CHAPTER 3

Process description and experimental setup

3.1 INTRODUCTION

The Engen refinery in South Africa is located next to the Wentworth residential area in Durban (Figure 3.1). It is the second largest refinery in South Africa, processing 20 million litres of crude oil per day. The products from the refinery are distributed by the Engen logistics and supply division, which has a network of 79 depots throughout Southern Africa, *via* the bulk storage and loading facility situated next to the refinery. The facility provides petrol to service stations by using road tankers as transport method; loading approximately 1,2 million m^3 petrol per year (Cool Sorption, 2001).

Figure 3.1 The Engen (Wentworth) refinery with the bulk storage and loading facility at the foreground.

A vapour recovery unit (VRU) was constructed and installed during 2001 in order to collect the vapour at the facility for processing at the recovery unit. This VRU was used for the experimental work conducted in this dissertation. In this chapter an overview of the unit and associated modifications to road tankers and loading facilities, as well as the carbon vacuum adsorption (CVA) process used to recover the collected vapour, is given. Thereafter the actual experimental setup is described.

3.2 PROCESS DESCRIPTION

3.2.1 Facility and road tanker set-up

There are 9 loading bays at the Engen loading facility for the loading of road tankers. Bays 1 to 2 are used for the loading of other products (like paraffin) and bays 3 to 9 for mainly petrol loading. A vapour header, as shown in Figure 3.2, has been added to the facility for the rerouting of the vapour from the road tankers to the VRU. At each of bays 3-9, vapour return hoses have been installed with adaptors to connect to the road tankers (Figure 3.3). The hoses are connected to vapour return lines (Figure 3.3), which in turn are connected to the vapour header.

Figure 3.2 Loading racks and vapour header leading to VRU.

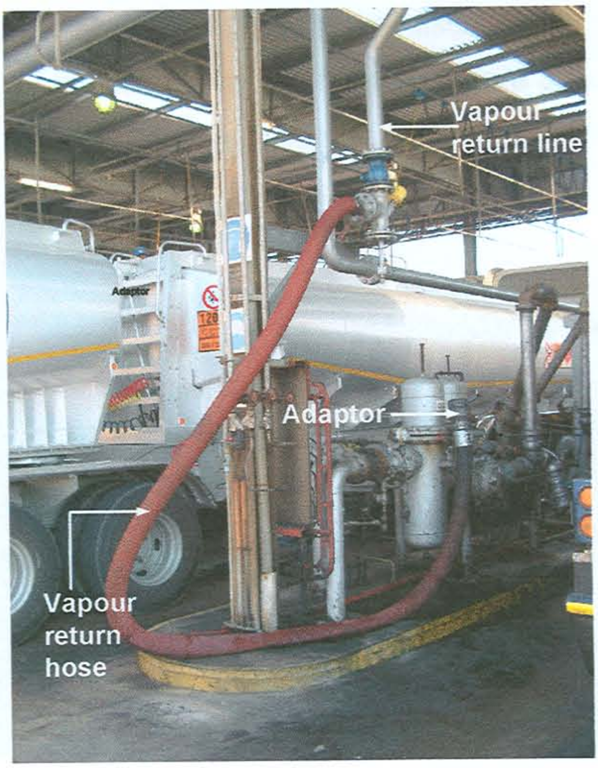

Figure 3.3 Vapour return hose for the transfer of vapour from a tanker to the VRU.

For the recovery of petrol vapour from road tankers to the VRU, certain modifications are required to existing tankers. Normally large road tankers can have up to 4 separate compartments, where each compartment has a pressure relief vent on top. For use at the Engen facility, tankers are adapted to allow for vapour collection/vapour balancing by connecting these vents to an existing manifold and extending it with additional piping, as shown in Figures 3.4 and 3.5.

During loading at the facility, a vapour return hose is connected to the tanker *via* a vapour return adaptor, connecting the tanker and the vapour return line (Figure 3.3). As a tanker is being loaded by using bottom loading (as shown in Figure 2.4), the petrol displaces the vapour in the compartment into the vapour return line. Due to the use of bottom loading, all the tankers must also be fitted with sensors to avoid overfilling. If overfilling occurs, liquid product will accumulate in the vapour return hose, which will prevent the discharge of vapour to the VRU through the vapour return line and vapour header (Figure 3.2).

