Global emissions due to urban transport and the potential for their reduction
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Abstract

The worldwide growth in the volume of transport is giving rise to increasing concern over the consequent increase in emissions. The rise in CO\textsubscript{2} emissions is hindering the drive to minimise the 'Greenhouse Effect' and other more noxious emissions are causing a deterioration in urban air quality. Urban transport is estimated to account for over 20\% of total CO\textsubscript{2} emissions in the USA, of which up to 50\% is due to energy wasted in braking. The figure worldwide could well be approaching this. Assuming that 60\% of this energy is recoverable through regenerative braking, it is possible that total global CO\textsubscript{2} emissions could be reduced by 4\% by implementation of currently available brake energy recovery technologies. The reduction in other emissions could be far more significant due to the optimised engine management systems which such technologies allow. This paper describes brake energy recovery technologies, and their introduction so far, in comparison with other measures such as use of alternative fuels.

1 Introduction

In 1996, transport accounted for 31\% of CO\textsubscript{2} emissions in the USA [1] and is rapidly becoming the dominant source of CO\textsubscript{2} emissions worldwide. This trend is gives rise to a corresponding increase in
noxious emissions such as NO\textsubscript{x}, CO, volatile organic compounds and particulate matter, which may be only partially offset by the introduction of catalytic converters. The environmental effects of this trend are becoming manifest, particularly in our cities, with noxious emission levels exceeding prescribed health limits. According to the London Atmospheric Emissions Inventory [2], the road transport sector is now the single major source of urban air pollution, in London, causing 75\% of NO\textsubscript{x}, 83\% of Benzene, 77\% of particulates, 97\% of CO and 53\% of volatile organic compounds, on top of 29\% of CO\textsubscript{2} emissions.

The level of particulate emissions is already exceeding limits set by the European Union in urban areas, and the levels of fine particulate matter (<PM10) containing volatile organic compounds (VOCs) are now considered a major health hazard and are estimated by Bown [3] to be the cause of over 10000 premature deaths in the UK per year.

According to Papacostas [4], 75\% of journeys made in the US are in urban areas. Hughes [5] gives the proportion of car traffic in urban areas (km per capita per week) also as 75\%. A conservative estimate of 60\% of all transport implies that urban road transport is responsible for over 18\% of global CO\textsubscript{2} emissions. The report of the Royal Commission [6] gives the harmful emission in urban areas as a proportion of total atmospheric emission due to UK road transport in 1990 as Particulate, 28\%; SO\textsubscript{2}, 38\%; NO\textsubscript{x}, 32\%; VOC, 61\%; CO, 62\%. One could deduce from this that the majority of particulate and SO\textsubscript{2} emissions are due to heavy goods vehicles operating at full load on motorways, whilst the volatile organic compound (VOC) and CO emission occurs mainly in urban areas and is due to part load operation of IC engines. These emissions pose a serious health hazard in urban areas.

2 Emission abatement technologies

There are a number of technologies which could potentially reduce vehicle emissions:

2.1 Catalytic converters

According to Whitelegg [7], catalytic converters could reduce NO\textsubscript{x} emissions due to road transport by up to 40\%, mainly due to the impact on petrol engine emissions. Hydrocarbon and CO emissions could be
reduced even further. However, because of the reduced efficiency of the engines, CO₂ emissions are thereby increased.

2.2 Use of compressed natural gas as a fuel

A reduction in pollution can be obtained by the use of compressed natural gas (CNG), which is mainly methane, in place of existing fuels. Table 2 shows a comparison by ARIC [8] of exhaust emissions (gm/km) for a small delivery van under the urban test cycle.

Table 2: Comparison of emissions by fuel use in urban transport (gm/km)

<table>
<thead>
<tr>
<th></th>
<th>Petrol</th>
<th>Diesel</th>
<th>CNG</th>
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<tbody>
<tr>
<td>CO</td>
<td>3.02</td>
<td>0.74</td>
<td>0.71</td>
</tr>
<tr>
<td>Total Hydrocarbons</td>
<td>0.47</td>
<td>0.16</td>
<td>0.61</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.28</td>
<td>0.77</td>
<td>0.14</td>
</tr>
<tr>
<td>Particulates</td>
<td>0.007</td>
<td>0.101</td>
<td>0.01</td>
</tr>
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Clearly, the conversion from petroleum fuels to CNG would result in a significant improvement in urban air quality.

Poulton [9] gives the possible reduction in CO₂ emissions due to conversion to CNG in urban transport as up to 33%. However, the effect on global warming could be offset by the corresponding increase in methane emissions.

2.3 Fuel saving measures

Fuel saving has the advantage of reducing all pollutants as well as CO₂ emissions. If 18% of global CO₂ emissions and 62% of urban CO and VOC emissions are due to urban transport then improvements in fuel efficiency could contribute significantly to a reduction in greenhouse emission and, at the same time, to an improvement in urban air quality. In order to improve fuel efficiency, one should take account of how energy is dissipated in urban traffic. The distribution of transmitted energy dissipation for a typical car is given by Hughes [5] as:
Table 1: Distribution of energy dissipation in a typical car.

