COBEM UBERLÂNDIA 2019

ABCM Associação Brasileira de Engenharia e Ciências Mecânicas

25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0298
NUMERICAL ANALYSIS OF THE USE OF A VVT SYSTEM IN A SPARK IGNITION INTERNAL COMBUSTION ENGINE

Daniel da Silva Tonon – ds.tonon@gmail.com
Jesuino Takachi Tomita – jtakachi@ita.br
Ezio Castejon Garcia – ezio@ita.br
Fábio Jairo Dias – fabioj.dias@outlook.com
Instituto Tecnológico de Aeronáutica – ITA
Divisão de Engenharia Mecânica
Praça Marechal Eduardo Gomes, 50
São José dos Campos – SP, 12.228-900, Brasil

Abstract. *Over the years, a number of new technologies have emerged on the market with regard to the operation of internal combustion engines. Some of these technologies are intended to provide control for the opening and closing of the engine intake and exhaust valves. This work presents a numerical analysis where the performance of a spark ignition internal combustion engine is evaluated considering the variation of the opening of its intake valve. The analysis is based on the control of the phase of the camshaft that control the operation of these valves. In this way, the closing of the inlet valve is already pre-established at the moment that the opening is specified. At the end of the work the results obtained with the model showed the possibility of obtaining an average gain of approximately 10% in the torque, and of 2.2% reduction in the specific fuel consumption.*

Keywords: *Internal Combustion Engine, Computational Simulation, Intake Valve Openning*

1. INTRODUCTION

One of the challenges faced by the automotive industry has always been to increase the energy efficiency of internal combustion engines. In order to reach this goal, several technologies have been developed. One of these refers to variable valve timing control systems (VVT) that were introduced because it was desired to extract the best possible performance for each engine speed range. For example, at a higher rotation it may be desired that the inlet valve be opened farther ahead than at low rotations, so that the engine has more time to admit air into the combustion chamber. The best-known variable valve control systems are the VVT-i, from Toyota Company, and the VTEC, from Honda Company. Other systems related to the control of valves are the Multiair from FIAT and the Valvetronic from BMW, but these are designed to control the lift of the intake valve.

The present work makes a study about the behavior of an internal combustion engine, in situations where a system is used to control the opening of the intake valve, but maintaining the duration of this opening fixed. In other words this work evaluates the performance of the internal combustion engine by varying the phase of the camshaft dedicated to the intake valves.

For the development of this analysis was used the software Diesel-RK®, of Russian origin, which has a 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 cooled 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).

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

3. VVT SYSTEMS IN THE SCIENTIFIC COMMUNITY

The study of variable valve control systems transcends industry and is also of academic interest. Thus, this part of the paper is dedicated to show some of the works that has been developed in the academic scope.

Fontana and Galloni (2008) numerically investigated the potential of a VVT system in an four stroke engine of 1368 cm³ displacement, with the aim of optimizing the performance and consumption of this machine. The system proposed by the authors would act by varying the phase of the camshaft, so that the engine axis itself could be used. By varying the phase of the camshaft it would be possible to control the loading of the engine in addition to increasing the exhaust gas recirculation (EGR) inside the combustion chamber. For the computational analysis, 1-D and 3-D models were used. The first has the scope to make the thermodynamic analyzes of the mechanism, while the second one would be responsible for analyzing more specific phenomena of gas movement. According to the analyzes made it would be possible, in some rotations, to reduce the load of the engine without the need to activate the throttle valve. Some results also show the reduction of the pumping lost power; under certain conditions, the results showed reductions of up to 47%. The study concludes that the benefits generated by the torque gain and reduction of fuel consumption justify the investment for the insertion of the proposed system, which is claimed to be low cost.

Nagaya et al (2005) proposed a valve control system capable of varying both the opening angle and the lift of the valves. This system would be controlled by the electronic control unit of the engine, which would perform both functions. To change the opening of the valves, the system uses a planetary gear set, which changes the phase of the camshaft. Already for the change of the lift, a system is used that is able to modify the vertical position of the camshaft. Based on the tests performed, the authors conclude that the proposed system is able to make this variation continuously, and that the delay time is less than 0.3 s, which is seen as a good enough performance for the system to be used for practical purposes. Other benefits generated, according to the authors, are the stability of the system, the low noise produced, low price, weight and controllability.

Sher and Bar-Kohany (2002), conduct a numerical investigation of the effects of using a VVT system on the torque and fuel consumption specific curves (sfc) of a four stroke internal combustion engine. The analyzes carried out by the authors took into consideration the opening point of the exhaust valve (EVO), and the opening and closing points of the inlet valve (IVO and IVC). The computational model used in the work was adjusted with experimental data. The authors concluded that, after all parameters optimized, the valve opening points would have a linear behavior with rotation. In addition, it was estimated that the modifications would generate a 13% reduction in sfc and a 6% gain in engine power, but no benefit in CO and NOx emissions was observed.

Bonatesta et al (2015) makes an experimental analysis of the influence of a VVT system on two internal combustion engines of four strokes, 3 cylinders, 1000 cm³ displacements and spark ignition, operating in partial loads. The first motor has a compression ratio of 12:1, injection in the door and has no overfeeding. The second one has a compression ratio of 10:1, direct injection and it is supercharged through a turbo-compressor set. The objective of the study was to find the optimum opening point of the valves in order to obtain maximum thermal efficiency and reduction of the sfc. The results showed that the modification of the valve opening points performed a good influence on the thermal efficiency for both motors at low loads. For the engine with lower compression ratio the intake valve advance continued to have a beneficial effect on medium loads, which can no longer be verified in the engine with higher compression ratio due to detonation problems. After optimizing the valve opening points, the study showed an 8% reduction in consumption for the engine with port injection, and 5% for the direct injection.

