Case Study 1 - Reducing Exhaust Particulates from Buses

1. Context

Hong Kong is a modern and bustling city. The economy owes much to the public transport services that bear people to and from work. One of these vital public services is provided by franchised buses. Each day, about 4 million passengers ride on these buses which are owned by private companies. The total number of franchised buses licensed in Hong Kong is just over 5,700 and this number contributes to Hong Kong's overall road traffic density, 275 vehicles per kilometer, which is one of the highest in the world.

Figure 1. Hong Kong's traffic on the go

2. Air Pollution Problem

Bus vehicles pose a particular problem in terms of impact on air quality. These vehicles are powered by diesel fuel which contributes major air pollutants in the form of carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x), ozone, volatile organic compounds (VOCs) and respirable suspended particulates (RSPs) which, owing to the high density of buildings, results in an accumulation of air pollutants at the roadside.

The Hong Kong Government is committed to reducing the air pollution caused by all diesel vehicles[1], and not just bus vehicles. The related clauses of the Policy Addresses in 1999 and 2000 include:

- To reduce particulates and nitrogen oxide emissions from vehicles by 80% and 30% respectively by 2005;
- To introduce ultra low sulphur diesel (ULSD) to Hong Kong; and
- To impose fines of HK$1,000 for smoky vehicles.

[1] Number of licensed diesel vehicles in Hong Kong is about 125,000 units with the following breakdown: 111,328 goods vehicles (89%), 7,361 non-franchised buses (6%) and 5,977 franchised buses (5%).

In addition, the Government has issued a requirement for all newly registered vehicles to comply with Euro III emission standards, i.e. standards that meet the public health and environmental requirements of the European Union.

All new buses purchased by the main franchised bus companies in Hong Kong meet Euro III emission standards. There are still though a number of buses on the street currently that do not meet these standards as shown in the table below:

No. of Buses (Approx.)				
Pre-Euro	Euro I	Euro II	Euro III	TOTAL
1,483	**1,366**	**2,566**	**791**	**6,206**

Table 1. Composition of Bus Vehicle Fleets in Hong Kong according to Emission Standards - as at 1 July 2005 (approx. figures)

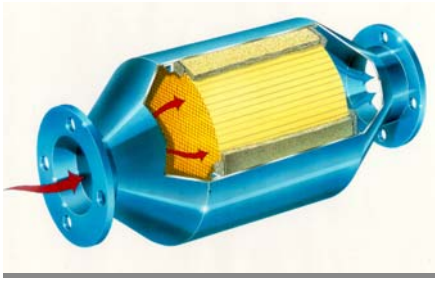

Figure 2. Diesel Oxidation Catalyst

From Table 1, it can be seen that there are some 5,400 bus vehicles that do not comply with the stated Euro III standard. In order for these buses to meet these standards, it is necessary for bus owners to treat the air emissions at the exhaust pipe through the use of catalytic converters. These converters, commonly know as diesel oxidation catalysts (DOCs)[2] would typically consist of a unit comprising a substrate-mounted precious metal catalyst within a honeycomb structure which is mounted onto the vehicle's exhaust system (see Figure 2). The catalyst removes CO, NO_X and unburnt hydrocarbons by converting these gases into air and water. DOCs are used in conjunction with low sulphur diesel as high concentrations of sulphur in the exhaust will poison the catalyst.

The majority of the pre-Euro and Euro I vehicles are either being phased out or have been retrofitted with DOCs; the Euro II and Euro III vehicles came with in-line converters already installed. The benefits associated with these converted buses are: improved odour, little maintenance and ease of fixture either as a bolt-in catalyst or catalyst silencer.

Whilst the CO, NOX and hydrocarbon levels are reduced, the DOCs do not fully address the problem of RSPs. The latter are 10 microns[3] or less in diameter (PM10), invisible to the naked eye and small enough to be inhaled. In general, the smaller the particulate matter the deeper it can penetrate into respiratory systems. Particulates smaller than 2.5 microns (also known as PM2.5) have been shown to damage lung tissue as well as aggravate existing respiratory and cardiovascular diseases. Medical professionals in Hong Kong have further highlighted the risks to asthma sufferers and people prone to heart and respiratory problems – specific health effects that are caused by RSPs. Under present conditions, DOCs are only able to remove 20-30% of particulates from bus vehicle emissions.

[2] Number of DOC fitted on franchised buses to date is 1,284 units.
[3] A micron is one millionth of a metre.

3. Solution

To tackle particulates, continuously regeneration trap (CRT) technology has been developed which acts as a filter to take out particulates. CRT can be an integral part of the vehicle exhaust system or retrofitted onto the exhaust pipe of the vehicle. It is technically suitable for most vehicle models in Hong Kong.

