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ИСПОЛЬЗОВАНИЕ СОИ СЕВЕРНОГО ЭКОТИПА НА БИОТОПЛИВО

ДЕВЯНИН СЕРГЕЙ НИКОЛАЕВИЧ, *д-р тенх. наук, профессор*[1]
E-mail: devta@rambler.ru

МАРКОВ ВЛАДИМИР АНАТОЛЬЕВИЧ, *д-р техн. наук, профессор*[2]
E-mail: vladimir.markov58@yandex.ru

ЛЕВШИН АЛЕКСАНДР ГРИГОРЬЕВИЧ, *д-р техн. наук, профессор*[1]
E-mail: alev200151@rambler.ru

КОБОЗЕВА ТАМАРА ПЕТРОВНА, *д-р с.-х. наук, профессор*[1]
E-mail: mgau0103@gmail.com

АЛИПИЧЕВ АЛЕКСЕЙ ЮРЬЕВИЧ, *канд. пед. наук, доцент*[1]
E-mail: al_new2003@mail.ru

[1]Российский государственный аграрный университет – МСХА имени К.А. Тимирязева; Российская Федерация, г. Москва, ул. Тимирязевская, 49

[2]Московский государственный технический университет имени Н.Э. Баумана; Российская Федерация, г. Москва, 2-я Бауманская ул., д. 5, стр. 1

В статье приведены результаты многолетних исследований по изучению масличной продуктивности и химического состава масла сои сортов северного экотипа в условиях Центрального Нечерноземья и возможности использования его на биодизель. Опыты по выращиванию сои проводились на опытном поле ФГБОУ ВО РГАУ-МСХА имени К.А. Тимирязева (2008-2019 гг.) на районированных ультраскороспелых сортах северного экотипа Магева, Светлая, Окская (группа спелости 000). Закладка опытов и анализ результатов исследований выполнены в соответствии со стандартными апробированными методиками. Показано, что в условиях высоких широт (57° с.ш.), ограниченных тепловых ресурсов Нечерноземной зоны России (сумма активных температур вегетационного периода – не более 2000°С) урожайность сои и продуктивность зависят от сорта и влагообеспеченности. В среднем по годам урожайность сои составила 1,94…2,62 т/га, масличная продуктивность – 388…544 кг/га, содержание масла – 19…20%, содержание в масле олеиновой и линолевой жирных кислот – 60%, их сбор с урожаем семян составил 300 кг/га. Установлено, что соевое масло и дизельное топливо, обладая близкими свойствами, смешиваются традиционными методами в любых пропорциях и образуют стабильные смеси, которые могут храниться в течение длительного времени. Экспериментальные исследования по использованию масла сои на биодизель были проведены на дизеле Д-245 (4 ЧН 11/12,5). Концентрации токсичных компонентов (СО, СНх, NOx) в отработавших газах дизеля определялись газоанализатором SAE-7532. Дымность отработавших газов измерялась дымомером МК-3 Hartridge. Экспериментально установлено, что перевод дизеля с ДТ на смесь 80% ДТ и 20% СМ приводит к изменению интегральных выбросов за цикл испытаний: оксидов азота в 0,81 раза, монооксида углерода – в 0,89 раза, несгоревших углеводородов – в 0,91 раза, то есть при его использовании в качестве моторного топлива на серийном дизельном двигателе снижаются выбросы всех газообразных токсичных компонентов. Подтверждена целесообразность использования сои северного экотипа на биотопливо.

Ключевые слова: соя, северный экотип, урожайность, белок, масло, насыщенные жирные кислоты, ненасыщенные жирные кислоты, биодизель, дизельное топливо, интегральный выброс.

