DEPARTMENT OF ENVIRONMENTAL AFFAIRS

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AIR POLLUTION CONTROL APPROACHES

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ACRONYMS

CO	Carbon Monoxide
CNG	Compressed natural gas
CP	Cleaner Production
LEV	Low Emission Vehicle
LPG	Liquefied petroleum gas
MTBE	Methyl tert-butyl ether
NO_x	Oxides of Nitrogen
TEL	Tetraehtyllead
ULEV	Ultra-Low Emission Vehicle
ZEV	Zero Emission Vehicle

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1. INTRODUCTION

Air pollution control methods are a fundamentally important component of air quality management and planning and are crucial in order to achieve and maintain an acceptable level of air quality. The objective of this booklet is to provide an overview of the theory of pollution control approaches, with regard to industrial, transportation and residential emissions. For industry this relates to controlling gaseous and particulate emissions as well odours and fugitive emissions. Transportation controls include implementing improvements to the fuel and vehicles used as well as proper management of traffic, whereas for residential emissions control of the source of pollution and ventilation is crucial to improving air quality. The control strategies for each of the above sectors are reviewed in more detail in the following sections.

2. POLLUTION CONTROL APPROACHES IN INDUSTRY

2.1 Cleaner Production

Cleaner production (CP) provides a format for proactive environmental management. CP has emerged in the past 10-15 years and embraces concepts of waste minimisation and pollution prevention at source, whilst incorporating both economic and environmental concerns. With the use of CP, the entire life-cycle of a product or processes is addressed, with the objective of reducing the risks to the environment (Hilson, 2003).

The United Nations Environmental Programme (UNEP) defines CP as ‘‘the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase the overall efficiency to reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society” (UNEP, 2001). A number of components of the service chain are integral in the importance of CP as they reduce the cost of product liability, waste management and promote occupational safety and sound environmental quality. These components are:

- Production processes

Waste reduction is encouraged at the source, as waste is indicative of inefficient use of the materials being used (UNEP, 2001). The aim in CP is to reduce all waste to a minimum, with the ultimate goal of zero waste discharge.

Non-polluting production should occur such that production processes occur in a closed loop, with zero contamination to the environment. This should be achieved by substituting non-toxic substances for toxic substances where available. If no suitable alternative to toxic materials are available, there is a need to eliminate spills, emissions and accidents that could result in toxic contamination.

Production energy efficiency is stressed such that efficient processes occur and allow for conservation of raw materials and energy

- Products

Work environments need to promote safety and health, such that the risks that workers are exposed to from factors such as radiation and physical hazards should be minimised. Workplaces need to be clean and the workers need to have the skills to perform the work processes. The final product needs to be environmentally sound, produced with minimal use of toxic materials and efficient use of energy. Packaging used for the product should be kept to a minimum and the type of packaging used should be environmentally friendly, that is, degradable or suitable for reuse and recycling opportunities.

These components of cleaner production allow for a reduction of negative impacts throughout the lifecycle of the product.

- Services

Environmental concerns need to be included in the design and delivery of services (UNEP, 2001). The ultimate objective of CP is to avoid generating waste in the first place. The generation of pollutant can be reduced or eliminated by increasing the efficiency in the use of raw materials, energy, water and other resources. This reduces the amount of any dangerous, polluting or contaminating substance introduced into the waste flows or released into the environment in any other way before being recycled, treated or discharged. The adoption of CP practices can involve the following steps:

- Simple process modifications

Process changes can be an effective tool in eliminating air-pollution emissions. This can be achieved by changing processes so that the raw materials and energy are used more efficiently. This will reduce the amount of waste produced and the energy used. For example, steel industries can switch from using raw ore to pelleted sintered ore. A further example is in the metal finishing industry, where drip trays can be used in between plating baths to collect droplets of solution and return it back to the bath for reuse. This reduces wastage of the chemicals used and also decreases the amount of pollution that enters the storm water drains.

- Product reformulation

The product needs to be redesigned to reduce environmental impacts of its production. This could involve changing the materials used in the product and increasing product durability.

- Raw material substitution

Offensive substances can be eliminated from processes which are causing air pollution by substituting these materials with other materials that perform as well in the process but also discharge innocuous products to the atmosphere or none at all. Toxic materials could be replaced with non-toxic materials. Fuels with lower sulphur content can be used so as to produce less sulphur compounds.

- Good housekeeping

This deals with improving operations and maintenance to reduce waste and improve efficiency. Open piles of chemicals should be covered with plastics or kept in enclosed storage facilities.

- Recycling

Recycling offers opportunities to limit environmental impact by decreasing waste volumes and the need for additional raw materials. Waste can be reused or recycled within the process undertaken. This can be linked to the idea of industrial ecology, where effluents and wastes from one process are used as the input materials for other processes or reused in further production. In this way the waste has an economic value, instead of having a disposal cost (Gibbs and Deutz, 2006).

CP is also seen as tool in promoting resource intensive and less polluting production technologies. It is further seen as a managerial catalyst that has shifted environmental values from mere regulatory compliance to the centre of production and process design in industries. It also leads to financial savings as the cost of the strategies employed in cleaner production is less than treatment and disposal costs (Hilson, 2003).