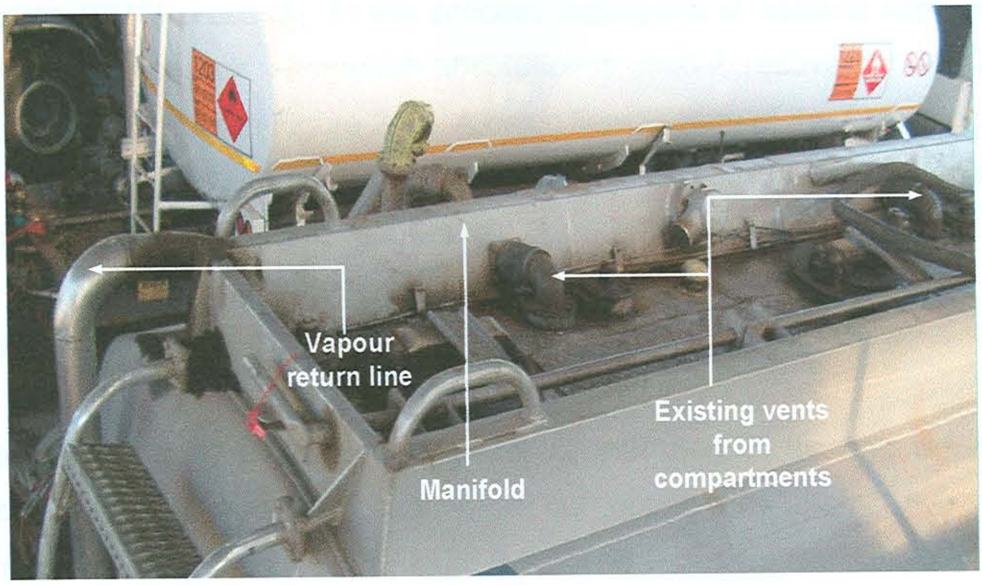

Figure 3.4 Top view of modified road tanker.

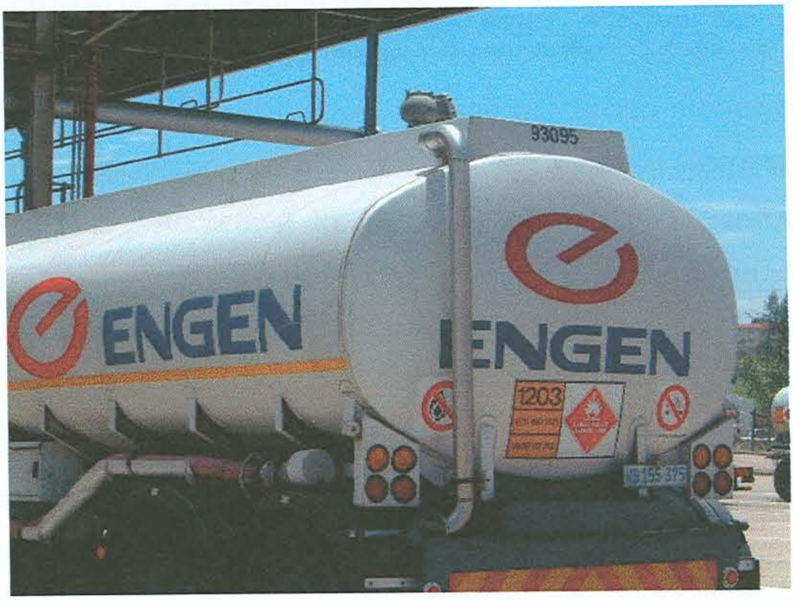

Figure 3.5 Modified road tanker to allow for vapour recovery.

3.2.2 Carbon vacuum adsorption process

After vapour collection, VOCs are recovered by using the carbon vacuum adsorption (CVA) process. In this process adsorption is used to separate the collected VOCs and air, after which absorption is used to recover the VOCs in a liquid state (as shown in Figure 2.9). A basic flowdiagram of the CVA process at the Engen facility can be seen in Figure 3.6, with Figures 3.7 and 3.8 giving the top and front view of the VRU respectively.