CRT relies on the catalytic oxidation of NO_X and hydrocarbons, followed by a filtration process during which particulate matter arising as soot is trapped and CO_2 is the resultant product (see Figure 3).

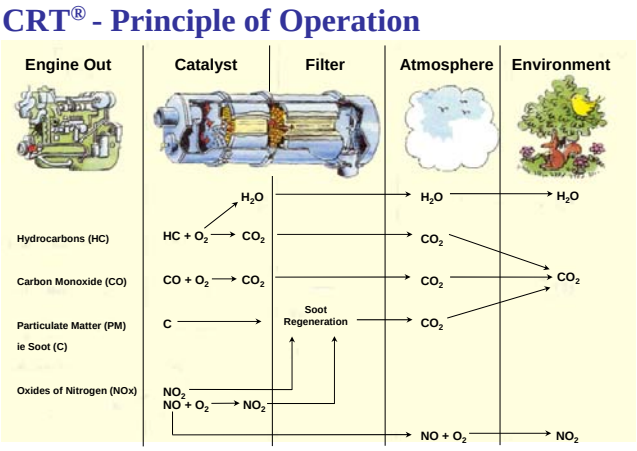

Figure 3. Continuously Regenerating Trap

The CRT is fitted onto vehicle exhaust pipes and, in general, black smoke and odour (characteristic signs of particulate emissions) are removed with drastic reductions of exhaust particulate emissions by up to 90%. The CRT provider is Eminox, a UK company, which specialises in manufacturing purpose-designed stainless steel exhaust systems for heavy duty diesel engines. Eminox uses precious metal catalysts provided by Johnson Matthey as part of a collaborative agreement between the two companies (see Figure 3a).

The advantage of CRT over conventional soot filters is that the latter must be replaced or the soot regenerated. Such previous technologies have been found to be unreliable & expensive. With CRT technology there is no need to change any parts.

Although CRT technology is currently not mandatory, the Government has been supportive and acknowledges its usefulness in particulate abatement for Euro II bus vehicles before the bus fleets convert to Euro III.

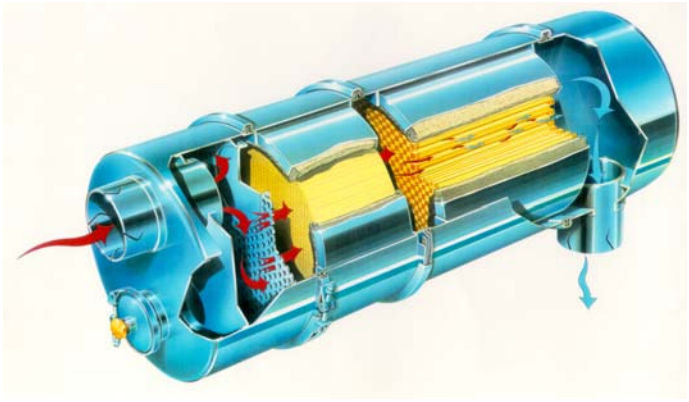

Figure 3a. CRT Equipment

4. Implementation

Currently there are roughly 960 CRTs fitted onto franchised buses belonging to Kowloon Motor Bus (560 units), Citybus (21 units), New World First Bus (225 units) and New Lantau Bus (61 units). Approximately one-third of CRTs have been retrofitted and the remainder line-fitted. The following companies provided information[4] on the technology:

- *In July 2001, New World First Bus invested over $75 million on Euro III buses for Hong Kong. These 12 metre-long air-conditioned double-decker buses are powered by EURO III engines with built-in CRT catalytic converters. Coupled with the advanced technology of the Volvo Emission Control System, Exhaust Gas Recirculation and fueled with ULSD, these buses not only conform to the very stringent EURO III emission standards but with levels comparative to EURO IV.*
- *The Kowloon Motor Bus introduced buses with Euro IV standard emissions in 2003, including the Super Bus and the state-of-the-art Wright Bus. Euro IV-standard emissions have been achieved by utilising available technologies to combine the Euro III engine and a continuously regenerating trap. At present, there are nearly 500 KMB buses achieving Euro IV-standard emissions.*