2.2 Pollution Control Technologies for Industries

Due to the environmental and health concerns, industries need to control their emissions. Industries may also be obliged to control dust, odours and other emissions by regulatory pressure. Industries may adopt methods such as cleaner production to reduce their emissions by introducing process and product modifications. Alternatively 'end-of-pipe' solutions may be adopted to reduce emissions. In this approach, no modifications are made to the industrial process being undertaken. Instead pollution reducing technologies are used, which reduce the volume of emissions that is generated. A brief description of the available technologies is provided in this section.

2.2.1 Filters

Filters are collectors in which dust is removed from the gas stream by passing the dust-laden gas through a fabric (woven cloth, felt or porous membrane). These devices are 'surface filters' in that the dust collects in a layer on the surface of the filter medium and the dust layer itself becomes the effective filter medium. During this initial period particle deposition takes place mainly by inertial and flow line interception, diffusion and gravitational settling. Once the dust has been fully established, sieving is the dominant removal mechanism. Filter design is related mainly to choices of gas filtration velocities and pressure drops and fabric cleaning cycles. The most common air filter is the baghouse filter which is made of fabric fiber materials (Perry *et al*., 1984).

2.2.2 Scrubbers

Scrubbers use liquid to collect dust and mist. These types of devices have been operational for over 100 years with numerous commercial designs available. The particulate scrubber may be considered to have two stages. The first being the contactor stage, where liquid as a spray is dispersed into the gas and the liquid droplets are the collectors of the dust particles. The second stage involved entrainment separation that uses an inertial separator to remove all droplets

produced in the scrubber. One of the most widely used particulate scrubbers is the venturi scrubber (Perry *et al*., 1984). A typical venturi-throat is shown below in Figure 1.

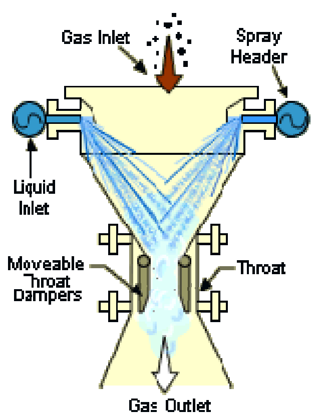

Figure 1: Venturi scrubber (EPA, 2006).

2.2.3 Mechanical Collectors

Mechanical collectors operate by inertial forces or gravity. The particle is removed from the gas stream by inertial forces or gravity. These devices are considered to be useful as a precleaning device that reduces the amount of particulates in the gas stream. Settling chambers and cyclones represent two main types of mechanical collectors. Cyclone separators are widely used for particulate matter control (Perry *et al*., 1984). Figure 2 shows a typical large-diameter cyclone system.

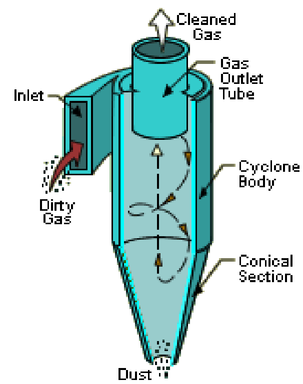

Figure 2: Cyclone (EPA, 2006).

2.2.4 Electrostatic Precipitators

Electrostatic precipitators use discharge electrodes for charging and collection of particles, working on the principle of charge neutralization. The discharge electrodes are found between ground parallel plates and a high voltage is applied to it which creates a corona discharge. This results in the negatively ionized gas molecules being formed. These ions are attracted toward the electric field and intercept particles present. The ion-particle bond is formed which becomes charged and therefore moves towards the collection plate (Perry *et al*., 1984). This process is depicted in Figure 3.

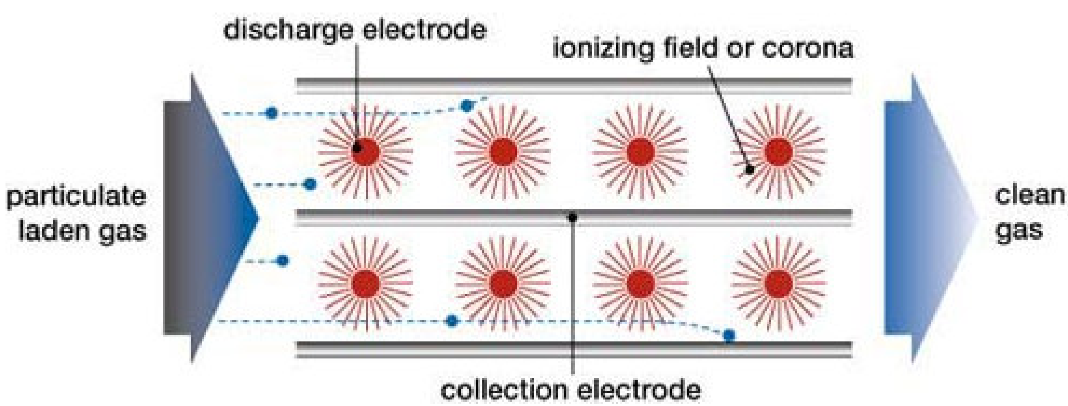

Figure 3: Top View of Electrostatic Precipitator Schematic Diagram (ASU-EE, 2003).

