Cairo Air Improvement Project

Compressed Natural Gas Component

Compressed Natural Gas versus Diesel, Results of Vehicle Testing at Misr Lab

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Tables, Figure, and Example

Acronyms and Abbreviations

CAIP	Cairo Air Improvement Project
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRM	Chain-ratio method
CTA	Cairo Transit Authority
CVS	Constant volume sampling system
EEAA	Egyptian Environmental Affairs Agency
GCBC	Greater Cairo Bus Company
GOE	Government of Egypt
HC	Hydrocarbons
IMTB	Inspection and maintenance of diesel transit buses
MOP	Ministry of Petroleum
NOx	Nitrogen Oxides
PM	Particular Matter
USAID	United States Agency for International Development

1. Introduction

The Cairo Air Improvement Project (CAIP) is funded by the United States Agency for International Development (USAID) and implemented in partnership with the Egyptian Environmental Affairs Agency (EEAA) and the Ministry of Petroleum (MOP). Its goal is to develop and implement measures to reduce air pollutants that have the most serious impact on human health in Greater Cairo. The prime contractor, Chemonics International, provided the technical expertise, project management, training, and equipment procurement in support of the GOE in its environmental objectives.

The Government of Egypt (GOE) and USAID have been working together to reduce harmful emissions from diesel-fueled buses, especially particulate matter (PM), through the introduction of a compressed natural gas (CNG)-fueled Pilot Bus Fleet program.

This report compares PM emissions produced by CNG and diesel-fueled buses and explores the impact of a program implemented for inspection and maintenance of diesel transit buses (IMTB).

2. Vehicle Testing Facility

The principal motivations for the introduction of compressed natural gas (CNG) buses were to reduce emissions of PM and other toxic tailpipe emissions, and to make use of Egypt's abundant natural gas. Based on emissions certification data, a reduction in carbon monoxide (CO) and nitrogen oxides (NOx) emissions were also anticipated.

A state-of-the-art heavy-duty chassis dynamometer emission test facility was constructed and equipped at the Misr Petroleum Company Research Center in Cairo. The lab was equipped with a chassis dynamometer, constant volume sampling system (CVS), full size dilution tunnel, a bench analyzer, and data acquisition and control systems. The lab is used to assess and quantify the actual air quality impacts of the CNG bus program.

During 2003, a series of emission measurements on diesel and CNG buses were conducted at this facility.

In addition to quantifying the emissions differences between the CNG and diesel buses, these measurements were designed to yield information on emission factors for heavy-duty diesel buses, and on the effectiveness of the IMTB program.

3. Bus Emission Tests and Data Analysis

The diesel and CNG buses were tested using two common emissions laboratory testing cycles, the "CBD 2" and the "Braunschweig Bus" driving cycle. Vehicle emissions vary according to the driving cycle. The "CBD 2" cycle is frequently used for chassis dynamometer emission tests in the U.S., and the Braunschweig Bus cycle is frequently used in Europe. The emissions testing equipment shows the relationship between various types of emissions, torque, and speed during the test cycles.

The current Cairo city bus fleet is comprised of a mix of vehicles up to 20 years old. Since the CNG buses being introduced were new, comparisons were made to newer diesel buses. The comparison diesel buses were Nasr model 966 buses equipped with turbocharged, water-cooled IVECO engines designed to meet Euro 2 emission levels.

Samples of buses were recruited from the two bus companies, Cairo Transit Authority (CTA) and Greater Cairo Bus Company (GCBC), and tested at the Misr Lab facility. The average emission results for the CBD2 cycle are compared in table 1 while those for the Braunschweig cycle are compared in table 2.

Table 1 Emissions from Diesel and CNG Buses in the CBD 2 Test Cycle

Pollutant / Bus Type	CO (gm/km)	CO_2 (gm/km)	NOx (gm/km)	HHC (gm/km)	PM (gm/km)	Fuel Economy (km/l)
Diesel Buses (Before Repair)	8.210	1187.736	9.425	3.874	1.0873	2.01
Diesel Buses (After Repair)	4.472	1153.651	7.574	2.145	0.5056	2.08
CNG Buses	1.653	1411.314	12.068	25.552	0.0590	1.24

Table 2 **Emissions from Diesel and CNG Buses in the Braunschweig Bus Test Cycle**

Pollutant / Bus Type	CO (gm/km)	CO_2 (gm/km)	NOx (gm/km)	HHC (gm/km)	PM (gm/km)	Fuel Economy (km/l)
Diesel Buses (Before Repair)	8.643	1250.062	9.757	2.845	1.3007	1.92
Diesel Buses (After Repair)	4.541	1201.509	6.512	1.247	0.5672	2.01
CNG Buses	2.705	1299.147	10.748	27.582	0.0797	1.19

Many of the diesel buses were tested both before and after smoke-related repairs as part of the IMTB program. In this program, the smoke opacities were measured and checked against a baseline of 20 percent permissible opacity.

