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NUMERICAL ANALYSIS OF THE VARIATION OF THE STROKE/BORE RATIO IN AN INTERNAL COMBUSTION ENGINE

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Abstract. *This work presents an analysis where the variation of the dimensions of the geometry of a combustion chamber of an internal combustion engine is evaluated. The analysis was conducted in such a way that the volume of the combustion chamber of the original engine was not altered, thus the piston diameter and stroke were varied, while maintaining a fixed displaced volume, comparing the results with the original stroke/bore ratio. The idea of the work is to determine which contribution of loss is most significant for the internal combustion engine, whether it is thermal and friction losses, or fluid dynamic and inertial losses. At the end of the study, it was not possible to obtain any type of benefit in relation to the original stroke/bore ratio, and the highest average gains recorded per engine speed were not higher than 1%.*

Keywords: *Internal Combustion Engine, Computational Simulation, Stroke/Bore ratio*

1. INTRODUCTION

Over the course of time many advances were made with internal combustion engines and new technologies were implemented to make it possible to increase the performance of these thermal machines. Some examples of these new technologies that may be mentioned are the camshaft control mechanisms, exhaust gas recirculation control technologies in the combustion chamber, among others. However, with this advent of new technologies, it is increasingly difficult to achieve improvements in performance and efficiency of these machines.

Although several techniques are discussed, little is said about the influence of the combustion chamber geometry of internal combustion engines on the influence that the surface/volume ratio has on thermal, friction, fluid dynamics and inertial losses. So this analysis becomes interesting for academic, or even practical purposes.

For the development of this analysis was used the software DIESEL-RK[®], of Russian origin, which has a free license for academic uses.

The engine used as a reference for the analysis is a four stroke engine, spark ignition of 1497 cm³ volumetric displacement, 3 cylinders, water cooling and using ethanol as fuel. The computational model of this engine, developed in the aforementioned software, was previously described in previous works by these same authors (Tonon, 2018).

2. DIESEL-RK SOFTWARE AND INPUT PARAMETERS

The Diesel-RK[®] software was developed to work with internal combustion engines of alternative type inside the Bauman Moscow State Technical University (BMSTU) in Russia, to be used as a tool in the research field (Kuleshov, 2004). Currently the tool has different versions, and one of them is available, free of charge, for academic use.

The creation of a model in the tool is based on the insertion of some geometric and operation parameters of the engine to be simulated. A more detailed description of the creation of the model can be seen in Tonon (2018). An important point to be mentioned is that the heat exchanges losses are analyzed by the Woschini model (1967) and the combustion model is characterized by the Wiebe curve (Ferguson and Kirkpatrick, 2001). Figures 1 and 2 show the windows, in the software, where these two parameters are inserts.

It is also necessary to insert the data of the fuel used, which in this case is ethanol, and which has its properties highlighted in Tab. 1. Part of these properties were determined experimentally and others were calculated using the method described by Lacava (2014).

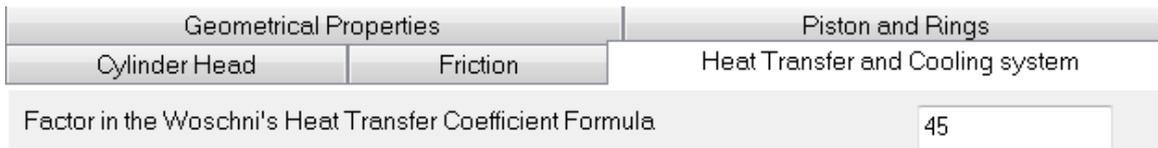


Figure 1. Woschni coefficient change window.

