Comparative analysis of the economic efficiency of using engine units on an industrial tractor of a 10 tons thrust class

G V Lomakin*, A A Dyakovon and S V Kondakov
South Ural State University, Chelyabinsk, Russia

* Lgeorge@yandex.ru.

Abstract. Creating competitive technology requires innovative solutions from the manufacturer. One of such solutions can be the use of power plants on an industrial tractor that simultaneously meet high technical, economic and environmental indicators. In this regard, the article presents a comprehensive analysis of the characteristics of the power plants under consideration, using the example of an industrial tractor with a thrust class of 10 tons.

Efficient use of fuel for performing mechanical work is an undeniable advantage when choosing an industrial tractor. Beside this, engine unit cost also forms the economic attractiveness of the final product. As an example, consider an industrial tractor class 10 tons produced by ChTZ-Uraltrak and DST-Ural, Figure 1a and b respectively.

The ChTZ-Uraltrak industrial tractor is equipped with D-180 engines manufactured by ChTZ and YaMZ-236 (Yaroslavl Motor Plant) [1], and DST-Ural machine of similar class can be equipped with engines YaMZ-236/238 and YaMZ-536 [2]. Modern tractor engine D-180 originates from the 60s of the 20th century. For many years of production, this engine has proven itself as a reliable and malfunction-proof, capable of operating in harsh climatic conditions. Engines of the Yaroslavl Motor Plant YaMZ-236/238 also originate from the 60s of the 20th century. Engines were originally designed for installing on wheeled commercial cargo vehicles. Due to the lack of a large range of tractor engines, tractor manufacturers began to work out the possibility of installing automobile engines of the YaMZ family on their vehicles. That is how engines YaMZ-236/238 and their modifications got additional use on industrial tractors.

Figure 1. a Product of ChTZ-Uraltrak; b Product of DST-Ural.
Under conditions of the face of fierce competition, the manufacturer is forced to continuously improve technical level of its products. Heart of the vehicle - its engine unit - can be considered as one of the main tools of modernization. Energy efficient engine unit allows not only efficient fuel burning, but also reducing emission into atmosphere toxic components with exhaust gases.

For ease of analysis, technical characteristics of investigated engine units are summarized in Table 1. Additionally present study includes in Table 1 YaMZ 53644 CNG, engine, that was not previously installed on the considered type of industrial tractor.

Under conditions of the face of fierce competition, the manufacturer is forced to continuously improve technical level of its products. Heart of the vehicle - its engine unit - can be considered as one of the main tools of modernization. Energy efficient engine unit allows not only efficient fuel burning, but also reducing emission into atmosphere toxic components with exhaust gases.

For ease of analysis, technical characteristics of investigated engine units are summarized in Table 1. Additionally present study includes in Table 1 YaMZ 53644 CNG, engine, that was not previously installed on the considered type of industrial tractor.

**Table 1.** Engines technical parameters.

| Parameters | D-180.100-6 | YaMZ 236M2 | YaMZ 238ND8 | YaMZ 536 | YaMZ 53644 CNG |
|------------|-------------|------------|-------------|-----------|----------------|
| $n_e$, min$^{-1}$ | 1,250 | 2,100 | 1,900 | 2,300 | 2,300 |
| $a_g$, g/kW\*h | 218 | 227 | 215 | 213 | 228.3 |
| $M_{max}$, N\*m | 1,260 | 667 | 1,280 | 1,226 | 1,098.7 |
| $N_e$, kW | 132 | 132 | 220 | 229 | 191.2 |
| $N_{ifM_{max}}$, min$^{-1}$ | 900-1,100 | 1,200-1,450 | 1,200-1,400 | 1,300-1,600 | 1,100-1,600 |
| $b_g$, g/kW\*h | 215 | 214 | 208 | 197 | 215.6 |
| Service life prior to overhaul, operating hours | 10,000 | 10,000 | 10,000 | 12,000 | 12,000 |
| Overall dimensions, mm, L/W/H: | 1,730/1,190/ /1,730 | 1,020/1,040/ /1,020 | 1,370/1,045 / /1,370 | 1,298/759/ /972 | 1,298/759/ /972 |
| Weight, kg | 1,890 | 890 | 1,180 | 640 | 700 |
| Environmental class | Euro - 0 | Euro - 0 | Euro - 1 | Euro - 4 | Euro - 5 |
| Average price of the internal combustion engine with VAT, thousand rubles. | 900 | 496 | 726 | 697 | 879 |

*a* - specific effective fuel consumption at the rated engine power.

*b* - minimal specific fuel consumption.

*c* - price of the internal combustion engine is dated 4 quarter of 2018, and is presented for information only.

Tractor engine D-180 (Figure 2) has several advantages, such as low crankshaft rotation speed, which does not require using additional gearboxes to reduce rotation speed, peak torque is achieved at low rotation speed, large weight, unpretentious and reliable in operation. In addition, engine can be equipped with a starting gasoline engine, which ensures a guaranteed start of the diesel (main) engine at below zero temperatures in conditions of the Far North.

