INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 17064–17071

Available online at www.sciencedirect.com

ScienceDirect

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

Investigation of air management and its impact on the overall electrical efficiency in a FC-APU operated with diesel

Karim Ghaib

Institute of Energy and Climate Research, Forschungszentrum Jülich GmbH, Jülich, D-52425, Germany

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form
21 July 2016
Accepted 23 July 2016
Available online 9 August 2016

Keywords:
Autothermal reforming
Auxiliary power unit
Balance-of-plant subsystem
Catalytic combustion
Electrical efficiency
High temperature polymer electrolyte membrane fuel cell

ABSTRACT

Auxiliary power units are systems that can provide all of the non-propulsion power in e.g. trucks or airplanes, thus offering increased efficiency and flexibility of power generation. At Forschungszentrum Jülich, an auxiliary power unit is being developed based on high temperature polymer electrolyte membrane fuel cell technology for operation with diesel for application in trucks. Its gross power output is currently 5000 W. One of the key development challenges is minimizing the power consumption of its balance-of-plant subsystems. Supplying air to fuel cell systems is often the largest consumer of parasitic power. This paper investigates the air requirements of the Jülich auxiliary power unit and the impact of these requirements on the overall electrical efficiency. The air requirements were simulated with the software Aspen Plus. Then, the power needed to provide the air was determined by testing commercial air supply machines. The results showed that providing the air required by the system led to a reduction in the system overall electrical efficiency of up to 15.33%.

Introduction

The use of auxiliary power units (APUs) as independent power supply devices in the transport sector significantly improves the efficiency of power generation and hence helps to reduce CO_2 emissions [1]. APUs can additionally extend the lifetime of the main engine [2]. In this context, one of the most promising energy conversion technologies with regard to high efficiency is the fuel cell. In addition to high efficiency, the fuel cell emits low levels of pollutants such as sulfur oxides (SO_x) and nitrogen (NO_x). SO_x emissions are low because the fuels used contain a low degree of sulfur or are desulfurized directly before use. NO_x emissions are low because even high-temperature fuel cells such as the molten carbonate fuel cell and the solid oxide fuel cell operate at temperatures well below those needed to form NO_x by thermally combining nitrogen and oxygen [3]. Moreover the noise levels of fuel cell systems are low.

Fuel cell system characteristics and APU requirements correspond in terms of efficiency, load, volume and weight [2], making the fuel cell an ideal power generator in APUs. However, the fuel cell comes in many varieties, each of which is classified according to the electrolyte. For APU applications, where the same fuel (e.g. diesel or kerosene) is used as for the main engine, the fuel cell should have a certain tolerance to CO and fuel impurities, an adequate lifetime and an appropriate startup [4]. The high–temperature polymer electrolyte

E-mail address: karimghaib@gmail.com.
http://dx.doi.org/10.1016/j.ijhydene.2016.07.185

membrane (HT-PEM) fuel cell is able to overcome all of these issues. In the recent years, much effort has been invested in its development, leading to some breakthroughs in the drive towards commercialization [5].

At the Institute of Energy and Climate Research at Forschungszentrum Jülich, an APU based on the HT-PEM fuel cell operated with diesel is being developed for application in trucks. Its gross power output is currently 5000 W. Fig. 1 shows a process flow diagram of the system. It consists of (i) a fuel processing unit (including autothermal reformer, high-temperature shift reactor and low-temperature shift reactor), (ii) a HT-PEM fuel cell module (the heart of the system), (iii) a catalytic burner and (iv) the balance-of-plant (or ancillary) components around the system comprising heat and medium management, power conditioning, and system controlling (the last two are not shown in Fig. 1). Inputs to the system are diesel and ambient air. Outputs are conditioned power, heat, water and off-gases. The fuel processing unit converts diesel into the fuel gas required by the fuel cell module. The fuel gas is fed to the anode, where hydrogen reacts electrochemically with oxygen from the air at the cathode producing power, heat and water. The exhaust-gas from the anode contains remains of flammable gases. Therefore it is fed to the catalytic burner, where part of the recovered heat is integrated into the system.

