ДВИГАТЕЛИ И ЭНЕРГЕТИЧЕСКИЕ УСТАНОВКИ

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RESULTS OF CREATING A COMBUSTION CHAMBER MODEL FOR SOLVING AN OPTIMISATION TASKS

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Abstract. *CFD tools were used to investigate the influence of combustion chamber geometrical parameters on the engine performance indexes. A number of geometrical shapes of the combustion chamber are analyzed. The results have proved that there is an impact of the combustion chamber geometry on pollutant emissions amount.*

Key words: *automobile diesel, CFD modeling, combustion chamber, pollutant exhausts.*

РЕЗУЛЬТАТЫ СОЗДАНИЯ МОДЕЛИ КАМЕРЫ СГОРАНИЯ ДЛЯ РЕШЕНИЯ ОПТИМИЗАЦИОННЫХ ЗАДАЧ

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Аннотация. *Использованы средства CFD-моделирования для исследования влияния геометрии камеры сгорания на показатели рабочего процесса двигателя. Проанализированы несколько вариантов форм камеры сгорания. Результаты демонстрируют влияние геометрических параметров камеры сгорания в поршне на количество выбрасываемых вредных веществ.*

Ключевые слова: *автомобильный дизель, CFD-моделирование, камера сгорания, выбросы вредных веществ.*

РЕЗУЛЬТАТИ СТВОРЕННЯ МОДЕЛІ КАМЕРИ ЗГОРЯННЯ ДЛЯ ВИРІШЕННЯ ОПТИМІЗАЦІЙНИХ ЗАДАЧ

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Анотація. *Використано засоби CFD-моделювання для дослідження впливу геометрії камери згоряння на показники робочого процесу двигуна. Створено і проаналізовано декілька варіантів форм камери згоряння. Результати демонструють вплив геометричних параметрів камери згоряння (КЗ) у поршні на кількість шкідливих речовин, що викидаються в атмосферу.*

Ключові слова: *автомобільний дизель, CFD-моделювання, камера згоряння, викиди шкідливих речовин.*

Introduction

Diesel engine has proved its efficiency in transport branch in European and American markets due to low fuel consumption, which 40 % less than modern spark ignition engines can show [1, 2]. Now major efforts for Diesel engines engineering targeted on decreasing soot and NOx pollutions with the same or lower fuel consumption levels. Because of huge differences of factors, which make influence on NOx and soot amounts in exhaust gases, the process of decreasing them both is a hard task. The second problem is the fact that methods to decrease soot amounts will increase NOx amounts, and vice versa. To solve this conflict there is necessity to perform extended investigations using modern analysis techniques. Optimization of key engine parameters, which determines internal processes, is the preferred way because this way could minimize amount of demanded changes in the target system construction. These key parameters are injection timing angle, injection pressure, appearance of injection process curve, nozzle design, shape of combustion chamber, turbocharging characteristics, exhausted gases recirculation.

Analysis of publications

Influence of combustion chamber shape on engine characteristics is the subject of many investigations [4–9]. It is known that in case of wisely designed combustion chamber amount of pollutant exhaustions could be decreased well, and power characteristics will stay almost still. The dependency of engine characteristics of the combustion chamber design is quite hard, because of direct influence on airflow and its interaction with fuel jets. The sources prove that optimization of combustion chamber design is a hard task, because CC design hardly depends of engine parameters and injection system design [10, 11]. Heywood [12] declares, that in case of constant compression ratio turbulence near the top dead center increases in case of decreasing diameter of CC, and that leads to decreasing soot formation, but increasing the level of NOx and CH. Swirl intensity in the CC depends of CC axle shift from cylinder axle.

In the source [4] there are results of experimental investigations of CC design influence on diesel engine characteristics. It shows that closed type CC decreases ignition timing, also as fuel consumption, and decreases soot / NOx amount in case of late injection. In the source [5] described the example of optimization and synchronizing the CC design parameters and injection system parameters. In case of decreasing the amount of fuel on the chamber walls dependency of intense air swirl decreases. Thus, part of the volume air-fuel mixture can be increased, and it will raise efficiency and decrease fuel consumption. It was shown that high-pressure injection systems like Common Rail [29] made fuel atomization and mixture formation without closed CC and intense swirl. In the source [6] was made experimental and computational investigation of CC shape and engine speed influence on the level of pollutant exhausts. It was found that CC shape provides more effect on engine characteristics at the low engine speed. At the high engine speed smooth CC surfaces, leads to decreasing of the soot level and increasing the NOx level. The best results received while fuel was injected in the CC bottom direction.

Therefore CC geometry and fuel jet parameters are important for engine characteristics improvement and decreasing pollutant exhausts, it is actual to combine investigations of its effects.

Goals and tasks for investigation

The goal of this work is to make background for choosing an optimal CC geometry and fuel injections parameters for diesel engine with direct injection. To reach this goal there are tasks to perform:

1. To make parametric model of the volume above piston.
2. To make injection process modeling using CFD tools, also to perform modeling of mixture creating, burning and exhausting processes.
3. To verify adequateness of modeling using experimental data.

