The Use of Hydrogen in as an Additive to Diesel Fuel on Autonomous Locomotives

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Abstract: The article discusses the option of using hydrogen on autonomous locomotives. A comparison of the efficiency of the main types of fuel is made and a choice is made in favor of hydrogen, which differs significantly from diesel fuel and other hydrocarbon fuels in three important physical and chemical parameters of combustion: the required combustion speed, ignition energy and the limit of flammability. There are three main ways of using hydrogen as fuel for diesel engines of autonomous locomotives. The most promising method is to supply gas to the cylinders of a diesel locomotive together with the charge air. To ensure reliable operation of a diesel locomotive when supplying hydrogen, a layout diagram with a developed hydrogen generator, a system for preparing and supplying hydrogen, as well as a system for measuring the parameters of a diesel locomotive with a hydrogen generator is presented.

1 INTRODUCTION

In Russia, the consumption of motor fuels annually amounts to more than 100 million tons, diesel fuel accounting for about 55 million tons. At the same time, railway transport is one of the most energy-intensive areas of industrial production, annually consuming up to 6% of diesel fuel (Gapanovich, 2012; Grigorovich, 2013; Kavtaradze, 2011).

In the conditions of limited reserves of oil fuel and its constant rise in price, the issue of using alternative fuels for JSC "Russian Railways" is relevant.

The reserves of hydrogen on earth are practically unlimited, so it is reasonably recognized as the fuel of the future. Hydrogen is not a fuel, but an energy carrier, since it is not contained in its pure form in nature. The main advantages of hydrogen: high specific heat of combustion, unlimited reserves and environmental safety (Table 1) (Petukhov, 2020; Nosyrev, 2016; Kamaltdinov, 2008).

In order to reduce the environmental burden on the environment, JSC "Russian Railways" plans to purchase locomotives running on natural gas and other alternative energy sources, namely locomotives with gas-piston, gas-diesel engines, as well as locomotives running on hydrogen fuel beginning with 2025. By 2030, it is planned to convert 25% of the fleet to gas (Kamaltdinov, 2008; Nosyrev, 2020; Fontana, 2002; Shudo, 2002).

The increased interest in the development of power plants based on hydrogen fuel cells makes it urgent to develop existing systems for generating hydrogen.

Table 1: Comparison of the efficiency of the main types of fuel.

Fuel type	Specific heat of combustion, MJ/kg	CO_2 emissions, kg	Cost, rub/m3
Hydrogen	120	0	27858
Natural gas	46	2.8	5,28-6,29
Diesel fuel	41	3.16	24190

There are several ways to produce hydrogen, including chemical reactions (Figure 1).

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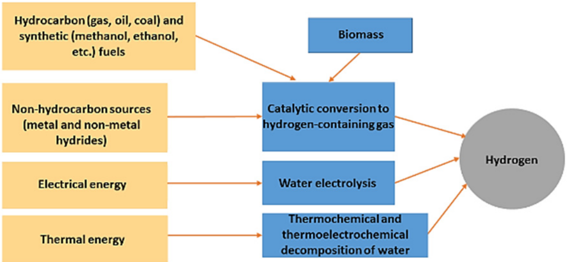

Figure 1: Methods for producing hydrogen.

2 EXPERIMENT

One of the problems of using hydrogen in power plants on autonomous locomotives is its placement and storage directly on board.

The most acceptable method of producing hydrogen, taking into account the minimum energy consumption, safety of operation and adaptability in heavy operating conditions of autonomous locomotives, is the use of an on-board hydrogen generator, which implements the chemical reaction of aluminum hydrolysis in aqueous solutions of salt alkalis.

The hydrolysis reaction is described in this case by the equation:

$$2AI + 2NaOH + 2H_2O \rightarrow 2NaAlO2 + 3H_2\uparrow$$

The resulting hydrogen is sent directly to the diesel engine of the locomotive. This eliminates the need to use various types of storage systems for hydrogen on board.

Tests carried out on the D-242 diesel engine in the laboratory "Locomotive Power Plants" of the FGBOU VO "SamGUPS" showed that the addition of hydrogen to diesel fuel in an amount of 2-5% increases the completeness of combustion and reduces the levels of emissions of harmful substances CH, CO, and also reduces the specific effective fuel consumption ge (Petukhov 2020). Increasing hydrogen volume fraction in the fuel mixture by more than 5% is not practical, as in this case the combustion temperature will rise and NOx emissions will increase.

