# COMPUTATIONAL MODELLING OF THERMAL STRESSES IN THE COMBUSTION CHAMBER OF A SPARK IGNITION ENGINE FUELED WITH ETHANOL- GASOLINE BLENDS

### Krisztina Uzuneanu, Tănase Panait, Dan Scarpete

***Abstract:****The heat transfer processes in piston head engine can be modeled with a variety of methods. These methods range from simple thermal networks to multidimensional differential equation modeling. The thermal stresses in the combustion chamber of an internal combustion engine are determined as a function of the level of temperature. Measuring the temperatures in different parts of the cylinder head, we can adjust the cooling, or we can improve the materials, or even we can improve the properties of the fuels. The present paper deals with the thermal stresses in the combustion chamber of a spark ignition engine fueled with a mixture of gasoline with ethanol.*
***Key words****: combustion chamber, piston head, cylinder head, temperatures, thermal stress, ethanol-gasoline*

## Introduction

The thermal stresses are due to the difference in the parts temperatures. These further depend on the speed and the way the heat is transferred to the parts, on the part shape, their thermal conductivity and cooling. The thermal state of the parts of an internal combustion engine has an effect on the strength characteristics of the material of which the parts are made, on the rate at which deposits appear on the parts, on the lubrication conditions of the parts, on friction, wear and stresses in the parts. The temperature of the parts has an effect on operating temperature of the lubricating oil and hence, on its viscosity, oil – film thickness which separates of the rubbing pair and the nature of friction.

If an ethanol - gasoline mixture is used to fuel an unmodified spark ignition engine a lower level of the part temperatures is obtained as compared with the case when only gasoline is used.

## 1. Piston head model

The level of the temperatures in the piston determines the regular operation of the whole engine.

It is the most important to determine the field of temperature in the piston head, in the centre and at the edge.

If we consider the piston head a symmetrical – axial body, the equation of conduction is:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} = 0 \tag{1}$$

Or using undimensional coordinates: $\eta = r/R$ si $\xi = z/\delta$ and $\Theta = \overline{T}_g - T$ the equation is written [5]:

$$\frac{\partial^2 \Theta}{\partial \eta^2} + \frac{1}{\eta}\frac{\partial \Theta}{\partial \eta} + \frac{R^2}{\delta^2}\frac{\partial^2 \Theta}{\partial \xi^2} = 0 \tag{2}$$

The solution is given by integration:

$$T = \overline{T}_g - \Theta = \overline{T}_g -$$
$$- \frac{\phi}{10^{-6}\pi\frac{D^2}{4}}\left(\frac{1}{\overline{\alpha}_g} + \frac{10^{-3}\delta}{\lambda_p}\xi + \frac{10^{-3}D}{\lambda_p}\eta\right)[K] \tag{3}$$

In the centre of the piston head the temperature is:

$$T_{cp} = \overline{T}_g - \frac{\phi}{A}\left(\frac{1}{\overline{\alpha}} + \frac{D}{\lambda_p}\cdot\varphi_1\right) \tag{4}$$

At the edge of the piston head the temperature is:

$$T_{ep} = \overline{T_g} - \frac{\phi}{A}\left(\frac{1}{\overline{\alpha}} + \frac{h}{\lambda_p} + \frac{D}{\lambda_p}\phi_2\right) \tag{5}$$

## 2. Experimental study of the piston head

The experiments conducted in the internal combustion engines laboratory of University "Dunarea de Jos" of Galati have mainly used a mixture of gasoline and ethanol to feed an unmodified spark ignition engine.

When blended with gasoline, the ethanol tendency to separate is much lower than the methanol. The high volatility of the gasoline alcohol blends is a significant inconvenient because they cause fuel losses by evaporation.

Thus, the temperature of the fuel constant level chamber reaches 50 to 55 degrees during operation and in summer even 80-85 degrees. The losses by evaporation of an engine supplied with 10% alcohol and gasoline increases by 90%.

The gasoline - alcohol blends behave normally relative to the abnormal detonation combustion also revealed by the increase in their self-ignition temperature. The generally high anti-detonation qualities of the gasoline-alcohol or gasoline ether blends can be turned into a good account by optimizing the fuel or the engine.

As far as the fuel is concerned, the basic gasoline composition (and therefore the fabrication technology) can be maintained. This is extremely important for prevention of the polluting exhaust gases.

Using pure ethanol to fuel engines is limited by the need to make significant changes to the fuel supply systems. Since the ethanol caloric power is twice lower than that of the gasoline, a double quantity of alcohol is necessary to reach the same output.

Pure ethanol supplying calls for specially designed and manufactured engines.

