GOVERNMENT OF CHILE
UNDER-SECRETARIAT of TRANSPORT

Vehicle Control and Certification Center

Under-Secretariat of Transport

"TRUCK FILTER PROGRAM"

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Acronyms

MR:	Metropolitan Region.
PPDA:	Prevention and Decontamination Plan for the Metropolitan Region of Santiago.
EPA:	Environmental Protection Agency
UNDP:	United Nations Development Programme
CONAMA RM:	National Commission of the Environment.
3CV:	Vehicle Control and Certification Center
ENAP:	National Oil Company
I.M. of Santiago:	Municipality of Santiago
CVS-CFV:	Constant Volume Sampling System by Critical Flow Venturi
CPC:	Condensation Particle Counters
TEOM:	Tapered Element Oscillating Microbalance
CRT:	Continuous Regeneration Filter
CCRT:	Continuous Regeneration Filter with Catalytic Coating.
LTF:	Commercial name for Donaldson’s continuous regeneration system
DPF DPX:	Commercial name for Engelhard’s continuous regeneration system
CARB	California Air Resources Board

1.- Introduction

As part of the Free Trade Agreement (FTA) between the United States and Chile, which includes cooperation aspects of environmental policies between both countries, the execution of a Project called “Diesel Vehicle Retrofit Pilot Project between Chile and the United States” was agreed. The execution of the experimental program linked to this Project was entrusted to this Center.

This program application segment was chosen given the high participation of trucks in the pollution by particulate material in the MR (13% according to PPDA 2003), and the requirement of the Prevention and Decontamination Plan for the Metropolitan Region (PPDA), which states that trucks should reduce their emissions through the use of post-combustion devices.

The 3CV participation was due to the fact that it is the only laboratory that has the necessary infrastructure for developing emission measurements of heavy-duty vehicles, as well as it has related expertise in previous studies such as:

- Particle Filter Program for public transportation buses of Santiago.
- Emission measurement for determining Emission Factors.
- Assessment programs of emission-reduction devices and/or additives or consumption improvement.

1.1 Participants

Tables 1, 2 and 3 show post-treatment institutions, companies and manufacturers, respectively, which participated in this program:

Table 1: Participating Institutions

Institution	Role
EPA U.S. Environmental Protection Agency	US$ 150,000 financing and Technical Support.
UNDP United Nations Development Programme	Management of EPA resources.
CONAMA RM National Commission of the Environment	General coordination of the project
3CV Vehicle Control and Certification Center	Design and execution of the experimental program
ENAP National Oil Company	Contribution of CHI $ 24,000,000 in city diesel

Table 2: Companies with participating trucks

Company/Institution	Role
Municipality of Santiago	Participation with three trucks, two garbage trucks and one dump truck.
Truck Drivers Confed.	Participation with 3 trucks.
Cecinas San Jorge	Participation with 2 trucks.
Private Trucks	Participation with 2 trucks.

Table 3: Post-treatment System manufacturers or representatives

Filters Manufacturers	Activity
HJS	Filter supply for two trucks
DONALDSON	Filter supply for five trucks
INTERNATIONAL	Filter supply for the three trucks of the M. of Santiago

2.- Objective

The objective of the present report is to inform about the outcomes of the operational and emission follow-up, as a result of the experimental program of the project.

3.- Description of the Laboratory

Emission measurements of the truck fleet were carried out at the 3CV's Heavy-Duty Vehicles Laboratory. This laboratory has a constant-volume sampling dilution system, with double dilution tunnel, analyzer bank for contaminant gas analysis and gravimetric system for particulate material. The sampling system complies with the specifications stated in Directive 1999/96 EC of the European Economic Community, for measuring heavy-duty vehicle engines. In any case, and in contrast to such Directive, the laboratory has a chassis dynamometer in replacement of an engine dynamometer. Following there is a thorough description of each equipment:

3.1 Chassis Dynamometer

Figure 1: Chassis Dynamometer

AVL-Zöllner electric dynamometer with simple 48-inch roller. The maximum load inertia capacity is 30 [ton] and its maximum power is 300 [kW]. The allowable maximum weight per axle is 10 [ton].

3.2 Dilution Tunnel

AVL-Pierburg double dilution, stainless-steel tunnel, with gravimetric sampling system for particulate material, according to European Directive 1999/96 EC.

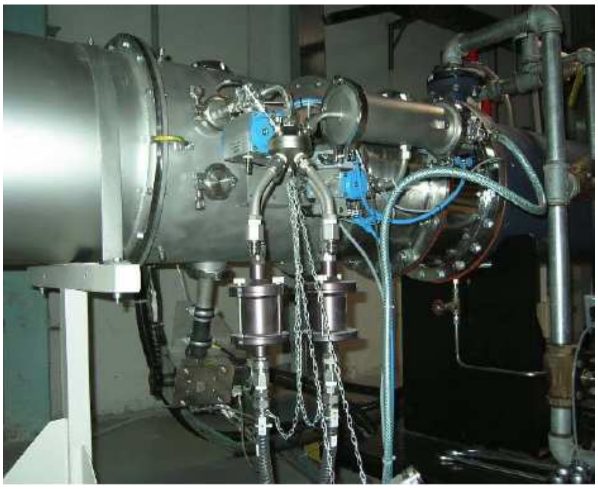

Figure 2: Double dilution tunnel.

3.3 CVS-CFV

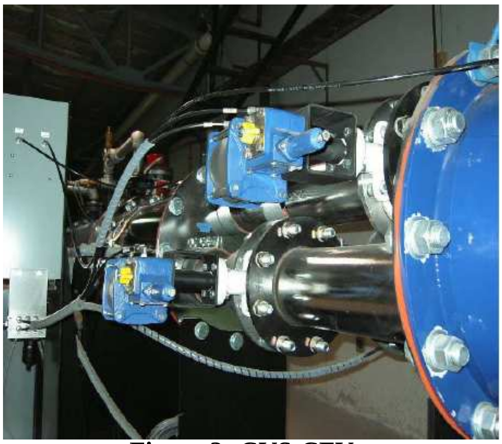

Figure 3: CVS-CFV.

Constant volume sampling system, through flow control by means of three venturis of 30, 40 and 50 [m3/min], which can operate in all their combinations. A heat exchanger regulates temperature of the exhaust gases in a controlled range of ±11 [ºK]. The equipment has two pairs of bags for accumulating samples of diluted exhaust gases and dilution air, separately in each pair.

3.4 Gas Analyzer Bank

Figure 4: AMA 4000 analyzer

AVL-Pierburg analyzer gas system, model AMA 4000, with FID method for total hydrocarbons (THC) and methane (CH_4). IRD method for carbon monoxide (CO) and carbon dioxide (CO_2), and CLD method for nitrogen oxides (NO_x) and nitrogen dioxides (NO_2).

