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J F. Ismatov
Tashkent State Technical University named after Islam Karimov, 100095, Tashkent, Uzbekistan, mr.aaa_93@mail.ru

A I. Yangibayev
Tashkent State Technical University named after Islam Karimov, 100095, Tashkent, Uzbekistan, avazyangiboyev88@gmail.com

N V. Vadulina
Ufa State Petroleum Technological University, momus7@mail.ru

A A. Jalilov
Tashkent State Technical University named after Islam Karimov, 100095, Tashkent, Uzbekistan

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MAIN FACTORS THAT INFLUENCE THE THERMAL STRESS STATE OF PISTON ENGINE PARTS

J.F. Ismatov[1]*, A.I. Yangibaev[1], A.A. Jalilov[1], N.V. Vadulina[2]
[1]Tashkent State Technical University named after Islam Karimov,
100095, University St. 2, Tashkent, Uzbekistan
[2]Ufa State Petroleum Technical University
1 Kosmonavtov st., 450064, Ufa,
Republic of Bashkortostan, Russia

Abstract. *The development of a holistic, effective, and scalable structure of economic management, as well as the introduction of a program to improve the technical level and efficiency of machinery, are two of the most important concepts for the deep reconstruction of the Republic of Uzbekistan's economic process. Vehicles with diesel engines are gradually being introduced to our country's car fleet. Modern diesel engines are being developed by boosting them: increasing the average effective pressure and speed. Therefore, high reliability and service life, fuel efficiency and environmental performance are the main criteria for their quality. Forcing diesels leads to an increase in thermal and mechanical stresses on the main parts of the cylinder-piston group (CPG) (piston, liner, cylinder head), a significant increase in their temperature, as well as the temperature of piston rings and valves. Overheating of components causes the creation of temperature fields with pronounced irregularities in temperature distribution and, as a consequence, the development of thermal strains, which causes the material's mechanical properties to deteriorate, the formation of fractures, and, eventually, the part's destruction. The task of shielding parts from the undue effects of high thermal loads from the working body, or, in other words, the task of designing a diesel engine with reduced heat recovery from the working body, becomes important in this regard. However, creating a highly efficient engine with reduced heat dissipation from the working body is associated with solving a number of other issues, primarily with meeting today's environmental requirements. First and foremost, this relates to the reduction of nitrogen oxides in the combustion products, while at the same time reducing specific fuel consumption. Prospects for the development of the diesel engine industry can be seen in a consistent increase in the specific performance by boosting the mean effective pressure with a simultaneous reduction in combustion heat losses, thermal insulation of the combustion chamber and use of the exhaust gas energy. All these measures are taken in order to bring the actual thermodynamic cycle closer to the theoretical adiabatic cycle. Existing assessments of the effectiveness of combustion chamber thermal insulation of diesel engines on the level of thermodynamic adiabatic cycle were based on qualitative rather than quantitative indicators, due to which the achieved effects were interpreted ambiguously by various researchers. The introduction of uniformity in methodology, metrics, and quantitative parameters for estimating the efficiency of using heat from fuel combustion in a diesel working cycle helps not only to identify the reached stage, but also to forecast future progress of the engine-building branch, demonstrating the problem's urgency.*

Keywords: *diesel, thermal insulation, fuels, piston, ceramic materials, combustion chamber, adiabatic engine thermodynamic cycle.*

INTRODUCTION. Thermally insulating the piston bottom, cylinder head plates, valves, and cylinder liners is a positive development in modern engine design for reducing heat transfer to the cooling system. Ceramic materials are one of the most promising materials for use as thermal insulators in piston engines due to their high heat resistance. Improving the thermal and mechanical properties of these materials to the required level will, through their use, make it possible to reduce the heat stress of components to the limit, reduce heat dissipation and utilize the thermal energy of exhaust gases with greater efficiency or create engines with no cooling system, the so-called adiabatic engines.

The adiabatic engine's concept is to build a combustion chamber (CC) with heat-resistant insulated walls (Fig. 1), whose unsteady temperature is exactly the same as the working body's unsteady temperature at any given time [8]. A illustration from a patent application filed in 1921 [9] is seen in Figure 2.