<table>
<thead>
<tr>
<th></th>
<th>Proportion of total energy</th>
<th>Proportion of transmitted energy</th>
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<tbody>
<tr>
<td>Air resistance</td>
<td>4%</td>
<td>22%</td>
</tr>
<tr>
<td>Rolling resistance</td>
<td>6%</td>
<td>33%</td>
</tr>
<tr>
<td>Braking</td>
<td>8%</td>
<td>45%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

The remainder of the total energy is mainly made up of engine losses which are assumed to be proportional to transmitted energy. In general, atmospheric pollution and fuel consumption due to road traffic can be regarded as proportional to energy consumption. There are various ways of achieving fuel saving which will now be discussed.

2.4 Reduction in atmospheric drag

Modern vehicle design has largely minimised aerodynamic drag and this form of energy loss occurs mainly outside urban areas, being dependent on the square of vehicle speed [11]. At steady speeds of around 120 km/h, aerodynamic drag causes about 70% of fuel consumption. A 10% reduction in such traffic speeds would lead to a 19% reduction in aerodynamic losses. Assuming such traffic constitutes 30% of road transport and therefore contributes 10% of global CO₂ emissions, speed reductions of this order could reduce global CO₂ emissions by about 1.3%.

2.5 Vehicle weight reduction

Reduction in vehicle weight would result in lower rolling resistance and a reduced energy requirement for acceleration. These currently account for 78% of energy consumption according to table 1. Overall weight reductions of between five and ten percent seem feasible [9], which, according to Poulton [10], could lead to fuel consumption reductions of between 1 to 3 percent on an urban cycle. However, the following section indicates that, in urban conditions, over half of the energy consumption (corresponding to losses in the transmission and brakes) is directly proportional to vehicle weight.
2.6 Brake energy recovery

The use of brakes is mainly confined to urban areas in which vehicles are subject to the fuel intensive urban cycle. Brake energy, accounts for 45% of the typical energy consumption of a car (table 1) and could thus be taken as an approximate figure for all land transport. Given that up to 60% of brake energy is recoverable through hybrid vehicle propulsion technology, introduction of this technology throughout motorised land transport could result in a 27% overall energy saving, reduction in fuel consumption and consequent reduction in CO$_2$ emissions due to urban transport and thus a 4.9% reduction in global emissions.

Conventional vehicles do not provide for brake energy recovery since some form of energy storage is needed. Electric vehicles do allow a limited amount of brake energy recovery, subject to the rather low storage efficiency of batteries. Also batteries are not able to accept high levels if input power needed to absorb brake energy and their use in this role is limited by their low cycle life.

3 Energy storage devices

Energy storage systems based on the flywheel are now being developed for the purpose of brake energy recovery. They have the advantage of allowing the primary power source to operate continuously with optimal load and minimum pollution. Two hybrid buses incorporating flywheel energy storage have been demonstrated, one in Munich [12] and one in Eindhoven [13]. Up to 30% fuel savings have been demonstrated, together with the virtual elimination of noxious emissions and a significant reduction in noise and vibration. The reduction in noxious emissions arises from the reduced size of the engine, continuous operation of the engine in conditions of optimal combustion, and the fuel saving due to brake energy recovery.

Investigation has been carried out, by computer simulation, into the operation of a hybrid articulated bus, whose propulsion system comprises a primary power source and an energy storage buffer. In order to assess the benefit of hybrid propulsion, the performance of the bus, operating between two stops 400m apart, has been simulated by Jefferson using SIMTRIP [15]. The following data for the bus have been assumed for this study:
Total mass of vehicle 25 tonnes
Traction power limit 250 kW
Maximum speed 50 km/h
Engine power 100 kW
Energy storage 3 MJ
Storage power loss 1 kW
Frontal surface area 8 m²
Efficiency of electrical machines 90 %

The propulsion system is assumed to comprise a primary power source (such as a diesel generator set) of 100kW constant power rating, and an energy storage unit and traction motors rated at 250 kW, which provides the power required for acceleration and enables brake energy recovery. The test shows that brake energy recovery results in an energy saving of 26%, and that the primary power, being decoupled from the vehicle power demand, is supplied intermittently at constant full load. If this is a diesel engine, then it can be operated at constant speed and load at high efficiency. The combination of high efficiency with reduced engine capacity and weight results in the significant saving in fuel and reduction in emissions. The system also permits the operation of the vehicle over short distances without the use of the engine.

The simulation study indicates that the energy used in the propulsion of a conventional bus in urban conditions is dissipated in the proportions shown below.

Engine losses 75.0 %
Transmission losses 4.9 %
Wheel resistance 9.8 %
Air resistance 2.5 %
Brakes 7.8 %

Total 100.0 %

Given that, in hybrid operation, the efficiency of the engine increases from 25% to 28%, the breakdown of energy consumption for the equivalent hybrid vehicle, as a proportion of the energy consumption of the conventional vehicle, is shown below for comparison.
These figures apply to buses. The equivalent figures for cars indicate that a higher proportion of energy is dissipated through aerodynamic drag and the scope for brake energy recovery is reduced to 23%, but it would still give a 4.1% reduction in global CO₂ emissions, even if only applied to urban transport.