3.5 Particle counter system

A system that has a thermodilution device that conditions the sample. Adjustable in dilution levels between

18 and 1800 times, and in temperatures between 0 and 400 ºC. CPC equipment (Condensation Particle Counter), allows measuring the amount of solid particle concentrations in the thermoconditioned sample, in size levels from 10 nm.

Figure 5: Solid particle counter system.

3.6 Mass measurement gravimetric method

Equipment AVL-Pierburg, model FP 4000 Advanced. This system controls sampling aspiration flows from the primary tunnel as well as from the secondary. It also senses the contra-pressure produced by filters, sample-taking times.

3.7 Equipment Integration

The laboratory equipment, except from the Thermodilutor-CPC and TEOM, is integrated through an Automatization System that controls and synchronizes the equipment operation, records measured values and estimates the THC, NOx, CO, CO2 and Particulate Material emissions during the trial, in grams per kilometer.

A general laboratory diagram is shown in Figure 7.

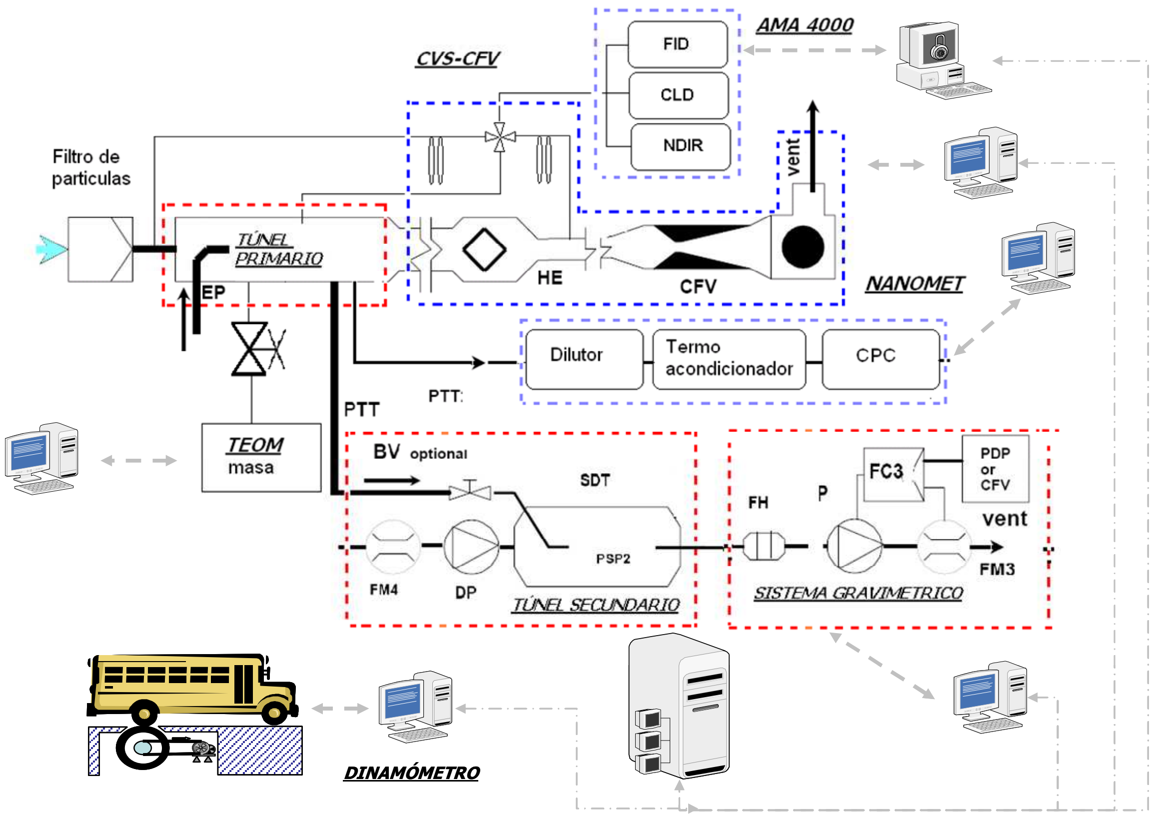

Figure 6: Heavy-Duty Vehicles Laboratory Diagram

Where,

P	:	Exhaust pipe of the tested vehicle.
HE	:	Heat exchanger.
CFV	:	Critical Flow Venturi
FID	:	Flame ionization detector.
CLD	:	Chemical luminescence detector.
NDIR	:	Non-dispersive infrared analyzer.
CPC	:	Particles counter
PTT	:	Particle transference tube.
SDT	:	Secondary dilution tube.
P	:	Sampling bomb.

4.- Analyzer Measurement Methods and Emission Estimate

During the development of the cycle the entire exhaust gases are collected through a probe that conducts them to the dilution tunnel, where they are mixed with properly filtered ambient air to generate a diluted sample. The constructive conditions of the tunnel allow a sample homogenization, which is then conducted to the different analysis instruments for determining the concentrations of each substance under study. The diluted gas flow is known and practically constant due to the use of the CVS-CFV equipment that has venturis whose calibration coefficients allow estimating such flow. For greater accuracy in flow estimate, the CVS-CFV equipment has a heat exchanger that regulates the temperature of the diluted sample at a range of ± 11 [°K].

4.1 AVL-Pierburg, AMA 4000 gas analyzer system

The physical principles and the measuring method for gas contaminant concentration are stated below.

4.1.1 Carbon Monoxide (CO) and Carbon Dioxide (CO2)

IRD method for both contaminants. In order to determine these contaminants, a diluted sample is extracted from the dilution tunnel and conducted to the NDIR gas analyzer bank. Inside this analyzer the concentration is determined with a 2-Hz frequency, and afterwards integrated to all the conduction cycle, estimating the average concentration for both contaminants. At the same time, another sample is taken to the sampling bag of the CVS-CFV equipment to be also accumulated throughout the cycle, and be analyzed at the end of the trial. This second value is contrasted with the modal result for validation.

4.1.2 Total Hydrocarbons (THC):

FID method for total hydrocarbons (THC). In order to analyze this contaminant a heated probe at 191[ºC] is used, which conducts the sample from the dilution tunnel to a FID analyzer. Values are sampled by the analyzer at a 2-Hz frequency, and afterwards they are integrated in order to determine the average concentration obtained for the cycle.

