Simulation of combustion in pre-chamber gas engine

The program DIESEL-RK supports general analysis and simulation of combustion in Spark Ignition (SI) gas and petrol engines including engines with pre-chamber. Gas with arbitrary composition may be used as a fuel.

It is assumed there are 2 zones in the cylinder volume: 1) a cold fresh charge; 2) a hot products of combustion. The zones are divided by a moving thin layer of flame front. The heat exchange, dissociation, mass exchange between zones are taken into account for each zone.

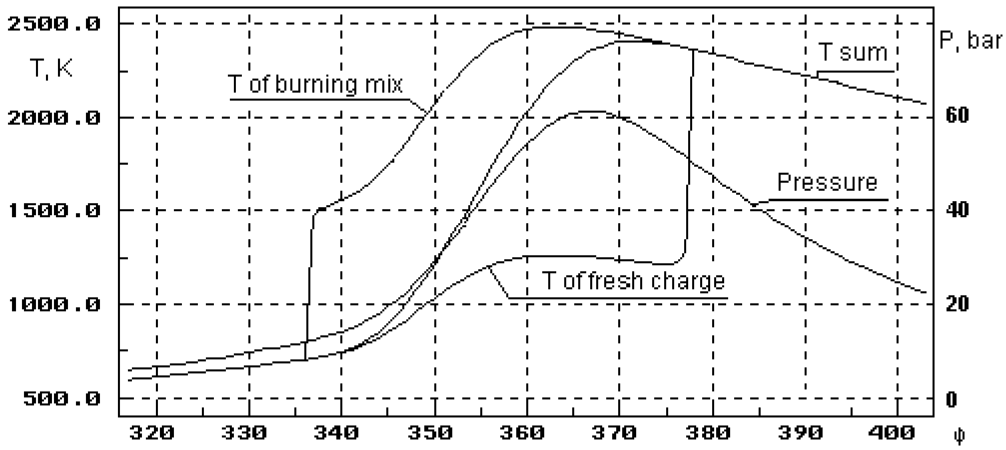

Fig 1. Curves of pressure and temperatures in the zones during combustion in SI petrol engine.

Simulation of gas engines

The program DIESEL-RK supports simulation and optimization of parameters of SI engines which use a natural or petroleum gas as the fuel, a syngas with arbitrary composition may be used as well. The properties of the fuel gas are calculated automatically by DIESEL-RK depending on gas composition. The engine may be equipped additionally with a pre-chamber which is charged with a rich mixture on the intake stroke. The spark ignition system ignites this rich mixture which creates a "flame jet" down into the lean mixture in cylinder and ignites it. In this case, parameters of gas are calculated separately for the main in-cylinder volume and pre-chamber. The gas velocity in the connective duct of pre-chamber is calculated with equation of non-steady gas motion:

$$W(x,\tau)\frac{\partial W(x,\tau)}{\partial x}+\frac{\partial W(x,\tau)}{\partial \tau}=-\frac{1}{\rho}\frac{dP(x,\tau)}{\partial x},$$

where: W is the gas velocity in the duct; P is the gas pressure; r is the gas density; x is the length of the duct, t is the time. The scheme of pre-chamber is presented in fig. 2.

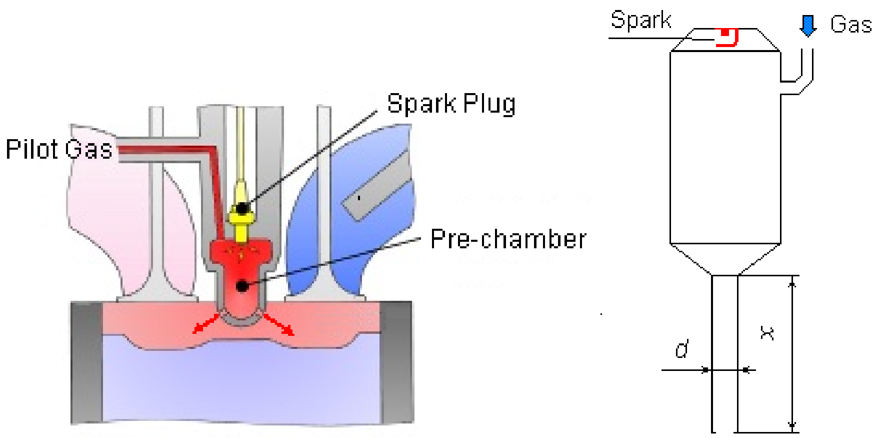

Fig 2. Scheme of pre-chamber.

The heat transfer factor for pre-chamber is calculated by the Woschni formula in which coefficient differs from original one.

