Two-Stroke Engines – Oxygenates Can Help Reduce Emissions

Air pollution caused by emissions from vehicle engines is a serious problem in metropolitan areas throughout the world – it is particularly severe in South Asia, where about half of all vehicles are two and three-wheel vehicles with two-stroke engines. As highlighted in Figure 1, this is a much larger percentage than for both Europe and the U.S.

![Figure 1: Global Automotive & 2-Stroke Markets](source: "Fuel Prices and Vehicle Taxation," GTZ 2001)

Table 1 demonstrates the extent of use for these types of vehicles. Because these vehicles are ubiquitous – the World Bank estimates between 75 to 100 million of them exist throughout South Asia – pollution caused by emissions from these engines is equivalent to as much as 5 billion midsize automobiles.

Two-stroke engines are much simpler than the standard four-stroke used in autos. They don’t have valves, which lowers weight, and they fire once each revolution (rather than once every other revolution as in four-stroke engines). This means more power for the given displacement of the engine. Although the two-stroke engine is powerful, their simple design means exhaust is flushed from the cylinder by the introduction of the fuel-air mixture for combustion in the next cycle. As a result, some unburned fuel is expelled with the exhaust, causing much greater emissions compared to other engines, and pollution that quickly adds up. The main pollutants of concern are hydrocarbons (HC), particulate matter (PM), and carbon monoxide (CO) – as much as 74% of HC (helps cause urban ozone/smog), 65% of PM, and 51% of CO emissions are contributed by two-stroke engines in two and three-wheeler vehicles.

Various policy options can be implemented by governments to address emissions from these vehicles. Because of the socioeconomic consequences, a large scale or immediate ban on two-stroke engine vehicles would be extremely difficult and costly. Mandating specification changes to two-stroke engine design, such as electronic ignition, improved compression ratio, or oxidative catalytic converter, can require greater costs and considerable time for fleet turn over to replace older engines. Smaller, cost-effective improvements include using the correct type and amount of lubricant in these engines, and carrying out regular maintenance to ensure...
proper operations to help reduce emissions. One highly-effective step is to use cleaner-burning fuel blended with oxygenates, such as Methyl-Tertiary-Butyl-Ether (MTBE) or fuel-ethanol, to improve combustion properties and lower emissions.

In various studies of two-stroke engines, the use of oxygenates (between 10 and 15 vol% MTBE, and 5 to 10 vol% fuel-ethanol) in petrol reduced CO emissions by at least 25%. When combined with oxidative catalytic converter, CO reductions were over 60%. HC emissions were slightly reduced in unmodified two-stroke engines, however, in combination with catalytic converter use, HC emissions dropped by 57% to 70%. The addition of oxygenates to petrol causes enleaning of the air/fuel mixture. This improves combustion and can lead to lower PM emissions. Tests by engine manufacturers show that oxygenates blended at allowable levels have no apparent affect on engine performance or durability. In some older engines, however, fuel-ethanol blends can show some materials compatibility concerns – seals and gaskets on older equipment could experience leakage if not properly maintained. Overall, improved fuel quality and use of oxygenates, like MTBE, can help to reduce emissions from two-stroke engines, lower urban air pollution, and improve public health.

Reference Sources:

