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DEVELOPMENT OF A FUEL HEATING SYSTEM FOR THE AGRICULTURAL AUTOMOTIVE DIESEL ENGINES USING EXHAUST GASES

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The article provides an analysis of the operation of automotive vehicles with a diesel engine in the cold season. The technical means used to maintain the optimal thermal regime of the diesel fuel system under low-temperature conditions are considered. The relevance of research aimed at improving the fuel heating system using exhaust gases is substantiated. A method for substantiating the parameters of the fuel heating system in the tank using exhaust gases and equipment used in experimental studies is proposed. This article presents conclusions derived from theoretical analysis and practical experiments, based on which a design and optimal parameters of the fuel heating system elements are proposed. It includes dependencies of fuel heating time in the fuel tank on engine operating mode, fuel mass in the tank, and ambient air temperature.

Research tests have established that the equipment of automotive vehicles with the proposed fuel heating system during operation in the cold season contributes to an increase in the average readiness coefficient of the vehicle from 0.81 to 0.87. The research findings can be applied when using automotive vehicles with a diesel engine in the winter season to improve their technical characteristics.

Key words: *automotive vehicles, diesel fuel, exhaust gases, heating system, readiness factor.*

ПАЙДАЛАНЫЛҒАН ГАЗДАРДЫ ҚОЛДАНА ОТЫРЫП, АУЫЛ ШАРУАШЫЛЫҚ АВТОТРАКТОРЛЫҚ ДИЗЕЛЬДЕРДІҢ ЖАНАРМАЙ ЖЫЛЫТУ ЖҮЙЕСІН ӘЗІРЛЕУ

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Мақалада жылдың суық мезгілінде дизельді автотрактор көліктерінің жұмысына талдау келтірілген. Төмен температура жағдайында жұмыс істегенде дизельді қоректендіру жүйесінің оңтайлы жылу режимін сақтау үшін қолданылатын техникалық құралдар қарастырылады. Пайдаланылған газдарды пайдалана отырып, отынды жылыту жүйесін жетілдіруге бағытталған зерттеулердің өзектілігі негізделген. Пайдаланылған газдарды және эксперименттік зерттеулерде қолданылатын жабдықты пайдалана отырып, бактағы отынды жылыту жүйесінің параметрлерін негіздеу әдістемесі ұсынылды. Бұл мақалада теориялық талдаулар мен практикалық тәжірибелер нәтижесінде алынған қорытындылар сипатталған, оның негізінде отынмен жылыту жүйесінің элементтерінің диаграммасы мен ұтымды параметрлері, отын бағындағы отынның қыздыру уақытының электр энергиясына тәуелділігі ұсынылған. Қозғалтқыштың жұмыс режимі, резервуардағы жанармайдың массасы және қоршаған ауа температурасы берілген. Зерттеу сынақтары жылдың суық мезгілінде пайдалану кезінде отынды жылыту жүйесі ұсынған автотрактор көлігінің жабдықтары техниканың орташа дайындық коэффициентін 0,81-ден 0,87-ге дейін арттыруға ықпал ететіндігін анықтады. Зерттеу нәтижелерін дизельді автотракторларды қыста пайдалану кезінде олардың техникалық сипаттамаларын жақсарту мақсатында қолдануға болады.

Түйінді сөздер: *автотрактор көліктері, дизель отыны, пайдаланылған газдар, жылыту жүйесі, дайындық коэффициенті.*