4.1.3 Nitrogen Oxides (NOx):

CLD method for nitrogen oxides (NOx). In order to determine this substance, a sample is extracted from the tunnel and conducted through a heated probe over 60 [ºC] to a CLD analyzer, where it is sampled with a 2-Hz frequency during all the cycle, and subsequently integrated for estimating the average value.

4.2 Particulate material

As far as particulate material is concerned, this laboratory measures mass emission by gravimetric method, measuring the amount of particles. These methods are the following:

4.2.1 Number of Particles:

In order to determine the number of particles, the sample of the tunnel is conducted towards a thermodilutor where it is diluted at a rate between 16 and 1800 times, in order then to pass through an evaporation tube where liquid substances present in the sample are removed. Due to previous dilution, volatile substance re-condensation is avoided down waters the evaporation tube. Such conditioned sample is analyzed by the CPC equipment, where solid particles per cubic centimeters are determined.

4.2.2 Particulate material by gravimetric method

The total mass of the particulate material (PM) is determined through the gravimetric method. To that purpose, a sample of diluted gases is extracted from the primary or secondary tunnel. Then it is conducted through filters that accumulate the particulate material. Those filters are weighed in a conditioned weighing chamber, previous 3 or more hours - stabilization, in conditions of controlled humidity and temperature. The mass of the particulate material is determined by the difference of weight of the filter with particulate material minus the weight of the filter measured before the trial (gravimetric method).

4.3 Mass Emission Estimate

Once determined the average concentrations of each contaminant during the cycle, the emission in mass is estimated through the following equation, except for the gravimetric method which directly gives in mass values:

$$E_i = \frac{V_{mix} \times \rho_i \times \left[E_{con\_i} - E_{fondo\_i} \times \left[1 - \frac{1}{FD} \right] \right]}{10^6}$$

Where:

E_i	:	Total mass emission in grams of contaminant *i* during the conduction cycle.
Vmix	*:*	*Total volume of diluted exhaust gases moved during the cycle.*
ρ_i	:	Contaminant *i* density
E_{con_i}	:	Concentration in parts per million [ppm] of contaminant *i* in diluted exhaust gases.
E_{fondo_I}	:	Concentration of contaminant *i* in dilution air, in [ppm]
FD	:	Dilution factor.

In the case of nitrogen oxides, the final result is multiplied by the correction factor by humidity (Kh).

In the case of the amount of particles, the value measured is corrected by a 15%-loss of particles in the thermo-conditioner. Bottom concentrations are the ones measured inside the tunnel without exhaust gases, inside the tunnel and the concentrations.

4.4 Performance Estimate

Fuel economy was determined by testing the amount of carbon in the exhaust gases. During combustion, most of fuel carbon turns into carbon monoxide and dioxide. The total mass of the fuel used during tests is estimated through the following formula:

$$M_{fuel} = \frac{\left[\left[\frac{12.011}{12.011 + \alpha \cdot (1.008)} \right] \cdot HC_{mass} + 0.429 \cdot CO_{mass} + 0.273 \cdot CO_{2mass} \right]}{\frac{12.011}{12.011 + \alpha \cdot (1.008)}},$$

Donde:

M_{fuel}	:	Mass of fuel consumed during the test.
HC_{mass}	:	Total hydrocarbon mass emitted during the test.
CO_{mass}	:	Total mass of Carbon Monoxide emitted during the test.
CO_{2mass}	:	Total mass of Carbon Dioxide emitted during the test.
α	:	Atomic proportion of hydrogen to carbon of diesel (1.91).

In order to estimate fuel consumption in volume, the commercial diesel density was considered as $\rho = 0.84$ [kg/l]. The distance covered by the vehicle, in order to express the consumption in [km/l], is the length of the conduction cycle tested, which is determined by the chassis dynamometer.

5.- Gear Cycle Simulation

In order to create the operative conditions of trucks, these were subjected to a driving cycle over the chassis dynamometer. This cycle is a representation of the load, speed and acceleration conditions to which the truck would be subjected to during the real operation at roads.

5.1 Gear Cycle.

In order to simulate the gear conditions, the two first phases of the ETC-FIGE cycle were used (known as the FIGE transient cycle). The following graph shows the cycle used.

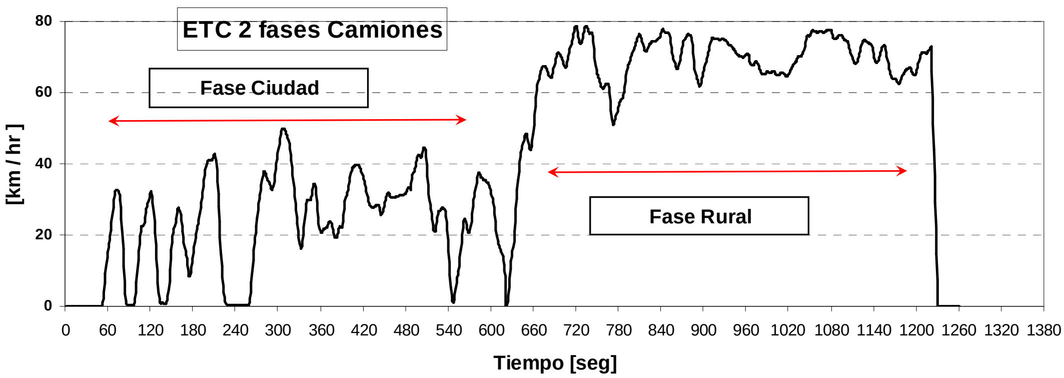

Figure 7: Phase 1 and 2 ETC-FIGE cycle

Table 4: Main features of the ETC-FIGE Cycle, phases 1 and 2

Features	Phase 1	Phase 2	Total Cycle
Nº points [seg]	600	600	1200
Idle [%]	12%	0%	6%
Operation [%]	88%	100%	94%
Acceleration [%]	64%	63%	63%
Braking [%]	26%	37%	37%
Av. Speed [km/h]	23.20	69.24	46.22
Av. Accel. [m/s^2]	0.61	0.59	0.60
Av. Braking [m/s^2]	-0.76	-0.69	-0.72
Max. Speed [km/h]	49.90	87.50	87.50

5.2 Load Simulation in the Chassis Dynamometer.

Since during the development of the emission trial the truck keeps steady over the dynamometer roller, the inertia, the friction force with the floor and the friction force with the wind that work over a truck when driven along a road, should be simulated by the dynamometer.

