THE WORLD BANK

ESMAP

Urban Air Pollution

South Asia Urban Air Quality Management Briefing Note No. 10

Tackling Diesel Emissions from In-use Vehicles

Black smoke belching out of diesel buses and trucks has come to shape the public image of air pollution in many cities. What causes diesel vehicles to be so visibly polluting? Is controlling smoke the best way to address the health impact of diesel emissions? What can we learn from other countries' experience in identifying and repairing gross diesel polluters?

Worldwide, diesel vehicles are attracting more and more attention from policymakers. As concerns about greenhouse emissions from the transport sector grow, diesel is increasingly seen as a more efficient fuel alternative to gasoline. As a result, future worldwide demand growth for motor fuels is anticipated to focus on diesel, while demand growth for gasoline is likely to stagnate.

At the same time, diesel exhaust contains harmful gases, liquid droplets and solid particles. The majority of the particles are sub-micron in size, the size fraction considered most damaging to health, and contain carbon, organics, sulfates and traces of metallic components. Emerging evidence about the negative health effects of diesel emissions has raised increasing concern, especially as chronic inhalation exposure to diesel particles has been shown to pose not only a chronic respiratory hazard, but also a potential cancer hazard.

In South Asia, as in the rest of the world, emissions from in-use vehicles are especially problematic. This note describes the major causes of high emissions, means of mitigating the emissions, and approaches to improving the monitoring of both new and old diesel vehicles.

Causes of High Smoke Emissions

A recent study investigating causes of high smoke emissions from diesel vehicles in India [1] identified overloading and lack of preventive maintenance as two major causes, with the problem being exacerbated by inferior quality engine replacement parts and fuel adulteration (for fuel adulteration, see Briefing Note No. 7 [2]).

Overloading

Trucks worldwide have traditionally been loaded to the maximum possible—often well beyond the designed load of the vehicle—in order to increase revenue and profit. In India, the principal long distance goods carrier is a two-axle, 9-ton truck. These are often overloaded to 14–20 tons on outward-bound trips although they operate closer to specifications on the return segment. When trucks are routinely overloaded, the following effects are typically seen:

- The engine has to work harder to produce the power needed, resulting in more smoke, especially among older engines.
- Working the vehicle harder tends to increase wear (affecting the engine, tires, brakes, and other vehicle components), but the vehicle is often not serviced any more frequently. As a result, the engine usually operates in a worse state of repair than a vehicle that is not routinely overloaded.
- Because the vehicle requires more power when overloaded, there is a tendency to over-fuel the engine. Over-fueling in turn is a significant cause of higher black smoke emissions.

In industrial countries, the more professional truck fleets have learnt that they are financially better off in the long run when they use newer trucks and operate within the vehicle specifications. This dramatically reduces their maintenance costs, and virtually eliminates vehicles breaking down on the road (a particularly high-cost problem for trucks carrying perishable cargo). The underlying conditions needed to promote this way of thinking, which can have a positive impact on both environment and safety, have yet to occur for most truckers in South Asia.

Lack of preventive maintenance

Many automotive repair garages in South Asia are under-equipped and in need of mechanic training. The prevalent culture of repairing vehicles when they break down rather than programming preventive maintenance is both the cause and effect of the lack of qualified technicians using good diagnostic and repair equipment. Rigorously enforcing emissions standards is the first step towards creating demand for upgrading and expanding service and repair facilities.

Mal-functioning and incorrect adjustment (through tampering or lack of regular vehicle service) of the engine's air system and fuel systems are important causes of high smoke emissions. Dirt, clogging, wear and incorrect pressure settings in diesel fuel injectors, together with inadequate repair and calibration of fuel injection pumps and turbochargers, are common causes of high visible exhaust smoke levels. Inadequate and dirty air filters and restrictive exhaust systems will increase smoke at high loads when the engine is operating at near full throttle or accelerating quickly. An engine in poor mechanical condition can also consume lubricating oil, thereby emitting higher levels of smoke and hydrocarbons. In terms of tampering, increasing the fuel delivery of the diesel fuel injection pump and resetting the engine's speed governor to a higher rpm (revolutions per minute) are two common practices, both with the potential to increase smoke emissions.

Inferior quality of spare parts

Throughout South Asia, there are different grades of spare parts, starting with genuine original equipment (OE) parts with guaranteed quality, followed by varying classes of less expensive parts with lower levels of quality. Most vehicle owners try, within their financial means, to use "closer to genuine" parts for critical assemblies such as engines and transmissions, and lower cost components for "non-critical" areas such as brakes and electrics.