РАЗРАБОТКА СИСТЕМЫ ПОДОГРЕВА ТОПЛИВА СЕЛЬСКОХОЗЯЙСТВЕННЫХ АВТОТРАКТОРНЫХ ДИЗЕЛЕЙ С ИСПОЛЬЗОВАНИЕМ ОТРАБОТАВШИХ ГАЗОВ

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В статье приведен анализ эксплуатации автотракторных средств с дизельным двигателем в холодный период года. Рассмотрены технические средства, применяемые для поддержания оптимального теплового режима системы питания дизеля при работе в условиях низких температур. Обоснована актуальность исследований, направленных на совершенствование системы подогрева топлива с использованием отработавших газов. Предложена методика обоснования параметров системы подогрева топлива в баке с использованием отработавших газов и оборудование, применяемое при экспериментальных исследованиях. В данной статье описаны выводы, полученные в результате теоретического анализа и практических экспериментов, на основании которых предложены схема и рациональные параметры элементов системы подогрева топлива, приведены зависимости времени нагрева топлива в топливном баке от режима работы двигателя, массы топлива в баке и температуры воздуха окружающей среды. Исследовательскими испытаниями установлено, что оборудование автотракторных средств с предложенной системой подогрева топлива при эксплуатации в холодный период года способствует увеличению среднего коэффициента готовности техники от 0,81 до 0,87. Полученные выводы исследований могут применяться при использовании автотракторных средств с дизельным двигателем в зимний сезон с целью улучшения их технических характеристик.

Ключевые слова: *автотракторные средства, дизельное топливо, отработавшие газы, система подогрева, коэффициент готовности.*

Introduction

The use of motor vehicles in agriculture is carried out all year round. It is also determined by the continuity of various production processes in all sectors of the economy. At the same time, the volume of transport work carried out in winter by car and tractors in the Republic of Kazakhstan is up to 20% of the annual volume [1, p.3]. In practice, it has been proven that the operation of automotive diesel engines at low temperatures (especially below -20°C) is accompanied by an increase in the number of failures of fuel systems due to the crystallization of free water in the fuel, paraffinization of fuel, the effect of frost formation in fuel tanks [2, p.3]. As a result of increasing the viscosity of the fuel, its pumpability through fuel pipelines, fuel filters and injectors deteriorates, which leads to an absolute cessation of fuel supply. At the same time, the driver's ability to detect and eliminate fuel system failures on the way is limited due to the complexity of the power supply system and severe temperature conditions. The waste heat generated during the operation of fuel cells can be used in various ways in the thermal control system of fuel cell vehicles using various system designs [3, p.5]. Even when using winter grades of diesel fuel, the possibility of failures of the diesel fuel system in low temperature conditions increases, which leads to a decrease in the operational performance of motor vehicles, an increase in repair costs and a decrease in the availability factor of equipment. Although only a small part can be converted into high-quality energy, there is still potential for further reduction of fuel consumption in diesel engines [4, p.7]. Currently, in order to eliminate cases of freezing of diesel fuel, various fuel heaters are actively used in the power supply system, the use of which requires additional energy sources. An analysis of the technical means used for heating fuel shows that not one of the types of heaters (flow, overhead, built-in) is not able to provide the required fuel temperature in the power supply system in all operating modes of automotive vehicles: starting and warming up the engine after prolonged parking; the process of moving equipment; short-term stop of the car or tractor with the engine running (idle mode); short-term stop with the engine not running. So, when starting the engine after a long parking period, the use of electric heaters of filters and fuel intakes is effective, when moving equipment, fuel heating in the tank due to exhaust gases, etc. In this regard, the most rational option is the integrated use of fuel heaters, which will ensure a stable fuel temperature in the power supply system, potential loading on the on-board electrical network of equipment and effective use of internal thermal reserves of automotive vehicles (exhaust gas heat).

The scientific papers of Khalturin D.V., Udler E.I. and others are devoted to the issues of ensuring the optimal thermal regime of the power supply system for automotive vehicles [5, p.3, 6, p.47]. Most of the research is aimed at studying the processes of heating fuel in the filter and main part of the fuel system, where electric current from the on-board network is used as an energy source. At the same time, in the works of Kurnosov A.F., Ivannikov A.B., Krokhta G.M. and others. Studies confirming the effectiveness of the use of exhaust gases (which account for up to 35% of the heat of the fuel burned in the engine) for heating components and assemblies of machines are presented [7, p.4, 8, p.28]. At the same time, the issues of using exhaust gases as a coolant when heating fuel in the fuel system of a car and tractors, substantiating the rational parameters of the heating system, and the influence of external factors on fuel temperature remain insufficiently studied. Well-known heaters of fuel tanks of automotive vehicles, operating on the basis of exhaust gases, do not always meet safety requirements, are complex and require changes in the tank design, which reduces their capacity [9, p.1].

