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INFLUENCE OF THE ADMISSION PROCESS ON EMISSIONS FROM AN ALCOHOL INTERNAL COMBUSTION ENGINE.

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Abstract. *Studies on pollutant emissions from internal combustion engines have been intensified due to increasing claims from environmental organizations. An important issue concerns load renovation. In this work gas emissions were studied in view of modifications on camshaft and diameter of the intake manifold, in a 2.0 liters ethanol engine. Exit concentrations of* CO_2*, CO, HC and* NO_x *have been measured. The results pointed out the best set up for reducing emissions. An analysis has been performed regarding the behavior of the various gases in view of different operational conditions.*

Keywords. Pollutant Emissions; Alcohol, Ethanol, Internal Combustion Engine.

1. Introduction

The control and reduction of emissions in mobile sources of pollution have been carried out for vehicles through more and more demanding norms. Taking advantage of control devices, the levels of emissions of that automobile type have been reduced substantially in the last twenty years. Those indexes reached a reduction of 87% for new cars and 78% for used cars (Alson, 1989). Most of those reductions can be attributed to the progress in the project of the engines and to the technology of emissions control. In spite of that improvement, the environment suffered consequences: greenhouse effect, ozone layer and climatic variations due to the emissions. This has been object of growing pressure and the application of more specific norms, besides the adoption of new strategies. Those strategies induce the use of cars powered by alternative fuels less pollutants, once the means and the available technologies of optimization and development of the projects and controls of emission of the new engines to reach the goals of that new reality seems to be draining (Gabele 1990).

In this context, the use of the ethanol as fuel has showed a great potential to assist on that new challenge of the modern automobile industry, which means to assist the current explosion of the growth of the number of vehicles guaranteeing a global balance of emissions inside of the levels demanded by the environmental laws.

Brazil was one of the only countries that went through the 1973 world energy crisis in an innovative way, creating the first program of substitution of gasoline by use of a clean, renewable, totally national fuel. The use of the energy generated from the photosynthesis became possible due to the wide offer of sugar-cane existent in the country, calculated at that time in two million hectares (Leão, 2003).

The result obtained by the Group of Latin-American Countries y Del Caribe Exportadores of Azúcar (GEPLACEA, 1999), showed in report that the ethanol use in Brazil has led to the reduction of emissions of pollutant gases, mainly monoxide of carbon (CO), hydrocarbons (HC) and oxides of nitrogen (NOx). Those data evidenced that the production of sugar-cane, the use of the ethanol as vehicle fuel and the bagasse for the power generation are activities that avoided the emission of 12,7 million tons of carbon composites a year in Brazil, corresponding at 20% of all the emissions for fossil fuels verified at the country. In this way, it was a pioneer, not only in the effective reduction of the emissions of gases related with the greenhouse effect, but also in the total elimination of the addition of the lead tetraetila on the gasoline. (GEPLACEA, 1999).

The characteristics of the last generation alcohol engines, that uses high performance catalyze, electronic injection, multipoint fuel injection and advanced sensors are (Branco & Szwarc, 1992):

-After combustion, ethanol provides greater number of molecules than the hydrocarbons (gasoline), producing bigger pressure in the expansion of the gases in the cylinders and consequently, larger useful work.

-The high antiknock characteristic of ethanol allows a larger compression rate of the mixture air-fuel, therefore, better thermal efficiency.

-The ethanol burns better with smaller emission of carbon monoxide and particulates.

-The larger latent heat of vaporization of the ethanol increases the global efficiency of the engine, for decreasing its rejection of heat, besides inhibiting the knock phenomenon.

-Due its smaller molecular structure (with just two carbons and simple connections), it allows smaller formation of carbon, causing a less radiant flame, what allows higher efficiency.

A specialized magazine carried out a comparative test among the new available popular cars in the Brazilian market powered by alcohol and gasoline, with engines 1.0 L, using the new available technologies, obtaining the results shown in Tab. (1).

Table 1. Comparison in the acting of the engines alcohol and the gasoline, 1.0 L, of the assemblers GM, FIAT and VW.

