Energy Conversion and Management 89 (2015) 63–70

Contents lists available at ScienceDirect

Energy Conversion and Management

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

An experimental investigation of CI engine operated micro-cogeneration system for power and space cooling

Rahul Goyal *, Dilip Sharma, S.L. Soni, Pradeep Kumar Gupta, Dheeraj Johar

Mechanical Engineering Department, MNIT, Jaipur, India

ARTICLE INFO

Article history:
Received 12 May 2014
Accepted 8 September 2014

Keywords:
Cogeneration
Micro cogeneration
Waste heat
Vapor absorption system
Space cooling
Performance
Specific fuel consumption
Emissions

ABSTRACT

This paper describes the performance and emission characteristics of a micro cogeneration system based on a single cylinder diesel engine. In this cogeneration system, in addition to the electricity generated from the genset, waste heat from hot exhaust gas of diesel engine was used to drive a combination of four units of Electrolux vapor absorption (VA) system for space cooling. The capacity and heat input of each unit of VA system was 51 l and 95 W respectively. A cabin of 900 mm width, 1500 mm length and 1800 mm height made of ply wood was fabricated as a space for air conditioning. A temperature drop of 5 °C was obtained in cabin at full engine load about 6 h after system start up. The reduction of CO_2 emission in kg per kWh of useful energy output was 19.49% compared to that of single generation (power generation only) at full load. The decrease in specific fuel consumption in case of cogeneration compared to that in single generation was 2.95% at full load. The test results show that micro capacity (3.7 kW) stationary single cylinder diesel engine can be successfully modified to simultaneously produce power and space cooling.

1. Introduction

Cogeneration and trigeneration have emerged as fast growing techniques to solve energy related problems, such as increasing energy demand, increasing energy cost, energy supply security and environmental concerns. Cogeneration and trigeneration respectively mean the production of two and three useful forms of energy from the same energy source [1,2]. Low grade waste heat available at the end of power generation process is utilized in heating and cooling/refrigeration. Cogeneration defines the simultaneous production of cooling/heating and power, while the trigeneration system defines the simultaneous production of cooling, heating and power from single energy source (i.e., the fuel only). A typical trigeneration system consists of a prime mover or the driving unit, electricity generator, thermally activated equipment and heat recovery system. There are various options for prime movers, such as, internal combustion engine, gas turbine, steam turbine, stirling engine. Prime mover drives a generator which provides electric power [3]. Waste heat (as a by-product) from the prime mover is recovered and used to (a) drive thermally activated components such as vapor absorption system or adsorption chiller or desiccant dehumidifier [4–6] and (b) to produce hot water, steam, warm air or other heated fluid through the use of heat exchanger. Depending upon the size, the cogeneration and trigeneration systems are classified as large, medium, small or micro cogeneration/trigeneration systems. Both cogeneration and trigeneration have application in commercial sector (office buildings, etc.) as well as in industrial sector [7–9].

A number of studies have been conducted to investigate the performance of a large scale cogeneration/trigeneration system [10–12]. However, very little work has been done in real life cases at small residential or commercial level especially for space cooling. Applying cogeneration/trigeneration technology to small scale residential use is an attractive option because of the large potential market. Khatri et al. [13] and Lin et al. [14] designed and analyzed micro trigeneration systems based on small diesel engines. The experimental results show that the idea of actualizing a household size trigeneration system is feasible and the design of such trigeneration system is successful. Angrisani et al. [15] carried out an experimental study to investigate the performance of both micro cogeneration system and micro trigeneration system. As per Angrisani et al., “a sensitivity analysis showed that the energy, environmental and economic performance of the system strongly depend on the share of cogenerated electricity used on-site, in particular in terms of economic feasibility with respect to a reference system”. Tiwari and Parishwad [16] have described the experimental investigation of an adsorption refrigeration system for cabin cooling of trucks using exhaust heat. Godefroy et al. [17] have

* Corresponding author.

http://dx.doi.org/10.1016/j.enconman.2014.09.028
0196-8904/

described the design, testing and mathematical modeling of a small trigeneration system based on a gas engine with 5.5 kW electricity output and an ejector cooling cycle, analysis of which shows that an overall efficiency of around 50% could be achieved. Huangfu et al. [18] had discussed the economic and exergetic analysis of micro scale combined cooling, heating and power system using small scale internal combustion engine with rated electricity power of 12 kW and an adsorption chiller with refrigerating capacity of 9 kW. Abusoglu and Kanoglu [19] described the thermodynamic analysis of the diesel engine operated cogeneration system and found that the thermal efficiency of the overall plant was 44.2% and exergetic efficiency was 40.7%. Rosato et al. [20] examined the performance of a residential building-integrated micro-cogeneration system during the winter operation by using the whole building simulation software TRNSYS. In this paper the simulation results were evaluated in terms of both carbon dioxide equivalent emissions and operating costs. Rosato and Sibilio [21] experimentally investigated the performance of an internal combustion engine based micro-cogeneration unit with 6.0 kW as nominal electric output during a 24 h dynamic test. The measured data have been compared with those that would be associated with the same while servicing the building with electricity from the central electric grid and heat from a natural gas fired boiler from energy, exergy and environmental points of view.