We can consider a case of spark ignition engine supplied by gasoline and by a blend of 10% ethanol and 90% gasoline (E 10). [2] The effective power of the engine is $P_e$ = 65 kW, the bore is D = 92 mm, $\overline{\alpha}_g$ = 350 W/m$^2$ K is an average heat transfer coefficient, $\lambda_p$ = 160 W/m K is piston thermal conductivity and $\phi_1$ = 1,02; $\phi_2 = \phi_2 (D,\lambda)$ $\phi_2$ = 1,28.

Using the equations (11) and (12) we obtain the temperatures in the center of the piston head and at the edge of piston head.

- In the case of gasoline supply:

$T_{cp}$ = 523 K - piston head center temperature $T_{ep}$= 474 K - piston head edge temperature

- In the case of ethanol – gasoline blend (E10) supply:

$T_{cpE}$ = 464 K - piston head center temperature $T_{epE}$ = 415 K, .- piston head edge temperature i.e. a reducing a level of temperatures in the center and at the edge of the piston with 11-12%.

The measured and theoretic temperatures are inputs to the ANSYS program to determine the temperature field, thermal stresses and deformations due to the temperature difference in the piston head.

The more recent computation finite element programs have implemented thermal finite elements too. For the purpose of this paper, use was made of the ANSYS program which contains 20 types of elements for the heat transfer out of which the types of "thermal elements" were used: for preset nodal temperatures, axial- symmetric solid, thin plate, three- dimensional solid [2].

Using these elements the piston and cylinder head were investigated in terms of thermal steady conditions and the temperature field, heat flow thermal stresses and displacements along different directions were obtained.

In the thermal approach, the rigidity matrix becomes conductivity matrix, the nodal displacement vector becomes the nodal temperature vector and the tensions become heat flows.

Fig. 1.
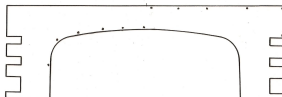
The input data in the program are:

longitudinal elasticity module, $E = 0{,}75 \cdot 10^{11}$ [N/m$^2$]

thermal conductivity, $\lambda_p = 160$ [W/mK]

Poisson's number, $\mu = 0{,}3$

linear thermal expansion coefficient, $\alpha = 20 \cdot 10^{-6}$ [K$^{-1}$]

model of calculation : static

label : PLANE 82

It is considered a section through piston head and the temperature measured in steady conditions are input data. The points in Fig. 1 indicate he places were thermocouples are put.

The field of temperature in the piston head shows the lower level when the engine is supplied with gasoline - ethanol blend (Fig. 2) than with gasoline (Fig. 3).
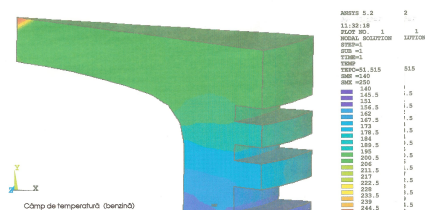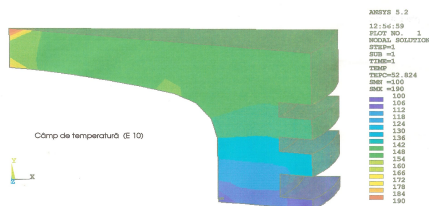
Fig.2                                                      Fig. 3

## 3. Experimental study of the cylinder head

A comparative study was carried out on a spark- ignition engine fueled with gasoline and a mixture of gasoline - ethanol. The engines parameters were : capacity $V_t = 2500$ cm$^3$, power $P_e = 65$ kW and speed n = 4500 min$^{-1}$. The engine was instaled on a testing stand. Chromel - alumel thermocouples were provided to measure the outlet gas temperature and the cylinder - head wall temperature near the inlet and outlet ports.

The temperature measuring points in the bridge between the valves, in the inlet and outlet valves are given in the figures 4, 5, 6.
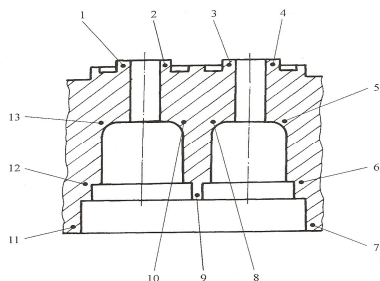
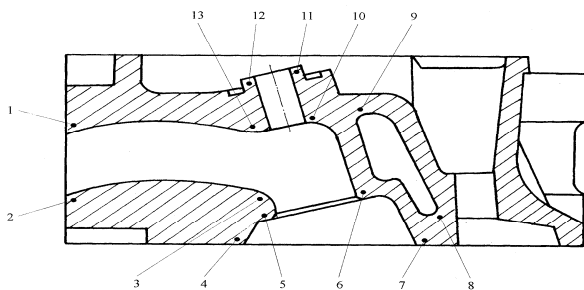Fig. 4.  Cross section at bridge between valves

