

Technical note

Hydrogen production and End-Uses from combined heat, hydrogen and power system by using local resources



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ARTICLE INFO

Article history:

Received 4 September 2013

Accepted 24 May 2014

Available online

Keywords:

Renewable energy
Hydrogen production
CHHP system
Hydrogen recovery
Hydrogen End-Uses

ABSTRACT

To address the problem of fossil fuel usage at the Missouri University of Science and Technology campus, using of alternative fuels and renewable energy sources can lower energy consumption and hydrogen use. Biogas, produced by anaerobic digestion of wastewater, organic waste, agricultural waste, industrial waste, and animal by-products is a potential source of renewable energy. In this work, we have discussed Hydrogen production and End-Uses from CHHP system for the campus using local resources. Following the resource assessment study, the team selects FuelCell Energy DFC1500™ unit as a molten carbonate fuel cell to study of combined heat, hydrogen and power (CHHP) system based on a molten carbonate fuel cell fed by biogas produced by anaerobic digestion. The CHHP system provides approximately 650 kg/day. The total hydrogen usage 123 kg/day on the university campus including personal transportation applications, backup power applications, portable power applications, and other mobility applications are 56, 16, 29, 17, and 5 respectively. The excess hydrogen could be sold to a gas retailer. In conclusion, the CHHP system will be able to reduce fossil fuel usage, greenhouse gas emissions and hydrogen generated is used to power different applications on the university campus.

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1. Introduction

The Missouri University of Science and Technology (Missouri S&T) campus in Rolla, Missouri, USA is a relatively small campus with 1.15 km² and approximately 6500 students on campus. Biogas produced by anaerobic digestion of wastewater, organic waste, agricultural waste, and industrial waste is a potential source of renewable energy. Treated biogas can be used to generate CHHP using a molten carbonate fuel cell. The paper investigates the use of a CHHP system at (Missouri S&T) campus, and we have discussed the Hydrogen production, recovery, cleaning, and End-Uses on the university campus from CHHP system by using local resources. The hydrogen generated by the CHHP system is used personal transportation, backup power, portable power, and mobility/utility applications at various locations on the campus [1–4]. The research presented in this paper was performed as part of the 2012 Hydrogen

Student Design Contest. In addition, the performance assessment of the CHHP system has higher efficiency than other distributed generation plants of similar size [5,6]. The CHHP system attains ultra high efficiency about 60–75% power and reducing gas [1].

2. Resource assessment

2.1. Feedstock source identification

During the assessment, “locally available feedstock” was defined as one which is within 20 km of Rolla. The largest source of locally available feedstock is MSW averaging 60 tons/day. Of this, approximately 33% is organic waste including 17% food waste. The campus plans to partner with the City of Rolla and will start an “Organic Waste Collection Program” to collect organic waste. Currently, the city offers residential curbside collection of recyclable materials at no extra cost.

Potential feedstock from the campus includes food waste and sanitary sewer. Food waste collected daily is mixed with the trash and the sanitary sewer and is connected to the city's main sewer

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Nomenclatures

AGO	anode gas oxidizer
AOG	anode outlet gas
CHHP	combined heat, hydrogen and power system
CHP	combined heat and power
DFC	direct fuel cell
GHG	greenhouse gas
HEX.W.G	heat exchanger water and gas
UPS	uninterruptable power supply

lines. Methods for feedstock collection, transportation, and storage were also identified and are tabulated in Table 1 [7,8].

3. Experimental procedure

3.1. DFC[®] technology status

FuelCell Energy offers three DFC[®] products; the DFC 300 T[™], DFC 1500[™], and DFC 3000[™], which are 350 kW, 1.4 MW, and 2.8 MW, power plants, respectively. The DFC[®] 1500[™] matches up well with the needs of a wastewater treatment plant, or a food processing facility where methane produced by anaerobic digestion can be efficiently utilized to produce electricity.

The DFC[®] technology offers higher net electrical efficiency and a cleaner exhaust stream when operating on biogas from an anaerobic digester than any competing conventional technology such as reciprocating engines or gas turbines. The DFC[®] systems also have a good heat-to-power ratio for support of digester operations.