2.2.5 Absorption Devices

Packed and plate towers are common devices that are used in the gas-absorption systems. These devices contain specific liquids that absorb the pollutant gases. The liquid used has to be non-flammable, non-viscous, chemically stable and non-corrosive. Water is generally used as a liquid when dealing with gases soluble in water. For light hydrocarbons oils can be used, whereas special chemical liquids are required for acid gases such as sulphur dioxide. The liquid that is used is therefore determined with respect to high solubility for the solute. Furthermore, the exit gas will be saturated with the liquid, which is lost. As a result low cost liquids would be preferable (Perry *et al*., 1984).

2.2.6 Adsorption Devices

Adsorption devices accumulate the solute molecules at the surface. The type of adsorbents used could be synthetic or natural and have a microcrystalline structure. Physical adsorption occurs at ordinary temperatures due to intermolecular forces, whereas at higher temperatures chemisorption occurs, where the absorbate is chemically bonded to the absorbent. Adsorption allows for possible product recovery and allows for contaminants from the process streams to be removed to very low levels.

Industrial adsorbents require large surface area per unit volume. There are limited solids that have sufficient adsorptive properties needed for gas cleaning. The solids that are used need to have a high rate of adsorption, low pressure drop and should be able to maintain their shape. The types of adsorbents used on a large scale include silica gel, activated carbon and activated ammonia. Activated carbon is the preferred adsorbent for vapours of an organic nature, whereas activated alumina and silica gel is considered more useful for the adsorption of water vapour.

2.2.7 Condensers

Condensers can be used to collect condensable emissions that are discharged to the atmosphere, particularly when the vapour concentration is high. This is usually accomplished by lowering the temperature of the gaseous stream although an increase in pressure will produce the same result. Industries generally employ the former approach, since pressure changes on large volumetric gas flow rates are often economically too expensive. There are two basis types of condensers that are used. These are contact and surface condensers. In contact condensers, the gaseous stream is brought into direct contact with a cooling medium so that the vapours condense and mix with the coolant. In the more widely used system of surface condensers, the vapour and the cooling medium are separated by a wall. The advantage with using this device is that the coolant may be reused after cooling. Condensers are typically used for pre-treatment prior to the use of more efficient control devices such as an absorber or adsorber.

In the selection of a control technology factors such as the availability of space, capital costs, operating costs and the contribution of the system to noise pollution on the plant are considered. The equipment that is selected should be capable of obtaining compliance with regulations and emission standards at the lowest cost (Perry *et al*., 1984). Table 1 presents general advantages and disadvantages of each type of air pollution control device discussed above.

Technology	Advantages	Disadvantages	Effectiveness
Filters	Dry collection allows for subsequent disposal or reuse. Filter materials vary in configuration which aid simple installation.	High maintenance costs. Flammability hazards occur with some gases. High temperatures are required (>288°C).	High collection efficiency of fine and coarse particulates (90-99.9%). Collection efficiency is independent of particulate loading.
Wet Scrubber	Collects particulates and functions as a gas absorber. Small space requirements. Secondary dust emissions do not occur.	Low capital costs. Product is collected wet Corrosion is possible. High maintenance costs	Effective collection of fine particulates (>99%). Works well at high temperatures and high humidity streams.
Cyclone	Relatively cheap and simple equipment. Allows for dry collection and disposal. Small space required.	Inability to handle tacky material.	High collection efficiency for particles >10 μ m, 70-90%. Ineffective for collection of submicron particles.
Electrostatic Precipitators	Relatively low operating costs. Dry collection and disposal of material. Capable of operating under high temperature and pressure. Designed for continuous operation.	High capital cost. Large space needed. Some particles are difficult to collect based on their resistivity. Ozone can be produced as a by-product during gas-ionization.	Designed to collect particles and liquids at high collection efficiency (>99%). Excellent removal of particles 0.1-10 μ m. Effective for trace metals, fog and mist collection.
Absorption devices	Low space requirements. Low capital cost. Capable of collecting particulates and gases. Relatively low pressure drop	Product collected wet High maintenance cost Plugging of plates by particulates is possible	95% collection efficiency
Adsorption devices	Product recovery is possible Product recovered can be returned to the process, limiting waste.	Expensive distillation possibly required for product recovery. Relatively high capital cost. Adsorbent quality decreases with increases to the number of cycles.	95% collection efficiency. Additional treatment is needed for recovered organics
Condensers	Coolant may be reused. Indirect-Contact condensers allow for pure product recovery.	Coolant requirements are expensive.	80% collection efficiency, which is dependent on low temperature or high pressure.

Table 1: Advantages, Disadvantages and Effectiveness of Industrial Pollution Control Devices (adapted from Burke *et al.*, 2000; Perry *et al.*, 1984 and Spellman, 1999).

2.3 Control of Odour

The development of odours can be minimized and reduced by process changes and containing the odour sources and off-gases at proper temperatures. Different types of odour control can be implemented, dependent on local conditions. Process modifications should be investigated as odour control measures are expensive and it would be necessary to compare the cost of the process changes to the cost of the alternative control measure. The main control measures for odourous gases are physical, biological and chemical (Tchobanoglous and Burton, 1991).

