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REDUCTION OF EXHAUST GAS TOXICITY IN TWO-STROKE INTERNAL COMBUSTION ENGINES

Two-stroke internal combustion engines (ICE) remain practically important in applications where high specific power, low weight, compactness, and structural simplicity are critical. They are widely used in motorcycles, small watercraft, handheld power tools, portable power units, unmanned systems, and special-purpose equipment. At the same time, two-stroke ICEs are characterized by increased exhaust gas toxicity due to the specific features of gas exchange, mixture formation, and lubrication.

The main causes of high exhaust toxicity are the loss of part of the fresh charge during scavenging, incomplete combustion of the air-fuel mixture, and the entry of fuel and oil combustion products into the exhaust gases. The overlap of exhaust and charging processes leads to the escape of unburned fuel into the exhaust system, which increases hydrocarbon emissions. The use of a fuel-oil mixture in conventional designs increases carbon monoxide emissions, smoke, and particulate formation. An additional negative factor is the limited capability for precise combustion control in carbureted systems.

One of the most effective ways to reduce toxicity is the use of direct fuel injection. This makes it possible to inject fuel after the main scavenging phase, thereby reducing fresh charge losses and unburned hydrocarbon emissions, while also improving fuel economy. However, this solution has several drawbacks, including increased design complexity, higher cost, and stricter requirements for fuel quality and maintenance. For small-scale equipment, such systems are often economically unjustified.

An important direction is the optimization of cylinder scavenging through improved shape and arrangement of scavenging and exhaust ports, tuning of wave processes in the exhaust system, and the use of resonant exhaust pipes. This improves cylinder clearing from residual gases and reduces fresh charge short-circuiting. However, such solutions are usually effective only within a narrow range of engine speeds and loads, and they also complicate engine manufacturing.

A reduction in toxicity can also be achieved by switching to a separate lubrication system. Metered oil supply reduces lubricant consumption, decreases the amount of lubricant combustion products in the exhaust gases, lowers deposit formation, and increases component life. At the same time, separate lubrication complicates the engine design and requires accurate oil metering, which is not always appropriate for equipment operating under severe or remote conditions.

Another promising measure is the use of catalytic converters, which reduce carbon monoxide and unburned hydrocarbon emissions. However, their efficiency in two-stroke engines is limited by the unstable composition of exhaust gases, the presence of fuel and oil residues that accelerate catalyst degradation, and the undesirable increase in the weight, size, and cost of the exhaust system.

A separate group of measures includes improvements in ignition systems, electronic fuel delivery control, and digital engine management algorithms. These systems enable more precise adaptation of engine parameters to changes in load and external operating conditions, thereby reducing toxicity and improving fuel efficiency. Their drawbacks include higher cost, more complicated diagnostics, dependence on electrical power supply, and greater sensitivity to moisture, vibration, and electromagnetic interference.

Additional reduction of exhaust toxicity may be achieved through the use of alternative fuels and modern synthetic lubricants. These can reduce smoke, carbon monoxide emissions, and deposit formation; however, they do not eliminate the fundamental disadvantage of the two-stroke cycle, namely fresh charge losses during scavenging.

Conclusion. Reducing exhaust gas toxicity in two-stroke internal combustion engines requires an integrated approach combining improved gas exchange, direct fuel injection, separate lubrication, catalytic aftertreatment, electronic control, and advanced fuels and lubricants. At the same time, each of these solutions has technical, economic, and operational limitations. Therefore, the most reasonable approach is a differentiated one, in which the level of engine modernization is determined by its application, operating modes, and economic feasibility.

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