Logistic Fuel Reformer for TARDEC

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Abstract: Ceramatec has recently constructed a non-thermal plasma reformer capable of processing Mil-Spec JP-8 (i.e. up to 3000 ppmv sulfur) into a stream of gas appropriate for a solid oxide fuel cell. The unit was prepared for TARDEC (i.e. Tank Automotive Research, Development and Engineering Center). The plasma reformer is capable of operating in a sulfur tolerant mode so liquid phase sulfur removal or hydro-desulfurization is not required. The unit is capable of a cold start and the reformate sulfur removal system can be regenerated without interrupting system operation. The system provides sufficient clean synthesis gas (i.e. carbon monoxide and hydrogen) to fuel ten (10) kilowatts of solid oxide fuel cells (i.e. assuming operation of the SOFC at 40% efficiency). The reformer uses the non-thermal plasma to form radicals to promote reforming much as would occur with a solid reforming catalyst. The plasma unit has the advantages of being insensitive to sulfur (i.e. it is essentially a continually renewing catalyst), creating a highly active reforming zone, being fuel flexible, and being capable of operating in a number of orientations for packaging.

Keywords: Reforming JP-8; plasma reforming; logistic fuel reforming; non-thermal plasma

Introduction

Operation on liquid hydrocarbon logistic fuels drawn from any available infrastructure, or from onboard the vehicle, is an absolute requirement for a truly useful and practical fuel cell power system for military applications. Unfortunately, catalytic steam reforming of these fuels has proven difficult due to adverse effects from the high aromatics content and deeply-bound sulfur on catalyst activity. In partial oxidation, catalytic partial oxidation (CPOX), and autothermal reforming (ATR) processes, a substoichiometric amount of air is combined with the fuel, and the mixture is burned (either with or without a catalyst) to generate synthesis gas used to fuel the fuel cell. Conventional partial oxidation processes have been plagued with soot and carbon deposition issues, and in some cases, the soot management system may be larger and more complex than the reformer. The thermal mass of the catalyst in the case of CPOX or ATR operation, the hydrogen required in a hydro-desulfurization system, and the operational difficulties associated with the partial oxidation process make each of these processes difficult to use for compact synthesis gas production.

Non-thermal plasma reforming is an approach that solves many of the above problems. This approach uses a low-amperage, high-voltage plasma arc to catalyze the reforming of the heavy hydrocarbons. The energy needed to complete the reformation process can be introduced by burning a portion of the fuel or by heat integration with the rest of the system. Much as would be accomplished by a solid catalyst, the non-thermal plasma creates radicals that promote the reforming process. Unlike the solid catalyst, the non-thermal plasma approach is not sensitive to sulfur since it is constantly renewed with each plasma arc generated and since there are no catalyst sites for sulfur to deactivate. Likewise, without the solid catalyst bed there is no thermal mass that must be heated to temperature and thus start-up time is substantially reduced. The unit may be started in a partial oxidation mode and then switched to steam reforming as temperatures sufficient to produce steam are reached. This provides substantial flexibility in operations by going from exothermic to endothermic operations dependent only on control algorithms and the mode that makes the most sense at a point in time. The system is flexible, sulfur tolerant, and consumes a minimum of the energy value of the synthesis gas produced. The system does need some electrical energy to produce the plasma (i.e. ~ 1-3% of the energy in the input fuel) and does not eliminate the sulfur from the synthesis gas but as stated it is not sensitive to this sulfur.

Non-thermal Plasma Reformer:

Ceramatec has developed an innovative, integrated process that retains the thermodynamic advantages of steam reforming and combines it with the robust, highly energetic reaction zone characteristic of partial oxidation. The process is easily scaleable for use in compact power systems, ranging from a few kilowatts to hundreds of kilowatts. A laboratory-scale reformer (Figure 1, next page) is compact, with an internal volume of 0.6 L and a reformation capacity of 5 kWt fuel rate. The plasma reformer generates a highly active, non-thermal plasma source of non-equilibrium electric discharges that act as an activation source for plasma chemical reactions.

