An Investigation into the Occupational Exposure of Service Station Pump Attendants to Low Levels of Benzene Present in Gasoline Vapour during Refuelling

Marcelle Chan-A-Sue, Isidro Espinosa & Shanomae Rose

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Abstract

This study covers an investigation into occupational exposure to benzene emitted from gasoline during refuelling in Greater Georgetown. Pump attendants are particularly vulnerable as they are constantly exposed to gasoline vapour during their work day. Two mathematical models were used to determine a concentration of benzene to which gasoline pump attendants could potentially be exposed. Then the potential health implications of this exposure were examined. The benzene exposure concentrations were found to be $1.5 mg/m^3$ and $0.4 mg/m^3$ for Shell and Guyoil Service Stations respectively, which are within the permissible exposure limits set by the developed world (e.g. by the National Institute for Occupational Safety and Health in the United States of America and countries of the European Union). Due to certain limitations of this research, future research using more accurate methods is required to determine a general occupational exposure for all pump attendants in Greater Georgetown at any given time, and measures to reduce exposure should be considered.

Keywords: occupational exposure, benzene, refuelling, gasoline

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Introduction
Background
In urban areas that have a higher population density and traffic-related air pollution, traffic is the most important source of air benzene concentrations (Vlachokostas *et al.*, 2011). Research has found that gas stations are the second major source of BTEX emissions (benzene, toluene, ethyl benzene and xylene) (Correa *et al.*, 2012, p. 164). Benzene emissions are always present in vapour form in vehicle fuel tanks and are forced out when the tank is filled with liquid fuel (U.S. Environmental Protection Agency Office of Mobile Sources, p. 3), with fuel benzene content having the greatest influence on benzene refuelling emissions into the atmosphere (Laing, 1986, p. 5). Presently, the benzene content in gasoline varies from less than 1% to 5% vol, depending on fuel quality, countries' legislation and season (Verma & Tombe, 2002).

It is very important to monitor benzene levels and assess air quality at a local scale since benzene has been found to have relatively high population risks (e.g. development of cancer) in various countries among hydrocarbon air pollutants (Vlachokostas *et al.*, 2011, p. 2585). Many of the toxicological effects due to gasoline exposure have been attributed to specific components of the mixture like benzene. Benzene is dangerous to human health as its toxic effects are mainly on the haematopoietic system and the immune system. Benzene has also been classified as a group A human carcinogen by the Environmental Protection Agency (the United States of America). In addition to occupational exposure to benzene, persons can increase their exposure and toxicity to benzene through lifestyle choices such as smoking and alcohol consumption.

Gas station service attendants are a particularly vulnerable group as they can be exposed to low levels of benzene during the refuelling of vehicles (at the vehicle/nozzle interface), and from ambient air concentrations of benzene, especially if they work in an urban area such as Georgetown, Guyana where there is heavy vehicular traffic as compared with other parts of the country. This occupational exposure is defined as the concentration of potentially harmful chemical, physical, or biological agents in the work environment that an employee can be exposed to during a specified period, i.e. the 8 hour work period (OECD, 1993, p. 12 and Reference.MD, 2012).

Within the last ten years Guyana has seen a significant increase in the importation and registration of vehicles in the country (Guyana Revenue Authority, 2010). These vehicles require refuelling, and so pump attendants today are being utilized more frequently to refill these vehicles. As such exposure to benzene during refuelling has increased over the years. Other potential sources of exposure are vapours from vehicle fuel tanks, fuel soaked rags or accidentally soiled clothing, and exhaust gases from tankers delivering fuel (Carrieri *et al.* 2006, p. 147).

Relevant agencies such as The Environmental Protection Agency (Guyana) and the Ministry of Labour, Human Services and Social Security (Guyana) lack the capacity to monitor benzene emissions and exposure concentrations. As a result, there has been no research on the occupational exposure to benzene during vehicle refuelling in Guyana. Therefore, it is unknown if pump attendants are being exposed to dangerous levels of benzene during their time at work. The main aims of this research were to estimate the occupational exposure of service station pump attendants to benzene during refuelling using mathematical models and to determine the possible health implications due this type of chronic low level exposure.

Literature Review

There are many differing views by international health agencies and scientific bodies on the health hazard due to the inhalation of gasoline (Keenan *et al.*, 2010, p. 293). Gasoline has been classed as a possible human carcinogen by the International Agency for Research on Cancer (IARC) based on the establishment of benzene (Group 1 Carcinogen, IARC, 1987) and 1, 3 butadiene as carcinogens. However, for benzene to be toxic it has to be metabolized to reactive intermediates (Snyder *et al.,* 1993, p. 293) in the liver. Since benzene is dangerous to human health, occupational limits have been set e.g. the National Institute for Occupational Safety and Health in the United States of America set the occupational limit value to 1ppm or 3.25mg/m^3.

