

Low Current Non-Thermal Plasma Assisted Hydrocarbon Reforming Hydrogen Rich Gas

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Abstract

Current trends in the automotive industry include the use of hydrogen, GDI engines, and PEM Fuel Cell systems. Hydrogen is becoming increasingly hard to come by, thus researchers are looking for ways to produce it on board automobiles through hydrocarbon reforming. In this study, we introduce the Plasma Fuel Reformer (PFR), a non-thermal device that uses the Partial oxidation process as its underlying mechanism. Plasma is created by PFR using air at higher pressures than the atmosphere. Plasma is generated by an electrode gap discharge and continuous air and fuel infusions. Exothermicity from partial oxidation generates the most heat. The unique Plasma Fuel Reformer (PFR) has three sections in a stack: fuel injection, plasma production fuel reaction, and heat exchanger. It reformats gasoline into hydrogen-rich gas under non-thermal circumstances. The first section briefly describes hydrocarbon reforming chemistry. the second section is non-thermal Plasma Fuel Reformer (PFR) technology and design. Hydrogen-rich gas (HRG) is the enhancement of extending lean limit gasoline direct injection engine operation conditions to reduce the emission.

Keywords: Non-Thermal Plasma Fuel Reformer, Hydrogen-Rich Gas, Gasoline

1. Introduction

Recent increases in environmental and pollution concerns have spurred scientific attempts to create renewable energy and power generation methods. While fossil fuels are a primary energy source, burning them emits significant amounts of C and NO_x, contributing to the greenhouse upshot. To meet rising energy demands and protect the atmosphere, cleaner and more efficient energy generation technologies are needed. The fuel cell technology is promising for meeting energy needs, particularly in transportation. Fuel cells produce energy by turning O₂ and H₂ into water without burning.

In this light, all the major global automobile manufacturers agree that producing hydrogen directly from gasoline is possible, Fuel reforming is already in use to produce hydrogen at a constant rate for use in a variety of chemical processes.

There are a few different catalytic reformers out there, and they're all used to reform fuel, but they each have their own set of issues. When Using conventional gasoline, the catalyzers quickly become polluted by either the sulfur in the fuel or carbon deposits. It's not just that they're pricey, but also that their lifespan is limited. Additionally, the initialization process takes too long (a few minutes) to be practical for use in a car.

One of the most sophisticated plasma-aided reforming teams is located at MIT's Plasma Science and Fusion Centre (PSFC). For concerns of energy efficiency, Cohn, Bromberg, Rabinovich, and coworkers shifted their focus away from building a thermal plasma-aided reformer. Possible uses include feeding hydrogen into a fuel cell, regenerating a NO_x absorber, enriching hydrogen-rich gas, or powering a spark-ignition engine [1].

Low energy electron beams: In this configuration, an electric arena is used to accelerate electrons twisted in a vacuum, and then those electrons enter the gas combination via an extraction window. The newest material is sufficiently permeable for energy electrons and can tolerate the pressure variance between the vacuum and the reaction chamber at atmospheric pressure. Metal membranes, such as those made of titanium, are used to shield against electrons with energies higher than keV. Ceramic materials such as SiN are useful for those with reduced energy requirements, as is the case here. In this configuration, a silicon platter with a SiN casing measuring 1 mm by 1 mm and 300 nm in thickness is used.

The generation of radicals, ions, and secondary electrons is aided by using low energy electron beams. The emissivity of electrons is also predetermined outside, thus it is not affected by changes in the chamber's pressure, temperature, or composition. Power output is restricted to 462 mW since a direct voltage source (10-14 kV) only delivers current up to 33 1A. The approach results in a spherical plasma zone with a relatively modest energy density (about 1 W/cm³) [2].

Discharge plasma The possibility of using reforming activities for gas augmentation has been investigated in tandem with fuel cell feed-in due to the difficulties of producing a renewed exhaust H₂-rich gas. The goal of the latter is to increase the concentration of hydrogen and other species for more complete combustion. H₂ does increase both the heating value and the flame speed. A small burner system with an integrated reforming unit (based on an arc discharge) was designed and built. To burn, a portion of the rich methane mixture is separated, transformed into mostly H₂, CO, and H₂O, and then pumped into a leaner mixture. The enriched hydrogen allows for a more stable flame than a standard burner, and this is the ultimate goal [3].