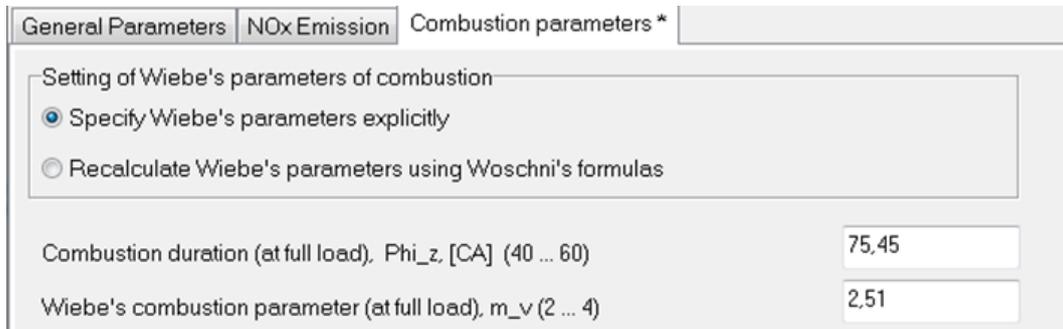


Figure 2. Input screen for Wiebe parameters.

Table 1. Parameters obtained for the equivalent fuel.

C [Mass Fraction]	0.4921
H [Mass Fraction]	0.1302
O [Mass Fraction]	0.3777
Lower Calorific Power [MJ/kg]	24.4
Fuel Density at 323 K at [kg/m ³]	783
Specific Heat of Vaporization [kJ/kg]	1019.22
Thermal Capacity of Fuel at Injection Temperature [J/kgK]	2405.6
Molecular mass [kg/kmol]	42.365

3. GEOMETRY OF THE COMBUSTION CHAMBER

The combustion chamber plays a key role in the design of internal combustion engines. In general, we could, from the combustion chamber, classify the combustion engines as being: undersquare, square or oversquare. This classification is done through the Stroke/Bore motor ratio, so that: an engine that has this ratio below one (the diameter is greater than the stroke) is said to be oversquare; an engine having this ratio equal to one (the diameter is equal to the stroke) is said square; an engine having this ratio greater than one (the diameter is smaller than the stroke) is said to be undersquare.

Considering a chamber of a certain displaced volume, as the diameter is increased, maintaining the same displacement, it becomes the most oversquare engine, and this will bring a series of consequences. Among them, one can cite the fact that making the engine more oversquare, reduces the average speed of the piston, for the same engine speed, reducing fluid dynamic losses and inertial demand (Millo, 2013), or one can maintain the same linear speed, thus increasing the engine speed and having the possibility of generating more power. A larger diameter also provides more space for valve placement on the head.

But not all the consequences are positive. According to Martins (2013), excessively oversquare engines have compression losses, and chambers with a high diameter have a worse burn than the smaller ones, and they have high thermal losses. To make this clear, see Fig. 3, which shows the behavior of the surface/volume ratio with the increase of the stroke/bore ratio, for a combustion chamber with a volume of 500 cm³.