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USE OF NORTHERN ECOTYPE SOYBEANS FOR BIOFUEL PRODUCTION

SERGEY N. DEVYANIN, *DSc (Eng), Professor*[1]
E-mail: devta@rambler.ru

VLADIMIR A. MARKOV, *DSc (Eng), Professor*[2]
E-mail: vladimir.markov58@yandex.ru

ALEKSANDR G. LEVSHIN, *DSc (Eng), Professor*[1]
E-mail: alev200151@rambler.ru

TAMARA P. KOBOZEVA, *DSc (Ag), Professor*[1]
E-mail: mgau0103@gmail.com

ALEKSEI YU. ALIPICHEV, *PhD (Ed), Associate Professor*[1]
E-mail: al_new2003@mail.ru

[1]Russian State Agrarian University – Moscow Timiryazev Agricultural Academy; Russian Federation, Moscow, Timiryazevskaya Str., 49

[2] Bauman Moscow State Technical University; Russian Federation, Moscow, 2nd Baumanskaya Str., 5, bld. 1

The paper presents the results of long-term research on the oil productivity and chemical composition of soybean oil of the Northern ecotype varieties in the Central Non-Black Earth Region. The authors consider its possible use for biodiesel production. Experiments on growing soybeans were carried out on the experimental field of Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (2008-2019) on recognized ultra-early ripening varieties of the Northern ecotype Mageva, Svetlaya, Okskaya (ripeness group 000). Tests were set and the research results were analyzed using standard approved methods. It has been shown that in conditions of high latitudes (57°N), limited thermal resources of the Non-Chernozem zone of Russia (the sum of active temperatures of the growing season not exceeding 2000°C), the yield and productivity of soybeans depend on the variety and moisture supply. Over the years, the average yield of soybeans amounted to 1.94 … 2.62 t/ha, oil productivity – 388 … 544 kg/ha, oil content – 19…20%, the content of oleic and linoleic fatty acids in oil – 60%, and their output from seeds harvested – 300 kg/ha. It has been established that as soybean oil and diesel fuel have similar properties, they can be mixed by conventional methods in any proportions and form stable blends that can be stored for a long time. Experimental studies on the use of soybean oil for biodiesel production were carried out on a D-245 diesel engine (4 ChN11/12.5). The concentrations of toxic components (CO, CHx, and NOx) in the diesel exhaust gases were determined using the SAE-7532 gas analyzer. The smoke content of the exhaust gases was measured with an MK-3 Hartridge opacimeter. It has been experimentally established that the transfer of a diesel engine from diesel fuel to a blend of 80% diesel fuel and 20% lubrication oil leads to a change in the integral emissions per test cycle: nitrogen oxides in 0.81 times, carbon monoxide in 0.89 times and unburned hydrocarbons in 0.91 times, i.e. when biodiesel as used as a motor fuel in a serial diesel engine, emissions of all gaseous toxic components are reduced. The study has confirmed the expediency of using soybeans of the Northern ecotype for biofuel production.

Key words: soybeans, Northern ecotype, yield, protein, oil, saturated fatty acids, unsaturated fatty acids, biodiesel, diesel fuel, integral emission

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Introduction. Vegetable oil has always been not only food, but also an industrial product used for the production of drying oils, varnishes, paints, soap, glycerin, and cosmetics.

An actively developing trend in the processing of vegetable oil is its use for producing biodiesel (BD) – a type of biofuel obtained from fats of vegetable and animal origin, using it in pure or mixed form to replace diesel oil fuel (DF).

In the world practice, rapeseed oil, sunflower oil, hemp oil, bottle tree oil, and soybean oil are most often used for its production.

The use of soybean oil (SO) for biodiesel is caused by the high level of its production (2/3 of the world) due to the widespread distribution of soybeans (fourth place in the world among cereals and legumes), as well as the content of up to 60% oleic and linoleic fatty acids, which facilitates its application in this area [1, 2].

In Russia, soybeans are cultivated primarily as a valuable high-protein crop (the protein content in seeds is about 40%) for the production of feed, while the conversion rate of soybeans into meat (poultry or pigs) is close to one, (i.e. 1 kg of meat requires 1 kg of grain soybean) [2, 3].

Soybean oil (its seeds contain 20…27% oil) in Russia, despite its high nutritional value (complies with the FAO / WHO standard), is practically not used for food purposes due to its specific taste and lack of corresponding food traditions.

