ProEcoPolyNet

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Best practice Sheet
"Annex 42: Fuel Cell CHP"

RTD Project Identification

RTD Project Name: FC+COGEN-SIM: IEA/ECBCS Annex 42 - The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems

RTD Contract No.: IEA/ECBCS Annex 42

Programme: Annex 42 operates under the auspices of the International Energy Agency's (http://www.iea.org) Energy Conservation in Community Systems (http://www.ecbcs.org/) program

Description of technology

Annex 42 considers modelling of various cogeneration technologies in the building environment. This Best Practice Sheet focuses on Fuel Cell CHP.

In a fuel cell, the chemical reaction of combustion is made using an electrochemical reaction where the reactants are separated by a tight membrane that only allows ions crossing. To complete the electrical balance, electrons have to move through a circuit, which produces a current. Depending on the type of membranes, the ions that will cross the membrane will be different: H+ for PEMFC or O2- in SOFC.

Proton Exchange Membrane Fuel Cell (PEMFC) technology involves the reaction of hydrogen with oxygen in the presence of an electrolyte to produce electricity without combustion and mechanical work. Water and heat are produced as by-products. The reaction is achieved through the electrochemical oxidation of a fuel (hydrogen) and the electrochemical reduction of oxygen. The following equations illustrate the electrochemical reactions:

Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode: $2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow 2H_2O$

Total Reaction: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

The amount of electricity that can be produced by the reaction is limited by the Gibbs free energy the remaining enthalpy of reaction is converted into heat. Furthermore, in order to maintain a sufficient driving force for the ions transfer through the membrane, the combustion can not be complete, the remaining fuel will be burned in an afterburner that will produce heat useful for cogeneration. The temperature of operation of the fuel cell has to be controlled according to the membrane specification. Therefore, the released heat can be harnessed for space and domestic hot water heating for residential, commercial or institutional applications. The hydrogen used as fuel can be produced from different sources such as natural gas, propane, coal, or through the electrolysis of water.

A fuel cell system consists of several subsystems, which include the fuel cell processor (i.e. hydrogen reformer), fuel cell stack, auxiliary systems required for operation and the inverter. The process of producing hydrogen from a fuel source such as natural gas is called reforming, and the process can either be internal reforming or external reforming depending on the type of fuel cell. The general design of most fuel cells is similar except for the type of electrolyte used. Currently, there are various types of fuel cell technologies in different stages of development. These include alkaline fuel cells (AFC), polymer electrolyte membranes (PEM), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), and lately, direct methanol fuel cells (DMFC). Amongst these, PEM and SO fuel cells have the highest potential for the residential sector.

Operating principle

The performance of fuel cell systems is a function of the type of fuel cell and its capacity. The optimization of electrical efficiency and performance characteristics of fuel cell systems poses an engineering challenge because fuel cell systems are a combination of chemical, electrochemical, and electronic subsystems25. Due to the several subsystem components of a fuel cell system laid out in series, the electrical efficiency of the system is a multiple of the efficiencies of the individual sections. The factors determining the electrical efficiency of a fuel cell include the fuel cell efficiency, the fuel conversion and the non converted fuel processing. The electrical efficiency is expressed by the ratio between the net electricity produced and the fuel consumed. The system efficiency is influenced by the quality of the system integration, for example the use of the depleted fuel to satisfy the energy requirement of the fuel processing.

Technical characteristics and operational data

Fuel Cell Type	PEMFC	PEMFC	PAFC	SOFC	MCFC
Nominal Electricity Capacity (kW)	**10**	**200**	**200**	**100**	**250**
Electric Heat Rate (MJ/kWh), HHV	**12**	**10.3**	**10**	**8**	**8.4**
Electrical Efficiency (%) HHV	**30**	**35**	**36**	**45**	**43**
Fuel Input (MJ/hr)	**105**	**2,110**	**2,005**	**845**	**2,110**
Operating Temperature [^oC]	**70**	**70**	**200**	**950**	**650**
Cogeneration Characteristics					
Heat Output (MJ/hr)	**42**	**760**	**780**	**200**	**465**
Heat Output (kW equivalent)	**13**	**211**	**217**	**56**	**128**
Total Overall Efficiency (%) HHV	**68**	**72**	**75**	**70**	**65**
Power/Heat Ratio	**0.77**	**0.95**	**0.92**	**1.79**	**1.95**
Net Heat Rate (MJ/kWh)	**6.7**	**5.5**	**5.1**	**5.5**	**6**
Effective Electrical Efficiency (%) HHV	**53.6**	**65.0**	**70.3**	**65.6**	**59.5**

