POSIBILITIES OF INCREASING THE EFFICIENCY AND ECOLOGICAL SAFETY OF DIESEL

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Abstract: *The authors put forward two potential possibilities of increasing the usage efficiency of heat energy fuel combustion in Diesel. The first one is the regeneration of exhausted gas heat and its kinetic energy with the advert of a supplement unit including in it self turbo-compressor, heat-exchanger, gas turbine, condenser, pump of high and low pressure. Meanwhile exhausted gases liberate their heat energy to return condensed water in the heat-exchanger that is conveyed by a pump of high pressure into for-chamber to be mixed with fuel as a catalyst and then into the combustion chamber. The second possibility includes full substitution of traditional fuel by hydrogen that is produced in an attached to the engine generator with the help of hydrolysis of alum-hydride. The received vapour-hydrogen mixture is conveyed into the working cylinder before adiabatic compression. Peroxide of hydrogen is conveyed into the combustion chamber as an oxidizer. As a result vapour phase is formed that turns vapour-turbine at an exit out of the working cylinder and then returns back for hydrolysis under pressure.*

Keywords: Diesel, alum-hydride, hydrogen, perhydrole, heat regeneration.

INTRODUCTION

In the nearest decades the consumption of oil by all kinds of vehicles will remain at the same great level. They practically depend on fossil fuel at 93% - 95%. The oil consumed by different vehicles makes 75% of world fossil fuel consumption. The consumption of the latter has risen nearly at 2.6 times lately for the last 30 years. Relatively it has risen at 30% (1990 - 2003) the amount of carbon dioxide emission by different vehicles. This trend will develop against the background of fossil fuels getting ever exhausted. Due to experts estimation, short fall will have been observed by 2050. Thus this problem of energy saving and the increase of fuel usage in the transport sphere is becoming the most important task. The evolution technologies are rapidly developing predominantly in the conception of hybrid motor vehicles. One of the ways of solving this problem is the regeneration of exhausted gas heat. The fraction of unused heat makes 60% - 70% for piston engines. Thus, in the scale of our planet as a whole an irrational loss of heat energy in the latter makes an astronomical figure, radically affecting the heat balance of planet as well as the ecology of the environment.

Practically this problem is solved with the help of turbo compressor being attached into the construction of engine for air input into the working cylinder. Only 15%-20% of exhausted gas energy is used in this case, however. The progress of turbo technique contributed to the fact that the part of vehicles with turbo supercharging makes nearly the half of the total number of motor vehicles produced 5 years ago and still goes on increasing.

The system of turbo supercharging has a number of serious drawbacks.

1. It is complicated has a low resource and it is connected with the work of the engine rigidly and complicated to that. It needs thorough service.

2. Another serous drawback is high dependence of turbo on the quality of oil that is imparted to bearings under pressure from the total system of greasing at high revolution and 800-900K. Under these conditions greasing characters of oil (its hardening) and, as a result, seizes the rotor.

The system of lost heat regeneration may be solved by increasing the degree of its usage with its introduction at the stage of fuel combustion. The most appropriate hot fluid transport medium for that is water input into circulation. It is proved in experiments that emulgated fuel by water burns out better than that without water. The presence of water vapours essentially improves the burning out and essentially decreases the temperature of gas phase simultaneously increasing useful pressure. This hinders the formation of nitrogen oxides.

Joint dozed out input of heated water and fuel provided to achieve this effect through the system of regeneration in a special for-chamber. This way makes possible the transmission of water into the ejector system preliminarily heated by exhausted gas. What is of great use is the regeneration of exhausted heat with its return into the main process. The illustration above shows the following technological peculiarities of the regeneration Diesel circle being described (Figure 1).