Reforming studies were designed for auto-thermal or steam reforming at 3 bar pressures and 773 K pre-heating temperatures. Non-sulfur synthetic gasoline termed California gasoline petroleum (average formula: C₇H_{15,2}) was tested. A 6.3 l stainless-steel cylinder has bond sets of electrodes making binary gliding arcs. The reactor scheme is on knife-shaped electrodes that are 45 mm long, 20 mm high, and 2 mm wide. Each pair of electrodes has a two-high voltage power supply particularly constructed. Both energy in AC (50 Hz) or DC settings on 5000 and 10,000 V potential differences.

The greatest power was 1000 W during runs. O/C proportions ranged from 0.3 to 1.2 and H₂O/C from 1 to 5. Fuel and water were premixed, but air was delivered separately [4].

Octane C₈H₁₈ is used as a petrol alternative because it has a fairly sophisticated H/C ratio (the effective petrol formula is C_{6.9}H_{12.5}) and may generate more hydrogen. The plasma reformer has a post-discharge reactor and a small non-thermal arc plasma torch. Plasma torch geometry resembles traditional high-current DC plasma systems. An enhanced velocity gas combination (preheated separately at temperatures adjustable flexibly between ambient temperature and 800 K) injected radially around the center electrode blows down a low current–high voltage arc discharge between the electrodes. The plasma reactor shape has been optimized for plasma uniformity and reagent mixing. About 350 cm³ is the reactor volume. The plasma zone creates radical species, and the post-plasma reactor performs the major chemical step. O/C and H₂O/C ratios can be continually changed to produce petrol flow rates up to 0.3 g/s. [5].

Precisely, a non-equilibrium throbbed discharge. This primary reactor is intended for dry reforming Partial oxidation of methane as well as steam reforming of hydrocarbons and alcohols (methane, propane, hexane, cyclohexane, methanol, and ethanol) [6,7,8].

The Partial oxidation of methane was investigated using plasma rather than pulse microwave discharge. Methane conversion research utilized both pulsed intermittent (3 cm wavelength, pulse power up to 3 kW, 1 ls pulse duration, and repetition frequency of 1 kHz) and continuous microwave discharge regimes. Before entering the testing chamber, heat the air/methane mixture to between 500 and 900 degrees Celsius. [9,10,11].

The use of plasma technology to reform fuel for hydrogen generation may be highly appealing if it could solve the issues seen in catalytic reformers. Catalysts play a crucial role in the reforming progression by generating sweeping species that boost the reaction. Plasma supplies the energy and generates the free radicals necessary for the fuel-reforming process. Multiple articles have shown that non-thermal plasma can act as a catalytic agent in the production of hydrogen [12-19].

The research discussed in this study aimed to create a non-thermal plasma prototype that could reform petrol under a wide variety of circumstances, including auto-thermal and vapor reforming. Gliding arc technology is the foundation of the reactor design process [13–26].

Partial-fuel oxidation can produce NO_x when air is used to supply oxygen. Consider this if the reformer provides hydrogen for fuel cell applications, particularly cars. NO_x, a harmful chemical, is restricted in production.

NO_x generation measurement is challenging due to the hydrogen present. So far, few research have been published on this topic [27,3]. Despite working in rich regimes, plasma reactors may emit significant NO_x levels. NO_x generation decreases with increasing air numbers and flows, owing to dilution. Increased airflow reduces heat release, resulting in reduced flame temperatures and NO_x output. Since NO_x generation is mostly thermal (occurs at high temperatures), the relative position of input power curves may be interpreted as more injected power, higher temperature, and higher NO_x production.

The use of thermodynamical models for events in non-thermodynamic equilibrium is worth discussing. Thermodynamic calculations are simpler than kinetics calculations, making it easier to predict vital process parameters. Short-term thermodynamic calculations are valid when response time is significantly less than residence duration [28].

Thermodynamic analysis of reforming of methane, propane, heptane, toluene, and petrol [29] was performed using ASPEN-PLUS software [30]. For the simulations, a Gibbs reactor was used to model the reformer with the assumption that it is in a state of thermodynamic equilibrium.

Researched the feasibility of producing hydrogen from regular gasoline and n-octane as a fuel cell feedstock. The processor is divided into three thermally connected reaction zones: an auto-thermal reformer, a high-temperature WGS reactor, and a low-temperature WGS reactor.

The temperature progression is meticulously studied, and the phases are dependent on several catalysts. About 35% H₂ (less than the theoretical value) and 1% CO can be found at the outlet. When heated too much, a catalyst loses its effectiveness [31].

