

Self sustained reformation of diesel fuel

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ABSTRACT: Reformation of diesel fuel was performed using a silicon carbide (SiC) block with penetrating walls. The atomized fuel was spray injected to the electrically heated block. The fuel-air mixture was reformed by partial oxidation and changed to synthesis gas including CO, CO₂, H₂O, O₂ & H₂. The composition of the reformed gas was measured with varying fuel-air ratios. The degree of reformation changes with the temperature and a maximum reformation efficiency of ~90% is attained at around 850 °C.

Keywords: Reformation, Synthesis gas, SiC block

1. INTRODUCTION

Synthesis gas has great value as a combustible gas and as intermediates in a number of chemical processes. Many methods have been tested for the reformation of heavy oil into synthesis gas, containing hydrogen, carbon monoxide and light hydrocarbons [1-4].

Our previous work was concerned with diesel fuel reformation to produce synthesis gas using a plasmatron [5, 6]. In this work we developed a thermally supported reformation system of diesel fuel using a SiC block with wall-through flow structure.

This reformation process favors high temperature conditions. These conditions were attainable by lowering the fuel-air ratio (lean condition). An abundance of air makes the oxidation reaction more complete and the additional reaction energy heats the reformer

to higher temperatures, where the diesel fuel is converted to synthesis gas more efficiently.

2. EXPERIMENT

2.1 Equipment

The reformer consists of three main parts. The first one is the active element – a 100 cell per square inch Si-C filter that has a diameter of 81 mm and length of 103 mm from Notox. The filter was used as a diesel particulate filter (DPF) in origin. The outside cylinder wall of the filter was coated with an electrically conductive paste, Pyro-Duct 597-C of Aremco Products Inc. The active electrode was attached to the central part of the reformer element. The second part is a spraying nozzle, Air atomizing 1/8JJAU-SS BSPI from Spraying Systems. Sometimes we made a modification to the nozzle to allow the introduction of a larger amount of air.

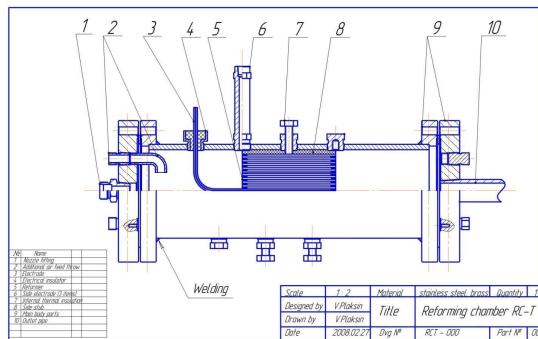


Figure 1: Reforming apparatus. 1. Nozzle fitting; 2. Additional air feed-through; 3. Electric feed-through; 4. Electrical insulation; 5. Reforming member; 6. Thermocouple fitting; 7. Side electrode; 8. Internal thermal insulator; 9. Main body parts; 10. Outlet pipe.

The last part is stainless steel housing, containing thermal insulation, an electric feed-through, openings to fixed and movable thermocouples, an opening to a pressure gauge, and an opening to the diesel fuel-air mixture input nozzle. The drawing of the system assembly is shown on Figure 1.

Several techniques, including plasma and catalysts, have previously been studied as reformers in converting liquid fuel into a gaseous fuel stream containing hydrogen and carbon monoxide as the major components. In all of the previous reaction elements the gas flowed mostly in the axial direction.

In this work we adopted a SiC DPF as the reaction element. The DPF is a wall flow monolith. This is a ceramic structure with many small, parallel channels running in the axial direction. The wall between the channels are made of porous material and adjacent channels in the wall flow filters are alternatively plugged at each end, thus forcing the gas to flow through the porous walls as shown on Figure 2.

By this arrangement the cross section of the gas flow increases dramatically near the porous walls. That means the velocity of the gas decreases drastically near the porous

walls and the contact area between the gas and reformer element is increased in equal proportion.

If the reformation reaction by partial oxidation is carried out mainly in the inter-wall space, the reaction efficiency will be high because the gas velocity is slower than the flame propagation velocity (reaction propagation velocity) near the porous walls. All of the gases passing through the walls remain in the reforming region for enough time for the reaction to proceed. If the reformation reaction is dominated by surface reactions, the reaction efficiency will also be high because of the increased surface area of the porous walls.