CFD model description

The tasks mentioned above have been solved with widely used by leader engineering companies CFD software AVL Fire (v. 2013.2) [13–15]. Math models that being used in calculations are well known and have good description in literature [16–25].

This investigation uses combustion model ECFM-3Z, which based on coherent flame model. ECFM-3Z (extended model of coherent flame, 3 – zoned) was developed especially for diesel combustion description [19, 20], it describes three main stages: ignition, combustion and diffusional burning.

Fuel atomization has been modeled by WAVE model, described in [22–24] that allows calculating primary and secondary atomization, and further behavior of droplets. In this model primary perturbation spreading in liquid surface is connected to physical and dynamical parameters of injected fuel and target environment. Dukowicz model used for heating and vaporization, this model is described in [25, 26]. Model uses one same droplets temperature. In addition, degree of droplet temperature change is derived from temperature balance, according to it heat transfer from gas to droplet leads to heating or participates in droplet vaporization. To calculate interaction between parcels stochastic model is being used [16]. According this model it is assumed that parcels fluctuation speed is changing according Gauss theory. In this investigation turbulence model k-ζ-f is being used. One of the advantages of this model – reliability for calculations with moving mesh elements, and compressed liquids/gases, i.e. common environment in the engines. Extended Zeldowich model [16] is being used for NOx creation processes. For describing the soot particles creating processes kinetic model is used [27]. This model is based on the detailed scheme of chemical reactions for soot particles creation and oxidizing. It contains reactions for poly-aromatic CH, creating mechanism for the soot particles during poly-aromatic molecules condensation, increasing of the soot particles, and pyrolysis of the acetylene and liquid carbon reaction of n-heptane oxidizing.

Object of investigation. Engine parameters

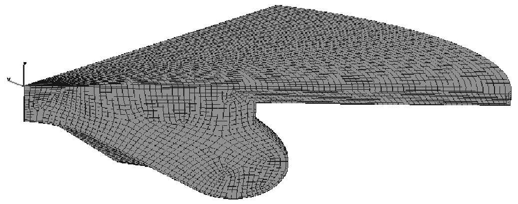
Experimental data that is demanded for modeling data validation was got during motor studies of test engine 1DTNA-2 [28]. Engine and fuel injection system parameters are shown in the table 1. Calculations were performed on part load regime at 3000 rpm.

Table 1 Engine parameters

Endine type	Diesel
Cylnders	1
Diameter of cylinder, mm	88
Stroke, mm	82
Compression ratio	18,5
Combustion chamber	Not divided
Nozzle count	6
Nozzle diameter, mm	0,2
Injection timing, crankshaft rotation degrees	20
Injection length, crankshaft rotation degrees	18
Injected fuel amount, kg	$6{,}7\text{x}10^{-6}$ x 6

Combustion chamber model

The model of 60-degree part of combustion chamber was prepared for this investigation, because this studies the injector with six uniformly distributed nozzles. Experience of AVL Fire users shows that such model type do not makes any effect on the calculation quality, but allows to dramatically decrease calculation time and to use this model in optimization processes. Finite-element mesh was prepared by AVL ESE Diesel Tool [16]. Picture 1 shows the CC model in TDC position. Calculations were performed from the intake valve closing moment to the exhaust valve opening moment. At the bottom of the CC additional mesh border layer was made to allow more accurate heat flow calculation near piston walls. The Final mesh contains 36025 cells at TDC piston position.



Pic. 1. Combustion chamber FEM

It should be noted that base CC shape is developed in ГП «ХКБД» КС for diesel 1ДТНА-2, supplied with 4 valve cylinder head and injector placed in the center cylinder axle.

Calculation model validation

For different calculation regimes model showed enough accuracy regarding to experimental data (table 2), and source [30].

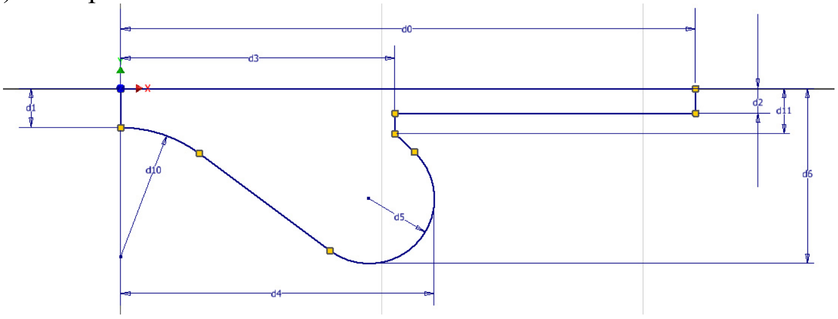
Table 2 Comparing of experimental and calculated data

Characteristic	Calculation	Experimental
Power N_i, kWt	12,86	12,7
g_i, г/(kWt per hour)	281,3	284,8
η_i	0,364	0,36

