Attachment 19:
280 Nutmeg Road

PureCell Model 400 Fuel Processing System (FPS)

The FPS converts pipeline-quality natural gas into hydrogen reformate – a hydrogen-rich gas that is delivered to the anode side of the fuel cell stacks. This module includes a condenser to recover water generated in the fuel cell reaction by condensing water vapor from the process exhaust. This eliminates the need for makeup water under most operating conditions. The recovered water is used in the steam reformation process. The main components of the FPS include the following:

Hydro-Desulfurizer

The desulfurizer system removes sulfur used as an odorant in natural gas, which is a poison to the catalysts used in the fuel cell systems. Sulfur is converted to zinc-sulfide, a non-hazardous waste, within the desulfurizer and remains there until an overhaul is required, nominally after 10 years. This system will also remove small amounts of oxygen in the gas.

Steam Reformer

Steam (H_2O) generated in the cell stack cooling loop of the TMS is combined in the reformer with methane (CH_4) in the natural gas to generate a gas composed of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2).

$2CH_4 + 3H_2O = 7H_2 + CO + CO_2$ *Equation 1*

Integrated Low-Temperature Shift Converter

The integrated low-temperature shift converter (ILS) generates additional hydrogen through a water-gas reaction in which CO and water is converted to hydrogen and CO_2. The reduced CO content minimizes its adverse effect on fuel cell stack performance.

CO + H2O = H2 + CO2 *Equation 2*

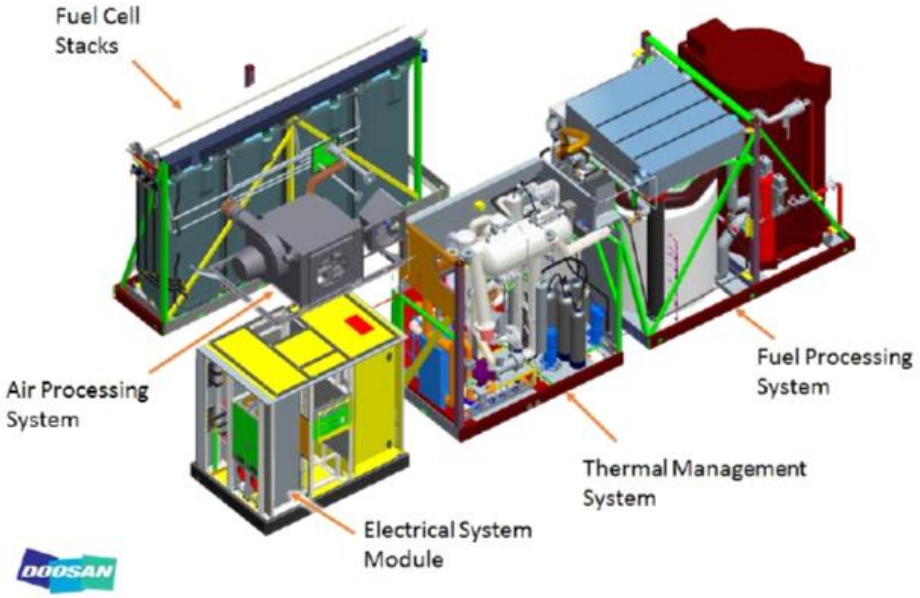

Figure 1. PureCell Model 400 Subsystems

Desulfurization Memorandum
PureCell® Model 400 Stationary Fuel Cell System

Date: 2017-01-05

Sulfur Background

Sulfur is present in pipeline natural gas. It is primarily used as an odorant so leaks can be detected. Unfortunately, sulfur is also a poison to fuel cell systems and exposure to sulfur will drastically reduce the life and efficiency of the fuel cell.

Types of sulfur found in natural gas vary from region to region. Some common examples are:

- Hydrogen Sulfide (H_2S)
- Tetrahydrothiophene (THT)
- Mercaptain – (MCP) - Broad family of sulfur molecules characterized by a sulfur atom attached to a hydrocarbon molecule or chain

The majority of it the odorants are organic with the exception of hydrogen sulfide. Standard pipeline natural gas contains up to 6 parts per million by volume (ppmv) sulfur on average with spikes as high as 30 ppmv possible. In order to successfully maintain operation of the fuel cell for a period of 10 years, the sulfur levels must be reduced to less than 0.02 ppmv, or a 99.7% removal rate. An additional benefit of this is that it removes sulfur dioxide from the emissions of the fuel cell power plant.

Sulfur Removal Techniques

Sulfur removal can be broken down into two main techniques, physical capture and reactive capture.

Physical capture involves using porous media such as activated carbon or molecular sieves to capture and concentrate the odorant before it enters the fuel cell. Doosan elected not to pursue this path due to several factors, including:

- The process concentrates the odorant and turned it into hazardous waste
- The concentrated odorant is highly toxic and requires specially trained personnel to handle the waste
- Would result in more service being required at customer sites to maintain the system

Reactive capture is the method used by Doosan to remove sulfur. It involves chemically reacting the odorant over a catalyst bed in order to separate the sulfur molecule. Once the sulfur molecule is separated from the odorant, the remaining odorant is destroyed in another catalyst bed. The sulfur molecule is then captured and converted to a compound called Zinc Sulfide.

$$*S + H_2 \leftrightarrow H_2S + * \qquad \textit{Equation 4}$$

$$H_2S + ZnO_{(s)} \leftrightarrow ZnS_{(s)} + H_2O \qquad \textit{Equation 5}$$

Note: * represents the non-sulfur odorant components

Doosan's system has been sized such that it will run for the 10 year service life of the unit and not need to be changed out. When the unit is removed from service, the decommissioning or refurbishment of the unit will be carried out by trained personnel and a company specializing in removal of the waste Zinc Sulfide will recover the spent material. Zinc sulfide has some commercial value, so that company will either process it and sell it or split it into Zinc and Sulfur and sell them separately.

Respectfully,
Jesse Hayes, Director, Product Management, Doosan Fuel Cell
195 Governors Highway
South Windsor, CT 06074
Jesse.hayes@doosan.com
(860) 560-3309