SI ENGINE WITH THE SECTIONAL COMBUSTION CHAMBER

Karol Cupiał, Arkadiusz Jamrozik

Częstochowa University of Technology
Institute of Internal Combustion Engines and Control Engineering
Al. Armii Krajowej 21, 42-200 Częstochowa

Abstract

Comparison of research dealing with real SI engine with the sectional combustion chamber and numerical model of this engine is presented in the paper. The numerical model of the engine was built using KIVA 3V code.

The results of numerical modelling are similar to those from real engine.

1. Introduction

Decrease of toxic ingredients in exhaust gases can be obtained by combustion of lean, heterogeneous air-fuel mixtures. One of the methods of lean mixture combustion is its lamination in the engine with the sectional combustion chamber.

Continuously increasing demands for cleanness of exhaust gases and engine efficiency cause the need of using better methods during designing process.

One of the research tools that are now most commonly used in combustion process analysis is numerical modelling.

Currently computer programs, which allow building and analysing three dimensions cases, are used for numerical modelling of engine cycle. Among these programs KIVA software worked out at Los Alamos National Laboratory in USA takes the lead [1], [2], [3]. The basis of model in KIVA is a system of equations of mass, momentum and energy conservation law and elements describing transient, three-dimensional flow field with chemical reactions (combustion). This software allows three-dimensional flows calculating in the chamber of any geometry with taking turbulence and heat transfer into consideration [4].

Three-dimensional model of air-fuel mixture creation and combustion process in SI engine with the sectional combustion chamber powered by liquid fuel was designed and analysed in KIVA 3V code. The results of numerical modelling were compared with measurements of two-stage combustion experimental engine built and developed in the Institute of Internal Combustion Engines and Control Engineering of Częstochowa University of Technology.

2. Numerical model

The engine's head cross-section is shown in figure 1. The working space of combustion chambers of analysed model was built in KIVA software in accordance with real engine geometric and is depicted in figure 2 as a grid made of 24700 cells and 27000 nodes. The sectional chamber consists of three combustion chambers: prechamber, chamber in piston and chamber in the cylinder of total capacity of 236,68 cm^3. Prechamber is about 4,5% of total combustion space and it is joined with other chambers by a canal of 6 mm in diameter.

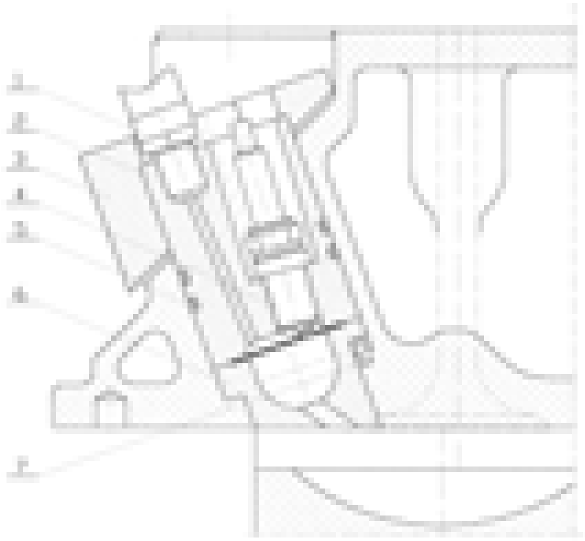

Fig. 1. *Experimental engine head with prechamber*
1 – flame extinguisher, 2 – prechamber body
3 – retaining cover, 4 – spark plug
5 – sealing ring, 6 – prechamber
7 – chamber dowel pin