In this regard, research aimed at improving the fuel heating system and the development of technical means to ensure the stable operation of the diesel engine power supply system for automotive vehicles when operating in low temperature conditions is relevant.

The purpose of the work. Improving the performance of diesel-powered motor vehicles when used at low temperatures by improving the fuel heating system.

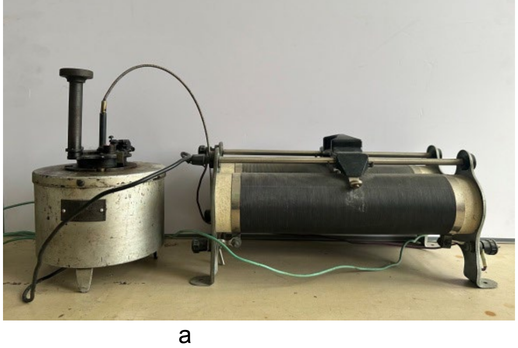
Tasks. Justify the parameters of the fuel heating system in the tank using exhaust gases. Establish the relationship between the fuel heating time in the tank and the engine operating modes, fuel mass and ambient temperature.

Materials and methods

An important parameter determining the possibility of using diesel fuel at low temperatures is its characteristics at low temperatures. Of particular importance is the flash point of the fuel – this is the minimum temperature at which fuel vapors heated in a closed vessel and forming a combustible mixture with the surrounding air begin to burn when a flame is brought to them. For diesel fuel intended for use in summer, this parameter must be at least 40 °C, for winter fuel – at least 35°C, and for Arctic fuel – at least 30 °C. The higher the flash point, the lower the risk of fuel ignition.

Figure 1 shows a device designed to measure the flash point of petroleum products in a closed vessel. The following elements are located on the upper lid of the vessel: a lever with a mechanism for moving it, an ignition initiator, a tube for a thermometer and an agitator with a flexible shaft. There are cutouts in the lid. In the inactive state, they are closed by a lever with two holes. When the lever is turned, the side cutouts in the lid open, and the protrusion rests against the lower part of the ignition initiator, tilting it towards the cutout in the lid. The lever and initiator return to the initial position occurs under the influence of a spring located in the rod of the lever movement mechanism.

A special device known as an agitator is used to mix petroleum products with air and its vapors. It consists of a rod with two pairs of blades fixed on it. The lower pair of blades mixes the oil product, while the upper pair mixes vapors with air. The rotation of the blades is carried out either manually or with the help of an electric motor, which provides a rotation speed in the range of 90-120 revolutions per minute.



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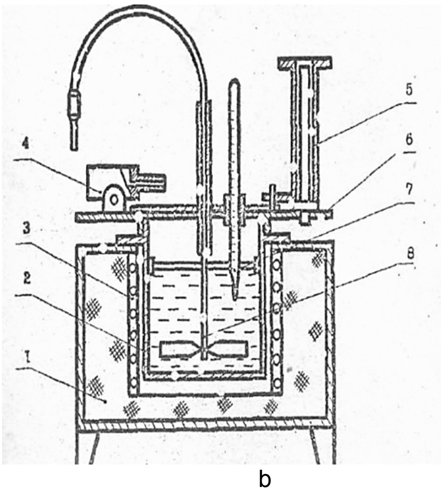


b

a – general view, b – scheme

1 – body; 2 – crucible; 3 – heating element; 4 – incendiary device; 5 – handle; 6 – flap; 7 – thermometer; 8 – agitator

Figure 1 – Flash point detection device

Studies to assess the efficiency of using exhaust gases to heat fuel in a fuel storage tank were conducted on the basis of an automotive diesel engine for a KamAZ-53215 truck with an engine power of 176 kW and a tank with a capacity of 350 liters.

