# CHAPTER 2

# Literature survey

## 2.1 INTRODUCTION

Petrol is a commodity used worldwide. During its use, carbon dioxide, nitrous oxides and hydrocarbons are emitted as a result of combustion processes taking place in a vehicle. Further emissions, consisting of hydrocarbons, take place during the storage and distribution of petrol due to evaporation.

The hydrocarbons emitted during petrol storage and distribution can be broadly classified as volatile organic compounds (VOCs). VOCs make up a major class of air pollutants and is a broad collective term for different organic compounds. These include pure hydrocarbons, partially oxidized hydrocarbons and organics containing chlorine, sulphur and nitrogen; with most VOCs being toxic and/or carcinogenic (Jo and Song, 2001).

According to Jeffery (1998), there is some discrepancy in the definition of VOCs used in international legislation. In the United States of America a VOC is defined as any compound of carbon that participates in atmospheric photochemical reactions, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides and carbonates and ammonium carbonate. The United Nations Economic Commission for Europe (UNECE) classifies VOCs based on their photochemical ozone creation potential (POCP). POCP is defined as the change in photochemical ozone production due to a change in emission of a particular VOC and can be determined by photochemical model calculations or laboratory experiments (Jeffery, 1998).

In the presence of sunlight, VOCs react with nitrogen oxides forming photochemical oxidants such as ozone. Groundlevel ozone (GLO) is a major component in the formation of smog, can migrate great distances and is a known greenhouse gas. Smog also adversely affects human health, vegetation and materials. Although VOCs and nitrogen oxides occur naturally, anthropogenic sources have greatly increased the concentration in the atmosphere. According to Sangster (1991), VOC emissions originate from:

- industrial and domestic solvents (40%);
- exhaust gases from motor vehicles (25%);
- evaporative and running losses from motor vehicles (10%);
- petrol distribution (3%);
- vehicle refuelling (2%);
- oil refining (3%); and
- 17% from other sources.

Although petrol distribution and vehicle refuelling contributes to only 5% of the total VOC emissions, these emissions are concentrated at petrol bulk storage facilities and service stations, highly frequented by people.

A typical petrol distribution system is shown in Figure 2.1. In South Africa, rail cars and pipelines are mainly used for the transportation of petrol from product storage facilities at refineries to bulk storage tanks at marketing depots, with marine vessels also used in other countries. From the marketing depots road tankers are used to transport the petrol to the service stations.

The control of emissions that occur during the transportation of petrol from bulk storage facilities to the ultimate consumer is represented by three stages, namely (Figure 2.2):

- Stage Ia involves the control of emissions that occur at facilities when road tankers are loaded;

- Stage Ib involves the control of emissions that occur when road tankers unload into service station storage tanks; and
- Stage II involves the control of emissions that are formed during vehicle refuelling.

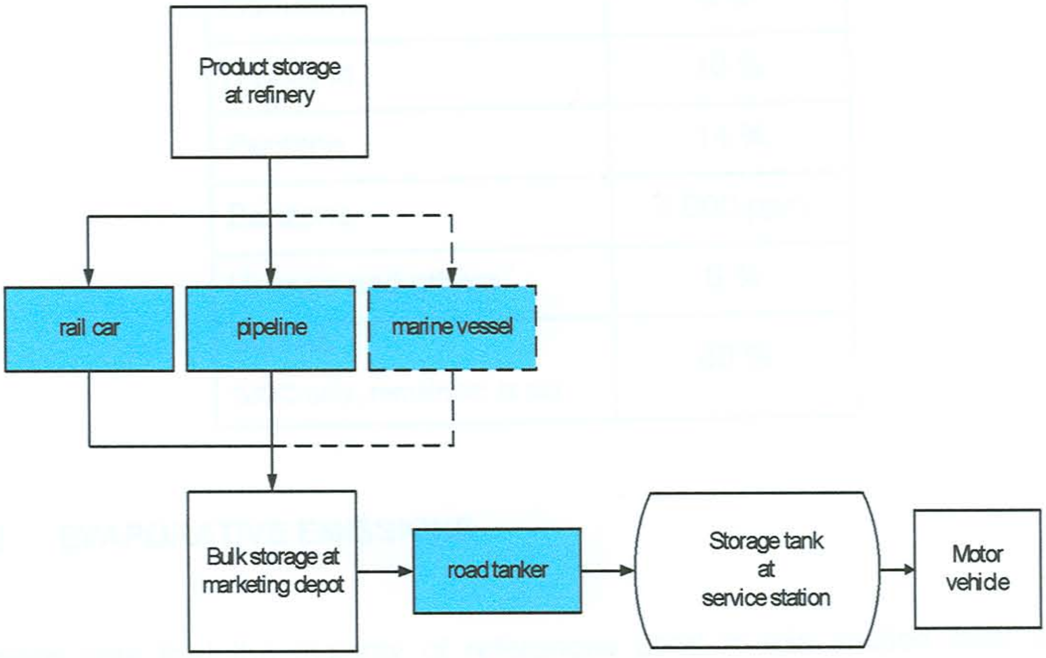

**Figure 2.1** Typical petrol distribution system.

During each of these stages evaporation losses occur, as shown in Figure 2.2. Evaporation occurs whenever petrol is introduced into a tank that has a vapour space (Hadley *et al.*, 1978:13). Unless the resultant vapour (a VOC/air mixture) is contained or suppressed by some means, a loss of product results. The VOC composition of petrol vapour; petrol being a mixture of compounds with different boiling points with the tendency of the lower molecular weight compounds to evaporate; is shown in Table 2.1 (Hansen, 1996).

**Table 2.1** Typical petrol vapour composition (only VOC).

| Compound | Volume |
|---|---|
| Ethane | Traces |
| Propane | 1,5 % |
| Isobutane | 8 % |
| n-Butane | 10 % |
| Pentane | 14 % |
| Benzene | 5 000 ppm |
| Hexane and others | 6 % |
| **TOTAL**<br>(VOC only, remainder is air) | **40 %** |

## 2.2 EVAPORATIVE EMISSIONS

Please note that the majority of references used in this section refer to the publication of Hadley *et al.* (1978). Although other sources were consulted and are available on this particular subject, for example EPA (1995), most of them where found to either refer back to the study conducted by Hadley *et al.* (1978), or do not provide the same in depth coverage of the Hadley study.