The success practices of Russian breeders and geneticists and the development of soybean varieties of the Northern ecotype in the past three decades, made it possible to introduce the crop to the European part of the country, significantly advancing it to the North (up to 56° North latitude), increasing the cultivated area from 500 thousand hectares in 1990 to 3.0 million hectares in 2020 with a gross grain harvest of about 3.0 million tons, and the production of soybean oil of 0.6 million tons/year [2].

In terms of its physicochemical properties, soybean oil is similar to the oils of other plant crops [4, 5-8]. Under normal conditions, it has a density of 915 to 930 kg/m^3, a kinematic viscosity from 59 to 72 mm^2/s, a pour point ranging from –15 to –18°C, and an iodine number from 120 to 141 units. Since the main properties of soybean oil are close to those of petroleum diesel fuels, it can be used as a motor fuel without significant changes in the engine design; it is only necessary to solve the problem of high viscosity.

Different solutions to this problem can be offered. As an option, an additional heater for oil can be introduced into the power system or oil is mixed with petroleum diesel fuel, just like in the case of the direct use of soybean oil. Use can also be made of the technology of chemical processing of oil into ether, which makes it possible to obtain biodiesel, but the process of using oil as a fuel is somewhat more expensive [9, 10].

For the widespread use of soybean oil as a fuel in agricultural production, the most attractive way is to use a blend of oil with diesel [11]. It does not require complex technological equipment for chemical processing of oil into biodiesel and does not require modernization of a diesel engine with a heating system for oil in the case of its pure supply. Soybean oil and diesel fuel are mixed by conventional methods in any proportion to form stable blends that can be stored for a long time. Therefore, this technology of using soybean oil as a motor fuel is especially promising for testing on a serial diesel engine.

Purpose of the study: to determine the oil productivity and fatty acid composition of the oil of Northern ecotype soybean varieties at high latitudes and to study the possibilities of using it for biodiesel production.

Materials and methods. Experiments on growing soybeans were carried out on the experimental field of Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (2008-2019) on recognized ultra-early ripening varieties of the Northern ecotype Mageva, Svetlaya, Okskaya (ripeness group 000). The experiments were set up and the research results were analyzed in accordance with the standard approved methods [2]. The chemical analysis of seeds was carried out at All-Russian Research Institute of Soybean Growing (Blagoveshchensk) using the NIR-42 installation.

Experimental studies on the use of soybean oil for biodiesel production were carried out on a D-245 diesel engine (4 CHN11 / 12.5) of the Minsk Motor Plant. The diesel engine was tested on a motor bench, which was equipped with a set of necessary measuring equipment. The concentrations of toxic components (CO, CH_x, NO_x) in the diesel exhaust gases (EG) were determined using the SAE-7532 gas analyzer. The smoke content of the exhaust gas was measured with a Hartridge MK-3 opacimeter.

Research results. Long-term studies have shown that soybeans can be successfully cultivated in high latitudes (including in the Central Non-Black Earth Region) with an average yield of 1.94…2.62 t/ha (Table 1). The maximum yield in all varieties was observed in years with optimal moisture supply; it amounted to 2.95 t/ha for the Okskaya variety, 2.74 t/ha for the Mageva variety and 3.12 t/ha for the Svetlaya variety. It has been found that moisture supply is an important factor limiting the yield of soybeans. As a subtropical crop, soybeans are more responsive to insufficient rather than excessive moisture. In addition, low moisture content cannot ensure sufficient biological nitrogen fixation characteristic of all legumes, so nitrogen nutrition worsens, the yield decreases and its quality deteriorates. As a result, in years with insufficient moisture supply, the yield of all varieties was significantly lower (in 1.99 times on average for all the varieties studied), as compared with the optimal moisture supply conditions. Excessive moistening also led to a decrease in the productivity of crops, however, to a lesser extent, in 1.04 times on average for the experiment, which did not exceed the value of an experimental error.