In order to correctly simulate the truck operation during the development of the cycle, power loss factors due to aerodynamic resistance and to wheels rotation, and the related mechanic components were considered. For this, the following load equation was used:

$$F_d = m \times a + m \times g \times f_{ro} + C_d \times A_f \times \frac{\rho}{2} \times v^2$$

Where:

F_d	Force simulated by the dynamometer.
$m \times a$	Inertia force.
$m \times g \times f_{ro}$	Force of rotation losses (Fo parameter in the chassis dynamometer)
$C_d \times A_f \times \frac{\rho}{2} \times v^2$	Force of aerodynamic losses (F2xv2 parameter in the chassis dynamometer)

m :	Vehicle mass. Considers the empty weight of the vehicle plus 50% of its passenger capacity.
a :	Instant acceleration of the vehicle during the cycle.
g :	Gravity acceleration.
fro :	Rotation loss coefficient.
Cd :	Aerodynamic loss coefficient.
Af :	Truck frontal area. Is the orthogonal projection area of the vehicle, onto a plane perpendicular to the longitudinal axle of the vehicle, including tires and suspension components, rounded off 0.1 [m2].
ρ :	Air density.
v :	Instant vehicle speed during the cycle.

In order to determine the fro and Cd coefficients, the values recommended in the study "Assessment and Reliability of Transport Emission Models and Inventory Systems ARTEMIS/ Heavy duty vehicle emissions / Final Report", were used.

6.- Truck Fleet Description

The fleet used during this program was selected considering the following three criteria.

6.1 Different work cycles

The work cycle is related to the operational conditions of the truck, both in speed, accelerations, load, idling, etc. Following there are some examples.

The first refers to the work cycle of garbage trucks, which is characterized by long periods at low speed and long periods at idling during garbage collection, and finally a period of medium and high speed, loaded, during its way to the landfill. For this application we counted on the participation of the Municipality of Santiago, which made available 2 garbage trucks for this program.

Another example included in the program is about refrigerated delivery trucks for supermarkets. The cycle is characterized by urban traffic cycles and long idling periods (refrigeration operation). This type of application was contributed by *Cecinas San Jorge* industry, with two light duty trucks.

The third example considers urban and inter-urban behavior cycle with heavy duty trucks. This type of application was contributed by the Truck Drivers Confederation (*Confederación de Camioneros*), with two container transport trucks from Valparaíso.

A dump truck also participated, which is used for aggregate transportation, having high load (full) and low load (empty) urban cycles. This last application is commonly used in the construction industry in the MR.

Other examples are the beton mixer trucks and a truck used for moving furniture, supplies and others, for events and meetings.

6.2 Different sizes

Another important aspect considered in the pilot fleet was the different-size truck range, as described in 6.4 of this report.

6.3 Different age and emission regulation

This aspect was also covered in a vast range of cases, with the participation of trucks without emission regulation, EUROI (or EPA91) and EURO II tucks. Likewise, the fleet was made up of 1992-2004 model year trucks (for further details see 6.4 of this report).

6.4 Truck descriptions

The following pictures and their charts show and describe the truck fleet used.

Figure 6: IVECO 190.30 T truck

Make:	IVECO 190.30 T
Plate:	DU 8696
Year:	1992
Regulation:	No
Power:	227 kW
Tare Weight:	6,500 Kg.
Max. Gross Weight:	45,000 Kg.
Type of vehicle:	Inter-urban Truck.

Make:	FORD CARGO 3530
Plate:	NS 8442
Year :	1996
Regulation:	Euro I
Power:	223 kW
Tare Weight:	5,600 Kg.
Max. Gross Weight:	26,500 Kg.
Type of Vehicle:	Interurban Truck

Figure 7: FORD CARGO 3530 truck

Figure 8: WOLKSWAGEN 14150 truck

Make:	WOLKSWAGEN 14150
Plate:	KP 1529
Year:	1993
Regulation:	No
Power:	112 kW
Tare Weight:	5,000 Kg.
Max. Gross Weight:	10,000 Kg.
Type of Vehicle:	Truck

Make:	MITSUBISHI CANTER
Plate:	XY 2195
Year:	2004
Regulation:	EURO II
Power:	80 kW
Tare Weight:	3,100 Kg.
Max. Gross Weight:	6,100 Kg.
Type of Vehicle:	Regrigeration Truck

Figure 9: Truck MITSUBISHI CANTER

Figure 10: KIA FRONTIER 3.0 truck

Make:	KIA FRONTIER 3.0
Plate:	XA 2910
Year:	2003
Regulation:	EURO II
Power:	60 kW
Tare Weight:	2,770 Kg.
Max. Gross Weight:	5,270 Kg.
Type of Vehicle:	Refrigerated truck

Make:	INTERNATIONAL 4900
Plate:	PN 1132
Year:	1996
Regulation:	EPA 91
Power:	145 kW
Tare Weight:	12,600 Kg.
Max. Gross Weight:	20,500 Kg.
Type of Vehicle:	Garbage disposal truck

Figure 11: INTERNATIONAL 4900 truck

Make:	INTERNATIONAL 4900
Plate:	PN 1118
Year:	1996
Regulation:	EPA 91
Power:	145 kW
Tare Weight:	12,600 Kg.
Max. Gross Weight:	20,500 Kg.
Type of Vehicle:	Garbage disposal truck

Figure 12: INTERNATIONAL 4900 truck

Make:	**INTERNATIONAL 4700**
Plate:	**NV 3996-2**
Year:	**1996**
Regulation:	**EPA 91**
Power:	**129 kW**
Tare Weight:	**8,000 Kg.**
Max. Gross Weight:	**18,000 Kg.**
Type of Vehicle:	**Dump truck**

Figure 13: WOLKSWAGEN 14150 truck

Make:	**WOLKSWAGEN 14150**
Plate:	**RE 1453**
Year:	**1997**
Regulation:	**EURO I**
Power:	**97kW**
Tare Weight:	**6,900 Kg.**
Max. Gross Weight:	**11,000 Kg.**
Type of Vehicle:	**Dump truck**

Figure 14: MACK DM 690 truck

Make:	**MACK DM 690**
Plate:	**XA 8940**
Year:	**2003**
Regulation:	**EPA 94**
Power:	**224 kW**
Tare Weight:	**13,000 Kg.**
Max. Gross Weight:	**19,000 Kg.**
Type of Vehicle:	**Beton Mixer Truck**

7.- Fleet Operational Follow-up

The operational follow-up consisted in recording temperatures and contra-pressures of the exhaust gases, both prior to the muffler (no-filter truck) and after the filter (truck with post-treatment system).

An operational follow-up of the experimental fleet was carried out before installing the filter, called "predataloging", i.e. operating trucks with muffler. The operational follow-up with filter was performed by post-treatment system representatives.