Table I: Distribution of Vehicles by Type in Selected South Asian Countries

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<tbody>
<tr>
<td>Cars</td>
<td>92,000</td>
<td>3,500,000</td>
<td>49,000</td>
<td>670,000</td>
<td>122,000</td>
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<td>420,000</td>
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<td>68,000</td>
<td>6,000</td>
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<tr>
<td>Light-duty gasoline</td>
<td>52,000</td>
<td>740,000</td>
<td>2,600</td>
<td>310,000</td>
<td>14,000</td>
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<tr>
<td>Heavy-duty diesel</td>
<td>55,000</td>
<td>5,200,000</td>
<td>46,000</td>
<td>750,000</td>
<td>235,000*</td>
</tr>
<tr>
<td>Two-stroke three-wheelers</td>
<td>68,000a</td>
<td>1,180,000</td>
<td>--</td>
<td>91,000</td>
<td>59,000</td>
</tr>
<tr>
<td>Four-stroke three-wheelers</td>
<td>7,600c</td>
<td>210,000</td>
<td>5,900c</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Two-stroke two-wheelers</td>
<td>200,000d</td>
<td>21,800,000d</td>
<td>110,000d</td>
<td>1,700,000d</td>
<td>424,000d</td>
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<tr>
<td>Four-stroke two-wheelers</td>
<td>35,000d</td>
<td>3,900,000d</td>
<td>19,000d</td>
<td>250,000d</td>
<td>75,000d</td>
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<tr>
<td>Total</td>
<td>523,000</td>
<td>37,200,000</td>
<td>232,000</td>
<td>4,000,000</td>
<td>936,000</td>
</tr>
</tbody>
</table>

Percentage of two-stroke vehicles: 51, 62, 47, 45, 52

Note: Because vehicle registration is by vehicle category and not by fuel type, these figures are based on assumptions about fuel use by each vehicle category. Breakdown should therefore be taken as approximations. Totals may exceed the sum of the individual categories because of other categories not listed, such as tractors.

a. All diesel vehicles except diesel cars.
b. Ninety percent of three-wheelers are assumed to be two-stroke engine vehicles.
c. The total number of three-wheelers in Nepal is 5,900. No estimates could be made of the breakdown of three-wheelers because of the large number of four-stroke engine diesel three-wheelers.
d. Eighty-five percent of two-wheelers are assumed to be two-stroke engine vehicles.

Source: Bangladesh Road Transport Authority; Society of Indian Automobile Manufacturers; Department of Transport Management, Kathmandu, Nepal; Economic Adviser’s Wing and Economic Survey, Government of Pakistan; Ministry of Transport and Highways, Sri Lanka.
As a follow-up to this month’s introductory story, ACFANews is pleased to have Mr. Iyer, with extensive experience, to share his expert views with us.

Q1: Please introduce yourself to the readers of ACFANews.

I am a mechanical engineer with specialization in the use of petroleum products in engines. I have worked with the Indian Institute of Petroleum and later with the R&D centre of the Indian Oil Corporation. For over 25 years, I have been with the Indian automotive industry, mostly with the two and three-wheelers. I have been taking an active part in various international conferences, particularly those in the South and Southeast Asian region. I have contributed to the guidebooks on vehicular emissions brought out by the Asian Development Bank (ADB) and German Gesellschaft fur Technische Zusammenarbeit (GTZ). I have been regularly attending the Better Air Quality (BAQ) workshops.

After retirement, I continue to serve as an adviser (technical) to the well-known two/three-wheeler manufacturer Bajaj Auto Ltd. I am also involved with other consultancy assignments, including some leading Indian oil companies.

Q2: We are seeing significant advances in fuel quality throughout the region to help reduce emissions. How are manufacturers of two-cycle engines advancing better designs to make sure they are fully compatible with these cleaner-burning fuels?

Normally, a fuel suitable for use in a four-wheeler engine is also good for the two and three-wheelers. This pertains to the traditional performance specifications such as vapour pressure, distillation characteristics, octane number, etc. One might even say that the performance requirements of small two-stroke and four-stroke engines are somewhat less stringent than those of four-wheeler engines. For instance, the octane number requirement of small two and three-wheelers is lower than that of four-wheel vehicles.

In modern four-wheel vehicles, the after-treatment devices impose a great demand on fuel specifications. For instance, the maximum sulphur content of gasoline is an important requirement for ensuring a satisfactory performance and durability of catalytic after-treatment devices. Earlier, it was the presence of lead in gasoline that seriously affected the life of catalytic converters.

