The effect of methanol combustion with separate feed in a diesel engine on emissions of toxic components

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Abstract. The results of the possibility of using methanol as an alternative fuel for tractor diesel engines are presented, as well as solving problems to reduce emissions of nitrogen oxides and other toxic components in exhaust gases. The most effective way to use methanol in internal combustion engines at present is to feed it directly into the cylinder of a diesel engine using a separate feed, which allows replacing up to 80% of oil fuel. The ignition of methanol in this case occurs due to the supply of a pilot portion of diesel fuel. This method, with some changes and additions to the design of a diesel engine, can be implemented on engines already in operation. Power and economic indicators, the content of toxic components in the exhaust gases when operating on diesel fuel and methanol with a separate feed, depending on the load change, were investigated and determined in detail. When replacing diesel fuel with methanol with a separate feed in a diesel engine, it is possible to achieve a 32% reduction in the content of nitrogen oxides in the exhaust gases and 86% on soot.

The effects of nitrogen oxides (NOx) are associated with the causes of death of forests, crops, and animal diseases. The first effect of NOx on the human body is expressed in irritation of the mucous surfaces. The threshold concentration of NOx is 25 mln\(^{-1}\), and the deadly concentration is 100 mln\(^{-1}\) [1-3].

The development trend of diesel vehicles poses the challenge for researchers and engineers to reduce the toxicity of exhaust gases from diesel engines, both new and in production.

Emissions of NOx, soot and other toxic components of diesel engines are largely determined by the nature of the flow of the workflow in the cylinder. Research at the Department of heat engines, automobiles and tractors Vyatka State Agricultural Academy it was found that the levels of NOx emissions, soot formation, CH\(_x\), CO, CO\(_2\) from the exhaust gases under other identical conditions affected the use of methanol (CH\(_3\)OH) in a diesel engine D – 21A1 (2H 10,5/12,0) produced by Vladimir Motorotraktor Factory [4-9].

As a result of the studies of the working process of the diesel engine 2H 10.5/12.0 when working on methanol with a separate supply, the values of the optimal installation angles of the fuel injection advance are determined: for diesel fuel - 34\(^{0}\), for methanol - 34\(^{0}\). At the same time, it is possible to maintain the power indicators at the level of a serial diesel engine with the supply of a minimum ignition portion of diesel fuel in the amount of 7% and the supply of methanol in the amount of 93% at the nominal mode. This achieves a diesel fuel economy of up to 87% by replacing it with methanol.

Experimental studies have determined the changes in the main power and economic indicators of diesel 2H 10.5/12.0 when working on methanol with a separate supply depending on the change in
speed, diesel fuel consumption during operation of a diesel engine on methanol with a separate supply is reduced by 83% at $n = 2000 \, \text{min}^{-1}$ and by 88% at $n = 1200 \, \text{min}^{-1}$, an increase in the effective efficiency coefficient when working on methanol is from 5% at $n = 2000 \, \text{min}^{-1}$ and 10% at $n = 1200 \, \text{min}^{-1}$[10-15].

Analysis of the exhaust gases of the diesel engine when working on methanol with a separate supply at the nominal mode showed a decrease in the: NO$_x$ at 32 %, soot at 86 %. Depending on the change in the speed, a reduction in the content of: NO$_x$ from 32 % to 36 %; soot from 6.5 to 5.6 times.

For the implementation of the working process of a diesel engine 2H 10.5 / 12.0 when using methanol as a motor fuel using separate feed, it is necessary to observe a minimum ignition portion of diesel fuel of at least 6.6 mg / cycle at the nominal rotational speed due to misfiring working mixture in the cylinder [16-19].

A prototype of a tractor with a power system modernized for operation on diesel fuel and on methanol with a separate feed is shown in Figure 1, which has improved environmental performance.