Characteristics	Corsa (GM) gasoline	Corsa (GM) alcohol	Palio (FIAT) gasoline	Palio (FIAT) alcohol	Gol (VW) gasoline	Gol (VW) alcohol
Maximum power (cv)	60,0	64,4	61	61	57	61,2
Maximum torque (Kgfm)	8,2	8,4	8,1	8,1	8,5	9,7
Top Speed (km/h)	150,0	153,4	148,2	144,6	147	146,1
0-100km/h (s)	17,3	15,7	16,8	19,2	17,5	19,1
80 – 120 km/h	28,7	23,2	26,0	33,0	22,9	24,6
Fuel consumption – city (km/l)	11,3	8,0	10,2	7,1	11,2	7,5
Cost per km – city	0,03 US$	0,02 US$	0,04 US$	0,03 US$	0,03 US$	0,02 US$
Fuel Consumption - road (km/l)	14,1	10,3	13,5	9,1	14,2	10,0
Cost per km – road	0,03 US$	0,02 US$	0,03 US$	0,02 US$	0,02 US$	0,02 US$
Price new car (US$)	4622,16	4622,16	5186,65	5186,65	5009,09	5009,09
Value tax in S.P.(US$)	98,01	92,33	118,18	105,11	126,14	103,69

Source: Magazine Auto Esporte, Nº: 416, 2001.Value of the conversion dollar: 1US$ = R$3,52.

This work show the influence in emissions indexes caused by the modification of the camshaft and the diameter of the intake manifold and by the use of a turbo charger of a 2.0 alcohol powered engine. The measured gases were CO_2, CO, HC, and NO_x.

2. Methodology

It was used for the dynamometric tests: an engine 1,998 liters, compression ratio 12:1, four cylinders, single-point electronic injection of fuel and alcohol powered. The bench was set up in a way to allow the storage of all important variables of operation of the engine, such as: torque, power, air and fuel consumption, speed, load (throttle position), atmospheric pressure, intake and exhaust manifold, as well as cylinder 4 pressure. Temperatures of engine oil, dry air, humid bulb, as well as of intake and exhaust gases, Fig. (1). All used instrumentation was calibrated appropriately and the uncertainty analysis of the measurements is detailed in (Pau et all, 2003). The procedure of the tests adopted a sequence that allowed the study of several configurations and operating conditions of the assembly. It was used two different types of intake manifolds with diameters of 31 and 33 mm, combined with three camshafts with the characteristics showed in Tab. (2).

Table 2. Open and close of the admission and exhaust valves.

	Admission		Exhaust	
Camshaft	Open bTDC	Close aBDC	Open bBDC	Close aTDC
267	15º	72º	64º	28º
277	15º	82º	59º	40º
285	23º	79º	60º	13º

For each set up the engine behavior was verified for 1500, 2000, 3000 and 4000 rpm, each with throttle openings of 30%, 50%, 70% and 100%. Combining the different parameters, we have got: 2x(4x4x3) + (2x4) = 104 tests. That strategy allowed us a very complete evaluation of the engine for the several configurations, in partial and full load conditionsand in the several speeds above mentioned.