The content of oil in the soybean seeds of the studied varieties was 19…21% on average in the experiment, while unsaturated fatty acids predominated in its composition, which determines its high nutritional value. Their content averaged 69.71% (Table 2). It is important to note that the content of oleic and linoleic fatty acids, which are most valuable for biodiesel production, was high (reaching 60%) in the oil, which is comparable to the varieties of Southern origin.

Table 1

Soybean yield of Northern ecotype varieties depending on moisture supply, t/ha

Таблица 1

Урожайность сои сортов северного экотипа в зависимости от влагообеспеченности, т/га

Moisture supply *Влагообеспеченность*	**Variety** / *Сорт*			**Average by varieties** *В среднем по сортам*
	Okskaya *Окская*	**Mageva** *Магева*	**Svetlaya** *Светлая*	
Excessive / *Избыточная*	2.87	2.56	3.02	2.81
Optimal / *Оптимальная*	2.95	2.74	3.15	2.94
Insufficient / *Недостаточная*	1.34	1.44	1.69	1.49
Average over the years* *В среднем по годам**	1.94	2.24	2.62	2.41

HCP_{05}, t/ha: 0.079

The average oilseed productivity of the varieties studied in the experiment was 482 kg/ha. It was significantly (1.90 times) less in dry years and slightly decreased in years with excessive moisture supply (1.04 times).

The maximum oil productivity was observed in the Svetlaya variety under conditions of optimal moisture supply – it amounted to 630 kg/ha with the highest output of oleic and linoleic fatty acids – 373 kg/ha.

Experimental studies were carried out on a D-245 diesel engine (4 CHN11 / 12.5) of the Minsk Motor Plant. The main parameters of the diesel engine are shown in Table 4.

The tests were carried out on diesel fuel (DF) and a blend of diesel fuel (80%) and soybean oil (20%). Table 5 shows the physicochemical properties of diesel fuel, soybean oil (SO) and their blend.

Table 2

Oil content (%) in soybean seeds and the content of fatty acids in the oil of Northern ecotype varieties (%), average experimental values

Таблица 2

Содержание масла, %, в семенах сои и жирных кислот в масле, %, сортов северного экотипа – в среднем по опыту

Moisture supply *Влагообеспеченность*	**Variety** / *Сорт*			**Average by varieties** *В среднем по сортам*
	Okskaya *Окская*	**Mageva** *Магева*	**Svetlaya** *Светлая*	
Oil content, % / *Содержание масла, %*	21.00	19.00	19.00	20.00
Saturated / *Насыщенные*				
Palmitic / *Пальмитиновая*	11.48	11.46	11.40	11.44
Stearic / *Стеариновая*	3.89	3.86	3.84	3.86
Total / *Сумма*	15.37	15.32	15.23	15.31
Unsaturated / *Ненасыщенные*				
Oleic – monounsaturated (A) *Олеиновая – мононенасыщенная (А)*	9.90	9.78	9.65	9.78
Linoleic acid – polyunsaturated (B) *Линолевая – полиненасыщенная (Б)*	50.76	50.15	49.55	50.15
Linolenic – polyunsaturated (C) *Линоленовая – полиненасыщенная (С)*	6.70	6.91	8.11	7.24
Sum A + B / *Сумма А + Б*	60.6	59.96	59.20	59.93
Sum A + B + C / *Сумма А + Б + С*	70.5	69.74	68.85	69.71

Table 3

Oilseed productivity of the Northern ecotype soybean varieties depending on moisture supply

Таблица 3

Масличная продуктивность сои сортов северного экотипа в зависимости от влагообеспеченности

Moisture supply *Влагообеспеченность*	**Variety** / *Сорт*			**Average by varieties** *В среднем по сортам*
	Okskaya *Окская*	**Mageva** *Магева*	**Svetlaya** *Светлая*	
Oil output, kg/ha / *Сбор масла, кг/га*				
Excessive / *Избыточная*	574	512	604	563
Optimal / *Оптимальная*	590	548	630	589
Insufficient / *Недостаточная*	268	288	338	298
Average over the years* *В среднем по годам**	388	448	524	482
Output of unsaturated fatty acids (oleic + linoleic), kg/ha *Сбор ненасыщенных жирных кислот (олеиновая + линолевая), кг/га*				
Excessive / *Избыточная*	347	306	357	337
Optimal / *Оптимальная*	357	329	373	353
Insufficient / *Недостаточная*	162	345	200	235
Average over the years* *В среднем по годам**	289	327	310	308