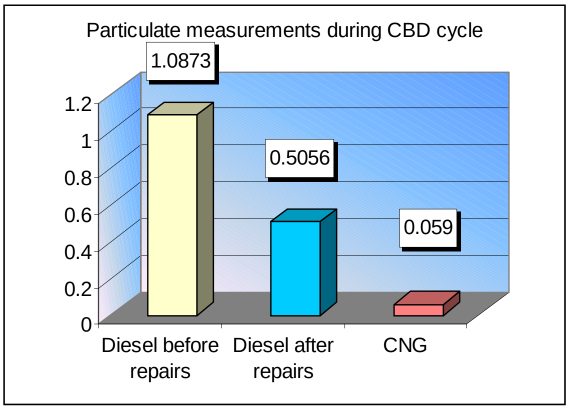
Emissions data were calculated, compared, and recorded for CNG and diesel buses before and after IMTB repairs for both the CBD and Brawnschweig testing cycles. Using PM data from tables 1 and 2, reduction in PM is shown in table 3 and figure 1.

Table 3 **PM Reduction with CNG vs. Diesel**

CBD Cycle – CNG vs. Diesel		Brawnschweig Cycle – CNG vs. Diesel	
Before Repair	After Repair	Before Repair	After Repair
94.57 %	88.33 %	93.87 %	88.05 %

Figure 1 **Reductions in Particulate Matter following IMTB Repairs**

Testing using the CBD Cycle



Testing using the Braunschweig Cycle

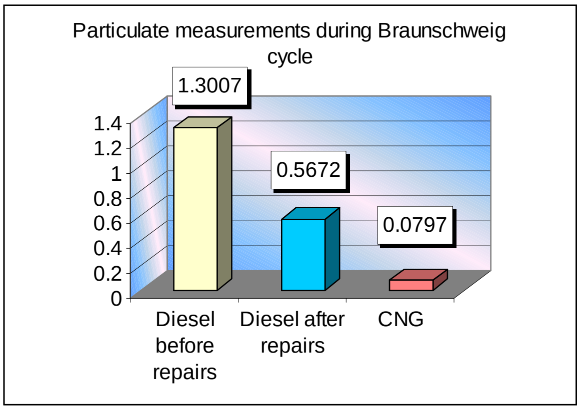


Table 4 shows the average PM reduction due to the IMTB Program.

Table 4 Average PM Reduction Due to the IMTB Program

PM gm/km – CBD Cycle		PM gm/km – Braunschweig Cycle	
Before Repair	After Repair	Before Repair	After Repair
1.0873	0.5056	1.3007	0.5672
0.5817		0.7335	
0.6576 gm/km			

Average reduction in PM was 91.21 percent.

Based on their certification results, the CNG bus engines were expected to produce a significant reduction in NOx emissions as well as PM. As the tables show, however, the measured NOx emissions from the CNG buses tested were actually higher than the diesels. The reasons for this unexpected result are unclear at this time, but are likely related to differences between the Federal Test Procedure used for emissions certification and the on-road driving cycles used in this study. Some recent studies in the South Coast Air Quality Management District of California have also shown higher-than-expected NOx emissions from heavy-duty CNG vehicles, including buses, and the reasons for this are under investigation.

Lean-burn CNG engines are known to exhibit relatively high emissions of total hydrocarbons compared with diesels, and this pattern is borne out by the data in tables 1 and 2.

Carbon monoxide (CO) emissions from both diesel and CNG buses are generally very low compared with those from uncontrolled gasoline vehicles. As the data shows, the CNG buses exhibited lower CO emissions than diesel.

PM production over 10 million kilometers is calculated in example 1.

Example 1 Calculation of the Reduction in Particulate Matter (PM) for CNG vs. Diesel

Data shown in tables 1 and 2 indicate the average of PM calculated for the CNG and diesel buses testing data on the CBD and Braun Cycles as follows:

- CBD cycle average

Calculation of the Reduction in PM for Diesel Due to IMTB Program

The Inspection and Maintenance for Transit Buses (IMTB) program was implemented during the CNG vs. Diesel testing program. The objective was to quantify the PM reduction because of the IMTB program.

As indicated in tables 1 and 2, the average PM values before and after repair for the CBD and Braunschweig cycles were calculated and the difference is quantified as shown in table 4.

- Reduction in PM per bus in 100,000 km per year = **65.760 kg/year**
- Projected annual reduction in PM for Greater Cairo Transit Diesel Buses (5000 buses) = **328.8 tons/year**