One of the key challenges in developing the Jülich APU is minimizing the power consumption of balance-of-plant subsystems, which depends on the system design, the characteristics of the components and of course the performance of the balance-of-plant subsystems. However, in the literature on fuel cell APUs, a large number of studies were carried out concerning fuel cells [6–8], fuel processing [9–11], system modeling [12–14] and so on. In contrast, it is very difficult to find studies on the parasitic power needed.

This paper investigates the air requirements and the resulting impact on the overall electrical efficiency in the Jülich APU. The objective hereby is to identify the potential for minimizing the power needed for air management in further stages of APU development.

The paper is organized as follows: Section power requirement for compression of gases deals with the power requirement for compression of gases, Section air requirement of the Jülich APU analyzes the air demand in the Jülich APU, Section characterization of air supply machines demonstrates the test rig for the characterization of air supply machines, Section evaluation of the impact of the current air management on the overall electrical efficiency of the system shows the characterization results of commercial air supply machines and evaluates the overall electrical efficiency of the system, and the conclusion is given in Section conclusions.

Power requirement for compression of gases

A commonly used method of supplying gas to fuel cell systems is the use of fans, blowers or compressors depending on the required pressure change for the system [15]. A compressor can be considered as a high-pressure pump for gas. High pressure is defined as conditions under which the gas pressure is changed by 30% or more. For smaller pressure changes, a fan or blower is suitable as a pump for gas [16]. Gas supply machines are principally powered autarkically in fuel cell systems where they are often the largest consumers of parasitic power and thus play an important part in the overall electrical system efficiency.

Generally, the power needed to drive a gas supply machine is most often given as:

$$P_{Ac} = \frac{P_{ls}}{\eta_{ls}} \quad (1)$$

where η_{ls} is the isentropic efficiency and P_{ls} the power required in case of an isentropic compression.

Gas is isentropically compressed without friction or heat transfer. While the entropy remains constant, the enthalpy increases from given initial pressure p_1 and temperature T_1 to given final pressure p_2. If the kinetic and potential energies are neglected, the enthalpy flow difference, which is the specific

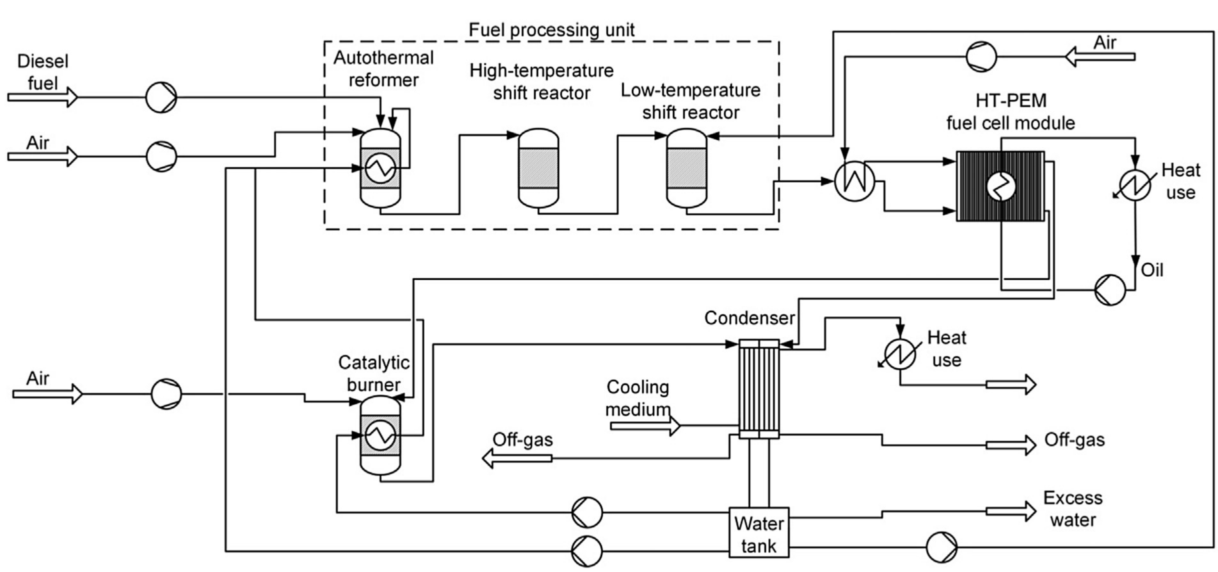

Fig. 1 – Process flow diagram of the Jülich APU.