HCP_{05}, kg/ha: 31
**HCP_{05}, kg/ha: 19*

Table 4

Diesel parameters D-245 (4 CHN11 / 12.5)

Таблица 4

Параметры дизеля Д-245 (4 ЧН 11/12,5)

Parameters *Параметры*	**Characteristics** *Значение*
Engine type *Тип двигателя*	**Four-stroke, in-line, diesel** *Четырехтактный, рядный, дизельный*
Number of cylinders *Число цилиндров*	4
Total capacity, l *Общий рабочий объем, л*	4,32
Compression ratio *Степень сжатия*	16
Rated speed, min^{-1} *Номинальная частота вращения, мин$^{-1}$*	2400
Rated power, kW *Номинальная мощность, кВт*	80
Cooling system *Система охлаждения*	**Forced liquid-type** *Водяная принудительная*
Fuel system *Система питания*	**Split-type** *Разделенного типа*
Fuel injection pump *Топливный насос высокого давления (ТНВД)*	**In-line type PP4M10U1f from Motorpal with an all-mode centrifugal governor** *Рядный типа PP4M10U1f фирмы Motorpal с всережимным центробежным регулятором*
Fuel injection advance angle, deg. *Угол опережения впрыскивания топлива, град. до ВМТ*	13
Fuel injectors *Форсунки*	**FDP-22 type** *Типа ФДМ-22*
Fuel injector nozzles *Распылители форсунок*	**Manufactured by Motorpal, DOP 119S534 type** *Фирмы Motorpal типа DOP 119S534*
Injection start pressure, MPa *Давление начала впрыскивания форсунок, МПа*	21.5

The tests of the D-245 diesel engine are presented in the modes of full regulatory characteristics on pure diesel fuel and on a blend of 80% diesel fuel and 20% lubricant. The physicochemical properties of this blended biofuel are closer to the properties of diesel fuel rather than those of lubricants, although its density and viscosity are still somewhat higher than that of diesel fuel (Table 5). This could be the reason for a slight increase in the specific (hourly) fuel consumption G_T by the fuel system during the transition from diesel fuel to the studied blended biofuel, because additional adjustments of the engine and fuel equipment were not made. Despite the increase in fuel consumption, the engine torque and its effective power remained practically unchanged (Fig. 1 and Table 5).

From the results obtained while testing a diesel engine (Fig. 1 and Table 5), it follows that the power indicators of the engine practically did not change (the changes in the torque Mk and the effective power Ne do not exceed 1%, i.e., they are within the measurement error) despite the fact that no additional adjustments of the injection pump were made. The change pattern in the speed n following a change in the effective engine power also remains the same. Consequently, switching the engine of a tractor or combine to a mixed fuel will not cause changes in the machine operation determined by the type of the work carried out. The introduction of mixed fuel does not require additional adjustments in the machine and its engine.

When switching from diesel fuel to the studied blended biofuel, the indicators of hourly and specific effective fuel consumption change. Thus, at the rated power mode with a crankshaft speed n = 2400 min^{-1}, the hourly fuel consumption G_T increased from 20.1 to 20.4 kg/h (by 1.5%), and the specific effective consumption g_e increased from 248.4 up to 253 g/(kWh) or by 1.8%, and at the maximum torque mode (n = 1500 min^{-1}) Gt increased from 13.1 to 13.5 kg/h (by 3%), and g_e increased from 226.2 to 232.2 g/(kWh), or 2.6%.