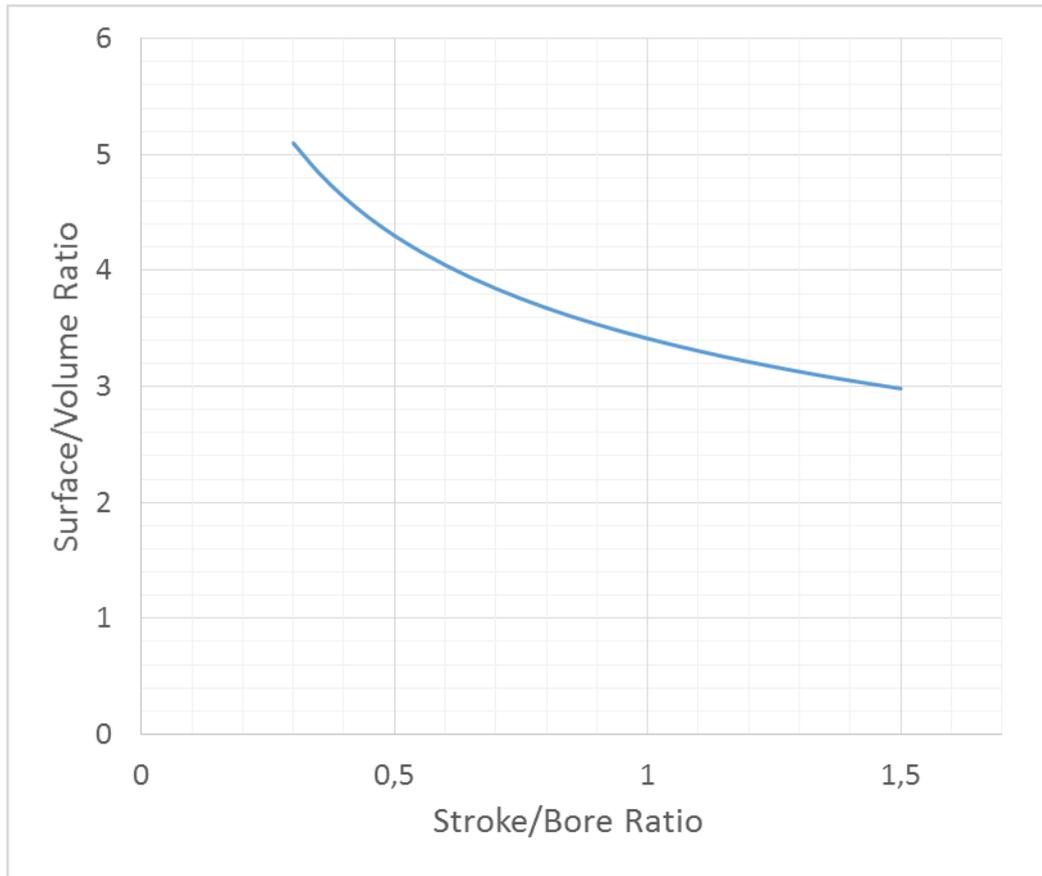


Figure 3. Behavior of the relation Surface/Volume with the relation Stroke/Bore.

Note that the behavior of the surface/volume ratio is decreasing when increasing stroke/bore ratio. Thus, the smaller the stroke/bore ratio, the larger the surface volume ratio, so that the engine becomes more oversquare, the more area it will have to change heat with the environment, thereby increasing the thermal losses of the engine. In addition, with the larger diameter, the perimeter of the cylinder is increased, so that the area of contact of the rings with the cylinder wall will also increase, generating greater losses by friction.

In this way, the great influence that the geometry of the combustion chamber exerts on the performance of a combustion engine is observed. The complexity of the phenomena associated with this make it difficult to state whether the variation of the stroke/bore ratio will bring benefits, without a more detailed analysis of the operation of the engine studied.

4. RESULTS AND DISCUSSION

The results presented in this paper are presented as percentages, for reasons of confidentiality of the company that submitted the data of the analyzed engine, which wishes to remain anonymous. Thus, torque results, which are usually presented in the Nm form, will be presented as a percentage of a reference value, which can also not be reported.

As already mentioned in the Introduction of this work, the stroke/bore ratio of the combustion chamber exerts a strong influence on the operation of internal combustion engines, and is used as a design parameter for these machines.

Usually the stroke/bore ratio is used to analyze if an engine is undersquare, square or oversquare, but for convenience, in this work the inverse of this relation will be used, that is, a ratio between bore/stroke. In this way, the more oversquare a combustion chamber is, the greater its bore/stroke ratio. The engine used has the bore/stroke ratio smaller than the unit, so it is a undersquare engine, which is expected for passenger cars.

The proposal in this part of the paper is to analyze if it is possible to obtain some kind of benefit by altering this relation in the engine studied. In this way we opted to analyze five new bore/stroke ratios, being 0.9, 0.925, 0.95, 0.975 and 1, that is, all undersquare and square geometries. The choice not to analyze chambers with this ratio higher than the unity is due to the fact that these are generally found in combustion engines for competition and have a deficiency in their durability. As the engine being analyzed is intended for passenger vehicles, ratios greater than unity are not usual, and therefore not interesting for this work.

