Cairo Air Improvement Project

Vehicle Emissions Testing Component

IMTB Program Summary Report

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Acronyms and Abbreviations

CAIP	Cairo Air Improvement Project
EEAA	Egyptian Environmental Affairs Agency
GOE	Government of Egypt
IMTB	Inspection/Maintenance for Transit Buses
MOSEA	Ministry of State for Environmental Affairs
OEM	Original equipment manufacturer
SAE	Society of Automotive Engineering
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) of the Ministry of State for Environmental Affairs (MOSEA), the Ministry of Petroleum (MOP), and the three Greater Cairo governorates. The project's goal is to initiate and implement measures to reduce air pollutants such as particulate matter (PM) that have the most serious impacts on human health in Greater Cairo.

There are more than 4,000 public transit buses in service in Greater Cairo. Almost all of them are powered by diesel engines and are major contributors to PM emissions.

A plan is in effect to convert diesel-powered vehicles to compressed natural gas (CNG) with special attention being given to transit buses. However, such a plan requires significant funding and time to implement.

Accordingly, the EEAA and USAID decided to execute an Inspection/Maintenance (I/M) program with the two bus companies operating in Greater Cairo, Cairo Transit Authority (CTA) and the Greater Cairo Bus Company (GCBC). This program is intended to significantly reduce PM and other related emissions from diesel powered transit buses.

This report describes the implementation of the Inspection/Maintenance for Transit Buses (IMTB) program at the bus companies in Cairo and presents the findings with recommendations for future activities.

2. Program Design

Phase I Measurements

The program was divided into two phases. During Phase I, a comprehensive assessment of the smoke opacity for CTA and GCBC transit buses was made and the worst polluters identified. Phase II focused on the diagnosis and repair of the diesel bus fuel systems as the most likely contributor to high emissions of PM.

Opacity meters were used as a means to identify which buses produced the most pollution. Opacity measurement procedures adhered to the Society of Automotive Engineering (SAE) standards for exhaust opacity measurement.

During Phase I, the smoke opacity of 3,399 buses was measured at 22 garages—18 at CTA and 4 at GCBC. The results are summarized in table 1.

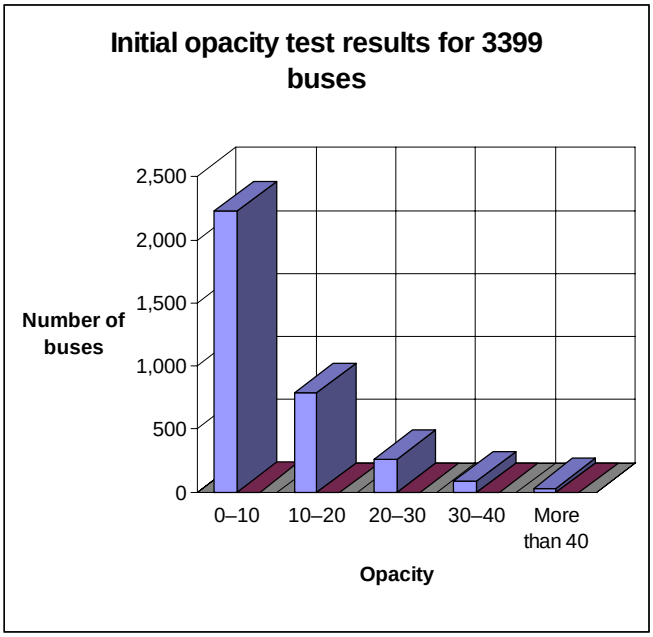
Table 1 Opacity from In-use Transit Buses

Opacity (%)	Number of Buses	Percentage of Buses
0–10	2,229	65%
10–20	791	23%
20–30	260	8%
30–40	88	3%
More than 40	31	1%
Total	3,399	100%

Figure 1 shows these results in graphic form.

The maintenance program was designed based on these findings. The remainder of this report describes the approach and results of the maintenance program.