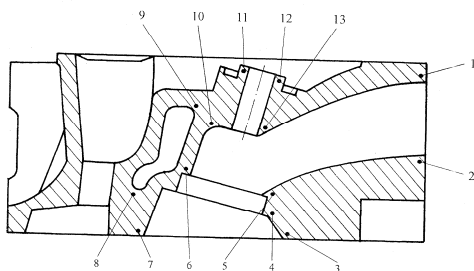Fig. 5. Cross section at admission area



Fig. 6- Cross section at exhaust area

The temperatures were read on a digital gauge type Multy-Tester. The first stage of the experiment was to supply gasoline to the engine.

The engine speed was kept constant n = 1000 min$^{-1}$ until relatively constant temperatures of the gas and the cylinder head wall near the input and output ports were reached. The temperature of the cylinder- head wall in the area of the gas inlet port stabilizes after $\tau \sim$ 30 min while in the of the gas outlet port after $\tau \sim$ 35 min.

With a speed of n = 1500 min$^{-1}$ the same measurements are taken and it is found that the cylinder head wall temperatures in the area of the gas inlet port stabilizes after ~ 30 min, in the area of the gas outlet port after ~35 and the gas temperature after 40 min.

With a speed of n = 2200 min$^{-1}$ it is found that the cylinder head wall temperature near the inlet port stabilizes after ~ 30 min, at the outlet port after ~ 30 min and the gas temperature after ~ 45min.

The engine was subsequently fuelled with different mixtures:
- mixture of 5% ethanol - 95% gasoline E5,
- mixture 10 % ethanol - 90 % gasoline E10,
- mixture 15 % ethanol - 85 % gasoline E15,
The experiments were made while keeping the speed to the same values as before.
The measured temperatures are inputs to the ANSYS program to determine the temperature field, thermal stresses and deformations due to the temperature difference in the cylinder head wall [5], [6] as you are seen in figs7, 8, 9.
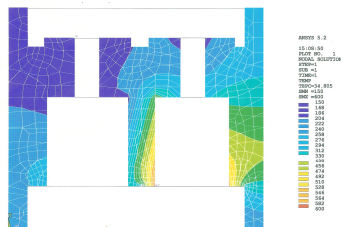
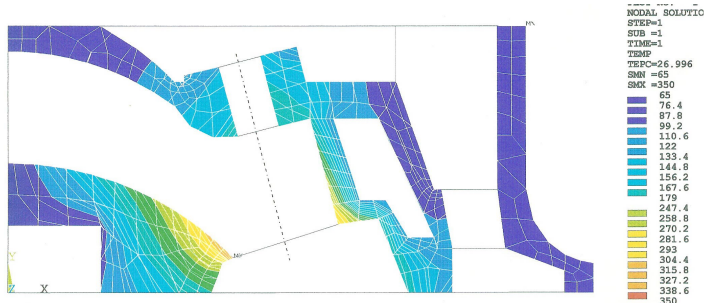Fig. 7 - Field of temperature at the bridge area of the cylinder head



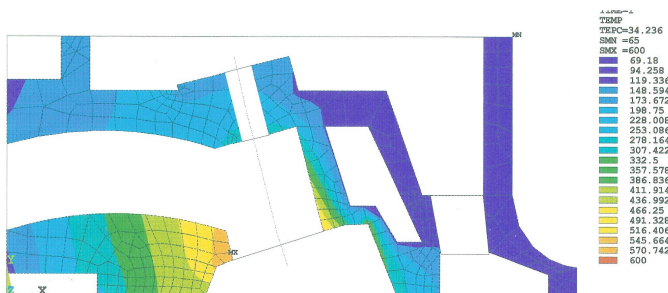Fig. 8 – Field of temperature at the inlet valve area



