OPACITY EMISSION INSPECTION FROM THE EXHAUST PIPE ON DUTY VEHICLES IN BELO HORIZONTE, MINAS GERAIS, BRAZIL.

Elisete Gomides Dutra

Fundação Estadual de Meio Ambiente de Minas Gerais – FEAM/MG. Av. Prudente de Morais, 1671, Bairro Santa Lúcia, Belo Horizonte - MG, CEP: 30.380.000. Tel: (31)3298-6445. E-mail: <u>eliseteg@feam.br</u>.

Ramon Molina Valle

Departamento de Engenharia Mecânica - Universidade Federal de Minas Gerais – UFMG. Av. Avenida Antônio Carlos, 6627, Pampulha, Belo Horizonte – MG, CEP: 31.270.901. Tel: (31)34995140. E-mail: Ramon@demec.ufmg.br

Edwan Fernandes Fioravante

Fundação Estadual de Meio Ambiente de Minas Gerais – FEAM/MG. Av. Prudente de Morais, 1671, Bairro Santa Lúcia, Belo Horizonte - MG, CEP: 30.380.000. Tel: (31)3298-6445. E-mail: edwanf@feam.br

E-man: edwameream.or

Luis Roberto D. Chaves

Secretaria Municipal de Meio Ambiente e Saneamento da Prefeitura de Belo Horizonte – SMMAS/PBH. Av. Afonso Pena, 4000, 6° andar, centro, Belo Horizonte - MG, CEP: 30.110.100. Tel: (31)3277-5207. E-mail: <u>luis.pbh@terra.com.br</u>

Márcio Cerqueira Batitucci

Empresa de Transporte e Trânsito de Belo Horizonte – BHTRANS. Av. Engenheiro Carlos Goulart, 900, Buritis, Belo Horizonte – MG, CEP: 30.455.700, Tel: (31) 3379-5735 E-mail: batitucci@pbh.gov.br

Elv Dias Duarte Júnior

Empresa de Transporte e Trânsito de Belo Horizonte – BHTRANS. Av. Engenheiro Carlos Goulart, 900, Buritis, Belo Horizonte – MG, CEP: 30.455.700, Tel: (31) 3379-5735 E-mail: elyddjunior@ig.com.br

Daniela Aparecida Oliveira

Departamento de Engenharia Mecânica - Universidade Federal de Minas Gerais - UFMG. Av. Avenida Antônio Carlos, 6627, Pampulha, Belo Horizonte – MG, CEP: 31.270.901. Tel: (31) 34995140. E-mail: <u>daniap@brfree.com.br</u>

Abstract.

Opacity inspections were realized at the exhaustion pipe of 200 Diesel heavy vehicles (bus and trucks) of the circulating fleet in Belo Horizonte, Minas Gerais, Brazil. The inspections were realized following the procedures of evaluation of the smoke indexes (opacity) of Diesel cycle vehicles in use, by the free acceleration method, according to the Brazilian standard NBR 13037 and with what was established by the CONAMA Resolution N° 251 of 1999. This methodology involves at first a **visual inspection**, to verify if the vehicle engine shows an irregular functioning, apparent emptying, violation of the sealing of supply pump, alterations in the exhausting system, in the air admission system, as well as emission of blue smoke; a **rotation test**, that is necessary to keep the engine mechanical integrity, and, finally, the **opacity test** of the exhaustion gas. From the analyzed sample, the total percentage of disapproval was around 86%, where 8,5% at the visual inspection, 59% at the measurement tests of maximum rotation and 18,5% at the opacity test. The high percentage of disapproval at the rotation tests shows that a significant parcel of the fleet on study falls in with an adulterated fuel supply system. The disapproval at the visual tests and at the opacity tests, totalizes 27%; they can be directly related with general maintenance state of the vehicles. The operational difficulties for the implementation of the proposed measurement methodology, defined by the National Council of Environment – CONAMA, are also presented and discussed.

1. Introduction

The population many times testifies the emission of black smoke above the acceptable limits emitted by Diesel vehicles. This smoke contributes too much for the high concentration of inhale particles in big urban centers, being the major responsible for the increase of the death rate and diseases caused by respiratory illness, especially of children and elders. The pollutants emitted by the exhaustion of the Diesel vehicles are constituted basically of fuel particles that weren't burned (soot); however, they can be minimized by an adequate maintenance of the fuel supply system and the exhaustion system of these vehicles.