According to Hadley *et al.* (1978:8), the average emission from a typical European petrol storage and distribution system, as shown in Figure 2.2, is 0,56 volume % of the petrol distributed. Therefore, for every 1 000 litres of petrol distributed (that is, petrol from the bulk storage facilities to the remainder of the distribution system); 5,6 litres are lost to the atmosphere through evaporative emissions. These emissions can be divided into four types, namely displacement, breathing and withdrawal, filling and refuelling emissions.

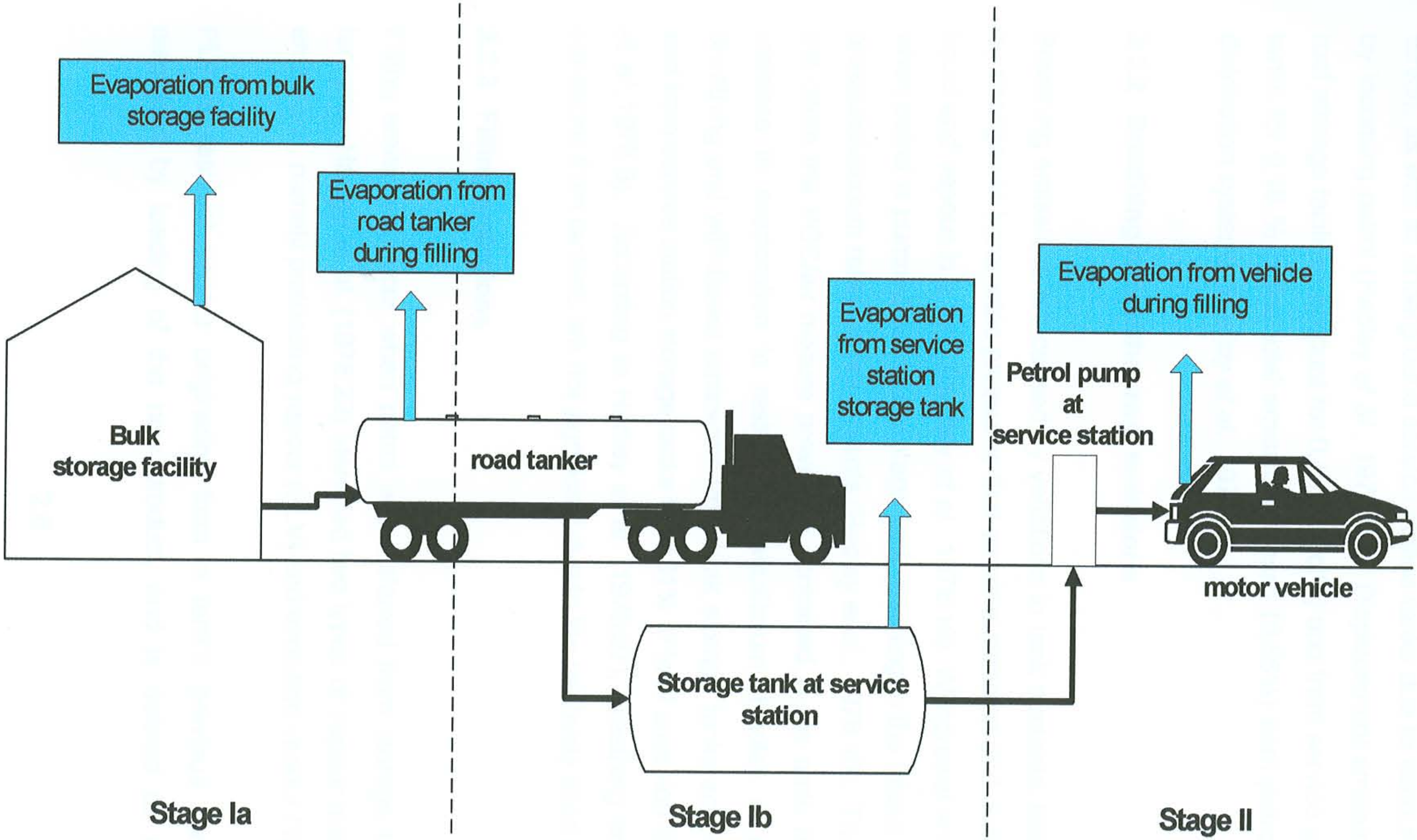

**Figure 2.2** Evaporative emissions from petrol storage and distribution systems.

### 2.2.1 Displacement emissions

Displacement emissions occur from fixed roof storage facilities (bulk storage tanks), as well as underground service station tanks due to vapour displacement by incoming petrol (Hadley *et al.*, 1978:16). Displacement emissions from fixed roof storage facilities account for 0,14 % (vol%) and from service station storage tanks for 0,16 % of the total emissions losses (0,56%) from petrol storage and distribution systems (Hadley *et al.*,1978:8).

### 2.2.2 Breathing and withdrawal emissions

Breathing emissions are caused by variations in tank contents, temperature and by changes in barometric pressures that cause expansion and contraction of the liquid and vapour in a tank (Hadley *et al.*, 1978:16). Withdrawal emissions occur when petrol is pumped out of a storage tank resulting in the intake of air through pressure/vacuum relief valves or vents (Hadley *et al.*, 1978:16). The incoming air will dilute the VOC/air mixture previously contained in the tank, resulting in an increase in evaporation to restore the equilibrium (Hadley *et al.*, 1978:16). Breathing and withdrawal emissions from bulk storage tanks account for 0,02% and from service station storage tanks for 0,01% of total emission losses (Hadley *et al.*,1978:8). According to Hadley *et al.* (1978:27), breathing and withdrawal emissions from tankers are not significant due to the relatively short transit times.

### 2.2.3 Filling emissions

Filling emissions occur when petrol is transferred from storage tanks to road tankers. Hadley *et al.* (1978:23) identified two types of vapour making up filling emissions, namely preloading vapour (PLV) and evolution vapour ($V_e$).

PLV is residual vapour originating from a tank's previous contents, being displaced by loading of the new product, and is defined as a fraction or percentage of full saturation, $C_p$. According to Hadley *et al.* (1978:24), typical $C_p$ values are:

- $C_p$ less than 1% ($C_p < 0{,}01$) when the previous contents of a road tanker were a non-volatile product;
- $C_p$ between 10% and 20% ($0{,}1 < C_p < 0{,}2$) when the previous contents of a tanker were discharged completely at one point;
- $C_p$ between 30% and 50% ($0{,}3 < C_p < 0{,}5$) when the previous contents were discharged at several occasions; and
- $C_p$ between 90% and 100% ($0{,}9 < C_p < 1{,}0$) when the contents of a tanker were discharged at a service station tank that allows for vapour return.