The schematic diagram of the system for enriching diesel fuel with hydrogen and its subsequent supply to the internal combustion engine is shown in Figure 2 and includes a circulation circuit of hydrogen-enriched diesel fuel with hydro-mechanical and hydrodynamic mixers (Nosyrev, 2016).

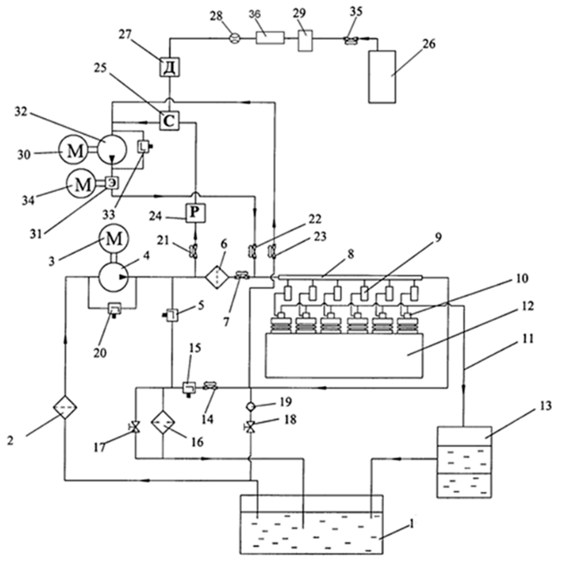

Figure 2: The system of preparation and supply of hydrogen to the diesel locomotive: 1 - fuel tank; 2 – coarse filter; 3,34, – electric motors; 4 – fuel pump; 5 – discharge valve; 6 – fine fuel filters; 7,14,21,22,23,35 – electrically controlled valves; 8 – fuel collector; 9 – high – pressure fuel pump; 10 – fuel nozzle; 11 – drain tube; 12 – diesel; 13 – sump; 15 - back – up valve;16 – fuel heater; 17 – fuel bypass valve; 18 – emergency power tap; 19 – return valve; 20,33 – pressure reducing valves; 24 – fuel flow meter; 25 – hydro – mechanical mixer; 26 – hydrogen generator; 27 – hydrogen dispenser; 28 – hydrogen flow meter; 29 – hydrogen purification filter, 31-hydrodynamic mixer; 32-enriched with hydrogen fuel supply pump , 36-hydrogen tank.

The circulation circuit allows you to enrich diesel fuel with hydrogen, directly during the operation of the diesel engine in the mode of multiple circulation and eliminates the ingress of hydrogen into the fuel tank of the locomotive.

For preliminary mixing of fuel with hydrogen under the action of centrifugal forces, a centrifugal hydro-mechanical mixer is installed in the system.

The main elements of the hydrogen generation system are a chemical reactor, in which hydrolysis is carried out, and a hydrogen storage receiver.

The hydrogen generator solves one of the most complex problems of fuel systems of hydrogen power plants – the problem of supplying the initial components to the chemical reaction zone depending on the diesel's demand for hydrogen, mixing them and clearly regulating the performance of the on-board hydrogen generator by a certain interaction of "working" reagents depending on the diesel load mode (Figure 3).