The analysis of the modification of this parameter is interesting because, there is no immediate results that can be predicted, since there are positive and negative consequences for both the reduction and the increase of this ratio. It is important to remember that oversquared engines have lower fluid dynamic and inertial request losses (Millo, 2013), however, they also have a higher surface/volume ratio, increasing losses due to thermal changes and friction (Martins, 2013).

Figures 4 and 5 show the influence of the variation of the chamber bore/stroke ratio on the engine torque, for a engine speed of 3500 rpm. Note that in Fig. 3 it is impossible to distinguish one curve from the other, analysis of this result in absolute scale causes the impression that all curves are superimposed. The differentiation of one curve from the other is possible only when the image is very close, as shown in Fig. 4. The average difference between the original configuration (Tonon, 2018) and the one with the highest torque is 0.7%, which shows that the gains and losses caused by the modification of the bore/stroke ratio are very close.

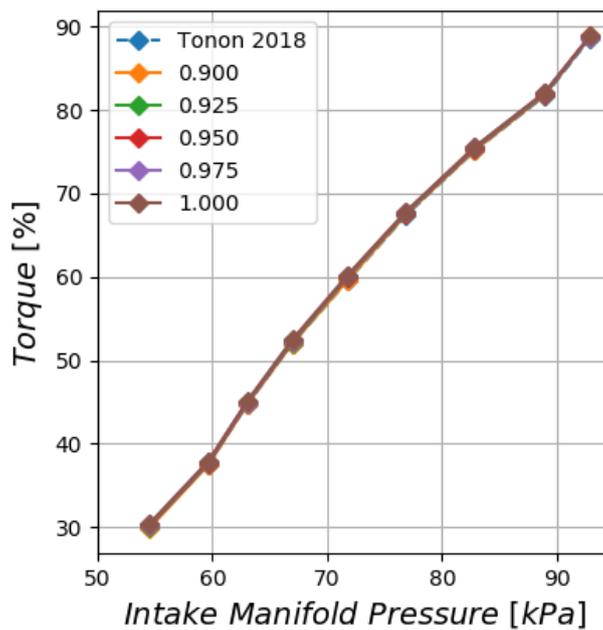


Figure 4. Comparison between different combustion chambers for 3500 rpm.

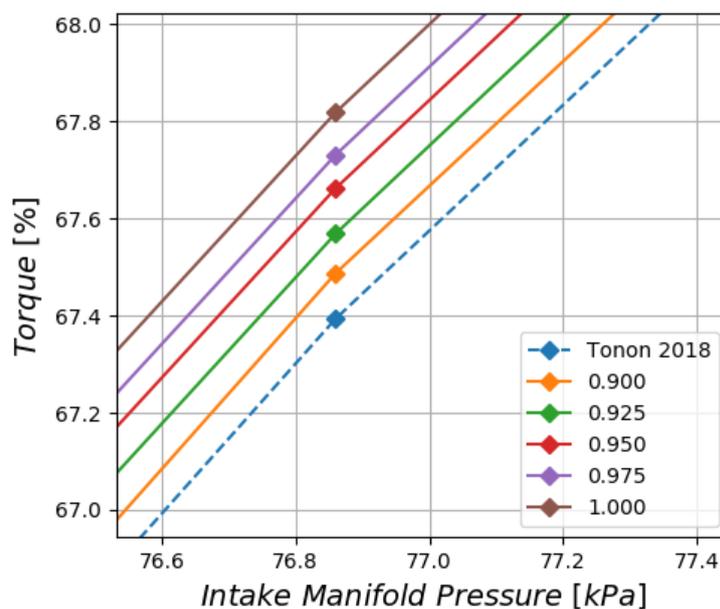


Figure 5. Approximate image of the comparison between different combustion chambers for 3500 rpm.