Based on the theory of engines and the theory of heat transfer, the amount of exhaust gases and their temperature, the potential amount of heat from the exhaust gases, the value of the heat flux used to heat the fuel from the heat transfer condition, and the time to heat the fuel were determined. The exhaust gas supply circuit into the subcortical space of the car includes a muffler, tee and fuel tank casing (Figure 2).

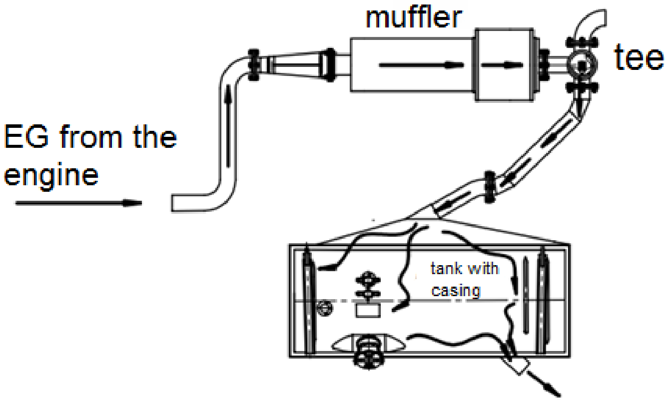
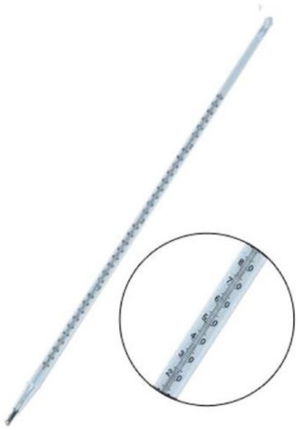


Figure 2 – Diagram of the movement of exhaust gases in the fuel tank heating mode

Exhaust gases from the engine pass through the muffler and enter the tee, where they are directed into the space between the casing and the tank (Figure 2). By washing the bottom of the tank and the side walls, the exhaust gases give off heat and go outside. When operating in normal mode, the valve in the tee is set to a position where gases are removed through it into the atmosphere.

To substantiate the parameters of the casing, experimental studies were conducted, where the optimization criterion was the distance from the inner surface of the tank to the outer surface of the shell. the casing r, which determines the parameters of the casing, taking into account the overall dimensions of the fuel tank. The following restrictions are accepted: the minimum value r =0.02 m (limited by the permissible exhaust resistance) and the maximum r=0.08 m (limited by the vehicle clearance). The experimental procedure provided for determining the time for heating diesel fuel $t_н$ in the fuel tank to a temperature of 10°C at a distance from the tank wall to the casing wall r = 0.02; 0.04; 0.06; 0.08 m. Each experiment was carried out in 3-fold repetition. The conditions for conducting experimental studies are as follows: diesel fuel grade DT-Z – minus 25-K2 according to GOST 305-2013, initial fuel temperature in the tank t_0= -14 °C, fuel mass in the tank M_{fuel} = 100 kg, fuel tank heating area $S_{p.b}$= 2.6 m2, engine crankshaft speed n=1600 $min^{-1.}$ The instruments and equipment used in experimental studies are shown in Figure 3.



a

b

c

a – laboratory thermometer TL-2 No. 1; b – tachometer PM10-R; c – stopwatch SDSPR-1-2.000