Adsorption

The first step for the recovery of petrol at the VRU is through adsorption. Collected vapour flows through a knock-out pot to one of the two carbon adsorption beds, (C1 and C2 in Figure 3.6). The two beds allow for continuous operation of the VRU, with the one bed adsorbing and the other being regenerated. For the purpose of this discussion bed C1 is in adsorption mode. The vapour enters at the bottom of C1 and VOCs are adsorbed onto the activated carbon. The cleaned air passes through the bed and is vented. This air is analysed for VOC (hydrocarbon) as well as carbon monoxide to give an indication of the effectiveness of the unit, as well as early warning of hot spots forming in the bed. According to Zerbonia *et al.* (2001), carbon monoxide concentration monitoring provides the necessary information for the safe operation of the carbon bed.

After a certain time of adsorption the bed can be divided into three zones: the inlet zone, mass transfer zone and the outlet zone. If the mass transfer zone reaches the top of the bed, breakthrough will occur and some of the inlet VOCs will escape into the atmosphere. At this plant an adsorption cycle of 15 minutes ensures that the breakthrough of VOC vapour does not occur. After the adsorption step in bed C1 ends (15 minutes), bed C2 is placed in adsorption mode and bed C1 is regenerated.

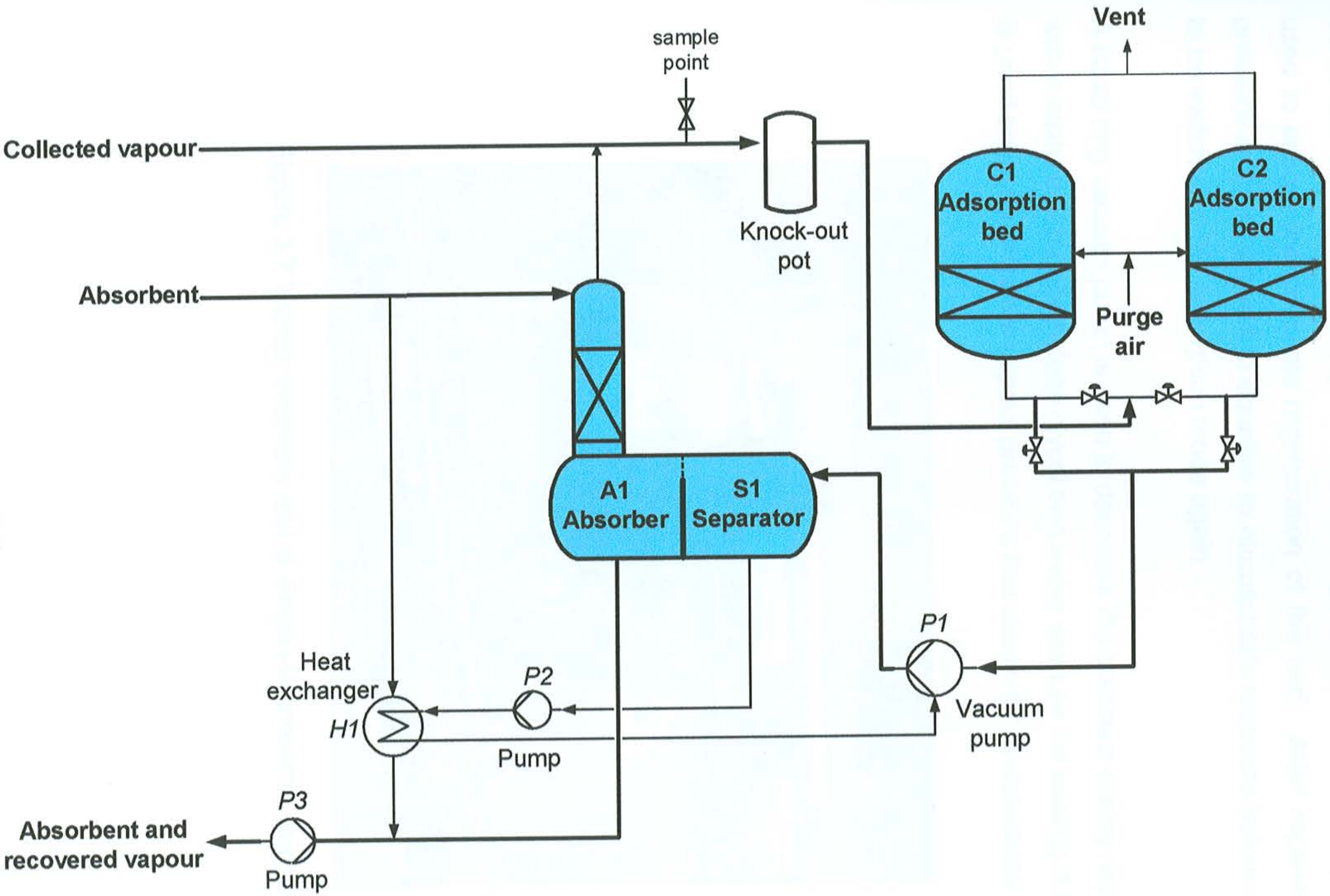

Figure 3.6 Carbon vacuum adsorption (CVA) process.

Regeneration

