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ANALYSIS OF THE FORD 1L ECOBOOST ENGINE VIA ENERGETIC BALANCE METHOD

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Abstract: *In this paper we use the amount of heat generated, transferred and then exhausted during the combustion process to calculate the amount of it used in generating power, evacuated through the cooling system and evacuated via exhaust gases.*
Keywords: *engine, thermal balance, thermodynamics*

1. FUNDAMENTAL DIMENSIONS AND INITIAL PARAMETER CALCULATION

As a work assignment, the Ford 1L EcoBoost M1DA engine (Figure 1) has been selected for analysis via the energy balance method shown hereafter. It is a modern intercooled DOHC 3 cylinder turbocharged engine that develops a peak power of 92 kW at 6000 rpm and 170 Nm torque between 1500 and 4500 rpm. Using the methods described in the reference materials we calculated the fundamental dimensions of the engine bore of 71.9mm and stroke of 81.9mm, both of which were rounded off. Per cylinder displacement of 0.33253 dm^3, ε=9.5 and λ=1 were used to calculate the trace of the p-V diagram (Figure 2) and the pressure-crank angle diagram. These were used to calculate the power, torque and consumption bands for the engine.
The initial parameters were also used in sizing and verifying the internal components of the engine along with the complementary subsystems (oiling, cooling, alternator, etc.) using the methods shown in the reference materials.

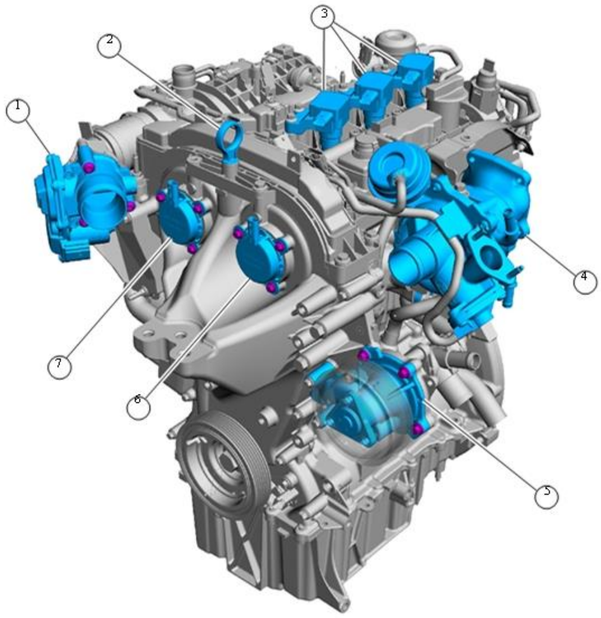

Figure 1 Engine pictured without cooling ystem

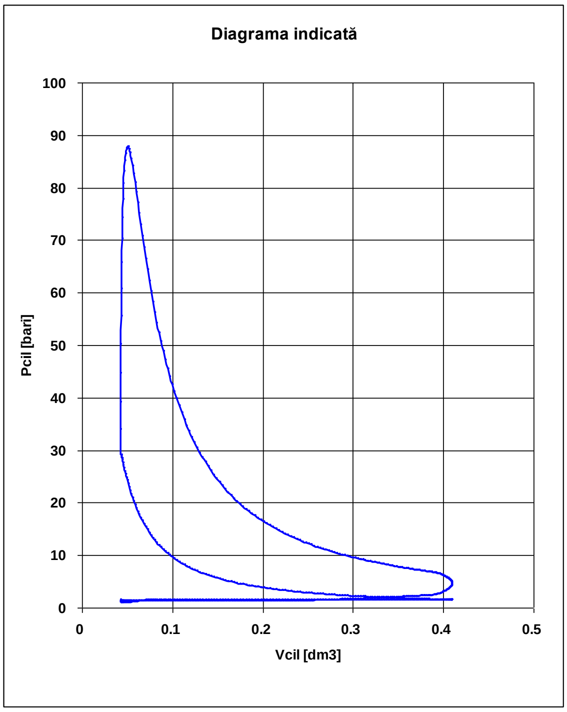

Figure 2 p-V diagram

2. ENERGETIC BALANCE OF THE M1DA ENGINE

We start our analysis by breaking down the exhaust gas composition needed for the computation of the burnt gas constant which is subsequently necessary in order to arrive at the specific heat characteristic of exhaust gases. (Figure 3)