Figure 3 – Instruments and equipment

For an experimental assessment of the efficiency of the spent gas fuel heating system, the time for heating the fuel in the tank t_n (to a temperature of 10 °C) was taken as a criterion, its determining factors were established – the mass of fuel in the M_{fuel} tank, the heating area of the fuel tank $S_{p.b}$, the initial temperature of the fuel in the tank t0, the operating mode of the engine n. Experimental studies were conducted according to the plan of a one-factor experiment. The variable factors were the mass of fuel in the tank M_{fuel} = 50; 150; 250 kg, engine operating mode n = 600; 1100; 1600; 2100 min-1, the initial fuel temperature determined by environmental conditions (air temperature) t_0= – 29; – 21; – 15; – 9 °C. The value of the heating area of the fuel tank was assumed to be the maximum $S_{p.b}$ = 2.6 m^2 based on the geometric dimensions of the bottom and side walls of the fuel tank. A fuel level sensor DTU was used to record the temperature and amount of fuel in the fuel tank during the movement of the DTU-2-06-410 with a measurement error of fuel level ± 0.25% and temperature ± 1 °C.

For a comparative assessment of a technical means equipped with a fuel heating system and a basic technical means with a diesel engine, when operating at low temperatures, an operational indicator was used – an average indicator of readiness for work, which was determined in accordance with GOST R27.010-2019 [10, p.22]. The time indicators of the operable and inoperable condition of the compared cars during the 3 winter months were determined by timing, taking into account the same amount of work performed by the cars.

Result of work

The amount of exhaust gases sent to heat the fuel tank varies depending on the operating mode of the engine. As the crankshaft speed increases, the amount of exhaust gases increases and, accordingly, the total amount of heat from them. Thus, when changing the crankshaft speed from 1000 to 2200 min^{-1}, the thermal power of the exhaust gases increases from 27.0 to 71.3 kW (under conditions of ambient air temperature -30 °C and exhaust gas temperature 200 °C). At the same time, only a part of the heat from the gases can be used to form a heat flow for heating the fuel, since it is limited by the heat transfer coefficient and the heating area (Figure 4).

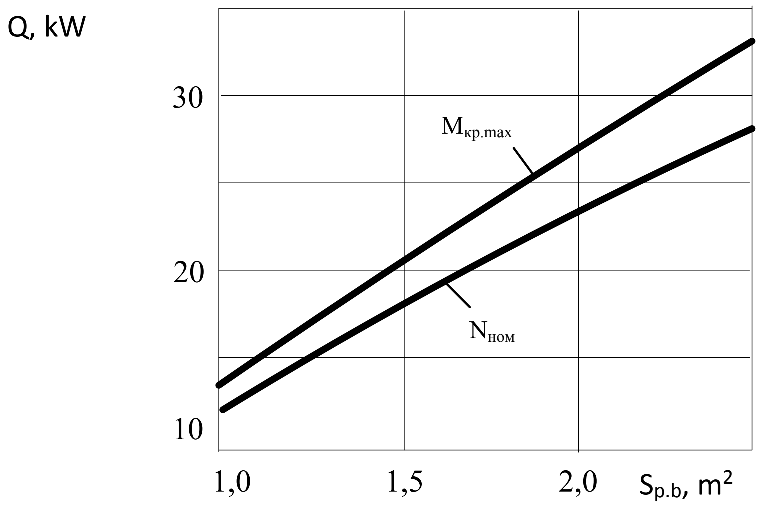


Figure 4 – Dependence of the heat flow power for fuel heating Q on the heating area of the fuel tank $S_{p.b}$ and the operating mode of the engine n

It can be seen from the graph in Figure 4 that with an increase in the heating area from 1.0 to 2.5 m^2, the power of the heat flow that can be used to heat fuel increases 2.5 times. In the case of an internal combustion engine operating at maximum torque of $M_{kr.max}$, the exhaust gas temperature is 50 °C higher, which provides an increase in the heat flow power for heating fuel up to 18% compared with the rated power mode (Figure 4).

Thus, in order to ensure the highest value of the heat flow power for fuel heating, it is necessary to take the maximum heating area determined by the design of the fuel tank.

To substantiate the design parameters of the fuel tank casing, an experimental dependence of the fuel heating time in the fuel tank t_n on the distance between the walls of the fuel tank and the casing r was obtained (Figure 5).