Verhelst et al (2010) makes an experimental study of the use of VVT systems in engines operating with hydrogen. For this was used an engine that uses, originally, gasoline but that could also could work with hydrogen. The results, using hydrogen, analyzed by the authors consider the engine operating under fully open throttle conditions. The results show that in medium and high speeds the optimization of the valve opening points allows to obtain an improvement in the volumetric efficiency of the engine. However, the authors state that at certain points the optimization of torque generates problems of NOx emissions, which can only be controlled by diluting the mixture, which would reduce torque.

Ashkezari et al (2016) proposes a numerical study to evaluate the performance increase and the reduction in the emission of pollutants from an internal combustion engine of compression ignition, using a system capable of varying the valve opening point and the lift of these. Some of its conclusions are based on the fact that with the modifications generated by the VVT and the change in the lift it is possible to intensify the mixing between air and fuel, increasing the performance and thus reducing the formation of particulate material, but these measures increase the NOx formation. A way to reduce NOx formation would be to delay the closing of the inlet valve, but this will lead to further formation of particulate matter.

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, results such as specific fuel consumption (sfc) and torque, which are usually presented in the form of g/kWh and Nm, respectively, will be presented as a percentage of a reference value, which can not be reported either.

As previously mentioned, the analysis of this work was developed by varying the opening point of the inlet valve (IVO). This was chosen because it exerts a strong influence on the performance of the engine, in addition to having an extensive range of work.

Figures 1, 2 and 3 show the comparison between the results of the reference model (Tonon, 2018) and those of the IVO adjustments for a 1750 rpm speed.

It is noted by these figures that there is a significant increase in torque and overall engine efficiency, at low loads, in addition to the sfc reduction. In general, the IVO to obtain these results was the one with the greatest advance available in the adjustment range. This result was expected, therefore, this is the position that would allow more unburned mass to be introduced in the cylinder. This fact also justifies the lack of gains for high load conditions, since in these, the IVO was already the maximum position. The average gain recorded for torque in this rotation is 20.6%, with an average reduction of 4% in sfc.

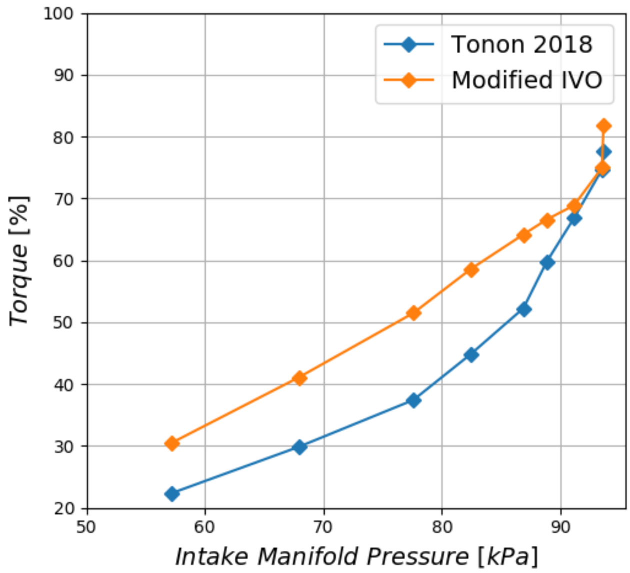

Figure 1. Torque results during the IVO modification phase for a 1750 rpm speed.

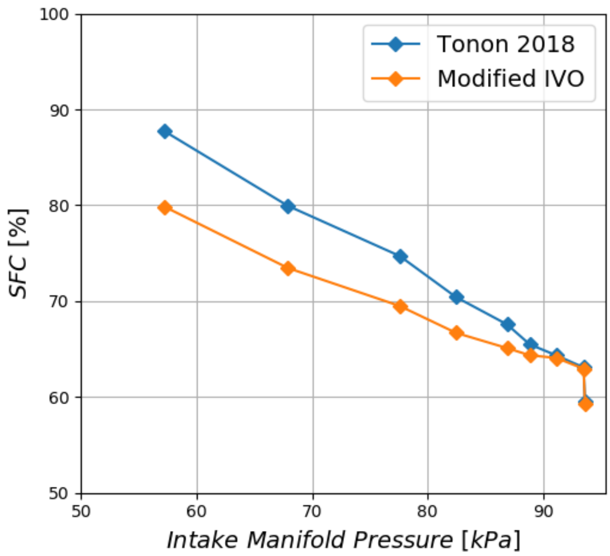

Figure 2. sfc results during the IVO modification phase for a 1750 rpm speed.