7.1 Operational Follow-up without filter (Predataloging)

An operational follow-up was carried out to the aforementioned fleet, except for the dump truck belonging to the Municipality of Santiago. This follow-up consisted in recording the temperature and contra-pressure of the exhaust gases before the muffler. The results of this campaign were submitted in a previous report developed by 3CV.

These results were used to create the tender conditions, in order the parties offering post-treatment systems to choose those applications that are more convenient to the features of their post-treatment systems.

The following table summarizes the operational conditions with which the post-treatment systems were bidded for the truck–application combination.

Table 5: Operational Conditions of the bidded fleet

PLATE	START SAMPLING	END SAMPLING	MED TEMP [°C]	MAX PRESS [mbar]	VALUES OVER 190 °C	VALUES OVER 250 °C	VALUES OVER 500 °C
RE 1453-K	Fri, 26-05-2006 7:11:26	Tue, 06-06-2006 12:17:34	297.1	66.0	82%	65%	0%
DU 8696-0	Fri, 09-06-2006 11:28:48	Thu, 22-06-2006 15:13:42	225.4	18.0	54%	43%	0%
XA 2910-9	Tue, 23-05-2006 11:11:01	Mon, 05-06-2006 14:15:24	200.2	284.0	43%	28%	2%
XY 2195-9	Wed, 24-05-2006 13:50:52	Monn, 05-06-2006 12:44:51	198.8	81.0	46%	28%	0%
KP 1529-3	Tue, 27-06-2006 15:39:12	Wed, 05-07-2006 12:38:59	187.3	288.0	42%	24%	0%
PN 1132-6	Wed, 07-06-2006 10:51:53	Wed, 14-06-2006 16:28:53	209.7	46.0	59%	20%	0%
NS 8442-7	Wed, 24-05-2006 12:30:22	Thu, 15-06-2006 0:03:07	162.1	54.0	30%	19%	0%
XA 8940-3	Tue, 27-06-2006 16:54:49	Tue, 04-07-2006 19:34:20	168.6	77.0	29%	13%	0%
PN 1118-0	Tue, 06-06-2006 13:18:11	Wed, 14-06-2006 16:02:13	161.3	63.0	22%	7%	0%

The first segments of Table 5 stands for trucks with high temperatures in the exhaust gases (in yellow), the second segment in blue stands for trucks with medium temperatures, and finally in grey the trucks with low temperatures.

The bidding process was managed by CONAMA RM, being awarded the filter technologies according to the following table.

Table 6: Awarded filters and companies.

PLATE	Technology	Filter supplier
RE 1453-K	Filter DPF CRT Closed	HJS
DU 8696-0	Filter DPF CCRT Closed	
XA 2910-9	Filter LTF Closed	DONALDSON
XY 2195-9	Filter LTF Closed	
KP 1529-3	Filter LTF Closed	
PN 1132-6	Filter DPF DPX Closed	INTERNTATIONAL
NS 8442-7	Filter LTF Open	DONALDSON
XA 8940-3	Filter LTF Open	DONALDSON
PN 1118-0	Filter DPF DPX Closed	INTERNTATIONAL
NV 3996-2	Filter DPF DPX Closed	INTERNTATIONAL

7.2 Operational follow-up with filter (dataloging)

In accordance with the bidding terms and conditions, this activity was carried out by the filter representatives.

The following graph summarizes the result of the operational follow-up for the contra-pressure variable produced by the muffler (before installing the filter), and the contra-pressure produced by the use of the filter in the output of the exhaust gases.

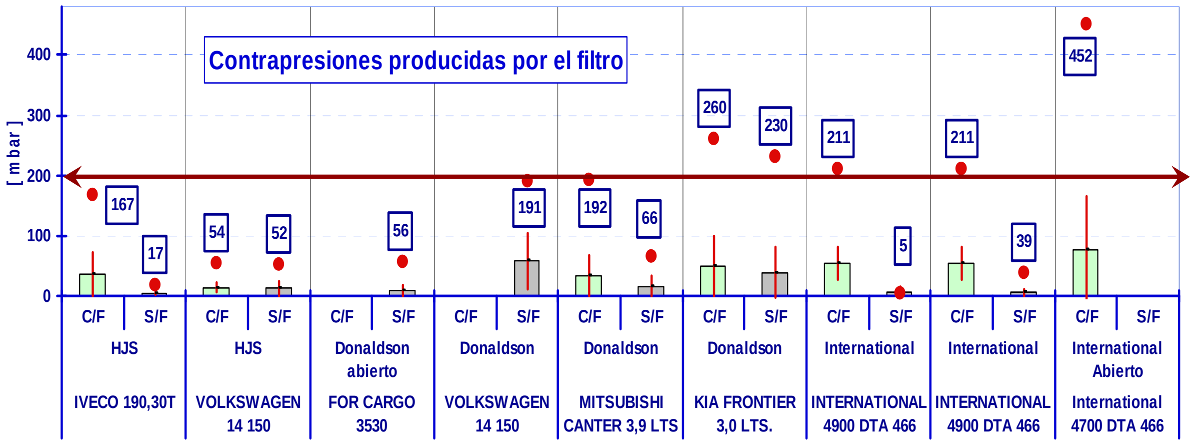

Figure 15: Contra-pressure

The graph shows a red line that corresponds to a 200-mbar value, which is the maximum recommended value in literature and legislation of other countries, as well as in our country, according to the Decree establishing the procedure of post-treatment system certification for buses. Notwithstanding the aforementioned, it is noted that other legislations[1] also establish as maximum contra-pressure limit the one recommended by the engine manufacturer.

As a result of the operational follow-up, it is shown that contra-pressures exceeded the 200 mbar when using *Internacional* post-treatment systems. In any case these values were considered acceptable by the engine manufacturer (*Internacional* itself).

As far as DONALDSON filters are concerned, the data are the ones gathered by 3CV, since the representative of these filters did not turn up, and was not possible to contact him during the second half of the experimental program. Additionally, values gathered by 3CV, with filter (W/F) represent few days of follow-up. In any case this filter presents contra-pressures below 200 mbar except for the KIA FRONTIER truck, which already presented contra-pressures over 200 mbar with the original system.

In the case of the beton mixer truck with Donaldson filter, there was no available information.

For the HJS systems, which have the best information of all the available ones, there is a good contra-pressure behavior.

8.- Emission Trial

Emission measurement was carried out at the 3CV's heavy-duty vehicles laboratory, under the configuration, equipment and method described in previous sections.

Certified diesel oil was used as fuel during trials. Its main feature is that it has less than 3 ppm of sulphur in volume. A description of the fuel is found in Annex 1.

Measuring trials were aimed at determining the efficiency of emission reductions.