Figure 1 Initial Opacity Test Results for 3,399 Buses



Phase II Approach

The overall design for the maintenance program included selecting buses to enter the program. As part of the IMTB program, the maintenance procedures that exist at the bus companies were reviewed. As a general practice, each bus is scheduled for a bi-weekly preventive maintenance, which includes engine oil and filter change, air filter cleaning or replacement, a complete vehicle inspection and repair of any malfunctioning systems. The bus companies agreed to enforce a maximum 20 percent opacity limit as an initial target for their buses as part of their routine maintenance programs.

Accordingly, a smoke-opacity measurement task was added to the preventive maintenance process to assess opacity in general and to identify buses with opacity readings above 20 percent as part of the criteria used to determine the "road worthiness" of the buses.

Buses with opacity levels above 20 percent were then subjected to diagnostics, which included testing each component in the fuel system. Once the problem was identified, it was repaired and the bus re-tested for opacity to ensure compliance after repair.

Diagnostic and Repair Equipment

CAIP conducted an international market survey and tendering process to determine the appropriate equipment for testing and tune-up. Based on this, CAIP purchased and equipped the garages with:

- 30 Wager model 6500 Opacity Meters
- SUN SMP 2000 Engine Analyzer to measure the performance of injectors, lines, and fuel pumps
- Bosch EPS 100 Injector Tester to check injectors for leaks, set injection pattern and pressure to those recommended by the OEM, along with EPS 738 Vacuum Device for collecting diesel mist during the test process
- Hartridge PM 1008 Test Bench, to test pumps and assist in restoring overhauled pumps to original specifications.

All equipment was delivered to the bus company garages, overhaul and repair workshops, and training centers. The bus companies allocated dedicated space for the IMTB equipment in each garage and workshop.

The bus company construction teams upgraded these locations and installed:

- Suitable lighting
- Flooring improvements
- Ventilation fans
- Air compressors
- Water
- Diesel fuel plumbing and test benches as required.

Training and Special Tools

CAIP assessed training needs as well as specialty tools requirements for both bus companies. Since all types of buses utilize Bosch fuel pumps, CAIP used the local Bosch dealer to provide necessary tools and training. Training covered pump dismantling and assembly, component inspection and replacement, proper cleaning techniques, utilization of special tools, and pump testing and set-up to original equipment manufacturer (OEM) specifications. Special tools for pump repair and calibration were procured by CAIP/USAID and delivered to each bus company. In-depth, hands-on training was provided to the technical crews.

During the IMTB program, the bus companies expanded their operations and added four new garages. To meet the needs of the bus companies, CAIP provided four additional smoke meters, engine analyzers, injector testers, air compressors, a test bench, and special tools for the maintenance, diagnosis, and repair of fuel injection pumps.

3. Sustainability

Sustainability was considered a key issue during the IMTB program design and several issues were particularly emphasized:

Database Monitoring

CAIP developed a basic database program for bus company personnel to track IMTB activities. The database allows each garage the ability to monitor the effectiveness of repairs as related to opacity and assists management in making decisions concerning the quality of locally purchased spare parts used in the fuel system or the needs for new engines.

Administration

The management of each bus company sent out an administrative notice allowing each garage manager to allocate funds to purchase consumables required for proper maintenance and pay for minor equipment repairs. The bus companies also allocated funds for equipment replacement, major equipment repairs, and new purchases. Accordingly, the IMTB equipment has been incorporated into the standard list of equipment purchases that the bus companies use when they build a new garage or upgrade an existing one.

Training of Trainers

The IMTB program included a comprehensive training program. More than 150 engineers and technicians were trained to operate and maintain each type of equipment.

The training center received the same equipment that was installed in the garages. Trainers received in-depth technical training on the equipment and on training methods.

The CTA training center integrated IMTB equipment operation as part of its curriculum. The center now has the training aids and capability needed to conduct IMTB equipment operational courses for all levels of technicians and engineers. The center has provided a few training courses under the supervision of the equipment suppliers.