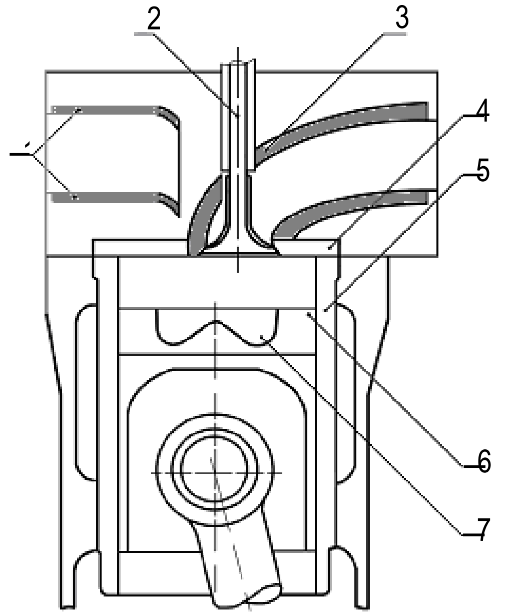

Fig.1. Isolated components of a diesel engine: 1 - inlet channel walls; 2 - exhaust valve; 3 - exhaust channel walls; 4 - bottom plate of the cylinder head; 5 - cylinder sleeve; 6 - bottom of the piston; 7 - combustion chamber

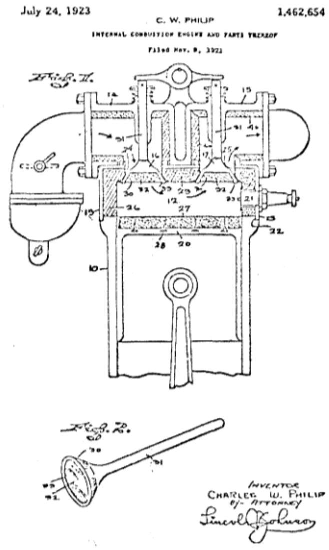

Fig.2. Title figure for the poster for an engine with an insulated combustion chamber

It should be noted that the term 'adiabatic engine' does not accurately describe engines in which the heat transfer between gases and walls is greatly reduced, but not completely eliminated, as required by the adiabatic process. A more accurate name for such an engine is "engine with reduced heat dissipation". A clear definition of these terms is given in [1].

Although there have been suggestions for the use of non-ceramic insulating materials 4 as well as combinations of metal and ceramic, it appears that the ideal insulating material should be a simple, low-cost ceramic capable of operating at temperatures up to 1000 ^{0}C and withstanding the conditions prevailing in the diesel engine. In addition to low thermal conductivity, the material should have a low coefficient of linear expansion, low heat capacity, density, a low modulus of elasticity combined with high impact toughness and sufficient strength, and satisfactory friction characteristics.

Currently, a material which meets all of the above requirements is unfortunately not known. It is therefore necessary to study the properties of the materials to be used at a very early stage of development. This study must be carried out under the conditions that actually exist in the diesel engine. At present, only a few ceramic materials have a service life of more than a few hundred hours.

The characteristic properties of ceramic materials that have found use or are recommended for use in insulated motors are shown in Table 1 [2].

Extensive research on the use of ceramics in internal combustion engines has been conducted by leading engine companies, plants and institutes [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 21].

In the US, with the exception of a small number of government-funded programs, the rest are run by individual firms with significant budgets. These include engine manufacturers - Cummins, Caterpillar, Ford, Detroit Diesel Allison, Garret Turbine Engine, Solar Turbine, Rochetdhyne; ceramic materials firms - Ai Research Casting, Carborundum, Coors, Corning Glass, General-Electric, Norton; construction materials firms - Kaman Sciences, Dow Chemical.

Diesels are mainly used in tractors due to their high fuel efficiency. The introduction of gas turbine supercharging has created conditions for further improvement of tractor diesel engines work processes and improvement of their specific and economic indicators. Application of turbocharging and supercharged air cooling allowed to increase liter capacity of tractor diesel engines up to 15-17 kW/l and reduce specific fuel consumption at nominal mode to 230-250 g/(kWh) [2, 16].

The temperature level of key components plays an extremely important role in all phases of the life cycle of reciprocating engines, from design through to operation. Since the thermal condition of engines has a significant impact on engine performance, including reliability, environmental and economic performance, the design of engines pays the utmost attention to ensuring acceptable levels of predicted component temperature performance.

The main part. An analysis of the factors influencing the temperature fields of the main engine parts allows us to divide them into the following groups:

1) the operating process which generates thermal loads on the heat absorbing surfaces of the cylinder and piston group components;

2) use of special design parts (availability of thermal protection, shields, thermal barriers, means of regulation of intensity of heat transfer process, thermophysical characteristics of materials of parts, etc.)

3) peculiarities of heat exchange processes in the combustion chamber and in the cooling system cavities (properties and thermophysical characteristics, mode and character of flow, condition of heat transfer media, condition of heat dissipating surfaces, their temperature and vibration level, presence of turbulators and other means of influence on the heat exchange intensity);

4) peculiarities of technological processes of parts production (presence on their surfaces of layers with special thermal-physical and physical-mechanical properties);

5) peculiarities of temporal processes occurring in the engine (change of clearances, shape and state of heat-absorbing and cooled surfaces, dynamics of scale, sludge, carbon deposits, varnish films, oxide films, triggering of coolant additives, wear of parts);

6) peculiarities of engine operation, including its technical condition, compliance with maintenance and repair rules.

