플라즈마트론을 이용한 디젤 엔진의 배연저감에 관한 연구

기호범*† · 김봉수** · 곽용환** · 김우형** · 임원경** · 채재우**

A Study on Emission Reductions of Diesel Engine Using Plasmatron Fuel Converter

Ho-Beom Ki, Bong-Soo Kim, Yong-Hwan Kwak
Woo-Hyung Kim, Won-Kyung Lim, Jae-Ou, Chae

ABSTRACT

Improvements in internal combustion engine and aftertreatment technologies are needed to meet future environmental quality goals. Plasmatron fuel converters provide a rapid response, compact means to transform a wide range of hydrocarbon fuels (including gasoline, natural gas and diesel fuel) into hydrogen-rich gas. Hydrogen-rich gas can be used as an additive to provide NOx reductions of more than 80% in diesel engine vehicles by enabling very lean operation or heavy exhaust engine recirculation. For diesel engines, use of compact plasmatron reformers to produce hydrogen-rich gas for the regeneration of NOx absorber/absorbers and particulate traps for diesel engine exhaust after-treatment could provide significant advantages. Recent tests of conversion of diesel fuel to hydrogen-rich gas using a low current plasmatron fuel converter with non-equilibrium plasma features are described.

Key Words : Plasmatron, Hydrogen-rich gas, NO_x, PM(Particulate Matter)

기 호 설 명

DE	Diesel Engine	BSU	Bosch Smoke Unit
GC	Gas Chromatograph	POX	Partial Oxidation

1. INTRODUCTION

Diesel engines(DE)are presently the most efficient vehicular propulsion systems. Heavy trucks and buses are powered almost exclusively by diesel engines worldwide. In Europe, diesel powered cars have been increasingly popular. The high reliability of these engines is an additional attractive feature. The diesel engine may become even more widely used in the future. However, significant further progress in diesel emission control is needed. Diesel particulate and nitrogen oxides, the two most troublesome components of diesel exhaust emissions, have adverse impact on urban air. The development of plasmatron has been pursued for the purpose of reducing engine exhaust pollutants by providing hydrogen-rich gas for combustion in diesel engine, as shown in Fig.1

Compact plasmatron fuel converter technology could also be used with NO_x absorber/absorber catalyst and particulate

* 인하대학교 열플라즈마환경기술연구센터
** 인하대학교 기계공학과 첨단환경기술연구실
† 연락저자, plasma5326@inhain.net

traps. NO_x absorber catalyst and particulate traps have been suggested for the decreasing emissions from DE. In order to regenerate the catalyst, a reducing agent is introduced into the exhaust. either directly injected by running the engine fuel rich during the regenerating period. Use of compact plasmatron reformers for generating hydrogen-rich gas for catalyst regeneration could provide important advantage. A schematic diagram of a plasmatron-NO_x catalyst system is shown in Fig.2.

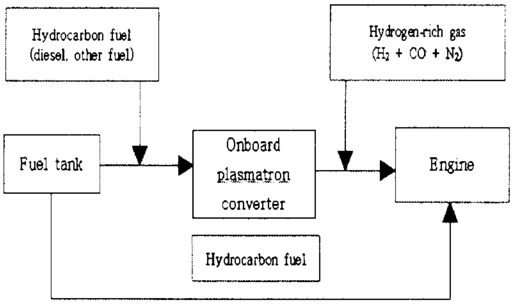


Fig. 1. Low emission concept

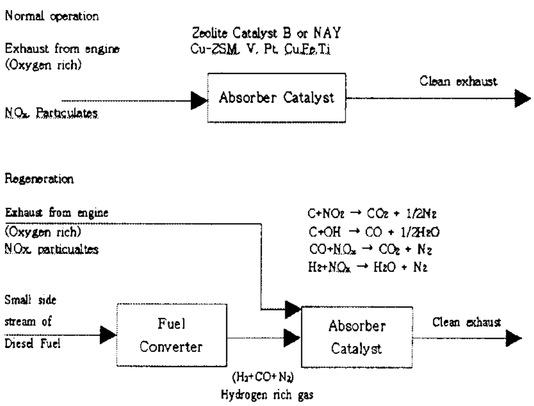


Fig.2. Diesel engine pretreatment concept.