The content of toxic components in the exhaust gases of a diesel engine, depending on the load change when operating on diesel fuel and on methanol with a separate feed depending on the load change at rotational speed ($n = 1800 \, \text{min}^{-1}$), is presented in Figure 2a. The figure shows that when the diesel engine runs on diesel fuel and the load increases, the content of nitrogen oxides in the exhaust gases increases from 225 ppm with $p_e = 0.127 \, \text{MPa}$ to 420 ppm with $p_e = 0.585 \, \text{MPa}$. At maximum load $p_e = 0.650 \, \text{MPa}$, the content of NO$_x$ in the exhaust gas was 380 ppm. There is an increase of 1.7 times. The soot content in the exhaust gases when the diesel engine is running on diesel fuel increases from 2.1 bosch at $p_e = 0.127 \, \text{MPa}$ to 6.5 bosch at $p_e = 0.650 \, \text{MPa}$, ie, it increases in 3.1 times. The content of CH$_x$ in the exhaust gakh with increasing load increases from 0.03% with $p_e = 0.127 \, \text{MPa}$ to 0.19% with $p_e = 0.650 \, \text{MPa}$. The growth is 84.2 %. The CO content in the exhaust gases increases from 0.08% with $p_e = 0.127 \, \text{MPa}$ to 0.48% with $p_e = 0.650 \, \text{MPa}$. The increase is 83.3%. The CO$_2$ content in the exhaust gases increases with a load from 0.80% with $p_e = 0.127 \, \text{MPa}$ to 4.0% with $p_e = 0.650$. The increase is 80 % [20-24].

The content of toxic components in the exhaust gases is significantly reduced throughout the load range. As the load increases, the NO$_x$ content in the exhaust gases increases from 215 ppm with $p_e = 0.127 \, \text{MPa}$ to 285 ppm with $p_e = 0.55 \, \text{MPa}$, and then decreases to 250 ppm with $p_e = 0.650 \, \text{MPa}$. The increase is 24.6 %. The relative soot content in the exhaust gases of a diesel engine running on methanol with a separate supply is also significantly reduced throughout the load range compared to diesel fuel, although it increases with increasing load. The content of soot in the exhaust gases at $p_e = 0.127 \, \text{MPa}$ is 0.1 bosch, and at $p_e = 0.650 \, \text{MPa} - 1.3$ bosch. The content of soot increases in 13 times. The content of CH$_x$ in the exhaust gas changes according to complex dependencies. At $p_e = 0.127 \, \text{MPa}$ and diesel engine running on methanol with a separate feed, the value of CH$_x$ in the exhaust gases is 0.28% and decreases to 0.12% with $p_e = 0.47 \, \text{MPa}$ and then increases to 0.23% with $p_e = 0.65 \, \text{MPa}$. Fluctuations in the content of CH$_x$ are 57%. The content of CO in the exhaust gases also varies
according to a complex relationship: first decreases from 0.28% with $p_e = 0.127$ MPa to 0.20% with $p_e = 0.5$ MPa, and then increases to 0.35% with $p_e = 0.65$ MPa. Fluctuations in the content of CO is 43%. The CO$_2$ content in the exhaust gases with a change in load increases from 0.80% $p_e = 0.127$ MPa to 4.0% with $p_e = 0.65$ MPa, or increases 5 times [25-28].

Assessing the changes in the content of toxic components in the exhaust gases of the diesel engine, the following can be noted. The NO$_x$ content during operation of a diesel engine on methanol with a separate supply is significantly lower than when working on diesel fuel in the entire range of load changes. Thus, at $p_e = 0.127$ MPa, the NO$_x$ content decreases from 225 ppm when operating on diesel fuel to 215 ppm when operating on methanol with a separate feed, or 4.4%. At $p_e = 0.55$ MPa, the decrease in the NO$_x$ content is even more significant. If, when working on diesel fuel, the content of NO$_x$ is 420 ppm, then at the same load, but when working on methanol with a separate supply, it is only 285 ppm. The decrease is 32%. At maximum loads (at $p_e = 0.65$ MPa), the reduction is from 380 ppm when the diesel engine runs on diesel fuel, to 250 ppm when running on separate feed methanol, or 34.2%.

![Figure 2](image)

**Figure 2.** The content of toxic components in the exhaust gases of a diesel engine 2H 10.5 / 12.0 when operating on diesel fuel and methanol with a separate supply depending on the load change: a - with $n = 1800$ min$^{-1}$; b - with $n = 1400$ min$^{-1}$; -- - diesel fuel, ------ - methanol with separate feed

The soot content when running on a diesel engine with methanol with a separate feed throughout the entire test range of loads is significantly reduced. Thus, at $p_e = 0.127$ MPa, the soot content decreases from 2.1 bosch when operating on diesel fuel to 0.1 bosch when operating on methanol with a separate feed. At maximum loads (at $p_e = 0.65$ MPa), the soot content decreases from 6.5 bosch when operating on diesel fuel to 1.3 bosch when operating on methanol with separate feed, or 5 times.

