THE EFFECT OF HYDROGENE ON DIESEL ENGINE SMOKE EMISSION

Ing. Králik, M., Ing. Jablonický, J. PhD., Ing. Kosiba, J., Ing. Hujo, Ľ, PhD., Ing. Angelovič, M.
Department of Transport and Handling - Faculty of Engineering - Slovak University of Agricultural in Nitra

Abstract: *Massive construction of diesel engine enables to use different types of fuels, eventually additives, which enables to reduce basic fuel consumption. Before different alternative fuels use, it is necessary to verify the performing of alternative fuels in diesel engine and their impact on exhaust engine emissions. We found out, using free acceleration measurement that enrichment of intake air with hydrogen results in modest increase of engine smoke emission, which is caused by higher reactivity of hydrogen compared to conventional fuels. Despite this disadvantage, enrichment of intake air results in the engine torque increase, which leads to the fuel consumption reduction.*

Keywords: DIESEL ENGINE, HYDROGEN FUEL, FUEL CONSUMPTION REDUCTION

1. Introduction

1.1 Formation of fuel mixture in diesel engines

The mixture in diesel engines is formed, when fuel is injected directly into the combustion chamber containing hot compressed air with certain preinjection. During injection, the fuel enters combustion chamber of engine formed in fuel beams, where fuel is diffused to very small droplets, sized only a few µm. This enables fuel atomization, which enables better access of fuel droplets to compressed air for easier ignition. After the injection and diffusion, the fuel starts to vaporize, creating heterogeneous mixture, which starts to ignite. Vaporization and combustion of fuel in combustion chamber starts where heat and oxygen have the closest access to the fuel surface i.e. external surface burns and the temperature increases inside of droplets. High temperature and high pressure cause molecules cracking at oxygen deficiency. If the oxygen is not distributed close to the fuel droplets, fuel will not burn, but leaves in exhaust gases formed in fine particles and soot. Time designed for mixture formation in engine combustion chamber is short, causing uneven fuel distribution in combustion engine. Therefore, real air excess in particular area of combustion chamber is different in every moment of combustion. It ranges from $\lambda = 0$ inside of fuel beam during injection to $\lambda = \infty$ in the area without fuel appearance.

1.2 Ignition and combustion of fuel mixture

Hardly vaporized liquid fuel is used in diesel engine, which contacts air in cylinder at the end of compressed stroke right before combustion. The fuel is injected into the air compressed from p_k = 3.5 to 5.5 MPa. Fuel beam is emerged from injection nozzle under the high-speed enters air in compressed area, forming a mixture of the air and diffused fuel. The heat of compressed air, from t_k = 800 °C to 900 °C quickly vaporizes diffused fuel and after the combustible mixture formation, the vapour is ignited from the heat of the air. The course of combustion depends on chemical reactions, heat exchange conditions and substances in the burning zone and heat removal zone, their concentration in the volume and other elements. Therefore, the speed of combustion process is evaluated according to the speed of entering components, respectively heat increasing speed.

Decomposition (cracking, cleavage) of carbon molecules occurs at a complete air deficiency (inside of droplet of liquid fuel) and at the high temperature resulted in carbon non-reaction and carbon solid particles (soot) formation in exhaust gases. These particles, together with carbon (soot) forms monitored diesel engine exhaust emission, which is evaluated such as engine smoke emission. The cause of high carbon leakage is a significant mixture inhomogeneity from $\lambda = 0$ inside of fuel droplets with complete oxygen deficiency to $\lambda = \infty$ in the area without fuel appearance. Therefore, carbon leakage depends significantly on diffused fuel quality at injection to cylinder. Oxygen delivery, necessary for oxidation, improves by increase of total amount of the air in cylinder.