The device has at least two diverging knife-shaped electrodes along which multiple electric discharges glide. These electrodes are immersed in a fast-flowing gas. The progress of an electric discharge is shown in Figure 1 (right). A high-voltage, single- or poly-phase, relatively low-current discharge is generated across a gas flow between the electrodes. The discharge forms at the closest point, spreads along the electrodes, and disappears; another discharge immediately forms at the initial spot. The geometry of the electrodes, flow conditions, and characteristics of the power supply determine the path of the arc. The electrodes do not need to be cooled, so the electrical energy is directly and totally transferred to the processed gas. The voltage can be as high as 20,000 volts. Multiple discharge systems can be installed for large gas flow rates. Any gas or vapor can be directly processed.

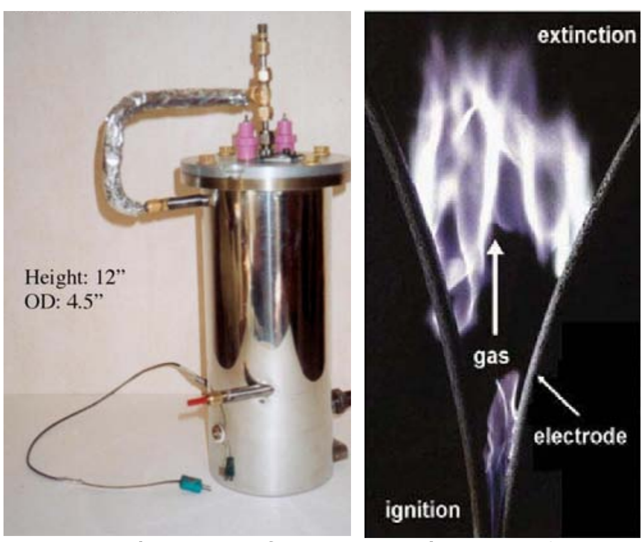

Figure 1. **Plasma reformer: 5-kWt JP-8 reformer (left); view of the electrodes (right).**

JP-8 fuel obtained from a Chevron refinery was reformed. The analysis provided by the refinery indicated that the fuel had a total sulfur of 430 ppmw and an aromatic content of 15.3 vol%. A reformate gas analyses using air for the oxygen supply performed over a 16-hour operation is shown in Figure 2. The H_2 + CO content of the reformate was around 30 vol%. Even with the 15% aromatic content of the JP-8, there was only about 1.5 volume % of methane in the reformate and negligible higher hydrocarbons.

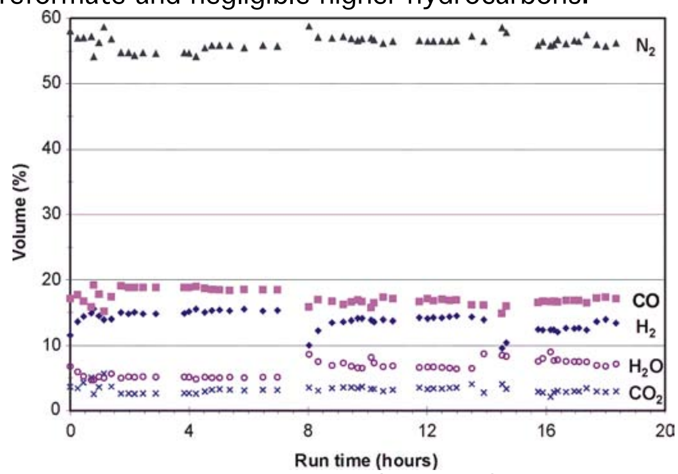

Figure 2. Gas composition of JP-8 reformate in POx mode

The plasma reformers are compact, easily scalable, and the electrical consumption is in the 1–3% range of a fuel cell's full load output, enabling high overall system efficiency. Tests have successfully reformed pipeline-grade natural gas, commercial propane, gasoline, and diesel fuel at atmospheric pressure, and with electrical power as low as 90 W for a 5-kWe fuel rate (about ~2% of the fuel cell output). The reformer continues to function well at reduced fuel flow rates; however, electric power input remains relatively constant and, thus, consumes a proportionally greater fraction of the input energy. The plasma reformer can operate in either a partial oxidation mode or a steam reforming mode if heat is available from a fuel cell or some other source. The steam reforming mode produces a synthesis gas that is substantially higher in energy content as is shown in Figure 3 below.