Evolution vapour ($V_e$) evaporates from the product itself when it is being loaded. Petrol can be loaded into a road tanker via top splash loading, submerged top loading or bottom loading. Most $V_e$ evaporation takes place during splash loading when the turbulence in a tank is at its peak. In order to estimate $V_e$, a parameter $V_B$ is used to represent the amount of splashing in a tanker during filling. $V_B$ is equal to the fraction of the original tank atmosphere that is assumed to be completely saturated during loading. Typical values for $V_B$ are (Hadley *et al.*, 1978:25):

- $V_B = 0{,}4$ for top splash loading,
- $V_B = 0{,}15$ for submerged top loading, and
- $V_B = 0{,}13$ for bottom loading.

Hadley *et al.* (1978:26) derived Equation 1 for the calculation of tanker filling emission ($E_f$) as a percentage of the petrol loaded:

$$E_f = f \times C_s \left[ C_p + V_B \left( \frac{1 - C_p}{1 - C_s} \right) \right] \qquad [1]$$

where: $E_f$ = filling emission (liquid equivalent) expressed as a percentage of the volume of liquid loaded;

$f$ = liquid to vapour volume equivalence factor ($f$ = 0,45 under European conditions, as derived in Appendix A);

$C_s$ = concentration of petrol vapour under equilibrium conditions (fully saturated), equal to the petrol true vapour pressure in bars (see Section 2.3, Hadley *et al.*, 1978:42);

$C_p$ = the average preloading vapour concentration expressed as a fraction of full saturation; and

$V_B$ = parameter representing the amount of splashing.

Hadley *et al.* (1978:48) calculated the values for emissions during tanker filling shown in Table 2.2, assuming that petrol from the tanker was discharged at one point only.

**Table 2.2** Filling emissions from road tanker loading.

| Activity | $C_p$ | $V_B$ | $E_f$ (%) |
|---|---|---|---|
| Top splash loading | 0,15 | 0,40 | 0,105 |
| Top submerged loading | 0,15 | 0,15 | 0,055 |
| Bottom loading | 0,15 | 0,13 | 0,050 |

### 2.2.4 Emissions from vehicle refuelling

When a motor vehicle is being refuelled at a service station the incoming petrol displaces the petrol vapour in the fuel tank, causing it to escape into the atmosphere. These emissions contribute to 0,18 volume % of the total emissions from petrol storage and distribution systems (Hadley *et* al., 1978:28).

## 2.3 FACTORS AFFECTING EVAPORATION

The main factors affecting evaporation are product (liquid petrol) properties, liquid/vapour interface areas and turbulence in the relevant liquid and vapour. Product properties that play a role during evaporation are vapour pressure and temperature. The higher either the vapour pressure and/or the temperature of a liquid, the higher the expected rate of evaporation. The vapour pressure of a petroleum product can be determined by using the Reid vapour pressure (RVP) method where RVP is also a generic term used for petrol volatility (EPA, 2003a). RVP is a standard laboratory method that measures the Reid vapour pressure of a substance at a temperature of 100ºF, or 37,8 °C (Hadley *et al.*, 1978:13). According to Hadley *et al.* (1978:14), the RVP is about 10% less than the true vapour pressure. Figure B.1 in Appendix B shows a nomogram for the determination of true vapour pressure from RVP at any temperature for different petroleum products (Hadley *et al.*, 1978:29).

The rate of evaporation is also proportional to the area of the liquid/vapour interface (Hadley *et al.*, 1978). By decreasing the liquid/vapour interface area, the amount of evaporation will decrease due to the limited amount of vapour space above the liquid (Hadley *et al.*, 1978:15).

Turbulence in the liquid and/or vapour will increase the rate of evaporation and reduces the time necessary to reach 100 % saturation in the vapour space via two mechanisms (Hadley *et al.*, 1978:15). When light hydrocarbons evaporate, the thin liquid surface layer becomes momentarily deficient in these molecules, slowing the rate of evaporation. However, when fresh petrol is loaded, the light hydrocarbons move to this region via diffusion and evaporation continues. This process is accelerated by mixing and/or turbulence in the liquid.

In the vapour space above the liquid, the hydrocarbon molecules are heavier than air and tend to accumulate as a layer just above the liquid surface, suppressing further evaporation (Hadley *et al.*, 1978:15). Turbulent movements in the vapour space caused by thermal convection currents or pressure vacuum valve air intakes accelerate evaporation.

## 2.4 CONTROL OF EMISSIONS

Emissions from petrol storage and distribution systems can be controlled in accordance to the hierarchy of methods presented in Figure 2.3. The hierarchy of these methods, namely prevention, minimisation, recovery and finally treatment; represents the ideal hierarchical order of managing emissions from petrol storage and distribution systems.

### 2.4.1 Emission prevention and minimisation

The same techniques are followed in both the prevention and minimisation of emissions. These include decreasing the volatility of petrol (by lowering RVP or introducing RVP limits) and its temperature, vapour balancing, minimising the liquid/vapour interface area and reducing turbulence.

It is common practice in large parts of Europe and North America to blend petrol to a predetermined RVP limit, depending on the season (Kojima and Mayorga-Alba, 1998). For summers the RVP of petrol is typically limited to between 48 kPa to 55 kPa and for winters between 70 kPa to 90 kPa, resulting in reduced emissions (Kojima and Mayorga-Alba, 1998). Although there has been a move in lowering the RVP limits generally, lower limits exist to avoid combustion problems in motor vehicles (Hansen, 1996).