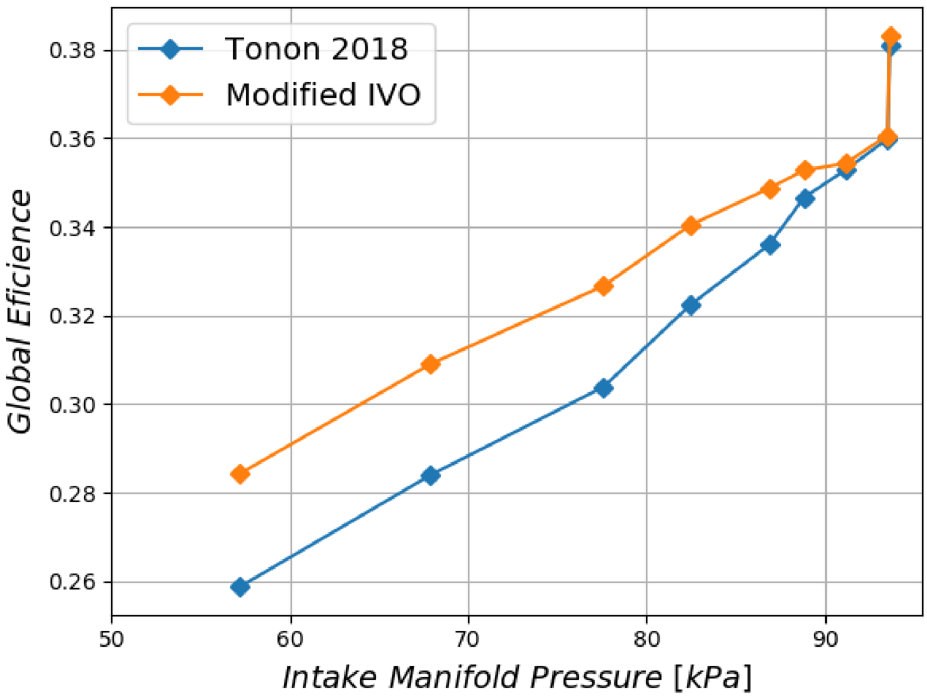

Figure 3. Overall yield results during the IVO modification phase for a 1750 rpm speed.

Figures 4, 5 and 6 show the comparison of the same results, however, for a 2500 rpm speed.

The behavior of the results for this speed is the same as for the previous one. A significant gain is observed at low loads; already in highs, this gain is almost nonexistent. This result was expected for the same reasons already cited in the previous speed. In this speed the average torque gain generated was 19.4%, and the mean sfc reduction was 4.7%.

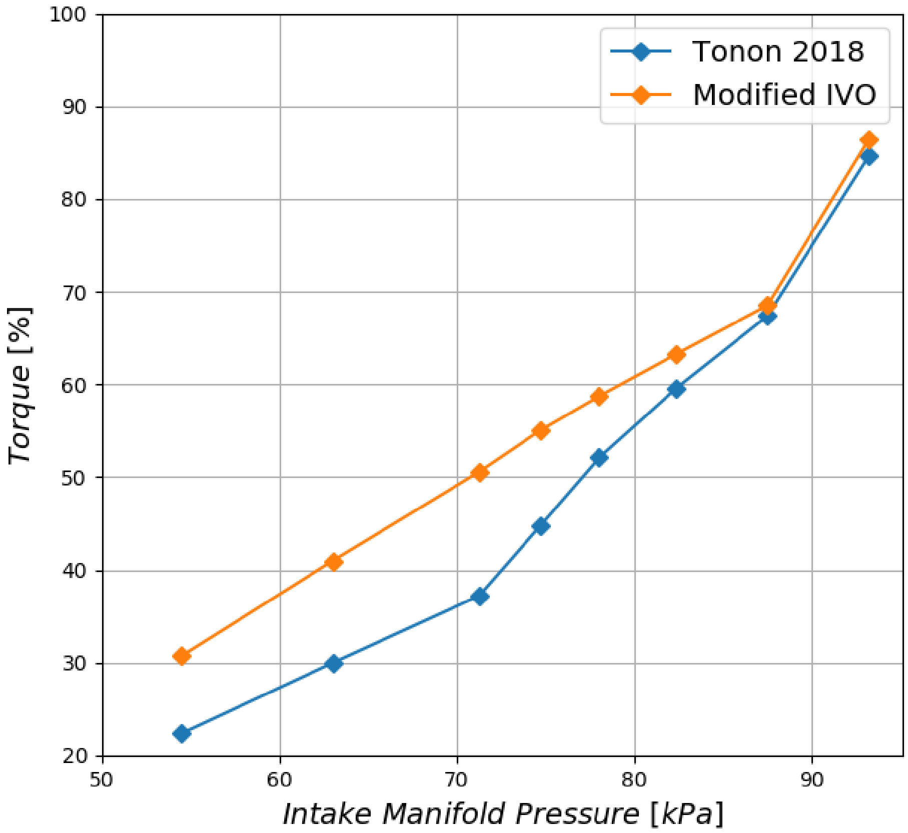

Figure 4. Torque results during the IVO modification phase for a 2500 rpm speed.

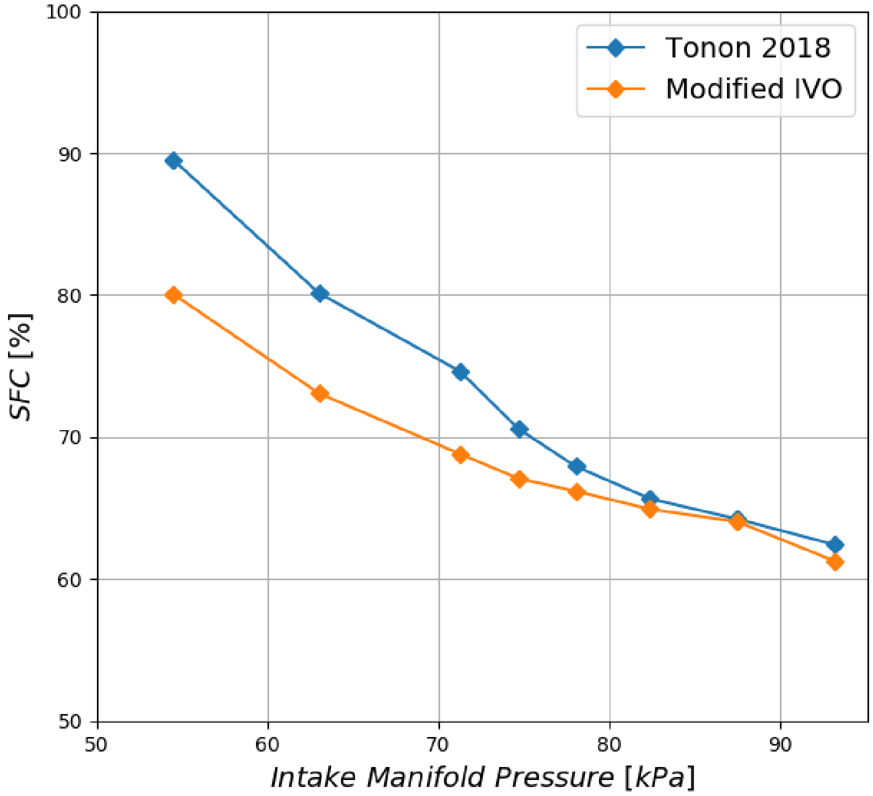

Figure 5. sfc results during the IVO modification phase for a 2500 rpm speed.