Regeneration of these adsorption beds takes place in two stages. For the first stage pressure is decreased by the use of a vacuum pump (P1) and most of the VOCs are desorbed. During the second stage a small amount of purge air is used to ensure the complete regeneration of the bed. After regeneration the pressure in C1 is allowed to equalise to atmospheric pressure before it is ready to be switched to the adsorption mode again.

A liquid ring vacuum pump is used to decrease the pressure during regeneration, with a mixture of monoethylene glycol and water used as the sealing fluid. Glycol is used because of its low vapour pressure that allows for an increased vacuum.

Figure 3.7 Vapour recovery unit at Engen-Wentworth, Durban.

Figure 3.8 Vapour recovery unit (front view).

Separation

During the second step of petrol recovery at the Engen VRU, the glycol and VOC vapour mixture are separated in the separator (S1, first part of the vessel in Figure 3.8). The concentrated VOC vapour flows from the separator to an absorber column, A1, where it is recovered. The sealing fluid, in this case glycol, is pumped (with P2) from the separator through a heat exchanger, H1 to remove the heat of compression from the glycol. The glycol is then recycled back to the vacuum pump. The coolant used in the heat exchanger is fresh petrol from a daily storage tank.

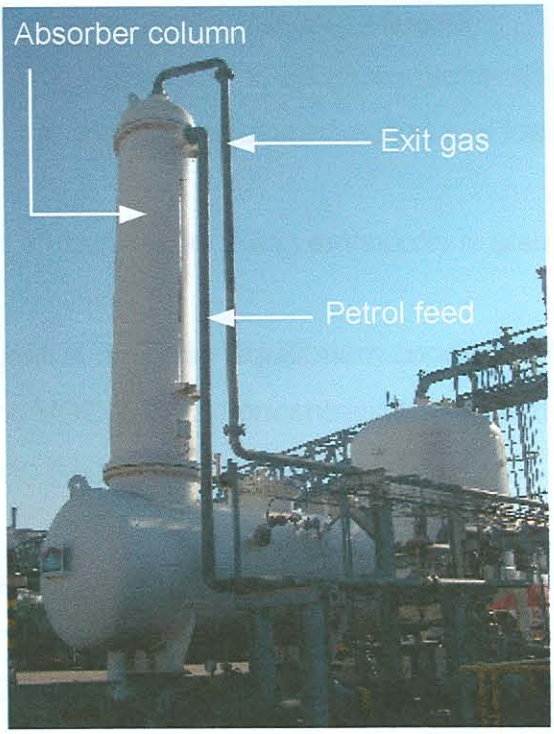

Figure 3.9 Separator and absorber column.

Absorption

The VOC rich vapour from the separator (S1) moves up into the absorber column (A1, shown in Figure 3.9) where petrol from the daily storage tank is used as absorbent. Any vapour that is not absorbed is recycled back to the carbon beds. The petrol product (containing the recovered vapour) from the absorber is pumped (P3) back to the daily storage tank.