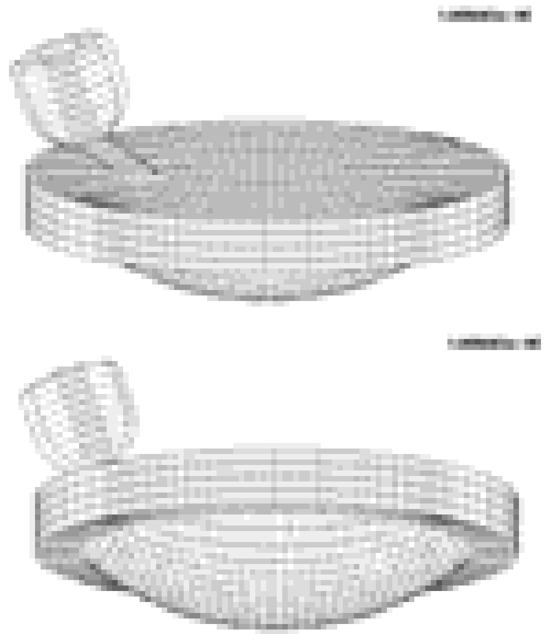

Fig. 2. *Geometric grid of combustion chambers of model engine in TDC*

3. Course of calculations

Calculation starts in BDC at the beginning of compression stroke for starting conditions established on the grounds of experimental measurements and lasts for few cycles until gaining numerical stability of solution.

Table 1

Chosen input parameters of modelled process

Quantity	KIVA symbol	Unit	Value
bore cylinder	bore	cm	12,0
stroke piston	stroke	cm	16,0
connecting rod length	conrod	cm	27,5
squish	squish	cm	1,38
engine speed	rpm	rpm	1,0e+3
temperature cylinder	tcylwl	K	450,0
temperature head	thead	K	450,0
temperature piston	tpistn	K	450,0
ignition factor	xignit	1	1,0e+4
ignition timing	calign	^{o} CA	-9,0
ignition duration	cadign	^{o} CA	10,0
injection timing	calinj	^{o} CA	-45,0
injection duration	cadinj	^{o} CA	30,0
fuel amount injection	tspmas	g	0,0014
injection course	pulse	1	1-sinus
temperature fuel injection	tpi	K	320,0
initial pressure	presi	dynes/cm^2	0,1e+7
initial temperature	tempi	K	365,0

At the beginning of compression there is lean air-fuel mixture in combustion chambers. 45° CA before BDC in the prechamber the lean mixture is enriched by injection of additional fuel. The ignition by spark discharge takes place in the prechamber 12° before TDC. As a result of pressure increase in prechamber burning rich mixture is forced into the main combustion chambers through the linking canal and lights lean mixture. Research was carried out for four values of combustion air factor - λ: 1.4, 1.6, 1.8, and 2.0.

4. Results of calculation

Visualisation of results is made after finishing calculation process. KIVA software generates plotgmv files, which are loaded into GMV postprocessor and allow visualisation of calculation results in any way [10].