8.1 Measurement planning

Emission trials considered initial measurements without post-treatment system (previous round), and two measurement rounds, where for each round it was measured with filter and without filter continuously. Filter manufacturers were responsible for removing the filter during measurements.

In the case of garbage trucks, during the initial rounds only free accelerations were measured, since up to that date the way to disconnect the second traction axle was unknown. Neither we have emission results in all the rounds for the beton mixer truck, because it was not possible at any moment to disconnect the double traction.

It is worth highlighting the fact that there were absences and flaws in vehicles that made all measurements impossible, being the most unfavorable case the impossibility to measure no-

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[1] CARB

filter emissions in vehicles equipped with DONALDSON system, due to absence of the representative.

The following table summarizes validated measurements for determining emission reduction efficiencies of these post-treatment systems.

The X represents a non-performed or invalid measurement, the √ stands for measurements performed.

Table 7: Measurement Activities

PPU	Make	Filter	Previous Round	Round 1		Round 2	
				W/ Filter	W/O Filter	W/ Filter	W/O Filter
DU 8696-0	IVECO 190.30T	Filter DPF CCRT Closed - HJS	√	√	X	√	√
NS 8442-7	FORD CARGO 3530	Filter LTF Open - Donaldson	√	X	X	√	X
KP 1529-3	VOLKSWAGEN 14 150	Filter LTF Closed - Donaldson	√	√	√	√	X
XY 2195-9	MITSUBISHI CANTER 3,9 LTS	Filter LTF Closed - Donaldson	√	√	√	√	X
XA 2910-9	KIA FRONTIER 3,0 LTS.	Filter LTF Closed - Donaldson	√	X	X	√	X
PN 1132-6	INTERNATIONAL 4900 DTA 466	Filter DPF DPX Closed -International	X	√	√	X	X
PN 1118-0	INTERNATIONAL 4900 DTA 466	Filter DPF DPX Closed -International	X	√	√	√	X
NV-3996-2	INTERNATIONAL 4700 DTA 466	Filter DPF DPX Closed -International	X	√	√	√	X
RE 1453-K	VOLKSWAGEN 14 150	Filter DPF CRT Closed - HJS	X	√	√	√	X
XA 8940-3	MACK DM 690	Filter DPF DPX Open	X	X	X	√	X

8.2 Emission Results

The following graphs show the outcomes with and without filter. Each bar was built with the average of available measurements. Lines in red represent the maximum value and the minimum value. Grey bars represent the measuring conditions without filter and the light blue ones the measurements with filter. The unit is in grams per kilometers of the two first phases of the ETC cycle. The identification of the truck as well as the brand and type of the filter (open and closed) are located at the abscise axis.

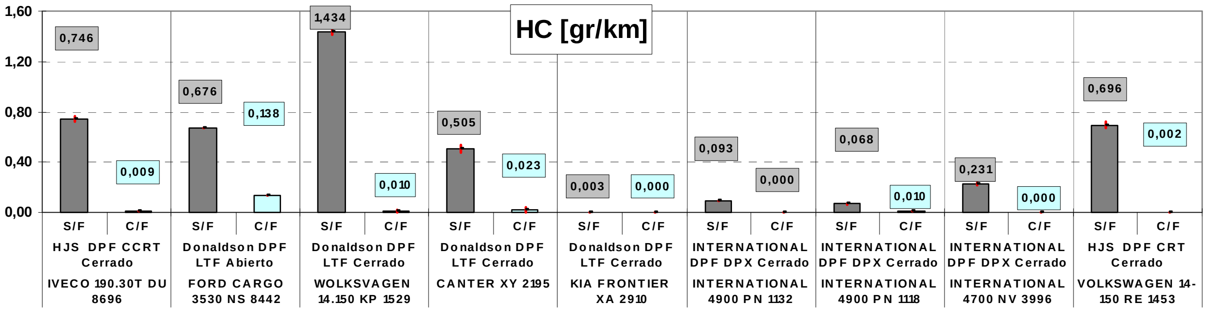

Figure 16: Hydrocarbon emissions with and without filter

Hydrocarbons (HC) cero-level emission values are at the uncertainty range level of the measuring method, due to the high efficiency in emission reduction of this contaminant using particle filters.

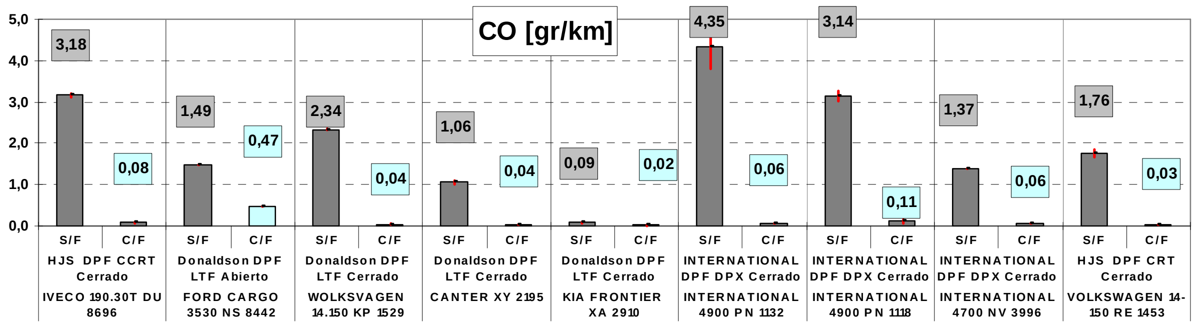

Figure 17: Carbon monoxide emissions

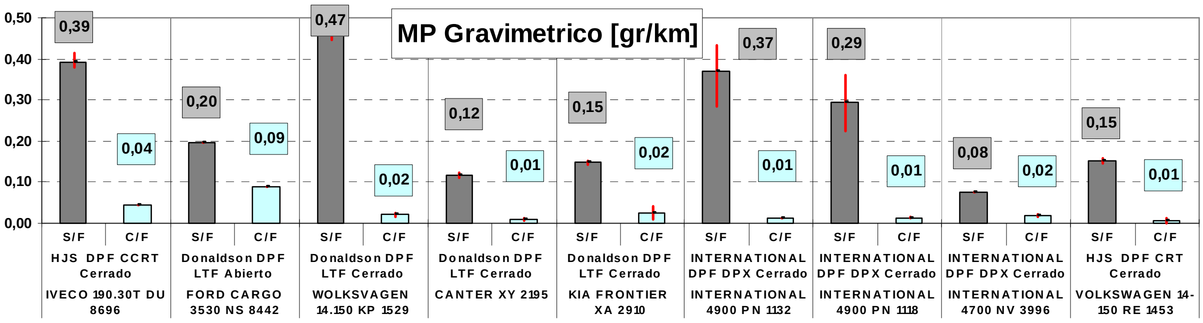

Figure 18: Particulate material emissions, gravimetric method

As it is the case of the hydrocarbon graph, we can see that the use of filters reduces carbon monoxide and particulate material emissions.