Physical methods include containment of gases with the installation of covers and hoods. Odours can also be removed by the gases passing through beds of activated carbon or through sand, soil or compost beds. Further, non-toxic gases could be diluted with odour free air as when the gases are mixed with the fresh air a reduction in the odour will occur. Alternatively the gases can be released through tall stacks for dispersion and dilution to occur. The use of masking agents is another means of physical control, whereby perfume scents are sprayed near offending odours in order to mask the original offensive odour. However, there are cases where the odour of the masking agent is worse than the original odour which highlights the limited value of this approach.

Chemical methods of control include scrubbing with various alkalis, whereby the odourous gas is passed through specially designed scrubbing towers. The costs of these applications may be high if carbon dioxide (CO_2) levels are high. Other control methods include chemical oxidation of offensive compounds, such that they are converted to non-offensive compounds.

Biological methods of control include the use of special biological stripping towers that are filled with plastic media, which maintain biological growths, which strip odourous compounds.

2.4 Control of Fugitive Emissions

Fugitive emissions occur from open sources and are termed ‘fugitive’ as they are not discharged in a confined flow stream (Abdul-Wahab, 2006). These emissions are unexpected or unplanned emissions and are generally difficult to quantify. Fugitive emissions consist of primary pollutants that are not a product of combustion or evaporation. These emissions occur in two broad categories, industrial sources and open dust sources (Kinsey and Cowherd, 1992).

Industrial fugitive emissions refer to the small amounts of process gases or fluids that escape to the atmosphere from flanges, valve stems, packing and seals and control valves (Kinsey and Cowherd, 1992). Monitoring and tightening of the packing nuts or bolts on flanges is a substantive part of good management strategies and housekeeping. In some cases, tightening of the packing nuts or bolts on flanges may be sufficient to reduce fugitive emissions (Griffin, 1994). Industrial fugitive emissions traditionally involve the capture and control of the emissions once airborne by means of capture and collection systems.

Open dust sources include, mining construction, rubber manufacturing, stone, clay or glass manufacturing and secondary metallurgical operations. Fugitive particulate emissions generally occur due to the handling and storage of bulk materials, entrainment by traffic and wind erosion (Vrins et al., 1998). The concentration of dust varies and is dependent on local conditions (topography, weather conditions and temperature inversion) and the nature and intensity of the local sources (Abdul-Wahab, 2006). Cement plants offer a prime example of fugitive dust emissions, where the dust is generated through leakages, spillages, handling, quarrying of the raw material (e.g. limestone) and the packing and transport of the product.

There are numerous options available for the control of these emissions. These include process modifications and adjusted work practices to bring about a reduction in the source extent. Preventative measures can be used to prevent or reduce the injection of particulate matter into the atmosphere. Such measures include:

- Passive enclosures

This involves partial or complete enclosure of the source of the emissions. The enclosures are some type of temporary arrangement or permanent structure. Examples of such structures include porous wind fences or portable windscreens (Fig. 4) which have been shown to effectively reduce the amount of emissions from exposed ground areas and active stock piles. These structures provide a sheltered region, reducing the wind-erosion potential of the surface (Kinsey and Cowherd, 1992).

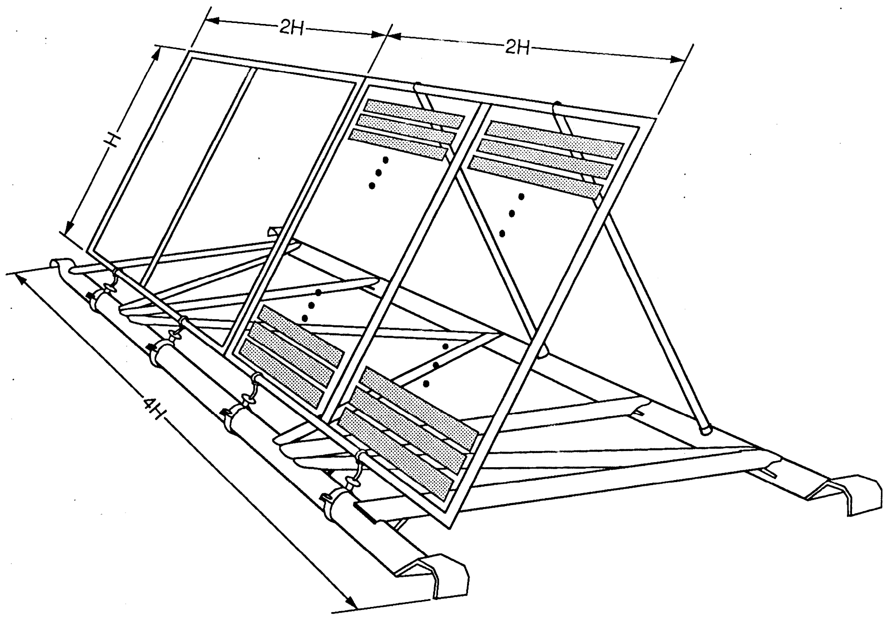

Figure 4: A diagram of a portable windscreen used at a coal-fired power plant (Kinsey and Cowherd, 1992).

- Wet Suppression

These systems apply water or a water solution (using a chemical agent) to the surface from which particulate materials are released. The types of chemical agents that are used can be either surfactants or foaming agents, which are used to bind the fine particles to the aggregate surface thus reducing its pollution potential. This is normally undertaken in processing operations and materials handling (Kinsey and Cowherd, 1992). Foam injection has been used with good success in reducing fugitive emissions. It involves adding a surfactant to a small amount of water, and vigorously mixing the two together. This forms small bubble high energy foam, which is more effective at wetting fine particles than untreated water. It should be noted that watering provides a temporary solution and must be repeated at regular intervals.