2. Chemistry of gasoline reforming

The following is a brief synopsis of the chemical reactions that are assumed to be occurring during the current plasma process. A chemical breakdown of how petrol is reformed can be found in references [16–19].

Hydrogen-rich gasoline is produced via non-thermal reforming of gasoline in this plasma process. The Partial oxidation reforming reactions create non-thermal reforming. Considering that the actual H₂O/C_nH_m ratio in conventional reactors is typically higher than the stoichiometric one, the surplus of water can convert CO, in a second reactor, into hydrogen using the water-shift reaction. While non-thermal reforming can be carried out in the absence of catalysts, their use enables the process to be carried out at lower temperatures and prevents the formation of carbon soot.

3. Non-thermal technologies: Low Current Plasma Tron

Plasma generates reactive species for chemical processes. Numerous plasma reactors have been developed to Partial oxidize or auto-thermally reform hydrocarbons [36–40]. There are few plasma reactors for hydrocarbon reforming [40, 41, 42]. Create non-thermal plasma. The discharge's high electrical power (over 20 kv) keeps neutral sympathetic and electrons at 5000K in thermal plasma. A high temperature in the reactor and energy ingesting make cooling the electrodes beneficial in minimizing thermal erosion. Since it requires a lot of energy, this technique is not suitable for GDI engines or fuel cell hydrogen generation. With a few hundred watts, non-thermal plasma is produced, where neutral species remain constant but electrons reach 5000 Kelvin. Here, plasma produces revolutionary and excited species to start and improve chemical processes, not energy. Non-thermal plasma works at lower temperatures, saving energy and cooling the electrodes less often. Its small size and light weight make non-thermal plasma reactors portable.

4. Plasma fuel reformer

The plamatron fuel converter efficiently generates hydrogen-rich gas under electrical power. A fluid flow controls plasma discharge quantity and shape. Plasmatrons' massive operational plasma discharge volume increases the volumetric effectiveness in chemical response initiation in a volume of large quantities fluid reaction flowing through a low electricity nonthermal plasma arc methodology system that spark plugs a first electrode and an additional electrode separated by an electrical insulator for discharging a fuel/air mixture. Schematic view

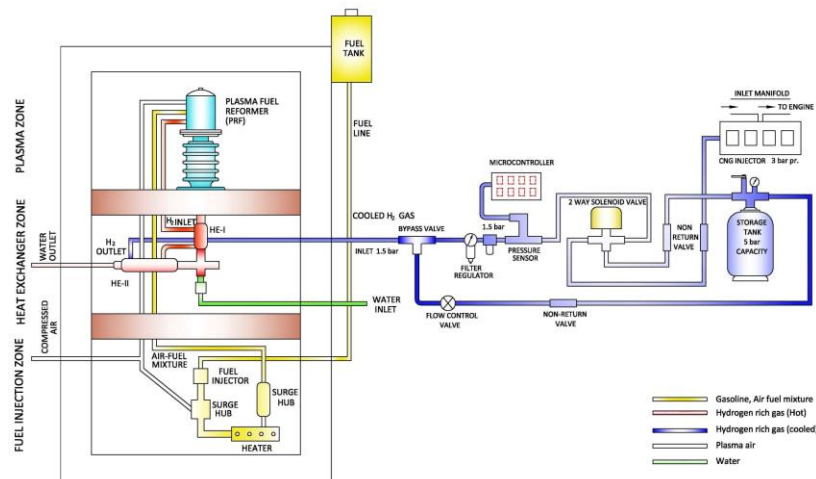


Fig.1 Schematic view of Non-Thermal Plasma Fuel Reformer



Fig.2 Schematic view of Non-Thermal Plasma Fuel Reformer hydrogen rich gas produce reaction zone

A power source is configured to produce voltage and current that is adequate to produce a plasma expulsion inside the emancipation volume. The primary and secondary electrodes are connected to this power source, which is situated appropriately. A plasma discharge's "cycle frequency" describes how often its discharges repeat itself. The chemical reaction initiated by each discharge will persist and propagate in the region of the rich fuel/air mixture local to the quasi-uniform volumetric plasma discharge, so the natural cycle frequency for the plasmatron fuel converter in the illustrative preferred embodiment will typically be on the order of numerous (1-20 kv).