Table 1.

Typical properties of ceramic materials intended for use in diesel engines with insulated combustion chambers

Material	Properties

	Thermal conductivity (λ)W/m ·0K	Modulus of elasticity(E)·10-3, MPa	Linear expansion coefficient (β)·10+6, 1/0К	Density (ρ), kg/m³	Thermal capacity (C), J/kg· 0K	ending strength at contact temperature (σ BRT), MGa	Impact viscosity (К1c), MPa * ml/2
Chemically bonded silicon nitride	18	170	3	2600	850	200	2,5
Hot-pressed and isostatically hot-pressed silicon nitride	25	310	3,4	3200	850	700	5
Sintered silicon nitride	22	300	3,3	3100	850	500	4,5
Sintered silicon carbide	75	400	4,6	3100	1000	500	4,5
Hot pressed silicon carbide	90	450	4,7	3200	1000	700	5
Alumina	33	380	8	4000	800	300	3,5
Zirconium dioxide	2,5	200	9,8	5700	400	500	10
Aluminium titanate	2	13	1,5	3200	880	35	-

In the development phase of new advanced diesel engines, the first two factors relating to the organization of the internal cylinder process and the use of insulated parts which form the combustion chamber are of particular importance. Therefore, it is these factors that are the focus of this paper. It should be emphasized that the nature of the flow of the working process directly affects the efficient and environmental performance of the engine, and the manufacture of insulated parts requires the use of special technology, taking into account the specifics of the intra-cylinder processes. In this connection, environmental issues were also considered in the research process, particularly the formation of nitrogen oxides (the most dependent of the harmful components on the temperature level of the working cycle) and the technology of composite powder production, the manufacture of composite thermally insulated parts.

The analysis of the above variables allows for the formation of a reasonable strategy for selecting control behavior on the expected level of component temperatures when taking into account the engine's requirements during design development. In this case, control behavior can be selected that have diametrically opposed effects on the temperature of data, based on a series of leading, key measures of engine efficiency. There are technological ways to lift the high temperature of the piston head to 850-900°C by raising thermal resistance in the head-trunk interface region (engines with minimal heat removal from the working body, boosted HVM engines), and to lower the temperature of components by increasing piston cooling or using thermally insulating material in other situations.

Recently, a large number of works have been carried out on increasing the intensity of processes of local heat exchange in the cavities of the internal combustion engine cooling system, development of methods for modeling and calculating the parameters of local heat exchange in the cooling system, methods for optimizing the flow distribution in the cooling system, The optimization of the form of temperature fields of parts of a cylinder-piston group (CPG), methods of intensification of local heat exchange at critical points, methods of calculation of parameters of local nonstationary heat exchange in the combustion chamber of internal combustion engines (ICE) [14, 15, 16, 17, 18, 22, 23, 24, 25, 26], development of means of increasing the efficiency of heat exchange apparatus.

Simultaneously, it should be noted that despite the existence of a number of works on the creation of complex methods for modeling the totality of thermal processes in ICE (workflow, heat transfer in the cylinder between the working body and main parts, thermal conductivity, thermal state and force interaction of parts), the created models do not fully meet the needs of practice design and fine-tuning of modern engines.

The need to create a method for joint modelling of the operating process and the thermal stress state of piston engines is dictated both by the practice of ensuring the durability and environmental friendliness of internal combustion engines and by the need to assess the heat release and thermal boundary conditions. The latter are necessary for modelling the temperature fields in various engine operating modes, since for the cylinder components such boundary conditions are formed as a result of periodic cyclic processes in the cylinder and on the component surfaces with relative motion of the mating surfaces.

A set of programs for personal computers, including programs for calculating the operation process, complex (radiation and convective) heat exchange in the combustion chamber, thermal and stress-strain state of parts is an essential element of the system of automated design of internal combustion engines, which is being developed intensively in different countries.

With the author's participation, problem-oriented software packages for the study of thermal and mechanical stresses of internal combustion engine parts were created [19,20], as well as a comprehensive mathematical model that includes models of the transport diesel engine operating process, heat exchange and the heat stress state. This composition of the complex model corresponds to the logical relationship between the physical processes in an internal combustion engine that affect the thermal and mechanical stress of its parts.

With the help of the complex approach, it is possible to solve the following problems: to optimize working conditions of parts of the given design; to optimize design of heat-treated parts and units, including parts with heat-emitting overlays and coatings, at the given way of organization of working process; to carry out verification of serviceability of designs. Application of such an integrated approach will make it possible to reduce the preparation time for production of new advanced engines.