The motivation of many modern researches in the development of advanced engines lies primarily in the field of lowering exhaust emissions. The main problem for DE is strong emission of soot and NO_x.

This technical paper summarize possibilities for use of compact plasmatron fuel converter for onboard-hydrogen generation that could provide new opportunities for improved diesel engine emissions control. Substantial improvements in DE efficiency through hydrogen enhanced lean burn may also be possible. The utilization of hydrogen mixture to the commercially available fuels would allow to increase the thermal efficiency of engine, reduce the cyclic variability and therefore to utilize the lean mixture.

2. EXPERIMENTAL METHOD AND CONDITIONS

Plasmatron fuel converters provide electrical discharges in flowing gases of hydrocarbon fuel and air. The resulting generation of reactive species in the flowing gases along with increased mixing accelerates reformation of hydrocarbon fuel into hydrogen-rich gas. Plasmatron fuel converters may also be utilized for increasing the gas stream enthalpy, further accelerating the reaction rates. These conditions facilitate the reforming of a wide range of hydrocarbon fuels into hydrogen-rich gas.

In this case there is just enough oxygen around to converter all the carbon in the fuel into CO. The partial oxidation reaction is exothermic. In the case of diesel oil, approximately 15% of the heating value of the fuel is released in the partial oxidation reaction.

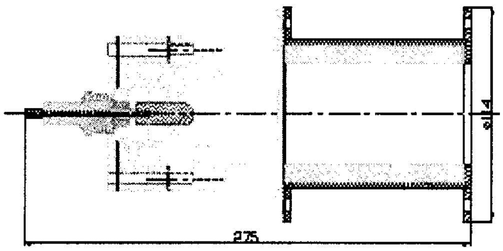


Fig.3. A schematic diagram of plasmatron

As shown in Fig.3, plasmatron consists of an anode (steel, cone-shaped form), cathode (automobile suppository), chamber of submission of a fuel mixture. The device operates at atmospheric pressure, with air as the plasma forming gas. Table 1 shows the parameters of a first generation fuel converter using a low current compact plasmatron. Typical electrical power levels are a few hundred Watts, on the order of 1-2% of the heating value power of the fuel that is processed by the plasmatron fuel converter.

Table 1. Parameters of plasmatron

Descriptions	parameter
Diameter x Length	114 x 275mm
Weight	2.5kg
Power	50-500W
Current	1-2A

Table 2. Specification of experimental engine

Description	Specification
Type	4 Cycle Water cooled precombustion Chamber Diesel Engine
No. of Cylinder	1
Piston Displacement	0.358 liter
Bore x Stroke	78 X 75 [mm]
Compression Ratio	24.9
Rated Power	5/2200[PS/rpm]
Maximum Power	6/2400[Ps/rpm]
Injection Timing	BTDC 10°
Fuel Injection Pressure	13.73 MPa
Injection Nozzle	Pintle Nozzle[1xΦ1mm]

The installation consists of plasmatron, extension reactor, cooling chamber, high-voltage discharge power supply, and flow meter for both fuel supply and air. Plasmatron consists of an anode(steel, cone-shaped form), cathode(automobile suppository), chamber of submission of a fuel mixture. Table 2 shows the specification of diesel engine has been used in experimental work.

3. RESULTS AND DISCUSSIONS

3.1 Partial oxidation (POX)

The POX mechanism uses fuel and oxygen to produce hydrogen by utilizing lower stoichiometric oxygen. It is easy to start a POX reactor quickly due to the high exothermicity of POX. Therefore, it is appropriate for small systems. However, the concentration of the hydrogen produced using POX is lower than that of using plasmatron.

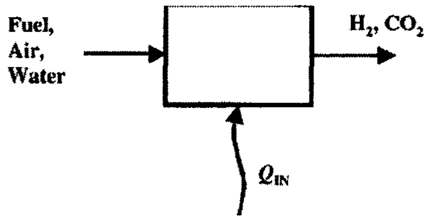


Fig.4 Schematic of the energy control volume used to define the thermal efficiency

The process diagram for evaluating the thermal efficiency is depicted in Fig.4. The fuel, and water enter the reformer and react (completely, we assume)to reform hydrogen and carbon dioxide. The process, as long as sufficient air is provided. In addition, the high temperatures associated with the POX process create difficulties with regard to materials selection.