1.3 The process of measurement at exhaust-emission control

Exhaust-emission control of diesel engine is realized according to steps and processes alleged in „Methodical advice for regular of emission control, administrative of emission control and specific of emission control", issued by Ministry of Transport Post and Telecommunications of the Slovak republic. According to fourth chapter of mentioned Guideline, following steps are realized at exhaust-emission control of the diesel engine vehicle:

1. Vehicle and engine identification,
2. Evaluation of controlled variables,
3. Visual control,
4. Engine conditioning,
5. Exhaust-emission measurement,
6. Data and measured values recording.

However, the entire exhaust-emission control is not necessary for our study; the next topic will deal with evaluation of controlled variables, engine conditioning and exhaust-emission measurement.

1.3.1 Evaluation of controlled variables

The variables designed by vehicle producer for the engine type alleged in Vehicle Registration Certificate and identified on vehicle are alleged in service information documents or specialized expert catalogues.

Engine temperature – is the main and significant variable at diesel engine. If the engine temperature is designed by producer, we use this data value; if the temperature variable is not designed, the temperature is evaluated at 80 °C for M_1 and N_1 vehicle category.

Idle rpm (speed) – rpm (speed) range is designed by subtracting of the 50 min^{-1} from the lower bound and by adding of the 50 min^{-1} to upper bound of the toleration band designed by producer.

Maximal engine rpm – the lower range value is presented by maximal power rpm designed by producer. Upper range value is maximal regulated rpm increased by 150 min^{-1}.

Maximal allowable smoke emission value – is a variable calculated as a corrected coefficient of absorption "x_L" increased by 0.5 m^{-1}. If corrected coefficient of absorption "x_L" is not alleged in Vehicle Registration Certificate, service information documents or specialized documents, the smoke emission "D" variable alleged in service information documents or specialized documents is detected.

Dispersion – the dispersion variable is evaluated at 0.5 m^{-1}.

1.3.2 Engine conditioning

The engine is conditioned to operating temperature by higher rpm running, short ride or by other method designed by producer (e.g. free accelerations to medium engine rpm).

1.3.3 Exhaust-emission measurement

First step is an engine temperature measurement. Engine temperature is measured in the location of oil level dipstick insertion and must achieve the bound designed by producer. If the required temperature has not been achieved, the measurement could continue even without one. After the temperature measurement, the speed indicator is connected to provide reliable and correct rpm measurement at all time of the measurement. Recorded idle rpm should range according to 1.3.1. After the idle rpm measurement, follows the maximal engine rpm measurement. Correct function of maximal rpm regulator is verified by slow gradual rpm increase. Recorded rpm should range according to 1.3.1. The measurement will be repeated, if recorded rpm are lower than those ones according to 1.3.1. If allowable rpm range is not achieved by following measurement, the measurement will not continue, because measured results would be non-relevant. In the case of overrevving of maximal engine rpm upper bound designed according to 1.3.1, the measurement will not continue because of engine damage thread.

Before exhaust-emission measurement, two “flush” accelerations are realized, designed for exhaust pipe washing from sedimentary soot. Flush acceleration is realized by quick accelerator pedal compression until 75% of maximal power rpm. The pedal is released after their achievement.

After flush accelerations, the measurement by free acceleration method is realized. The accelerator pedal is compressed quickly (max. for 1 second) for maximal batch of fuel achievement and is released after maximal engine rpm achievement and after the rpm are recorded by indicator. After the pedal release, a waiting for the idle engine rpm achievement according to 1.2.3 as well as for turbocharger rpm decrease in the case of supercharged engines is necessary. Maximal value of coefficient of absorption, idle rpm, maximal rpm and acceleration time is recorded.

The smoke emission variable is calculated from measuring data. Smoke emission is calculated according to relation 1, as an arithmetic mean of coefficients of absorption “k” values detected from last three recorded free accelerations.

$$D = \frac{k_N - k_{N-1} - k_{N-2}}{3}$$

where:
D – calculated smoke emission value, m^{-1},
k – measuring coefficient of absorption value, m^{-1},
N – measurement serial number.

