

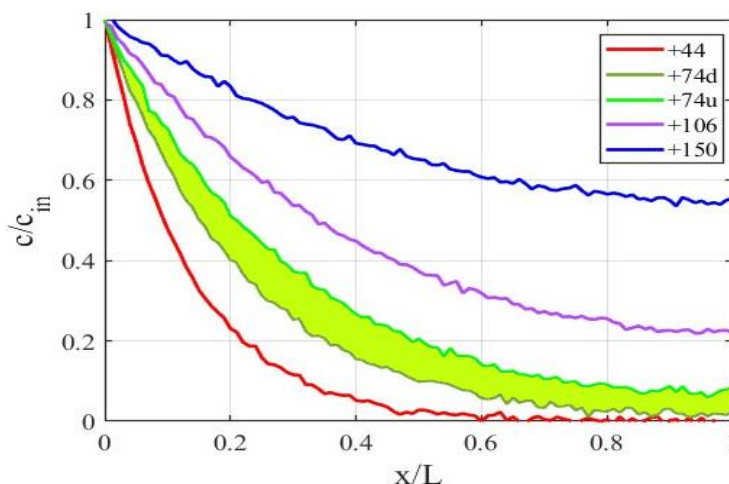


Fig. 1. Results of modeling changes in the concentration of certain classes of ore particle size in the oversize product of a screen

Conclusions. The proposed model allows for changes in the particle size distribution and density of the oversize product to be taken into account, which makes it possible to develop a strategy for automated process control. Further research should be aimed at refining the model parameters and developing intelligent control systems for fine wet screening.

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FUEL ECONOMY CALCULATION RESULTS GAS ENGINE BY CYCLE PREHEAT AND START-UP ON A MATHEMATICAL MODEL IN APPLICATION COMBINED HEATING SYSTEMS

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The article presents the results of mathematical modeling and fuel economy calculations for a gas engine equipped with a combined heating system during pre-start and start-up cycles. A mathematical model was developed to evaluate the fuel efficiency and environmental performance of the K159M2 internal combustion engine using a system for pre-starting and accelerated warm-up (SPC). The model incorporates data from experimental studies and takes into account the influence of coolant circulation speed, temperature variations, and thermal accumulator operation. Simulation results demonstrate that

the implementation of SPC reduces the warm-up time by 16–38%, fuel consumption by up to 75%, nitrogen oxide emissions by 93–98%, and particulate matter emissions by 88–94%, compared to a conventional cooling system. The use of the combined heating system ensures stable engine operation, improved fuel economy, and significantly enhanced environmental performance. The proposed mathematical model allows accurate prediction of temperature dynamics, thermal energy requirements, and emission characteristics during the pre-start heating and warm-up phases, providing an effective approach for optimizing cold-start conditions in gas engines.

Introduction. Accelerated warm-up elements include solenoid valves and a liquid pump, which allows modulating the circulation of the coolant (OR) depending on its temperature, to ensure effective warming up of the internal combustion engine. The peculiarity of the construction and operation of the SKP is as follows: if the temperature of the coolants of the cooling system (CO) of the internal combustion engine is below the maximum permissible level ($40\text{ }^{\circ}\text{C}$), then to carry out the process of warming up and starting the internal combustion engine, the TA is first put into operation and passes the liquid coolant CO through the TA using its own pump, which takes the heat accumulated by the heat-accumulating material (TAM) and transports it inside the small circulation circuit of the internal combustion engine CO until the set temperature is reached in it ($40\text{ }^{\circ}\text{C}$).

Analysis of recent research. According to the results of bench tests of the K159M2 engine equipped with a SPC in the laboratory conditions of the Gas Institute of the National Academy of Sciences of Ukraine [1], it was found that the use of SPC improves fuel efficiency (total fuel consumption for warming up) when starting and warming up after starting the internal combustion engine when it is operating at idle. In addition, the warming up time of the internal combustion engine is significantly reduced in the range from the ambient temperature to the “hot start” temperature and to the temperature at which it is possible to accept the load by the engine. At the same time, the environmental performance of the engine is improved, in particular, nitrogen oxide emissions and particulate emissions are reduced, in the same operating temperature range.

Problem statement. To assess the effectiveness of the use of the SPC, it is advisable to determine the fuel efficiency and environmental performance of a stationary internal combustion engine according to the cycle of pre-start warm-up, start-up and accelerated warm-up after start-up using a mathematical model when using a combined warm-up system.