Assessing the content of total hydrocarbons in exhaust gases, we can state the following patterns: the content of CH$_x$ when the diesel engine runs on diesel fuel increases as the load increases, and when running on methanol, the content of SH$_x$ first decreases and then increases and has values higher than when running on diesel fuel in the entire load range. With $p_e = 0.127$ MPa and diesel engine running on separate methanol, the value of CH$_x$ is 0.28%, and when operating on diesel fuel, it is 0.03%. Then the content of CH$_x$ when the diesel engine runs on methanol with a separate feed is reduced to 0.12% at $p_e = 0.47$ MPa. The value of the content of CH$_x$ when working on diesel fuel is 0.07%. Then the value of CH$_x$ increases to 0.23% with $p_e = 0.65$ MPa, while when operating on diesel fuel, the content of CH$_x$ is only 0.19% [29-32].
It should be noted that when a diesel engine runs on methanol with a separate feed, the CO content in the exhaust gases at low and medium loads increases (up to $p_e = 0.55$ MPa). When working on methanol with separate feed and $p_e = 0.127$ MPa, the CO content is 0.28%, and when working on diesel fuel, it is 0.08%. There is an increase in 3.5 times. However, with an increase in the load, the CO content when operating on methanol in the exhaust gases of a diesel engine decreases and, at a value of $p_e = 0.55$ MPa, is compared with the values of the CO content when operating on diesel fuel and is 0.21%. With a further increase in the load, the content of CO when operating on methanol with a separate feed is below the values of the content of CO when working on diesel fuel and at $p_e = 0.65$ MPa is 0.35% versus 0.48%, respectively. The decrease is 27%. This is due to the fact that total hydrocarbons and carbon monoxide are products of incomplete combustion and that the increase in their percentage in the exhaust gases is influenced by the deterioration of the combustion process at low loads due to the oversupply of the mixture due to ignition by diesel fuel. As a result, at low loads, the process of flame front propagation and the entire combustion process as a whole proceeds more sluggishly, contributing to incomplete combustion of the fuel and, consequently, deterioration of the effective efficiency.

The CO$_2$ content in the exhaust gases of a diesel engine with a load change depends little on the type of fuel and varies almost according to one dependence, although the CO$_2$ values when the diesel engine is running on methanol with a separate feed in the entire range are higher than the CO$_2$ content values when operating on diesel fuel and increase from 1.80% at $p_e = 0.127$ MPa to 4.6% at $p_e = 0.65$ MPa, while when working on diesel fuel under the same loads, the CO$_2$ content in the exhaust gases is 0.8% and 4.0%, respectively. There is an increase in 2.25 and in 1.15 times respectively.

The content of toxic components in the exhaust gases of a diesel engine, depending on the load change during operation on diesel fuel and on methanol with a separate flow depending on the load change at rotational speed ($n = 1400$ min$^{-1}$), is presented in Figure 2b. The figure shows that when the diesel engine is running on diesel fuel with an increase in load, the NO$_x$ content in the exhaust gases increases from 265 ppm with $p_e = 0.127$ MPa to 480 ppm with $p_e = 0.53$ MPa. At maximum load $p_e = 0.635$ MPa, the NO$_x$ content in the exhaust gases was 430 ppm. There is an increase in 1.81 times. The content of soot in the exhaust gases when the diesel engine is running on diesel fuel increases from 2.45 bosch at $p_e = 0.127$ MPa to 4.9 bosch at $p_e = 0.65$ MPa, i.e., in 2 times. The content of CH$_4$ in exhaust gases with increasing load increases from 0.06% at $p_e = 0.127$ MPa to 0.36% at $p_e = 0.635$ MPa. There is an increase in 6 times. The CO content in the exhaust gases increases from 0.13% with $p_e = 0.127$ MPa to 0.55% with $p_e = 0.635$ MPa. There is an increase in 4.23 times. The CO$_2$ content in the exhaust gases increases with load from 1.25% $p_e = 0.127$ MPa to 3.8% with $p_e = 0.635$ MPa. There is an increase in 3.04 times.