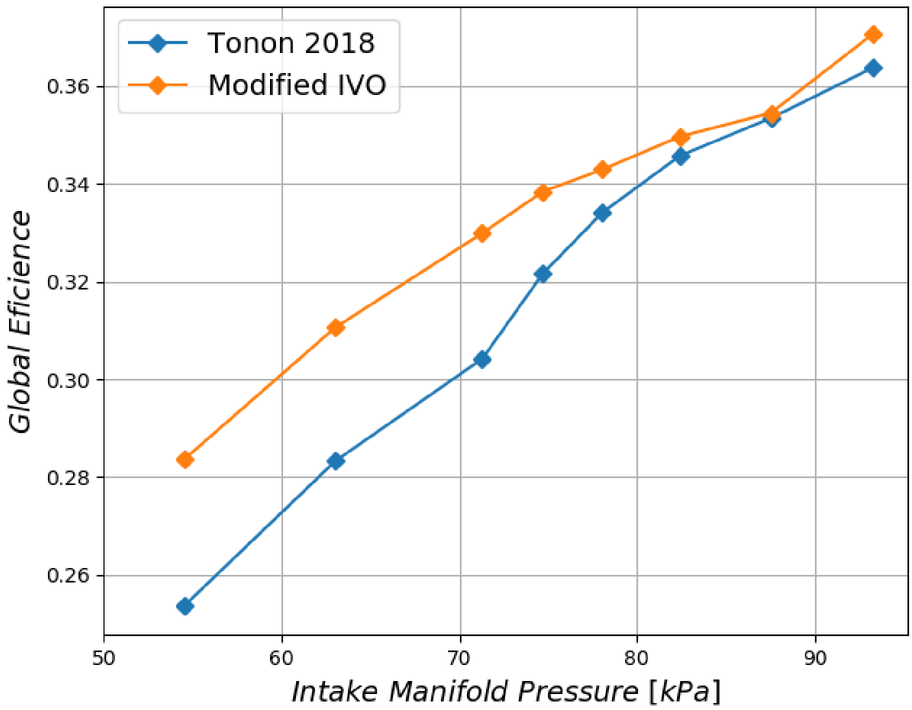

Figure 6. Overall yield results during the IVO modification phase for a 2500 rpm speed.

Figures 7, 8 and 9 show the comparison of the same results, however, for a 3500 rpm speed.

Although the behavior of the results is similar, it is noted that there were no results as representative as in previous speeds. Gains are more moderate and present only under lower load conditions. The explanation for this continues being that the IVO was already in its maximum position, from loads higher than 70 kPa. The average torque gain was 9%, while the average sfc reduction was 2.6%.

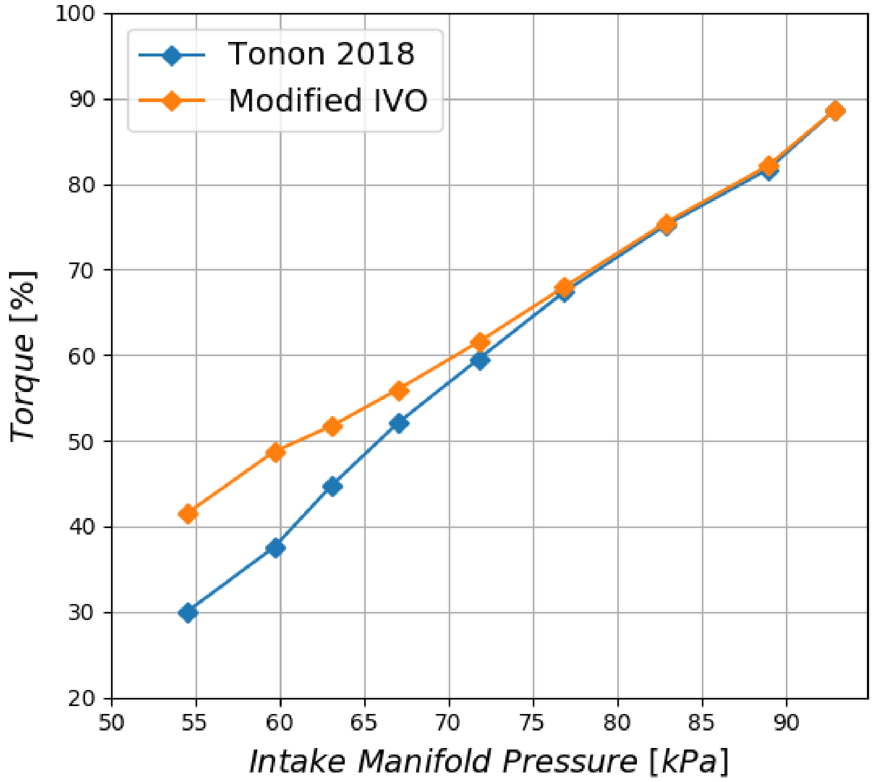

Figure 7. Torque results during the IVO modification phase for a 3500 rpm speed.