The engine components that most affect emissions are probably fuel injection pumps, fuel injectors and turbochargers. Because of the high cost of these components, a significant fraction of these parts are repaired rather than replaced, using components from alternative sources, some with dubious quality.

Identifying Gross Polluters

Some of the problems outlined above can be better addressed if emission standards are more strongly enforced through an effective vehicle emissions inspection program. Ideally, diesel vehicles that emit disproportionately high levels of fine particulate matter should be identified and required to be repaired. Identifying those diesel vehicles that are high particulate emitters, however, is problematic, because the test procedures currently used in the emissions inspection test centers do not readily identify mass particulate emissions.

Smoke tests

The most common procedure for testing emissions from in-use diesel vehicles is the snap (also called free) acceleration test defined according to the Society of Automotive Engineers' SAE J1667 (in North America) or ECE R24 (in Europe) standards. The test specifies that, with the transmission in neutral, the throttle pedal should be pushed rapidly but not abruptly to its full-throttle position, accelerating the engine from low idle to its maximum governed speed. This is repeated several times and the average of the maximum exhaust gas opacity in each test is computed.

Reproducibility is poor when this test procedure is utilized by a large number of testers using different equipment, especially in an environment where financial incentives are offered to testers to pass smoking vehicles. Slight differences in the time taken to accelerate the engine from low idle to maximum governed speed can lead to very different exhaust opacity readings. Therefore, the rate of acceleration for each engine type needs to be more precisely defined. Each instantaneous reading should be corrected for gas temperature, pressure, humidity and altitude, as required in the SAE J1667 standard. As discussed in Briefing Note No. 9 [3], any dilution of the exhaust gases with clean air will lower smoke readings. This in turn means applying other controls to detect this practice. Furthermore, it is extremely difficult to get rpm readings from diesel engines, particularly the older ones, yet accurate rpm readings are essential to add to the controls as well. Finally, the ECE R24 procedure, but not SAE J1667, verifies that the engine cylinders' combustion chambers have reached their normal operating conditions by detecting decreasing opacity readings in consecutive tests and reports results only after these conditions have been stabilized.

As the above discussion shows, carefully defined test protocols need to be followed strictly to have acceptable reproducibility across different operators and instruments at different test centers. Otherwise, a conscientious vehicle fleet owner regularly checking emissions by conducting in-house smoke tests may find that properly maintained vehicles routinely fail in the mandatory emissions tests. This and the resulting driver harassment was in fact one of the complaints voiced in the assessment of the emissions program in India [1]. Further procedural improvements can be introduced to reduce the opposite kind of error, by which grossly emitting vehicles are allowed to pass the test.

Shortcomings with smoke tests

Even when prosperly administered, smoke test still have two distinct problems to be addressed. One set of concerns can be addressed in part by using a more reproducible (and more expensive) form of opacity testing, called a dynamometer test, which can also simulate real-world driving conditions much better than snap acceleration. The second problem cannot be, as it underscores the fundamental shortcoming of measuring smoke (see next section).

(1) The snap acceleration test is not representative of normal operating conditions. More specifically, it is easier to prepare a vehicle to pass a snap acceleration test than a test under load using a dynamometer, especially if a transient (as opposed to steady-state) loaded test is used. In Hong Kong, for example, the environment officials found that diesel vehicle owners temporarily adjusted the fuel injection pump, enabling high smokers to pass the snap acceleration smoke test. When the officials tried to close this loop-hole

by introducing the so-called lug-down dynamometer test (test conducted at full throttle, with the dynamometer load gradually increased to slow down the engine speed so that the engine is laboring, or "lugging"), they found that the pass rate fell dramatically from 90% to 15% [4].

Further, smoke measurements depend heavily on the drive cycle for a given vehicle-fuel combination. One study [5] shows that smoke opacity measurements using different drive cycles on a loaded dynamometer were poorly correlated with each other for light-duty vehicles. The two lowest correlation coefficients were –0.16 and 0.0, the highest 0.73. The correlation coefficients for heavy-duty vehicles were higher, with the lowest coefficient being 0.20 and the highest 0.92. This implies that the same vehicle may have quite low readings under one drive cycle and high ones on another, and yet there may not be a "typical" drive cycle for all vehicles.

(2) A smoke test procedure, however well carried out, cannot be used for controlling anything other than visible smoke. An important question is then whether visible smoke can act as a proxy for particulate matter, the pollutant with demonstrated health effects.