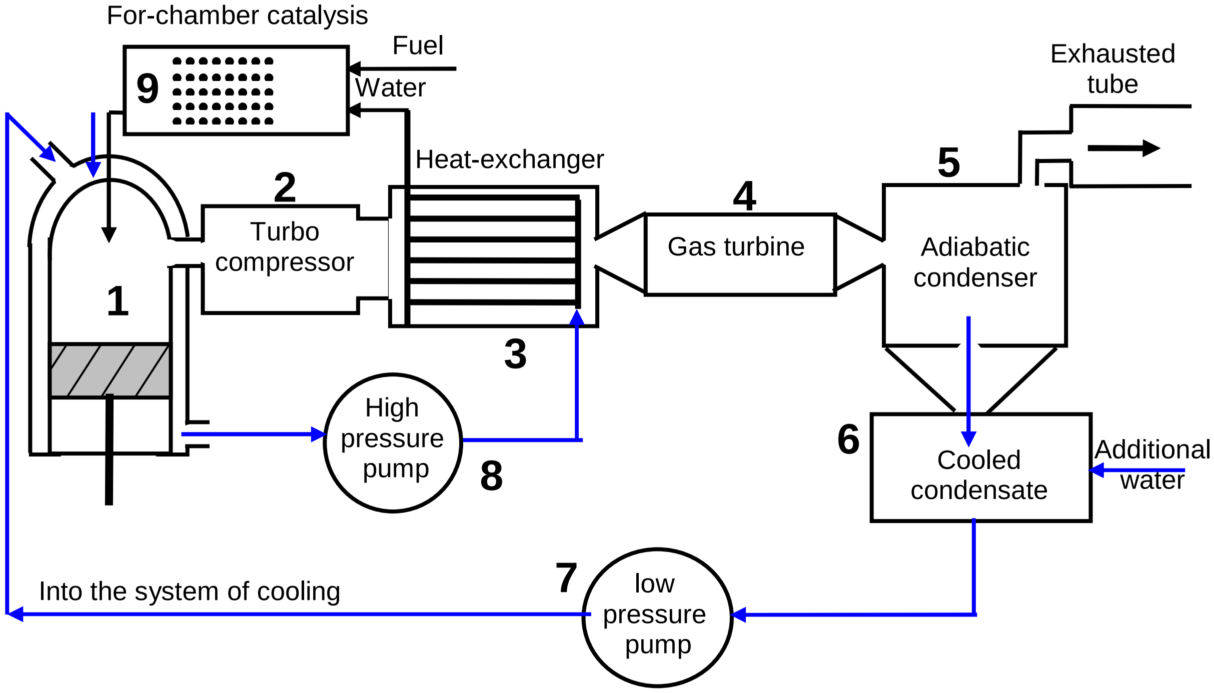

Figure 1: The principal scheme of regeneration of heat in an ideal Diesel cycle

Leaving the working cylinder exhausted gases pass turbo-compressor with coefficient of compressing 1.5 – 2.0 increasing its heat irradiation in the proceeding heat exchanging process. In the tube heat-exchanger (3) gases convey heat to the on-coming stream of water. The latter circulates under pressure for retaining a liquid state, formed by water pump of high pressure (8) at the entrance into the heat exchanger. Due to thermodynamic state in the water-vapour system (300-350^{o}C) at pressure not less than 12.0 - 16.0 MP is the most rational and technologically acceptable range of parameters for maximizing water heat saturation. In this case thermical heat capacity of vapour phase is nearly equal to water heat capacity, with heat volume not less than 1600-1700 kJ per kg. It means that one gram of water in these circumstances enables to carry the supply of heat - more than 2000-2200 J or about 50%-60% of initial gas heat. After heat exchanger gas phase has about 500-600K, pressure 0.2 - 0.25 MP and heat potential. Its kinetic energy may be additionally used in gas turbine set (4) for producing energy. In case the efficiency of gas turbine set is 0.25 – 0.27 about 14-15 kW per hour energy may be theoretically produced, part of it (5 kW) is used for the operation of turbo-compressor, the other part (about 7.0 kW) – for water pump and the rest part - for the compressor so that to charge air into working cylinder before adiabatic compression.

After gas-turbine gases will have pressure about 0.12–0.15 MP at 385-400K. Then they get into the chamber of adiabatic expansion (5) and vapour is condensed. After that condensate (6) is conveyed into the cooling system of the engine by the low pressure pump, where it is heated. Thus, part of the heat lost by the walls of combustion chamber is regenerated for the basic process. Heated water being condensed, exhausted gases contains only CO_2 and N_2 which are emitted through exhausted tube.