Afterwards, we calculate the fuel flow per cycle and cylinder which is used along with the Vibe method to plot the speed and quantity of heat generated against crank angle during the combustion process by the quantity of fuel revealed through the analysis of the exhaust gases. (Figure 4)

Through the differential expression of the first law of thermodynamics and knowing the fundamental parameters of the engine, we can extract the apparent quantity of heat generated per crank angle degree. This is used to retrace the p-V and heat release per crank angle diagram without cooling. (Figure 5, Figure 6) We also model and trace the evolution of temperature and pressure during the combustion cycle. (Figure 7).

To arrive at the heat transferred to the main engine parts, we will need the average heat of said parts (Table 1), the area of each part at every point in the combustion process and the global coefficient of heat exchange. The global coefficient of heat exchange is calculated using Woschnis correlation. (Figure 8) [2}

Table 1: Average heat of parts in contact with the burnt gases

No.	Part	Temperature[K]	Temperature[ºC]
1	Piston	503	230
2	Valve head	383	110
3	Cylinder	393	120

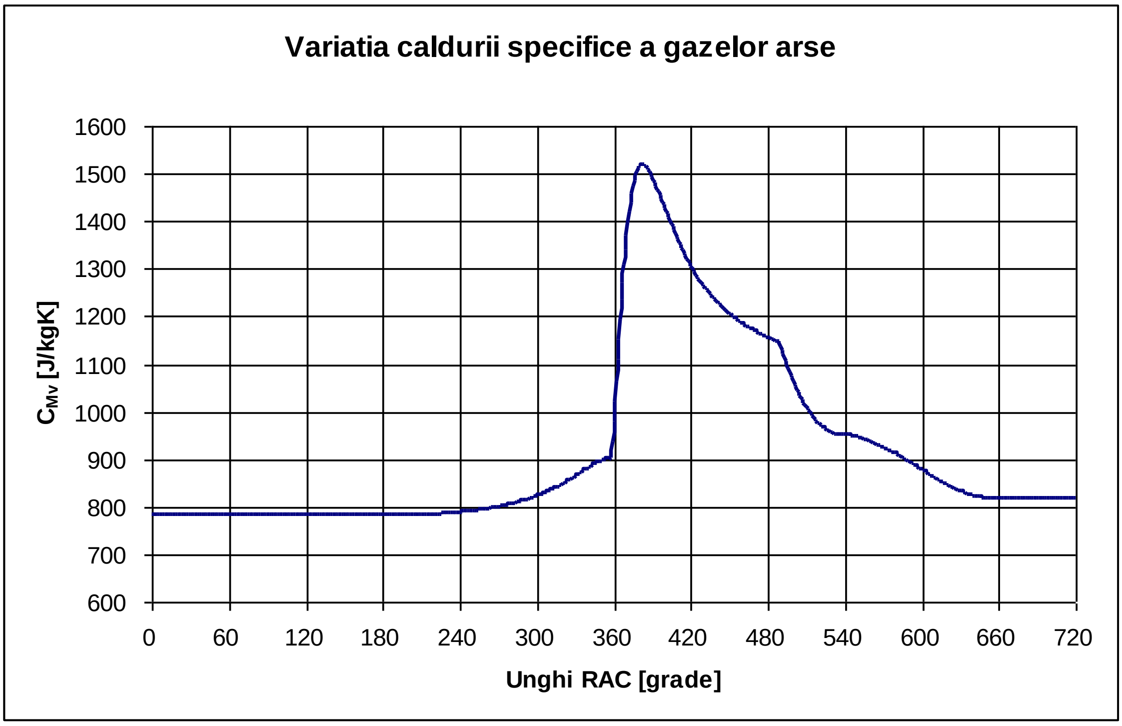

Figure 3 Specific heat variation of burnt gasses