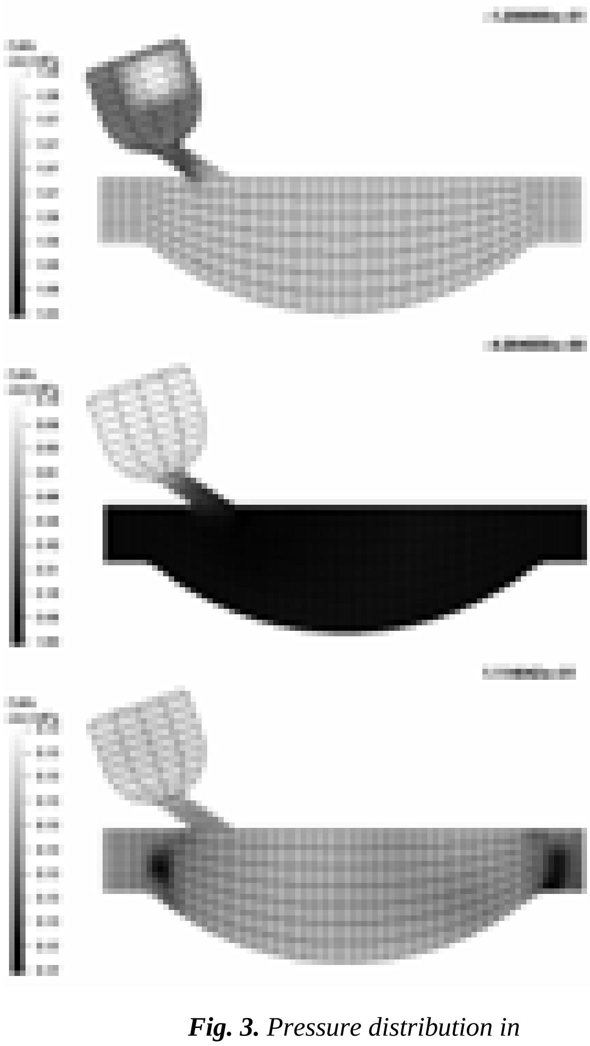

Fig. 3. *Pressure distribution in combustion chambers of model engine*

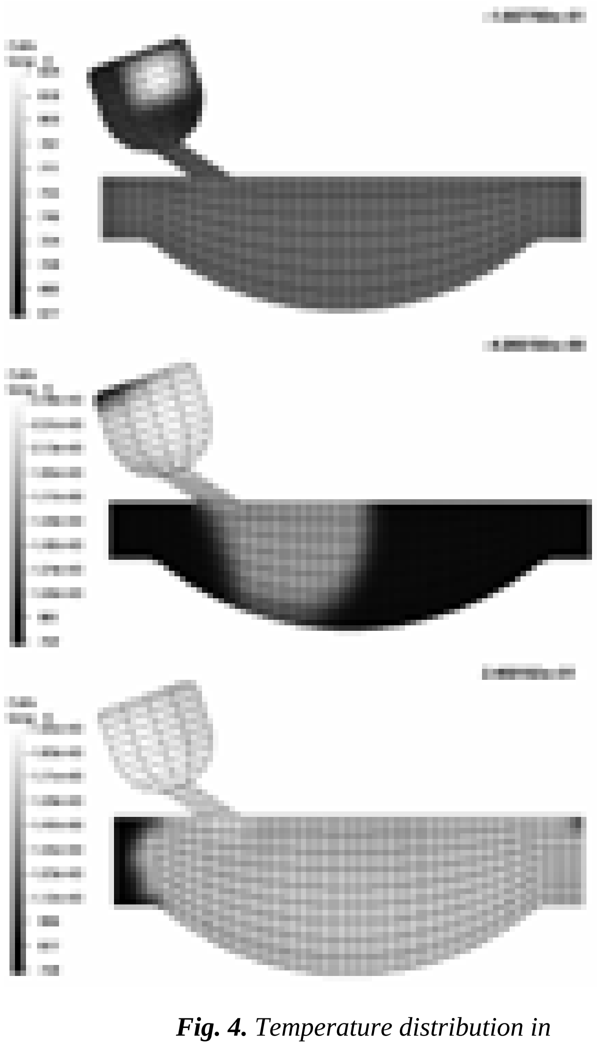

Fig. 4. *Temperature distribution in combustion chambers of model engine*

Figures 2 and 3 depict sample pressure and temperature distribution for specific crank angles while mixture of λ=2.0 combustion. Ignition moment of rich mixture in prechamber at 12° CA before TDC, maximal pressure in prechamber at 5° CA before TDC, maximal fuel temperature and moment of lean mixture ignition in cylinder, maximal pressure and temperature in cylinder at 11° and 24°CA after TDC are shown in these figures.

After finishing calculation dat files can be used to determine pressure and temperature of combustion process in function of crank angle.