With the objective of the reduction of these indexes and also to stimulate the technological development at the automotive area, in 1986 the Federal Government instituted the Program of Control of Air Pollution by Automotive Vehicles – PROCONVE. The actuation of PROCONVE had the objective of controlling the emissions of the new and used vehicles.

The control of emissions of atmospheric pollutants by the exhaustion of the new vehicles began in 1986, with National Council of Environment - CONAMA Resolution N° 18. The opacity maximum limit of $2.5m^{-1}$ was certified for urban bus manufactured on October 1st 1987 and by other vehicles manufactured on January 1st 1989 (phase 1 of PROCONVE). The pollutants emission control of exhaust gas started on January first of 1994 with introduction and gradual reduction of the limits of emission of CO, HC and NO_x (phases II, III and IV of PROCONVE). The CONAMA stablished, by the Resolution N° 8 of 1993, that since march 1st 1994 all homologation process and Diesel engine certification must include the smoke index on free acceleration specified by manufacturers, so guarantying the correct engine regulation. Since January 1st of 2000, starting phase IV, it was not more specified a single value for smoke emission maximum limit to these vehicles. Table 1 shows the gradual reduction phase of pollutants emission limits for new duty Diesel cycle vehicles.

PROCONVE	Implantation	СО	HC	NOx	Smoke	
Phases	Date	(g/kWh)	(g/kWh)	(g/kWh)	(m^{-1})	
Phase I	1/10/1987	-	-	-	2,5	
Phase II	1/01/1994	11,2	2,45	14,40		
Phase III	1/01/1996	4,9	1,23	9,00		
Phase IV	1/01/2000	4,0	1,10	7,00	-	

Table 1 - Pollutants	emission	limits	through	exhaust	pipe	of	new	duty
Diesel cycle vehicles.								

Source: CONAMA Resolution Nº 8/1993.

For vehicles in circulation, the PROCONVE established the implantation of the Program I/M – Program of Maintenance and Inspection of Vehicles in Use by the environment institutes of each state and city, linked to the annual license of vehicles. The Program I/M consists on maintenance condition inspection of vehicles to guarantee the certificate pollutants emission levels. The Program I/M for Diesel vehicles involves the smoke index measurement (opacity) in free acceleration and the comparison of these measurements with the established maximum limits by the National Council of Environment -CONAMA. For vehicles manufactured until 1995, the maximum limits are established in the CONAMA Resolution N° 251 of 1999; for vehicles that have been manufactured since 1996, the maximum limits are declared by the manufacturer (IBAMA, 2005).

The Environment Foundation of Minas Gerais State – FEAM associated with the City Hall of Belo Horizonte (Environment and Sanitation Bureau; Transport and Transit Company of Belo Horizonte – BHTRANS) and Federal University of Minas Gerais State (Mechanical Engineering Department) to obtain technical qualification for measuring emissions of pollutants. This technical cooperation resulted in the research project "Vehicular Inspection: Qualification and Initial Evaluation" that has been developed since 2003, measuring the emissions of the circulating fleet of Belo Horizonte. The partial results of the Diesel heavy vehicles measurements are presented in this article.

2. Methodology

The inspections are realized following the procedures of measurement of the smoke index (opacity) of used Diesel heavy vehicles using the method "Free Acceleration", according to the Brazilian Standard NBR 13037 that was established by the CONAMA Resolution N° 251 of 1999. By this resolution, the inspection must be made in three stages: firstly it is realized the visual inspection to verify if the vehicle engine shows any irregular functioning, apparent emptying, violation of the sealing of supply pump, alterations in the exhausting system and in the air admission system, as well as emission of blue smoke (carbon particles, lubricant oil and fuel partially burned). If the vehicle presents some of these irregularities, it will be reproved at the visual inspection, ending the procedure of inspection.

For the vehicles approved at the visual inspection, the next test is the measurement of rotation. For measurement of rotation of low gear and maximum free rotation it is used a sensor of universal type manufactured by MAHA. This sensor

measures the rotation by the noise emitted by the engine. In places where background noise intervenes in the measurement of rotation, it is used an inductive sensor coupled to the injector tube. Test of rotation is necessary to keep the engine mechanical integrity. In this test, the normal work temperature of the engine and the normal operation conditions must be kept. The temperature of engine is measured through oil temperature. The software (developed by NAPRO, 2001, in accordance with the NBR 13037 and CONAMA Resolution N° 251 of 1999) registers the angular speed both in slow gear and in maximum free acceleration. The speed of maximum free acceleration is obtained accelerating the engine slowly until it reaches the maximum angular speed without load, so certifying the stability of the engine. These two measurements must be inside the recommended zone by the vehicle manufacturer, respecting a tolerance of ± 100 rpm. Otherwise the vehicle will be reproved. If some abnormality occurs during the engine acceleration, the vehicle will be also reproved.