Figures 6 and 7 show the same problem of the previous results, but for the engine speed of 6500 rpm.

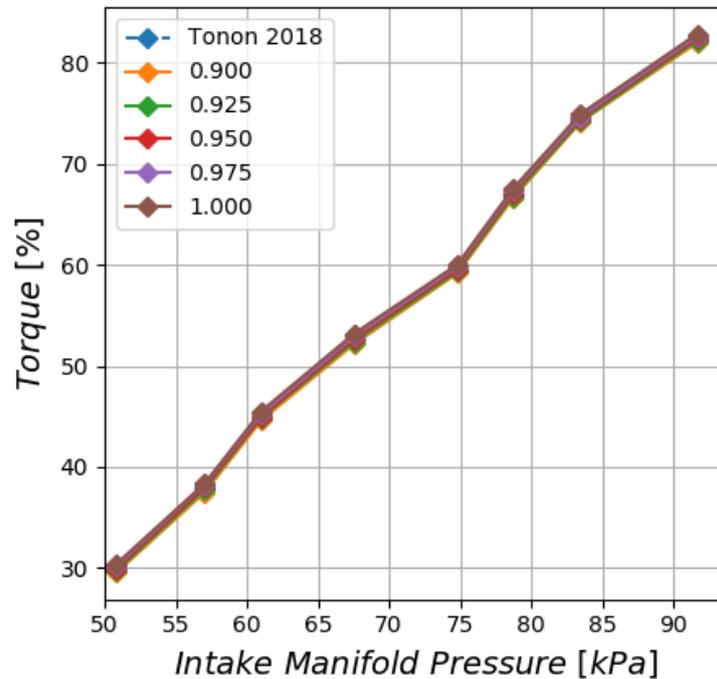


Figure 6. Comparison between different combustion chambers at 6500 rpm.

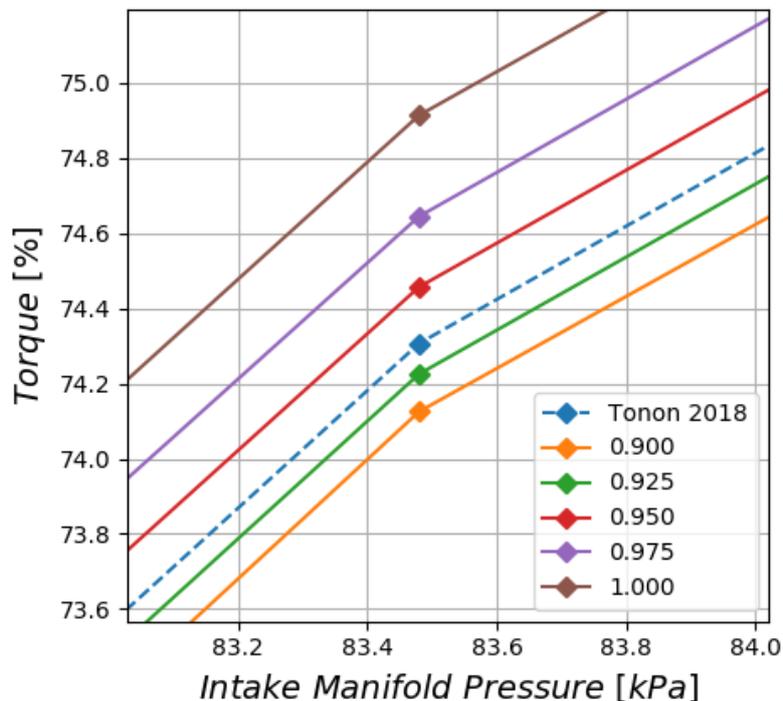


Figure 7. Approximate image of the comparison between different combustion chambers at 6500 rpm.