Main material. In the course of research, a mathematical model for calculating fuel efficiency and environmental performance of the K159M2 engine when using the SPC during start-up and warm-up was developed, and after conducting experimental studies, it was refined [2], which allows obtaining urgent (hourly) parameters, fuel efficiency indicators and environmental performance of the engine in the process of its implementation of the pre-start thermal preparation mode from the ambient temperature to the “hot start” temperature and the possibility of accepting the load. The mathematical model takes into account the features of using the SPC on the K159M2 engine. To form the initial data base of the developed mathematical model, experimental data on the design and working process of the internal combustion engine were used, and the initial data on the working process of the studied internal combustion engine were also calculated. For this purpose, the Diesel-RK software package was used (a program of the thermodynamic program class, i.e. the engine cylinders are considered in it as open thermodynamic systems) [3], which is intended for the calculation, analysis and research of two-stroke and four-stroke internal combustion engines. As a result of the preparation of the necessary initial data, the dependences of pressure, temperature in the cylinder and temperature in the exhaust manifold on the crankshaft rotation of the internal combustion engine at a speed of 700 were obtained $\times \text{B}^{-1}$, which were subsequently used in the mathematical model. Also, the mathematical model includes polynomial dependencies obtained by processing the results of bench tests of the K159M2 engine, namely, the dependencies of fuel consumption during engine warm-up: with a standard cooling system, and elements of accelerated engine warm-up (EPA) installed in the CO of the ICE, with an experimental SPC installed on the ICE and preliminary engine warm-up to “hot start” temperatures, namely: $40\text{ }^{\circ}\text{C}$, $50\text{ }^{\circ}\text{C}$ and $60\text{ }^{\circ}\text{C}$. [4]. As well as the components of the mathematical model, according to the provisions of [4], the equations of the developed method for monitoring the thermal parameters of the cooling system of the K159M2 engine were refined according to the data of the natural characteristic of CO. First of all, this concerns the regularities of the engine cooling process. In the mathematical model, as its dominant parameter when choosing the criterion for permissible cooling of the K159M2 engine, the parameters of

the temperature change at the inlet to the engine cylinder block were introduced. Due to this, it was possible to predict the dynamics of the drop in engine temperature indicators in time in the mathematical model and to give appropriate recommendations regarding the amount of thermal energy, intervals and duration of pre-start preparation of the engine from the thermal accumulator of the phase transition of the SPC.

To take into account the specifics of the application of the SPC in the CO of the internal combustion engine, the mathematical model includes the conditions, basic assumptions and model representations necessary for building a mathematical model of the functioning of the SPC of the internal combustion engine with the TA of the adopted design, at which the SPC is turned on, operated and turned off. The model is based on the well-known formula [5] for determining the specific heat flow through a flat wall:

$$q = \frac{t_{fj} - t_f}{\frac{1}{\alpha_{fj}} + \frac{\delta}{\lambda} + \frac{1}{\alpha_f}}, \quad (1)$$

where t_{fj} and t_f - the temperature of the gases in the cylinder and the coolant, respectively; α_{fj} and α_f - the heat transfer coefficient of the gases to the wall and from the wall to the liquid, respectively; λ - the thermal conductivity coefficient; δ - wall thickness.

Since the gas temperature is not required for this case, we transform formula (1) by taking out t_{fj} and α_{fj} inserting the value of the wall temperature on the gas side (t_w), we obtain:

$$t_w = t_f + q \left(\frac{1}{\alpha_f} + \frac{\delta}{\lambda} \right). \quad (2)$$

Analyzing the formula (2), it can be noted that the change t_w , according to the given law, is possible, either by affecting the temperature of the coolant t_f , which is not very effective, or by affecting the intensity of heat transfer α_f . Other parameters are either constant for this design $\left(\frac{\delta}{\lambda}\right)$, or are set by the engine operating mode (q). Mathematical modeling was carried out under the conditions of installing the SPC on the K159M2 engine stationary electric unit DGMA-48M1, the parameters of which are included in the mathematical model. The simulation was carried out under the following conditions when using the VG thermal energy utilizer: without using the SPC; when using the SPC with operating elements of the SPPD with disconnected elements of the SUTTA; when using the SPC with operating elements of the SPPD and SUTTA. In the process of modeling, a cycle of pre-starting warm-up and starting of the ICE was formed from the beginning of the discharge of the TA (the beginning of the thermal preparation of the ICE) to its full charging, which is determined by the temperature of the phase transition of the TAM. During the simulation, the processes of pre-starting warm-up of the ICE K159M2 at different fixed ambient temperatures were considered, but the results were selected for the temperatures most characteristic of the region, namely: 20 °C, 0 °C, -20 °C.