If the vehicle is approved in both tests (visual and rotation), the last test (opacity) will be realized according to the Brazilian Standard NBR 13037. This Standard describes the method for measuring the exhausting gas opacity of Diesel vehicles, in free acceleration, using the opacymeter. The opacymeters of partial flow, LCS2100 model, manufactured by Sensors, were used. In this procedure, the smoke is collected by a sounding lead of capitation introduced into the exhaust pipe; this sounding lead conducts this smoke to the opacymeter. The opacymeter, temperature and rotation sensors are attached to a computer for data acquisition, as showed in Figure 1.



Figure 1 - Photos of equipment with assessorial of mobile and fixed units of vehicular emission inspection.

The opacity test is realized according to the following procedure: the engine in low gear is accelerated in a continuous and fast way until it reaches the end of the accelerator course, reaching the maximum free rotation. The maximum free rotation must be held for a maximum of 5 seconds, after that the software will register the opacity value. After the first measurement, the accelerator will be released and the engine will be stabilized, so the software will request a new acceleration and will register the second opacity value. The procedure will be repeated 10 times or less and will identify the maximum value of opacity. At the end, the sounding lead of capture will be taken off from the exhaust pipe to obtain the zero value of opacity and the test will be validated. The software will discard the first three measurements of opacity, while the other measurements will be considered valid just when, in four consecutive measurements, the difference between the maximum and minimum values will not be bigger than 0.25m⁻¹ and these measurements can't have a decreasing order. The final result is the arithmetic average of the four consecutive values considered valid.

From the Diesel heavy vehicles that circulate in Belo Horizonte, a sample of 200 vehicles was inspected. The results presented in this article aren't conclusive since the number of sampled vehicles doesn't represent the fleet of Diesel heavy vehicle of Belo Horizonte yet. Currently, Belo Horizonte has a fleet of 32.938 Diesel heavy vehicles registered (DENATRAN, 2005).

3. Results and analysis

3.1 Definition of the sampling size

Analyzing the results of the inspections of opacity, we decided to group the vehicles into 5 bands of manufacture: until 1987, 1988-1993, 1994-1995, 1996-1999, 2000-2003. These bands were defined by observing the maximum limits of emission of atmospheric pollutant defined in the CONAMA Resolutions N° 18 of 1986, N° 8 of 1993. Until 1987, there wasn't exigency in the control of atmospheric pollutant emissions for new heavy vehicles or used vehicles. In the other bands, the new vehicles must obey the phases of gradual reduction of the emissions limits defined by CONAMA (IBAMA,

2004). The objective of these bands of manufacture is to avoid a comparison of the emissions of vehicles produced in very different conditions of technology.

The size of the sample was defined for each band of manufacture through the Simple Aleatory Sampling Method, considering the Normal Distribution, level of confidence of 95% and the error of estimation "d". The sizes of samples were calculated by the Equation 1 (MINGOTI, 2005) and are shown in the Table 1.

$$n = \frac{N\sigma^2}{(N-1)(d/1,96)^2 + \sigma^2}$$
(1)

Where "n" is the size of sample, N is the total number of Diesel heavy vehicles registered in Belo Horizonte, " σ " is the standard deviation for opacity and "d" is the error of estimation. The value of "N" for each band of manufacture of the vehicles produced until 2001 was provided by DETRAN/MG in September of 2001, and for the band from 2001 to 2003, the number of vehicles of the fleet was estimated by the increasing rate of fleet of Minas Gerais (DENATRAN, 2005).

Analyzing the coefficients of variation of the opacity measurements obtained for each band of manufacture, the error of estimation was defined equal to 20% of the emissions limits established by the CONAMA Resolution N° 251 of 1999. The limits of opacity considered have been: 2,5m⁻¹, for all inspected vehicles. Table 2 also shows the total of inspected vehicles and the inspected vehicles that had opacity measurement on each band of manufacture.

Year of	Estimated sample size ⁽¹⁾	Total of inspected	Inspected vehicles that had
Manufacture		vehicles (2)	opacity measurement
Until 1987	6	72	5
1988 - 1993	53	44	4
1994- 1995	17	26	7
1996 - 1999	20	32	8
2000 - 2003	10	26	18
TOTAL	106	200	42

Table 2 – Sample size and number of inspected Diesel heavy vehicles.