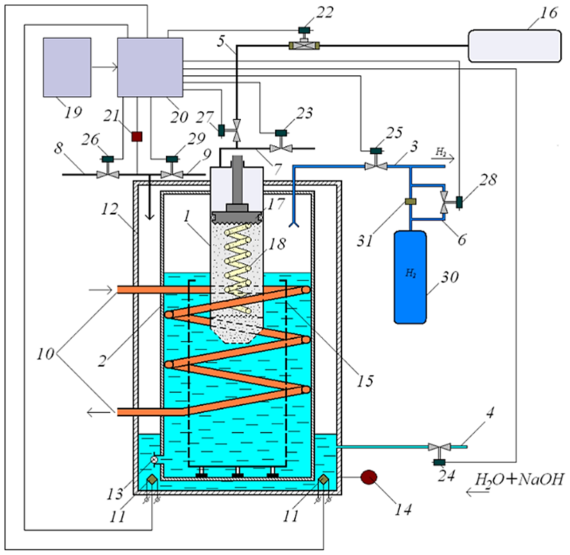

Figure 3: Diagram of the developed continuous-acting hydrogen generator: 1 – pasty reagent, 2 – reaction vessel, 3 – hydrogen delivery line, 4 – liquid reagent supply line, 5 – control line, 6 – bypass line, 7 – control line insert, 8 – boost line, 9 – boost line insert, 10 – heat exchanger, 11 – starting heaters, 12 – bypass tank, 13 – shut – off element, 14 – temperature sensor, 15 – container on legs for collecting reaction products with holes on the side surface, 16 – inert gas cylinder, 17 – piston, 18 – return spring, 19 – software device, 20 – control unit, 21 – pressure sensor, 22 – tunable gearbox, 23, 24, 25, 26, 27, 28, 29 – electrically controlled valves, 30 –consumption capacity, 31–check valve.

The generator is based on a method for producing hydrogen by reacting aluminum with an aqueous solution of alkali (Nosyrev, 2016).

3 RESULTS

To assess the effect of the addition of hydrogen in an amount of 5% on the environmental characteristics of the ChME3 diesel locomotive, tests were carried out in the conditions of the rheostat testing station and the environmental control point of the Samara locomotive depot. Hydrogen was supplied at a pressure of 0.1-0.4 MPa in an amount of 5% by weight relative to diesel fuel.

For the supply of hydrogen, jets with hole diameters of 1.15; 1.51; 2.05 mm were manufactured to control the flow rate at all positions of the driver's controller (PCM) of the locomotive. The test results are shown in Figures 4-6.

The dependences (Fig. 4) show that when the hydrogen consumption increases to 0.85 g/s, the maximum effect of reducing the smoke content is observed.

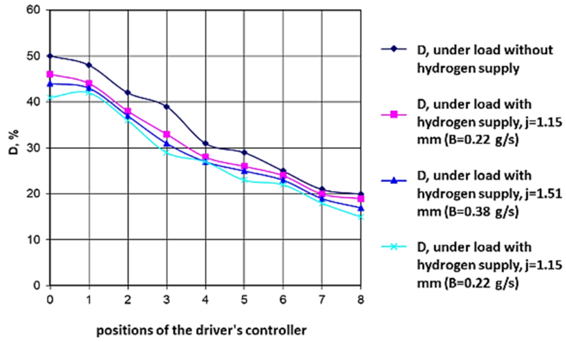

Figure 4: Dependence of the smoke content D on the PCM on diesel fuel and with 5% H_2.

The results of measuring carbon monoxide CO emissions at a hydrogen consumption of 0.22, 0.38, and 0.85 g/s are shown in Figure 5.

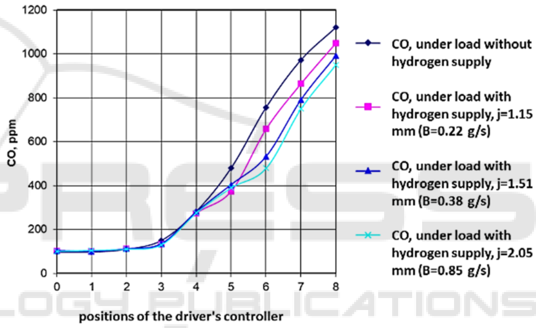

Figure 5: Dependence of CO emission levels on PCM on diesel fuel and with 5% H_2.

As Figure 6 shows, when the hydrogen consumption increases to 0.85 g / s, a significant reduction in CO emissions is observed, which confirms the influence of hydrogen additives on the kinetics of the ignition and combustion processes of hydrocarbon fuels. When hydrogen is supplied, carbon monoxide CO emissions at 0-4 PCM practically do not change, and at 5-8 positions they increased by 16-26%. The results of NOx measurements during the tests carried out under the load of the diesel locomotive ChME3 to assess the effect of the supply of hydrogen to the air receiver are shown in Figure 6.

As can be seen from Figure 6, emissions of nitrogen oxides NOx at 0-4 PCM increase by 2-18%, and at 5-8 positions they decrease by 7-8%, depending on the hydrogen consumption. The reason for the increase in NOx emissions was an increase in the combustion temperature of the fuel-air mixture

(Szwaja, 2009; Shirk, 2008; Caton, 2009; Chintala, 2017; Ji, 2009; Taxon, 2002).