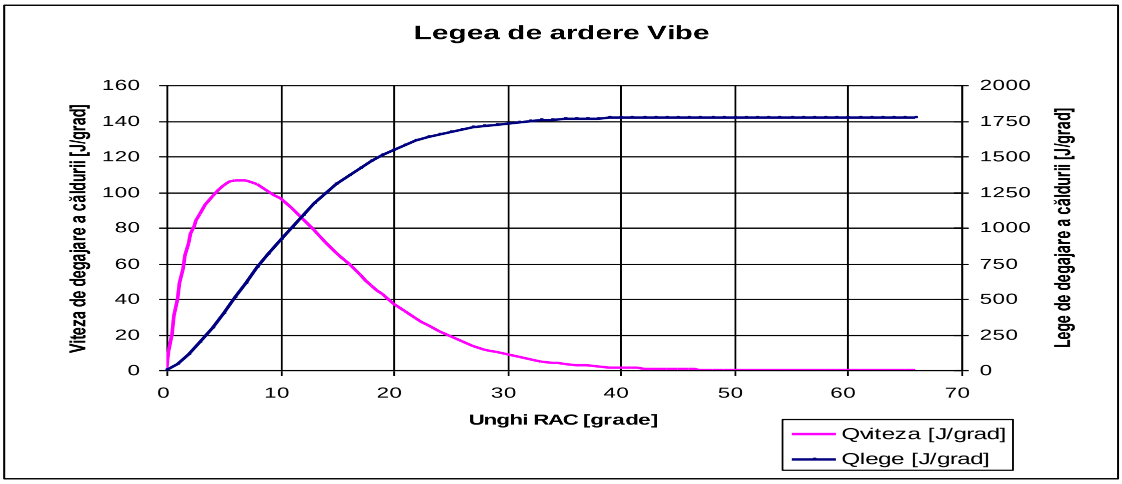

Figure 4 Speed and quantity of heat transfer

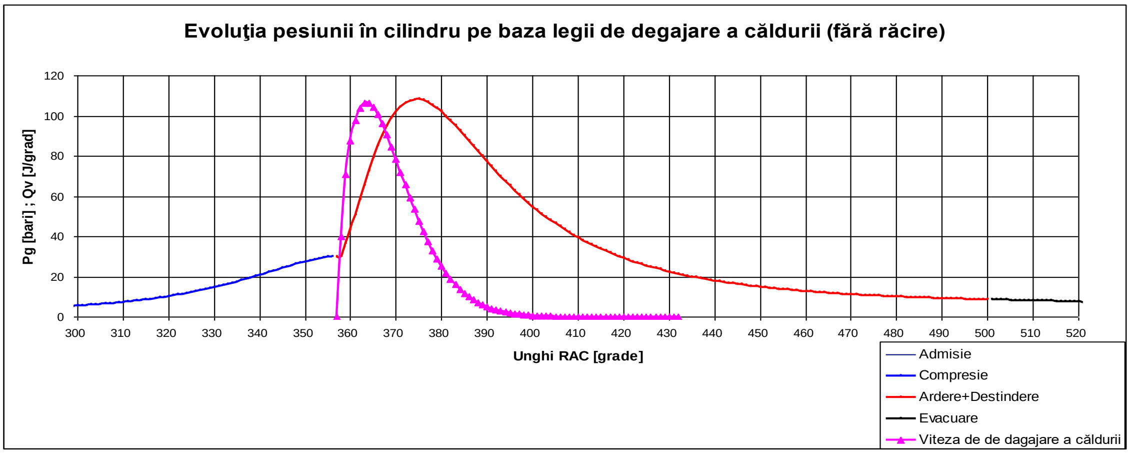

Figure 5 Cylinder pressure evolution according to the law of heat transfer

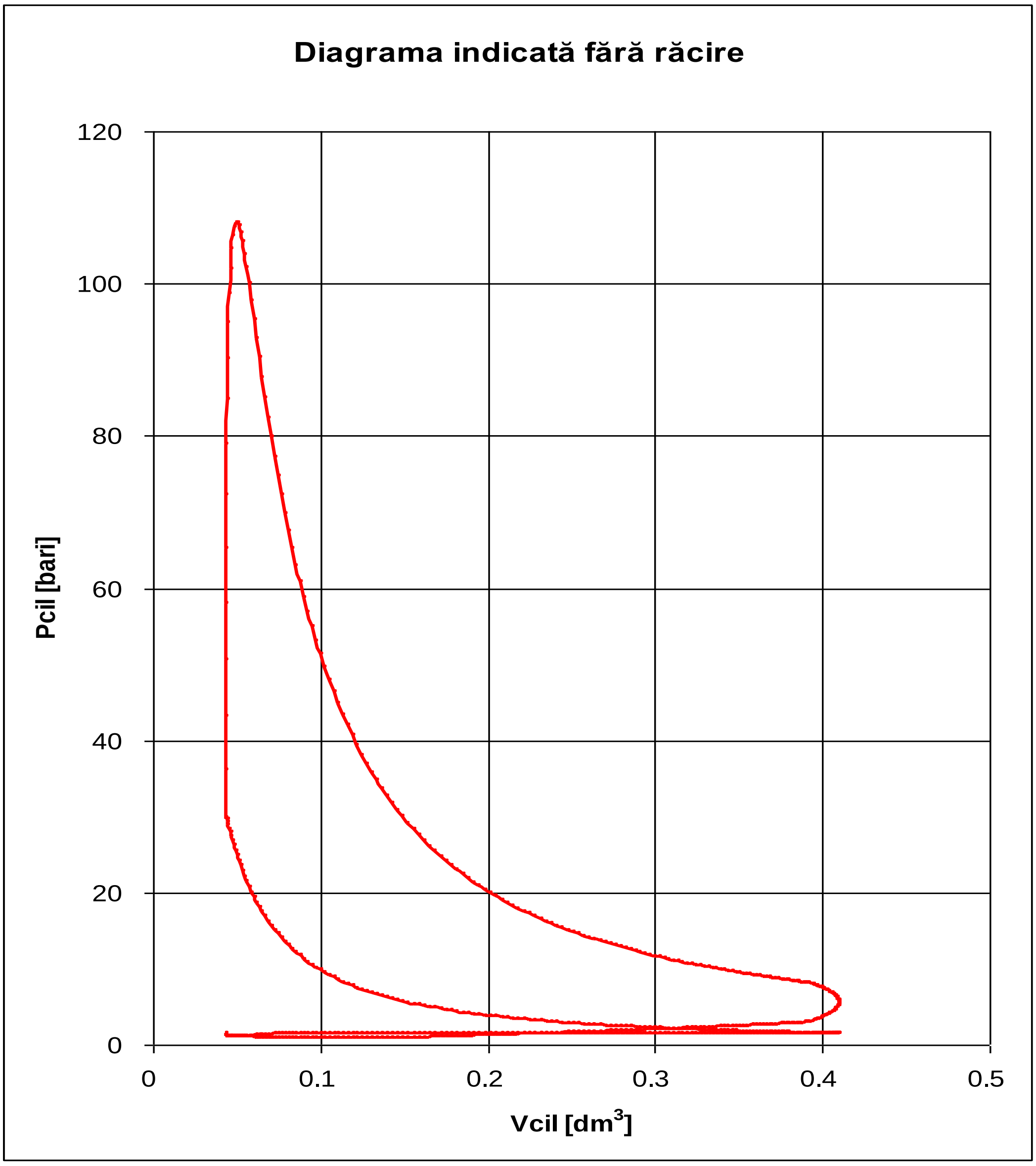

Figure 6 p-V diagram without cooling

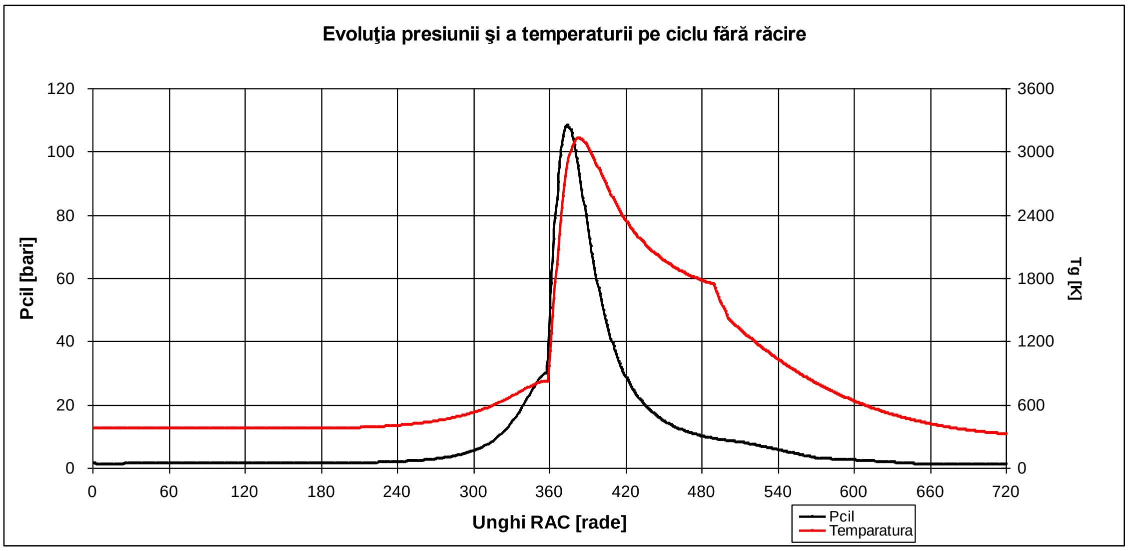

Figure 7 Evolution of pressure and temperature per cycle without cooling

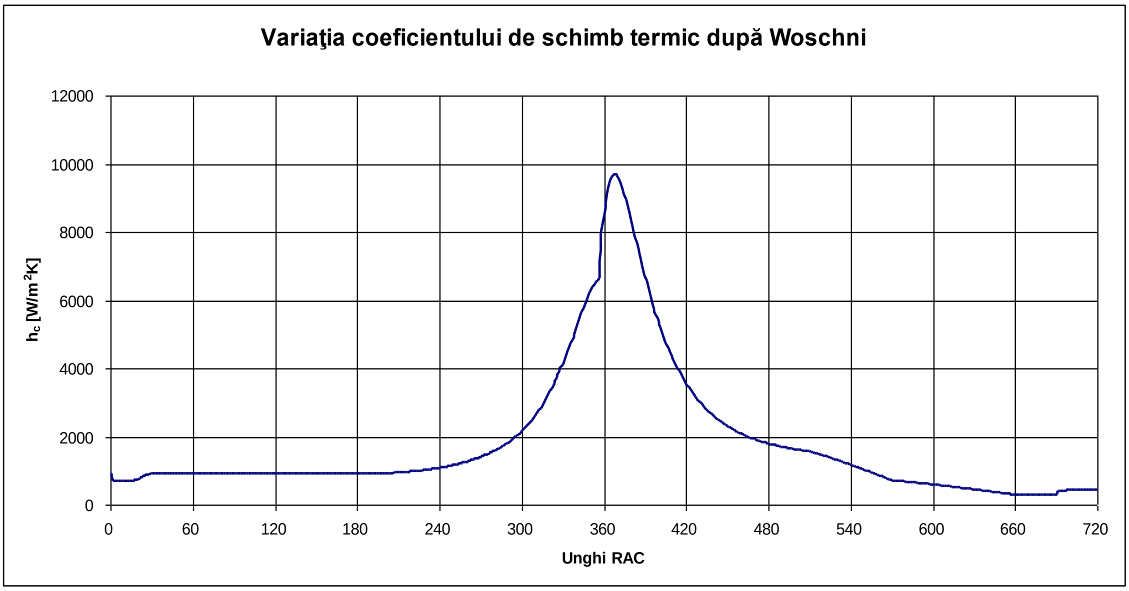

Figure 8 Fluctuation of the thermal exchange coefficient according to Woschni correlation

From previous calculated points, we can calculate and plot the heat transferred to each part in contact with the combustion gasses which is then summed up to show the total amount of heat transferred to parts and then dissipated through the cooling system. (Figure 9, Figure 10) We then use this to calculate the temperature per cycle with cooling and use this to retrace the pressure per crank angle diagram (Figure 11) and the p-V diagram (Figure 12) which are over layer with the previous ones. From these we can extract the quantity of useful work performed by the expansion of the combustion gasses, that is used in determining the indicated power. This along with the mechanical efficiency adopted is used to compute the effective power and work values. [11]