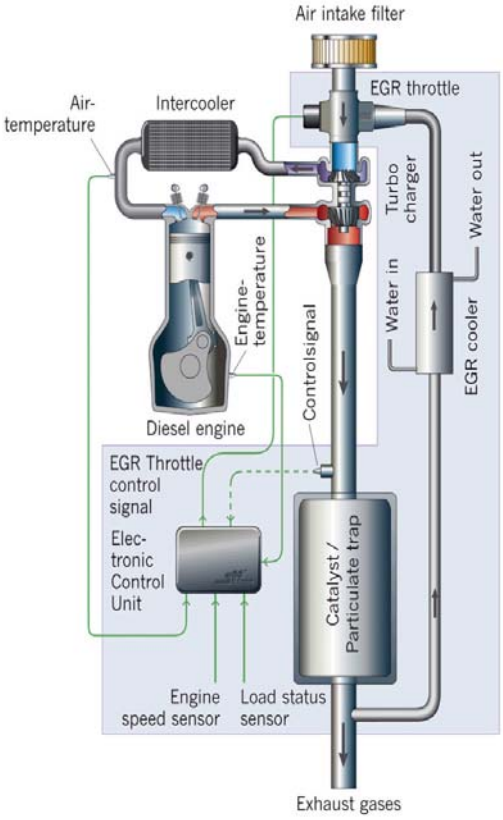

Figure 4 In-line CRT

- *Citybus operates 1,100 buses, which ply through the streets of Hong Kong. For this, [the company] has adopted stringent engineering standards and maintenance procedures to ensure all buses are within and even exceed the Government emission standards. Furthermore, over 90% of the bus fleet comply with strict Euro II emission standards. The first Euro III bus joined the Citybus fleet in 2002. Pre-Euro II buses are either being re-engined to meet the Euro standard, or are retrofitted with [continuous regeneration traps and] catalytic converters.*

Overseas, over 10,000 CRT devices have been fitted to bus vehicles in cities like London, Paris and Stockholm, where such measures are, in some cases, mandatory.

5. Outcomes

[4] Taken from the company web-sites.

The retrofitting of CRTs has had a dramatic effect on reducing particulate emissions from vehicle exhausts[5]. In addition, NO_x, CO and hydrocarbons have been reduced and carcinogenic pollutants have also been eliminated.

Based on lab tests[6], actual results are given below in Table 2.

	Euro II	Euro II plus CRT	Environmental Saving (kg/year)
RSP	15	1	14
HC	61	4	57
CO	87	8	79
NO_X	543	471	72

All figures are in kg per year, based on an annual mileage of 100,000 km.

Table 2. Effect of CRT on Euro II engines

6. Cost Benefits

The average cost of a CRT unit is HK$50,000 per unit. The maintenance cost is about HK$3,000 per year.

Whilst there is no direct cost saving or benefit from the retrofitting of CRTs, the reduction of particulate emissions by up to 90% has a beneficial outcome on public health as well as the environment. According to the report "Study of Economic Aspects of Ambient Air Pollution on Health Effects" carried out by Hong Kong University in 1998, an increase in $\mu g/m^3$ of particulates correlates directly with increases in respiratory disease mortality costs, a factor which is costing the taxpayer millions to support the healthcare system in Hong Kong.

7. Transferability

There are still some 2,500 Euro II buses that have yet to be retrofitted. Many of these buses were commissioned between 1998 and 2001, and - given that the lifespan of buses is 17 years - there is still a period of at least a decade before these models are replaced by newer vehicles. At this stage though, retrofitting with CRT in Hong Kong is not mandatory.

CRT fitment records in other major European cities, London, Paris, Stockholm and Belgium are 7,000, 2,900, 1,500 and 500 respectively.

Taking another case, there are about 345,000 private vehicles, a quarter of which are diesel-based. Many of these meet Euro II standards or less and have never been

[5] Daily PM reduction level is estimated as **93.6 kg** based on the following assumptions: 867 buses fitted with CRT; PM emission level (Euro II) - 0.15g/kWh; average engine power output - 80kW; average operation time - 10 hrs/day; and CRT PM reduction efficiency - 90%.

[6] Source: Millbrook Report MBK980431 on Euro II Scania P94 310 Bhp distribution vehicle.

retrofitted with particulate traps. Similar to the franchised buses, there are no mandatory measures for retrofitting private vehicles with CRT.

8. Conclusions

CRT technology is being widely used in Hong Kong on franchised buses but there are still a number of vehicles that could be fitted - with resulting benefits to the environment and public health. According to the Hong Kong University's research, improved air quality can significantly reduce health-related costs and help preserve Hong Kong's environment.

Figure 5. A clean machine

Lessons learnt include:

- CRT is proven technology and over 100,000 units have been fitted worldwide. In Hong Kong, 800 bus vehicles are using this technology;
- In most cases CRT is considered to be costly but the environmental and public health benefits are significant; and
- CRT may possibly be standard equipment for future vehicle applications to meet more stringent emission standards in the future.

Contact:
Dr. Raymond Yuen (Eminox Limited)
Details to be advised