Value dispersion “r” of coefficients of absorption from last three recorded free accelerations cannot exceed 0.5 m^{-1}. Dispersion “r” is a difference between maximal and minimal value of measuring coefficients of absorption “k” from last three recorded free accelerations.

$$r = \max(A, B, C)$$

2. Utilized tools

The measurement was realized on Citroen Xsara vehicle, 1999 vintage with DHY engine type. Main parameters of DHY engine are presented in table 1.

Table 1: *Main parameters of DHY engine*

Engine type (producer label)	DHY (XUD9TE/L3)
Number of cylinders / engine capacity, pcs/cm^3	4/1905
Engine compression ratio, :1	21.8:1
Maximal power / Maximal power rpm, kW/min^{-1}	66/4000
Engine valvetrain	OHC
Number of valves per cylinder, pcs	2

Limiting rpm variables, as well as smoke emission and dispersion variables were evaluated from information alleged in AUTODATA 2007 technical literature presented in table 2. The variables were processed according to 1.3.1 and are presented in table 2.

Table 2: *Variables designed and processed for exhaust-emission measurement*

Variables		
	Designed by producer	Processed according to 1.3.1
Engine temperature, °C	80	80
Idle rpm (speed),	750 – 850	700 – 900
Maximal engine rpm	4 975 – 5 275	4 000 – 5 425
Maximal smoke emission	3.00	3.00
Dispersion	0.5	0.5

3. Own study

The measurement were realized at Commissioned technical service for emissions control, which disposes of measuring devices used for exhaust-emission measurement at emissions control workstations, as well as of etalon, which is used for comparison test realization, when new measuring device suitability is being verified. As measuring device (same as being used at emissions control workstations), we used ATAL AT 605 with accredited software version 1.12.3.SVK and measuring chamber LCS 2400 with 0976 serial number. Etalon used for comparison tests realizations is according to Commissioned technical service measuring device AVL DiSmoke4000 with software version 4000SK-1.05 and with 1161 serial number. Measuring variables measured with hydrogen fuel producter utilization are presented in table 3 and variables measured without hydrogen fuel utilization are presented in table 4.

Table 3: *Engine measuring variables with alternative fuel utilization*

Measuring device type	AVL DiSmoke 4000			ATAL AT 605		
Measuring variables						
Engine temperature, °C	unmeasurable			94		
Idle rpm (speed)	860			850		
Maximal engine rpm,	4 510			4 860		
Maximal smoke emission, m^{-1}	0.30			0.36		
Dispersion, m^{-1}	0.04			0.01		
Measuring parameters						
Acceleration	1.	2.	3.	1.	2.	3.
Idle rpm (speed)	850	850	860	850	840	850
Maximal engine rpm,	4 840	4 760	4 750	4 600	4 620	4 760
Acceleration time, s	0.85	0.85	0.76	1.01	1.15	1.33
Coefficient of absorption	0.32	0.28	0.31	0.36	0.35	0.36

It is obvious from the measuring values, that measuring variables of coefficients of absorption and maximal smoke emission are at hydrogen fuel utilization higher than at usual conventional fuel utilization. This slight increase is caused by more reactive hydrogen, diffused in compressed air, which absorbs more oxygen causing that injected fuel cannot oxidate completely and then at compressed, as well as at combustion temperatures occurs cracking and decay of molecules causing higher emittance of fine particles.

Table 4: *Engine measuring variables without alternative fuel utilization*

Measuring device type	AVL DiSmoke 4000			ATAL AT 605		
Measuring variables						
Engine temperature, °C	unmeasurable			97		
Idle rpm (speed)	860			870		
Maximal engine rpm,	4 840			4 850		
Maximal smoke emission, m^{-1}	0.27			0.31		
Dispersion, m^{-1}	0.01			0.03		
Measuring parameters						
Acceleration	1.	2.	3.	1.	2.	3.
Idle rpm (speed)	850	850	850	840	840	850
Maximal engine rpm,	4 800	4 760	4 840	4 670	4 720	4 690
Acceleration time, s	0.93	0.89	0.93	1.16	1.36	1.66
Coefficient of absorption	0.28	0.27	0.28	0.29	0.32	0.32