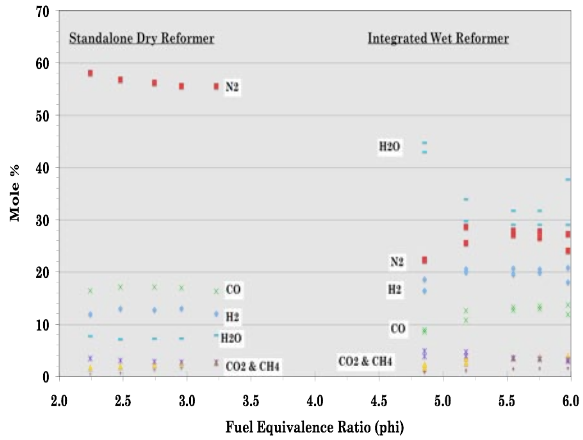

Figure 3: Comparison of partial oxidation and steam reforming JP-8 reformate composition

The heating value of the JP-8 reformate in a partial oxidation mode is about 73% of theoretical while the value in steam reforming mode is ~ 92% of theoretical. The higher percentage of hydrogen in steam reforming mode is from part of the oxygen for the reforming being supplied by the steam and thus hydrogen is generated.

A significant advantage of the plasma reformer is that it may be arranged in a number of configurations. The flow may be arranged to allow for linear flow, upward flow, downward flow, or other configurations dependent on application and size constraints. The recently completed TARDEC contract used an M-shaped configuration as shown in Figure 4 below.

TARDEC Contract:
This contract involved design, fabrication and delivery of a non-thermal plasma reformer that is capable of producing enough synthesis gas to fuel 10 kWe of solid oxide fuel cells. The unit included a sulfur removal unit fabricated by IntraMicron that was capable of on-line regeneration of the sulfur capture material. The unit did not include the solid oxide fuel cells but was designed to be relatively compact and have the potential to be integrated with solid oxide fuel cells in the future. The design is shown in an artist's conception in Figure 4 (a) below. The unit consists of two M-shaped plasma units with a heat exchanger between them. The plasma units are located in the center leg of the M shaped units. If fuel cells were to be added, the enclosure would be expanded slightly and the fuel cells placed between the heat exchanger and reformer for heat integration.

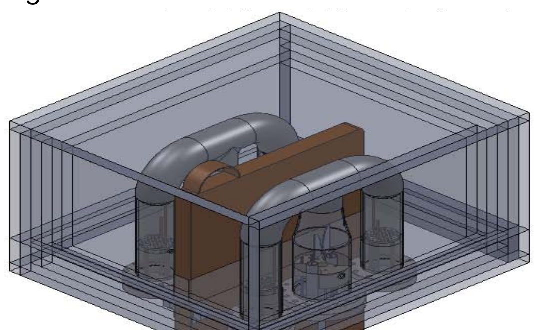

Figure 4: Design of 10 kWe plasma reformer

Figure 5 shows the as-built unit. The unit is ... lelivers ... at an ... it was ... with ... will be ...). The ... eeding ... de fuel ... te but

Figure 5: As built TARDEC reformer

Summary:
Ceramatec has developed a reforming technology that can successfully reform a variety of logistic fuels used by the military. The plasma-catalyzed reformer has been demonstrated to be sulfur-tolerant in reforming JP-8 fuel containing over 400 ppmw total sulfur and in excess of 15 volume % aromatics. Non-methane hydrocarbon slip is negligible. The reformer operation is soot free and the power consumption for the plasma was of the order of 1 – 3% of fuel LHV.