After heat-exchanger water (570 – 620K) is conveyed into the for-chamber (9) of mixing and catalysis, where fuel is transferred under a proper pressure. Due to adiabatic expansion in the for-chamber, water and fuel are changed into vapor state and being mixed they homogenized into a heated water-fuel mixture. Apart from it catalyst is set in the for-chamber enabling additional reaction of water and fragments to hydrocarbon parts of fuel that form alcohol radical group after the scheme:

$$C_nH_{2n+2} + (H_2O)_m + catalyst = C_nH_2(OH)_m + kH_2$$

In this process hydrogen is formed as an additional fuel. Apart from it partial destruction of complex hydrocarbon leads to the formation of much simpler one. Combustion of such synthesized fuel in oxygen takes place with lowered range of activation at a higher level of homogenization of air-fuel mixture. Thus heat producing aptitude of fuel mixture is increased and combustion kinetics is improved as well. This effect allows to lower the expenditure of fuel largely.

The total calculation of parametrical characteristics of such ideal thermodynamic cycle, using different variants of regenerated heat input into the process of combustion, is shown in comparison with the basic cycle. Table 1.

The volume of the working cylinder – 2.4 dm^3 (at ratio of isolated portion of fuel 0.114g for one cycle) and the rate of air pressure – 17 without super changing is taken for the basis of calculations.

Due to the above demonstrated calculations of an ideal Diesel cycle the temperature in the combustion chamber essentially decreases while heat is rege- nerated, thermical cycle efficiency increases considerably rising the useful work and regeneration heat efficiency. As a result the power of the engine rises greatly or fuel is saved under the constant quantity of useful work. As it appears, on the one hand there may be the possibility of increasing the

Table 1: Parametrical characteristics of heat regeneration in ideal Diesel cycle.

Parametrical characteristics	Basic cycle	Heat regeneration, J			
		+500	+1000	+1500	+2000
q_{comb} – heat received by fuel combustion (J).	5083	5083	5083	5083	5083
Q_{reg} - regenerated heat (J)	-	500	1000	1500	2000
q_1 – total heat input into the process (J).	5083	5583	6083	6583	7083
q_2 – residual heat after adiabatic expansion (J).	1995,3	2117,8	2253,8	2425,0	2564,8
q_3 – heat disposed out of the cycle (J).	1995,3	1617,8	1253,8	925	564,8
T_2(after adiabatic compression),K	850	850	850	850	850
T_3 (after isobaric expansion), K	2245,8	2087,6	1985,7	1916,5	1856,3
T_4 (after adiabatic expansion).	1096,1	986,1	920,8	847	837,8
P_2(after adiabatic compression),P	$48{,}5\cdot10^5$	$48{,}5\cdot10^5$	$48{,}5\cdot10^5$	$48{,}5\cdot10^5$	$48{,}5\cdot10^5$
P_4 (after adiabatic expansion), P	$3{,}68\cdot10^5$	$3.3\cdot10^5$	$3{,}1\cdot10^5$	$2{,}9\cdot10^5$	$2{,}8\cdot10^5$
Thermic efficiency	0,607	0,621	0,630	0,632	0,638
Efficiency of heat usage	-	0,710	0,794	0,859	0,920
The work of the cycle	3085,4	3467	3832,3	4160	4519
Expenditure of fuel (dm^3/100 km)	20	16,5	14,9	13,7	12,6
Saved fuel against equality of work	0	17,5	25,5	31,5	37

efficiency of diesel engines at 30–35%

and on the other hand –decreasing toxic gas wastes into the environment at 30% – 35%. The scale of existing park of diesel engines and diesel-generators in transport-energy sector will allow getting a greater economic and ecological effect. More than that the level of dependence of internal-combustion engine on the instability of fuel market is lowered to a great extent.

Another trend in increasing the efficiency of internal combustion engines is linked with full diversification of hydrogen-carbon fuel, with its full substitution by an alternative, renewable, ecological fuel. These requirements are met with the usage of hydrogen. The resources and the product of the usage of the latter are ordinary water, with practically inexhaustible and renewable reserves. Thus, unbounded renewable energetic process «$H_2O+Q \rightarrow (H_2+O_2) \rightarrow (H_2O+Q)$» is realized, i.e. the basis of a stable global development [1].