The heat release in the pre-chamber is calculated using the Wiebe formula. The combustion in the main volume of cylinder begins after some fraction of enthalpy of burning gas swept out from the pre-chamber. Experience shows: the burning in cylinder has begun after that than 15 ... 20% of pre-chamber burning gas has escaped into cylinder. To make the model suitable for research the pre-chamber volume effect the special expression was developed for definition the moment of cylinder charge burning start:

$$S\, I^*_{pc} + m\, C_p\, T\, V_{pc} / V_c \quad > \quad C_{pc}\, m\, C_{po}\, T_o\, ;$$

where: $S\, I^*_{pc}$ is total enthalpy exhausted from pre-chamber;

C_p, T are current cylinder heat capacity, temperature;

m is mass of in-cylinder gas at the moment of start of flow from pre-chamber;

V_{pc}, V_c are pre-chamber volume and compression volume;

C_{po}, T_o are heat capacity at $T=T_o=473$ K,

$C_{pc}= 0.25$ is a calibration factor. The more C_{pc}, the late start of burning.

The heat release in the main chamber is approximated by the Wiebe formula too.

The calculation of gas parameters (pressure, temperature, composition) in the pre-chamber is carried out during whole cycle.

The knock limit is calculated with Dauaud-Eyzat formula.

Results of simulation of MTU 396 gas engine with pre-chamber is presented below. (The MTU 396 gas engine is a natural aspirated diesel being converted for operation with a natural gas). Comparison of calculated and experimental curves of pressure in the cylinder is presented in fig. 3. The in-cylinder average temperature and pre-chamber temperature are presented in the fig. 4.

MTU 396 gas engine specification

Cylinder Bore, mm	165
Stroke, mm	185
Number of cylinders	8
Compression ratio	13.5
Pre-chamber volume, cm^3	35
Connect duct bore, mm	8
RPM	1521
Power, kW	270
Ignition timing, CA deg. BTDC	40
The air/fuel ratio in the cylinder	1.1
The air/fuel ratio in the pre-chamber	0.87

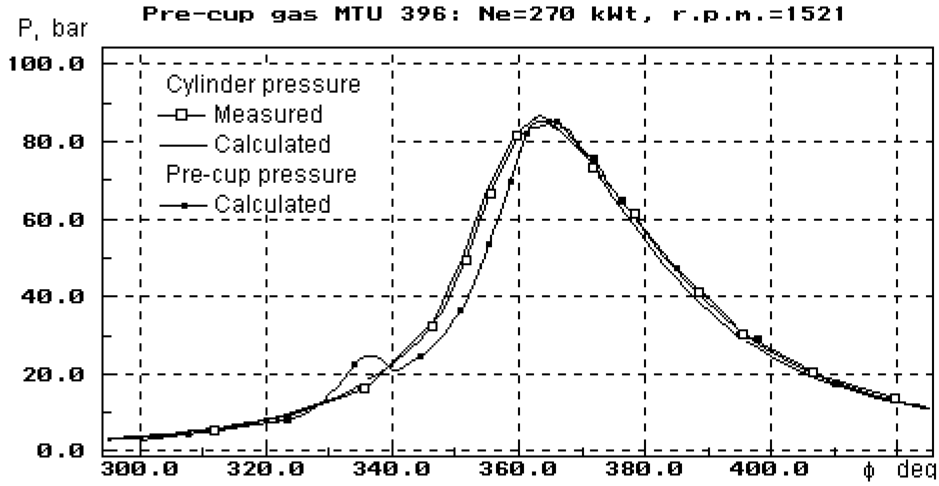

Fig 3. Pressure in the cylinder and in pre-chamber.

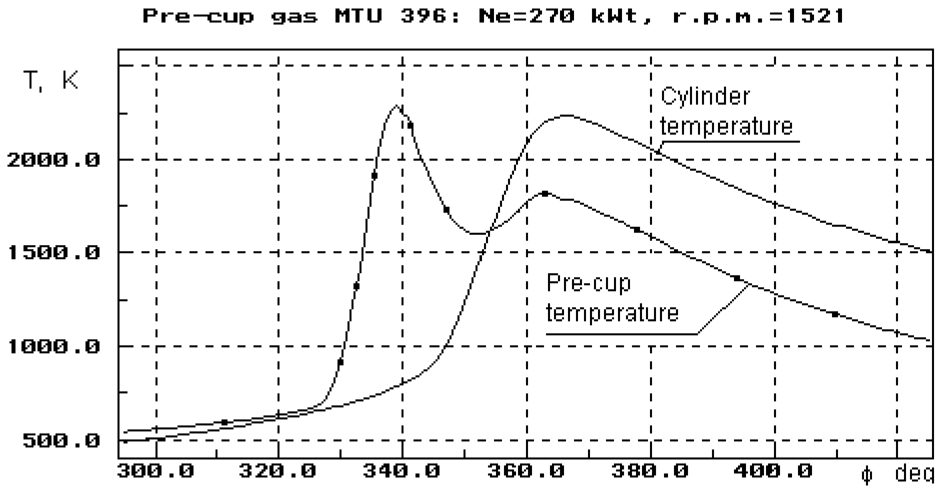

Fig 4. The in-cylinder average temperature and pre-chamber temperature.