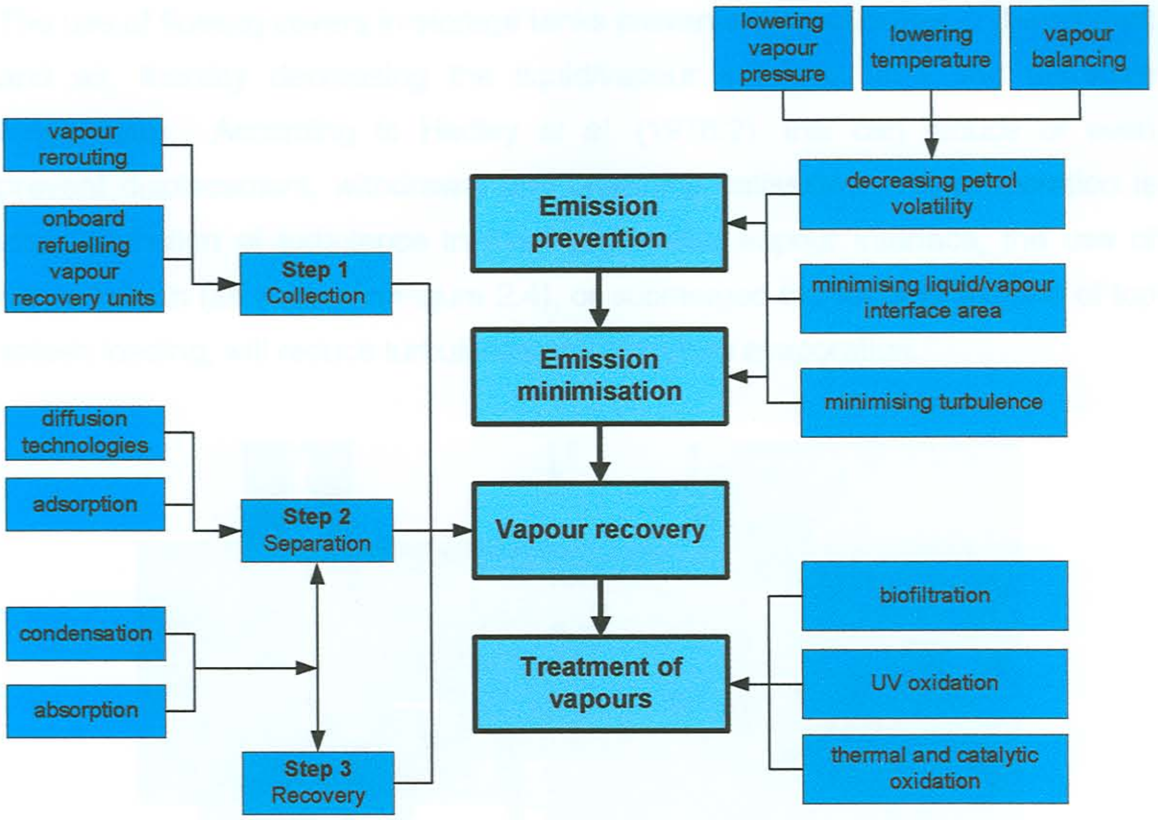

**Figure 2.3** Hierarchy of vapour emission control.

Lowering the temperature that petrol is stored at will decrease the true vapour pressure and therefore decrease the amount of evaporation. Methods in reducing petrol temperature include painting of storage tanks in sun reflecting colours (for example, silver and white) and the use of underground storage tanks.

Vapour balancing involves a vapour retrieval system whereby vapour displaced from tanks/tankers receiving petrol is returned to the tanks/tankers delivering petrol. For example, vapour formed during vehicle refuelling is rerouted back to the service station storage tank. The liquid inside the service station storage tank will only evaporate until the vapour in the air space above the liquid reaches a certain pressure, therefore less evaporation will occur due to the returned vapour (Jeffery, 1998).

The use of floating covers in storage tanks prevents contact between the product and air, thereby decreasing the liquid/vapour interface area and therefore evaporation. According to Hadley *et al.* (1978:2), this can reduce or even prevent displacement, withdrawal and breathing emissions. As evaporation is also a function of turbulence in the liquid and/or vapour interface, the use of either bottom (as shown in Figure 2.4), or submerged top loading, instead of top splash loading; will reduce turbulence and therefore evaporation.

**Figure 2.4** Bottom loading.

### 2.4.2 Vapour recovery

Vapour recovery is a broad term for a process where petrol vapour, which would normally escape into the atmosphere, is recaptured and recovered into the liquid state. It involves the:

Step 1 collection of VOCs/air mixture,
Step 2 separation of VOCs from air, and
Step 3 the recovery of the separated VOCs into liquid state.

Recovery systems generally consist of vapour collection or balancing systems; using either condensation, absorption, diffusion and/or adsorption technologies to recovery vapour emissions.

***Collection of vapour***

Vapour collection (Step 1) can take place during either or all of the three stages of the petrol storage and distribution system identified in Section 2.1. Stage I collection involves the collection of vapour formed during road tanker loading at terminals (Stage Ia) and unloading at service stations (Stage Ib). Road tankers are modified to allow for the collection/rerouting of vapour from the road tanker to a vapour recovery unit (VRU) (Stage Ia) and from the service station storage tank to the road tanker (Stage Ib). Modifications involve the closing of vents on a road tanker and service station storage tank and the addition of piping and equipment to allow for vapour collection/rerouting.

The collection of vapour during Stage II involves vapour formed during vehicle refuelling. Two methods can be used. The first method involves the return of vapour to the service station storage tank when refuelling by using a specially modified petrol-filling nozzle, as shown in Figure 2.5. The second method is when the emissions are captured on the vehicle itself by Onboard Refuelling Vapour Recovery (ORVR) units, usually consisting of carbon canisters (Jeffery, 1998).

Once the vapour has been collected, various processes or combinations of processes can be used to separate and recover the vapour (Steps 2 and 3). These include condensation, absorption, diffusion and adsorption.

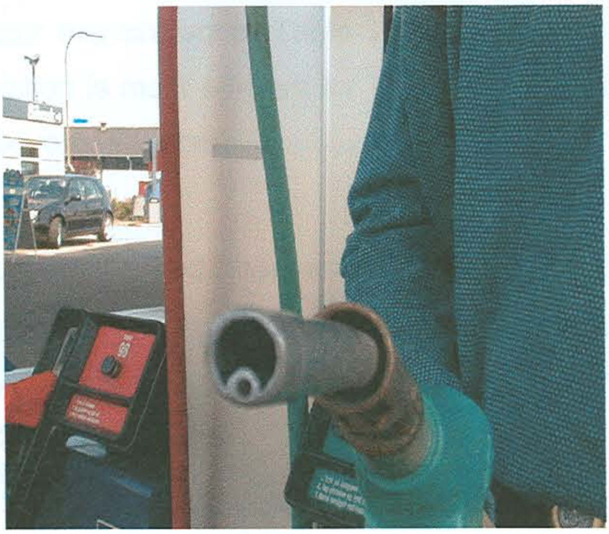

**Figure 2.5** Petrol nozzle at service station adapted for the collection of vapour.

### *Condensation*

Condensation of a vapour into liquid can be achieved by compression (increase in pressure) or cooling (decrease in temperature), with separation and re-condensation taking place in a single process as shown in Figure 2.6. However, compression is normally ruled out due to risk of explosion (Jeffery, 1998). Cooling can be achieved by either mechanical refrigeration or using liquid nitrogen (cryogenic condensation) as the cooling medium (Jeffery, 1998).