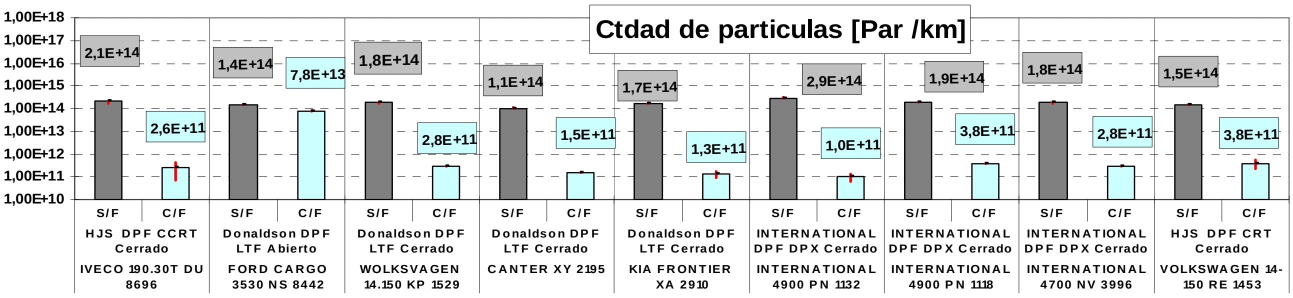

Figure 19: Solid particle emissions

In the previous graph, where the particle emission scale is logarithmic, it may be seen that truck emissions fall in about 3 levels of magnitude, which represents a 99.9 % approximately. The exception is the open filter (2nd truck) that falls from $1.4x10^{14}$ to $7.8x\ 10^{13}$, a 50 % approximately.

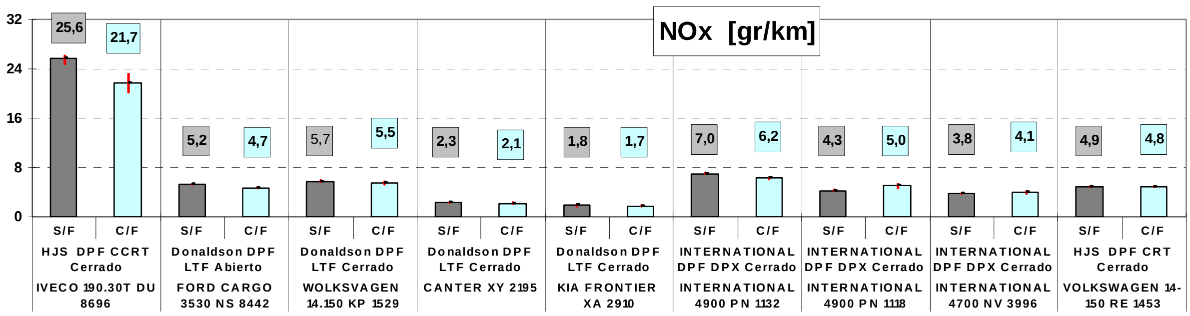

Figure 20: Nitrogen oxide emissions

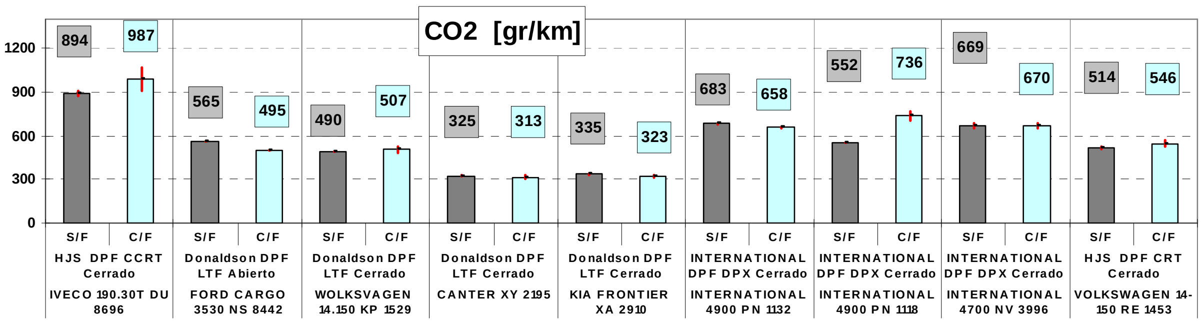

Figure 21: Carbon dioxide emissions

In these two last contaminants it may be seen that there is no notorious influence when using post-treatment systems.

A greater analysis is given further on.

8.3 Emission reduction efficiency

The following graph shows the percentage of emission reduction when using post-treatment systems. For this, emissions of the truck working without filter were considered as baseline situation that means this stands for 100%. This graph shows the percentage variation of emissions for the PM, CO, HC, CPC (amount of particles), NOx and CO2. In blue tonality it is shown the variation average for the 8 technologies that use closed filters. To the right of this blue bars it is shown the percentage variation of emission reduction of the only open filter measured..

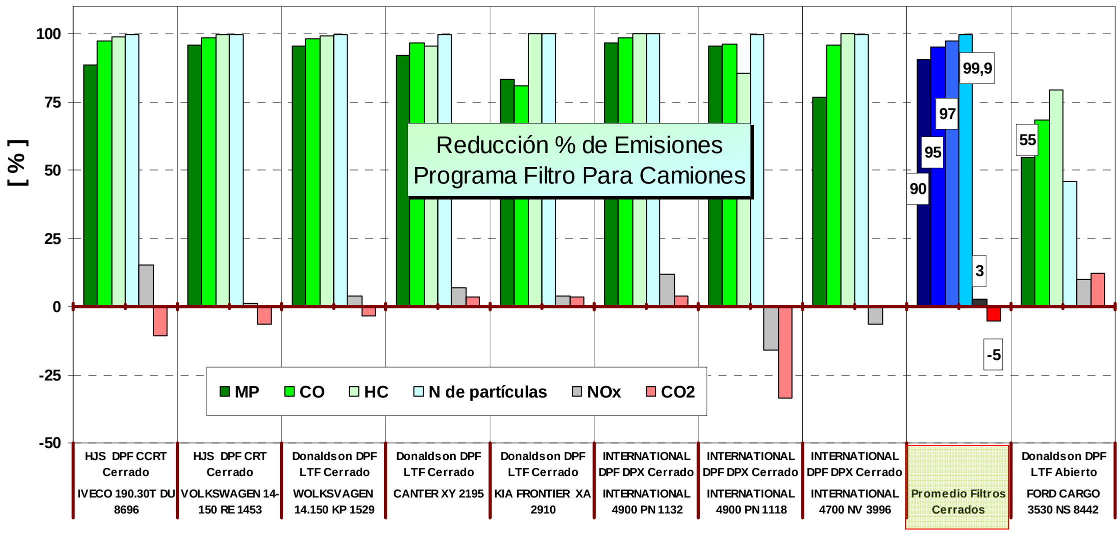

Figure 22: Percentage emission reduction

It may be seen that closed filters reduce PM in 90% in average for this technology. In the case of open filters, the only filter used achieved a 55%-reduction.