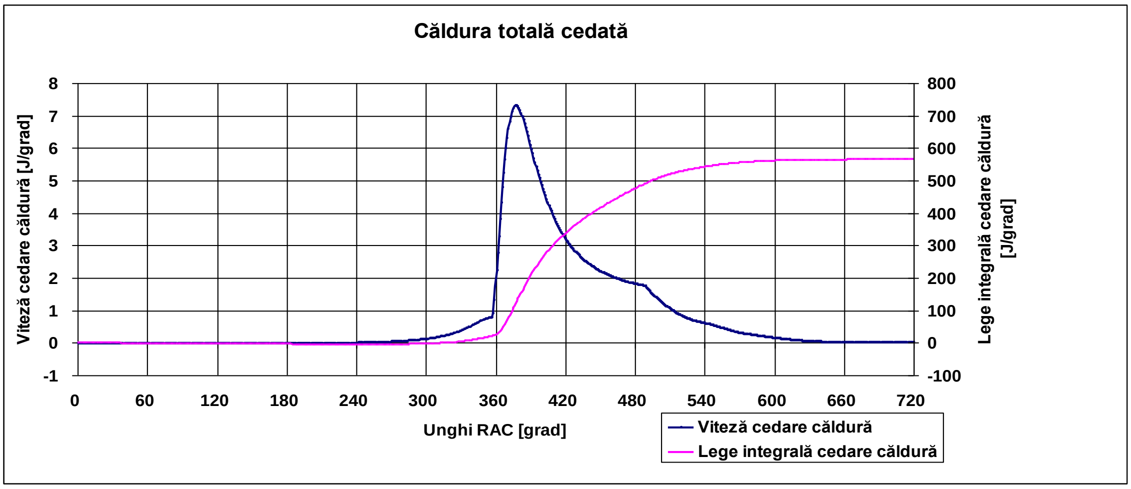

Figure 9 Total amount of heat transferred to parts in contact with combustion gasses