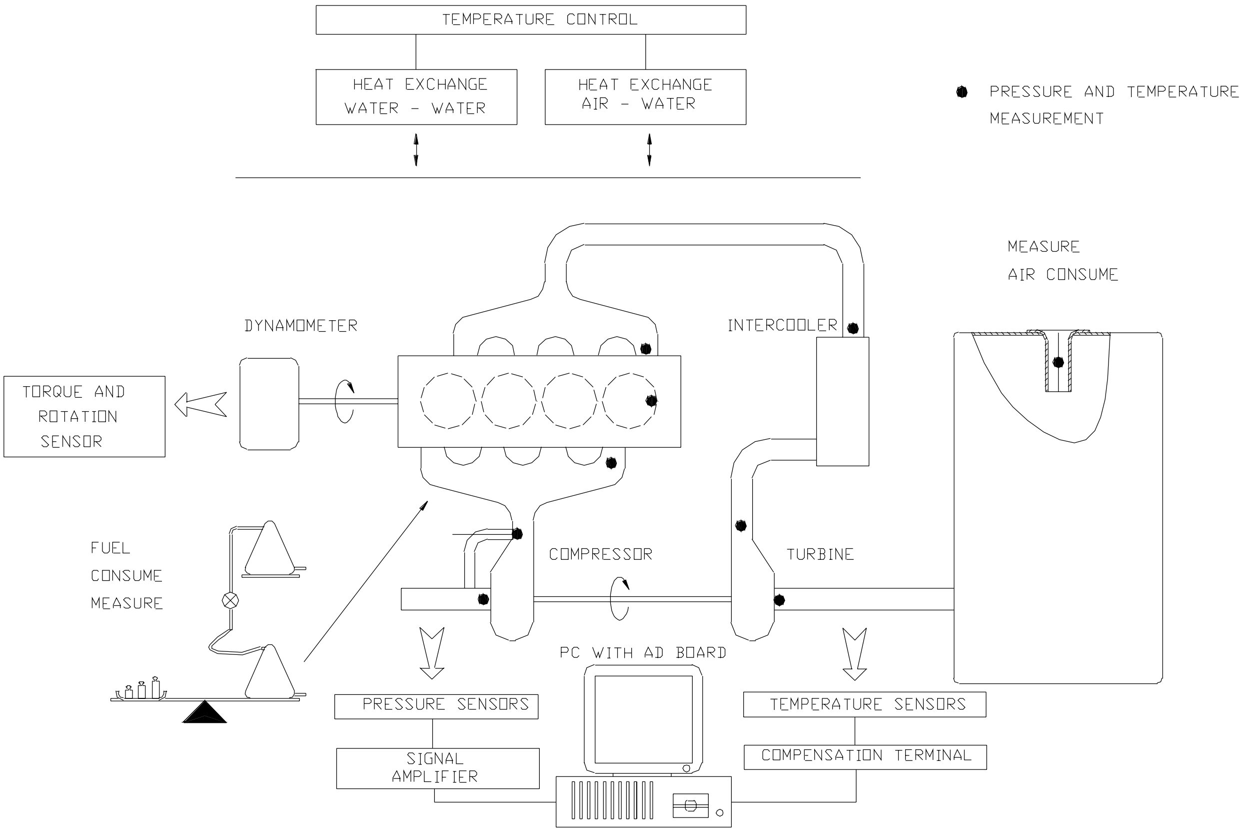

Figure 1. Engine bench test, including instrumentation.

3. Analysis and results

The analysis of the emissions obtained in all tested configurations will also be presented in the form of graphs, allowing, for each load regime, to do a comparison of all the arrangements data.

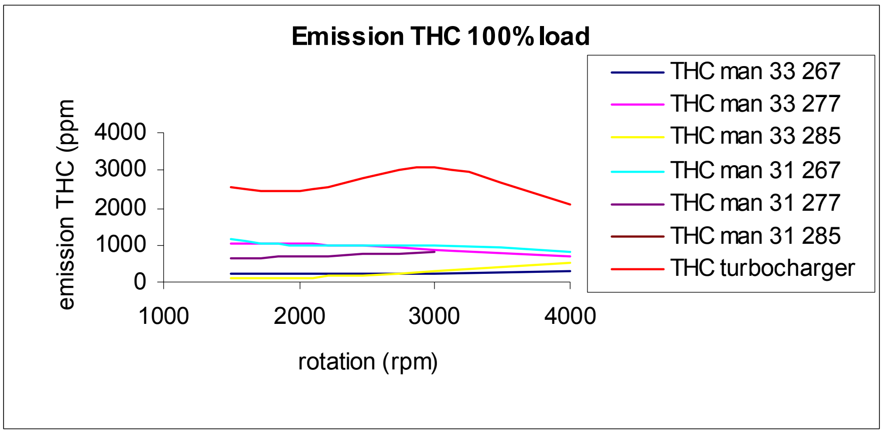

Figure 2. THC Emissions at 100% throttle.