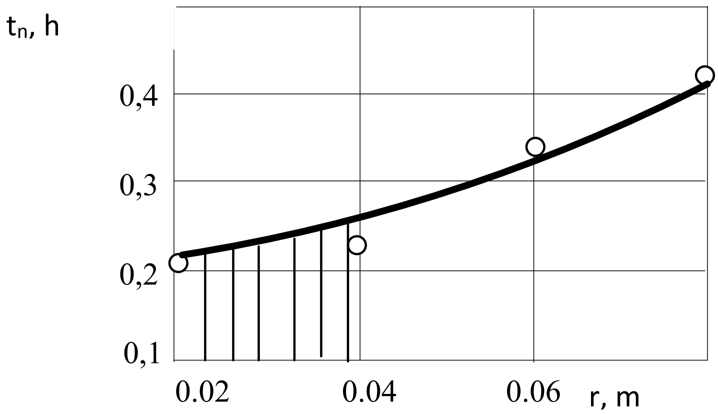
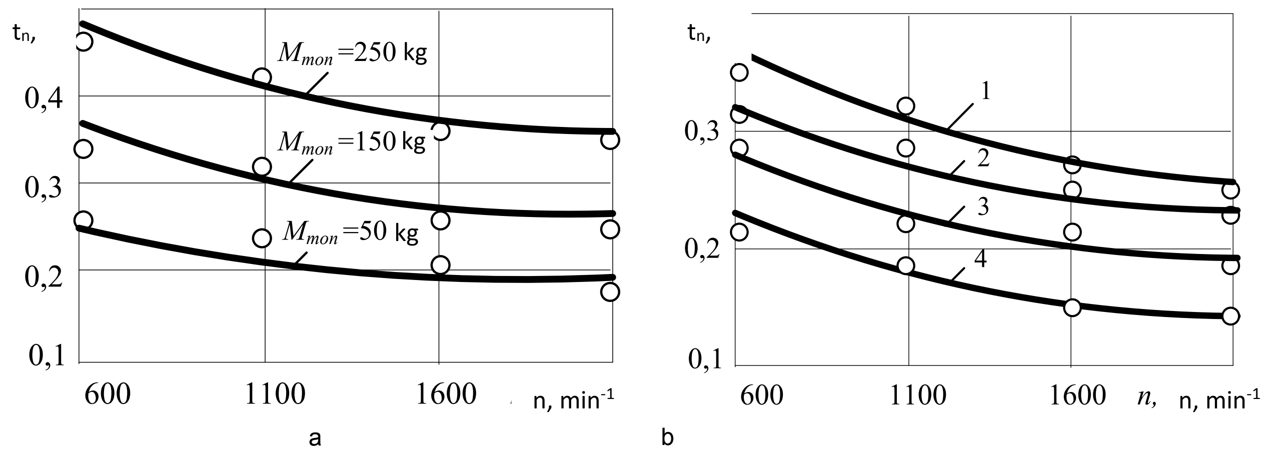


Figure 5 – Dependence of fuel heating time t_n on the distance between the walls of the fuel tank and the casing r

From the graph, it can be seen that with an increase in the distance between the walls of the fuel tank and the casing r from 0.02 to 0.08 m, the heating time of the fuel t_n increases by 2.0 times (Figure 5). With a rational value of r = 0.02-0.04 m, the following design parameters of the casing are accepted: length – 1.19-1.23 m, height – 0.69-0.73 m, width – 0.57-0.61 m.