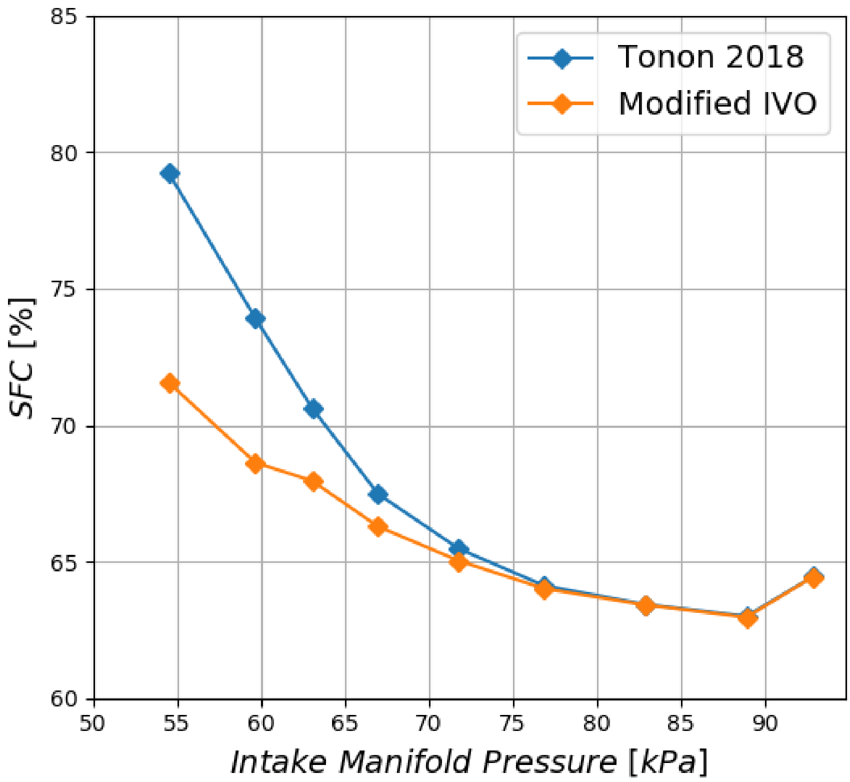

Figure 8. sfc results during the IVO modification phase for a 3500 rpm speed.

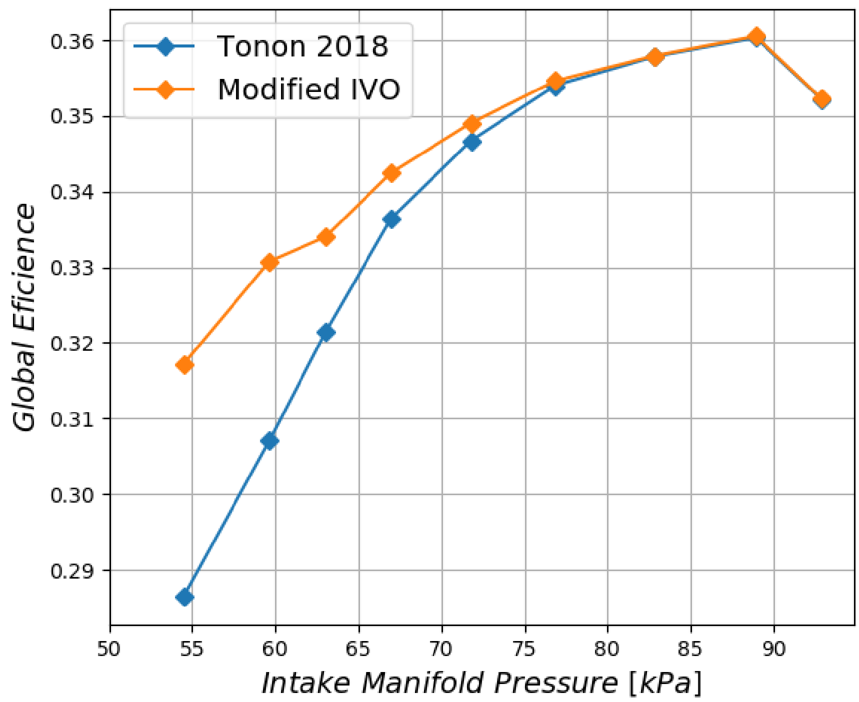

Figure 9. Overall yield results during the IVO modification phase for a 3500 rpm speed.

Figures 10, 11 and 12 show the comparison of the same results, however, for a 5000 rpm speed.

Although it behaves similarly to the other speeds, the gains obtained with the variation of IVO at 5000 rpm are smaller, which was already expected, for the same reason mentioned in the 3500 rpm speed, that is, the value of the openning was already very close to its maximum position. The average torque gain for this speed was 5.9%, while the mean sfc reduction was 1.8%.