According to (Sher, 1998), the hydrocarbons (THC) emission is decreasing with engine speed, due to the increase of turbulence in higher speeds, allowing a more complete combustion. This effect was also verified in most of the tested arrangements, with a naturally aspirated engine, Fig. (2). The two groups that emitted less hydrocarbons were "man 31 285" and "man 33 285", showing that the camshaft 285 has allowed a more complete combustion. On the other hand, the turbocharged group (red curve) had much higher indexes then the other configurations, but also maintaining the tendency to decrease with the increase of the speed. It is stood out that the use of the turbocharger increased in average about three times the emission of THC.

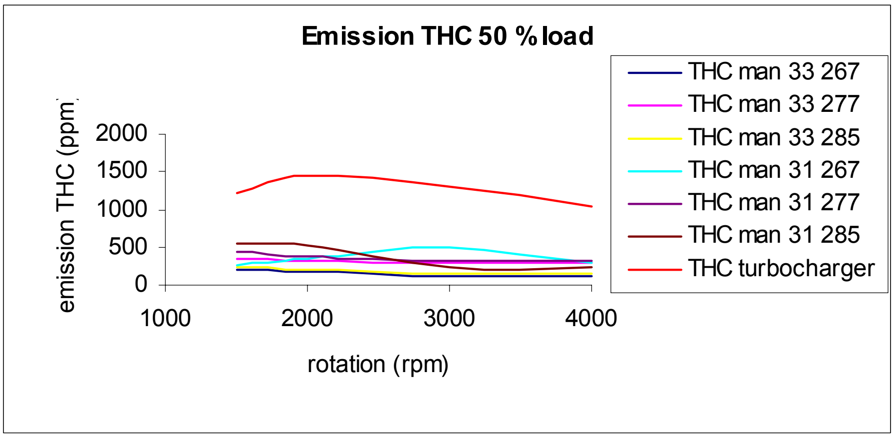

Figure 3. THC Emissions at 50% throttle.

In figures (2) and (3), the tendency to decrease THC emissions in higher speeds was maintained for all arrangements, and showed that the arrangement that has the camshaft 285 emitted less THC in all rotations, at 100% open throttle, as well as at 50%. The configuration with man 31 267 presented higher indexes for both100% and 50% open throttle, especially for rotations over 2500 rpm. The turbocharger assembly emissions stayed at about three times the other arrangements' emissions. This behavior can be explained by oil contamination of the intake mixture, raising the THC emissions when burning with the mixture, since the turbocharger uses engine oil to lubricate its axle. This was verified in the arrangement disassembling, when a considerable amount of oil was observed in the intake manifold and in the TBI.

The same evaluation will be presented for the carbon monoxide (CO). CO results from an incomplete combustion usually caused by the lack of oxygen in the burn process. Therefore it should reach its minimum values for slightly poor mixtures.

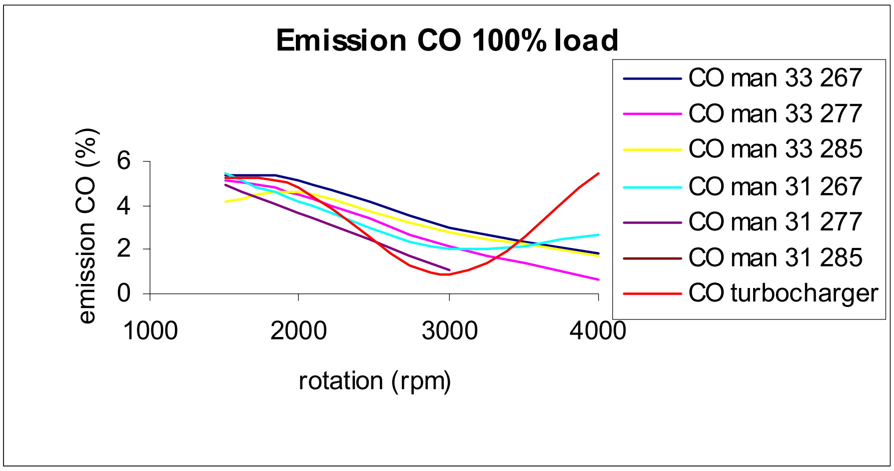

Figure 4. CO Emissions at 100% throttle.