Fig. 9 – Field of temperature at the outlet valve area

From the data analysis the following conclusions are reached:
- The temperatures measured when the engine is fueled with 5% ethanol - 95 % gasoline E5 are equal to the temperatures taken when the engine is fueled with gasoline only.
- The temperatures recorded when 10 % ethanol - 90 % gasoline E10 is fed to the engine are lower than in the case of the classical gasoline supplying.
- When the mixture of 15 % ethanol - 85 % gasoline E15 is used, the temperatures are lower by 1- 2 degrees than that measured when E10 is fueled, but there were some difficulties when the engine was started. [1], [3]
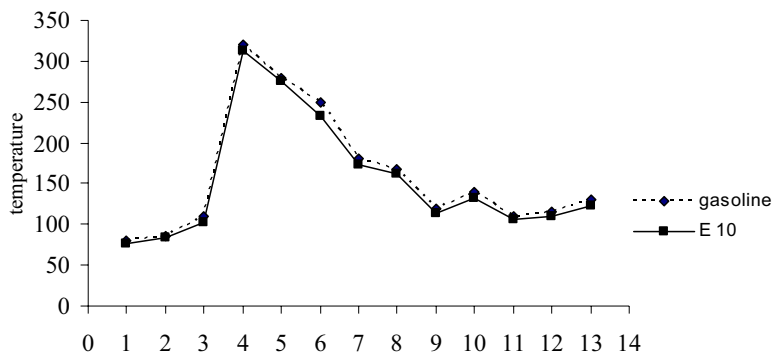
Fig. 10. Temperature in the cylinder head wall in the inlet valve area [$^0$C]:
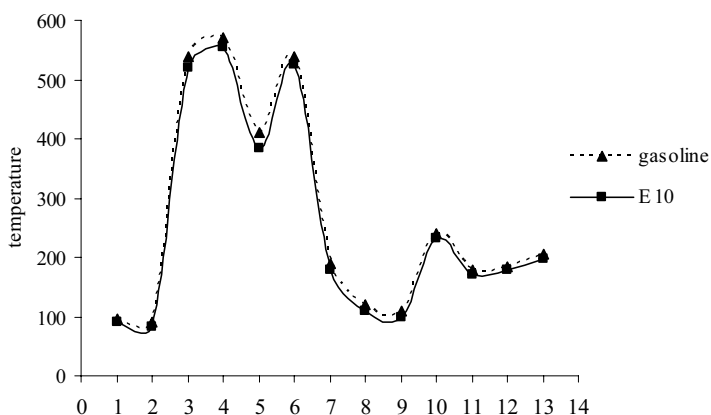


Fig. 11. Temperature in the cylinder head wall in the outlet valve area [$^0$C]:
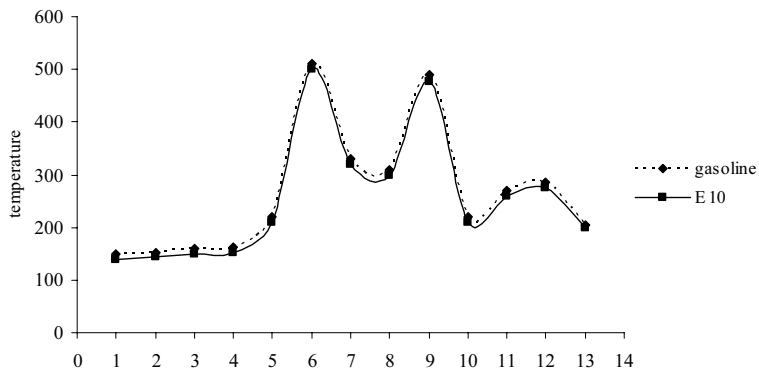


Fig. 12. Temperature in the cylinder head wall in the area between the inlet/outlet valve [$^0$C]:

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Using these elements the piston and cylinder head were investigated in terms of thermal steady conditions and the temperature field, heat flow thermal stresses and displacements along different directions were obtained [4], [5].

## Conclusions

The physical and chemical properties of the ethanol are significantly different from those of the conventional liquid oil fuels.

An efficient use of alcohols as fuels calls for construction modifications and adjustments to the engine in order to diminish the negative influences and turn into good account the good properties. That is why, to avoid modifications to the spark ignition engine, the use of the mixture E10 (10 % ethanol -90% gasoline) is worth being considered.

Using this mixture to fuel the spark ignition engine, a number of positive results are obtained, such as:

- a lower polytropic exponent of compression which results in lower pressures and temperatures by the end of the compression and burning and also lower burnt gas mean temperatures, [2],[4];
- the mean thermal stress of the spark ignition engine is lower when using E10 then gasoline in the same engine operating conditions;[4]
- the extent  to which heat is saved by using E10 shows that, although the engine efficiency does not increase, supplying two types of fuels to the same engine represents an important research trend;[3]
- the tendency to reduce the effective power at a constant fuel rate as a consequence of the combustion value which is much lower than that of the gasoline,
- the decrease of polluting emissions when using E10 indicates that the future belongs to those engines able to operate while protecting the environment, the atmosphere, i.e. life.[2]

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**The paper is reviewed.**