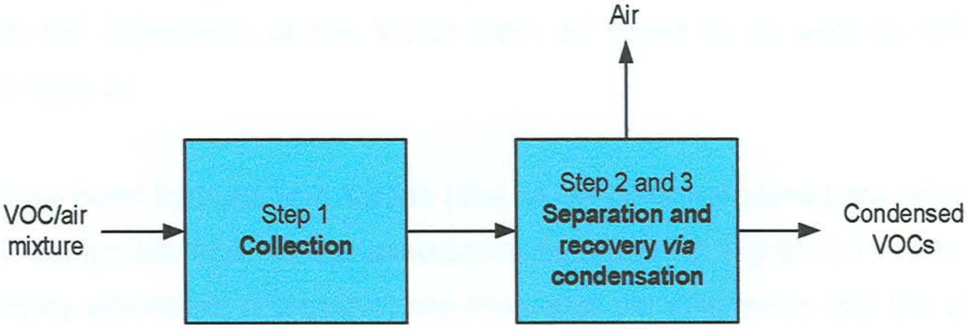

**Figure 2.6** Flowdiagram for condensation as vapour recovery process.

The advantages and disadvantages of using condensation for separation and recovery of petrol vapour are shown in Table 2.3. According to Ruddy and Carroll (1993), condensation is most efficient for VOC recovery at relatively high VOC concentrations (above 5 000 ppm).

**Table 2.3** Advantages and disadvantages of condensation.

| Advantages | Disadvantages |
|---|---|
| Moderate efficiencies, 50-90% (Ruddy and Carroll, 1993). | Energy requirements of mechanical refrigeration are high (Jeffery, 1998). |
| Simple, flexible, safe process (Jeffery, 1998). | Nitrogen source needed for cryogenic condensation. |
| Can handle wide range of products (Jeffery, 1998). | May result in the generation of a wastewater stream (Dunn and El-Halwagi, 1996). |

### *Absorption*

The application of absorption is well known in the chemical process industry. When a vapour stream containing VOCs is brought in contact with a hydrocarbon liquid, the VOCs in the vapour will be absorbed into the liquid due to molecular forces. The absorption of the VOCs in the vapour depends on the vapour pressure and the temperature of the absorbent, as well as the liquid-vapour equilibrium. In the case of absorption as vapour recovery method, absorption is used for the separation of the VOCs from air (Step 2) as well as the final, recovery Step 3.

Low boiling point hydrocarbon liquids (like crude oil or kerosene) are often used for VOC separation from air via absorption, as shown in Figure 2.7. The VOCs and primary absorbent (kerosene) are then split via distillation and the primary absorbent recycled and used again (see Figure 2.7). The VOCs is then absorbed into petrol (secondary absorbent) and thereby recovered into the liquid state. Absorption is also used for recovery after separation methods like adsorption or with the use of membranes.

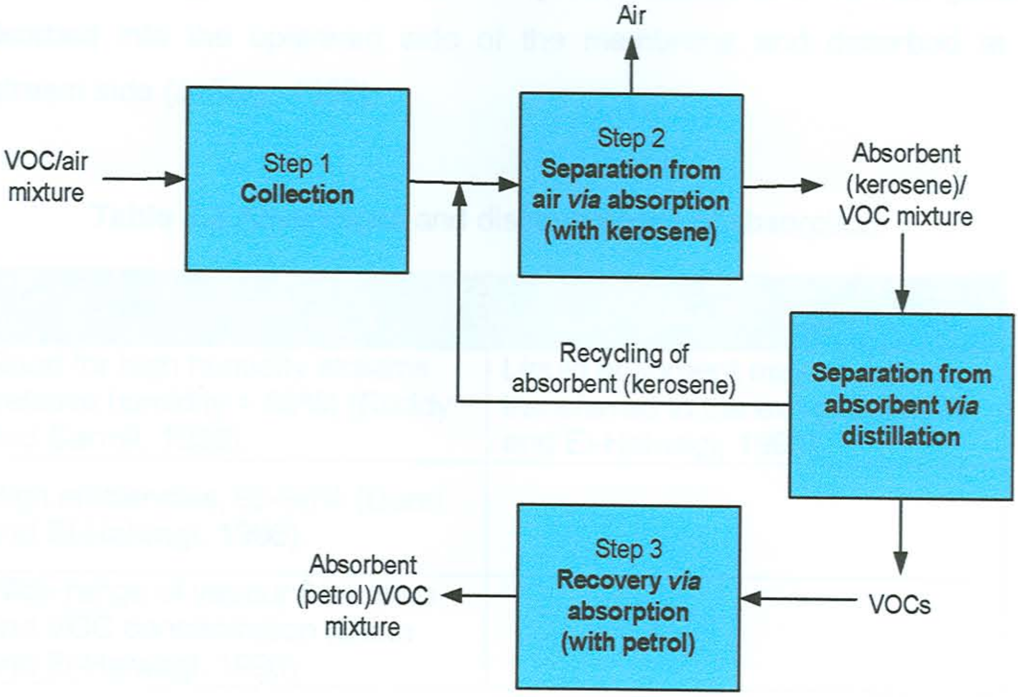

**Figure 2.7** Flowdiagram for absorption vapour recovery process using kerosene and petrol as primary and secondary absorbents respectively.

Advantages and disadvantages of absorption as a vapour separation and recovery method are shown in Table 2.4. Absorption can be used for high vapour flows and VOC concentrations ranging between 500 ppm to 5 000 ppm (Ruddy and Carroll, 1993).