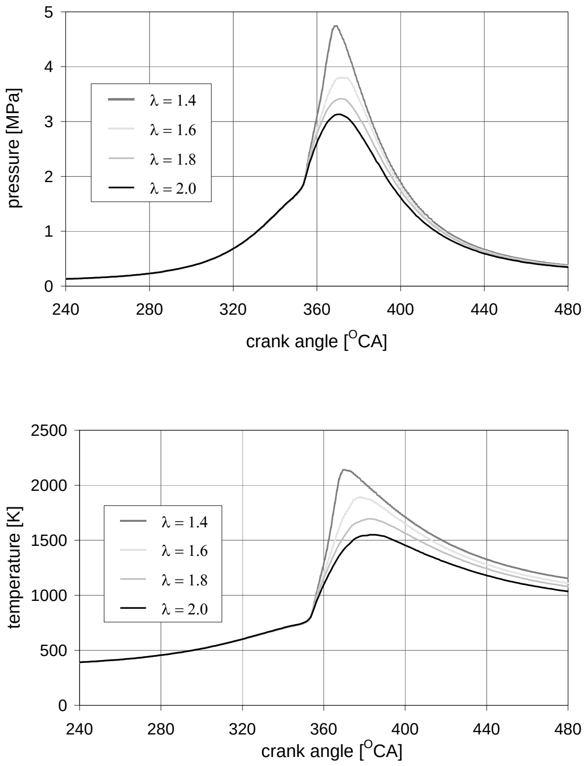

Fig. 5. *Average pressure and temperature in KIVA 3V model*

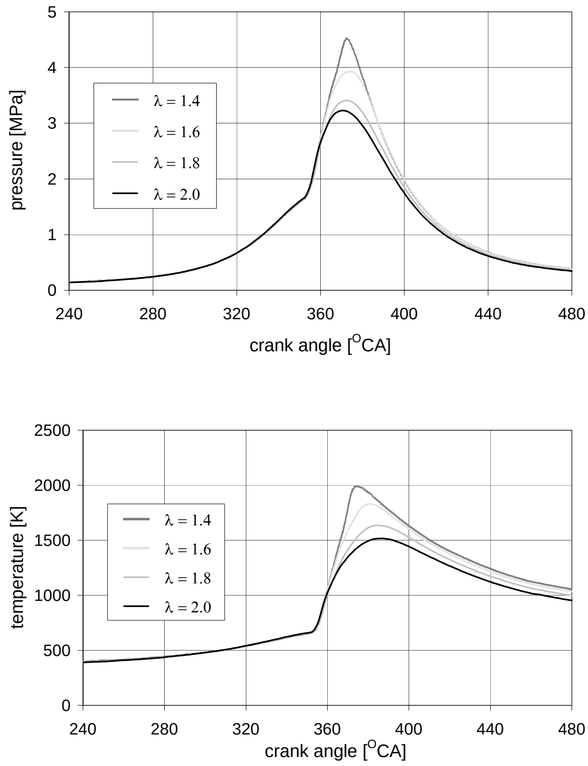

Fig. 6. *Pressure and temperature of experimental engine*

Comparing simulation results obtained form KIVA 3V with results of real engine cycle analysis obtained from SILNIK software [9], which is based on zero-dimensional combustion process model, reveals that maximal cycle temperature calculated in KIVA for all range of combustion air factor values is approximately 100K higher than temperature calculated on the grounds of indicating of real engine.

KIVA 3V software allows specifying toxic ingredients of exhaust gases in working spaces of the engine. Among many harmful exhaust gas ingredients the most difficult in SI engine is limitation of nitric oxides (NO_x) emission. Figure 7 shows example of nitric oxide concentration in combustion chambers for combustion air factor 2.0 only in prechamber. Sufficient high temperature and adequate conditions to nitric oxides creation exist only in prechamber as opposed to main combustion chamber.

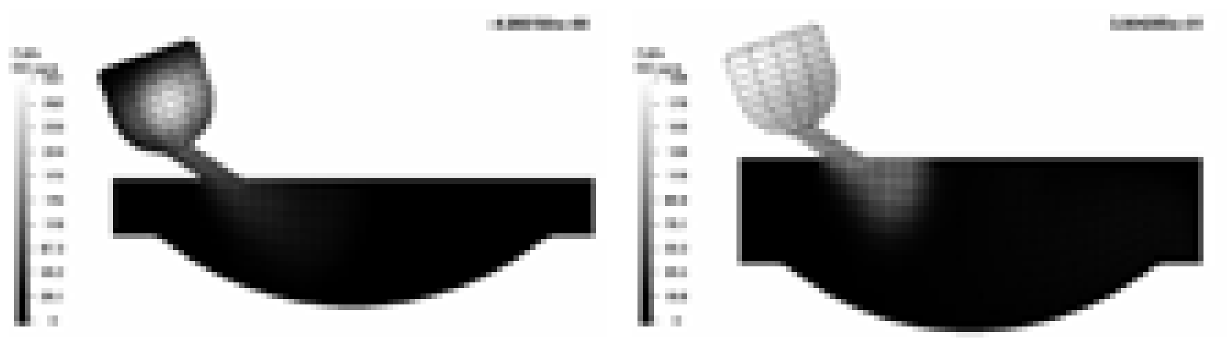

Fig. 7. *Nitric oxide concentration in combustion chambers of model engine for λ=2.0 at 5^o CA before and 30^o CA after TDC*

Course of nitric oxides creation in combustion chambers in function of crank angle is depicted in figure 9. Little differences between results of numerical modelling and measurements escalate along with increase in combustion air factor.