Table 1. Specification details of Non-Thermal Plasma Fuel Reformer

Non-Thermal Plasma Fuel Reformer	Parameters
Diameter of anode	1.8 mm
Volume – fuel	0.4 – 0.6 kg/h
Arc Length	25 -35 mm
Arc – Input	12 V
Arc - Output	15,000 V
Arc – Frequency	50 Hz
O ₂ /C ratio (A)	0.6 to 0.85

The PFR utilizes the benefits of a Partial oxidation process in order to function. **Fig.2** Air is used as the plasma-forming gas in the PFR device, and it functions at pressures higher than the air around it. An ongoing discharge across an electrode gap generates a plasma area into which air and fuel are delivered constantly. The Partial oxidation process provides most heat due to its exothermicity. The Partial oxidation reaction releases around 15 percent of the fuel's heat energy in the circumstances of liquid fuels. The Plasma Fuel Reformer (PFR) is a focused portion of equipment with three distinct but interconnected sections: the fuel injection zone, the plasma generating-fuel reaction zone, and the hotness exchanger zone. The AFR range for the PFR is 4-6, therefore it requires a minimum air pressure of 1.5 bar and a fuel flow rate of 0.4-0.6 kg/h. the nonthermal plasma reaction produced hydrogen-rich gas

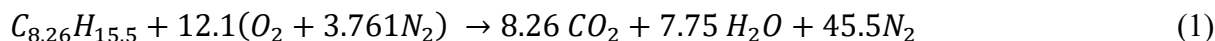
A quasi-uniform volumetric plasma release causes "volumetric ignition" of chemical reaction in the bulk fuel/air mixture. Plasma and expanded volumetric discharge maximise plasma-fuel/air mixture interaction and reactivity. Select a plasma and liquid turbulence rich air-fuel mixture for the most efficient chemical reaction. Based on the air-fuel ratio, the oxygen-carbon (O/C) ratio can be anywhere from 1 for stoichiometric Partial oxidation to 2 for (CH₂)_n liquid hydrocarbon fuels. The optimal O/C ratio for stacking is 1.2, however 1 is acceptable. Reformer efficiency and gas composition as a function of operating factors (pressure, temperature, air-to-ratio, input flow rates) are of primary interest at present.

5. Thermodynamics Analysis

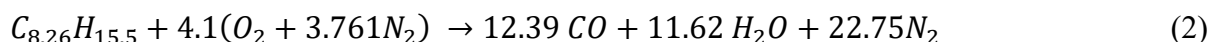
This investigation evaluates the thermal efficiency of a plasma fuel reformer (PFR) using Partial oxidation (POX) reforming thermodynamics. In a combination of air and fuel, the PFR generates plasma with varying electron, ion, and gas temperatures. Plasma enhances Partial oxidation of gasoline fuel in reformers. The application pertains to PFRs, but excludes chemical kinetic effects of ions, making it applicable to different systems. The research solely considers plasma's impact on conversion efficiency by include electrical power in the definition.

6. Result and Discussion

The plasma fuel reformer (PFR) generated hydrogen moles, carbon monoxide moles, plasma discharge's electric power added to the gas, the hydrogen input flux, the petrol input flux, and the reduced temperature of combustion for each. One mole of gasoline stoichiometric combustion $C_{8.26}H_{15.5}$



One mole of gasoline Partial oxidized $C_{8.26}H_{15.5}$



Data from electrical characterizations have been stored on a personal computer with the help of a numerical oscilloscope and an oscilloscope, The high voltage across the electrodes was successfully measured. A 20 KV @ 10 ohm resistance was attached connecting the electrode in question while the secondary electric circuit, and the voltage was measured with a high voltage probe to determine the spark plug excessive voltage electric current. To calculate how much gasoline was transformed into hydrogen, carbon monoxide, and light hydrocarbons by the plasma reactor, we need to know the conversion rate.

6.1 Non-thermal plasma gasoline Partial oxidation hydrogen-rich gas production chemical reaction

Calculate molar fluxes by monitoring dry gas volume flow at output and element product ratios (H_2 , CH_4 , CO , CO_2 , and overall hydrocarbon absorptions). The CO/CO_2 ratios Non-thermal plasma reformation. The initial set of tests have been performed under non thermal circumstances with a fuel input power of 20 kv. The various experimental outcomes are presented in Table 2. Maximum hydrogen concentration was achieved at a petrol equivalency ratio of 0.10 to 0.68. In Fig. 4, we see how the equivalency ratio of gasoline produced by non-thermal plasma reforming changes as a function of air ratio (from 0.10 to 0.68).