Table 5

Physicochemical properties of the studied fuels

Таблица 5

Физико-химические свойства исследуемого топлива

Properties *Свойства*	**DF** *ДТ*	**SO** *СМ*	**Blend of 80% DF and 20% SO** *Смесь 80% ДТ и 20% СМ*	**Change in the blend as to the amount of diesel fuel** *Изменение в смеси относительно ДТ*
Density at 20°C, kg/m³ *Плотность при 20°C, кг/м³*	830	923	848.6	1.02
Kinematic viscosity at 20°C, mm²/s *Кинематическая вязкость при 20°C, мм²/с*	3.8	65	8	2.11
Surface tension coefficient at 20°C, mN/m *Коэффициент поверхностного натяжения при 20°C, мН/м*	27.1	33	n	
Net calorific value, MJ/kg *Низшая теплота сгорания, МДж/кг*	42.5	37.3	41.46	0.98
Cetane number *Цетановое число*	45	38	n	
Auto-ignition temperature, °C *Температура самовоспламенения, °C*	250	310	n	
Cloud point, °C *Температура помутнения, °C*	-25	-10	n	
Pour point, °C *Температура застывания, °C*	-35	-18	n	
Amount of air required for the combustion of 1 kg of fuel, kg *Количество воздуха, необходимое для сгорания 1 кг топлива, кг*	14.16	12.38	13.804	0.97
Content, % by weight / *Содержание, % по массе:*				
- C	87	77/5	85.1	0.98
- H	12/6	11/5	12.4	0.98
- O	0.4	11	2.5	6.30
Total sulfur content, wt% *Общее содержание серы, % по массе*	0.2	0.005	0.161	0.81

Note: "n" – properties were not determined; for the blend, the volume percentage of the components is indicated.

The effective efficiency of the diesel engine h_e in these modes did not decrease, and even slightly increased in the nominal power mode at n = 2400 min^{-1} (Table 6). This leads to a conclusion that the efficiency of using a blended fuel in an engine is not inferior to that of diesel fuel, and an increase in specific fuel consumption is associated with a decrease in the calorific value of the mixed fuel, which is 2% lower than the calorific value of diesel fuel (Table 6).

The increased oxygen content in the mixed fuel by a factor of 6.3 as compared with diesel fuel (Table 5) led to a noticeable decrease in exhaust gas smoke (Kx on the corrector branch of the regulatory characteristic). So, in the maximum power mode at n = 2400 min^{-1}, the transition from diesel fuel to a blend of 80% diesel fuel and 20% lubricant was accompanied by a decrease in Kx from 16 to 8% on the Hartridge scale or in 2 times, and in the maximum torque mode at n = 1500 min^{-1} from 43 to 27% or in 1.6 times (Fig. 1, Table 6).

The environmental characteristics of the D-245 engine were assessed based on the experimental results of its studying at 13-stage test cycle modes of UNECE Regulation 49, which are presented in Table 7. Specific emissions of toxic components of nitrogen oxides e_{NOx}, carbon monoxide e_{CO} and unburned hydrocarbons e_{CHx} were determined in accordance with the UNECE Regulation 49methodology.

The results of studying the toxicity of exhaust gases of a diesel engine show the advantages of using blended biofuel as compared with diesel oil fuel. As follows from Table 7, the conversion of a diesel engine from diesel fuel to a blend of 80% diesel fuel and 20% SO leads to a change in the integral emissions for the test cycle of nitrogen oxides e_{NOx} in 0.81 times, carbon monoxide e_{CO} in 0.89 times and unburned hydrocarbons e_{CHx} in 0.91 times, i.e. emissions of all gaseous toxic components are reduced.