From the analysis of Figure (4) and checking the values of the air/fuel ratio in the measured data, it was verified that the mixture was closer to the stoichiometric ratio in rotations over 3000 rpm, what allowed the decrease of carbon monoxide emissions. For lower rotations the mixture was slightly rich, corroborating the obtained data. The arrangement with man 33 267 was the most emitting in all rotations. The one with man 31 285 was the less emitting until 3000 rpm, from where it was exceeded by the one with man 33 277, for the naturally aspired assembly. The increase of CO starting from 3000 rpm in the red curve (turbocharger), is explained by the excess of air caused by the action of the turbine. This excess of air, which can be verified in Figure (5), in the red curve, has taken the air/fuel ratio very close the superior inflammability limit of the alcohol vapor (3,5-18 kg of air per kg of fuel) (Spiers, 1952), affecting the combustion process, causing the increase of the CO index. This means that even with the excess of air (mixtures very poor, λ=1,7), the little amount of fuel existent was not completely burned because its mixture was close to that limit.

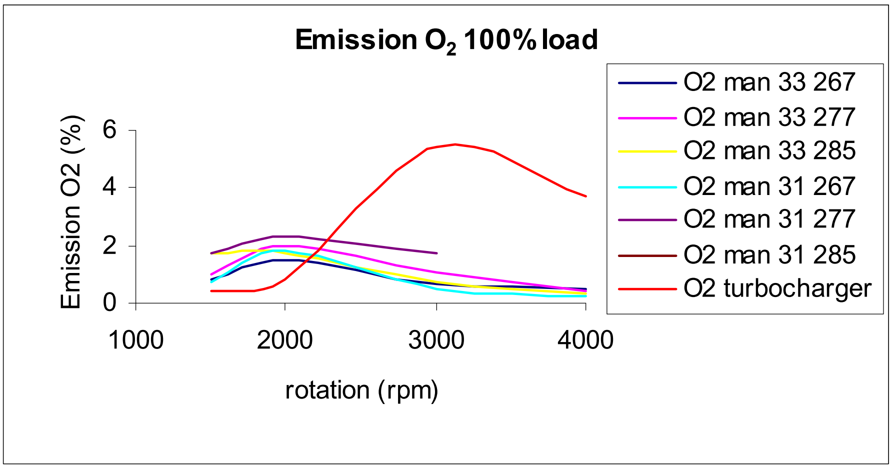

Figure 5. O_2 index at 100% throttle.

Another factor that contributes for the behavior of CO emissions for the turbocharged assembly for rotations over 3000 rpm (turbocharger), concerns the application of the Arrhenius law, which theorize the exponential decay of the chemical reaction rate of the carbon with the decrease of the temperature, according to Figure (6). Therefore, the decrease of the CO reaction rate prevents it to be oxidized to CO_2, in the expansion phase, causing the increase of its index (Kuo, 1996), and the consequent decay of CO_2 emissions in that operation condition.

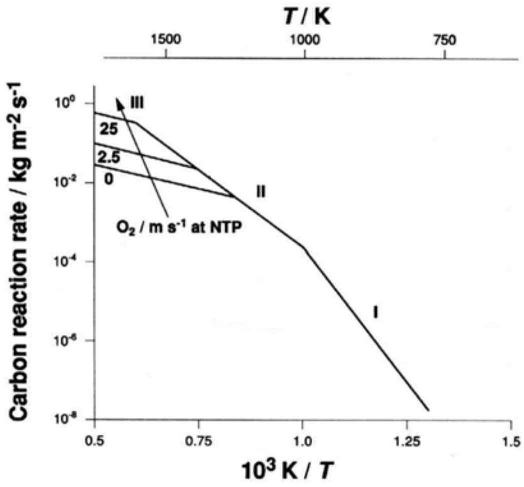

Figure 6. Law of Arrhenius, carbon reaction rate with temperature.