The study of the effects of variables that determine the time interval for heating diesel fuel in the car tank was conducted on the basis of experimental studies, which resulted in the dependences $t_n = f(M_{fuel}, t_0, n)$ (Figure 6).



a – at t_0 = – 29; b – at M_{fuel} = 150 kg;
1 – t_0= – 29°C; 2 – t_0= – 21°C; 3 – t_0= – 15°C; 4 – t_0= – 9°C

Figure 6 – Dependences of the fuel heating time t_n on the operating mode of the engine n, the mass of fuel in the M_{fuel} tank and the ambient air temperature t_0

It can be seen from the graph (Figure 6a) that with an increase in the mass of fuel in the tank from 50 to 250 kg, the time for heating the fuel increases by 1.7-1.8 times. When the ambient temperature decreases from t0 from -9°C to -29°C, the period required to heat the fuel in the fuel tank to a temperature of 10°C increases by 40.0-44.1% (Figure 6 b). With an increase in crankshaft speed n from 600 to 2100 min-1, there is a decrease in fuel heating time by 24.2-34.4% (Figure 6 a, b).

As a result of a comparative assessment, it was found that the average readiness coefficient of a truck equipped with the proposed fuel heating system during operation in the cold season was 0.87, and the base car was 0.81.

Discussion

The possibility of using exhaust gases to heat fuel in the tank arises when the car engine is running during cargo transportation, or in idle mode during parking and stops. The potential thermal power of the exhaust gases is quite sufficient to effectively heat the fuel in the fuel tank of an automotive vehicle, but its use is limited by the coefficient and area of heat transfer, as a result, only a part of the thermal power of the exhaust gases is used to heat the fuel. The power of the heat flow used to heat the fuel depends on two main factors – the heating area of the fuel tank and the temperature of the exhaust gases (Figure 4). The first factor is determined by the geometric dimensions of the fuel tank of the car with a capacity of 350 liters, where it is possible to use the bottom and side walls of the tank for heat transfer, the total area of which is the maximum heating area $S_{p.b}$ = 2.6 m^2, the second factor is the operating mode of the engine. With an increase in the speed of the crankshaft of the internal combustion engine, the number of exhaust gases increases and, accordingly, the flow rate of gases blowing over the heat transfer surfaces, which leads to a more stable temperature regime of gases in the contact zone with the tank walls. This statement corresponds to the results of experimental studies, so with an increase in rpm n from 600 to 2100 min^{-1}, the time for heating fuel in the tank with exhaust gases t_n decreases by 25-35% (Figure 5, a, b). During operation of the internal combustion engine at maximum torque speeds, the exhaust gas temperature increases due to more intensive fuel combustion.

The use of a casing in the proposed fuel heating system with parameters justified by the criterion of minimum time spent on heating diesel fuel t_n creates conditions for effective heat transfer without significant loss of coolant temperature.

As a result of an experimental assessment of the factors determining the time for heating fuel in the car tank, it was found that the main effect on this parameter is the volume of fuel in the tank, so reducing the mass of fuel in the tank by 50 kg reduces the time for heating fuel by an average of 25%. With a decrease in the temperature regime of atmospheric conditions and, accordingly, the initial temperature of the fuel in the tank by 6-8 ° C, the time required for heating the fuel increases by an average of 18%.

In general, the developed diesel fuel heating system using exhaust gases allows for 0.5 hours to provide fuel heating in the tank of the KamAZ-53215 truck automotive diesel to positive temperature values in the cold season and maintain the required fuel temperature of 10-20 °C during operation of the car.

As a result of the integrated use of fuel heaters (an overhead fuel filter heater and the use of exhaust gases to heat the fuel tank), a stable start of the car engine is ensured at low temperatures and the optimal fuel temperature in the fuel design system, preventing the likelihood of "snagging" fuel in fuel lines during the operation of the car. The use of an integrated option for heating the fuel of an automotive diesel engine on a KamAZ-53215 car in the cold season contributes to an increase in the average equipment availability coefficient from 0.81 to 0.87.

Conclusion

Based on theoretical studies, the dependences of the heat flow power for fuel heating Q on the heating area of the fuel tank $S_{p.b}$ and the engine operating mode n have been established.

A scheme for supplying exhaust gases to the undercarriage of the car, which includes a muffler, tee and fuel tank casing, has been proposed. As a result of experimental studies, rational design parameters of the fuel tank casing were substantiated: length – 1.19-1.23 m, height – 0.69-0.73 m, width – 0.57-0.61 m.