At present leading energetic and automobile corporations are investing great funds into prestigious hydrogen projects which foresee the usage of hydrogen as a fuel in automobiles after the followings basic schemes:

- pressed hydrogen + fuel sells + electromotor;

- pressed hydrogen + internal combustion engine;

- pressed hydrogen + petrol + internal combustion engine.

These conception schemes with fuel sells are being worked out by such companies as GM in their experimental modules Hy-Wire. Chevrolet Equinox Fuel Sell with powerful electromotor and nickel-metal hydride thrust accumulators, which are charged by fuel sells. The modules Honda Civic FCX are designed in analogy. This conception scheme foresees full substitution of the existing structure of motor engineering.

The second scheme is used by BMW and Mazda, considering that the transformation of traditional internal combustion engines into hydrogen ones make them not only ecologically preferable but thermical efficiency of the new design is much higher with better flexibility of work, combining high dynamics with zero exhaustion. What is the most important is that these automobiles are adapted to the existing structure motor engineering.

The third scheme has been designed by BMW Company that prepared for the serial production the version of its own BMW-7Series (BMW 750-hl). Its automobiles work on both petrol and fluid hydrogen.

Comparing the above mentioned schemes it is necessary to underline that the efficiency of the first scheme is almost twice as much as the second one that must increase the run of vehicle. At the to same time this transformation of transport according to the first scheme will lead total and full substitution of the whole service system and production infrastructure. It is too problematic for the world economy in the next coming decades.

Apart from all above considered hydrogen systems there is rather a serious issue – the storage of hydrogen due to its very low volume energy intensivity. Owing to this it should be compressed or liquefied. If we take the first scheme hydrogen is contained in two or three special cylinders about 150-170 dm^3 in volume under pressure 30-40 MP (it equal to 4.2-4.5 kg) that provides 350-450 km of run, but in internal combustion engine it is only 180-250 km, i.e. 3-6 times less than petrol or diesel engines.

Another grave issue is connected with great explosiveness of hydrogen mixed with air, as 4-5kg of compressed to 30-40 MP hydrogen possesses 80-90kg trotil equivalent of explosive potential. This can’t but cause a psychological discomfort of passengers and the drivers. In case of an accident or in case of terrorist actions, it may cause unpredictable catastrophe in the city section.

One of the most efficient ways of solving this problem is keeping hydrogen with the help of a number of metal hydrides stable in the range of ordinary temperatures of their possible usage in automobiles (0 - +200^0 C). Alum-hydride (AlH_3) is the most preferable one in this respect.

For example, in the conditional volume of alum-hydride tank (150 dm^3) there is 22.2kg of hydrogen and being hydrolyzed it may be 44kg. Besides considerable quantity of heat (15.5-18.0 MJ per kg AlH_3 or approximately 3700 MJ in the variant 150 dm^3 AlH_3) is emitted by hydrolysis. Thus, total theoretical potential of AlH_3 may reach 8500 MJ per 150 dm^3 AlH_3 that is 1.8 times more than similar volume petrol or 15.7 times more than in case of hydrogen compressed to 35 MP [2].

Alum-hydride is also more convenient as it is rather stable in the interval of -50 +90^o C; it is not-explosive and non-toxic. Its transportation and storage may be carried out without special means of safety and high qualified personnel. In addition used aluminum matrix after hydrolysis is not lost as it is returned to the basic technological complex for the regeneration of hydride. Finally alum-hydride may be used in the existing diesel systems with an additional process of hydrolysis AlH_3 in a separate H-generator with the formation of gaseous hydrogen and hard phase Al_2O_3.

Returned water is conveyed for hydrolysis in order to increase the heat balance of gas phase and to decrease thermic potential. It is necessary to mention that the temperature of vapour-gas phase falls considerably, its heat intensivity rises and pressure gets higher. Consequently this action increases the efficiency of the following processes of compress, combustion and expansion. In this condition vapour-hydrogen mixture at high temperature and under high pressure enters compression stage that presents fuel mixture [3]. After its compression as an oxygen source liquid perhydrole (H_2O_2) is conveyed into the combustion chamber. At a high temperature perhydrole is dissociated into water and atomized oxygen with additional heat being emitted. Possessing high reaction ability atomized oxygen in its turn burns hydrogen rather actively and completely. As a result only water is formed in the vapour phase that is removed into the system of the generator as an additional water for hydrolysis but not into the exhausted tube.