### 4 Additional benefits

#### 4.1 Electric transmission

The hybrid bus with electric transmission has many of the advantages of electrified transport, including low noise and vibration, and the possibility of low floor design. Additional benefits would include an improvement in comfort, reliability, safety and performance. The performance of the hybrid vehicle should be equal to that of the corresponding electrified transport, with uniform controlled acceleration and deceleration and absence of jerk, which is a source of discomfort and even of danger to passengers. Comfort, safety, accessibility and reliability are all seen as essential if car users are to be persuaded to travel by bus, and maximum environmental benefit to be achieved. Any transfer from private to public transport will result in a reduction in energy consumption.

Table 2 shows the relative energy consumption for different travel modes, for average and maximum occupancy, according to Hughes [5]. Buses and diesel multiple unit trains are shown to be the most energy efficient form of motorised transport. The predicted consumption for the hybrid bus and railcar are also shown for comparison (in italic). A 10% shift from private to public transport typified by a 10% shift from a typically loaded small diesel car to a standard single deck bus would result in an approximate 6% reduction in energy consumption in land transport additional to any benefit from the introduction of hybrid propulsion.
Table 2: Energy consumption (per passenger-km) by mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>MJ per passenger-km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>typical load</td>
</tr>
<tr>
<td>Car, small diesel</td>
<td>1.3</td>
</tr>
<tr>
<td>Car, large petrol</td>
<td>3.0</td>
</tr>
<tr>
<td>Express coach</td>
<td>0.4</td>
</tr>
<tr>
<td>Minibus</td>
<td>0.8</td>
</tr>
<tr>
<td>Single deck bus</td>
<td>0.6</td>
</tr>
<tr>
<td>Underground train</td>
<td>1.5</td>
</tr>
<tr>
<td>Suburban diesel train</td>
<td>0.6</td>
</tr>
<tr>
<td>Suburban electric train</td>
<td>1.8</td>
</tr>
<tr>
<td>Intercity electric train</td>
<td>1.3</td>
</tr>
<tr>
<td>Intercity diesel train</td>
<td>0.9</td>
</tr>
<tr>
<td>Hybrid single deck bus</td>
<td>0.45</td>
</tr>
<tr>
<td>Hybrid suburban train</td>
<td>0.45</td>
</tr>
</tbody>
</table>

4.2 The use of hydrogen as a fuel

Technology already exists for conversion of hydrogen into electricity by use of IC engines and gas turbines, and fuel cells may supersede these in the future. Such systems could provide the primary power for the complete range of zero emission hybrid vehicles for land transport. Two problems remain, namely, storage of hydrogen on board the vehicle and the provision of a hydrogen supply infrastructure. Hydrogen storage is the subject of much research and development at present with the most likely form of storage, in the short term, being containment under pressure. Safety criteria would be similar to those for compressed natural gas, already widely used as a fuel. Storage of hydrogen at low temperatures and as hydride compounds is under investigation and may become viable in the longer term.

The supply of hydrogen at filling stations presents a cost penalty which will probably result in the technology being introduced in fleet transport before its acceptance for use in private cars. The production, storage and transport of hydrogen is also an important consideration. Hydrogen could be produced by use of surplus (off peak) electricity generated from natural sources such as hydro, wind, wave and solar power, through electrolysis of water and stored and distributed in a similar way to natural gas, providing an effective method of large scale energy storage.
4.3 Probable impact of fuel cell technology

In the medium term, fuel cells could provide the primary power for hybrid buses and railcars. Such vehicles are already under development [15] and the fuel supply infrastructure for public transport and other fleet transport operation is quite feasible. The brake energy recovery technology described in section 3 makes the introduction of fuel cells more viable since, in a hybrid configuration, they need only deliver a constant, relatively low level of power, for which they are suited. Fleet transport, road and rail, presently accounts for about 34% of CO₂ emissions due to land transport in the UK (Hughes, 1993) and therefore 8% of overall CO₂ emission. This represents the possible reduction due to the use of hydrogen as a fuel in fleet transport.

5 Summary

This paper has described various measures for reducing CO₂ and other emissions due to urban transport. To summarise:

Brake energy recovery in urban transport could lead to a 5% reduction in global CO₂ emissions and the necessary hybrid arrangement incorporating energy storage could lead to the virtual elimination of noxious pollutants from urban traffic, with consequent major improvement to air quality in our cities.

The use of compressed natural gas as vehicle fuel could also lead to a significant improvement in air quality but the effect on global warming may be adverse due to emissions of methane.

The use of hydrogen as a fuel could potentially provide the largest overall benefit provided its production was, itself, emission free. Its efficient use through brake energy recovery and the use of fuel cells for primary power should be a key objective in urban transport planning, in order to meet urban air quality and greenhouse gas emission targets.

References

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[10] Ibid p98