### *Diffusion technologies*

The application of diffusion technologies such as membranes for the control of petrol vapour is relatively new. The membranes separate VOCs from the air that can then be recovered by absorption or condensation, as shown in Figure 2.8. There are currently two types of membranes used for the separation of VOCs from air, namely diffusion membranes and solubility membranes (Jeffery, 1998). Diffusion membranes act like a sieve where the molecules in the vapour are separated according to their size. Solubility membranes allow certain gases to be adsorbed into the upstream side of the membrane and desorbed at the downstream side (Jeffery, 1998).

**Table 2.4** Advantages and disadvantages of absorption.

| Advantages | Disadvantages |
|---|---|
| Good for high humidity streams (relative humidity > 50%) (Ruddy and Carroll, 1993). | Liquid absorbent may be transferred to the exit gas (Dunn and El-Halwagi, 1996). |
| High efficiencies, 95-98% (Dunn and El-Halwagi, 1996). | |
| Wide range of vapour flow rates and VOC concentration (Dunn and El-Halwagi, 1996). | |

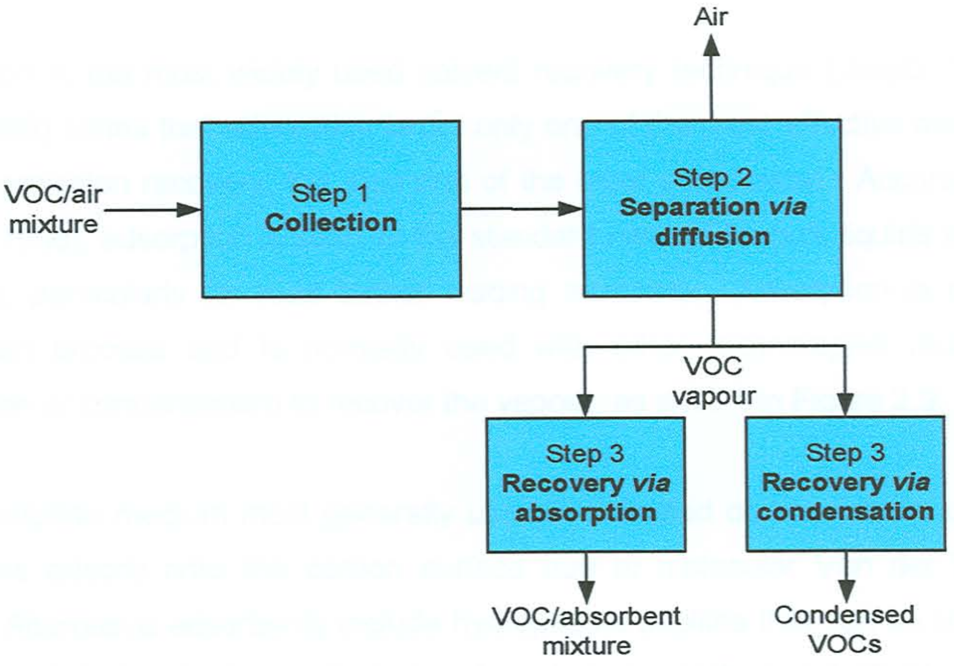

**Figure 2.8** Flowdiagram for using diffusion technology as vapour recovery process.

Advantages and disadvantages of using membranes for VOC/air separation are shown in Table 2.5.

**Table 2.5** Advantages and disadvantages of diffusion technologies.

| Advantages | Disadvantages |
|---|---|
| Recovery of between 95 and 99% (Ohlrogge, Peinemann, Wind and Behling, 1990). | Constant vapour flow rates are necessary, but buffer tanks are a major safety concern. |
| Safe process and operational flexibility (Jeffery, 1998). | High power consumption (Jeffery, 1998). |
| Very wide range of product handling, for example, hydrogen sulphide, acetone, methyl tertiary butyl ether (MTBE), ethyl acetate. | Post treatment system needed in the case of very high emission standards (Ohlrogge *et al.,* 1990). |

***Adsorption***

Adsorption is the most widely used solvent recovery technique (Jacob, 1991). Ruhl (1993) states that adsorption is not only one of the most effective methods of VOC emission recovery, but also one of the most economical. According to Jeffery (1998), adsorption is seen as the standard method for bulk liquids vapour recovery, particularly for road tanker loading terminals. Adsorption is only a separation process and is normally used with other technologies (such as absorption or condensation) to recover the vapour, as shown in Figure 2.9.

The adsorption medium most generally used is activated carbon, where certain molecules adsorb onto the carbon surface due to molecular Van der Waals forces. Alternative adsorbents include hydrophobic zeolites that can be used at higher humidity levels than activated carbon, but at a higher cost (Ruhl, 1993). The VOCs are recovered by regeneration or desorption of the adsorption medium. Two regeneration technologies are currently in use, namely:

- Thermal regeneration

Steam, hot nitrogen and hot flue gases are some of the heat sources used for this type of regeneration. According to Young and Tuttle (1997), thermal regeneration has been the traditional method for maintaining the effective working capacity of activated carbon in many vapour phase applications. *In situ* thermal systems usually have at least three carbon adsorber vessels, one on-stream receiving the vapour, the second being heated for regeneration and the third being cooled before being used again (Young and Tuttle, 1997). The major advantage of thermal regeneration is the large effective working capacity that is created by this regeneration process (Young and Tuttle, 1997). The process is used in applications where the contaminant concentration is low and with high gas temperatures. Disadvantages of thermal regeneration are the time required to heat and cool the carbon; and mechanical damage to the activated carbon because of heating and cooling cycles resulting in more frequent replacement of the carbon.

- Pressure swing and purge regeneration

Pressure swing regeneration involves the decrease in system pressure to desorb the VOCs and a purge stream aids in the removal of VOCs from the carbon bed. This system only requires two carbon beds, the one being on-stream receiving contaminated gas while the second is being regenerated. Two types of pressure swing methods have been used, firstly where adsorption takes place at elevated pressure and the pressure is lowered to regenerate the carbon. Secondly where adsorption takes place at or near atmospheric pressure and during regeneration the pressure is reduced by mechanical means (vacuum pump). According to Young and Tuttle (1997), the benefits of pressure swing regeneration is the longevity of the carbon (up to 12 years), the flexibility of the system, simplicity of the system (only two carbon beds) and the fact that no contaminated condensate has to be treated.

