines and batteries. Rational matching of these two power sources can keep engine working in the best economic zone. At the same time, it can improve the emissions (Li et al., 2005b; Li et al., 2006).

For evaluating environmental benefits of this HPGHP system, fuel-consumed rate, fuel-consumed flow, fuel conversion efficiency and Life cycle assessment (LCA) which is an analysis tool of researching environmental impact of products from raw material gaining, manufacturing, operating and wasting were used to analyze environmental impact analysis of this system. Using LCA to evaluate environment impact generally needs to consider human health, ecosystem quality and resource consumption. LCA system consists of four stages: target and scope setting, life cycle inventory, impact assessment and explaining (Fan and Meng, 2007).

2. Hybrid-power gas engine heat pump

2.1. Systematic theory

Fig. 1 is the diagram of HPGHP working principle. The system has two power sources-the engine and battery, and both of them can be a separate power source to drive heat pump system (Chau and Wong, 2002; Huang and Tzeng, 2004; Li et al., 2007). The gas engine is connected with the compressor as the main shaft through the pulley, and the motor connects the compressor as a vice shaft through the pulley. The battery connects to the motor through electrical connection (Mechanical Engineering and Motor Engineering Manual Editing Committee, 1997).

According to the speed of compressor, there are four operating modes of HPGHP: Mode 1, the gas engine can drive the compressor to run the heat pump system alone that the range of compressor speed is from 1150 to 1900 rpm. Mode 2, the gas engine does not work and the motor drives the heat pump system alone that the range of compressor speed is from 750 to 1150 rpm. Mode 3, the gas engine can drive the compressor, along with driving motor (as a generator) to generate, at the same time, electrical energy is stored in the battery that the range of compressor speed is from 750 to 1150 rpm. Mode 4, the gas engine and electric motor (used as the electric motor) operate simultaneously to drive the compressor that the range of compressor speed is from 1900 to 2400 rpm. Battery is in a discharged situation at this time, so the gas engine is the main power source and motor is used as an auxiliary power source.

2.2. Controlling strategy

Aiming at the minimizing fuel consumption of the entire HPGHP system, experimental prototype is designed to use Baseline control strategy, combining with optimal curve control strategies of the gas engine. The optimal curve control strategy straightens out the operating point of the lowest gas engine fuel consumption when running under a certain speed or under certain load through studying the characteristic curve of the gas engine (Morteza et al., 2006; Niels et al., 2003; Tsai et al., 2007). Therefore, the control strategy is based on this optimal curve to achieve the following situations:

1) When the gas engine speed is lower than the starting speed, the engine shut down and the motor start to drive system;
2) When the required torque of the gas engine is higher than the gas engine minimum torque, according to the current state of charge (SOC), If the $SOC < SOC_{max}$, the gas engine works in the corresponding speed curve point and the rest power is stored in the battery;