Oxyhydrogen Gas Mixtures Application for Recovery of Diesel Particulate Filters

Evgeni Dimitrov [1, a)], Deyan Deltchev[2, b)] and Alexander Tsankov[2]

[1] Department of Combustion Engines, Automobile Engineering and Transport,
Faculty of Transport, Technical University of Sofia
8, Kliment Ohridski Blvd., 1000 Sofia, Bulgaria
[2] New Energy Corporation Ltd
26, Nesho Bonchev, 1000 Sofia, Bulgaria

a) Corresponding author: etzd@tu-sofia.bg
b) d.deltchev@newenergycorp.eu

Abstract. The article presents a technology for the recovery of diesel particulate filters (DPF) by means of an oxyhydrogen gas flame. The technology is developed and implemented by New Energy Corporation. The technology is carried on a disassembled DPF from engine exhaust system. The technological process involves activities such as: control of the initial technical condition of the contaminated DPF and preparations for recovery procedure; procedure for DPF recovery; control of DPF technical condition after recovering. The effectiveness of the applied technology has been tested in the laboratory base of the Technical University of Sofia, Department "Combustion engines, automotive engineering and transport". The experimental test includes a quantitative assessment of the change in exhaust gases opacity and other indicators of a single-cylinder diesel engine operated without DPF, with contaminated DPF and with DPF after recovery.

INTRODUCTION

Oxyhydrogen gas mixtures (HHO) contain hydrogen and oxygen, which are in volume ratio two to one. Discoverer of the HHO is the Bulgarian Yul Braun, whose real name is *Iliya Valkov*. In this regard, oxyhydrogen gas mixtures are also known as "*Brown's Gas*" (BG). Most often, BG is produced by electrolysis of water solution of potassium (*KOH*) or sodium (*NaOH*) hydroxide. The ionic current between the electrodes is formed by the positive potassium K^+ or sodium Na^+ ions and the negative hydroxide ions OH^-. The electrolysis is made in the working cells of the HHO generator by the following chemical reactions [1-3]:

$$H_2O + electrical\ \ energy \to H_2 + \frac{1}{2}O_2; \tag{1}$$

$$Anode\ \ (+): 2OH^- \to \frac{1}{2}O_2 + N_2O + 2e^-; \tag{2}$$

$$Cathode\ \ (-): 2H_2O + 2e^- \to H_2 + 2OH^-. \tag{3}$$

$$Overall: 2H_2O \to 2H_2 + O_2. \tag{4}$$

One of the applications of Brown's gas is as an additional fuel for the internal combustion engines (ICEs). Both in petrol and diesel engines, oxyhydrogen gas mixture is fed continuously into the engine intake system. Operation of ICEs with added oxyhydrogen gas mixture depends significantly on: HHO flow rate, efficiency of HHO generator and the source of electrical energy for water electrolysis. Most of the studies [4-8] found an improvement of fuel consumption and ecological performance of the engine operated with additional oxyhydrogen gas mixture. However, the authors have unpublished experimental results that show worse effective performances of diesel engine on its operation with oxyhydrogen gas mixture and HHO generator power supply from the engine electrical sources.

Characteristically, the oxyhydrogen flame has adaptive features, meaning that it has the ability to change its thermal characteristics when in contact with different substances [9]. The Brown' gas exhibits low temperature flame. However, this flame can vaporize tungsten [10]. In this regard, oxyhydrogen mixtures are used in technological processes such as: welding, cutting, melting and parts cleaning [9, 11 and 12]. It should also be pointed out that there are extensive research studies on the application of Brown's gas in medicine [13].

Modern internal combustion engines are subject to increasingly stringent requirements regarding the concentration of toxic components, greenhouse gases and particulate matters in exhaust gases. To meet these requirements, different systems are used to neutralize the toxic components contained in the exhaust gases of internal combustion engines [14-16]. Reduction of particulate matters content in the exhaust gases of diesel engines is achieved by means of particulate filters (DPF). The main part of the particulate matters is soot, i.e. free carbon in dispersed state. The particulate filter is limited in size and the accumulated soot must be removed periodically. In operating conditions, the removal of the soot accumulated in the DPF is carried out by regeneration of the filter. Oxidation reactions related to the burning of the soot take place during DPF regeneration. Regeneration can be passive or active.