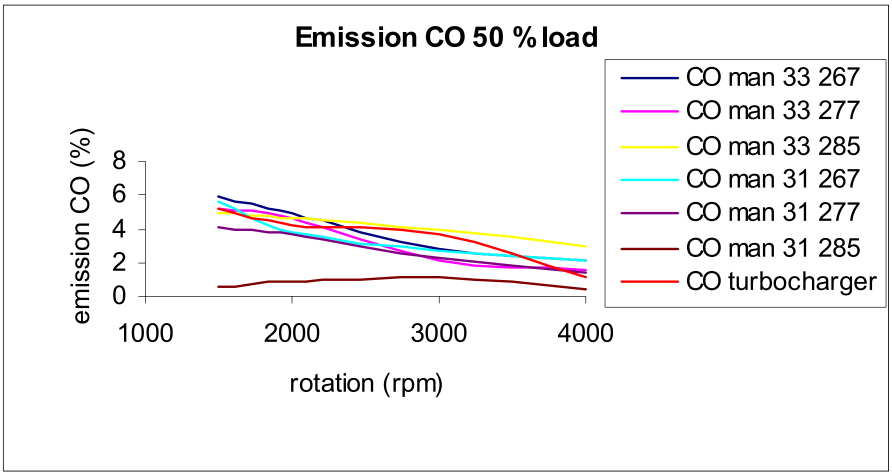

Figure 7. CO Emissions at 50% throttle.

The general behavior, for load 50%, stayed in whole the curves, Fig. (7), and the manifold 31 285 had smaller index in all the rotations. The arrangement col 33 285 had the largest values to leave 2500 rpm. The found values demonstrate that the aspired motor worked in the strips of rotations tested with slightly enriched mixtures, checked by the data of the Figure (8).

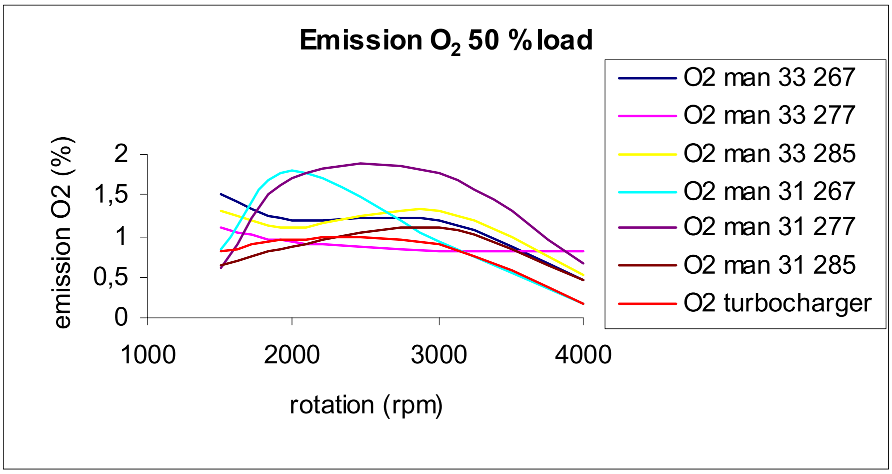

Figure 8. O_2 Index at 50% of throttle.

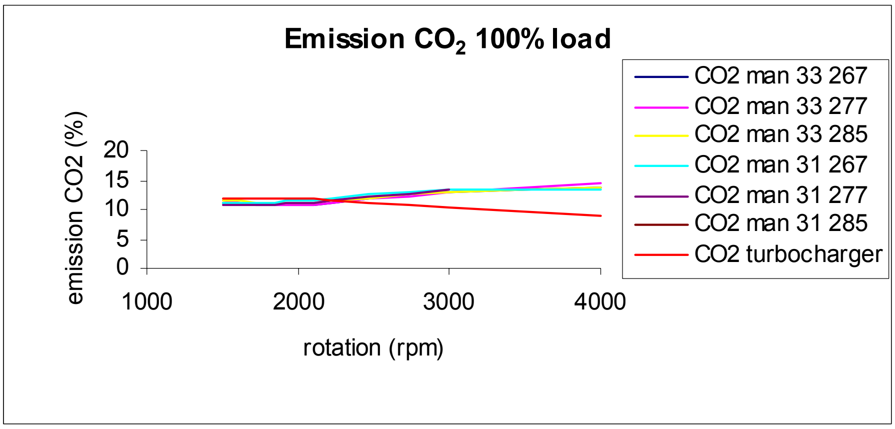

Figure 9. CO_2 Emissions at 100% throttle.