The design discussed in this paper has three major systems: (i) anaerobic digestion system, (ii) CHHP system consisting of a DFC1500[™] fuel cell unit, and (iii) hydrogen compression, storage, and dispensing system [1–3].

3.2. Anaerobic digestion system

Digester and biogas production are shown in Fig. 1(a)[2,3,9]. Biogas from the anaerobic digestion is stored in a buffer tank which supplies biogas to the gas treatment system. The treatment system uses pressure swing adsorption (PSA) technology to separate methane present in the biogas [10,11]. The design included the PSA unit for the following reasons [1–3,8]:

- The DFC[®] fuel cell units cannot accept H₂S, water (H₂O), and other impurities in its input fuel [12].
- Inlet fuel pressure to the fuel cell should be between 2 and 2.4 bar [9,13].
- The biogas output from the digester can vary due to disruption in the feedstock availability or other unforeseeable reasons. In this case, the system will have to use natural gas purchased from utility company to provide any unmet fuel demand by the fuel cell [14].
- The product gas from the PSA unit is expected to have an average heat content of 37 MJ/m³ [15]. The process and flow during the biogas treatment is depicted in Fig. 1(b) [1,3].

3.3. DFC1500[™] FuelCell power plant

The anaerobic digester system will be able to supply 90% of fuel for the DFC1500[™] unit from locally available feedstock. The remaining 10% fuel required will be purchased from the utility company. In order to accommodate the fluctuations in gas quality, the natural gas used in the design is assumed to contain 98% methane and 2% carbon dioxide (with an average heating value of 37 MJ/m³). Fig. 2(a) shows the reactions taking place inside the fuel cell [1–3,7].

3.3.1. AOG calculations

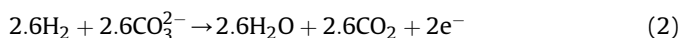
The anode outlet gas calculations are made based on the AOG composition calculation document provided by FuelCell Energy [16]. It is assumed that all methane entering the DFC[®] unit is internally reformed and converted to hydrogen and that only 65% (the fuel utilization rate) of the H₂ produced is reacted at the anode to produce electricity. In order to reflect the AOG composition, it is assumed that One third of the 35% hydrogen produced is back-shifted to produce H₂O and CO. Based on these assumptions and the processes taking place inside the fuel cell, the following Equations (1)–(5) for every 1 mol of methane (CH₄) entering the anode side are obtained.

Internal reforming:



Assuming 1 mol of CH₄ is fed to the DFC[®] system; 4 mol of hydrogen will be produced. But, only 65% of the hydrogen (i.e. 2.6 mol) reacts at the anode and will result in the following equation.

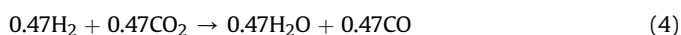
Corresponding reaction at anode:



The remaining 35% of the H₂ (1.4 mol) and the entire CO₂ (1 mol) from Equation (1) goes directly to the AOG. Combining the products from (2) and 1.4 mol of H₂ and 1 mol of CO₂ from (1) results in the following AOG composition.



But in reality, another internal reaction takes place in the DFC[®] fuel cell. One third of the H₂ in Equation (3) (i.e. 0.47 mol) needs to be back-shifted to H₂O and CO resulting in Equation (4).



Combining Equations (3) and (4) yields the following products:

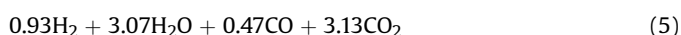


Table 1
Feedstock availability, collection, transportation and storage.

Type of feedstock	Source	Collection		Transportation
		Frequency	Collection point	
Dog and cat food waste	Royal canin	Daily	Warehouse	Semi-trailer
Food waste	University courts	Daily	Food court	Pickup truck
Wood chips	University power plant	Daily	Delivered at site	Trailer truck
Waste water	SE Wastewater Treatment Plant	Daily	Delivered at site	Used at facility
MSW	Rolla municipal solid waste	Weekdays	Organic waste collection program	Trash truck
Brewery waste	Public House Brewery	Weekly	Brewery	Pickup truck
Grape skin, rice hull and vines	St. James Winery	Seasonal	Winery/vineyard	Semi-trailer
Timber	MTNF	Seasonal	MTNF	Trailer truck

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