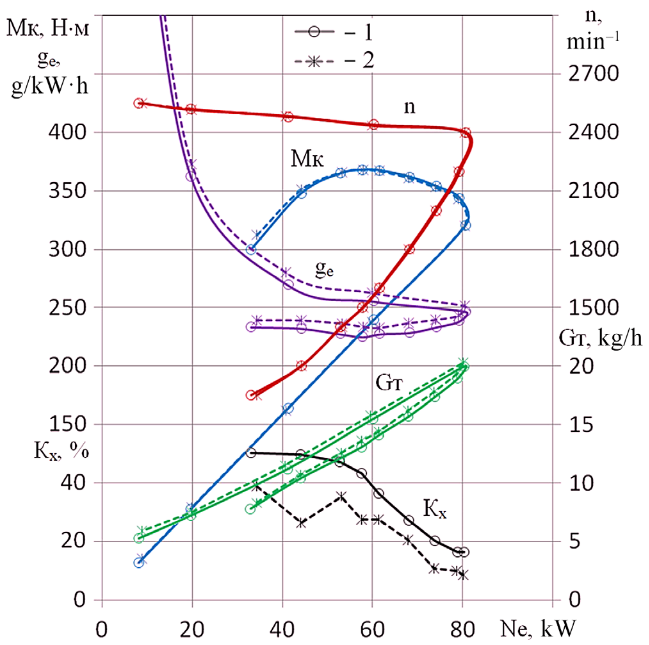

Fig. 1. Regulatory characteristics of the D-245 diesel engine when operating on various fuels:
1 – diesel fuel; 2 – a blend of 80% DF and 20% SO;
n – crankshaft speed, min^{-1}; $M_к$ – diesel engine torque, N·m;
g_e – specific effective fuel consumption, g/kW·h;
Gт – hourly fuel consumption, kg/h; K_x – exhaust gas opacity, %;
N_e – effective engine power, kW

Рис. 1. Регуляторная характеристика дизеля Д-245 при работе на различном топливе:
1 – ДТ; 2 – смесь 80% ДТ и 20% СМ;
n – частота вращения коленчатого вала, мин$^{-1}$;
$M_к$ – крутящий момент дизеля, Н·м;
g_e – удельный эффективный расход топлива, г/кВт·ч;
Gт – часовой расход топлива;
K_x – дымность отработавших газов, %;
N_e – эффективная мощность двигателя, кВт

Thus, the data given in Tables 6 and 7 confirm the possibility of improving the environmental performance of the D-245 diesel when shifting from diesel fuel to a blend of 80% diesel fuel and 20% SO. So, at the modes of maximum power and maximum torque, when a blend of 80% DF and 20% SO was supplied to the combustion chamber of a diesel engine, the exhaust gas opacity decreased by 37…50% as compared to using a standard diesel fuel. When studying the indicators of a diesel engine running on the considered fuel blend, a decrease in the 13-stage cycle modes of integral specific mass emissions of all three gaseous standardized toxic components of exhaust gas was noted: e_{NO} – by 19%, from 7.02 to 5.68 g/(kWh); e_{CO} – by 10.9%, from 1.72 to 1.54 g/(kWh); e_{CH} – by 9.3%, from 0.79 to 0.72 g/(kWh).

It should be noted that the obtained indicators for the engine indicate a possibility of maintaining the energy characteristics of the machine (without losing its performance), without making design changes to the engine or adjusting it. On the one hand, this simplifies the process of using a blended fuel on the machine, and on the other hand, it allows achieving even greater energy performance of the engine by optimizing the design and adjustments of the fuel equipment when operating on the blended biofuel. For example, an increased stock of smoke in the exhaust gases allows operating with increased fuel supplies, thus providing both more power at the nominal mode and an increased torque backup, increasing its adaptability to overloads.

It should be noted that soybean oil obtained as a by-product of protein feed production for cattle can be also used for producing blends of DT and SO. Suitable for technical use are vegetable oils from seed oil grown in unfavorable environmental conditions (land located near highways, oil storage facilities, environmentally harmful industries, etc.).

Low-quality and expired vegetable oils, frying oils – waste from the food industry and public catering facilities can also serve as raw materials for the production of motor fuels.