In both power generation and cogeneration applications, fuel cell systems have excellent load following characteristics. Fuel cell stack efficiency improves at lower loads, resulting in an increase in system electrical efficiency that is relatively steady down to one-third to one-quarter of rated capacity

Location and use

- *Private Buildings*
- *Residential Buildings*
- *Commercial Buildings*
- *Public Buildings*
- *Others*

Capital investment and maintenance costs

Fuel Cell Type	PEMFC	PEMFC	PAFC	SOFC	MCFC
Nominal Electricity Capacity (kW)	**10**	**200**	**200**	**100**	**250**
Variable Service Contract ($/kWh)	**0.0121**	**0.0087**	**0.0087**	**0.0102**	**0.0072**
Variable Consumables ($/kWh)	**0.0002**	**0.0002**	**0.0002**	**0.0002**	**0.0002**
Fixed ($/kW-yr)	**18.0**	**6.5**	**6.5**	**10.0**	**5.0**
Fixed ($/kWh @ 8,000 hrs/yr)	**0.0023**	**0.0008**	**0.0008**	**0.0013**	**0.0006**
Stack Fund ($/kWh)	**0.0188**	**0.0132**	**0.0193**	**0.0125**	**0.0350**
Stack Life (yrs)	**4**	**4**	**5**	**8**	**4**
Recovery Factor (%)	**50**	**35**	**30**	**20**	**30**
Net O & M cost ($/kWh)	**0.033**	**0.023**	**0.029**	**0.023**	**0.043**

► *Maintenance*

Fuel cells have the potential for very low maintenance costs because they have fewer moving parts when compared to reciprocating engines and micro-turbines. However, maintenance of ancillary systems such as pumps and fans needed for operating fuel cell systems can increase maintenance costs. In addition, these ancillary systems can cause an increase in both scheduled and unscheduled downtime

The maintenance cost for the commercially available PAFC systems (200 kW) including an allowance for periodic stack replacements is from 0.02 - $5 $/kWh (0.016 – 3.92 €/kWh). It is assumed that the higher costs have been obtained from laboratory trials. Periodic stack replacement alone for the commercially available 200 kW PAFC fuel cell is estimated to be around 0.0193 $/kWh (0.0151 €/kWh). The cost to replace a 10kW PEM fuel cell stack is estimated to be 0.0188 $/kWh (0.0147 €/kWh), while the estimated cost to replace a 200kW PEM fuel cell stack is 0.0132 $/kWh (0.0104 €/kWh), and 0.0125 $/kWh (0.0098 €/kWh) to replace a 100 kW SOFC fuel cell stack

State of Development/Market implementation

- *Prototype*
- *Field tested*
- *Demonstration*

CO2 and primary energy savings

Fuel Cell Type	*PEMFC*	*PEMFC*	*PAFC*	*SOFC*	*MCFC*
Nominal Electricity Capacity (kW)	***10***	***200***	***200***	***100***	***250***
Electrical Efficiency (%) HHV	***30***	***35***	***36***	***45***	***43***
Emissions Characteristics					
NOx [g / MWh]	***27***	***27***	***14***	***23***	***27***
CO [g / MWh]	***32***	***32***	***23***	***18***	***18***
Unburned Hydrocarbons [g / MWh]	***5***	***5***	***5***	***5***	***5***
CO2 [kg / MWh]	***617***	***531***	***515***	***413***	***431***
Carbon [kg / MWh]	***168***	***143***	***141***	***111***	***118***

Notes: Emissions adjusted to 15% oxygen. Emissions do not account for cogeneration operations.

Benefits and obstacles

The advantages of fuel cell cogeneration systems include low noise level, potential for low maintenance, excellent part load management, low emissions, and a potential to achieve an overall efficiency of 85-90% even with small units. Stationary power fuel cells typically burn natural gas, and release fewer environmentally harmful emissions than those produced by a combustion cogeneration plant. With a fuel cell, carbon dioxide emissions may be reduced by up to 49%, nitrogen oxide (NOX) emissions by 91%, carbon monoxide by 68%, and volatile organic compounds by 93%. Low emissions and noise levels make fuel cells particularly suitable for residential, commercial and institutional applications. However, the high cost and relatively short lifetime of fuel cell systems are their main drawback. Ongoing research to solve technological problems and to develop less expensive materials and mass production processes are expected to result in advances in technology that will eventually reduce the cost of fuel cells.

Contact and further information

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