After a long operation period, a certain amount of soot and oil deposits accumulate in the filter. These accumulations cannot be removed by filter regeneration. In such a case, it is necessary to restore the operability of the filter. Most often, the recovery of DPF operability is accomplished by way of washing with special detergents. Washing is performed in special service benches. Removal of deposits can also be done in special furnaces.

PURPOSE OF THE ARTICLE

The purpose of the present paper, in light of the foregoing, is to advance a technology that was developed in the company "New Energy Corporation" for the recovery of diesel particulate filters by means of an oxyhydrogen gas flame.

DESCRIPTION OF THE TECHNOLOGICAL PROCESS

The technology for DPF recovery is based on the properties of the oxyhydrogen flame and is applicable for DPF that is removed from the engine exhaust system. The technological process includes the following activities:

- Control of the initial technical condition of the contaminated DPF and preparation to recovery procedure.
- Recovery procedure.
- Control of DPF technical condition after recovery procedure.

The initial technical condition of the contaminated DPF is controlled by visual inspection, measuring the mass and checking the particulate filtration efficiency of the filter. Closer visual inspection reveals cracks and defects in the integrity of the filter. *Maktronic MK-30A* precision scales are used to measure the weight of the filter with an accuracy of 5 g. The clogging of the filter is controlled by connecting it to a vacuum system. The pressure drop of the contaminated DPF should also be measured. Before the recovery procedure, all DPF sensors must be disassembled, and provisions should be made for an easy access to the filter element– Fig. 1. The appearance of a contaminated particulate filter is shown in Fig. 2.