In the Figure (9), the values found for the carbon dioxide maintained inside of the strip found in the literature between 10 and 15%, being the largest values for superior rotations. There was not any significant difference in the behavior of the arrangements of the engine with conventional admission. The fall behavior in the emission of the CO_2 for the group turbocharger in rotations above 3000 rpm, it is also explained by the fact of the existence of air excess that decreased the temperature of the combustion camera hindering the reaction of the carbon and hydrogen with the O_2, effect that was also verified in the curve of emission of THC.

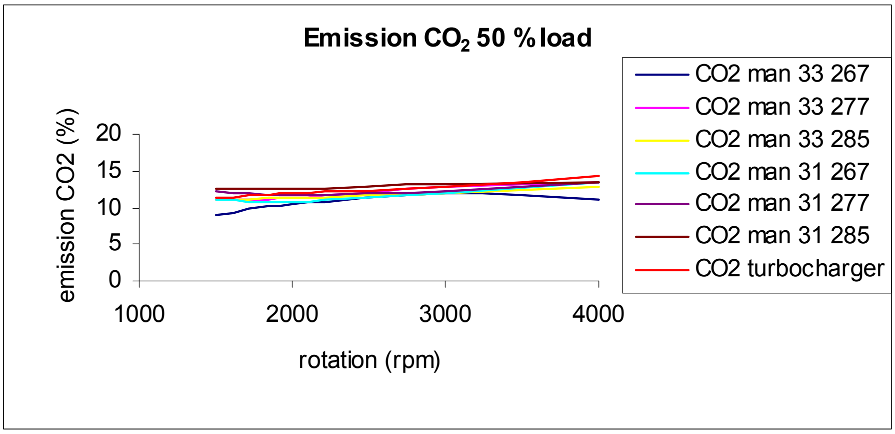

Figure 10. CO_2 Emissions at 50% throttle.

In the same way that in the behavior the full load, Fig. (10), also for all the arrangements the results came in the expected strip, staying between 10 and 15% with the increase for superior rotations. In this load regime, it was not felt in the operation of the turbocharger the inflamabilidade problem, already explained previously, that besides also had its influence negative in the power curve in the regime of 100% to 4000 rpm.

The temperature pick in the combustion camera and the duration of that effect has a decisive influence in the emission of NO_x. The behavior of the emission of NO_x with the factor of air excess λ, follows the increase tendency in the areas where the mixture is rich ($\lambda < 1$), and decreasing for the regimes where it is poor ($\lambda > 1$). The analysis of Fig. (11) and Fig. (12), it should be done tends as reference the behavior obtained in the graphs of Fig. (5) and Fig (8), that show the indexes of O2 reached respectively at 100% and 50% of load.

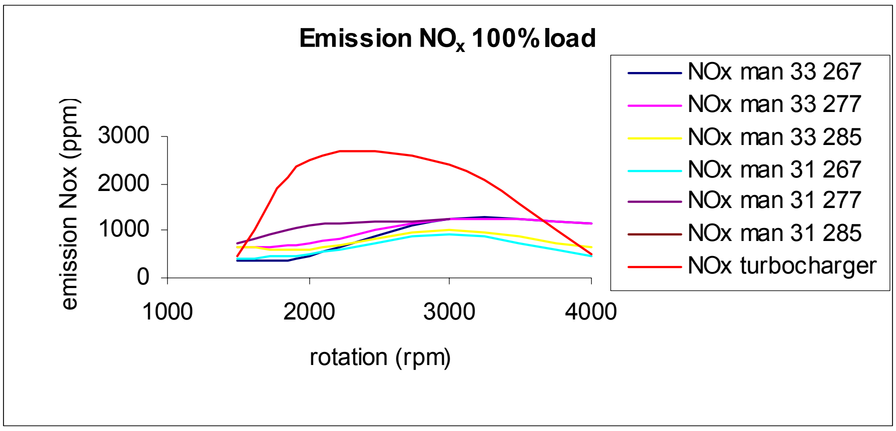

Figure 11. NO_x Emissions at 100% throttle.