Each bus company has a team of inspectors who visit garages and workshops to monitor operations and procedures. The technical members of these teams received training on the operation and maintenance of the IMTB equipment. The scope of work of the inspectors includes checking IMTB equipment status and monitoring the IMTB program operation.

4. Data Findings and Analysis

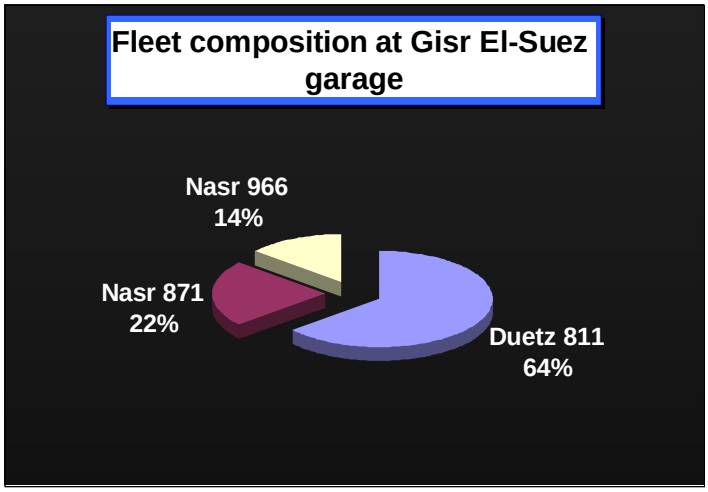
The data analyzed in this report was collected from CTA's largest garage, Gisr el-Suez Garage, over a period of 4 months. During this period, emissions opacity was measured as part of the routine bi-weekly scheduled preventative maintenance for buses.

Gisr el-Suez garage was selected because its fleet is representative of the entire fleet for both bus companies. Consequently, the data collected were expected to reflect the status of the entire bus fleet. Specifically:

- Gisr el-Suez garage operates the largest number of buses among all transit garages.
- The buses includes all diesel-bus models available at both bus companies:
  - Duetz 811
  - Nasr 871
  - Nasr 966
- Gisr el-Suez garage was among the first garages where equipment was installed and consequently among the first to initiate the program
- Its fleet combines buses with new, old, and rebuilt engines.

A total of 264 full-size buses were tested at Gisr el-Suez garage. The distribution of the three bus types is shown in figure 2:

Figure 2 Vehicles Tested by Bus Type



Opacity Profile

Figure 3 Opacity Before and After Repairs

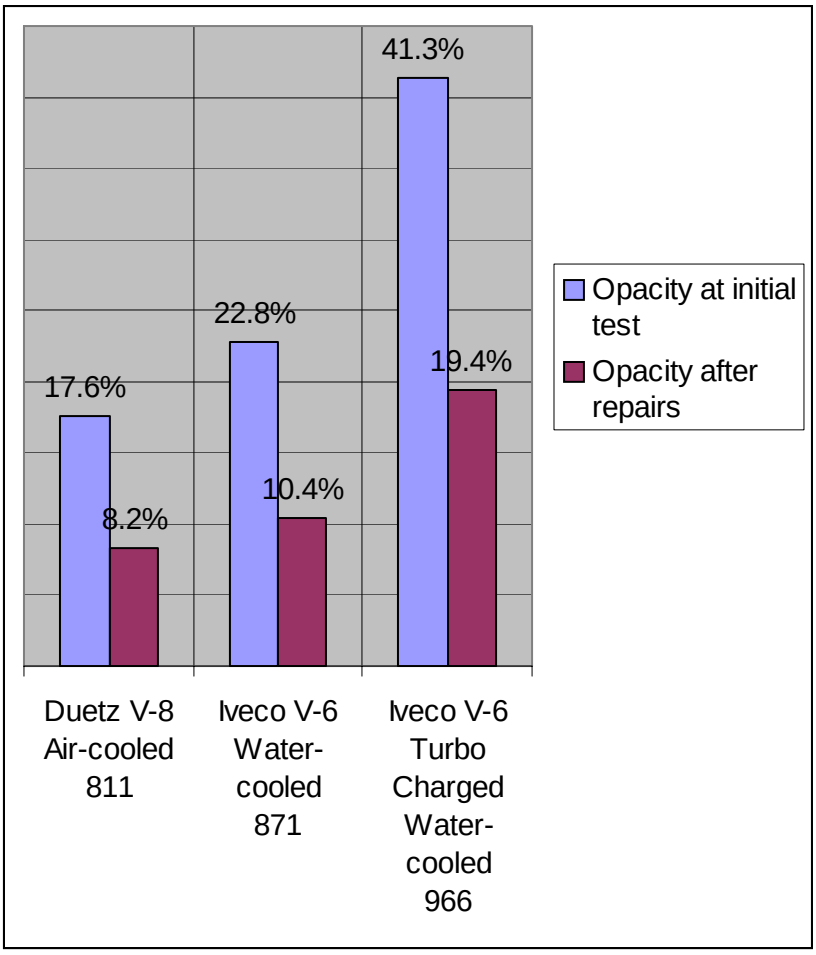


Figure 3 presents the opacity profile by fleet type for the 264 buses tested at Gisr el-Suez garage. At the beginning of the study period, each bus was tested to establish the existing exhaust opacity. Duetz 811 had an initial average opacity of 17.6 percent while Nasr 871 had 22.8 percent and Nasr 966 had 41.3 percent.

Opacity measurements were repeated during the subsequent routine maintenance program, and buses that had opacity readings in excess of 20 percent were diagnosed and repaired. All others were subjected to routine maintenance procedures only. Opacity measurements (the "after" measurements) were taken for each bus model after maintenance and/or repairs.

After maintenance and repair, the average opacity dropped to 8.2, 10.4, and 19.4 percent for models Duetz 811, Nasr 871, and Nasr 966 respectively. The opacity varied by fleet type due to the age of the various fleets and the use and condition of the engines.

The average opacity reduction for the Duetz 811 and Nasr 871 was 53 percent. The average opacity reduction for the Nasr 966 model was 54 percent . A "weighted average" reduction in opacity of 53.2 percent was realized for the fleet.

Because opacity measurements were incorporated into the routine maintenance procedures, all buses had repeated opacity measurements taken regardless of whether they met the baseline 20% opacity criterion that was originally established. It was discovered that the buses that had less than 20% opacity, when subjected to routine maintenance also achieved significant opacity reduction. As an example, in figure 3 (above), the Duetz 811 had an initial average opacity of 17.6 percent and therefore not all buses of this model would have qualified for specific diagnosis and repair.. The buses did however achieve a 53 % opacity reduction by undergoing routine, scheduled maintenance.

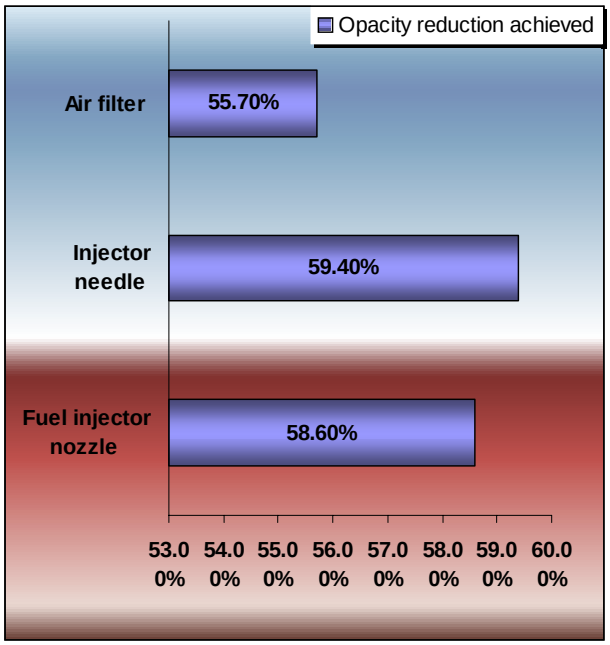
Tune-up Analysis

Opacity measurements were taken each time a bus had a preventive maintenance inspection. If the opacity exceeded 20 percent , the bus was diagnosed and repaired. The bus was also checked after repairs to ensure the opacity had been reduced to a maximum of 20 percent before being released into revenue service. The bus would be checked again at its next scheduled preventive maintenance inspection. If the opacity measurement were above 20 percent , the bus would undergo further repairs. Based on this process, a rate of failure was determined for each fleet type.