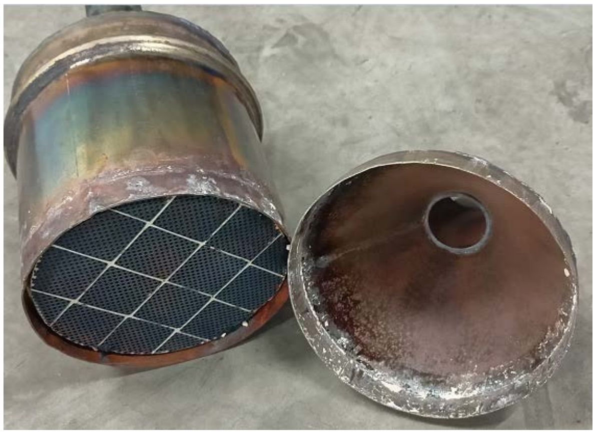

FIGURE 1. Prepared for recovery DPF

FIGURE 2. Appearance of a dirty filter element

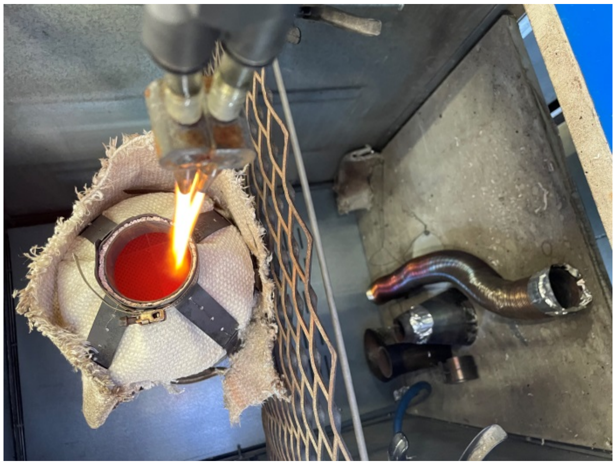

FIGURE 3. Recovery procedure

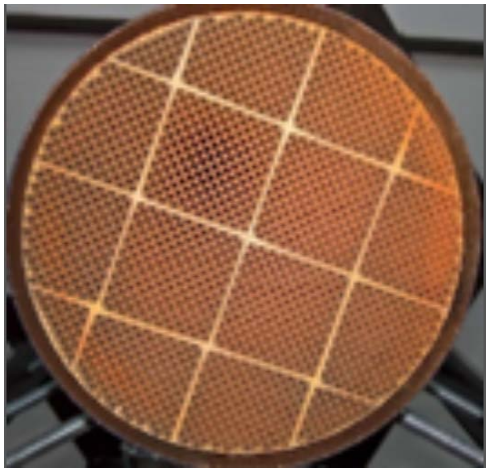

FIGURE 4. Outward appearance of a recovered filter element

The procedure for recovery of contaminated DPF is performed on a stand. The main part of the stand is a generator of oxyhydrogen gas mixture *VST - 12C*. The functional features of the HHO generator are described in [6]. The prepared DPF is setting in a heat-resistant adjustable cone. The outlet of the particulate filter is connected to the stand exhaust system. A special gas burner is positioning above the heat-resistant cone. There are registered utility models for the generator and the burner. The recovery procedure is performed with an oxyhydrogen gas flame – Fig. 3. The flame must not touch the filter element. During the recovery procedure, the temperature in the chamber of the heat-resistant cone is maintained within 830 ± 10 ^{o}C. At this temperature there is an optimal course of the recovery processes in the DPF. The temperature of gases on DPF outlet is also controlled. In the normal course of the recovery processes, this temperature is in the range of 350-400 ^{o}C. The recovery procedure continues until the temperature of the gases leaving DPF begins to decrease gradually. At this point, the filter element has an orange-red colour, with a tendency to darken – Fig. 3. When the inside of the filter element darkens, the burner is removed and the supply of HHO is stopped. After the oxyhydrogen flame is extinguished, the particulate filter is gradually cooled to ambient temperature. The outward appearance of the recovered filter element is shown in Fig. 4.

At the completion of the recovery procedure, all sensors and removed elements are re-assembled to the DPF body, i.e. the particulate filter is brought to its original equipment. The control of the technical condition of the recovered DPF is carried out by measuring its mass and its permeability. They technical devices are the same as those used for the initial control of the DPF technical condition.

CHECKING THE EFFECTIVENESS OF TECHNOLOGY

Verifying the efficiency of the technology for DPF recovery by oxyhydrogen flame has been made by comparing the effective performance of a diesel engine in its operation without DPF, with contaminated DPF and recovered DPF. The test object is a four-stroke single-cylinder air-cooled diesel engine DV-550. Some of the parameters of the engine are: cylinder bore D = 91,5 mm; stroke S = 85 mm; compression ratio ε = 17,5; direct fuel injection and partially stratified mixture formation; rated effective power N_e = 8 kW at speed n = 3000 min^{-1}.

The comparison has been made in a test laboratory 28 kW at the Department "Combustion Engines, Automobile Engineering and Transport", Technical University of Sofia. The setup of the test bench is displayed in Fig. 5. The laboratory is equipped with direct-current dynamometer *SAK 28*, which has a maximum braking power of 28 kW at a speed of 4000 min^{-1}. The power indexes of the engine are measured via a dynamometer and a volume flow meter is used to determine the fuel consumption B_h and the brake specific fuel consumption b_e. The flow meter operates by measuring the time necessary for a known volume of liquid fuel to enter the engine. The volume of fuel is measured with accuracy of 0,2 cm^3. The ecological performance of the engine is measured with a gas analyzer "*Texa Gasbox*" (Italy). The exhaust gas opacity R_h is measured using the "*Hartridge*" method with a "*Tecnotest* 495/1" smoke meter (Italy), with an accuracy of 0,1%. The engine exhaust gas temperature is measured with a thermocouple (type - *K*) and a digital thermometer with an accuracy of 1 °C. The thermocouple is mounted on the engine exhaust pipe, 100 mm away from the engine exhaust manifold flange.