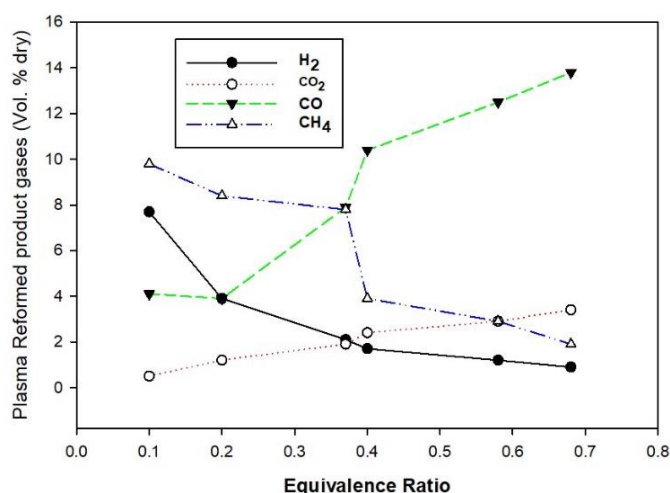


Fig. 4 Evolution of non-thermal plasma reforming dry output gas composition as a function of air ratio

Maximum hydrogen content Excellent Plasmatron plasma reforming, hydrogen 25%, standard plasma Hydrogen 18%, $O_2/C=0.6$ gas, ideal plasmatron 26 percent carbon monoxide, the usual plasma-reformed gas with $O_2/C = 0.16$ percent carbon monoxide, theoretical plasmatron Nitrogen 49%, Typical Plasma-Reformed Gas at $O_2/C = 0.6$, Nitrogen 54%, The Optimal Plasmatron Carbon Dioxide 0%, Typical Plasma-Formed Gas at $O_2/C = 0.6$, $CO_2 = 12\%$

Theoretical and Experimental operational of gasoline fuel for plasma fuel reformer operation @ mass flow rate 0.45 kg/ hr

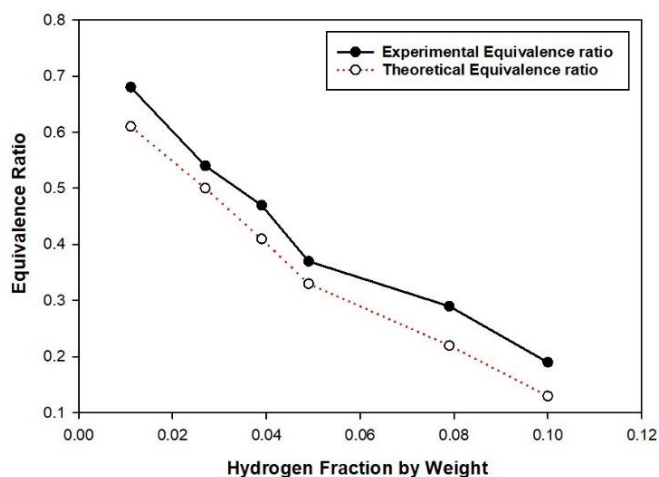


Fig. 5 Equivalence ratio between theoretical and experiment as a function of fuel hydrogen content

As seen in Fig. 5, as the gasoline and rich air ratio increases, the plasma fuel reformer produces a higher concentration of hydrogen rich gas that is converted.

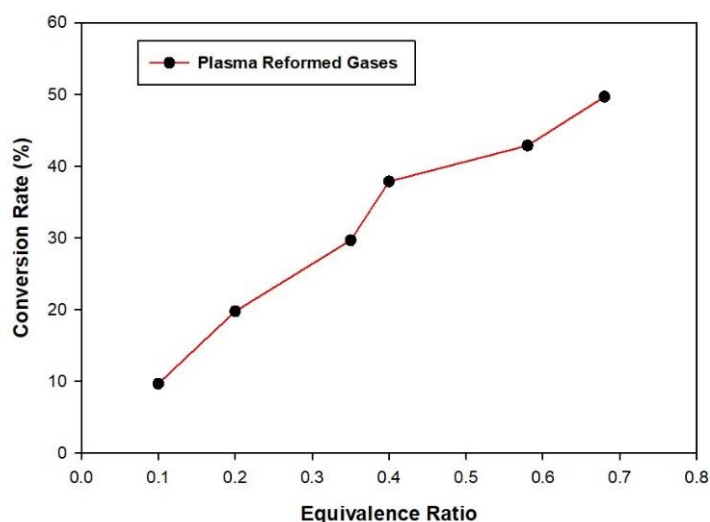


Fig. 6 Non-thermal reforming circumstances and the subsequent evolution of the conversion rate Relative value

The reformer effectiveness shifts in direction as the CO concentration and rises together through the air ratio, reaching a maximum of 12.3% with an air ratio of 0.1 to 0.68 (Fig. 6). Reformer efficiency and conversion rate both improve while operating at a higher temperature while using a greater air-to-fuel ratio.