The content of toxic components in the exhaust gases is significantly reduced throughout the load range. As the load increases, the NO$_x$ content increases from 245 ppm with $p_e = 0.127$ MPa to 300 ppm with $p_e = 0.55$ MPa, and then decreases to 280 ppm with $p_e = 0.635$ MPa. The increase is 18.3%. The content of soot when working on methanol with a separate supply is significantly reduced in the entire range of loads. The content of carbon black with $p_e = 0.127$ MPa is 0.1 bosch, and with $p_e = 0.635$ MPa - 1.0 bosch. The content of soot increases in 10 times. The content of CH$_4$ varies according to a complex relationship. At $p_e = 0.127$ MPa and diesel engine running on methanol with a separate feed, the value of CH$_4$ is 0.22% and decreases to 0.10% with $p_e = 0.55$ MPa, and then increases to 0.14% with $p_e = 0.635$ MPa. Fluctuations in the content of CH$_4$ are 54.5%. The CO content also varies with complex dependencies: first decreases from 0.32% with $p_e = 0.127$ MPa to 0.20% with $p_e = 0.50$ MPa, and then increases to 0.27% with $p_e = 0.635$ MPa. CO fluctuations are 37.5%. The CO$_2$ content with a change in load increases from 1.25% with $p_e = 0.127$ MPa to 3.8% with $p_e = 0.635$ MPa, or increases in 3.04 times.

Assessing the content of toxic components in the exhaust gases of a diesel engine, we can note the following. The NO$_x$ content when the diesel engine is running on methanol with a separate supply is significantly lower than when operating on diesel fuel, in the entire range of load variation. So, at $p_e = 0.127$ MPa, the content of NO$_x$ decreases from 265 ppm when operating on diesel fuel to 245 ppm
when operating on methanol with a separate feed. At $p_e = 0.53$ MPa, the decrease in the NO$_x$ content is even more significant. If during diesel engine operation on diesel fuel NO$_x$ content is 480 ppm, then at the same load, but when operating on separate supply of methanol, it is only 300 ppm. The decrease is 37.5 %. At maximum loads (at $p_e = 0.635$ MPa), the reduction in NO$_x$ ranges from 430 ppm when operating on diesel fuel to 280 ppm when operating on methanol with separate feed, i.e. by 35%.

The soot content is significantly reduced when the diesel engine is running on methanol with a separate supply in the entire study load range. Thus, at $p_e = 0.127$ MPa, the soot content is reduced from 2.45 bosch when the diesel engine is running on diesel fuel to 0.2 bosch when working on methanol with a separate supply. The decrease is 12.2%. At $p_e = 0.585$ MPa the reduction of soot significantly. If while working on diesel fuel the content of soot is 4.15 bosch, then at the same load, but when the diesel engine is running on methanol with a separate supply, it is only 0.75 bosch. The decrease is 5.5 times. At maximum loads (at $p_e = 0.635$ MPa), the reduction is from 4.9 bosch when the diesel is running on diesel fuel and 1.0 bosch when the diesel is operating on methanol with separate feed, or 4.9 times.

Estimating the content of total hydrocarbons in the exhaust gases, it is possible to constant the following patterns: when a diesel engine runs on diesel fuel, the content of CH$_4$ increases with increasing load, and when operating on separate supply of methanol, the content of CH$_4$ decreases first and then increases. With $p_e = 0.127$ MPa and diesel engine running on separate methanol, the value of CH$_4$ is 0.22%, and when operating on diesel fuel, it is 0.06%. The growth is 72.7 %. The contents of CH$_4$ when working on diesel fuel and methanol are compared and amount to 0.13% with $p_e = 0.37$ MPa. The content of CH$_4$ when working on methanol is reduced to 0.10% with $p_e = 0.55$ MPa, while the value of the content of CH$_4$ when working on diesel fuel is 0.24% and then increases to 0.14% with $p_e = 0.635$ MPa, while the content of CH$_4$ when working on diesel fuel is 0.36%. The decrease is 61 %.

It should be noted that when a diesel engine runs on methanol with a separate feed, the content in the exhaust gases is CO at low and medium loads (up to $p_e = 0.47$ MPa). When working on methanol with separate feed and $p_e = 0.127$ MPa, the CO content is 0.32%, and when working on diesel fuel it is 0.13%. The increase is 59.4 %. However, with an increase in the load, the content of CO when working on methanol with a separate supply decreases and at a value of $p_e = 0.47$ MPa is compared with the values of the content of CO when working on diesel fuel and is 0.20 %. With a further increase in the load, the content of CO when operating on methanol with a separate feed lies below the values of the content of CO when working on diesel fuel and at $p_e = 0.635$ MPa is 0.27% versus 0.55%. The decrease is 51 %. The content of CO$_2$ when the load changes only slightly dependent on the type of fuel and varies almost one of dependence, although the CO$_2$ values when operating on methanol, with separate supply throughout the range of higher values of CO$_2$ when operating on diesel fuel and increasing from 1.80 % $p_e$ to 0.127 MPa to 4.5%, $p_e$ = 0.635 MPa, while when operating on diesel fuel at the same load the CO$_2$ content is 1.25% and 3.8%, respectively.

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