The results for this engine speed are those that presented the highest average gain for the entire engine speed range, and even then, it was around 1%, again showing that the gains and losses caused by the modification of the bore/stroke ratio have approximately the same influence in the absolute value.

To complement what was shown in the previous figures, the results for other engine speeds are also presented, which are shown in Fig. 8, 9 and 10.

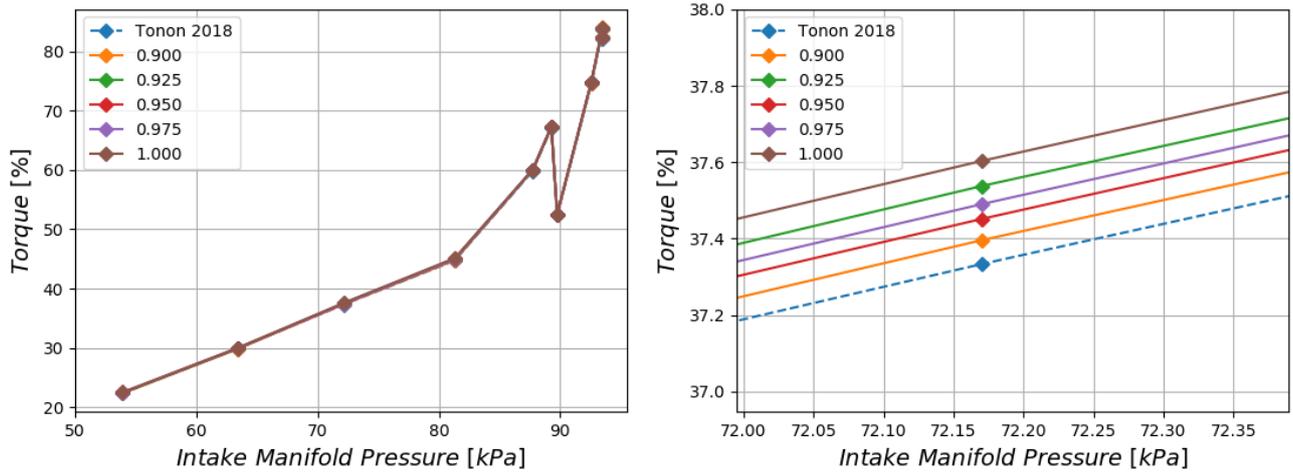


Figure 8. Results of combustion chamber analysis for 2000 rpm.