Table 6

Indicators of the D-245 diesel engine running on petroleum diesel fuel and its blend with SO

Таблица 6

Показатели дизеля Д-245, работающего на нефтяном ДТ и его смесях с СМ

Indicators of diesel engine *Показатели дизеля*	**DF** *ДТ*	**Blend of 80% DF and 20% SO** *Смесь 80% ДТ и 20% СМ*	**Change in the indicator** *Изменение показателя*
Hourly fuel consumption G_T, kg/h / *Часовой расход топлива G_T, кг/ч:*			
- in a rated power mode / *на режиме номинальной мощности*	20.1	20.4	1.015
- in a maximum torque mode / *на режиме максимального крутящего момента*	13.1	13.5	1.031
Diesel torque Mk, N·m / *Крутящий момент дизеля Mк, Н·м:*			
- in a rated power mode / *на режиме номинальной мощности*	322	320	0.994
- in a maximum torque mode / *на режиме максимального крутящего момента*	368	368	1.000
Specific effective fuel consumption g_e, g/(kW·h) *Удельный эффективный расход топлива g_e, г/(кВт·ч):*			
- in a rated power mode / *на режиме номинальной мощности*	248.4	253	1.019
- in a maximum torque mode / *на режиме максимального крутящего момента*	226.2	232.2	1.027
Effective diesel engine efficiency / *Эффективный КПД дизеля:*			
- in a rated power mode / *на режиме номинальной мощности*	0.341	0.343	1.006
- in a maximum torque mode / *на режиме максимального крутящего момента*	0.374	0.374	1.000
Exhaust gas opacity Kx / *Дымность ОГ Kx:*			
- in a rated power mode / *на режиме номинальной мощности*	16	8	0.500
- in a maximum torque mode / *на режиме максимального крутящего момента*	43	27	0.628

Table 7

Environmental indicators of the D-245 diesel engine observed during bench tests

Таблица 7

Экологические показатели дизеля Д-245 при стендовых испытаниях

Indicators of diesel engine *Показатели дизеля*	**DF** *ДТ*	**Blend of 80% DF and 20% SO** *Смесь 80% ДТ и 20% СМ*	**Change in the indicator** *Изменение показателя*
Integral specific mass emissions at 13-stage cycle modes, g/(kW·h): *Интегральные удельные массовые выбросы на режимах 13-ступенчатого цикла, г/(кВт·ч):*			
- **nitrogen oxides** e_{NOx} / *оксидов азота* e_{NOx}	7.02	5.68	0.810
- **carbon monoxide** e_{CO} / *монооксида углерода* e_{CO}	1.72	1.54	0.891
- **unburned hydrocarbons** e_{CHx} / *несгоревших углеводородов* e_{CHx}	0.79	0.72	0.907

Conclusions

1. The yield of soybean varieties of the Northern ecotype in conditions of high latitudes (57°N) of the Non-Black Earth Zone of Russia averaged between 1.94 and 2.62 t/ha over the years of study. The maximum yield of the studied varieties was observed in years with optimal moisture supply: 2.95 t/ha – for the Okskaya variety, 2.74 t/ha – for the Mageva variety, and 3.12 t/ha – for the Svetlaya variety. In years with insufficient moisture supply, the yield of all varieties was significantly lower (in 1.99 times on average for varieties).

2. The oil content in the seeds of the studied varieties in the experiment averaged between 19 and 21%, while unsaturated fatty acids predominated in its composition (69.71%). The content of oleic and linoleic fatty acids, most valuable for biodiesel, was high in the oil (reaching 60.00%) and was comparable to the varieties of Southern origin.

3. Oilseed output of the studied varieties averaged 482 kg/ha, it was significantly (1.90 times) lower in dry years and slightly decreased in years with excessive moisture (1.04 times). The maximum oil productivity was observed in the Svetlaya variety under conditions of optimal moisture supply – it amounted to 630 kg/ha with the highest output of oleic and linoleic fatty acids – 373 kg/ha.

4. The use of mixed fuel (0.8 DT and 0.2 SO) in the tractor or combine engines did not lead to changes in the machine performance, because the power indicators of the engine remain practically the same as compared with diesel fuel. Conversion of equipment to mixed fuel does not require additional adjustments in the machine and its engine.

5. The use of blended fuel instead of diesel oil fuel made it possible to reduce the opacity of exhaust gases by 37…50% and reduce the integral indicators of standardized toxic emissions with exhaust gases in the test cycle (according to UNECE Rules 49): by 19% – for nitrogen oxides, by 10.9% – for carbon monoxide and by 9.3% –for hydrocarbons.

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