By measuring values analysis, we detected another change in engine operating characteristics in relation to fuel utilization. At hydrogen fuel utilization, the free acceleration time is lower by 0.1 than at free acceleration of engine with usual conventional fuel. This fact can cause a slight increase in engine torque, thereby an increase of engine flexibility. Slight increase in torque causes a psychological moment for driver, who is not forced to increase a batch of fuel significantly, e.g. at trailer dragging or at uphill ride etc. This fact causes a fuel consumption decrease.

4. Conclusion

An enrichment of intake air by diesel engine with hydrogen fuel causes a slight increase of smoke emission of diesel engine. This fact is caused by more reactive hydrogen, which absorbs more oxygen at compressed stroke causing that after injection of conventional fuel to the cylinder, there is not enough disposal oxygen for complete reaction of conventional fuel, diesel fuel. At our tested vehicle, the measuring smoke emission at alternative fuel use was 0.30 m^{-1} by AVL 4000 measuring device and 0.36 m^{-1} by ATAL AT 605 measuring device. Without alternative fuel use, the measuring smoke emission was 0.27 m^{-1} by AVL 4000 measuring device and 0.31 m^{-1} by ATAL AT 605 measuring device. It is obvious, that slight increase occurs in smoke emission by 0.03 m^{-1} at AVL 4000 measuring device utilization and by 0.05 m^{-1} at ATAL AT 605 measuring device utilization. This minimal increase of smoke emission has not a significant effect on vehicle operation or on emissions control evaluation, where 3.00 m^{-1} is a maximal limit. Another benefit is a slight increase of engine torque causing fuel consumption decrease, e.g. at trailer dragging or at uphill ride or at frequent starting up of the vehicle etc. Therefore, this device utilization could have an economical significance by decrease of vehicle fuel expenses.

5. Acknowledgement

Supported by the Ministry of Education of the Slovak Republic, Project VEGA 1/0857/12 “Reduction of unfavorable impacts of agricultural and transport machinery on environment”.

6. References

BERNÁT, R. – HORKA, M. – KROČKO, V. – ZÁLEŽÁK, Z. 2009. Vplyv alternatívnych palív na kvalitu povrchu spaľovacieho priestoru motora (Influence of alternative fuels on quality of combustion chamber surface of engine). In Kvalita a spoľahlivosť technických systémov. Nitra: SPU, 2009. ISBN 978-80-552-0222-8.

HLAVŇA, V. a i. 2000. Dopravný prostriedok – jeho motor. Žilina: Žilinská univerzita, 2000, 442 s. ISBN 80-7100-665-3

HORKA, M. – BERNÁT, R. – ZÁLEŽÁK, Z. – BENEŠ, L. 2008. Poškodzovanie funkčných dvojíc spaľovacieho priestoru pri použití bioplynu (Damage of functional pairs of combustion chamber by using biogas). In TechMat 2008 – Perspektivní technologie a materiály pro technické aplikace. Pardubice: Univerzita Pardubice, 2008. s. 93-96. ISBN 978-80-7395-136-8.

JANOŠKO, I. - PETROVIC, A. 2006. Monitoring of power consumption of communal vehicle with big capasious stock. In XXXVII. medzinárodná vedecká konferencia KOKA. Praha 2006, 6 s. ISBN 80-213-1510-5.

JANOŠKO, I. 2007. Virtuálne monitorovanie parametrov motorov (Virtual monitoring of engine parameters). In KOKA 2007, XXXVIII. medzinárodná konferencia katedier a pracovísk spaľovacích motorov českých a slovenských vysokých škôl, 17.-19. 9. 2007. - Bratislava: STU, SR, 2007. ISBN 978-80-227-2714-3

MAJDAN, R. - BALOG, J. Diagnostika palivovej sústavy vznetového motora. In Najnovšie trendy v poľnohospodárstve, v potravinárstve a v odpadovom hospodárstve, s. 162-168. Nitra :SPU v Nitre, 2006. ISBN 80-8069-690-X.