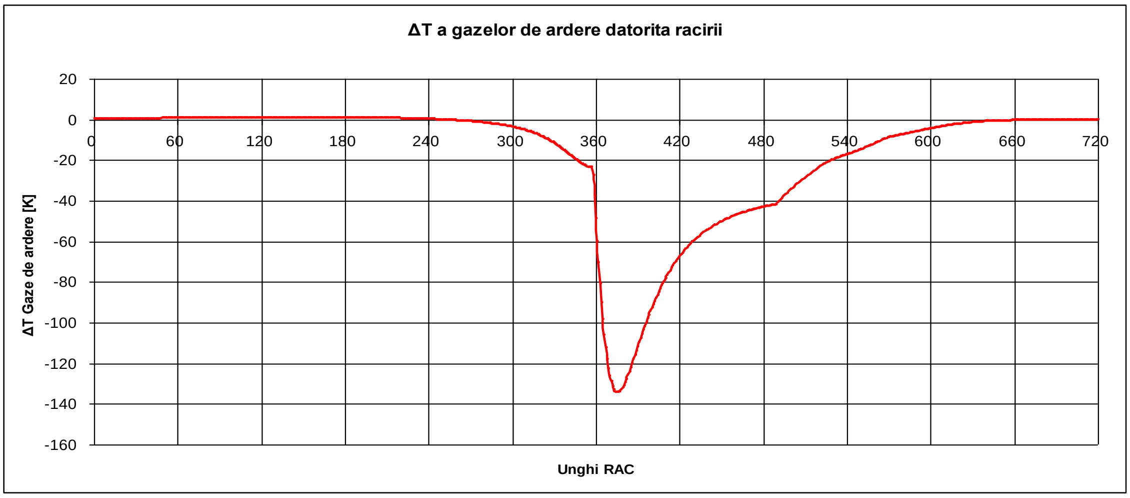

Figure 10 Temperature drop of combustion gasses due to cooling

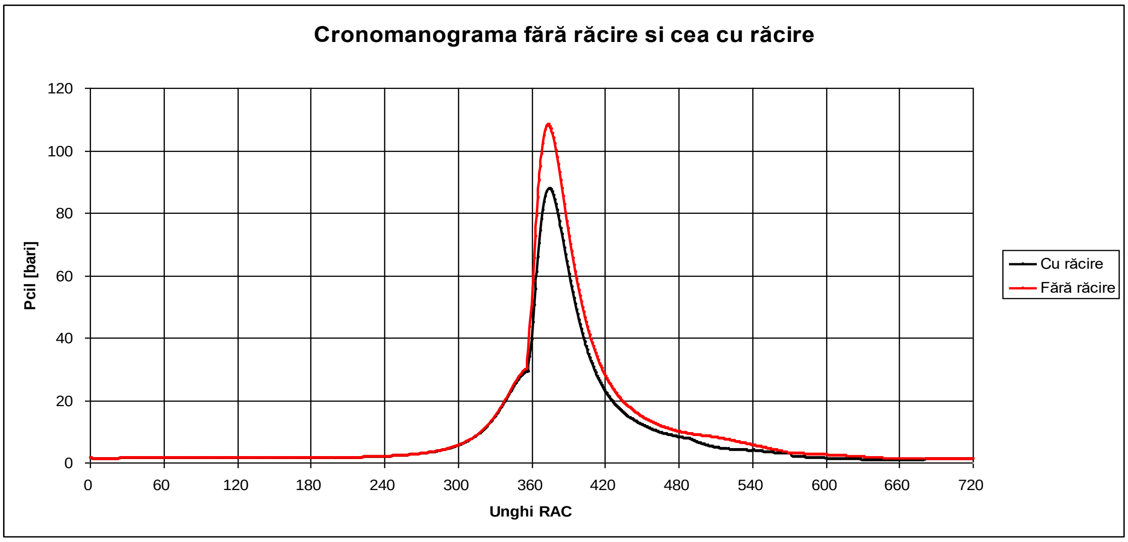

Figure 11 Cylinder pressure per crank angle diagram

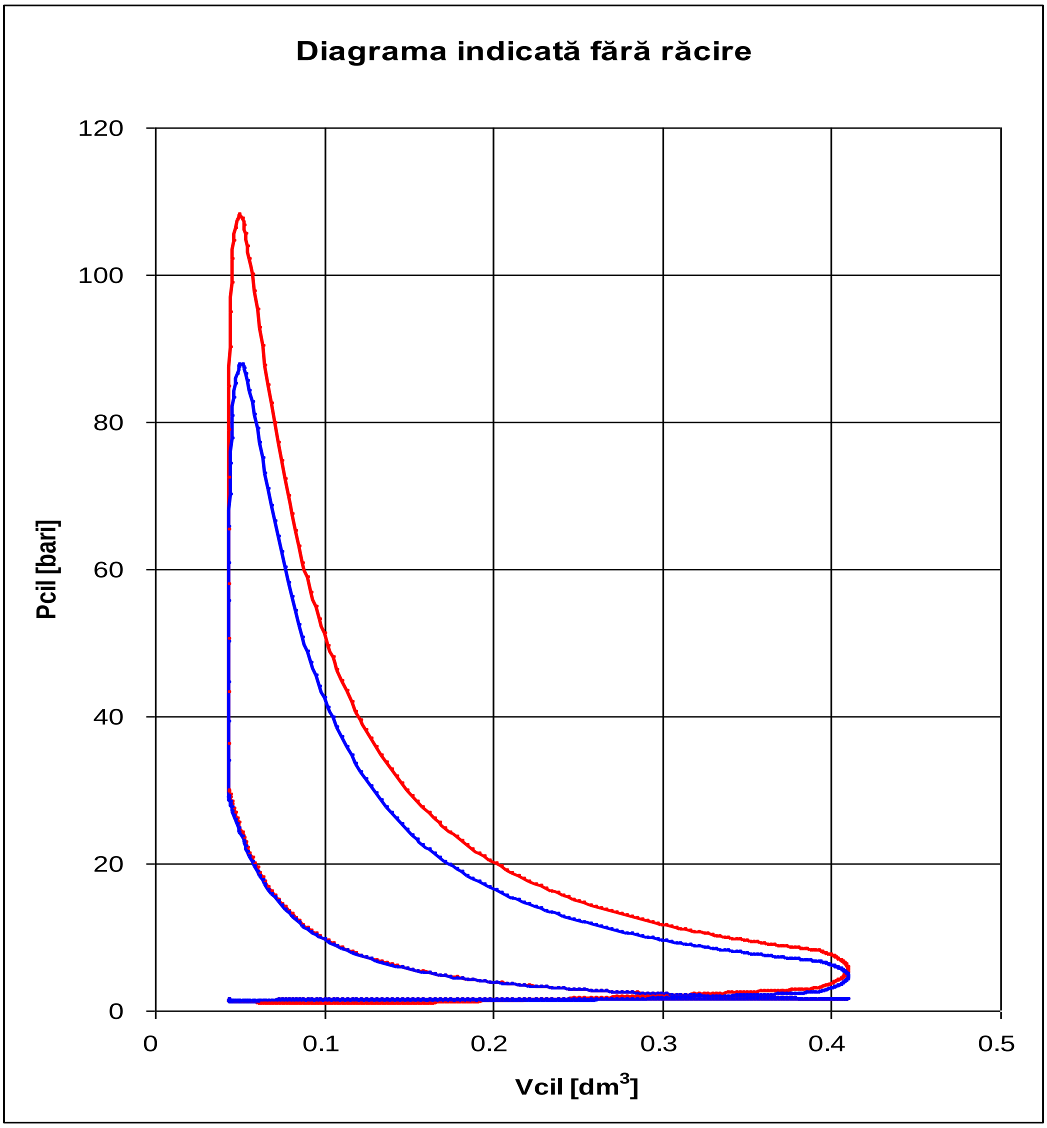

Figure 12 p-V diagram overlayed with cooling (blue), without cooling (red)

3. RESULTS OF THE ENERGETIC BALANCE CALCULATIONS

Knowing the heat dissipated through cooling Q_R=565.32 [J/cycle], measuring the average temperature of the exhaust gasses exiting the engine T_{EVMed}=1110[K] , using the calculated specific mass of said gasses m_g=0.00054[kg/cycle] and their initial temperature T_0=293[K] we can calculate the amount of heat removed from the engine via the exhaust Q_{EV}=489.598[J]. These values can be compared to the value determined experimentally (Table 2, Figure 13)