The disadvantages include increased specific fuel consumption and high cost in comparison with YaMZ engines, using diesel fuel. Low environmental class, precluding using equipment in closed
and poorly ventilated areas.

Guaranteed service life, during which the engine will meet requirements of the regulatory and technical documentation is equal to 10,000 operating hours.

Figure 2. Tractor engine D-180, produced by ChTZ-Uraltrak.

Engines YaMZ-236M2 (Figure 3a) and YaMZ-238 (Figure 3b), have following advantages: low cost, ability to choose different engine modifications with different levels of power boosting, and compliance with the environmental class up to EURO 2 [3]. Lower specific fuel consumption for the supercharged modification of the YaMZ-238ND8 engine at the rated power modes and at the maximum torque mode by 3 - 6 g/(kW * h), respectively, in comparison with the D-180 tractor engine (Table 1).

Figure 3. a YaMZ-236 M2; b YaMZ-238.

Following are disadvantages of the YaMZ-236/238 engines family: low weight and high rotational speed of the crankshaft, in comparison with the tractor engine D-180. A special case is the naturally aspirated modification of the YaMZ-236M2 engine is less economical, the specific effective fuel consumption in the rated power mode is 227 g/(kW * h) versus 218 g/(kW * h) in D-180, maximum torque is almost 2 times less in comparison with the D-180 engine (see Table 1).

YaMZ-536 engine (see photo at Figure 4a) in terms of the specific effective fuel consumption at the maximum torque mode significantly surpasses the YaMZ-238ND8, YaMZ-236M2, and D-180 engines by 11–18 g/(kWh), respectively (see Table 1). The emission of harmful components with exhaust gases level corresponds to the environmental class EURO 4. The advantages also include the service life, increased to 12,000 operating/hours before the overhaul. Using modern family of YaMZ-536 engines imposes additional expenditures for purchasing the engine itself and for its maintenance.
In addition, maintenance of electronic engine systems requires using expensive diagnostic equipment. Engine weight is not an advantage for the industrial tractor in question.

In the frames of the Government of Russian Federation order on transferring to gas fuel at least half of public transport, the largest engine manufacturers in our country, including the Yaroslavl Motor Plant, began mass production of commercial vehicles engines, running on natural gas (CNG is compressed natural gas). One of the models of such engine is presented by the engines of the Yaroslavl Motor Plant YaMZ-53644 CNG (Figure 4b).

![Image of engines](image)

**Figure 4.** a YaMZ-536; b YaMZ-53644 CNG.

Technical parameters of the engine (see Table 1) are significantly lower than of its analogue YaMZ-536, running on diesel fuel. Specific effective fuel consumption of a gas engine is comparable to the fuel consumption of D-180 and YaMZ-236M2 engines. But it must be borne in mind that methane is 4 times cheaper than diesel fuel. YaMZ-53644 CNG environmental class corresponds to the environmental class EURO 5, which makes it possible to use the equipment in closed and poorly ventilated areas. Gas engine service life before overhaul is 12,000 operating hours. Using of a gas engine in an industrial tractor increases its cost due to the high cost of the engine, which is comparable to the cost of the D-180 engine. Engine maintenance requires expensive consumables and complex diagnostic equipment.

Choosing optimal speed mode of the engines under study can be illustrated by a reduced external speed characteristic (Figure 5).

Maximum torque and minimum specific fuel consumption for the D-180 engine is located in the crankshaft rotational speed range of 900–1,000 revolutions per minute. For the YaMZ-236M2 engine optimum range of operation where maximum torque is achieved at minimum specific fuel consumption is equal to 1,200–1,500 revolutions per minute. Optimal mode of operation for the YaMZ-238ND8 engine will be at crankshaft speeds of 1,300–1,500 revolutions per minute. For the YaMZ-536 engine optimal rotational speed range is equal to 1,200–1,600 revolutions per minute. In addition, optimal gas exchange processes at these crankshaft rotational speeds allow for a constant peak torque and minimum specific effective fuel consumption. The YaMZ-53644 CNG gas engine will produce a constant maximum torque at the minimum specific effective fuel consumption in the crankshaft speed range of 1,100–1,700 revolutions per minute.
Let’s analyze the fuel consumption of the engines under study, data for which are summarized in Table 2.

Figure 5. Reduced external speed characteristic of considered engines.
Table 2. Fuel consumption of engine for a 12 hours shift.

| Load, kW | D-180.100-6 | YaMZ 236M2 | YaMZ 238ND8 | YaMZ 536 | YaMZ 53644 CNG |
|----------|--------------|-------------|-------------|----------|----------------|
| 50       | 154          | 153         | 150         | 141      | 154            |
| 70       | 215          | 214         | 210         | 197      | 216            |
| 80       | 246          | 245         | 240         | 225      | 246            |
| 90       | 276          | 275         | 270         | 253      | 277            |
| 100      | 307          | 306         | 300         | 281      | 308            |
| 110      | 338          | 336         | 330         | 310      | 339            |
| 120      | 369          | 367         | 360         | 338      | 370            |