Thus, discharged heat may be practically completely returned in the initial process, enabling to grow the general efficiency of such regenerative H-Diesel. Such a process of thermodynamic cycle enables to carry out the whole process in rather mild thermical conditions but under an increased pressure that raises the resource of cylinder block. Simplified modeling after a standard scheme, similar to a traditional ideal internal combustion engine cycle, was conducted. Fractional relation of heat of hydrolysis, dissociation and regeneration were considered as the basis of calcu- lations which were similar to traditional cycle of Diesel (3084 J while burning 0,114g of fuel for one cycle). The most preferable variant by its parametrical characteristics was chosen on the basis of comparing them. It is noted in bold type (Table 2).

Analyzing the charge of basic thermodynamic parameters and characteristics of H-Diesel cycle the following conclusion may be drawn. (Table 2).

Table 2: Thermodynamic characteristic of H-Diesel

Cycle	Diesel	**H-Diesel**								
Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
m, g	0,114	0,045			0,04	0,045			0,04	0,04
$m_{per.}$	-	0,153			0,136	0,153			0,136	0,136
H_2O	**-**	**3,0**				**4,0** г				**5,0**
ε	17	20								25
$q_{hydr.}$	-	596	596	596	530	596	596	596	**530**	530
$q_{regen.}$	-	1300	1400	1500	1500	1400	1400	1500	**1500**	1500
$q_{diss.}$ $q_{comb.}$	-	444	444	444	357	444	444	444	**357**	357
q_1	-	1080	1080	1080	960	1080	1080	1080	**960**	960
q_2	5083	3395	3464	3592	3323	3395	3500	3599	**3329**	3332
	1995	1606	1656	1833	1783	1582	1678	1783	**1746**	1802
t_2	298	704	726	746	734	612	627	642	**634**	570
t_3	850	1557	1596	1633	1610	1382	1411	1441	**1423**	1370
t_4	2246	1709	1748	1784	1746	1501	1530	1559	**1529**	1455
t_5	1096	697	722	738	717	605	619	631	**617**	583
t_6	-	346	354	352	340	341	340	341	**329**	345
p_2	1,0	2,4	2,4	2,5	2,5	2,05	2,1	2,16	**2,13**	1,91
p_{3-4}	48,5	104,5	107,1	109,5	108,1	92,1	94,5	96,8	**96,6**	114,6
p_5	3,68	2,3	2,4	2,47	2,4	2,3	2,1	2,1	**2,1**	2,7
η_t	0,607	0,903	0,903	0,908	0,915	0,917	0,920	0,921	**0,926**	0,909
Work (J)	3084	3066	3154	3261	3040	3113	3222	3316	**3083**	3030

m – mass of AlH_3 for hydrolysis (g), $m_{per.}$ – mass of perhydrole (g), H_2O – mass of returned water for hydrolysis (g), ε – degree of compression, $q_{hydr.}$- heat of hydrolysis (J), $q_{regen.}$ – regenerated heat (J), $q_{diss.}$ – heat of dissociation (J), $q_{comb.}$ – heat received by fuel combustion (J), q_1 – total heat conveyed in to process (J), q_2 – heat after adiabatic expansion (J), t_2 – temperature before adiabatic compression (K), t_3 – temperature after adiabatic compression (K), t_4 – temperature after combustion (K), t_5 – temperature after adiabatic expansion (K), t_6 – temperature of water after the heat-exchanger (K), p_2 – pressure before adiabatic compression (P), p_{3-4} – isobaric combustion pressure (P), p_5 – pressure after adiabatic expansion (P), η_t - thermical efficiency.

Temperature. In all examined variants a regular increase of this parameter is observed when the quota of regenerated water is increased. At the same time if the quantity of additional water for hydrolysis is increased, the temperature in the working cylinder is decreased with equal quantity of regenerated heat.