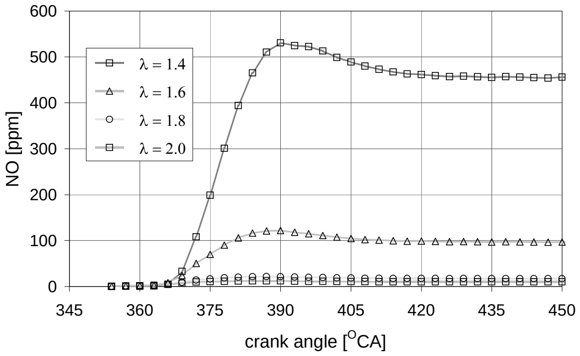

Fig. 8. Nitric oxide emission of model engine

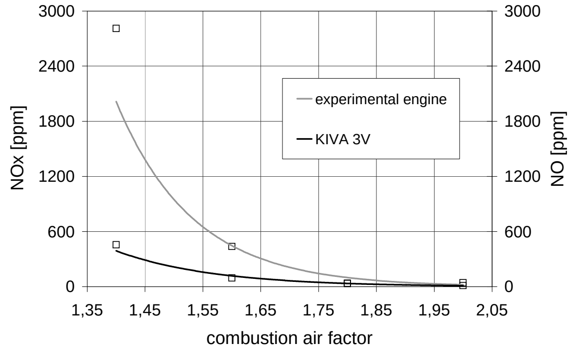

Fig. 9. *Nitric oxide emission of model engine in comparison with emission of experimental engine*

5. Summary

Numerical modelling results reveal that mathematical two-stage combustion in SI engine with prechamber model illustrates real processes in working spaces of experimental engine in a good way. Satisfactory compatibility of numerical modelling and experimental research results was gained. Moreover, usefulness of numerical modelling of flow processes as a tool, which assists during designing and developing combustion systems, was proved one more time.

References:

1. Amsden A.A.: *KIVA-3V, A Block-Structured KIVA Program for Engines with Vertical or Canted Valve*, Los Alamos National Laboratory, LA-UR-97-689 (February 1997);
2. Amsden A.A.: *KIVA-3, A KIVA Program with Block-Structured Mesh for Complex Geometries*, Los Alamos National Laboratory, LA-12503-MS, 1993;
3. Amsden A.A, O'Rourke P.J., Butler T.D.: *KIVA-II, A Computer Program for Chemically Reactive Flows with Sprays*, Los Alamos National Laboratory, LA-UR-11560-MS (May 1989);
4. Kowalewicz A.: *Systemy spalania szybkoobrotowych tłokowych silników spalinowych*, WKŁ, Warszawa 1980;
5. Niewiarowski K.: *Tłokowe silniki spalinowe*, WKŁ Warszawa 1983;
6. Rychter T.J., Teodorczyk A.: *Modelowanie matematyczne roboczego cyklu silnika tłokowego*, PWN, Warszawa 1990;
7. Bernhardt M., Michałowska J., Radzimirski S.: *Motoryzacyjne skażenie powietrza*, WKŁ Warszawa 1976;
8. Szczęsny P.: *Wpływ rodzaju modelu termodynamicznego procesu spalania na obliczenia udziałów składników toksycznych spalin silnika gazowego*, IV Międzynarodowa Konferencja Naukowa – Silniki Gazowe 1997;
9. Cupiał K.: *SILNIK – wersja 2001.5 – program do opracowywania wykresów indykatorowych*, Instytut Maszyn Tłokowych i Techniki Sterowania, Częstochowa 2002;
10. Ortega F.A.: *GMV version 2.5, General Mesh Viewer, User's Manual*, Los Alamos National Laboratory, LAUR 95-2986.