Ionization:

$$e + A \rightarrow A^{+} + 2e \qquad (1)$$

Dissociation:

$$e + AB \rightarrow A + B + e \qquad (2)$$

Dissociative Recombination:

$$e + AB^{+} \rightarrow A + B^{*} \qquad (3)$$

Dissociative Electron Attachment:

$$e + AB \rightarrow A + B^{-} \qquad (4)$$

Under ideal stoichiometric partial oxidation conditions, the partial oxidation reaction is

$$C_nH_m + n/2\, O_2 \rightarrow nCO + m/2 H_2$$

The partial oxidation balances when n/2 moles of O_2 are provided for each mole of fuel. Partial oxidation systems can be characterized by the oxygen ratio $A=O_2/C$, which is 1/2 for an ideal product mixture of CO and H_2.

The net enthalpy change for the partial oxidation reaction is

$$\Delta H_R = nh^f_{CO} + \frac{m}{2}h^f_{H_2} - \left(h^f_{C_nH_m} + \frac{n}{2}h^f_{O_2}\right)$$
$$= nh^f_{CO} - h^f_{C_nH_m}$$

because the formation enthalpies of elements are zero(by definition). For heptane, the idealized partial oxidation step is exothermic, with an enthalpy changes of $\Delta H_R = -140$ kcal/mol of fuel at the nominal conditions of

298K and 1atm.

3.2 Analysis of syngas(H_2+CO) from plasmatron

At the work of current 2A and initial voltage 500W(air flow 100L/min, fuel~1m/s) are obtained. As it is visible from the reduced data, that in products of decomposing of fuel, the quantity of NO_x is sharply reduced and the contents CO_2 is augmented. For NO_x reduction in DE, the hydrogen-rich gas produced by plasmatron fuel converter is used as an additive. It indirectly confirms weep of reaching such as:

$$CO + NO_x \rightarrow CO_2 + N_2$$

and

$$H_2 + NO_x \rightarrow H_2O + N_2$$

Table 3. Syngas from diesel fuel

Compositions	Concentration, %
H_2	13.29
CO_2	7.02
C_2H_6	3.37
N_2	65.01
CO	8.25
CH_4	1.73

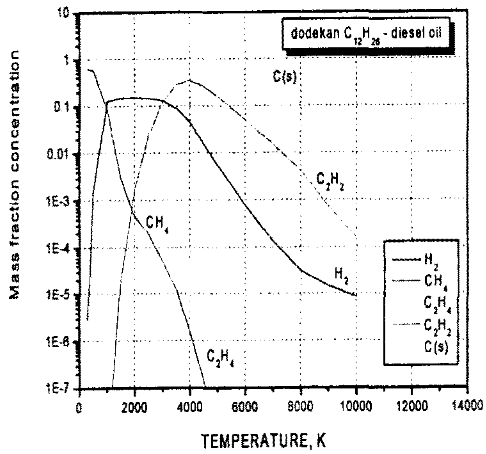
with products of decomposing of fuel (H_2+CO+N_2). Results of decomposing of diesel fuel showing in Table 3.

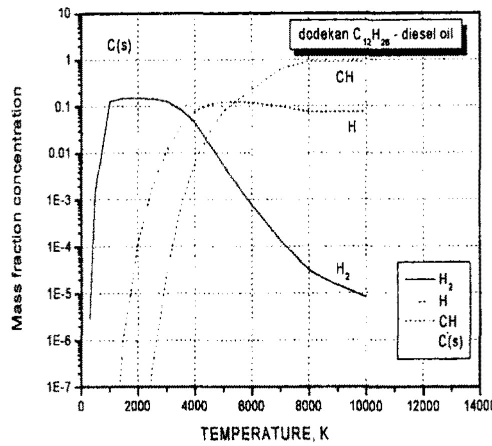
Table 3 shows the optimized results of the tests The best results so far were obtained with near stoichiometric partial oxidation reforming. Very small amounts of methane and carbon dioxide were obtained. These results are preliminary. The reactor design is evolving, with the goals of increasing the recuperation of the heat (regeneration), decreasing heat losses and optimizing the residence time(space velocity).

