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Abstract: *Precision agriculture is an effective tool for innovative development of the agricultural sector of Ukraine, especially the Southern region, which is characterized by arid conditions and limited water resources. Its implementation on the basis of digital technologies, intelligent irrigation systems and modern agricultural machines ensures increased productivity, rational use of resources and sustainable development of agricultural production.*
Keywords: *precision agriculture, intelligent irrigation systems, modern agricultural machinery, digitalization of agricultural production, Southern region of Ukraine, sustainable development, innovative technologies.*

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UDC 621.43.019:004.942

Evaluation of fuel efficiency and ecology of gas ice with combined heating system: simulation of cold start and warm-up

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Abstract: *The paper presents the results of calculating the fuel efficiency and environmental performance of the YAMZ-536 internal combustion gas engine during the pre-start warm-up and start-up cycle using a combined warm-up system. It has been established that the combined preheating system reduces the preheating time by*

16–38%, reduces fuel consumption by 62–75%, and significantly reduces nitrogen oxide and particulate emissions compared to the standard cooling system. The results confirm the effectiveness of the PHA in improving fuel efficiency and reducing harmful engine emissions during cold starts.
Keywords: *internal combustion engine; phase change heat accumulator; mathematical model; fuel efficiency; cold start; cooling system.*

Introduction. Based at the Faculty of Engineering and Energy of Mykolaiv National Agrarian University, the Department of Tractors and Agricultural Machinery, Operation and Technical Service is conducting comprehensive research on the implementation of a combined preheating system (CWS) for pre-start preparation and intensification of the thermal state of the YMZ-536 internal combustion engine. The peculiarity of this system lies in the combination of a phase transition heat accumulator with accelerated warming elements, which ensures stable operation of the power plant in low temperature conditions. The system design allows the accumulation of thermal energy from exhaust gases in an amount sufficient to warm up the engine from the minimum calculated ambient temperature to optimal start-up parameters. Thanks to the integration of solenoid valves and a liquid pump into the experimental circuit, it is possible to precisely modulate the circulation of the coolant depending on its current thermal state, which ensures effective bringing of the engine to operating mode with minimal wear on parts.

The peculiarity of the SKP operation is that when the temperature of the cooling system (CS) coolant is below 40 °C, the TA is turned on first. The internal pump circulates the fluid through the accumulator, where it absorbs heat from the heat-accumulating material (HAM) and transports it to the small cooling circuit until the set temperature of 40 °C is reached. After that, the engine is started and the accelerated warm-up system is activated. When the temperature in the small circuit reaches 80 °C, the SKP switches to TA charging mode for its subsequent reuse.

Analysis of recent studies. Bench tests of the YAMZ-536 power unit equipped with a combined heating system (CHS) showed a significant increase in fuel efficiency. In particular, a reduction in the total amount of fuel consumed for engine temperature preparation during start-up and subsequent operation without load was recorded.

The temperature parameters of the cylinder were also determined based on the height of the cooling cavity, and the temperature changes at various points in the liquid cooling system were obtained depending on external conditions. The assessment of the thermal capacity of the TA confirmed its ability to maintain conditions for a “hot start” for a long time, which ensures effective pre-start preparation and the overall operability of the SKP.

Problem statement. To evaluate the effectiveness of the SKP, it is advisable to use a mathematical model to determine the fuel efficiency and environmental performance of a stationary internal combustion engine during the pre-start preparation, start-up, and accelerated warm-up stages.

Main material. Creating an effective method for analyzing fuel efficiency and environmental performance of internal combustion engines using SCP during start-up and warm-up is a pressing scientific task.

The main characteristic of the studies conducted is the calculation of the heat transfer coefficient using the Nusselt number. In this model, the Reynolds criterion is calculated based on the average fluid velocity and the equivalent channel diameter.

To ensure high accuracy in predicting the temperature state of internal combustion engine components, a methodology was used that requires analysis of local heat transfer characteristics. This approach allows for detailed consideration of the unevenness of heat flows in individual areas of surfaces instead of using generalized average values.

To take into account the specifics of the SKP in the cooling system, the mathematical model includes conditions, assumptions, and model representations of its operation with the selected design. These parameters determine the moments of switching on, operation, and switching off of the system. The methodological basis of the model is the classical equation for determining the specific heat flux through a flat wall:

$$q=\frac{t_{\int_1}-t_{\int}}{\frac{1}{\alpha_{\int_1}}+\frac{\delta}{\lambda}+\frac{1}{\alpha_{\int}}}$$

where $t_{\int_1}$ and $t_{\int}$ - are the temperatures of the gases in the cylinder and the cooling liquid, respectively; $\alpha_{\int_1}$ and $\alpha_{\int}$ - are the heat transfer coefficients of gases to the wall and from the wall to the liquid, respectively; λ is the thermal conductivity coefficient. δ is the wall thickness.

Since the gas temperature is not required in this case, we will transform formula (1) by removing $t_{\int_1}$ and $\alpha_{\int}$ from it and inserting the temperature of the wall on the gas side (t_w), into it, we obtain:

$$t_w=t_{\int}+q\left(\frac{1}{\alpha_{\int}}+\frac{\delta}{\lambda}\right)$$

Analyzing formula (2), it can be noted that changing t_w, according to a given law is possible either by affecting the temperature of the coolant $t_{\int}$, which is not very effective, or by affecting the heat transfer intensity $\alpha_{\int}$. Other parameters are either constant for a given design $\left(\frac{\delta}{\lambda}\right)$, or are set by the engine operating mode (q). Mathematical modeling was performed under the conditions of installing an SKP on a YMZ-536 engine of a stationary electric unit DGMA-48M1, the parameters of which are included in the mathematical model. The modeling was carried out under the condition of using the heat energy recovery device in three modes: without using the SKP, with the SKP with the SPDP elements operating and the heat accumulator control system (SUUTTA) turned off, as well as with the SPDP and SUUTTA elements operating together. During the study, a complete cycle of pre-start preparation and start-up of the internal combustion engine was formed — from the beginning of the heat accumulator discharge to its full charge, which is determined by the phase transition temperature of the heat accumulator. The modeling considered the processes of warming up the YAMZ-536 engine at different ambient temperatures, but the values most characteristic for the region were selected for analysis: 20 °C, 0 °C, and -20 °C.

The results of the study show that increasing the coolant circulation speed from 0.08 m/s (standard pump at idle speed) to 0.22 m/s (SKP circulation pump) provides a significant effect. In particular, warm-up time is reduced by an average of 14%, and fuel consumption by 25%. Environmental performance also improves: particulate emissions are reduced by 28% and nitrogen oxides by 23%.

Conclusion. Thus, the assessment of the effectiveness of the SKP confirmed that the use of the system in the pre-start warm-up and start-up cycle of the internal combustion engine significantly improves fuel efficiency. In addition, the introduction of the SKP is an effective way to improve the environmental performance of the engine without increasing fuel consumption.

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