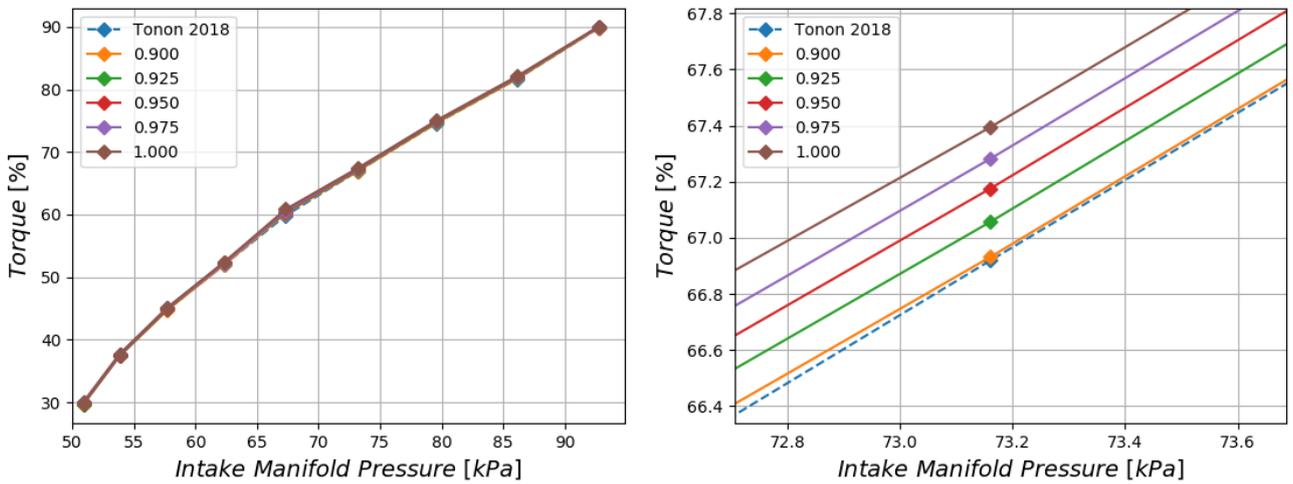


Figure 9. Results of the combustion chamber analysis for 4000 rpm.

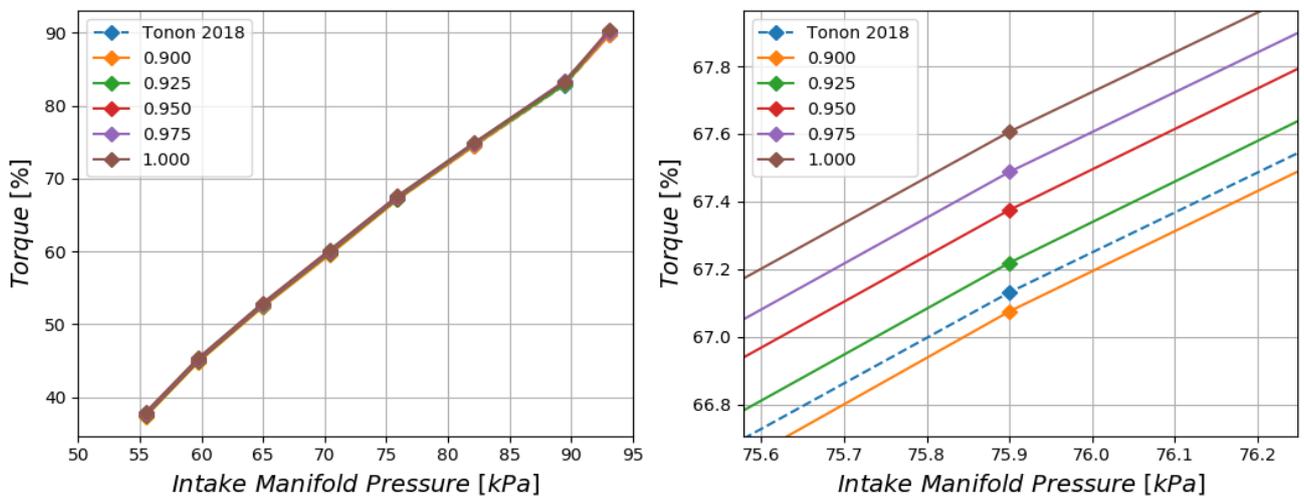


Figure 10. Results of combustion chamber analysis at 5000 rpm.

5. CONCLUSION

In this work, a study was carried out proposing the modification of the combustion chamber of an internal combustion engine used in a passenger vehicle, where 5 new bore/stroke ratios were proposed, being 0.9, 0.925, 0.95, 0.975 and 1. During the work it was not possible to obtain any type of benefit in relation to the original bore/stroke ratio, and the highest average gains recorded per speed were not higher than 1%. These results show that the fluid dynamic and inertial gains obtained by becoming the engine more oversquare, have the same absolute value than the lost through higher friction and thermal losses.

Despite this indication, however, it is not possible to say surely if this change would not really be able to bring some kind of benefit, since in the analysis of these results it must be taken into account that there is an inaccuracy of the software used and the models adopted by this one.

The authors recommend that experimental tests be developed in order to quantify more accurately the different plots of energy losses involved, in order to allow a better analysis of the effects of the modifications proposed in this work.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE

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