FIGURE 5. Appearance of the experimental setup

The research methodology involves the registration of three load characteristics of the engine at speed - n = 2000 min^{-1}. The first characteristic is basic, i.e. operation of the engine without DPF. The other two characteristics are taken with DPF as part of the engine exhaust system. In the second characteristic, the particulate filter is dirty. In the third characteristic, the engine operates with restored DPF in its exhaust system. To bring the test results together, the characteristics data are taken by the following conditions: the same adjustment (according to manufacturer prescriptions) of the engine fuel system; the same engine thermal conditions; uniform atmospheric conditions, i.e. the characteristics data is obtained and collected on one and the same day.

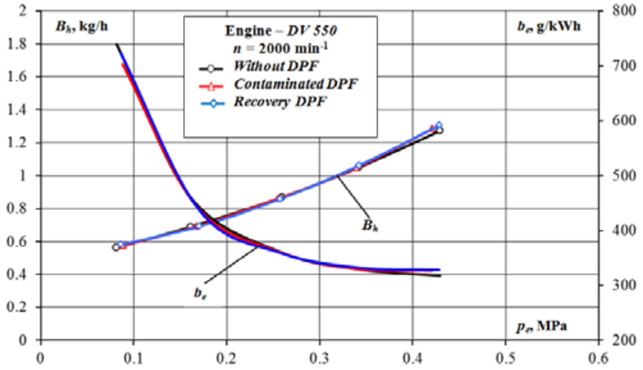

FIGURE 6. Comparison of `fuel consumption B_h and brake specific fuel consumption b_e of a *DV 550* diesel engine at speed n = 2000 min^{-1}, variable load and operation: without DPF, with contaminated DPF and with DPF after recovery

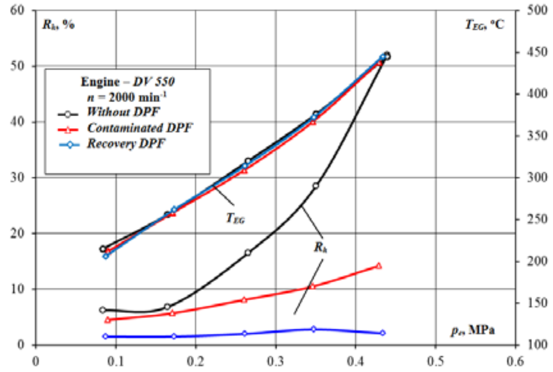

FIGURE 7. Comparison of exhaust gas opacity R_h and exhaust gas temperature T_{EG} of a *DV 550* diesel engine at speed n = 2000 min^{-1}, variable load and operation: without DPF, with contaminated DPF and with recovery DPF

Some of the experimental results are shown in Fig. 6 and Fig. 7. Their analysis shows the following:

- The presence of DPF in the engine exhaust system does not significantly affect its economic performance. The differences between the fuel consumption B_h and the brake specific fuel consumption b_e (in all the three modes of operation) are within the measurement accuracy.

- The changes in the engine exhaust gas temperature, operating with and without a DPF, are insignificant – within 3%.
- When the engine operates with a DPF, the engine exhaust gas opacity is extremely lower. At high loads, the decrease in the exhaust gas opacity is 25 times lower in cases when the engine operates with a recovered DPF as against that of the engine operating without a DPF. In the same modes (high loads) and operation of the engine with a contaminated DPF, the decrease in the exhaust gas opacity is 3,6 times lower as opposed to that of the engine operating without a DPF.
- The greater reduction in the exhaust gas opacity of the engine operating with a recovered DPF proves the effectiveness of the technology for particulate filter recovery accomplished through the use of oxyhydrogen gas mixtures.

CONCLUSIONS

In light of the foregoing, the following conclusions can be drawn:

1. The application of oxyhydrogen gas mixtures in the recovery of particulate filters ensures full restoration and regeneration of their working capacity.
2. The presence of a particulate filter secures very low levels of the diesel engine exhaust gas opacity.
3. The availability of DPF has a negligible effect on the economic performance and exhaust gases temperature range of diesel engines.