It should be noted that temperature conditions in a traditional diesel are different from that in H-Diesel. The temperature in the working cylinder of the latter is much higher before and after adiabatic compression but at the end of the combustion and adiabatic expansion it is lower. On the one hand it proves less contrast and more softness of the operational regime of H-Diesel, on the other hand it has an important role in a considerable growth of its thermical efficiently.

On the whole the functional dependence of temperature both on pressure, degree of compression, the masses of additional water for hydrolysis, and the quantity of regeneration heat is observed.

Pressure. Unlike traditional diesels, H-Diesel differs from them by rather high pressure even at the stage of adiabatic compression at adequate degrees of compression. It is caused due to higher pressure of vapour-hydrogen charge that is conveyed into the working cylinder after hydrolysis of alum-hydride. The quota of additional water influences the quantity of pressure at the same extent. It is noteworthy that at the end of the adiabatic expansion pressure is lower at 1.5 times. It testifies more effective usage of energy for the accomplishment of work despite the lowered level of temperature.

Thermical efficiency. An ideal thermodynamic H-Diesel cycle considerably differs by its high thermical efficiency caused by higher temperature and the pressure at the beginning and the end of the adiabatic compression. This effect is achieved not the expense of negative work at its compression but basically with the help of the realized chemical energy in hydrolysis of alum-hydride. Besides this the increase of efficiency is connected with the growth of the quota of additional water for hydrolysis and the rise of the quantity of regenerates heat.

The work of the cycle. When parametric characteristics of H-Diesel and of a traditional diesel were calculated the equivalence of received work was chosen as a common nominator. Relatively to these characteristics the comparison was carried out to find out specific expenditure of energy for accomplishment of equal work. If a traditional diesel spends 5083 J of initial energy to achieve work 3084 J but H-Diesel spends only 3329 J (variant 9), i.e. 1.5 times less. Besides the part of energy of fuel itself (alum-hydride) is only 45 % (1490 J) or 3-4 times less than diesel fuel. It means that H-Diesel will work 3.4 times longer at an adequate power of engine and at an equal volume of initial fuel.

Perhydrole. The basic purpose employing perhydrole is receiving oxygen by dissociation of perhydrole. Having higher temperature of boiling (150 ^{0}C) perhydrole may also be employed for cooling the working cylinder of the engine instead of the existing system of cooling. It is noteworthy that the heat received from the walls of the cylinder returns to the combustion chamber for accomplishing the work.

It is also important that in the process of dissociation of perhydrole oxygen is formed in an atomic form, its stability for recombination grows at high temperatures. Alongside that its reactionary ability of interaction with heated hydrogen is great. This enables more active and full combustion of hydrogen (1.87 times higher).

The heat conveyed into H-Diesel makes up the sum of proportional quantities of hydrolysis heat of AlH_3 (16%), regenerated heat after adiabatic expansion (45%), dissociation of perhydrole (11%) and hydrogen combustion (29%), i.e. energetic qantity of initial hydrogen is only about 30%. Total efficiency of using heat energy grows to 0.93 in an ideal H-Diesel cycle.

CONCLUSION

Rough calculations reveals that a traditional diesel with cylinder volume 2.4 dm^3 and 2000 min^{-1} expends 5080 J of heat energy (0.114g diesel fuel) on useful work 3080 J per one cycle. For hour of constant work the expenditure of diesel fuel will make up 5080•2000•60 = 610 MJ (13.5kg). While performing adequate work H-Diesel spends 3330 J in one cycle (0.04g AlH_3) 3330•2000•60 = 399.6 MJ per hour, the part of alum-hydride here equals 115.9 MJ (~0.97kg H_2 or 4.8kg AlH_3). In terms of diesel fuel tank 150dm^3 (120kg of diesel fuel) or 220kg of AlH_3 (44kg H_2) in the first case engine works 120 :13.5 = 8.9 hours. In the second case (H-Diesel) 220:4.8 = 45.8 hours. Thus, having equal volume of fuel tank the run of H-Diesel excels that of traditional diesel 5.15 times. What is of great significance is that only water equal to the expenditure of perhydrole is damped into the environment.

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