- Stabilization of Unpaved Surfaces

Unpaved surfaces such as open areas, storage piles and unpaved roads can be stabilized which leads to a reduction of particulate emissions. Physical stabilization methods can be used which include compaction fills. Vegetative stabilization can be used on materials that are inactive and involves the use of various types of flora to control the effects of wind erosion.

Chemical suppressants may also be used and include the use of salts, wetting agents, petroleum derivatives and plastics.

- Paved Surface Cleaning

Good housekeeping practices involve the periodic removal of exposed dust-producing materials, thus reducing the potential for dust generation. Street cleaning is also a useful method for reducing surface loading, by reducing the amount of debris. Common methods that can be used are mechanical cleaning (sweeping), vacuum cleaning and flushing.

3. POLLUTION CONTROL APPROACHES IN TRANSPORTATION

Transport is recognized as an increasingly significant source of air pollution due to the combustion of liquid fossil fuel and is the fastest-growing source of greenhouse gas emissions in developing countries in particular (Gan, 2003). Vehicular emissions are a function of the vehicle technology and fuel quality. The following sections provide brief descriptions of the tools available control of vehicular emissions.

3.1 Emission Control Technology

3.1.1 Catalysts

The petrol blend used by majority of vehicles has a mixture of aromatic hydrocarbons and paraffins, which combust at very high temperatures in the air. As a result of the incomplete combustion of these compounds there are many harmful exhaust emissions that occur, that include hydrocarbons (or volatile organic compounds), nitrogen oxides (NO_x) and carbon monoxide (CO), which contribute to the formation of ground level smog.

Catalyst technologies have been instrumental in the reduction of tail pipe emissions. A catalyst is a substance that enables a chemical reaction to occur without itself being changed during the reaction. Catalytic converters are vital controls in preventing hydrocarbons, NO_x and CO from entering the atmosphere as the catalyst allows for the combustion of these organic pollutants at lower temperatures that would be occur in the absence of the catalyst (Heck and Farrauto, 2001). There are two main types of catalysts that are in general use in transportation, the oxidation catalyst (2-way) and the oxidation-reduction catalyst (3-way) catalyst (Heck and Farrauto, 2001). The dominant catalyst support for the auto exhaust catalyst is a monolith or honeycomb structure. Figure 5 shows a typical auto catalyst design. Catalysts are effective in the reduction of pollution, reducing the amount of photochemically reactive hydrocarbons by 95% and the ability to reduce the concentrations of carbon monoxide to below 1%.

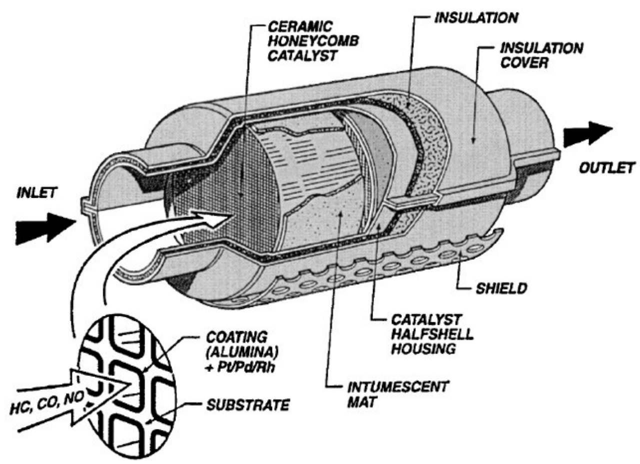

Figure 5: Automotive catalyst structural design with honeycomb support and mounting can (Heck and Farrauto, 2001).

Research and development is now focused on achieving low emission vehicles and a number of new approaches to the use of catalyst are being investigated. Particular focus is on reducing hydrocarbon emissions that occur in the cold start portion of the vehicle operation. Numerous technologies are proposed to control the cold start hydrocarbon emissions. These include, closed-coupled catalysts, hydrogen traps, preheat burners and exhaust gas ignition (Heck and Farrauto, 2001).

3.1.2 Direct Injection Technology

In diesel engines the fuel is injected under high pressure directly into the combustion chamber, which allows for accurate control of fuel use, improving fuel economy. In gasoline-fuelled engines, the fuel is injected directly into the cylinder, allowing the engine to operate at higher air to fuel ratios. Direct injection allows for greater fuel control and lean combustion (Graham, 2005).

3.1.3 Gasoline-Electric Hybrids

There are parallel or series drives that combine performance and efficiency. In the parallel drive systems an internal combustion engine is used to generate electricity that is used to power the electric propulsion motors. In the series system, an internal combustion engine is used to generate electricity that is stored in batteries which is then drawn by the motor for power. This technology allows for rapid acceleration to occur with low emissions occurring. Another feature is that regenerative braking is used, such that when the vehicle slows down or stops, energy is not lost but stored in the batteries (Graham, 2005).