⁽¹⁾Minimum number of vehicles to be inspected with opacity measurement. ⁽²⁾ Total sample, including vehicles reproved in the two first tests.

The vehicles inspected were manufactured between 1964 and 2003 and 36% of them (72 vehicles) were manufactured until 1987 (before the PROCONVE). These vehicles have different types of engine: 98 vehicles are naturally aspirated, 46 are turbocharged with LDA and 56 are turbocharged. LDA (Adequacy of the Debited Load) is the system of control of the bomb of fuel injection for adequacy of its debit for the pressure of feeding of the turbo.

3.2 Results of the visual inspection test

For the 200 analyzed vehicles, 17 were reproved at the visual inspection, especially because they emitted a blue smoke and apparent emptying, indicating a lack of engine maintenance. In relation to the type of engine, 14 are naturally aspired and 3 are turbocharged with LDA

3.3 Results of the rotation test

At the rotation tests of maximum free acceleration, the percentage of reproved was more expressive, around 59%. This disapproval was due to, in most cases; the fact that the engine exceeded the maximum rotation limit because of alteration of the mechanical injection pump sealing. It is a serious fact that can be punished because the owner didn't obey the law. Figure 2 shows the percentage of reproved vehicles in the maximum free rotation test versus the bands of manufacture of these vehicles.



Figure 2 - Percentage of reproved vehicles at the maximum free rotation tests versus the band of manufacture.

The total number of disapproval at the rotation test was 118 vehicles and most of them were reproved because of an intentional adulteration of the mechanical system of oil supply. This fact doesn't represent only a deficiency of maintenance, but mainly a lack of environmental conscience of the owners. It's important to point out that 71 of these vehicles are naturally aspired, 38 are turbocharged with LDA and only 9 are turbocharged. These numbers shows that, being a great part of these vehicles aspired, it is easy to obtain the power gain through the alteration of the pump seal. Figure 1 shows biggest percentages of disapproval for the bands of older vehicles, until 1987 and between 1988 and 1993, being of approximately 85% and 81%, respectively.

Figure 3 shows the relation between the averages of the maximum free rotation in the rotation test of the reproved vehicles and the averages of the limits indicated by the manufacturer versus the bands of manufacture. In the realized tests, there weren't disapproval due to low gear rotation.



Figure 3 - Averages of the maximum free rotations measured and indicated by the manufacturer.

Figure 3 shows clearly that the older fleet has the higher alterations of maximum free rotation; being responsible by a bigger production of soot in Diesel motors. The vehicles manufactured after 1994 have a smaller distance between the averages of measured rotation and the average of the indicated rotation. These results tend to confirm the gain obtained with the phase P-IV established by PROCONVE for vehicles manufactured since 1994 and the implantation of the electronic system for Diesel engines.

3.4 Results of the opacity tests

The 65 vehicles approved at both visual inspection and rotation test were submitted to the opacity test. Around 57% of them (37 vehicles) were reproved. Because 23 of them had differences between the measurements bigger than $0.25m^{-1}$ or they were in decreasing order (non valid measurements) and 14 had averages of 4 consecutive measurements bigger than the maximum limits allowed by the legislation (valid measurements). In this test were considered the maximum limits correspondents to $2,5m^{-1}$, for vehicles with natural aspired engines or turbocharged with LDA, and $2,8m^{-1}$ for the vehicles with turbocharged engines, according to CONAMA Resolution N° 251 of 1999.

The disapproval in this test is directly related to a lack of maintenance of the vehicles: insufficient cooling system (the engine doesn't reach the normal work temperature), obstructed air filter, consumed injector peak or non-regulated, low pressure at the pump, carbonization in the combustion chamber, and others.

Figure 4 shows the average, maximum and minimum of opacity versus band of manufacture of the 42 vehicles, for which the measurements of the opacity were considered valid (28 approved and 14 reproved because the measurements of opacity were over the limit) versus band of manufacture of these vehicles. Practically all the vehicles manufactured from 2001 and that were submitted to the opacity test have low index of soot. Consequently, they were approved at the opacity test.



Figure 4 - Average, maximum and minimum of opacity versus band of manufacture of the vehicles submitted to the opacity test.

Figure 4 shows a relatively low average of opacity for the first band of year of manufacture (until 1987) and values of maximum and minimum next to this average. It is important to stand out that of 72 vehicles of this band, 13 vehicles were reproved in the visual inspection and 50 were reproved in the free maximum rotation. Consequently, the test of the opacity was only made for 9 of these vehicles. The values of opacity for the bands of the year of manufacture 1988-1993 and 1994-1995 are bigger than the values of opacity for the first band. These results are not conclusive because for these bands the number of vehicles with opacity inspection is very inferior to the number necessary to compose the samples. The maximum and minimum values of the bands: 1988-1993, 1994-1995 and 1996-1999 are relatively distant of the respective averages, indicating the trend of variation of the measurements of opacity for these vehicles.

