Compliance of modern agricultural tractors presented on Russian market with global emission standards

S A Davydova and I A Starostin

Federal Scientific Agroengineering Center VIM, 5, 1st Institutsky Proyezd, Moscow 109428, Russia

E-mail: davidova-sa@mail.ru

Abstract. The paper discusses the problem of compliance of diesel engines of agricultural tractors that are available on the Russian market with international environmental regulations and standards. Based on the data presented on the official websites of agricultural machinery manufacturers, an analysis of modern domestic and foreign tractors is performed. The performed studies allow concluding that in Russia there is a serious problem associated with the mismatch of agricultural tractors available on the Russian market with the of Stage and Tier global emission standards; 87 % of domestically produced agricultural tractors correspond to low emission classes (Euro 0, Euro 2, Tier 2, Tier 3); 78 % of the examined imported models of tractors from leading world manufacturers comply with emission classes below Tier 4. Methods for improving diesel engines towards reducing the amount of harmful substance emissions into the environment are described: adjustable turbocharging, aftercooling, partial exhaust gas recirculation, electronically controlled Common Rail, and exhaust gas purification and aftertreatment systems are used.

1. Introduction
In accordance with the Strategy for Scientific and Technological Development of the Russian Federation, one of the development priorities for the next 10-15 years is the transition to a highly productive and environmentally friendly agricultural farming; therefore, one of the pressing issues is the environmental friendliness of agricultural tractors.

The emission class of modern agricultural tractors reflects the level of harmful substance emissions from engines into the environment. This indicator is quite important, because harmful emissions not only pollute the atmosphere, but also subsequently settle in the soil, which affects the composition and quality of the resulting food. The exhaust gases generated during the combustion of diesel fuel contain CO$_2$, H$_2$O, N$_2$, carbon monoxide CO, nitrogen compounds, which are a mixture of various oxides (NO, N$_2$O, etc.), various non-oxidized hydrocarbon compounds C$_X$H$_Y$, aldehydes, and particulate matter: soot C, oil aerosols, unburned fuel, engine wear products and other components.

In 2019, 4.2 million metric tons of diesel fuel was delivered to Russian agricultural organizations, which is 11 % of the total diesel fuel consumption in Russia (38.2 million metric tons). At the same time, about 1.5 million metric tons of hydrocarbons, 1 to 1.5 million metric tons of particulate matter (the majority of which is soot) and 500,000 metric tons of sulfur (IV) dioxide are emitted from diesel fuel combustion products in Russia [1], which causes serious harm to the environment. Therefore, agricultural tractor models must meet the highest global environmental standards.

2. Materials and methods
The study was based on data and information materials of leading agricultural machinery
manufacturing companies published on official websites, in periodicals, and the regulatory framework. Methods of complex structural-dynamic analysis, an expert-analytical method of processing information, and other methods of economic theory were used in the research process.

3. Results and Discussion

Requirements for diesel engine exhaust gases were started to be introduced from the beginning of the two thousandths (figure 1). Currently, the following environmental standards for the limitation of the harmful emissions of agricultural machinery engines have been effective: Stage IV standards in EU countries, since 2013; Tier 4 standards in the USA, since 2008; standards according to GOST R 41.96-2011 (UNECE Regulation No. 96) (equivalent to Stage III standards) in Russia, since 2013. However, the EU is already considering a draft of new stricter Stage V emission standards, and Tier 5 is discussed in the USA.

| Power, kW | Stage I | Stage II | Stage III A | Stage III B | Stage IV |
|----------|---------|----------|-------------|-------------|---------|
| 19...37  | CO: 6.5, CH: 1.3, NOx: 9.2; Dispersed particles/soot: 0.85 | CO: 5.5, CH: 1.5, NOx: 8.0; Dispersed particles/soot: 0.8 | CO: 5.5, NOx: 7.5; Dispersed particles/soot: 0.6 | CO: 5.5, CH: NOx: 4.7; Dispersed particles/soot: 0.025 |
| 37...56  | CO: 5.0, CH: 1.3, NOx: 7.0; Dispersed particles/soot: 0.4 | CO: 5.0, CH: 1.1, NOx: 6.0; Dispersed particles/soot: 0.3 | CO: 5.0, CH: NOx: 4.2; Dispersed particles/soot: 0.8 | CO: 5.0, CH: NOx: 4.7; Dispersed particles/soot: 0.025 |
| 56...75  | CO: 4.5, CH: 1.0, NOx: 6.0; Dispersed particles/soot: 0.2 | CO: 4.0, CH: 0.9, NOx: 5.5; Dispersed particles/soot: 0.15 | CO: 4.0, CH: NOx: 3.5; Dispersed particles/soot: 0.025 |
| 75...130 | CO: 3.5, CH: 0.8, NOx: 4.5; Dispersed particles/soot: 0.05 | CO: 3.5, CH: 0.6, NOx: 4.0; Dispersed particles/soot: 0.02 | CO: 3.5, CH: NOx: 3.0; Dispersed particles/soot: 0.025 |
| 130...560| CO: 3.0, CH: 0.4, NOx: 3.0; Dispersed particles/soot: 0.01 | CO: 3.0, CH: 0.2, NOx: 2.5; Dispersed particles/soot: 0.005 | CO: 3.0, CH: NOx: 2.0; Dispersed particles/soot: 0.005 |