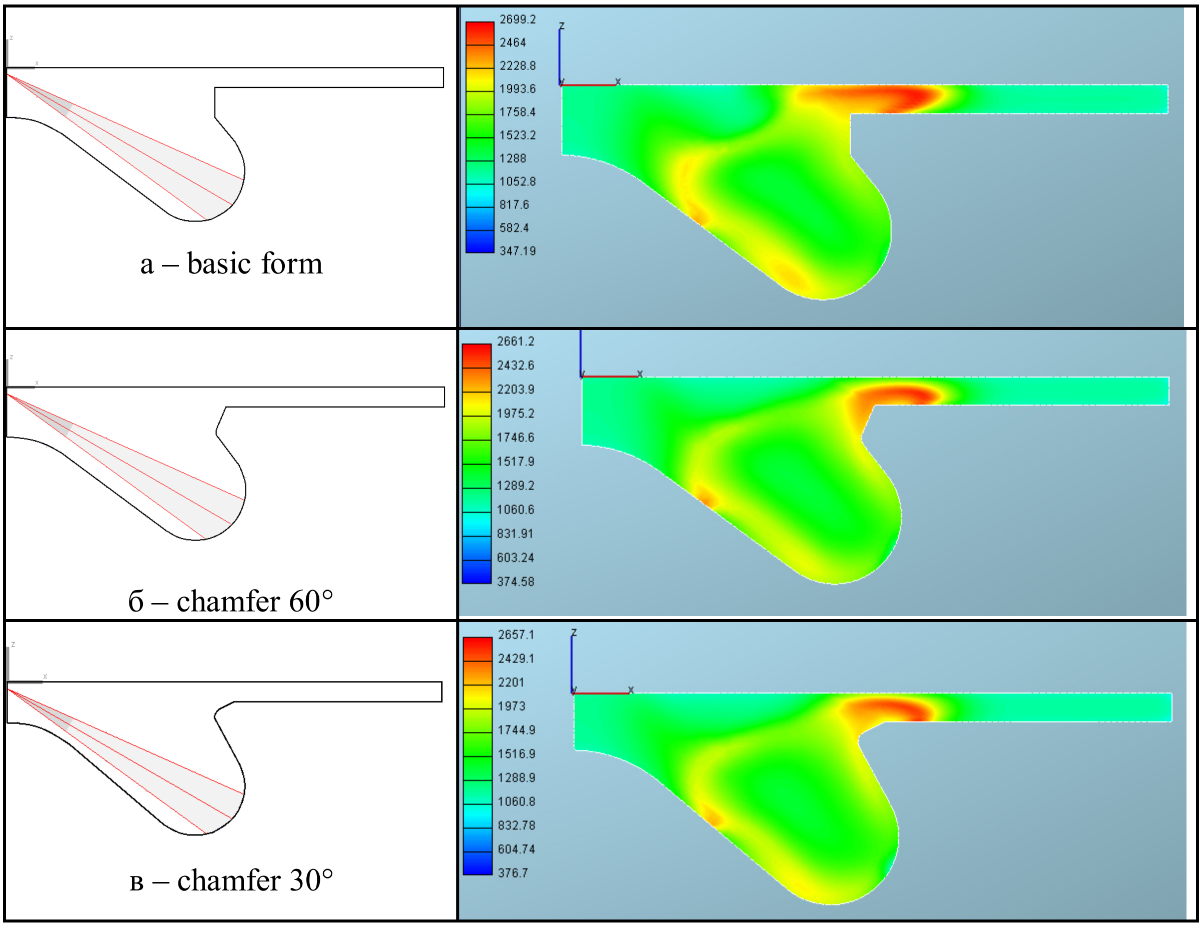
NOx exhaust dependency from CC shape

Investigated engine uses combustion chamber which shape makes significant effect on air flow and therefore on fuel distribution and mixture formation; also influence on burning completeness and pollutant exhausts amount. Picture 2 shows CC scheme with main dimensional parameters.

This work demonstrates solution for influence determination of geometrical elements for CC shape on engine toxic characteristics. Particularly, there are 3 shape variants with changed bowl entrance (pic. 3). Compression ratio in al three variants is constant.



Pic. 2. Combustion chamber parametric sketch



a – basic form

б – chamfer 60°

в – chamfer 30°

Pic. 3. Geometry variations for investigated combustion chamber and its effect on temperature distribution (TDC position)

Pictures 3 shows calculations for NOx in exhaust gases. As one can see from the chart, the bowl entrance shape has significant effect on NOx amount.

Therefore, influence of separate CC shape geometry elements on work cycle is determined, next step — is to prepare methods of optimization CC shape based on investigation of parameters area. First, preparation of income data, different CC shape variations. Second, FE calculation of prepared data, and then determining of toxic and power parameters for each variant, making an area of investigated parameters, deriving the borders and optimal point area [29].

Conclusions

The parametric model of combustion chamber for 4DTNA-2 has been created and tested. This model allows varying main shape parameters and can be used in optimization tasks.

The combustion chamber variants have been prepared; modeling of internal diesel processes has been performed. Toxic characteristics changes, connected to geometrical CC parameters found. In the way of changing the bowl entrance shape, it is possible to decrease NOx level in two, three times.

Modeling results of mixture formation, injection and burning with basic CC shape showed adequate precision.

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