It may be seen that CO and HC emissions are reduced in 95% and 97% respectively, being higher in average to the 90% obtained for particulate material.

Higher reductions are seen in the amount of particles. In average, these post-treatment systems reduce a 99.9%, which is common in bibliographic references.

NOx emissions (5th grey bar), for closed filters, fall in 6 closed filters and increase in 2 filters. In average, emissions fall 3 %.

In average, CO2 emissions increase 5% (red bar). However it is considered that there is a bias in these values, due to the different environmental, maintenance and mechanical conditions of trucks, because it was necessary to use measures from different measuring rounds. This situation was explained in section 8.2.

9.- Conclusions and Comments

Closed particle filters with continuous regeneration (CRT, CCRT, LTF, DPX), tested in the program, in high and medium temperature trucks, showed high efficiency in reducing CO (95%), HC (97%), PM mass (90%) and ultrafine particles (99,9%). In the case of engines operating at low temperatures, there are closed systems (internationally certified), that could not be tested due to the lack of EPA or CARB certification.

In the case of engines operating at low temperatures open filters were used, which showed less efficiency in reducing CO (68%), HC (80%), PM mass (55%) and ultrafine particles (46%). Additionally, due to their operating principle, open filters do not guarantee steady efficiency during their real operation.

The available contra-pressure data showed an appropriate operation of closed systems, and when contra-pressure values increased the reference value used (200 mbar), these complied with the values accepted by the engine manufacturer or were similar to the values with the original system.

10.- Recommendations

Due to the different technical and operational conditions of the truck fleet, and to the local and the fleet's operational features, it is necessary to have a wide range of solutions certified at local and international level.

In order to certify these systems, it is necessary to develop *ad-hoc* regulations that consider the peculiarities of this segment (operation cycles, types of trucks, etc.). Taking into consideration the particular purposes of the information gathered in this program, it is recommended in general not to use it as part of any certification process.

Depending on the technical and operational features of trucks being retrofitted, certified solutions will be of different sophistication and costs. So it is not recommended to implement similar demands for all trucks, but to use incentives as a way of implementation.

Among the regulation to be created, it will be necessary to standardize the format of the information register or dataloging, because the registry systems provided by the post-treatment systems manufacturers not always have enough information.

Annex 1

Features of diesel oil used in trials.

Certificate 3401632 Haltermann Products Page 1

Date: 09.11.2007 Certificate of Analysis

File copy
DEXIMA SA Fax: COA ARCHIVE
LOTA 2257
PROVIDENCIA SA $$$0687127 CHILE

Cust P.O.: 77176 Dlvy Note: 20334248 30
Cust Ref: Order No.: 51053596

Material: Diesel Test Fuel VD 10-03-06
172 KG LINED STEEL DRUM GMID: 240323
Cust Mtl:
Batch: VD18513A52
Orig. Batch:6
Analyzed: 29.05.2007

Dlvy Qty:L 206,0
Vehicle: WL-Z 180

Ship from: Haltermann Products Werk Hamburg 02 Germany
Dow Olefinverbund GmbH, Schlengendeich 17, 21107 Hamburg
ISO 9001 Certified

Feature	Units	Results VD18513A52	Limits Minimum	Limits Maximum	Method
Cetane Number tested by subcontractor	-	54,0	52,0	54,0	ISO 5165
Cetane Index	-	57,8	50,0	----	EN ISO 4264
Density @ 15degC	kg/m3	835,1	833,0	837,0	ISO 12185
Distillation IBP	degC	227,6	----	----	ISO 3405
Dist. 10% v/v	degC	248,6	----	----	ISO 3405
Dist. 50% v/v	degC	275,4	245,0	280,0	ISO 3405
Dist. 90% v/v	degC	325,4	----	----	ISO 3405
Dist. 95% v/v	degC	346,1	340,0	350,0	ISO 3405
Dist. 250degC	% vol	11,5	----	----	ISO 3405
Dist. 350degC	% vol	95,7	----	----	ISO 3405
Distillation FBP	degC	358,1	----	370,0	ISO 3405
Flash Point	degC	101	55	----	ISO 2719
Cloud Point	degC	-16	----	-5	ISO 3015
CFPP	degC	-17	----	-15	EN 116
Viscosity @ 40degC	mm2/s	3,362	2,500	3,500	ISO 3104
Sulfur	mg/kg	2	----	10	EN ISO 20846
Corrosion - Copper max. 1		1A			ISO 2160
Carbon Residue 10% Dist. Residue	% wt	< 0,01	----	0,20	EN ISO 10370
Ash Content tested by subcontractor	% wt	< 0,001	----	0,010	ISO 6245
Water	% wt	0,0024	----	0,0200	ISO 12937

Certificate 3401632 Haltermann Products Page 2

Date: 09.11.2007 Certificate of Analysis

Cust P.O.: 77176 Dlvy Note: 20334248 30
Cust Ref: Order No.: 51053596

Material: Diesel Test Fuel VD 10-03-06
172 KG LINED STEEL DRUM GMID: 240323
Cust Mtl:
Batch: VD18513A52
Orig. Batch:6
Analyzed: 29.05.2007

Feature	Units	Results VD18513A52	Limits Minimum	Maximum	Method
Strong Acid Number	mg KOH/g	< 0,01	----	0,20	ASTM D974
Oxidation Stability	mg per 100mL	< 0,1	----	2,5	ISO 12205
tested by subcontractor					
HFRR (wsd 1,4)	micron	264	----	400	ISO 12156-1
Aromatics, Poly (2+	% vol	1,6	----	2,0	EN 12916

The certificate is electronically generated and valid without signature.

Laboratory is accredited acc. DIN EN ISO / IEC 17025, DAR DAC-PL-416-05-40
Christine Behrens, Phone ++49-40 75104-136

For inquiries please contact Customer Service or local sales

Haltermann Products - Werk Hamburg
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Schlengendeich 17 · 21107 Hamburg