![Table of diesel engine emission standards](image-url)
In the past 10 years, in the context of current globalization, in order to avoid the need to develop separate engines for each market, the Tier and Stage standards have become similar in terms of guidelines and nomenclature. The convergence of standards for the regulation of harmful emissions between countries is due to rapidly developing international economic relations, as well as the need to protect the environment. International conventions serve as a tool for rapprochement in this area. Globalization, which is gaining momentum, has no tendency to develop and adopt global standards, since the transition to one or another standard requires significant financial investments in updating the production, and not every country or company can do this. To limit the level of harmful emissions from diesel engines, many countries use mainly Stage / Euro standards, while the Tier standards are used for low-power diesel engines. Japan is developing its own standards for regulating exhaust emissions, while these standards do not rely on Tier and Stage / Euro; however, they do not differ significantly from them.

Many countries of Africa and West Asia require only having performed regular MOT tests, and the introduction of Euro 1-2 is only planned in the near future.

In Russia, the level of emissions of off-road engine engines was regulated as follows:
- By GOST R41 96-99 (UNECE Regulation No. 96) equivalent to Stage I in the period from 2000 to 2008.
- By GOST R41 96-2005 (UNECE Regulation No. 96) equivalent to Stage II from 2008 to 2018.
- By GOST R 41.96-2011 (current) equivalent to Stage IIIA from 2013.

The strategy for the development of agricultural engineering in Russia for the period until 2030 plans, from 2020, to switch to equipping self-propelled machinery with engines that comply with Tier IV standards, while agricultural machinery entering the Russian market is subject to mandatory certification for compliance with the technical regulations of the Customs Union (TR CU 010 / 2011) titled “On the safety of machinery and equipment” and the technical regulation of the Customs Union (TR CU 031/2012) titled “On the safety of agricultural and forestry tractors and trailers for them”. The specified technical regulations contain mandatory requirements limiting the content of harmful substances in the exhaust gases from vehicle engines [2].

However, despite all the measures taken by the government, current Russian agricultural tractors have an emission class much lower than that in Europe and the USA; the lag behind Europe in introducing environmental standards is more than 5 years (figure 1). This fact is confirmed by a performed by the authors comprehensive structural-dynamic analysis of the performance of diesel engines of agricultural tractor equipment (Table 1) produced by the main enterprises of Russia [3].
**Table 1. Performance of diesel engines of Russian-made agricultural tractors**

| Tractor model        | Engine model         | Engine power [kW] |
|----------------------|----------------------|-------------------|
| VTG-90A              | A-41SI-02            | 64                |
| VTG-90M              | D-245-582            | 70                |
| Belarus 320.4        | Lombardini LDW 1603/B3 | 26.5            |
| Belarus 622          | Lombardini LDW 2204  | 46                |
| Belarus 892.4        | Lombardini LDW 1603/B3 | 26.5            |
| Belarus 921          | Lombardini LDW 1603/B3 | 26.5            |
| Belarus 1523         | Lombardini LDW 1603/B3 | 26.5            |
| Belarus 2022.3       | Lombardini LDW 1603/B3 | 26.5            |
| Agromash 85 TK       | D-145T               | 62.5              |
| Belarus-82.1         | D-243                | 59.6              |
| Belarus 92P-CH       | D-245.5              | 66                |
| Belarus 921          | D-245.5              | 66                |
| Belarus 1523         | D-260.1              | 114               |
| Belarus 2022.3       | D-260.4S2            | 156               |
| Agromash-TG-150      | D-442-16 (AMZ)       | 95.5              |
| Uralets 244          | TMZ 8481.10          | 260               |
| K-730 (K-744 R1) Standard | YaMZ -65854     | 220               |
| Belarus 1221.2       | D-260.2              | 96                |
| Belarus 2022.3       | D-260.4 S2           | 147               |
| BTZ-181              | YaMZ-238KM2-3        | 140               |
| K-707T Baltiets      | YaMZ-238-ND5         | 220               |
| K-730 (K-744 R2) Premium | TMZ 8481.10          | 260               |
| K-742 (K-744 R4) Premium | Mercedes OM460LA.E3A/3 | 428            |
| K-9400               | Mercedes OM 457 LA   | 295               |
| K-730 (K-744 R3)     | YaMZ-238-ND5         | 220               |
| K-742 (K-744 R4)     | YaMZ-238-ND5         | 220               |
| Agromash-90TG        | D-41SI-02            | 69.1              |
| KhTZ-150K            | YaMZ-236D-3          | 128.7             |
| K-730 (K-744 P1) Standard3 | TMZ 8481.10-11      | 220               |
| K-702M-SKhT T1       | YaMZ-238-ND5         | 220               |
| K-735 (K-744 R2) Standard | TMZ 8481.10          | 257               |
| K-702M-SKhT T2       | YaMZ-238-ND5         | 257               |
| K-702M-SKhT T3       | TMZ-8481.10-02       | 228               |
| K-702M-SKhT T4       | TMZ-8481.10-04       | 309               |
| K-739/40 (K-744 R3)  | TMZ-8481.10-02       | 287               |
| K-742 (K-744 R4) Standard | TMZ-8481.10-04      | 420               |