To maintain the 20 percent opacity limit, it was found that repeat repairs were required at the rate 40 percent for the Duetz 811, 42 percent for the Nasr 871 and 41 percent for the Nasr 966. Based on these rates of failure (percentage of opacity test failures during 4 months of routine inspections), buses would require a tune-up approximately every 9 months in order to maintain a 20 percent opacity limit.

Out of the 112 buses requiring repair as a result of bi-weekly checks during the 4 months, 13 needed fuel injector nozzle replacement. An opacity reduction of 58.6 percent was achieved after nozzle replacement and full injector cleaning for that group of buses. Fourteen buses required an injector needle replacement. An opacity reduction of 59.4 percent was achieved after replacing an injector needle. Six buses required air filter cleaning or replacement with an average opacity reduction of 55.7 percent being achieved. Figure 4 shows the reduction in emissions opacity achieved by repair type.

Figure 4 Opacity Reduction Achieved



One important note regarding the reductions in opacity gained from the various types of repairs: the required repairs for any vehicle are well known; however, the parts required and the opacity reduction realized will depend entirely on the condition of the vehicle. As a further clarification, the reductions in opacity occurred as a result of repairing and/or replacing certain fuel system components and are not indicative of opacity reductions that will be achieved any time similar repairs are done on another type of vehicle.

5. Conclusions

The IMTB program is a complementary program to the existing routine repair and maintenance procedures at the bus companies. The program produced a substantial decrease in opacity over the short period during which data for this report was gathered. More opacity reduction benefits could be expected from the program over time, especially if the bus companies strictly enforce the quality assurance/quality control procedures that have been developed and implemented.

As most fleet maintenance managers know, investing in proper maintenance extends equipment life and improves fuel efficiency. Although the IMTB program was not designed with cost analysis as a focus, the cost benefits realized from a proper preventive maintenance program are recognized in the transit industry. In the end, the effect of the IMTB program would be a pronounced decrease in the need for engine overhauls and a reduction in fuel consumption as well.

The data collected in this report is from one garage. Because this garage has a fleet profile similar to the company fleet, it is projected that the opacity profile and data analysis of the garage is similar to that of the entire fleet. The enforcement of a 20 percent opacity limit has resulted in an average opacity reduction of 53.2 percent from buses initially exceeding this limit.

Bus companies should continue enforcing the IMTB program. Inspectors should conduct random testing at garages to ensure compliance with set limits and proper maintenance procedures. Enforcing the IMTB program also reinforces the newly acquired skills of the garage staff.

Bus companies can further utilize the equipment for the IMTB program to:

- Evaluate the quality of fuel system spare parts such as nozzles, and consider the findings during procurement evaluation
- Purchase individual spare parts for repairing injectors, such as springs, in addition to buying complete nozzles kits
- Study the effect of engine oil and filter changes frequency on opacity.

The bus companies could utilize the mass emissions measurement capabilities at Misr Lab to enhance this inspection and maintenance program. Misr Lab could run tests on buses before and after tune up. Tests could include PM, hydrocarbons, carbon

monoxide, and fuel consumption. The results of such tests can provide CTA and GCBC with more detailed and in-depth information about exhaust opacity, fuel consumption, engine oil types, and frequency of oil changes.

Incorporating opacity limits into the existing routine maintenance procedures has been a resounding success. The reduction in visible tailpipe emissions from public transit buses is obvious to any observer of traffic in the Greater Cairo area.