3.3 Thermodynamic calculation prediction for the fuel reforming

When the hydrocarbon in the liquid or vapor state is heating it is decomposing to the species with a small molecular mass. We used the plasma discharge, where the temperature are very high and we have made a calculation with a program of the thermodynamic equilibrium in the temperature dependence in the range of temperature from 500 to 10000K.

Fig.4 shows the Thermodynamic calculation of reformed hydrogen by heating value to a plasmatron in a test stand. This process the reforming and have been used for the changing the fuel content and it's modification for more good application in any states. A first generation low current plasmatron fuel converter with a hydrogen yield of 75% was employed. For this hydrogen yield it was necessary to process about 35% of the fuel in the plasmatron fuel converter in order to obtain 13% hydrogen addition. The test were carried out in 1-cylinder DE.





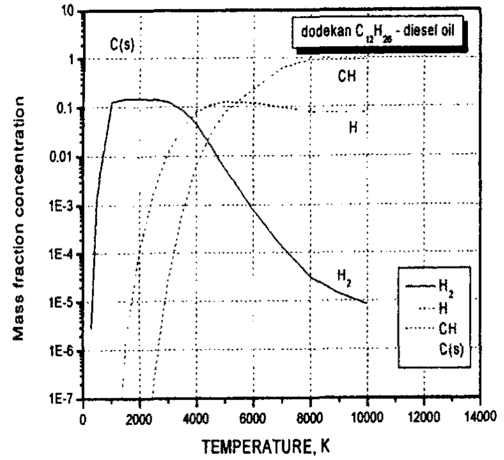


Fig.4. Thermodynamic calculation of reformed fuel by plasmatron

3.4 Plasmatron on diesel engine

In contrast to well established beneficial effects of hydrogen addition in DE. There have not been extensive investigations of the effects of hydrogen on diesel engine operation. However there are some promising indications from the small amount of work that has been done. Hydrogen addition provides more rapid burn because of its high flame speed. Rapid burn could facilitate leaner operation and more complete combustion. Pollution from engine operation could be significantly decreased.

Hydrogen addition has been shown to decrease both PM and NO_X from diesel engine. Hydrogen addition could also facilitate diesel engine cold start. Hydrogen can be injected with the air without ignition due to the low concentration of hydrogen and the high temperature required for hydrogen spontaneous ignition(in the absence of hot spots in the cylinder).

Fig.5, Fig.6, Fig.7. Fig8 shows the variation of optimum hydrogen energy input for the lowest PM and NO_X according to engine speed(rpm) and loads.