In addition to the increased efficiency, the reformer element can act as a heat reservoir to conserve the temperature of the reformer. Heat loss to the environment can be compensated with heat from the exothermal reformation reaction. If the temperature is raised high enough, the reaction can be self-sustained.

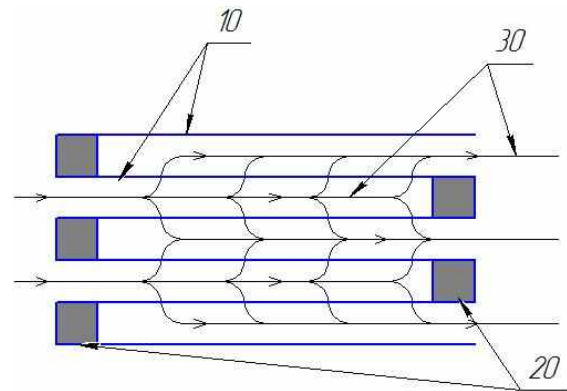


Figure 2: Schematic plan view of the reforming agent. 10. Porous wall between the channels; 20. Alternate end plugs; 30. Gas flow pattern through walls.

Due to the increased efficiency of the reformation system we can eliminate the use of a catalyst for accelerating the reaction. Not using a catalyst saves on fabrication cost and

increases the immunity to impurities in the fuel.

The picture of the whole reformer system is shown in Figure 3.



Figure 3: The reformer with fuel tank under pressure, flow meter & gas sampling pump.

2.2 Experiment

The SiC monolith is electrically conductive, with some amount of resistance so that it is used as a heating element. But, the resistance changes with the temperature non-linearly. The change of resistance with temperature is as shown on Figure 4. The temperature at half of the radius of the reformer was measured while applying electric power. The resistance was calculated from the voltage and ampere relationship. The resistance of the SiC reformer element decreases in value from over 1000 Ω at room temperature to the saturation value of around 5 Ω at temperatures of above 300 $^{\circ}\text{C}$.

Initially the SiC block was heated by applying electric power through several steps. At first AC 100 V was applied for about 10 min. until the temperature became 150-160 $^{\circ}\text{C}$. After this temperature the resistance of the block decreased to below 100 Ω . At this time, the current was limited because fixing the voltage leads to a steep increase of

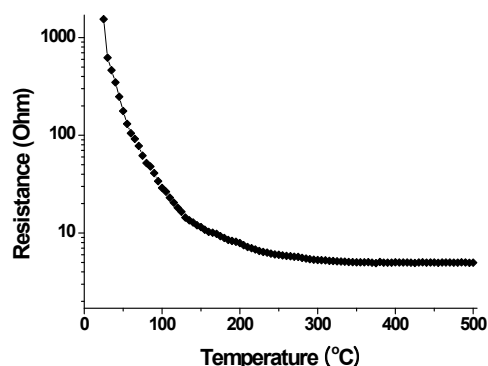


Figure 4: Electric resistance depends on the temperature of the SiC reformer.

current and can cause damage to the equipment. In the next stage DC 70 V – 15 A was connected. It started in a 70 V – 1 A voltage limitation mode, and in a few minutes finished in a 20 V – 15 A current limitation mode, at temperatures of about 230 $^{\circ}\text{C}$. The last power source to be connected was 50 V – 200 A. Using this one we gradually increased current from 15 A to 40 A during 20 min., reaching a temperature of about 550 $^{\circ}\text{C}$.

At this moment the diesel spray was switched on – the fuel and air flow rates about 6 ml/min, and 20 l/min, respectively. The fuel-air mixture starts to burn and the thermal energy from the chemical reaction works together with the DC to heat the block. At 800 $^{\circ}\text{C}$ the DC is turned off to prevent overheating. The reaction can then be sustained without the addition of outside energy.

The amount and ratio of fuel and air in the mixture was adjusted to maintain the proper temperature (800-1200 $^{\circ}\text{C}$) inside the reformer and obtain maximum yield of products. The ratio of air to fuel flow rate should be close to the optimum stoichiometric relationship for the partial oxidation reaction as shown in Ref. 5.

$$Q_{\text{AIR}} \{ \text{L/min} \} \approx 3 Q_{\text{FUEL}} [\text{mL/min}]$$

The concentrations of CO, CO₂, O₂ and H₂O in the reformed gas were measured by GASTECH gas analyzer tubes. The conversion rate of the reformation was checked by the concentration of CO in the reformed gas because CO concentration is directly related to the degree of partial oxidation.