In accordance with the data provided, about 5% of 39 models of domestic wheeled and caterpillar tractors comply with Stage II; 5% comply with Tier 3A; 20% comply with Tier 3; 18% comply with Tier 2; 3% comply with Tier 1; 8% comply with Euro 5; 5% comply with Euro 4; 5% comply with Euro 2; 31% comply with Euro 0. Thus, most agricultural tractors produced in Russia have a low emission class (Euro 0, Euro 2, Tier 2, Tier 3), and about 50% of agricultural tractors equipped with diesel engines enter the domestic market of Russia, whose specifications mainly indicate compliance with Euro standards. However, Russian agricultural machinery manufactured for export is compliant with Stage and Tier standards.
In addition to domestic-made tractors, numerous models of foreign manufacturers are represented on the Russian market, such as Claas, Fendt, John Deere, Massey Ferguson, Case IH, Valtra, New Holand, etc. (Table 2) [3].

An analysis of foreign models of agricultural tractors, which are widely represented on the Russian market, for compliance with environmental standards showed that 44 % of tractors are delivered to Russia, whose engines comply with the Tier 3 emission standard, 34 % of them comply with the Tier 2 emission standard, and 22 % of them comply with the Tier 4 emission standard.

| Tractor model        | Engine model             | Engine power [kW] |
|----------------------|--------------------------|-------------------|
| MF7624               | AGCO POWER               | 173               |
| MF8737               | AGCO POWER               |                   |
| MF5200D              | V2403CR-T                | 40.8              |
| Kubota M100GX        | Kubota V3800-TI-CRS      | 74.6              |
| Kubota M135GX        | V6108-TI-CRS             | 100.7             |
| John Deere 7830      | Tech Plus                | 150               |
| John Deere 7930      |                          | 162               |
| John Deere 8310R     | John Deere PowerTech Plus| 228               |
| Fendt 936            | Deutz                    | 243               |
| John Deere 8370R     | John Deere PowerTech Plus| 272               |
| John Deere 9470R     | John Deere PowerTech     | 346               |
| New Holland TD5.110  | S8000                    | 81                |
| ANT 4135F            | Zetor 1605               | 100.2             |
| Deutz-Fahr Agroplus F410 | SDF 1000               | 63                |
| Case Maxxum 140      | FPT                      | 103.7             |
| Case FARMALL JX110   | S8000                    | 81                |
| Case PUMA 155        | Case IH, Fiat Power Train| 116               |
| Claas Arion 630C     | DPS                      | 107               |
| Claas Arion 640C     |                          | 114               |
| New Holland T6050    | NEF                      | 93                |
| Claas Axion 820      | DPS                      | 139               |
| New Holland T7060    | FPT NEF                  | 157               |
| Case PUMA 210        | Case IH, Fiat Power Train| 157               |
| Claas Axion 850      | DPS                      | 171               |
| Versatile 320        | Cummins QSC 8.3          | -                 |
| New Holland T6090    | NEF                      | 121               |
| Versatile 340        | Cummins QSL 9.0          | -                 |
| Case MAGNUM 340      | Case IH, Fiat Power Train| 250               |
| Claas AXION 930      |                          | 259               |
| Claas AXION 940      | FPT                      | 282               |
| Claas AXION 950      |                          | 306               |
| CH MT685             | Agco Sisu Power          | 272               |
| New Holland T9.505   | FPT Cursor 13            | 369               |
| Claas XERION 4500 Trac | Case Caterpillar C13     | 330               |
| Claas XERION 5000 Trac | DEUTZ 1013              | 132               |