3.1.4 Diesel Particulate Filters

Diesel particulate filters provide one of the most effective methods of reducing particulate emissions from diesel vehicles. The devices are fitted in the exhaust line and collect the particulate matter by filtration, which is then combusted by oxidizing agents in the exhaust gas. Catalysts are used in commercial operations to control temperatures and allow for the application of efficient dust oxidation agents. These devices have been widely applied to large vehicles such as buses and construction equipment, whereas their use in passenger vehicles is still limited (Ntziachristosa *et al*., 2005)

3.2 Fuel Control

3.2.1 Fuel Quality Improvement

Gasoline may be reformulated to reduce the volatility of the mixture. The volatility of fuel is the tendency of fuel constituents to vaporize and thereby escape from the liquid phase. Therefore if the volatility is reduced there will be a reduction in air pollution due to evaporative losses. This reduction is obtained by achieving better octane ratings with the addition of additives such as tetra-ethyl lead (TEL) or oxygenates (oxygen-containing organic compounds) such as methyl tert-butyl ether (MTBE).

TEL has been used as an additive in fuel as a cheap source of octane. Lead is known to have adverse health effects and is also incompatible with control technologies as the active surfaces of catalysts are inactivated by lead compounds. This has led to most countries adopting legislative bans and controls on the lead content in fuel (Bunce, 1994). In South Africa unleaded petrol has been available since 1996. As of January 2006, lead is no longer added to petrol and petrol companies are not marketing leaded fuel (SAPIA, 2006).

Due to such controls on lead other additives such as MTBE have been used as well as aromatic and alkylated hydrocarbons, in order to obtain higher octane ratings. However, there are problems with the use of these additives as the use of aromatic compounds increases the risk of exposure to benzene and MTBE is considered to be hazardous to groundwater supplies (Bunce, 1994).

An alternative to lead additives in petrol is ethanol that is produced by sugar, which is recognized as being a good source of octane. Ethanol is considered a cheaper source of octane and presents a lower health risk. Further, it would create a platform for the formation of biomass-derived fuel systems.

Sulphur levels in diesel fuel have to be controlled so as to lower diesel particulate emissions. In South Africa, there are two grades of diesel that are available which differ based on their sulphur content. The standard grade diesel available has 500 ppm sulphur and the other grade contains 50 ppm sulphur (SAPIA, 2006).

3.2.2 Alternate Fuels

Natural gas is viewed as being a cleaner source of energy as compared to petrol or diesel fuel. It is thought to be useful as natural gas is non-reactive and is not involved in photochemical smog generating reactions. However vehicles would still require catalysts to control the emissions as methane is the major hydrocarbon in the natural gas. Compressed natural gas is thought to be a good alternative fuel for spark-ignition engines, however, sufficient reserves of natural gas are necessary for it to be a serious consideration. Further, compressed natural gas has the potential to allow for greater engine efficiency if the vehicle engine is designed for compressed natural gas operation and is operated with engine control systems, resulting in lower exhaust emissions.

Liquefied petroleum gas (LPG) is also considered as being a clean fuel alternative to gasoline, as it is completely combusted in engines thus reducing its pollutant emissions (Chang *et al*., 2001).

Alternative diesel fuels also exist, these include biofuel and diesel blends such as ethanol-diesel-fuel. These types of bio-diesel fuels can be used as diesel substitutes, requiring little or no modifications to the engine. These blends have been shown to have equal or superior fuel properties to regular diesel fuel (Shi *et al*., 2006).

In South Africa, initiatives are under way to produce cleaner burning fuel. One such initiative is the use the plan to use surplus maize to make biofuel, namely ethanol.

3.3 Clean Fuel Vehicle Technology

Clean fuel vehicles adhere to stringent emission standards. These include Low Emission Vehicle (LEV), Ultra-Low Emission Vehicle (ULEV) and Zero Emission Vehicle (ZEV). Low emission vehicles and ultra low emission vehicles use clean fuel technology and are powered by alternative fuels such as compressed natural gas and liquefied petroleum gas (Hao *et al*., 2006)

An example of a ZEV are electric vehicles, which offer an environmentally friendly opition to urban transportation as they are enabled by high-efficiency electric motors and controllers and are powered by alternative energy sources. These vehicles have no emissions and therefore have the potential to reduce air pollution due to transportation. However, the impediments to the use of electric vehicles are the limited range that is available to the public and the lack of infrastructure to support their usage.

3.4 Fiscal incentives

Fiscal incentives can be employed in the purchase of new cars, where financial subsidies can be applied to encourage the selection of low-emission vehicles. Subsidies can be implemented for in-use vehicles to be part of a retrofit programme that is the installation of devices such as catalytic converters. Owners of older vehicles that are in use that have high emissions should be given financial incentives for retirement or scrapping of their vehicles. Figure 6 shows fiscal incentives can be used during the lifetime of a vehicle. Further, local parking fees or congestion fees can be implemented in urban areas in order to reduce transportation stress (Hao *et al*., 2006).