In India and other Asian countries, the availability of lead-free gasoline has also become an essential requirement for two and three-wheelers. All two-stroke engines used on two and three-wheelers in India started using oxidation catalytic converters since the year 2000. Widespread availability of lead-free fuel, basically for four-wheel vehicles, also became an advantage for two and three-wheelers. This was necessitated by the very stringent exhaust emission standards in India that became applicable from that year. In Taiwan, China, the use of oxidation catalytic converters started a few years ahead of India.

Q3: In your view, is the need for continued air quality improvements - through further emissions reductions from vehicles - pushing toward transition away from two-cycle engines to four-cycle ones?

That is broadly the current scene in most of the Asian countries. Countries like India that traditionally produced two-wheelers with two-stroke engines are now rapidly shifting to four-stroke engines. In India, the proportion of two-wheelers using four-stroke engines in the annual sales has shown an impressive growth – from around 10% in 1996 to over 75% in 2004 (refer to Figure 1). However, in India, there have been other factors that have contributed to this shift; the most important one
I believe that with the introduction of further stringent emission standards – from the year 2008/2010 in India and the Euro III – would be difficult even for the four-stroke engines to meet without use of almost car-like technologies such as fuel injection and three-way catalytic converter with a feedback control. In this situation, the two-stroke engine with fuel injection and oxidation catalytic converter might be seen with a renewed interest as providing a more cost-effective solution.

Q4: Blending oxygenates, such as methyl tertiary butyl ether (MTBE), to petrol is proven to lower carbon monoxide (CO) emissions and improve engine combustion performance. Do you see this strategy as key to help improve two-cycle engine efficiency and lowering emissions levels, particularly for the existing fleet?

In India, our experience with gasoline and oxygenates such as MTBE is limited since use of such fuels is not yet widespread. However, one would expect that there would be a decrease in the CO emission of two-stroke engines. I refer to the “engine-out” emissions before the catalytic converter. I would agree with you that the use of fuel using oxygenates might have a salutary effect on the CO emission of existing fleet of two-wheelers, particularly those not using catalytic converters.

Q5: With fuel reformulations and quality improvements taking place, are there any problems, such as material compatibility concerns, for already in use two-cycle engines? What steps can be taken by drivers to ensure that their engines operate properly?

We have a great deal of field experience in India of using gasoline with 5% ethanol in two and three-wheelers. The Indian government had, some time ago, mandated the use of 5% ethanol in gasoline in some parts of the country – in states with capacity to produce adequate quantities of ethanol. Though this mandate has been relaxed for some time due to certain problems with supplies and pricing of alcohol, it is likely to be introduced again. In fact, the government has a plan to progressively increase the dosage of ethanol to 10%.

The field experience showed problems of material compatibility on some old models of two-wheelers. Fuel system components such as carburetor float needle valve, were found to be particularly vulnerable to attack by ethanol leading to their malfunction. However, replacing the affected parts with new ones – used in later models – took care of the problems. This problem is unlikely to be a matter of great concern considering that a vast majority of two-wheelers have been functioning without any problems. There is also a greater awareness among users and service personnel of the likely problem due to use of gasoline-ethanol blends and the corrective action that needs to be taken.

Q6: Based on your extensive experience in engine technology developments, do you have any recommendations that can lead to continued emissions improvements for two-cycle engines?

As I mentioned before, interest in two-stroke engines may get revived in the near future. Indications are that the use of electronically-controlled air-assisted fuel injection can lead to a significant reduction in emissions and improvement in fuel economy that are comparable to four-stroke engines. However, the greatest factor that stands in the way of widespread acceptance of this technology is the high cost of the injection system. My recommendation would be that vehicle manufactures and fuel injection system manufacturers must work together to bring down the cost of the system to levels acceptable in developing countries such as India and China.