The analysis of the curves in Fig. (11) shows us the same tendency of elevation of the levels of emissions with the increase of the rotation for the different assemblies of the aspired engine. This is due to the fact that the temperatures of the gases in the exhaust for the larger band of rotation were shown very superior to the other ones. The NOx is intimately related with high temperatures in the combustion, we found the explanation of this behavior here, because we can verify in the data of measured the higher temperatures of the exhaust coinciding for the regimes of larger indexes of emission of NO_x. Already in the case of the engine turbocharged, this effect was moved little more for the band of rotation 2000–3000 rpm, being about 2,5 times largest indexes of that aspired engine. Starting from 2500rpm the turbine entered in operation provoking the excess of air, Fig. (5), resulting in the decrease of the temperature of the combustion camera, as verified in the exhaust gases 113º C, taking to strong fall of the emission of NO_x

Already for the tested at 50% of load Fig. (12), we had the behavior, very different from the arrangements that used the 277command, because the index of emission of NO_x arose well mainly in relation to the other configurations above the 2500 rpm. Attempted for the fact that for this arrangement we had a larger index of oxygen emission and the levels of temperature of the exhaust gases reached o landing of 550º C against 250º C for the other arrangements, favoring that behavior.

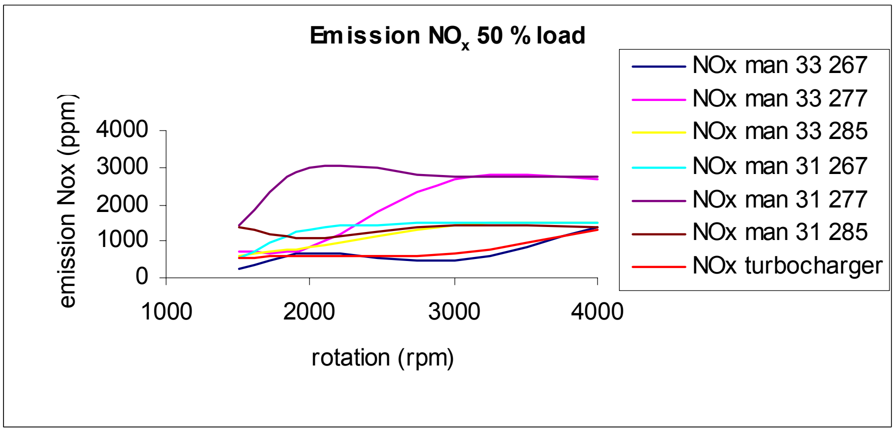

Figure 12. NO_x Emissions at 50% throttle.

4. Conclusion

Making a general analysis of all the accomplished assemblies and compared them under the point of view of the developed power, the arrangement man 33 277 was the best configuration for regimes of 70% and 100%, but for the regimes of 50% and 30% the arrangement man 33 267 was better. With relationship to the torque that tendency of superiority of the first commented arrangement maintained for discharge regimes, being overcome by the arrangement col 33 267 for the drop regimes, where intensified the difference for larger rotations. The behavior of the obtained specific consumption didn't present significant differences among the configurations tested with the 33 manifold, however, when used the 31manifold was verified strong differences among the three camshaft used for the regimes of 50% and especially for the 30% of load, where happened unstable of operation of the engine, not being possible the obtaining of data for the command 285 (above 1500 rpm).

With relationship to the use of the turbocharger, a comparative analysis in everybody load regimes were harmed, once the beak injector of fuel imposed a restriction with relationship to the necessary feeding of the flow of fuel in the regimes of high. Logically a very superior return of that group was waited in relation to the aspired engine, what has been only verified for the regime of 30% load and lower rotations for 50%, representing a medium gain of 30% of power and torque.

With relationship to the obtained emissions understood that behavior of the arrangement man 33 267 would be recommended by occupying a position intermediary between the tested configurations, associated to the fact of having presented a good performance in the torque curves, power and specific consumption. In a general way there was not any discrepancy in the results, except the group turbocharger that also operated out of the conditions operation optimal.

5. Gratefulness

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