Particle Number Measurements of a CNG Euro VI Bus Operating in the Bogota’s Public Transport System

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1. Introduction

- Bogota D.C. is the Capital of Colombia
- Bogota´s Population is 8 Million Inhabitants
- Bogota D.C. is located at 2650 masl.
- Bogota D.C. is the third largest city in Latin America.

**BOGOTA’s OBJECTIVES AND GOALS**

- Reduce \( \text{PM}_{10} \) by 10% and implementing the equipment for monitoring \( \text{PM}_{2.5} \) in the city
- Reduce CO, NOx, THC and PM of public transport by 10%.
- Reduce the causes of cardio-respiratory diseases

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**10 Year Plan of Air Quality Improvement In Bogota**

- Air Quality Monitoring
- Control to Mobil and Industrial Sources of emissions and Control to Automotive Diagnostics Centers
- Design an Early Warning System
1. Introduction

1. PT: before 2001
   Fuel: More than 1.200 ppm [S]

2. PT+ BRT (2001-2014)
   Fuel: Less than 50 ppm [S] since 2010

3. SITP (Starting 2012 - 2014)

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**Stage of the Public Transport**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Vehicles/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008</td>
</tr>
<tr>
<td>SITP</td>
<td>1.070</td>
</tr>
<tr>
<td>Stage I</td>
<td></td>
</tr>
<tr>
<td>Stage II</td>
<td></td>
</tr>
<tr>
<td>Stage III</td>
<td></td>
</tr>
<tr>
<td>Zonal</td>
<td></td>
</tr>
<tr>
<td>Traditional public transport</td>
<td>16.168</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>17.238</td>
</tr>
</tbody>
</table>

Source: Compile SCA, 2014 by information from Transmilenio S.A, 2013

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**Annual average PM$_{10}$ level (µg/m$^3$)**

Source: SDA, 2014

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Source: Transmilenio - 2013
1. Introduction

Objective:

The objective of this work was to obtain the fuel efficiency and the emission factors of a CNG Euro 6 bus running under local conditions and compare them to diesel engine technology.
### 2. BUS SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.V.W.</td>
<td>24600 kg</td>
</tr>
<tr>
<td>Curb Weight</td>
<td>15600 kg</td>
</tr>
<tr>
<td>Gross Axle 1 Weight</td>
<td>7100 kg</td>
</tr>
<tr>
<td>Gross Axle 2 Weight</td>
<td>11500 kg</td>
</tr>
<tr>
<td>Gross Axle 3 Weight</td>
<td>6000 kg</td>
</tr>
<tr>
<td>Displacement Volume</td>
<td>9.3 L</td>
</tr>
<tr>
<td>Cylinders</td>
<td>5</td>
</tr>
<tr>
<td>Emission Standard</td>
<td>Euro 6</td>
</tr>
<tr>
<td>Max Torque. (1100-1400 rpm)</td>
<td>1600 Nm</td>
</tr>
<tr>
<td>Max Power. (at 1900 rpm)</td>
<td>250 kW</td>
</tr>
<tr>
<td>Exhaust Aftertreatment System</td>
<td>3-Way Catalytic Converter</td>
</tr>
<tr>
<td>Transmission Reference</td>
<td>ZF 6 AP 1400 B (Ecolife)</td>
</tr>
<tr>
<td>Type</td>
<td>Automatic</td>
</tr>
<tr>
<td>Retarder</td>
<td>ZF - Automatic</td>
</tr>
</tbody>
</table>
3. EXPERIMENTAL SETUP

TWO TYPES OF TEST WERE CARRIED OUT:

1. ON-BOARD TESTING (AT G.V.W.)
2. CHASSIS DYNAMOMETER TESTING

TWO PARAMETERS WERE OBTAINED:
1. FUEL EFFICIENCY
2. EMISSION FACTORS
3. EXPERIMENTAL SETUP (ON-BOARD TESTING)

SEMTECH-G: gas emissions testing monitor measures emissions of CO, CO₂, total Hydrocarbons (THC), NO, and NO₂. The Semtech-G unit uses infrared absorption technology to measure CO and CO₂, ultraviolet absorption technology to measure NO and NO₂, and a flame ionization detector to measure total hydrocarbon emissions. The Semtech-G is also equipped with a GPS device to measure location and speed and it has been approved by US-EPA.

NanoMet³ Portable solid particle counter provides a complete data string with following values:

- particle number concentration (#/cm³)
- average size (nm), 10...700 nm (within mode diameter of 10...300 nm)
- calculated particle mass (mg/m³)
- LDSA–Lung Deposition Surface Area (μm²/cm³)

Dekati Elpi Plus and FPS4000. Real time number size distribution and concentration measurement.

6 nm – 10 μm, 14 size fractions
3. EXPERIMENTAL SETUP (ON-BOARD TESTING-ROUTE)

Length of the route: 73.9 km
Maximum Slope: 16%.
First Zone: Heavy Traffic (Average Speed: 12 km/h)
Third Zone: Moderate Traffic (Average Speed: 20 km/h)
Fourth Zone: Highway (Average Speed: 30 km/h)
The bus stops at all bus stops for 2 minutes.
There are 62 bus stops.
Data Collected: Total Distance: 798 km, Total Time: 42:15 [hh:mm]
3. EXPERIMENTAL SETUP (DYNO TESTING)

DYNO Specifications
Mustang Dinamometer
MD – 400 HD Eddy Current Chassis Dynamometer
775 horsepower (578 kW) @ 100 mph (161 km/h), cold condition
DYNO Procedure:

1. To run the vehicle in the fourth gear to get a relation 1:1 (engine/transmission)
2. To get the maximum power and torque increasing load.
3. To decrease the load up to 75, 50, 25 and 0%.
4. RESULTS (CNG-EURO VI BUS VS DIESEL EURO V AND IV BUSES)

On-road testing

*Source: Contract # 013-2012. Environmental Secretary of Bogota and National University of Colombia Articulated Buses for 160 and 260 passengers.