Moving Towards Euro III and Euro IV Emission Limits

In-line with Beijing’s aim to improve their air quality by the 2008 Winter Olympics, starting end of 2005, Beijing implemented Euro III emission standards for light-duty gasoline and heavy-duty vehicles. Early this month, the Hong Kong Legislative Council approved the Air Pollution Control Regulation implemented Euro IV emission standards on new light-duty vehicles.
4th PCFV General Partnership Meeting

The 4th General Partnership Meeting of the United Nations Environment Programme’s (UNEP) Partnership for Clean Fuels and Vehicles (PCFV) was held 14 and 15 December 2005, in Nairobi, Kenya. The two-day meeting covered the 2005 activities report, 2006 – 2007 work programme, and discussions on setting measurable goals for leading issues being addressed by PCFV. The Partnership was established at the World Summit on Sustainable Development in September 2002 to reduce vehicular air pollution in developing countries through the promotion of clean fuels and vehicles. As an industry representative partner to the PCFV, ACFA is actively engaged to assist in providing support in promoting the use of cleaner fuels for cleaner air.

The 4th General meeting involved specific discussions on setting measurable goals for several critical issues being advanced by the PCFV, including:

- Global campaign for the elimination of leaded petrol worldwide.
- Establishing the new vehicles working group and confirming its mandate.
- Promotion of catalytic converters (petrol engines) and after use treatment technologies (diesel engines) for use with cleaner fuels.

During the General Partnership Meeting, the new Advisory Group selection occurred and its composition for 2006 and 2007 was decided. Finally, the meeting examined the financial status and future plans and directions for the Partnership. The PCFV website is located at www.unep.org/pcfv/main/main.htm.

A classic example of how the PCFV can be instrumental in leading policy changes is the recent ACFA Newsletter (Vol. 3, No. 10) article on India’s lack of cleaner-burning petrol supplies to match its auto industry’s ability to make improved, lower-emissions vehicle engines.

Air Toxics Clearly Reduced with Reduced Benzene Content

Environment Canada recently released a report on the Effect of the Benzene in Gasoline Regulations for 2004, an annual summary of the composition of gasoline reported under national regulation (benzene is a known human carcinogen). The report includes discussion of how refiners, blenders, and importers are responding to the regulation, including the use of oxygenates. Implemented in 1999, the regulations limit benzene content to 1 vol%, and freeze aromatics levels at 1994 levels. The regulations allow use of either a yearly pool average or a flat limit as the basis for compliance. The regulations also set a limit for the “benzene emission number” of gasoline, a number that relates gasoline composition to estimated emissions of benzene from vehicles.

The report on 2004 benzene levels shows a current national average content of 0.7 vol% – over 50% reduction since 1998 (see Figure 1). More significantly, Environment Canada has found urban monitoring shows average ambient benzene concentrations have declined by 63% between 1991 and 2004 - even as gasoline aromatics content has remained relatively constant (see Figure 2). This air toxics reduction clearly indicates the importance of reducing benzene content in gasoline – an effort that is spreading worldwide particularly as part of the World Wide Fuels Charter.

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Gasoline suppliers must also report the type and amount of oxygenate that they use in gasoline. Based on this latest report, the average level of MTBE use has been declining since 2000, while the average level of fuel-ethanol use has expanded. Table 1 compares data for a number of parameters – oxygen content, sulphur levels, vapour pressure, benzene volume, etc., – as reported by Canadian refiners and importers.

Table 1: Canadian Gasoline – Select Properties Reported for 2004

<table>
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<tr>
<th></th>
<th>Reported Max.</th>
<th>Reported Avg.</th>
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<tr>
<td></td>
<td>Importers</td>
<td>Refiners</td>
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<tr>
<td>Oxygen (wt %)</td>
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<tr>
<td>Sulfur (mg/kg)</td>
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<td>295</td>
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<tr>
<td>Vapor Pressure (kPa)</td>
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<td>E200 (vol %)</td>
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<td>E300 (vol %)</td>
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<td>Aromatics (vol %)</td>
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<td>BEN</td>
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Source: Environment Canada.

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