The dependences of the heating time of fuel t_n in the car tank on the operating mode of the engine n, the mass of fuel in the M_{fuel} tank and the ambient air temperature t0 are established.

A system for the integrated use of fuel heaters (overhead fuel filter heater and spent gas fuel tank heating) on an automotive diesel engine for a truck is proposed, the use of which in the cold season provides an increase in the average equipment availability coefficient in comparison with the base from 0.81 to 0.87.

The obtained research results can be used in the operation of automotive diesel engines in the cold season in order to improve their operational technical and operational efficiency.

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АДАПТИВНЫЕ МОРФОЛОГИЧЕСКИЕ РЕАКЦИИ ИВЫ БЕЛОЙ *(SALIX ALBA L.)*, ПРОИЗРАСТАЮЩЕЙ В ПОЙМЕ РЕКИ БУХТАРМА КАТОН-КАРАГАЙСКОГО ГНПП

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В статье рассмотрены адаптивные морфологические реакции ивы белой (Salix alba L.), произрастающей в Катон-Карагайском государственном национальном природном парке. В Катон-Карагайском государственном национальном природном парке (ГНПП), были проведены исследования лесных экосистем на пробных площадях общей площадью 5,9 га. В состав древостоя первого яруса входят ива белая (Salix alba L.) и берёза бородавчатая (Betula pendula), со средним диаметром ствола 16,1 см и средней высотой 4,3 м. Ива белая в данном районе оценивается как "здоровая" с индексом относительного жизненного состояния (ОЖС) 87,5%. Содержание хлорофилла, а в листьях варьирует от 0,55 до 0,6 мг/г сырой массы, хлорофилла b – от 0,11 до 0,14 мг/г, каротиноидов – от 0,13 до 0,14 мг/г. Почвенные условия характеризуются высоким содержанием подвижных элементов питания в горизонте. А: щелочногидролизуемого азота 99,13 мг/кг, подвижных соединений фосфора 22,7 мг/кг и обменного калия 160,8 мг/кг. Реакция почвенной среды преимущественно нейтральная pH 6,76, содержание гумуса в верхнем горизонте 5,41 %. Данные исследования подтверждают высокое биоэкологическое состояние древостоев и почв в пойме реки Бухтарма, что является важным для дальнейшего мониторинга и сохранения этих экосистем.

***Ключевые слова:** пойменные леса, Ива белая, жизненное состояние, хлорофилл, Катон-Карагайский ГНПП.*

КАТОН-ҚАРАҒАЙ МҰТС БҰҚТЫРМА ӨЗЕНІНІҢ ЖАЙЫЛМАСЫНДА ӨСЕТІН АҚ ТАЛДЫҢ (SALIX ALBA L.) МОРФОЛОГИЯЛЫҚ БЕЙІМДЕЛУ РЕАКЦИЯЛАРЫ

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Мақалада Катон-Қарағай мемлекеттік ұлттық табиғи саябағы аумағындағы өсетін ақ талдың (Salix alba L.) бейімделгіш морфологиялық реакциялары қарастырылған. Катон-Қарағай мемлекеттік ұлттық табиғи саябағында (МҰТС), жалпы ауданы 5,9 га болатын сынақ алаңдарында орман экожүйелеріне зерттеулер жүргізілді. Бірінші қабаттағы ағаш жамылғысының құрамына ақ тал (Salix alba L.) және ілгек жапырақты қайың (Betula pendula) кіреді, олардың орташа дің диаметрі 16,1 см, орташа биіктігі 4,3 м. Аталған аймақтағы ақ талдың өміршеңдік жағдайы «сау» деп бағаланады, салыстырмалы өміршеңдік индексі (СӨИ) 87,5%-ды құрайды. Жапырақтардағы а хлорофилл мөлшері 0,55-тен 0,6 мг/г шикі массаға дейін, b хлорофилл – 0,11-ден 0,14 мг/г