REFERENCES

1. Y. Wu, Ch. Xie, A. Burke, H. Zhao, M. Miller, and S. Warner, “Experimental Investigation of Producing Brown's Gas using a Metal-Plate Electrolyzer for Diesel Vehicle Applications”, in *Energy Technoly*, **5** 2 (2017), pp. 244-252.
2. B. Sivakumar, S. Navakrishnan, MR. Cibi and R. Senthil, “Generation of brown gas from a dry cell HHO generator using chemical decomposition eaction” in *IOP Conf. Series: Materials Science and Engineering* **1130** 012002 (IOP Publishing, 2021), doi:10.1088/1757-899X/1130/1/012002.
3. A. Sudrajat, E. Handayani, N. Tamaldin, A. Yamin and G. Tribo “Principle of generator HHO hybrid multistack type production technologies to increase HHO gas volume”, in *SHS Web of Conferences* **49** 02016 (ICES, 2018), https://doi.org/10.1051/shsconf/20184902016.
4. T. Nabil, “Efficient Use of Oxy-hydrogen Gas (HHO) in Vehicle Engines”, in *Journal Europeen des Systemes Automatises*, **2** 1 (2019), pp. 87-96, https://doi.org/10.18280/jesa.520112.
5. E. Leelakrishnan, N. Lokesh, H.Suriyan, “PERFORMANCE AND EMISSION CHARACTERISTICS OF BROWN’S GAS ENRICHED AIR IN SPARK IGNITION ENGINE”, in *International Journal of Innovative Research in Science, Engineering and Technology*, **2** 2 (2013), pp. 393-404.
6. E. Dimitrov, D. Deltchev, V. Serbezov and S. Pantchev, “Research of oxyhydrogen gas mixture influence upon diesel engine performance”, in *MATEC Web of Conferences* **133** 04001 (2017), doi: 10.1051/matecconf/201713304001.
7. N. Chraplewska, K. Duda, M. Meus, “EVALUATION OF USAGE BROWN GAS GENERATOR FOR AIDED ADMISSION OF DIESEL ENGINE WITH FERMENTATIVE BIOGAS AND PRODUCER GAS”, in *Journal of KONES Powertrain and Transport*, **18** 3 (2011), pp. 53-60.
8. K. Ambarev, “Experimental study of diesel engine at work with Brownian gas”, in *Machine Mechanics*, **2** 115, (Technical University Varna, 2016), pp. 24-27, (in Bulgarian).
9. Y. Lee, S. Lee, B. Jeong, H. Mok and G. Choe, “Development of a Welding Machine System Using Brown Gas by Improved Water Electrolyzation”, in *Journal of Power Electronics*, **5** 4 (2005), pp. 305-311.
10. M. King, “Water Electrolyzers and the Zero-Point Energy”, in *Physics Procedia* **20** (Elsevier, 2011) pp.435–445, doi:10.1016/j.phpro.2011.08.038.
11. K. Borse, J. Chavan, A. Ingale, K. Jejure, S. Bakal. “Water powered hydrogen gas welding & cutting”, in Proceedings of the **“***7th International Conference on Science*, *Technology* and *Management*”, (Guru Gobing Singh Polytechnic, Nashik, 2017), pp. 214-218.
12. P. Kumar, K. Prabha, Ch. Priyadarsini and S. Swetha, “Development and Applications of HHO Water Based Flame Torch”, in *International Journal of Recent Technology and Engineering*, **7** 6S (2019), pp. 515-517.

13. E. Mohaupt, P. Madl, "Brown's Gas for Health: Background, Observations and Medical Data", in WATER **11** (2020), pp. 109-131.
14. P. Dimitrov, *Process control systems for internal combustion engines (Part I)*, (Technical University of Sofia, 2015), pp. 252-266, (in Bulgarian).
15. K. Reif, *Dieselmotor-Management* (Springer Vieweg, 2012), pp. 374-384.
16. P. Dimitrov, *Process control systems for internal combustion engines (Part II)*, (Technical University of Sofia, 2015), pp. 151-159, (in Bulgarian).