At the specified temperature regimes, the system operates as follows: the internal combustion engine warm-up from the TA lasts 862 s, 1433 s, 1956 s, respectively, then upon reaching the OC temperature of 50 °C, the internal combustion engine is started and combined with its warming up from the TA and the thermal energy of fuel combustion to the OC temperature of 85 °C in 570 s, after reaching the OC temperature of 85 °C, the TA is charged, which lasts 460 s, 1697 s, 1876 s, respectively. While the OC warm-up using the classical method will last 1350 s, 1810 s and 2715 s, respectively. From these dependencies it can be seen that the internal combustion engine with the SPC warms up to a temperature t °C 40 (50/60) °C respectively in 1343 (1433/1541) s., which is less by 486 s. (27%) and 196 s. (21%) / 288 s. (16%) compared to warming up the ICE with standard CO to a temperature of 50 °C, which is 1829 s. At the same time, the engine consumes less fuel by 0.895 (0.789 / 0.643) m³, which is less by 2.259 kg. (72%) (2.359 kg. (75%) / 2.504 kg. (79%)) compared to warming up the ICE with standard CO to a temperature of 50 °C, which is 3.147 m³. The engine emits less nitrogen oxide emissions by 0.333 (0.246 and 0.154) g, which is 5.864 g (94%) less (5.617 g (96%) / 5.617 g (96%)) compared to warming up the ICE with standard CO to a temperature of 50 °C, which is 5.864 g. Particulate emissions are reduced by 0.056 (0.044 / 0.030) mg, which is 0.570 mg (90%) less (0.582 mg (91%) / 0.596 mg (95%)) compared to warming up the ICE with standard CO to a temperature of 50 °C, which is 0.626 mg. Thus, comparing the warm-up time of t , s., hourly fuel consumption GT, emissions of nitrogen oxides NO, of solid particles K during start-up and warming it up to the temperature of "hot warm-up", it is seen that the SPC allows to significantly improve the indicators of warm-up time (up to 16-38%), and environmental friendliness (for NO* up to 93-98%, and for A' up to 88-94%) and economy (up to 62-75%) of the

experimental internal combustion engine when solving the problems of cold start based on TA and accelerating the internal combustion engine warm-up using the SPC. The results of the study also show that by increasing the circulation speed of the OC flow in the CO of the ICE from 0.08 m/s (which corresponds to the circulation speed of the OC when warming up the ICE at idle with a standard pump) to 0.22 m/s (which corresponds to the characteristics of the SKP circulation pump), we obtain a reduction in the warm-up time g.s. on average by 14%, fuel consumption for warming up GT by 25%, reduce emissions of particulate matter K during warming up by 28%, and nitrogen oxides NO_x during warming up by 23%.

Conclusion. Thus, the assessment of the effectiveness of the use of SPC in the cycle of pre-starting and starting the internal combustion engine confirmed the improvement of fuel efficiency when working with the combined heating system, as well as the effectiveness of the use of SPC as one of the directions for improving the environmental performance of the internal combustion engine without worsening fuel efficiency.

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MODELING OF WORKING PROCESSES OF ENGINES OPERATING ON GASEOUS FUELS

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This paper examines a promising approach to reducing operating costs of internal combustion engines: converting them to run on gaseous fuel. The challenge with this method is the fundamental change in the operating conditions of most powertrain components and assemblies, which requires careful preliminary analysis. To address this issue, a mathematical model was developed, which is a universal system of volume balance differential equations. A key advantage of the proposed model is its capability to interact with other subsystems—such as intake and exhaust manifolds—via feedback loops, enabling comprehensive simulation of heat and mass transfer, mixture formation, fuel supply, and air exchange processes. Implemented in the MathCAD environment, the model is currently adapted for high-speed, naturally aspirated gas engines with external mixture formation and a cylinder diameter of 70–95 mm. The developed approach provides a reliable tool for predicting key engine performance parameters, optimizing operating conditions, and reducing the time and cost of experimental refinement during the conversion of conventional engines to gaseous fuels.