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BIOFEAT: Biodiesel fuel processor for a vehicle fuel cell auxiliary power unit☆ Study of the feed system

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Abstract

An integrated auxiliary power unit (APU) based on a 10 kW_e integrated biodiesel fuel processor has been designed and is being developed. *Auto-thermal reforming* (ATR) and *thermal cracking* (TC) were considered for converting the fuel into a hydrogen-rich gas suitable for PEM fuel cells. The fuel processor includes also a gas clean-up system that will reduce the carbon monoxide in the primary processor exit gas to below 10 ppm via a new heat-integrated CO clean-up unit, based on the assembly of catalytic heat exchange plates, so as to meet the operational requirements of a PEMFC stack. This article is devoted to the study and selection of the proper feed strategy for the primary fuel processor. Different pre-treatment and feed alternatives (e.g. based on nozzles or simple coils) were devised and tested for the ATR processors, which turned out to be the preferred primary processing route. A nozzle-based strategy was finally selected along with special recommendations about the constituent materials and the operating procedures to be adopted to avoid coking and nozzle corrosion as well as to allow a wide turn down ratio.

Keywords: Biodiesel; Fuel processor; Auxiliary power unit; Auto-thermal reforming; Thermal cracking; Vehicle

1. Introduction

The goal of the European-funded project *Biodiesel fuel processor for a fuel cell auxiliary power unit for a vehicle* (BIOFEAT) is to develop an auxiliary power unit (APU) based on a 10 kW_e fuel cell stack fed by an integrated biodiesel fuel processor. The purposes of the project are the reduction of tailpipe emissions, the promotion of the use of renewable fuels and an increase in fuel economy compared to currently employed auxiliary power generation systems. The modular 10 kW_e biodiesel fuel processor is capable of feeding a solid oxide or a polymeric membrane fuel cell stack (PEMFC) that will generate electricity for the auxiliary power unit on a family car or a truck [1].

Significant market penetration of fuel cell systems for traction purposes is expected to take place only in long term. Higher application opportunities in the medium term (5–7 years) are expected in the field of auxiliary power generation for vehicles, thereby allowing the de-coupling of traction and peripherals-powering (air-conditioning, steering-by-wire, lights,. . .) needs [2]. These expectations are based on the lower nominal power of APUs and by the increasingly stable power demand required by the peripherals [3].

Biodiesel is the chosen feedstock in BIOFEAT, because it is a completely natural and renewable fuel. It is a 100% vegetable oil produced mainly from field crops in Europe, whereas elsewhere in the world, it is even made from recycled cooking oil. In the past decade, biodiesel has been gaining worldwide popularity as an alternative energy source

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because of its many benefits. Besides the huge reduction in greenhouse gas emissions it entails, this environment friendly fuel reduces tailpipe emissions, visible smoke and noxious odours. Biodiesel is non-toxic and biodegradable, handling and storage are safer than conventional petroleum diesel fuel. Its cost compares well with other alternative fuels. Biodiesel also operates well in a conventional diesel engine with few engine modifications and no performance penalty.

2. Overall fuel processor description

The BIOFEAT fuel processor consists of a number of stages (Fig. 1). The main component is the *primary fuel processor* that converts the feedstock into a hydrogen-rich gas. One of the major objectives of the project is to select either *thermal cracking* (TC) or *auto-thermal reforming* (ATR) as the preferred primary processing technique. Two separate research groups undertook this work (Johnson–Matthey for the ATR, University of Duisburg-Essen for the TC). In parallel, two other activities considered the *requirements for conditioning the biodiesel* prior to entry into the primary fuel processor and the *treatment of the exit gas* from the primary fuel processor for a PEMFC system. The outlet gases of the primary fuel processor are indeed suitable for a SOFC, but a PEMFC requires a *gas clean-up system* to reduce the carbon monoxide level below 10 ppm.