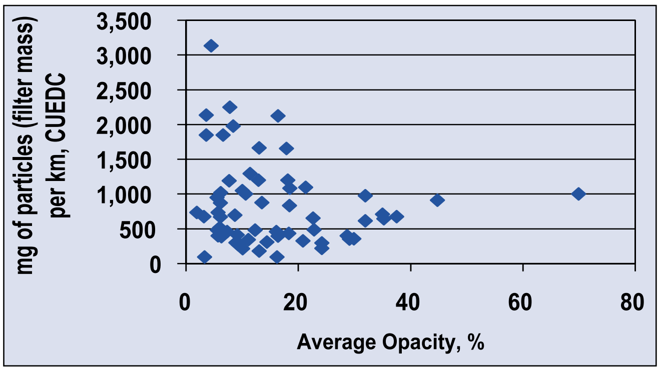
Correlation between smoke opacity and fine particulate emissions

The diesel engine pollutant of greatest health concern is fine and ultra-fine particles. If a diesel-vehicle testing program does not lead to the reduction of fine particulate emissions, then it shall have failed in its ultimate objective, the reduction of pollutants that damage the public's health. The question immediately arises, therefore, as to how closely correlated is "smoke" with fine particulate matter.

To answer this and other questions, the National Environment Protection Council (NEPC) of Australia commissioned eight projects to collect data on the diesel vehicle fleet and emissions characteristics with the objective of developing cost-effective emissions management measures [6].

Figure 1, taken from a project report by Peter Anyon and others [7], indicates a very poor correlation between visible smoke measured using snap acceleration and mass particulate emissions measured in a dynamometer test using a drive cycle for estimating "real-world" emissions from vehicles in urban areas. The cycle used, called the Composite Urban Emissions Drive Cycle (CUEDC), consists of four segments: congested, minor roads, arterial roads and highway/freeway driving. The figure illustrates that a number of high particulate emitters have quite low scores on smoke emissions registered during the free acceleration test, while some of the high "smokers" have relatively low particulate emissions compared to the true gross polluters. That is to say, snap acceleration smoke tests run the danger of misclassifying gross polluters as relatively clean and low polluters as high emitters.

Figure 1. Correlation between Average Smoke Opacity in Snap Acceleration and Mass Particulate Emissions in Loaded Transient Tests



The above report also compares the results of the so-called 10-second smoke test—used in enforcing Australia's national standard for smoke emissions—to smoke opacity and mass particulate emissions measured in transient dynamometer tests. In a test specifically carried out on an incline, 32% of those that were identified as smoky vehicles were also found to be high particulate emitters in the CUEDC, but 68% of smoky vehicles were found to be low particulate emitters. Overall, the on-road smoke checks classified a higher number of vehicles as high emitters than mass particulate measurements.

An unfortunate scenario, from the point of view of managing a vehicle inspection and maintenance program, would be one in which vehicle repair lowers particulate emissions but increases smoke. Such a case was indeed confirmed in the NEPC's diesel program whereby for two vehicle categories (1996-2000 diesel buses heavier than 5 tons and goods vehicles heavier between 12 and 15 tons for the first, and 1996-2000 goods vehicles heavier than 25 tons for the second), particulate emissions decreased by 38% and 14% on average after repair but opacity readings increased by 29% and 10%, respectively [8].

In light of the above, snap acceleration smoke tests cannot be viewed as a means of identifying high particulate emitters, but rather as diagnostic tests to identify malfunctioning and defects among older engine vehicles with mechanically controlled fuel systems. For this category of vehicles, these smoke tests may be especially helpful for identifying tampering to increase power by over-fueling. However, given the poor correlation between smoke and particulate emissions, and the poor correlation among the results of smoke tests on the same vehicle using different drive cycles, it would make sense to set relatively lenient standards to identify the most serious smoke emitters so as to minimize chances of false failures.

Snap acceleration smoke tests are not at all effective for modern, electronically controlled engines or turbo-charged engines with boost control. For these vehicle categories, an alternative test procedure has to be identified. Studies to date suggest that at a minimum dynamometer-based loaded tests are needed, but they are expensive to set up for heavy-duty diesel vehicles. The series of studies in Australia recommend a short dynamometer-based test with transient acceleration segments using a laser light scattering photometer to measure mass particulate emissions. However, this test is still at the pilot stage with no wide application.