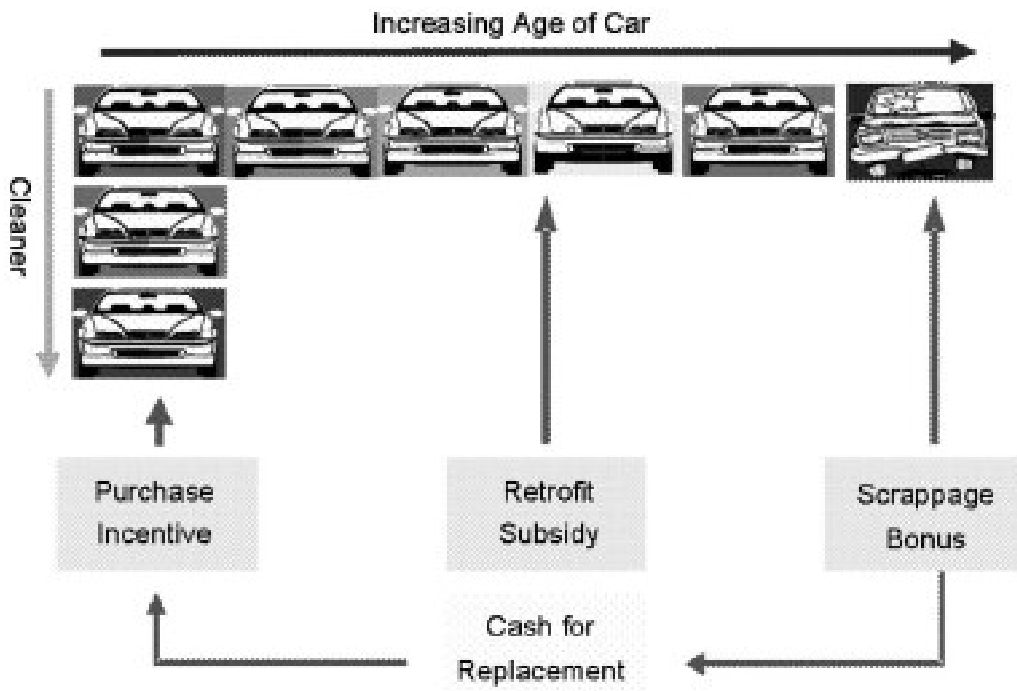

Figure 6: Use of fiscal incentives during the lifetime of a motor vehicle (Hao *et al*., 2006).

3.5 Transportation and Land-Use Planning

An increase and improvement to public transportation will lead to reduced private vehicle use. Traffic flow has to be increase in order to decrease congestion. Methods of achieving this would be though improving road infrastructure. Less congestion will lead to lower average trip time, which will aid in decreasing contaminant emissions. Traffic should also be diverted away from populated areas, which requires land-use planning. This will involve the use of zoning codes, land-use controls and land-use planning policies (Hao *et al*., 2006).

In South Africa, there are plans in the Gauteng province, to relieve congested highways and provide an alternative to road transport through the development of a mass rapid transit railway system *GAUTRAIN*. This is an 80 km railway system intended to link Johannesburg, and Pretoria as well as Sandton and the Johannesburg International Airport (Davy, 2005). It is suggested that the environmental benefits of this project may be neutral, as there will be a reduction in pollution from vehicular transportation but an increase in the pollution that results from the generation of the electricity to power *GAUTRAIN*. An artist's interpretation of GAUTRAIN is presented in Figure 7.

Figure 7: Artist's impression of the Gautrain (Davie, 2005)

4. POLLUTION CONTROL APPROACHES FOR RESIDENTIAL EMISSIONS

Residential emissions occur due to indoor and outdoor sources. Indoor sources include kerosene heating, wood burning, tobacco smoke, asbestos and formaldehyde. Outdoor emissions are primarily those from combustion products (Bunce, 1994).

4.1 Source Control

Source control involves the removal, modification or substitution of the pollutant source. This is particularly relevant for sources such as asbestos, formaldehyde and tobacco smoke. Asbestos and formaldehyde can be controlled by regulations in manufacturing of products that typically use these components. This is an effective way to solve identifiable pollution problems.

Emissions from outdoor sources are typically from petrol and vapours from residential vehicle garages. This can be controlled by tightening the interface between the garage and the house. For example, in homes where the garage is attached to the house, vehicles should not be left with the motor running as this will allow for carbon monoxide infiltration into the home (Bunce, 1994).

4.2 Control of combustible emissions

One method of controlling indoor combustible emissions is to make improvements to the stove that is utilized for combustion. For example, old kerosene space heaters that burn fuel at higher temperatures and therefore release more pollutants, should be replaced. Well constructed and maintained stoves have been shown to have lower pollution emissions. Improvements can also be achieved by applying good engineering, with the installation of catalytic converters, fluidized beds or secondary combustion chambers.

However, such technological controls used to reduce pollution effects from emissions associated with indoor heating are expensive and alternative solutions are required for developing countries. One solution lies in providing heat to groups of buildings from a single source in the form of electricity. In South Africa the mass electrification programme which began in 1991, has electrified over 3.3 million homes (Spalding-Fecher and Matibe, 2003). However, despite electrification, D-grade coal continues to be an important source of energy to low-income households in South Africa (Spalding-Fecher *et al*., 2000).

The technology that is seen as being the least cost option for long-lasting heat, with reduced pollution, is the Basa njengo Magogo fire ignition method. This method uses a top to bottom approach to starting a fire, where coal is placed at the bottom of the container, followed by paper and sticks. The paper is lit to burn the wood and when the wood burns handful amounts of coal are added on the top. This is different from the conventional bottom to top method of starting a fire, where the coal is placed at the top of the fire burning container. The different methodologies for the Basa njengo Magogo and conventional fires are depicted in Figure 8.