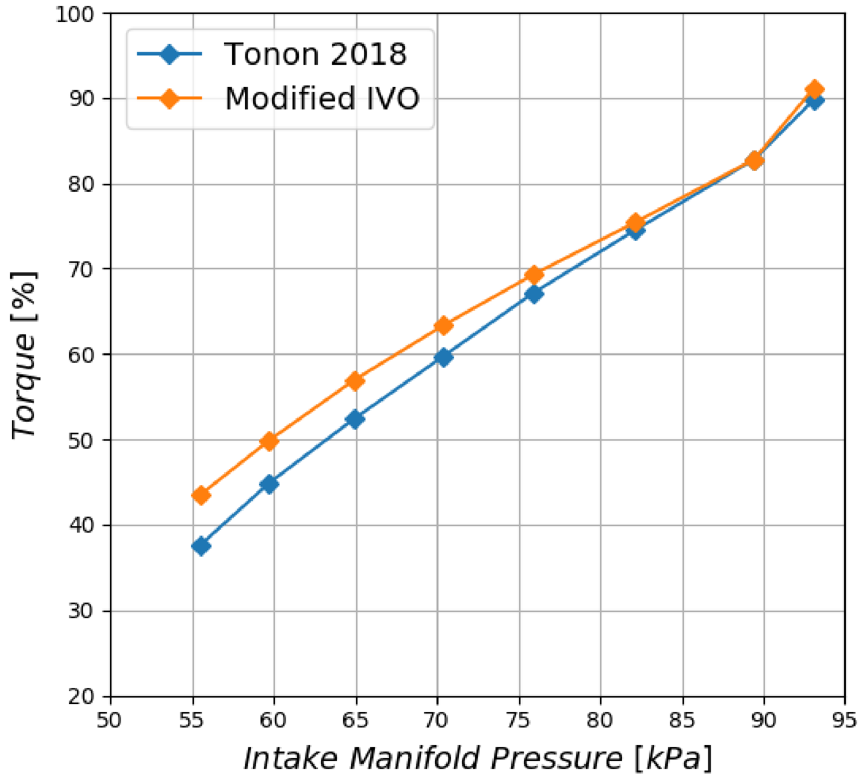

Figure 10. Torque results during the IVO modification phase for a 5000 rpm speed.

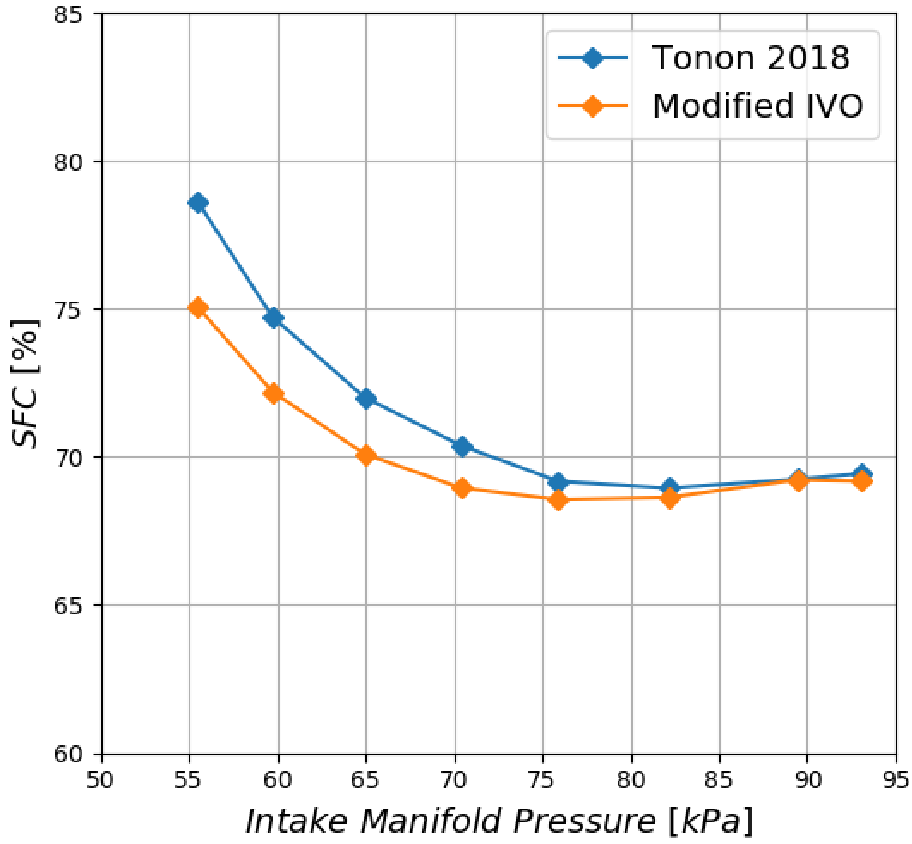

Figure 11. sfc results during the IVO modification phase for a 5000 rpm speed.

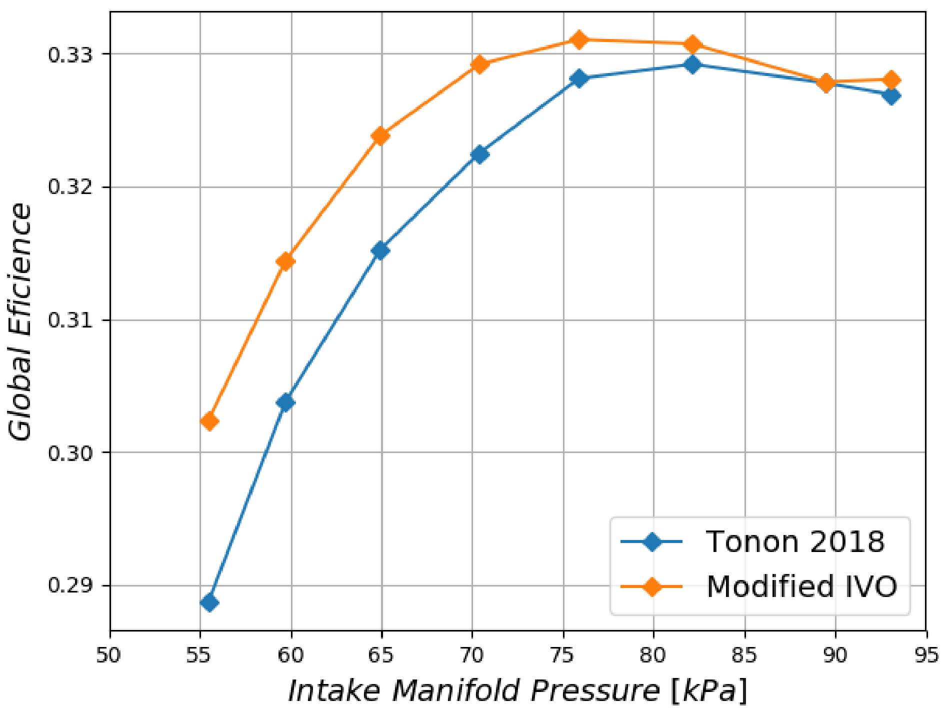

Figure 12. Overall yield results during the IVO modification phase for a 5000 rpm speed.