Finally, it is important to view the limitations of smoke tests in broader perspective. Smoke is a public nuisance, and more importantly, smoke harms public health. High smoke emissions, even if particulate emissions prove to be relatively low, suggest that there is something wrong with the vehicle settings or parts. Given the technical problems associated with measuring particulate emissions in a garage setting, smoke tests will continue to play an important role in emissions testing programs for the foreseeable future.

Conclusions

Identifying gross diesel polluters is significantly more difficult than identifying gross gasoline polluters. One serious problem is the lack of a relatively inexpensive and quick method for measuring particulate emissions, the pollutant of most concern in South Asia. There is no simple road map, and a multi-prong strategy is needed.

- In order to encourage the development of adequately equipped and staffed service and repair facilities, more efforts should be directed at improving vehicle emissions inspection and enforcing standards.
- There is a need to raise public awareness and create market conditions that make over-loading commercially unattractive.
- There needs to be tighter control over the quality of spare parts.
- The most commonly used test for diesel vehicles—snap acceleration smoke test—can play a limited but useful role, provided that the test procedure is carefully defined to ensure repeatability and the test protocol is strictly enforced.
- The smoke standards for snap acceleration tests should be lenient or else there is a serious danger of having a high false-failure rate. The test should be seen primarily as a means of identifying the grossest of gross polluters among old technology engine vehicles.
- For modern engine vehicles as well as high annual mileage commercial vehicles, serious consideration should be given to adopting dynamometer-based tests. This will also enable setting tighter smoke standards, monitoring of nitric oxide, and meaningful measurements of CO and hydrocarbon emissions.
- Given the high costs of dynamometer testing facilities, especially for heavy-duty diesel vehicles, using visual smoke checks as a screening tool—whereby those judged to be visible smokers are sent to test centers with dynamometers—may help to reduce the overall cost of the diesel emissions inspection program. While visual checks are subjective and potentially more prone to corruption, using them as a screening tool so that those who conduct the checks cannot fine motorists may help to minimize corruption.

References

1. John Rogers. 2002. *Assessment of the Pollution Under Control Program in India and Recommendations for Improvement*, prepared for the World Bank, October. Available at <http://www.worldbank.org/sarurbanair>.
2. South Asia Urban Air Quality Management Briefing Note No. 7. 2002. "Catching Gasoline and Diesel Adulteration," July. Available at <http://www.worldbank.org/sarurbanair>.
3. South Asia Urban Air Quality Management Briefing Note No. 9. 2002. "Making Vehicle Emissions Inspection Effective—Learning from Experience in India", November. Available at <http://www.worldbank.org/sarurbanair>.
4. W.C. Mok. 2001. "The Experience of Hong Kong SAR, China, in Controlling Smoky Vehicles." Available at <http://www.worldbank.org/wbi/cleanair/caiasia/learningactivities/bangkok_documents/present11.ppt>.
5. National Environment Protection Council. 2001. *Proposed Diesel Vehicle Emissions National Environment Protection Measure Preparatory Work, In-Service Certification Correlation Studies*. Available at < http://www.ephc.gov.au/pdf/diesel/Correlation_Studies.pdf>.
6. Environment Protection and Heritage Council. *Diesel Vehicle Emissions Preparatory Projects*. Available at <http://www.ephc.gov.au/nepms/diesel/diesel_prepare.html>.
7. National Environment Protection Council. 2000. *Proposed Diesel Vehicle Emissions National Environment Protection Measure Preparatory Work, In-Service Emissions Performance – Phase 2: Vehicle Testing*. Available at <http://www.ephc.gov.au/pdf/diesel/diesel_project2_2.pdf>.
8. National Environment Protection Council. 2001. *Proposed Diesel Vehicle Emissions National Environment Protection Measure Preparatory Work, In-Service Emissions Testing – Pilot Study, Fault Identification and Effect of Maintenance*. Available at <http://www.ephc.gov.au/pdf/diesel/PilotStudy.pdf>.

This briefing note was prepared in November 2002 as part of the South Asia program on urban air quality management, funded in part by the joint UNDP/World Bank Energy Sector Management Assistance Program (ESMAP).
The objective of the program is to support the region-wide process of developing and adopting cost-effective and viable policies and efficient enforcement mechanisms to reverse the deteriorating trend in urban air.
A full set of briefs and other materials are available at <http://www.worldbank.org/sarurbanair>.

For further information, contact

Sameer Akbar (sakbar@worldbank.org) or Masami Kojima (mkojima@worldbank.org) about this program, and John Rogers (jrogers@trafalgar-mexico.com) about this note.