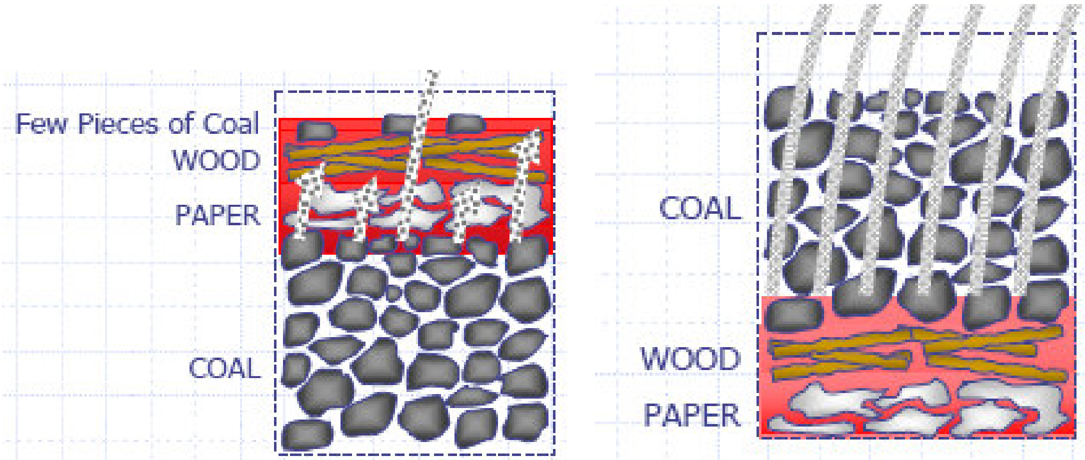

Figure 8: Basa njengo Magogo fire method (left) and conventional fire method (right) (EnerKey, 2006)

The Basa njengo Magogo fire method has been shown to produce a significant reduction in smoke (Fig. 9) and pilot projects carried out by the Department of Mineral and Energy (DME), have shown substantial savings in the amount of coal that is used per month per household.

Figure 9: Smoke emissions using traditional D-grade coal from the Basa njengo Magogo fire (left) and a conventional fire (right) (Wagner *et al*., 2005)

Research has also been focused on the development of low-smoke fuels as an alternative to the burning of D-grade coal that is commonly found in the South African domestic market. Natural low-smoke coals such as anthracite and lean bituminous coal are found in South Africa and the use of such coals could lead to a reduction in indoor emissions. Investigations into the use of D-grade coal and low-smoke fuels in the Basa njengo Magogo method ignition has shown significant reductions in particulate emissions compared with conventional coal fires as shown in Figure 10, with particulate emissions from the conventional coal fire being as much as three times higher than the four Basa njengo Magogo fires.

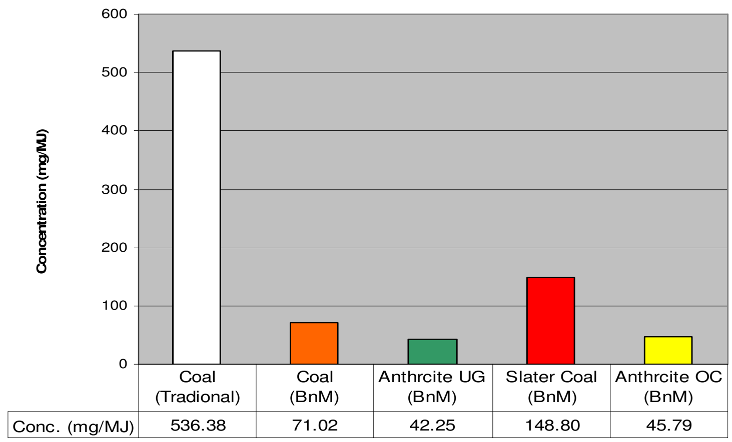

Figure 10: Particulate emissions for the traditional ignited coal fire and four Basa njengo Magogo fires (Le Roux *et al*., 2005)

4.3 Ventilation

Ventilation is a means of diluting or eliminating contaminated air and also serves as a way to properly distribute outside air in the building. Houses may not receive adequate air due to airtight designs, which necessitates mechanical ventilation in order to allow for flow of outside air into the building.

4.4 Air Cleaning

Technological devices can be used to eliminate or reduce pollution emissions. These include filtration devices, which are considered to be the most effective for improving indoor air quality. The use of such devices is most effective when there is source control and adequate ventilation.

4.5 Public Education

This approach would be an economically viable and effective method to controlling pollution. The public would need to be educated and made to fully understand the origin of pollutants and the effects these pollutants could potentially have on their health. Public cooperation will help to reduce their exposure to the pollutants. Targeted technical guidance and training can be provided for audiences who have the potential to influence building air quality or occupant health. These include architects, mechanical engineers, building owners, facility managers and homebuilders.

4.6 Legislation

Legislative controls can be implemented to meet safety concerns. General prohibitions on open burning would result in residents seeking alternatives to burning such as recycling and composting. Outdoor wood-fired boilers and furnaces can be prohibited.

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