3. RESULTS AND DISCUSSION

We initiated the reformation reaction by electrical heating. The reformation reaction became self-sustained after reaching a temperature of 800 °C. Varying the ratio and flow rates of fuel and air can control the temperature.

It is worth noticing that the temperature profiles are different in the cases of electrical and reaction heating. When the power electrode is located in the center of the block, at temperatures below 400 °C the neighboring four holes shine, indicating temperatures above 800 °C. With the increase of temperature the central part remains the brightest. On the contrary, burning fuel heats all the block radii uniformly and there is no significant difference in the color of the reformer.

Though a low fuel flow rate probably can maintain the reaction, the resulting CO

concentration was only 5-7 %, because the temperature was quite low.

The exit area of the reformer at these low flow rates was not red hot. Only the inlet of the reformer was red hot, while part of the fuel-air mixture passed through the region with decreased temperature. The reaction was not uniform and part of the fuel did not undergo the reaction.

In Table 1, we show the measured concentration of CO, the maximum concentration of CO that can be possibly obtained for the given fuel and air flow rates, and conversion rate, defined by the ratio of measured CO concentration to the maximum possible CO concentration, corresponding to 100 % conversion.

When the temperature was below 800 °C, the CO concentration at the outlet did not exceed 10 %, equivalent to about a 40 % conversion rate. At temperatures of about 850 °C, a conversion rate of 90% was achievable (see Nos 6, 7 in Table 1). These temperatures are stable and can be controlled by the amount (see Nos 1, 6, 7 in the Table) and quality (see Nos 1, 3-5

in the Table) of the supplied mixture quite accurately.

Usually the temperature is high when the airflow rate is high because the excess oxygen in the reformation process induces greater exothermal oxidation reactions. When the fuel flow rate increases, the temperature also

Table 1: Conversion rates of the reformation dependence on the temperature, fuel and air flow rates.

No	Fuel mL / min	Air L / min	Temp. °C	CO %	CO max possible, %	Conversion rate
1	7	22	806	18	24	0.75
2	6.7	23	814	14	23	0.61
3	6	22	812	14	22	0.64
4	8.3	22	809	17	25	0.68
5	9	22	806	15	25	0.60
6	9	27	853	23	25	0.92
7	10.3	30	872	22	25	0.88

increases.

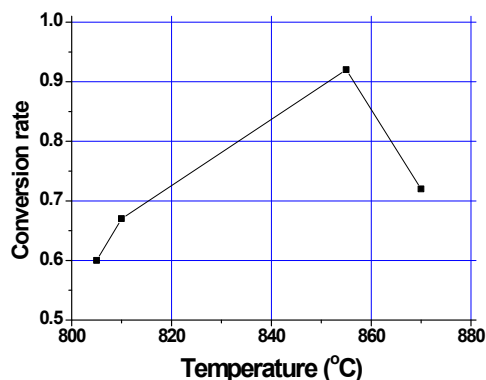


Figure 5: The reformation conversion rate is dependent on temperature.

In Figure 5, the dependence of the conversion rate on temperature is shown. The maximum conversion rate of over 90 % was achieved at a temperature around 850 °C. At higher temperatures, which correspond to lean conditions, the conversion rate becomes lower because the fuel/air ratio departs from the optimum value. Carbon then begins to be converted to CO₂ rather than CO, by total oxidation. The achieved conversion rate is reasonably high compared to that of a catalyzed reformer, due to the benefit of the reformer structure mentioned earlier [7].

4. CONCLUSION

A new reformation device based on a SiC ceramic wall flow monolith was developed. The diesel fuel-air mixture was injected into the reformer by a nozzle. By applying electric power, the reformer was heated and the reformation reaction would occur. The electric power should be controlled, taking into consideration the non-linear change of resistance in the SiC block. The reformation reaction of partial oxidation can be self-sustained at temperatures of about 800 °C. The process can then run without external

power when the reaction becomes self-sustaining.

The conversion rate was checked by the CO concentration in the reformed gas. A maximum conversion rate of about 90% was achievable without catalysts at temperatures around 850 °C, due to the structural benefit of the reformer.

ACKNOWLEDGEMENT

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