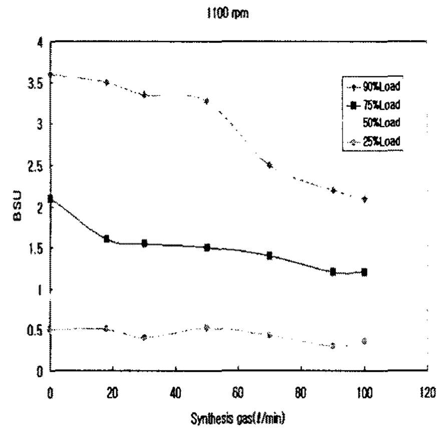


Fig.5 Variation of PM at 1100rpm

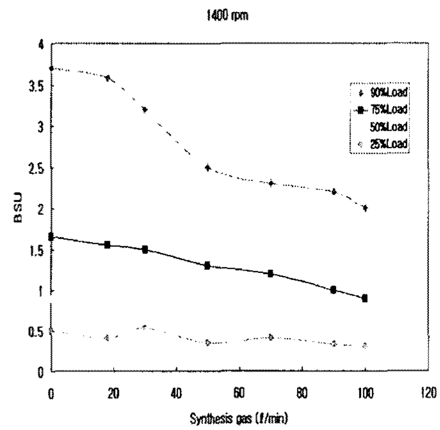


Fig.6 Variation of PM at 1400rpm

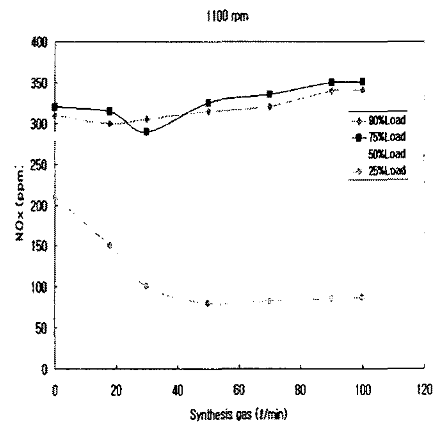


Fig.7 Variation of NO_x at 1100rpm

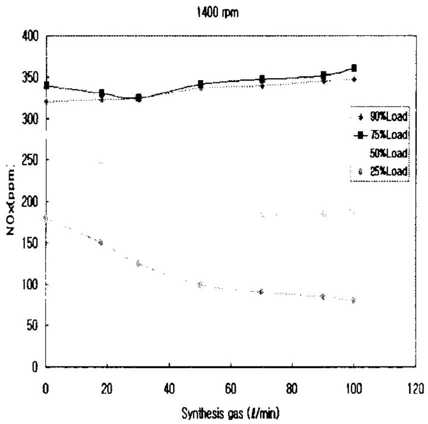


Fig.8 Variation of NO_x at 1400rpm

Overall, the present work has shown the potential of the application of fuel reforming to allow successful in DE. The feasibility of onboard plasmatron fuel converter on DE and it has been shown that potentially the actual reformer hydrogen-rich gas product can be utilized to improve the DE performance and emissions.

4. CONCLUSIONS

The characteristics of plasma reformer are experimentally investigated for diesel engine emission control. Experimental analyses are performed in order to optimize plasma reformer and to find the influence of plasma conditions on hydrogen production. Through GC-TCD analysis, the gas composition after plasma reaction is investigated and the concentration change of hydrogen, carbon-monoxide, and several hydrocarbon species is studied.

1) Characteristics of plasma reformer for diesel emission control are studied. Plasma reformer boosts partial oxidation between diesel fuel and oxygen, which generates hydrogen-rich gas. Plasma reformer has advantages such as rapid response, compact size, and etc.
2) In hydrogen-rich gas generated by plasma reformer, there are carbon monoxide, carbon dioxide, oxygen, the species of hydrocarbon as well as hydrogen. As increase the applied current to the reformer, the concentration of hydrogen increase accordingly.
3) Through this study, the basic characteristics of plasma reformer were studied, and the engine experiment with this reformer will be done in the laboratory in the next step for investigating the removal efficiency of NO_x and of PM at each driving conditions of diesel engine.

ACKNOWLEDGEMENTS

This work was supported by the Regional Research Center for Environmental Technology of Thermal Plasma (ETTP) at Inha University designated by MOCIE (2006)

REFERENCES

[1] Chmela F.G., Kapus P.E. Automotive Engines for Alternative Fuels. // "Advanced Engine Technology for Low Emission" Proceedings of 1995 Seoul Motor Show Seminar, PP.1-14.
[2] Kyaw Z.H., Watson H.C. Hydrogen Assisted Jet Ignition for Near Elimination of NOx and Cyclic Variability in the S.I. Engine.//. 24th Symp. (Int.)on Combustion; the Combustion Institute, 1992,pp.1449-1455.
[3] Karpov V.P., et.al. // Joint meeting of Russian and Japanese sections of Combustion Institute. Chernogolovka, Moscow Region, 1993, p.79.
[4] Goussak L.A., Karpov V.P. // Arch. Termodynamiki I Spallania, 1978, Vol.9, N2, p.347.
[5] Shmelev V.M. // Problemi mashinostroenija I avtomatizatzii, 1999, N2, p.39-47.
[6] Ramos J.I. International Combustion Engine Modeling. //HPB, New York, 1989,p.422
[7] Bromberg L, Cohn DR, Rabinovich A, Alexeev N. Plasma catalytic reforming of methane. Int J Hydrogen Energy 1999;24:1131
[8] Cohn DR, Ravinovich A, Titus CH, Bromberg L. Near term possibilities for extremely low emission vehicles using on-board plasmatron generation of hydogen. Int Hydrogen Energy 1997;22:715
[9] James EP, Wagner GJ, Epling WE, sanders MS, SCONO$_x$ TM and SCOSO$_x$TM sorbate catalyst. SAE paper