3.3 THEORETICAL FILLING EMISSION CALCULATION

Equation 1 introduced in Chapter 2 was used for the calculation of the theoretical filling emission for the conditions at the Engen facility. In this equation a factor f (liquid to vapour volume equivalence factor) is used. This factor was derived (as shown in Appendix A) for typical European product properties and conditions and had to be adapted for the South African situation. The average product temperature in Durban was expected to be much higher than the temperature of 15°C used in Appendix A and was measured during fuel loading

As shown in Equation 1, road tanker filling emissions is also a function of the:

- VOC vapour concentration under equilibrium conditions (fully saturated, C_s),
- average preloading VOC vapour concentration (C_p), and
- amount of splashing (V_B).

The average preloading vapour concentration (C_s) was determined from the nomogram in Appendix B. As shown in Table 3.1, the average RVP at the Engen facility for 2002 varied within a certain range during the year (Kemp, 2003). There is, however, a maximum allowable RVP of 75 kPa for leaded and unleaded petrol, according to standards by the South African Bureau of Standards (SABS, 1995 and SABS, 2001). As the RVP and the temperature do not remain constant and varied within a certain range, different C_s values were determined at different values within the range.

The preloading vapour concentration (C_p) was determined by assuming that all the tankers discharged completely at only one point.

The amount of splashing (V_B) could be quantified by knowing the type of loading method that was used. All the tankers at the Engen-Wentworth facility load *via* bottom loading, therefore the value of V_B was known.

Table 3.1 Average RVP (in kPa) values at Engen, Wentworth for 2002.

Month	Average RVP values (kPa)	
	Engen 95 Unleaded	Engen 97 Leaded
January	60,0	65,9
February	65,4	67,9
March	60,5	67,2
April	71,2	66,9
May	64,7	65,0
June	62,5	59,6
July	58,1	67,2
August	57,0	62,4
September	70,7	69,5
October	66,7	68,7
November	58,8	61,8
December	60,9	65,0

3.4 EXPERIMENTAL METHOD AND SETUP

Vapour from road tankers is a mixture of VOCs and air and therefore the VOC concentration in these mixtures had to be determined for calculation of experimental filling emissions. For the conversion of the VOC vapour to a liquid equivalent value, the factor f specified in Equation 1 had to be calculated for South African product properties and conditions. Data was obtained from the Fuel-Facs^{+}® information management system employed at the Engen facility (CSI, 2002). This system records the following data (see Appendix C) automatically when a road tanker is loading any product at the facility:

- road tanker name and number,
- type of product loaded,
- start and stop time,

- gross (measured at ambient temperature) and net (measured at 20ºC) product quantity loaded, and
- product temperature.

All the tankers that load at the Engen facility are recorded and no notification of the tankers that connect to the VRU is made by the Fuel Facs^{+}$_{®}$ system, although all tankers loading petrol and diesel have to connect to the system according to facility management. To ensure that only the tankers that did connect to the system was taken into consideration for calculation purposes; the numbers of the tankers that did connect to the system was noted manually. Tankers not connecting, even though they have been adapted for this purpose, and incorrect operating practices were also noted.

As shown in Appendix C, the product loading data was only available as total volume loaded over a known time period and therefore the product flow rate had to be calculated.

An ultrasonic flow meter (Panametrics, Model GM 686) was installed in the vapour header (ID 250 mm) connecting the loading racks with the VRU. The ultrasonic flow meter measures the vapour flow (VOC/air mixture) from the road tankers that are connected with the VRU *via* the various connection hoses described in Section 3.2.1. According to McCarthy (1999), ultrasonic flow meters are increasingly gaining acceptance from measuring gas flow because of the following advantages:

- high accuracy,
- high repeatability,
- negligible pressure drop, and
- low maintenance.

There are two main types of ultrasonic flow meters, namely transit time and Doppler. The meter installed at the Engen facility is of the transit time type where the flow velocity is measured by measuring the time difference for sound to travel a fixed distance with and against the direction of flow by transducers. Figure 3.10 shows a simplified schematic representation of such a meter, with the transducers mounted in diagonal mode, and Figure 3.11 the installation at the Engen facility.