As can be seen from Fig. 1, turbocharged and direct-injection diesel engines are the most economical. Prospects for the development of modern diesel engine building are seen in increasing the average effective cycle pressure to 1.5-1.8 MPa, which will require improvements in the operating process through an optimum combination of combustion chamber layout, gas dynamic environment and fuel injection process parameters through the use of electronically controlled fuel supply systems. This means a reduction in the ignition delay, controlled combustion and main combustion periods.

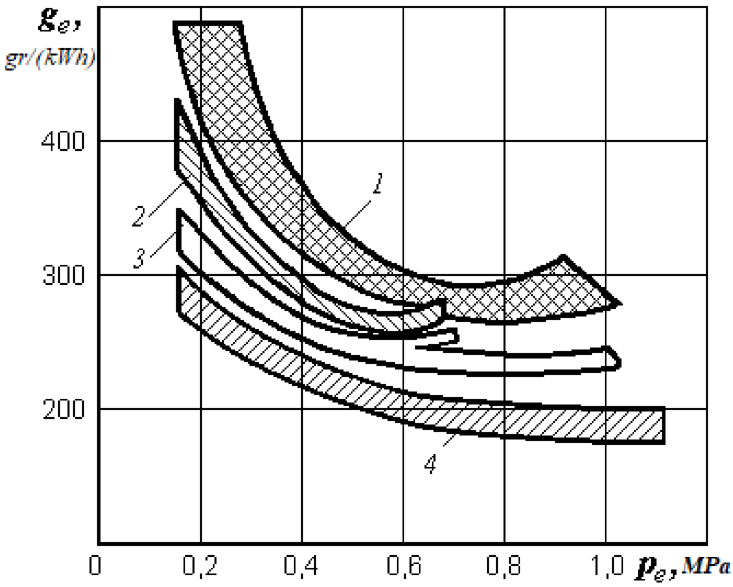

Fig. 1. Efficiency of different types of internal combustion engines
1 - inlet injected petrol engines; 2 - pre-chamber or swirl chamber diesels; 3 - direct injection diesels; 4 - turbocharged and direct injection diesels

There are also large reserves in the area of reducing the unproductive loss of combustion heat by insulating the combustion chamber volume and partially by expansion (table 2) [2].

Table 2.

Forecast of improvement in ATD parameters

Year of implementation	Diesel specification	Average effective pressure, MPa	Specific fuel consumption, gr/(kWh)	EFFICIENCY
1975—1980	Split combustion chamber, turbocharger with intercooled air	0,8—1,0	258—285	30—33
1985	Direct injection, turbocharging with intercooled air	1,3	210—231	37—40
1986—1992	Semi-adiabatic (with ceramic parts), turbocharged with intercooled air	1,5	192—204	42—44,5
1988—1992	Turbo-compound diesel (power transfer from turbine to crankshaft), electronically controlled	1,8	172—197	43—49
1988—1994	Adiabatic diesel, turbocharged and intercooled	1,6	182—187	45—47
1992—1995	Adiabatic turbo-compound diesel engine with reduced friction losses	1,7	152—167	51—56
2000—2005	Work on the Rankine cycle	1,8	141—146	58—61

Increasing the average effective pressure will reduce the overall dimensions and weight of diesel engines, but at the same time requirements to ensuring their reliability (service life) will increase due to improvements in manufacturing technology, application of new materials (plastics, composites, ceramics, special lubricants, etc.), improvement of calculation methods for strength and reliability.

CONCLUSIONS. The reduction of heat flow to the cooling system by thermal insulation of the combustion chamber walls is a promising path in the development of modern engine design. The structure of the operating process, the use of special design components, and the peculiarities of heat transfer processes in the combustion chamber all have an effect on the engine's efficient and environmentally sustainable performance, as well as the creation of temperature fields in the cylinder-piston group parts.

The implementation of a system for the combined simulation of the operating process and the thermal stress condition of an engine with decreased heat dissipation allows for the development of a sound approach for the selection of control behavior at the expected temperature level of the components, thus taking into consideration the reliability and environmental efficiency of internal combustion engines.

Environmentalists' the demands for lower hazardous exhaust emissions would necessitate the automation and remote control of diesel motors, combustion systems, and cars in general using microprocessor technology.

The need for renewable fuels, as well as alternatives for using fuels with a broad variety of fractions, has arisen as a result of price fluctuations in the global oil sector, along with forecasts of fossil resource depletion.

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ELECTRIC VEHICLE INTERNAL SUPPORT SYSTEM

J.E. Safarov[1*], M.A. Khudoyberdiyev[1], B.B. To’ychiboyev [1], L.V. Kravchenko[2]
[1]Tashkent State Technical University named after Islam Karimov,
100095, University St. 2, Tashkent, Uzbekistan
[2]Don State Technical University, Gagarina, 1, Rostov-na-Donu Rossiya, 344002

Abstract. *At present, it remains relevant to protect the environment around the world, to prevent the deterioration of ecology, to ensure the health of people, to reduce the amount of exhaust*