For rotations above 5000 rpm, no benefit is generated, since the values assigned to IVO are already very close to the maximum point. Figures 13, 14 and 15 show the results for a 6500 rpm speed.

Note that there is no benefit from altering the IVO parameters in this speed. As already mentioned, this behavior is repeated for the other speeds above 5000 rpm.

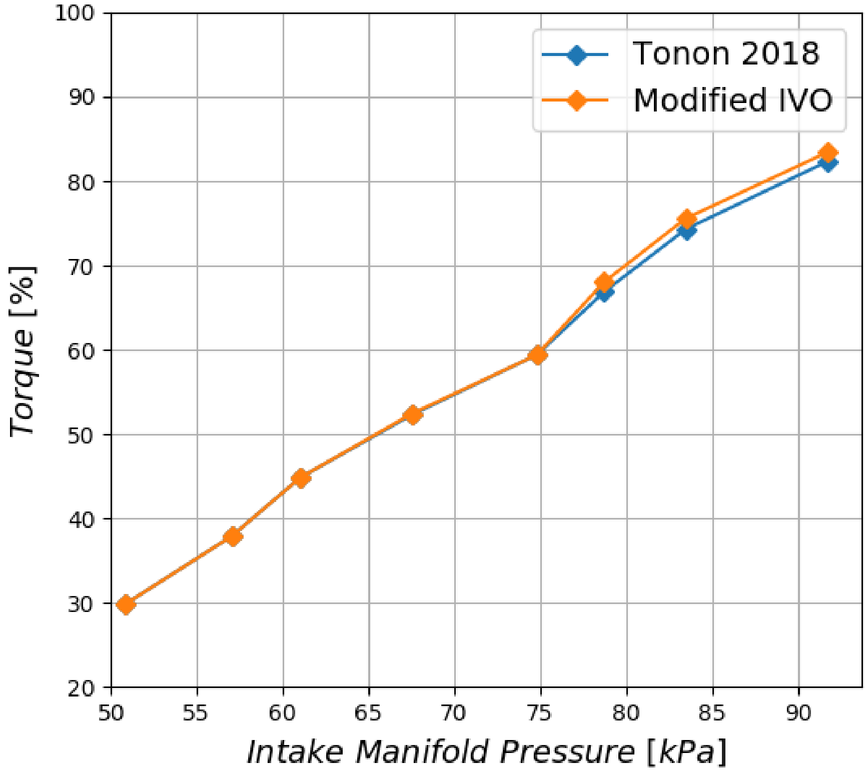

Figure 13. Torque results during the IVO modification phase for a 6500 rpm speed.

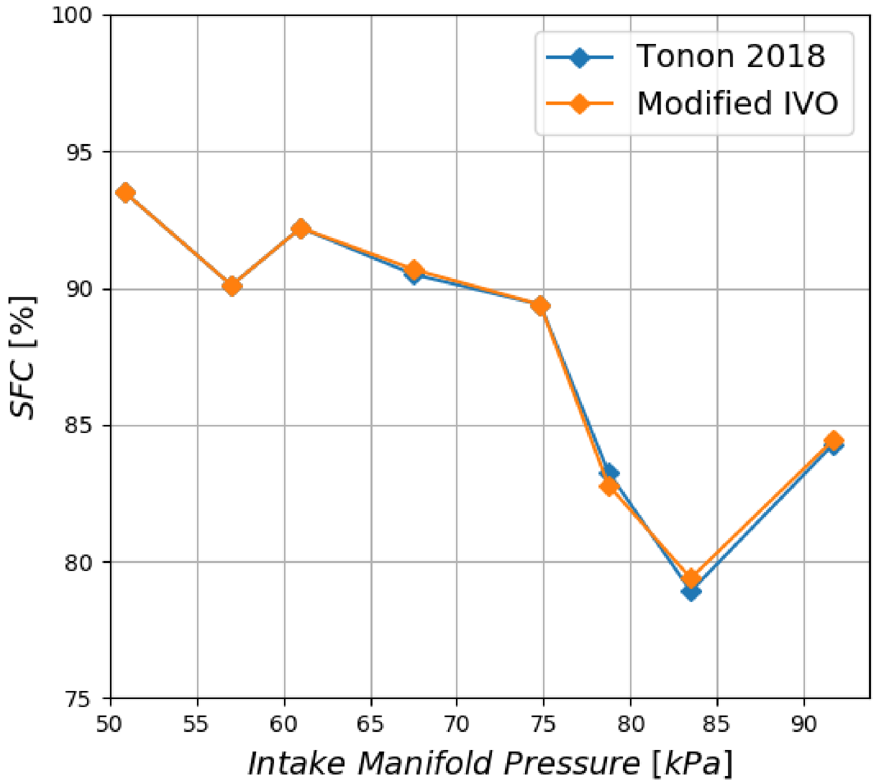

Figure 14. sfc results during the IVO modification phase for a 6500 rpm speed.