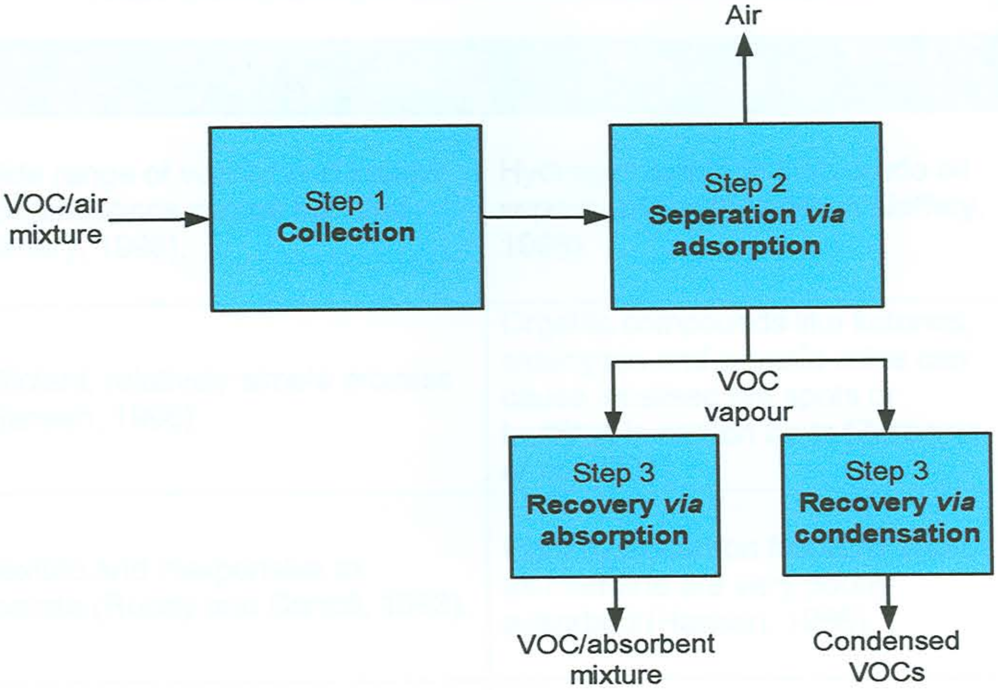

**Figure 2.9** Flowdiagram for using adsorption as vapour recovery process.

Advantages and disadvantages of adsorption as a separation method are shown in Table 2.6.

### 2.4.3 Treatment of vapour

Technologies such as biofiltration, UV oxidation, thermal and catalytic oxidation are some of the methods that could be used to treat vapour containing VOCs. These methods are destructive but in some cases remain the only viable option. Destructive methods have been losing ground with legislative agencies because of the formation of carbon dioxide (a greenhouse gas) and the loss of useful product. According to Moretti and Mukhopadhyay (1993), the selection of destruction versus recovery technologies is usually based on the economic benefit of recovering the VOCs in the waste stream.

**Table 2.6** Advantages and disadvantages of adsorption.

| Advantages | Disadvantages |
|---|---|
| Wide range of vapour and vapour concentrations can be handled (Jeffery, 1998). | Hydrogen sulphide from crude oil vapour poison the carbon (Jeffery, 1998). |
| Efficient, relatively simple process (Hansen, 1996). | Organic compounds like ketones, aldehydes and organic acids can cause localised hot spots or bedfires in carbon beds (Zerbonia *et al.*, 2001). |
| Flexible and inexpensive to operate (Ruddy and Carroll, 1993). | Light hydrocarbon fractions such as methane are very poorly adsorbed (Hansen, 1996). |
|  | Carbon performance decreases with high humidity vapour streams (relative humidity > 50%). |

Aizpuru *et al.* (2001) concluded that the use of biofiltration is an attractive process for VOC treatment, with a high removal efficiency, that could be improved. It involves the use of a packed column that is seeded with microorganisms that allow for the biodegradation of the VOC to water and carbon dioxide. Packing materials include peat, compost, soil, heather branches, bark and more recently sludge from sewage treatment plants (Aizpure *et al.*, 2001).

UV oxidation uses oxygen-based oxidants (ozone and peroxide) to convert VOCs into carbon dioxide and water in the presence of UV light (Moretti and Mukhopadhyay, 1993).

According to Jacob (1991), thermal oxidation (incineration) is one of the most popular methods of dealing with VOCs in industrial exhaust streams. Thermal oxidizers can achieve efficiencies between 95 and 99%, operating at temperatures between 700 and 1 000 °C (Ruddy and Carroll, 1993). Catalytic oxidizers operate at lower temperatures (370 – 490 °C) due to the use of catalysts, achieving a removal efficiency of between 90 and 95% (Rudy and Carroll, 1993). Thermal and catalytic oxidizers are the most popular VOC treatment methods in use today, because of their broad applicability to a wide range of VOC emission streams (Moretti and Mukhopadhyay, 1993). These methods are technically simpler than vapour recovery, but require a high level of safety considerations (Jeffery, 1998).

## 2.5 LEGISLATION REGARDING EVAPORATIVE EMISSIONS

In November 1991, the Protocol to the Convention on Long-range Transboundary Air Pollution on the Control of Emissions of VOCs (shortened VOC protocol) was adopted and became effective on 29 September 1997 (UNECE, 2002). It forms part of the Geneva Convention on Long-range, Transboundary Air Pollution that was established and undersigned in 1979 by the United Nations Economic Commission for Europe (UNECE) (Fenger, 1999). UNECE includes countries in North America, Europe and Central Asia. The VOC protocol specified three options for emission reduction targets of which one had to be selected by a country, either upon signature or upon ratification. These options were:

| | |
|---|---|
| Option 1 | 30% reduction in emissions of VOCs by 1999, using a year between 1984 and 1990 as basis. |
| Option 2 | The same reduction as for Option 1 within a Tropospheric Ozone Management Area (TOMA), ensuring that by 1999 total national emissions do not exceed 1988 levels. |

Option 3 Where emissions in 1988 were low enough not to exceed certain specified levels, countries may opt for a stabilisation at that level of emission by 1999.

Table 2.7 shows the options selected by the various member countries of UNECE.