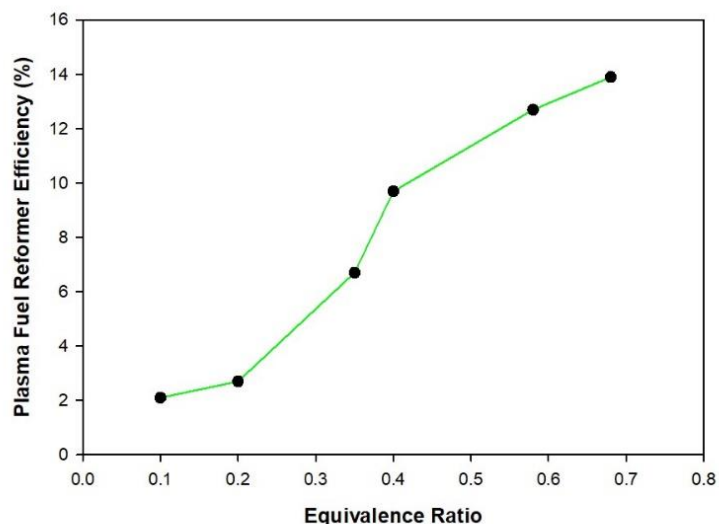


Fig. 7 Efficiency fluctuations in a reformer under non-thermal reforming settings as a function of air ratio

6.2 Non-thermal plasma gasoline reforming's chemical efficiency,

Nearly 15% of fuel heating system value is released during Partial oxidation. The equilibrium gas species from the POX reaction (Eq. 2) is illustrated in Table 2.

Equivalence Ratio (λ)	Fuel Power Supply	Fuel Pressure in (bar)	H ₂	CO	N ₂	CO ₂	H ₂ O
0.4	20 kv @ 10 ohms	1.5	16.97	15.87	63.87	0.89	2.89
0.5	20 kv @ 10 ohms	1.5	18.84	16.47	59.81	1.39	4.77
0.6	20 kv @ 10 ohms	1.5	19.99	16.79	56.14	1.48	6.67

Reformer efficiency and conversion rate improve with increasing temperatures and high air ratios, with a maximum efficiency at non plasma operating temperature 1110 K

Conclusion

The data stipulated here are from the development of a non-thermal plasma reactor for gasoline reforming.

This work aimed to design a compact plasma reformer for fuel cells, GDI Engine, use and establish hydrogen production using non-thermal plasmatrons. The plasmatron's large effective discharge volume increases chemical reaction efficiency in a low-current plasma arc system with spark plug first and second electrodes. Plasma discharges efficiently ignite at many radial and axial positions due to their comparatively long pathways along the primary direction of flow. Low oxygen/fuel ratios can limit Partial oxidation reactions, hence various radial and axial sites along the flow axis enable fuel/air mixture reaction initiation.

Ideally, gasoline is atomized and introduced from the top electrode center. To atomize the fuel, use the right nozzle design, with or without air assistance. The nozzle can reduce fuel deposition and condensation on electrodes when using liquid hydrocarbons by creating a fine jet of fuel droplets. Spray perspectives of and degrees are suitable.

Non plasma operating temperature 1110 K for a wide fuel power range (Spark energy 20 kv @ 10 ohms), density, and durability. The straightforwardness of the technique and inexpensive cost of materials make it appealing for commercial use.

The AFR, or oxygen-carbon (O/C) ratio, can range beginning 1 for Stoichiometric to rich air fuel ratio of $\lambda = 0.4$, $\lambda = 0.5$, $\lambda = 0.6$, control the gasoline injector Partial oxidation gasoline composition (C_8H_{18}). Non thermal plasma activated to produce the hydrogen-rich gas exhibits volumetric ignite due to Partial oxidative reformation of hydrocarbon fuel.

The performance of non-plasma reformer produce hydrogen rich gas fraction rate by weight 0.10 and conversion rate 54%, plasma fuel reformer efficiency 14 % fuel injection pressure boost efficiency. A significant technological effort is needed to enhance hydrogen output and chemical efficiency in plasma reactors.

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