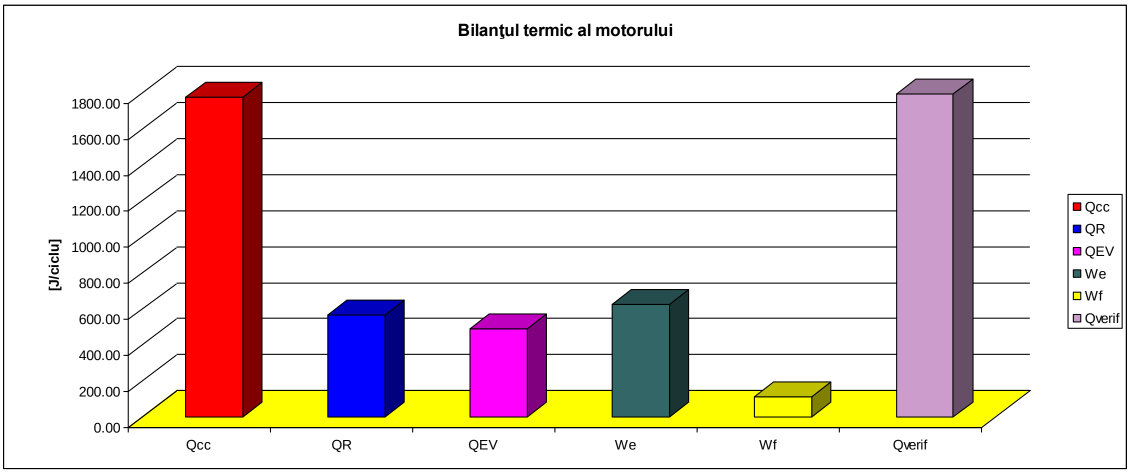

Figure 13 Visual representation of Table 2

Table 2: Comparison of calculated and experimental verification heat and power values

No.	Heat/Cycle	Symbol	Monocylinder	Monocylinder	Polycylinder	Percent
			[J/cycle]	[kW]	[kW]	%
1	Total heat delivered/cycle	Q_{cc}	1774.47	88.72	266.17	100.00
2	Heat removed by cooling and oiling	Q_R	565.32	28.27	84.80	31.86
3	Heat removed by exhaust	Q_{EV}	489.60	24.48	73.44	27.59
4	Effective mechanic work	W_e	624.06	31.20	93.61	35.17
5	Work lost in friction	W_f	110.13	5.51	16.52	6.21
6	Total	Q_{verif}	1789.11	89.46	268.37	100.82
7	Error		-14.63	-0.73	-2.93	-0.82

The error of 0.82% is congruent with the domain of cyclic variation

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