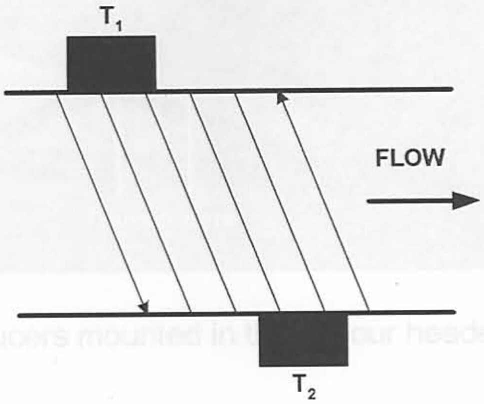

Figure 3.10 Ultrasonic flow meter with transducers (T_1 and T_2) in diagonal mode.

From Figure 3.10; the transit time (t_{12}) of an ultrasonic signal travelling with the flow is measured from transducer 1 (T_1) to transducer 2 (T_2). When this measurement is completed, the transit time (t_{21}) of an ultrasonic signal travelling against the flow is measured from T_2 to T_1. As the dimensions of the internal piping and the distance between the transducers are known, the gas velocity can therefore be determined.

The ultrasonic flow meter measures the vapour flow through the vapour header continuously but the data can only be recorded at specified time intervals (ranging from a few seconds up to 3 minutes). For the comparison of petrol loading data with the vapour flow data, the same time interval had to be used. The shortest interval used to record the product data was 1 minute and could not be changed. The vapour flow data was therefore recorded every ten seconds and converted to one minute averaged values by the multiplication of the velocity by the internal area of the vapour header (ID = 250 mm).

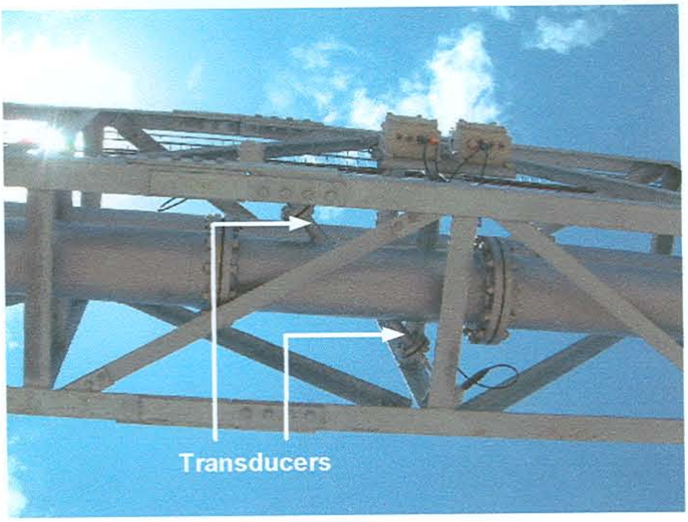

Figure 3.11 Transducers mounted in the vapour header at the Engen facility.

The ultrasonic flow meter measures the velocity of the VOC/air mixture through the vapour header, and because only the flow rate of the VOCs were of importance; the concentration of the VOC/air mixture at the Engen-Wentworth facility had to be known. Appendix D shows the volumetric concentration of vapour at different temperatures for petrol with an RVP of 70 kPa and 90 kPa, respectively. This was used in conjunction with grab samples of the vapour from the vapour header to verify the vapour concentration.

Vapour samples were taken upstream of the VRU at the sampling point in the vapour header (see Figure 3.6). Thermal tubes and glass samplers were used for taking vapour samples during different days, an hour apart each time. For the thermal tube sampling a syringe was used whereby a fixed, known volume of the VOC/air mixture was drawn into the tubes filled with various adsorbents. Using the glass sampler, the VOC/air mixture was allowed to flow into the sampler over some time without any external pressure. Gas chromatography and flame ionization spectroscopy was used to analyse the VOC concentration in both types of samples and analysed by two independent laboratories to determine the organic content.