Average fuel consumption per shift, liters

272 271 266 249 273

Cost of fuel, in rubles per shift

12,405 12,347 12,117 11,366 4,365

Due to the lack of statistical data on the real modes of operation of an industrial tractor, the data presented in Table 2 are conditional. When filling in the table, we assume that during the shift a tractor works with a different load from maximum (maximum torque mode) to idling at a forced idle. We take 12 hours of work as one shift. As mentioned earlier, the engine works with different loads, for example, if there is more downtime, then it is advisable to take a smaller load, see Table 2, column 1. If the tractor works most of the time with an average or full load, then from the Table 2 accept the values, corresponding to the average or full load. Average fuel consumption per shift, specified in Table 2, is defined as the arithmetic average for each engine separately. After analyzing Table 2, we can conclude the following: D-180, YaMZ-236M2 and YaMZ-53644 CNG engines consume most fuel to produce a unit of power, then goes YaMZ-238ND8, the most economical was YaMZ-536, the difference between the most consuming and the most economical engines was 23 liters of diesel fuel. In cash maximum difference is slightly more than 1 thousand rubles. Gas engine consumption in liters is comparable to the fuel consumption of D-180 and YaMZ-236M2 engines. But at the same time, a liter of gas is almost 4 times cheaper than a liter of diesel fuel. Therefore, per shift, the gas engine YaMZ-53644 CNG in comparison with the D-180 and YaMZ-236M2 can reduce fuel costs up to 8 thousand rubles, which is 63–65 % of the fuel cost per shift for D-180 and YaMZ-236M2 engines. Comparison of the most economical diesel engine YaMZ-536 with gas YaMZ-53644 CNG engine also allows reducing fuel costs up to 7 thousand rubles, which is 60–62% of the fuel cost per shift for YaMZ-536.

Table 3. Expenses for inter-seasonal engine maintenance.

| Spare parts              | D-180.100-6 | YaMZ 236M2 | YaMZ 238ND8 | YaMZ 536 | YaMZ 53644 CNG |
|--------------------------|-------------|------------|-------------|----------|----------------|
| Type of engine oil / price for 1 l. | M8Г2К/91.25 | M8Г2К/91.25 | M8Г2К/91.25 | SAE 10w-40/390 | SAE 10w-40/390 |
| Engine oil               | 2,920       | 2,281.25   | 2,920       | 8,775    | 8,775          |
| Filling volume           | 32          | 25         | 32          | 22.5     | 22.5           |
| Oil filter set           | 100         | 2,076      | 2,076       | 616      | 616            |
| Fuel filter set          | 1,690       | 1,082      | 1,082       | 2,516    | 3,316          |
| Air filter set           | 1,060       | 735        | 735         | 825      | 1,495          |
| Antifreeze               | 6,828       | 2,160      | 4,552       | 3,651    | 3,651          |
| Technical maintenance cost, rub | 12,598     | 8,334.25   | 11,365      | 16,383   | 17,853         |
The lowest maintenance costs are accounted for by YaMZ-236M2 engines, followed by YaMZ-238ND8 and D-180. The greatest expenses fall on engines YaMZ-536 and YaMZ-53644 CNG. Increase in maintenance costs is due to the higher cost of spare parts and using expensive lubricating oil.

**Conclusions**
- Variant of the YaMZ-236M2 engine has the lowest cost and minimal maintenance costs, so the YaMZ-236M2 engine is selected for the project to create a stepless differential steering mechanism for a 10 t track-type tractor.
- Using of the YaMZ-536 engine on an industrial tractor in comparison with the D-180, YaMZ-236M2 and YaMZ-238ND8 engines provides fuel savings per shift from 5% to 8%, respectively. If we consider possibility of installing the gas engine YaMZ-53644 CNG, then savings on fuel per shift can reach up to 65%.
- The YaMZ-536 and YaMZ-53644 CNG engines provide virtually unchanged (constant) torque and minimum specific effective fuel consumption in a wide range of crankshaft rotational speeds.
- Inter-seasonal maintenance of the YaMZ-536 and YaMZ-53644 CNG engines in comparison with the YaMZ-236M2, YaMZ-238ND8 and D-180 engines is somewhat more expensive, since more expensive consumables and technical fluids are used. In addition, engines of the YaM-536 family require using expensive diagnostic equipment.
- The YaMZ-536 and YaMZ-53644 CNG engines comply with the high environmental standards EURO 4 and EURO 5, respectively. High environmental class allows using equipment in closed and poorly ventilated areas.

**Acknowledgements**
The work has been performed with the financial support of the Ministry of Science and Higher Education of the Russian Federation as a part of complex project to create a high-tech production «Development of a stepless differential steering mechanism with tracking control system for new generation off-road and road-building machines» under the agreement No. 074-11-2018-006 d.d. May, 31, 2018 between the Ministry of Education and Science of the Russian Federation and Manufacturing company “Khodovyesystemy” in cooperation with the head executor Federal State Autonomous Educational Institution of Higher Education “South Ural State University (National Research University)”.

**References**
[1] http://chtz-uraltrac.ru/catalog/categories/3.php
[2] http://tm10.ru/catalog/buld18/
[3] https://www.ymzmotor.ru/catalog/#sect-dvigateli