Table 2. Performance of diesel engines of foreign agricultural wheeled tractors.
John Deere 6150M 110
John Deere 6155M 114
John Deere 6170M PowerTech E 121
John Deere 6175M 129
John Deere 6195M 143
MF8690 AGCO POWER 272
John Deere 8295R 217
John Deere 8320R John Deere PowerTech Plus 235
John Deere 8335R 250
New Holland T8.380 FPT Cursor 9 229
New Holland T8.410 250
Case STEIGER 450 Case IH, Fiat Power Train 336

In most cases, agricultural tractor manufacturers achieve compliance with Tier 1 thru Tier 3 standards by improving the design of engines [4-7] without or with limited use of exhaust gas aftertreatment / oxidation in the exhaust system. The 56 to 130 kW power range engines mainly use the Common Rail system, which has ample opportunities to change the injection rate, injection advance angle and number of injections per cycle. The engines of this power range use turbochargers having a constant geometry and an actively controlled bypass valve. The exhaust gas recirculation (EGR) system with aftercooling operates under high pressure, therefore, electronic control of the amount of exhaust gas that is bypassed is used.

The following technological solutions are mainly used in engines having a power up to 560 kW: an electronic fuel injection system; internal exhaust gas recirculation; delayed fuel injection angles; external exhaust gas recirculation; diesel particulate filter (DPF); pre-chamber injection; controlled filter regeneration; a gasoline engine equipped with a three-way catalytic converter; oxidative catalytic converter fitted with a particulate filter; reagent neutralization.

The engines having a power of more than 560 kW mainly use an electronic fuel injection system without exhaust gas recirculation; exhaust gas recirculation with external aftercooling; DPF; electronic fuel injection equipment with exhaust gas aftertreatment.

Thus, the most common engines for tractors of medium and high power are turbocharged ones and those equipped with aftercoolers. Taking into account the requirements for the exhaust gases of tractor engines, foreign companies offer electronic fuel management systems as standard equipment. SCR technology is also used, that is to say, the exhaust gas Selective Catalytic Reduction (using urea reagent), to reduce NOx in the exhaust gas in an exhaust system with AdBlue (aqueous urea solution) dosage.

The implementation of the described technologies complicates the design of engines often leading to their appreciation, lower power and efficiency. For example, the heat dissipation of Stage IV engines is higher than that of Stage IIIIB engines, so manufacturers pay particular attention to increasing the power of their cooling systems. In this regard, a characteristic trend is observed: when switching to Stage V engines, many foreign companies have planned to exclude the EGR system from their design to reduce engine heat generation (down to 40 %) and, accordingly, the necessary cooling system performance (engine cooler dimensions).

In addition, it is becoming increasingly difficult for manufacturers to meet stringent requirements with existing solutions. In this regard, recent developments have been intensively performed in the field of using biodiesel, compressed gas, and creating a fully electric tractor. The development of the latter in the future would make it possible to remove the issue of the harmful effect of the exhaust gases of agricultural tractors on the environment.

4. Conclusion
The performed studies allow concluding that in Russia there is a serious problem associated with the mismatch of agricultural tractors available on the Russian market with the of Stage and Tier global emission standards; 87 % of domestically produced agricultural tractors correspond to low emission classes (Euro 0, Euro 2, Tier 2, Tier 3); 78 % of the examined imported models of tractors from leading world manufacturers comply with emission classes below Tier 4. One of the reasons for this is the lag in the introduction of standards that limit harmful emissions from agricultural machinery. The in-
Introduction in Russia of environmental standards that correspond to the world level will help reducing the negative impact of the exhaust gases from agricultural tractors.

To ensure compliance of modern tractors with emission requirements, both foreign and domestic manufacturers introduce various innovative solutions in diesel engines aimed at reducing exhaust toxicity. To do this, adjustable turbocharging, aftercooling, partial exhaust gas recirculation, electronically controlled Common Rail, and exhaust gas purification and aftertreatment systems are used. All this complicates the design of engines, often leads to higher cost of tractors while lowering their power and efficiency. In addition, it is becoming increasingly difficult for manufacturers to meet stringent requirements with existing solutions. In this regard, recent developments have been intensively performed in the field of using biodiesel, compressed gas, and creating a fully electric tractor that does not emit exhaust gases during its operation.

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