The novelty of the current study was to investigate the feasibility of successfully modifying a micro capacity (3.7 kW) stationary single cylinder diesel engine to simultaneously produce power and space cooling using engine exhaust heat operated vapour absorption refrigerators since the earlier works did not use micro-cogeneration systems especially for space cooling using small vapour absorption system. In this work, for space cooling, four units of Electrolux vapor absorption system, each with a capacity of 51 l and heat input of 95 W, were used. Exhaust gas from the engine was the source of thermal energy to provide heat to the four generators of the VA system.

2. Experimental setup and research methodology

Fig. 1(a) and (b) show the schematic layout of the experimental setup and photograph of cogeneration test rig in the laboratory respectively. The experimental setup for the study consisted of a single cylinder, four stroke, water cooled, constant speed, 5 HP (3.7 KW) diesel engine of Kirloskar make (Model AV1, detailed specifications are given in Table 1) coupled with electric generator and Electrolux vapor absorption system (four units) for space cooling. Four identical VA units were arranged in rectangular pattern with two rows and two columns consisting of two VA units each. Henceforth, the four VA units will be addressed as top left, top right, bottom left and bottom right VA units according to their position in the VA system while looking from the front of the VA system.

Air flow rate was determined using air box method by measuring the pressure drop across a sharp edge orifice of air surge chamber with the help of a manometer. Burette method was used to measure the volumetric flow rate of diesel. Governor was used to keep engine rpm constant while varying the load on engine for creation of various test results. The load was varied by switching on the desired numbers of electric bulbs. Digital tachometer was used to confirm that the engine speed remains constant under varying load conditions.

A wooden cabin of 900 mm width, 1500 mm length and 1800 mm height was fabricated for test of space cooling which is shown in Fig. 2(a). The front view of the VA system is shown in Fig. 2(b). For proper insulation of cabin, so as to minimize the loss of cooling effect, nitrile rubber was used on the rear wall of cabin, over which glass wool layer was used and further on the top of glass wool, aluminum foil was pasted, hence, giving the cabin rear a three layer firm insulation cover. The side wall of the cabin which was adjacent to the engine was provided with thermal insulation by 3 layers of 25 mm thick thermocol sheets making it a 75 mm insulating layer of thermocol. The cabin roof was provided with one layer of 25 mm thermocol sheet above the ply wood ceiling. The other two walls did not need insulation as those were away from the engine. The insulation is shown in Fig. 2(c). Two fans were used to reduce the excessive heat from top left and top right condensers as shown in Fig. 2(d). Also, two fans were used between VA system and cabin to suck the cold air from evaporator coil and deliver it into the cabin. The power required to run the fans (i.e. 100 W for four fans) was supplied by the engine genset.

AVL make DITEST (AVL DiGas 4000 light) 5 gas analyzer was used to analyze the exhaust emission from the engine. The exhaust emission included NO_x, CO, HC, CO_2 and O_2, out of which, CO, HC and CO_2 were measured by NDIR Technique and NO_x and O_2 were measured by electrochemical sensors. It gives HC and NO_x emissions in PPM and that of other gases in percentage. Smoke in exhaust was measured with the help of AVL smoke meter. Detailed specification of exhaust gas analyzer and AVL smoke meter is shown in Table 2.

Combination of four units of Electrolux vapor absorption system, each with a capacity of 51 l and heat input of 95 W, was used for space cooling. This type of cooling system is also called three fluids absorption system. The three fluids used in the system were ammonia, hydrogen and water. Ammonia was used as refrigerant because it possesses most of the desirable properties for refrigerant. Hydrogen being the lightest gas was used to increase the rate

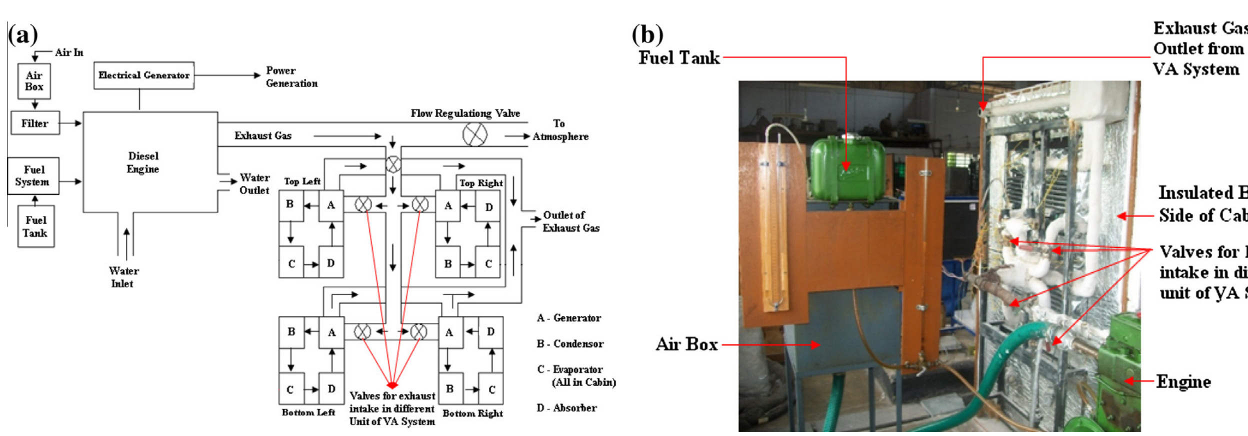

Fig. 1. (a) Schematic layout of experimental setup for cogeneration system and (b) photograph of the cogeneration test rig in the laboratory.