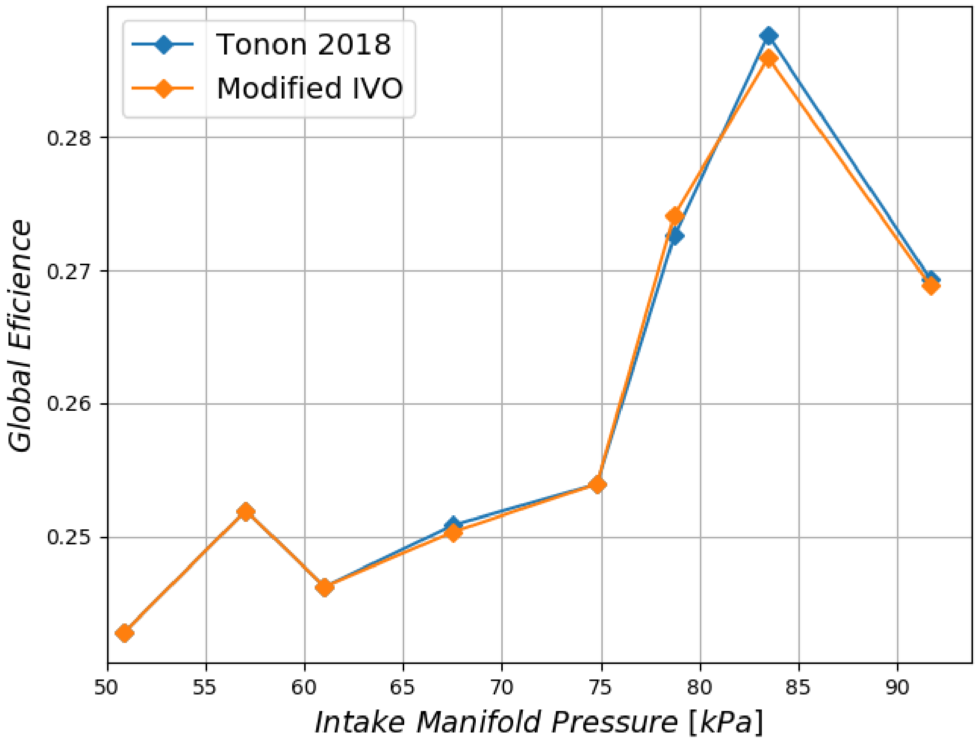

Figure 15. Overall yield results during the IVO modification phase for a 6500 rpm speed.

Figures 1 to 15 show the results of 5 engine speeds analyzed, which were selected in order to show the general behavior of the engine by its range of operation. However, the work analyzed a total of 14 speeds, with a total of 121 different operating conditions.

Considering all 14 speeds and 121 operating conditions analyzed in the engine, an average gain of 10% in torque is reached, with an average reduction of 2.2% in sfc. However, it should be remembered that these values are much higher for lower speed and load conditions.

5. CONCLUSION

In this work was carried out a numerical study proposing the change of the opening point of the intake valve through the phase change of its camshaft.

The results of the simulations showed that it would be possible to obtain average gains for torque (considering all 121 conditions analyzed) of 10%, with a mean sfc reduction of 2.2%, but the results for points at low speed and low load, can present benefits of more than 20% in torque and 11% in sfc.

It is believed, however, that the benefits seen in the simulations cannot be applied due to limitations of emissions of pollutants, since limiting the entry of fresh mass inside the combustion chamber lower temperatures will be reached, also reducing the generation of some pollutants, such as NOx. Further limiting the fresh mass input, the net fuel consumption will also be reduced, so that in situations where the vehicle is stationary, that is, without load, it is desirable that a sufficient condition be established only to keep the combustion engine running.

Thus, this availability of benefits is probably known by the automaker that provided the experimental data, but the limitations must be imposed to the satisfaction of environmental standards. Therefore, there is a probability that these results do not have a practical application, however, they help strengthening the quality analysis of the computational model developed previously (Tonon, 2018).

6. ACKNOWLEDGEMENTS

Daniel da Silva Tonon thanks CNPq for the research grants 132726/2016-5, 141288/2018-3 and 141837/2019-5.

7. REFERENCES

Ashkezari, A. Z., Nezhad, A. H. and Farahat, S., 2016. “Reduction of pollutant emissions by developing a variable valve timing system in a direct injection diesel engine using computational fluid dynamics modeling”. American Institute of Chemical Engineers, Vol. 35, n. 5, p. 1430-1440.

Bonatesta, F., Altamore, G., Kalsi, J. and Cary, M., 2015. "Fuel economy analysis of part-load variable camshaft timing strategies in two modern small-capacity spark ignition engines". Applied Energy, Vol. 164, p. 475-491.

Ferguson, C. R. and Kirkpatrick, A. T., 2001. Internal Combustion Engines Apllied Thermosciences. John Wiley & Sons, New York, 2nd edition.

Fontana, G. and Galloni, E., 2008. "Variable valve timing for fuel economy improvement in a small spark-ignition engine". Applied Energy, Vol. 86, p. 96-105.

Kuleshov, A., 2004. "Diesel-RK: engine simulation tool". 5 Aug. 2017 <http://diesel-rk.bmstu.ru/Eng/index.php?page=Main >.

Lacava, P. T., 2014. Elements of Combustion. Internal Publication – Technological Institute of Aeronautics, São José dos Campos.

Nagaya, K., Kogayashi, H. and Koike, K., 2005. "Valve timing and valve lift control mechanism for engines". Mechatronics, Vol. 16, p. 121-129.

Sher, E. and Bar-Kohany, T., 2002. "Optimization of variable valve timing for maximizing performance of an unthrottled SI engine : a theoretical study". Energy, Vol. 27, p. 757-775.

Tonon, D. S., Dias, F. J. and Garcia, E. C., 2018. "Computational simulation of a four-stroke ethanol-fueled internal combustion engine using Diesel-RK software". In *Proceedings of the 17th Brazilian Congress of Thermal Sciences and Engineering – ENCIT 2018.* Águas de Lindóia, Brazil.

Verhelst, D., Demuynck, J., Sierens, R. and Huyskens, P., 2010. "Impact of variable valve timing on power, emissions and backfire of a bi-fuel hydrogen/gasoline engine". Hydrogen Energy, Vol. 35, p. 475-491.

Woschni, G., 1967. "Universally Applicable Equation for the Instantaneous Heat Transfer Coefficient in the Internal Combustion Engine". SAE paper, Vol. 76, n. 670931.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.