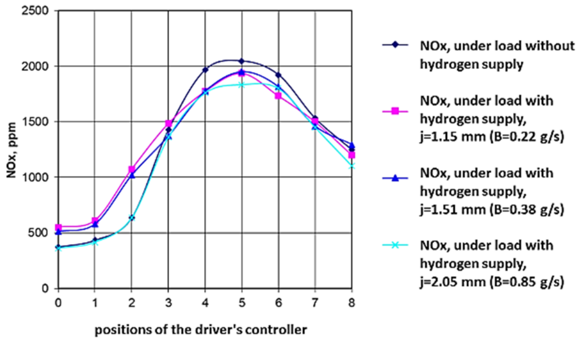

Figure 6: Dependence of NO_x emission levels on PCM on diesel fuel and with 5% H_2.

4 CONCLUSIONS

Thus, the developed hydrogen generator and the experimental work carried out on the use of hydrogen fuel allow us to recommend for JSC "Russian Railways" the use of hydrogen as an additive to diesel fuel, natural gas and to a gas-diesel mixture on autonomous locomotives.

REFERENCES

Gapanovich, V. A., Avilov, V. D., Arzhannikov, B. A., 2012. *Energy saving in railway transport: textbook for universities*. MISiS House. p. 620.

Grigorovich, D. N., 2013. Formation of proposals for the use of hydrogen fuel in railway transport taking into account the analysis of foreign experience. *Bulletin of the Joint Scientific Council of JSC "Russian Railways"*. 6. pp. 37-49.

Kavtaradze, R. Z., 2011. *Thermophysical processes in engines converted to natural gas and hydrogen*. Publishing House of the Moscow State Bauman Technical University. p. 238.

Petukhov, S. A., Lazarev, V. E., Asabin, V. V. et al., 2020. *Resource saving and energy efficiency of diesel engines: monograph.* Samara State University of Railway Transport, Samara: SamGUPS. p. 138.

Nosyrev, D. Ya., Mishkin, A. A., 2016. *Prospects of application of aluminum-hydrogen energy in railway transport: monograph.* Samara: SamGUPS. p. 160.

Kamaltdinov, V. G., Abeliovich, E. V., 2008. Influence of the composition of two-component fuel on the combustion process in an engine with volumetric self-ignition from compression. *Bulletin of SUSU. Series: Mechanical engineering.* 23(123). pp. 46-53.

Nosyrev, D. Ya. et al., 2020. Improving the environmental safety of diesel locomotives by enriching diesel fuel with hydrogen. *Ecology and Industry of Russia.* 24. 5. pp. 51-57.

Fontana, G., Galloni, E., Jannelli, E. et al., 2002. Performance and Fuel Consumption Estimation of a Hydrogen Enriched Gasoline Engine at Part–Load Operation. *SAE Technical Paper Series.* 2002-01-2196. pp. 1-5.

Shudo, T., Ono, Y., 2002. HCCI Combustion of Hydrogen, Carbon Monoxide and Dimethyl Ether. *SAE Technical Paper Series.* 2002-01-0112. pp. 1-6.

Szwaja, S., Rogalinski, K. G., 2009. Hydrogen Combustion in a Compression Ignition Diesel Engine. *International Journal of Hydrogen Energy.* 34. 10. pp. 4413-4421.

Shirk, M. G., McGuire, T. P., Neal, G., Haworth, D. C., 2008. Investigation of a Hydrogen–Assisted Combustion System for a Light-Duty Diesel Vehicle. *International Journal of Hydrogen Energy*. 33 (23). pp. 7237-7244.

Caton, P. A., Pruitt, J. T., 2009. Homogeneous Charge Compression Ignition of Hydrogen in a Single-Cylinder Diesel Engine. *International Journal of Engine Research*. 10 (1). pp. 45-63.

Chintala, V. A., Subramanian, K. A., 2017. Comprehensive Review on Utilization of Hydrogen in a Compression Ignition Engine under Dual Fuel Mode. *Renewable and Sustainable Energy Reviews.* 70, pp. 472-491.

Ji, C., Wang, S., 2009. Effect of Hydrogen Addition on Combustion and Emissions Performance of a Spark Ignition Gasoline Engine at Lean Conditions. *International Journal of Hydrogen Energy.* 34 (18). pp. 7823-783.

Taxon, M., N., Brueckner, S., R., Bohac, S., V., 2002. Effect of Fuel Humidity on the Performance of a Single-Cylinder Research Engine Operating on Hydrogen. *SAE Technical Paper Series.* 2002-01-2685. pp. 1-20.