**Table 2.7** Options selected by countries regarding 1991 VOC Protocol.

| Option | Base year | Countries |
|---|---|---|
| 1 | 1984 | Liechtenstein, Switzerland, United States of America. |
|  | 1985 | Denmark. |
|  | 1988 | Austria, Belgium, Estonia, Finland, France, Germany, Netherlands, Portugal, Spain, Sweden, United Kingdom. |
|  | 1990 | Czechoslovakia, Italy, Luxembourg, Monaco, Slovakia. |
| 2 | - | There are TOMAs in Norway and Canada. |
| 3 | - | Bulgaria, Greece and Hungary. |

Legislation in Europe and the USA aimed at reducing the emissions from petrol storage and distribution facilities, to comply with the above mentioned VOC protocol, are limiting VOC emissions by the gradual extension of controls down the fuels distribution chain (Munn and Kornelius, 2002). VOC legislation and regulations for Europe and the United States of America are summarised in Sections 2.5.1 and 2.5.2. An overview of air pollution legislation in South Africa is given in Section 2.5.3.

### 2.5.1 Overview of VOC emission legislation in Europe

Although minimum standards of emission control have been agreed between countries in Europe, the method of application is left to individual countries and differences do occur (Munn and Kornelius, 2002). The European directive on Integrated Pollution Prevention and Control (IPPC) (Directive 96/61/EC) governs pollution prevention in the industrial sector. The basis for the directive is the use of best available technology (BAT). The first major legislation in Europe regarding VOC emissions was under the German TA Luft 1981 legislation where VOC emissions could not exceed 150 mg/m$^3$ vented (Sangster, 1991). This remains the most stringent legislation regarding allowed VOC emissions.

In some European countries (Sweden, Denmark) the oil industry voluntarily installed Stage Ia and Ib control facilities to pre-emp perceived legislation at that time (Sangster, 1991). The EU 94/63/EC Directive of 1995 requires the control of VOC emissions resulting from the storage and distribution of petrol from bulk storage facilities to service stations (Stage I). Countries within the EC were required to make the directive law by December 1995 (Jeffery, 1998). According to the Institute of Petroleum (2002), Directive EU 94/63/EC made vapour recovery a requirement from December 1998 for existing terminals loading more than 150 000 ton per annum and for service stations handling more than 1 000 m$^3$ per annum.

### 2.5.2 Overview of VOC emission legislation in the USA

The regulatory environment in the USA is highly structured and a combination of regulations and permits are used to achieve results (Munn and Kornelius, 2002). The Environmental Protection Acency (EPA) enacted the first control measures dealing with Stage I operations in 1970 (Sangster, 1991). Stringent controls are applied in certain areas of petrol distribution, such as road tanker loading and unloading, and vehicle refuelling (Jeffery, 1998). The EPA also established national ambient air quality standards (NAAQSs) to limit levels of criteria pollutants. The criteria pollutants are particulate matter, sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide and lead. Geographical areas that meet NAAQSs are classified as attainment areas, and the others as non-attainment areas. The classification of these areas determines the type and the severity of emission control that has to be used.

The Clean Air Act (CAA) of 1990 has six titles that, *inter alia*, direct the implementation, maintenance and enforcement of the NAAQSs through a variety of mechanisms. For example, Title I requires the reduction of VOC emissions in areas that exceed the NAAQS for ozone of 0,08 ppm as an 8 hour average (Fenger, 1999) and Title III addresses the reduction of hazardous pollutants.

The Code of Federal Regulations (CFR) contains regulations for the achievement of the CAA and its amendments objectives and is divided into 50 titles. Almost all environmental regulations appear in Title 40 (EPA, 2003b). For example, Regulation 40CFR63 (CFR, 2001), Subpart XX (Standards of Performance for Bulk Gasoline Terminals) stipulates that emissions from vapour collections systems may not exceed 35 mg total organic compound (TOC) per litre of petrol loaded.

### 2.5.3 South African air pollution legislation

Currently South Africa does not have legislation regarding the use of vapour recovery systems for VOC emission control *per se*. In addition, the country does not have established ambient air quality standards or an overall approach that includes ambient air monitoring and emission inventories to enhance the level of air quality on a country-wide basis (Lents and Nikkila, 2000). The Atmospheric Pollution Prevention Act (No 45 of 1965), as amended, is the primary mechanism in South Africa for the management and control of air pollution. Although part of this act deals with the control of emissions from motor vehicles (only diesel), the bulk storage of liquid petroleum products (scheduled process, no 14(b)) and hydrocarbon gas is classified as an noxious or offensive gas, it does not specifically include the control of VOC emissions from the evaporation of petrol during loading, unloading or vehicle refuelling by the mandatory use of vapour recovery processes. However, the guidelines used by the Chief Air Pollution Control Officer (CAPCO) for the issue of permits to operators of such processes states, *inter alia*, that a fugitive emission monitoring and maintenance programme must be implemented at all plants. This should also include positive identification of all sources of VOCs, estimation of the emission rate, as well a programme of preventative maintenance to minimise such emissions (CAPCO, *s.a.*). Fugitive emissions include the release of gases from anthropogenic activities, such as the storage and transportation of fuel, and therefore the emissions from the storage and distribution of petrol falls under the guidelines discussed above.

Apart from the present drafting of new air legislation, namely the Air Quality Bill (SA Bill, 2003), that makes transitional provision for ambient ozone ($O_3$) concentrations; VOC emissions are only addressed (partly, together with other pollutants) via the Refinery Managers Environmental Forum (RMEF), which was formed in 2000 by representatives of the major oil fuels manufacturing facilities (Caltex, Engen, Natref, Petro SA, Sapref and Sasol). The forum encourages the sharing of ideas and practices with the aim of promoting a standard of environmental governance in the refineries (Lents and Nikkila, 2000). Due to the formation of the RMEF the refinery industry has become involved in Good Neighbour Agreements (GNAs) and Environmental Management Co-operation Agreements (EMCAs) that have the potential to reduce VOC and other emissions. However, Lents and Nikkila (2000) state that this is a short term solution as these agreements only focus on air quality issues on a localised scale.

Notwithstanding the present state of legislation with regard to VOC emission control, South Africa also struggles with all the environmental constraints associated with a developing country. These include insufficient resources, both manpower and financial, for the effective enforcement of environmental legislation (Friend, 2001). This view is confirmed by Munn and Kornelius (2002), who stated that the biggest difference between South Africa and other countries is the local lack of capacity and resources available, to the government, in order to manage air quality issues. It is unlikely that South Africa will provide the level of resources available elsewhere so it is important that South Africa learn from other countries those measures that can be adopted that are the most successful and require the least resources to implement (Munn and Kornelius, 2002).