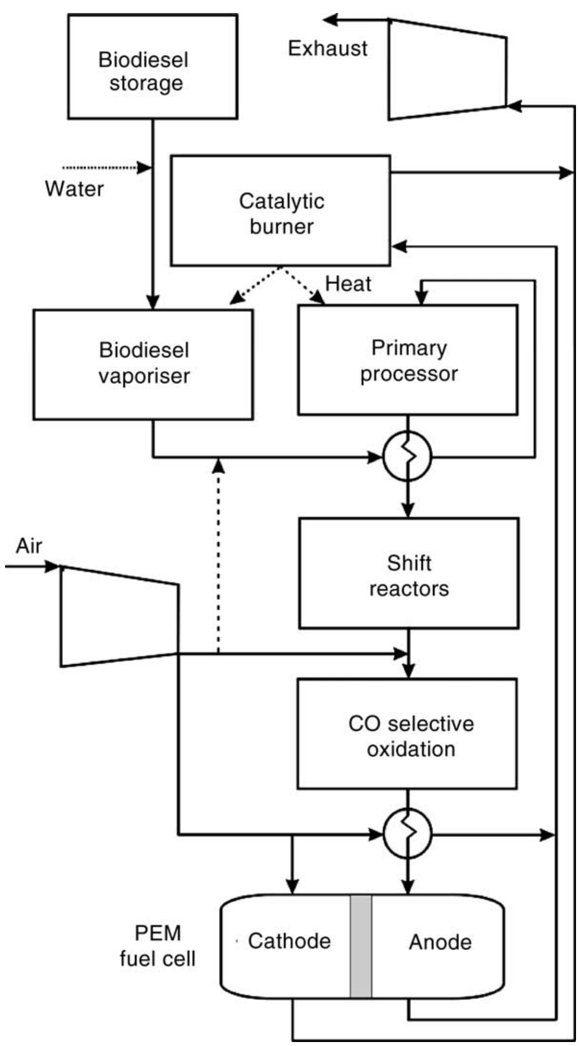

Fig. 1. System layout for the BIOFEAT APU based on the biodiesel fuel processor. After conversion in the primary reactor, the reformate stream is purified from CO in the water gas shift and in the CO clean-up reactors.

The *thermal catalytic cracking* (TC) of biodiesel is an innovative approach for the generation of a hydrogen-rich gas with a gas quality that is similar, if not even better in terms of hydrogen concentration, to steam reforming. First, the fuel is decomposed to produce hydrogen:

$$C_{19}H_{36}O_2 \rightarrow 17C + 2CO + 18H_2 \quad (1)$$

then, the solid carbon is regenerated via endothermic gasification:

$$C + H_2O + (O_2) \rightarrow CO + H_2 \quad (2)$$

The proposed biodiesel thermal cracker reactor consists of two reactors; one is used for hydrogen production by cracking; the other is being regenerated by gasification of the solid carbon with steam and air-yielding hydrogen, carbon monoxide, carbon dioxide and methane. The overall product gas contains about 70% hydrogen. The anodic off-gas from the fuel cell is fed back to the diesel burner of the cracker, with an increase in the overall system efficiency and a reduction of NO_x, SO_2 and soot emissions [4].

The *Auto-thermal reforming* (ATR) has been used to generate a hydrogen-rich reformate from a wide range of fuels including methanol, natural gas, LPG and more recently gasoline [5]. This process uses a combination of partial oxidation and steam reforming within the same catalyst bed to reform the fuel. Steam and air are fed into the reformer at a temperature ranging between 350 and 500 °C depending on the catalyst activity. The reactions that take place in an ATR reactor are reported below.

Partial oxidation:

$$C_{19}H_{36}O_2 + 8.5O_2 \rightarrow 19CO + 18H_2 \quad (3)$$

$$H_2 + 0.5O_2 \rightarrow H_2O \quad (4)$$

$$CO + 0.5O_2 \rightarrow CO_2 \quad (5)$$

Steam reforming and water gas-shift reactions:

$$C_{19}H_{36}O_2 + 17H_2O \rightarrow 19CO + 35H_2 \quad (6)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (7)$$

After a preliminary study of both fuel-processing methods, the *auto-thermal reformer was selected as the best choice for the biodiesel processing.* The selection criteria for the most proper reforming strategy are described elsewhere [6,7].

In a biodiesel fuel-processing system based on auto-thermal reforming, typical reformate gases contain about