MÜLLEROVÁ, D. - JABLONICKÝ, J. - HUJO, Ľ. - KOSIBA, J. 2011. Detection of emission in combustion engines exhaust. In Machines, technologies, materials : international virtual journal for science, technics and innovations for the industry. - Sofia : Scientific - Technical Union of Mechanical Engineering. ISSN 1313-0226, 2011, year 5, iss. 4, p. 53-56.

MÜLLEROVÁ, D. - MACKELLAR, L. - SCHIESS, I. - JABLONICKÝ, J. - PRÍSTAVKA, M. 2011. Operating parameters and emission evaluation of tractors running on diesel oil and biofuel. In Research in Agricultural Engineering. - Praha : Ústav zemědělských a potravinářských informací. ISSN 1212-9151, 2011, vol. 57, special iss., p. S35-S42.

MÜLLEROVÁ, D. - JABLONICKÝ, J. - ŽIKLA, A. 2009. Prevádzkové parametre vznetového motora s bionaftou (Operation parameters of diesel engine with biodiesel). In Advances in Automotive Engineering : selected papers, volume III, 2009. - Nitra : SPU v Nitre, 2009. ISBN 978-80-552-0257-0, vol. III, p. 58-66.

PODOLÁK, A. – LENĎÁK, P. 2003. Motorové vozidlá 1. Nitra: SPU Nitra, 2003, 180 s. ISBN 80-8069-804-6

S-EKA. 2002. Základné školenie odborne spôsobilých osôb. Učebné texty. Nitra: S-EKA, 2002, 95 s.

S-EKA. 2006. Príručka technika emisnej kontroly na vykonávanie emisných kontrol cestných motorových vozidiel so zážihovým motorom a s nezdokonaleným emisným systémom, so zážihovým motorom a s zdokonaleným emisným systémom, so vznetovým motorom. Nitra: S-EKA, 2006

SLOBODA, Aurel - BUGÁR, Tibor - SLOBODA, Aurel - PIĽA, Ján - TKÁČ, Zdenko. Konštrukcia automobilov I. : piestové spaľovacie motory : teória, konštrukcia, riziká. 1. vyd. Košice : Technická univerzita, 2010. 323 s. ISBN 978-80-553-0414-4.

TAKÁTS, Michal. 1997. Měžení emisí spalovacích motorů. Praha: ČVUT, 1997. ISBN 80-01-01632-3

TKÁČ, Zdenko - GÁLIK, Roman - KROČKO, Vladimír. Hodnotenie vlastností ekologickej kvapaliny a jej vplyv na spoľahlivosť techniky. In Zbirnik naukovich prac nacionaľnogo agrarnogo universitetu. Tom XV, s. 237-243. Kijiv : Nacionalnij agrarnij universitet, 2003. ISBN 966-7906-06-X.

TRNKA, Jaroslav – URBAN, Jaroslav. 1992. Spaľovacie motory. Bratislava: Alfa, 1992, 568 s. ISBN 80-05-01081-8

VITÁZEK, I. - HAVELKA, J. 2011. Kvalita plynného paliva v sledovanom období (Quality of fuel gases in the monitored period). In Sborník příspěvku „30. setkání kateder mechaniky tekutín a termomechaniky“. Liberec: TU, 2011. ISBN 978-80-7372-747-5.

VLK, František. 2003. Automobilová technická príručka. Brno: František Vlk, 2003, 791 s. 1319 obr. ISBN 80-238-9681-4

ŽIKLA, Anton - DRABANT, Štefan - TKÁČ, Zdenko - ABRAHÁM, Rudolf. Skúsenosti a možnosti využitia bionafty v poľnohospodárstve. In Traktori i pogonske mašine, 2005, roč. 10, č. 3, s. 26-32. ISSN 0354-9496.