**Source: National University of Colombia, 2014
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**Source: National University of Colombia, 2014
4. RESULTS (CNG-EURO VI BUS VS DIESEL EURO IV BUSES)

The maximum particle number per cm³ for the CNG Euro 6 Bus was 950,000. The average was 56,000.

The maximum particle number per cm³ for the Diesel Euro IV Bus was 32 millón. The average was 13 millon.
### 4. RESULTS (CNG-EURO VI BUS VS DIESEL EURO V AND IV BUSES – ON ROAD TESTING)

<table>
<thead>
<tr>
<th>Bus</th>
<th>Fuel Consumption (gal/100 km)*</th>
<th>Actual Weight (kg)*</th>
<th>Gal/ton*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG-Euro 5-Cummins</td>
<td>16.09</td>
<td>17,300</td>
<td>0.930</td>
</tr>
<tr>
<td>Diesel Engine (Hybrid) - Youngman</td>
<td>10.32</td>
<td>16,780</td>
<td>0.615</td>
</tr>
<tr>
<td>Diesel Engine-Euro 4-Cummins</td>
<td>16.99</td>
<td>17,310</td>
<td>0.982</td>
</tr>
<tr>
<td>Diesel Engine – Euro 5 (Hybrid) Volvo</td>
<td>11.12</td>
<td>17,100</td>
<td>0.649</td>
</tr>
<tr>
<td>Diesel Engine – Euro 4 – Hino</td>
<td>14.52</td>
<td>16,020</td>
<td>0.906</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tested Vehicle</th>
<th>Fuel Consumption (gal/100 km)</th>
<th>Actual Weight (kg)</th>
<th>Gal/Ton**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scania K340</td>
<td>16.65</td>
<td>21720</td>
<td>0.767</td>
</tr>
</tbody>
</table>

*Source: Contract # 013-2012. Environmental Secretary of Bogota and National University of Colombia

**Source: National University of Colombia, 2014
4. Results (CNG-EURO VI BUS VS DIESEL EURO II, III, AND IV BUSES – DYNO TESTING)

<table>
<thead>
<tr>
<th>Plate</th>
<th>Id.</th>
<th>Brand</th>
<th>Model</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEF604</td>
<td>B115</td>
<td>Volvo</td>
<td>DH12C (Euro III)</td>
<td>1.83E+07</td>
<td>3.20E+07</td>
<td>4.02E+07</td>
<td>6.41E+07</td>
</tr>
<tr>
<td>SHN775</td>
<td>T086</td>
<td>Volvo</td>
<td>DH10A (Euro II)</td>
<td>2.55E+06</td>
<td>5.23E+06</td>
<td>4.23E+06</td>
<td>7.51E+06</td>
</tr>
<tr>
<td>VEE166</td>
<td>S157</td>
<td>Scania</td>
<td>DC9 21310 (Euro III)</td>
<td>4.70E+06</td>
<td>4.21E+07</td>
<td>4.51E+07</td>
<td>5.87E+06</td>
</tr>
<tr>
<td>WCR421</td>
<td>--</td>
<td>MB</td>
<td>Atego 1006 Euro IV</td>
<td>2.32E+06</td>
<td>3.57E+06</td>
<td>5.36E+06</td>
<td>2.80E+06</td>
</tr>
<tr>
<td>SIE057</td>
<td>U130</td>
<td>MB</td>
<td>OM 449 LA (Euro II)</td>
<td>1.01E+06</td>
<td>4.54E+06</td>
<td>3.23E+06</td>
<td>16.01E+06</td>
</tr>
<tr>
<td>VHM490</td>
<td>M028</td>
<td>VOLVO</td>
<td>DH10A (Euro II)</td>
<td>2.35E+06</td>
<td>4.22E+06</td>
<td>3.91E+06</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Contract # 015-2013. Environmental Secretary of Bogota and National University of Colombia

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Número de Partículas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scania K340 (Euro VI)</td>
<td>0%: 1.8E+04, 25%: 2.2E+04, 50%: 1.7E+04</td>
</tr>
</tbody>
</table>

Source: National University of Colombia, 2014
5. CONCLUSIONS

• Fuel Efficiency of the CNG Euro 6 Scania bus is 0.76 equivalent diesel gallons per ton. Fuel Efficiency of Diesel vehicles Euro IV and V is roughly 0.9 gallons per ton (18% higher compared to Euro 6 Bus). A Hybrid Vehicle 0.64 gallons per ton (14% lower compared to Euro 6 Bus)

• Total Hydrocarbons, Carbon Monoxide, Nitric Oxides, and Particle Matter are extremely lower for the CNG Euro 6 Bus compared to Diesel Euro IV and V Buses.

• Particle Number Concentration of CNG Euro 6 bus was extremely lower compared to Diesel Euro II, III, IV and V buses. Euro 6 technology emits in the order of $10^4$ particles per cubic centimeter and Euro 2, 3, 4, and 5 emit in the order to $10^6$ particles per cubic centimeters.
6. ACKNOWLEDGMENTS

We thank to:

• Scania staff.
• Gas Natural S.A. – ESP (Natural Gas provider)
• Environmental Secretary of Bogota.
• Transmilenio S.A. Staff
7. QUESTIONS