Figure 5 shows the relation between the disapprovals at different tests of inspection, showing the total sampled vehicles. Figure 5 shows clearly that great part of the disapproval due to speed (maximum free rotation), mainly for the first band of manufacture (50 reproved vehicles between 72 inspected vehicles, i.e., 69% of disapprovals). For the others bands of manufacture, the percentages of disapproval are: 77% (1998-93), 58% (1994-95), 44% (1996-1999), 20% (2001-03). The proportions of disapproval due to visual test are: 18% (until 1987), 2% (1989-1993), 4% (1994-95), 3% (1996-1999), 4% (2001-2003). The proportions of disapproval due to opacity are: 10% (until 1987), 14% (1989-1993), 31% (1994-95), 35% (1996-1999), 12% (2001-2003).



Figure 5 - Total number of disapproval during inspection of Diesel heavy vehicles that circulate in Belo Horizonte.

Figure 6 shows the percentage of approved and reproved inspected vehicles during a visual inspection, a rotation test and the opacity test of the exhaustion gas.



Figure 6 - Percentage of approved and reproved inspected vehicles during inspection of Diesel heavy vehicles that circulate in Belo Horizonte.

3.5 Problems found at the realization of the inspections of Diesel heavy vehicles

According to what was established at the CONOMA Resolution N° 16 of 1995, the vehicle manufacturer must fix a label with the value of the smoke index (opacity) in free acceleration at the B column of the front right door of the vehicle, being the manufacturer responsible by the declared opacity value. The resolution also establishes that this label must be adhesive and resistant to the weather.

The same resolution established that the service manual of the vehicle must has the value of the smoke index in free acceleration, the angular speeds (rpm) at low gear and maximum free rotation; the correction factor or the already corrected value for altitudes higher than 350m. These in formations must be enlightened for a correct maintenance of the vehicle. However, this Resolution hasn't been accomplished and most of the vehicles don't have this label and manual, making difficult the realization of the tests and the vehicular inspection at all.

4. Conclusions

During the inspections, it was verified that the mechanical injection pump adjustment seal was adulterated in more than 59% of the vehicles, especially in the oldest vehicles. The owners do that because they want to obtain a higher maximum engine rotation and, consequently power gain. Nevertheless, these vehicles pollute more and turn their circulation infeasible, especially in the big urban centers. The maximum rotation registered was bigger than the maximum free rotation specified by the manufacturer. Generally it means alteration at the mechanical pump seal of fuel injection, occasioning as main consequence the emission of black smoke by the exhaustion, which certainly does not pass on the opacity test and the life of engine is reduced.

The Diesel heavy vehicles with electronic control system that are already manufactured in Brazil contribute little to minimize the soot emission. Their contribution will happen in medium long-term with the increasing of the number of these vehicles. The great advantage of this system is that doesn't permit the adulteration of the engine maximum rotation; besides it allows higher fuel injection pressure, reducing the soot emission.

The results shown in this article, although partials, indicate a tendency that a great part of fleet of Belo Horizonte has adulterated mechanical system, compromising the results that were foreseen with the implantation of the Program of Control of Air Pollution by Automotive Vehicles – PROCONVE. Consequently, the air quality conditions, especially in the big urban centers, have gotten worse. Therefore, it's evident the necessity of an effective inspection of the maintenance conditions of the Diesel heavy vehicles that circulate in Belo Horizonte, which can be done through the implantation of the Inspection and Maintenance Program of Vehicles in Use.

The project of inspection of the fleet of Belo Horizonte by sampling will continue until that the representation of the fleet has been obtained so that the measurements will show a scenario about the index of disapproval of these vehicles and the level of emission of pollutants by this fleet. For a better trustworthiness of the results of the Project, the sample will be composed of at least 15 vehicles with measurement of opacity in each band of year of manufacture. Not only the composition of this fleet but also the index of disapproval are important information to dimension the space, number of equipment and workers for the Maintenance Program of Vehicles in Use.

5. Acknowledgements

The authors are grateful to *Fundação de Amparo a Pesquisa de Minas Gerais - FAPEMIG* for all support given to the project. This support permitted *the participation of the mechanics engineering students in the development of this work*.

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