Methods Used to Determine Occupational Benzene Exposure

There have been several studies done which try to assess the occupational exposure to benzene. The methods employed some form of scientific testing in order to estimate the concentration of benzene that persons were exposed to during refuelling of vehicles. Models (mathematical and computer) were also used to estimate exposure. For instance, a study by Karakitsios *et al.* (2007) in Greece used a computer model to predict an exposure to benzene for filling station employees and compared the results to those obtained from passive sampling. In another study done by Vainiotalo *et al.* (1999) on customer exposure to benzene during gasoline refuelling, there was also comparison of exposure between a rural and an urban gas station. Both gas stations had stage I vapour recovery systems that collect vapours during unloading but not stage II recovery, which collects vapours released from a vehicle's gasoline tank during refuelling. Even though the study was done on customers, the method can be applied to gas station service attendants. Air samples were collected from the customers' breathing zones in charcoal tubes during refuelling. Samples were then analysed in a laboratory and the concentration of benzene determined.

Exposure to benzene can also be determined by means of biological testing by testing for certain biological indicators. Phenol is the main metabolite of benzene, and it has been found in the literature that the phenol concentration in the urine of exposed workers can be used as an index of internal dose because the urinary level is highly correlated with external benzene exposure (Celik & Akbas, 2005, p. 110). In the research done by Celik and Akbas (2005, p. 110) the mean urinary phenol levels of the pump attendants could be attributed to occupational exposure when the subjects considered shared the same demographic parameters e.g. diet, smoking, ingestion of medicine.

Health Consequences Due to Low Level Occupational Exposure
Low level occupational exposure to air benzene is considered to be less than 10ppm (ATSDR, 2000, p. 13). Chronic toxicity in humans occupationally exposed to benzene include haematological (aplastic anaemia and pancytopenia), mutagenic (chromosomal aberrations), and carcinogenic (acute non- lymphocytic leukaemia) (Duarte- Davidson *et al.*, 2001, p. 3). "Most of the evidence for this derives from industrial studies of workers exposed to benzene, often as a constituent of a complex mixture."

In a study done by Terry *et al.* (2005) in the U.S. and Canada statistically significant associations were found between acute myeloid leukaemia (AML) and several occupations, one of which included gas station pump attendants. However, one study which focused on the risk of cancer and exposure to gasoline vapours in the Nordic countries (i.e. Denmark, Norway, Sweden, France and Finland) concluded that pump attendants with average level of exposure to benzene <1ppm, showed no excess risk of leukaemia, specifically AML (Lynge *et al.*, 1997, p. 457). Interestingly though, they had an elevated risk of other types of cancer such as pharyngeal, laryngeal, lung etc. (Lynge *et al.*, 1997, p. 457).

Generally, there is conflicting evidence on potential haematological effects of benzene at low concentration levels (Swaen *et al.* 2010, p. 94). A study conducted concluded that petrol (containing benzene) exposure can be associated with geno-toxic effects on the lymphocytes (Celik & Akbas, 2005, p. 110). The results showed that the proliferation of human lymphocytes was significantly inhibited, indicating immune-suppression in the pump attendants when compared to the control group (Celik & Akbas, 2005, p. 109). On the other hand, Swaen *et al.* (2010)

conducted a study in the Netherlands which found that workers exposed to low benzene concentrations were not at risk for haematological effects.

Additionally, benzene has been shown to cause sperm aneuploidy at exposures less that 10ppm, even as low as less than 1ppm (Xing *et al.*, 2010, p. 833). This can indicate that the current PEL for benzene is not sufficient enough to protect men from reproductive damage.

Methodology

Description of Study Area

The petrol companies identified for this research project were Sol Guyana Inc., the Guyana Oil Company Limited and Texaco located within greater Georgetown. Initially, the study was to be done at these three main petrol companies. However, permission to conduct the research was only given by the head offices of Sol Guyana Inc. and the Guyana Oil Company Limited. The research was done at seven service stations, as this was the total number of Shell and Guyoil Service Stations within Greater Georgetown. Georgetown is one of the six urban municipalities of Guyana (NDS, 2001, chapter 21) and is the capital city. Greater Georgetown is 39km^2 encompassing Cummings Lodge on the East Coast of Demerara and Agricola on the East Bank of Demerara (Urban Environment Outlook, GEO Georgetown, 2009, p. 13). Greater Georgetown was chosen because more of the gas/service stations would be captured in the survey. Another reason for choosing this urban area is that pump attendants there would be more susceptible to benzene exposure due to the higher traffic flow.
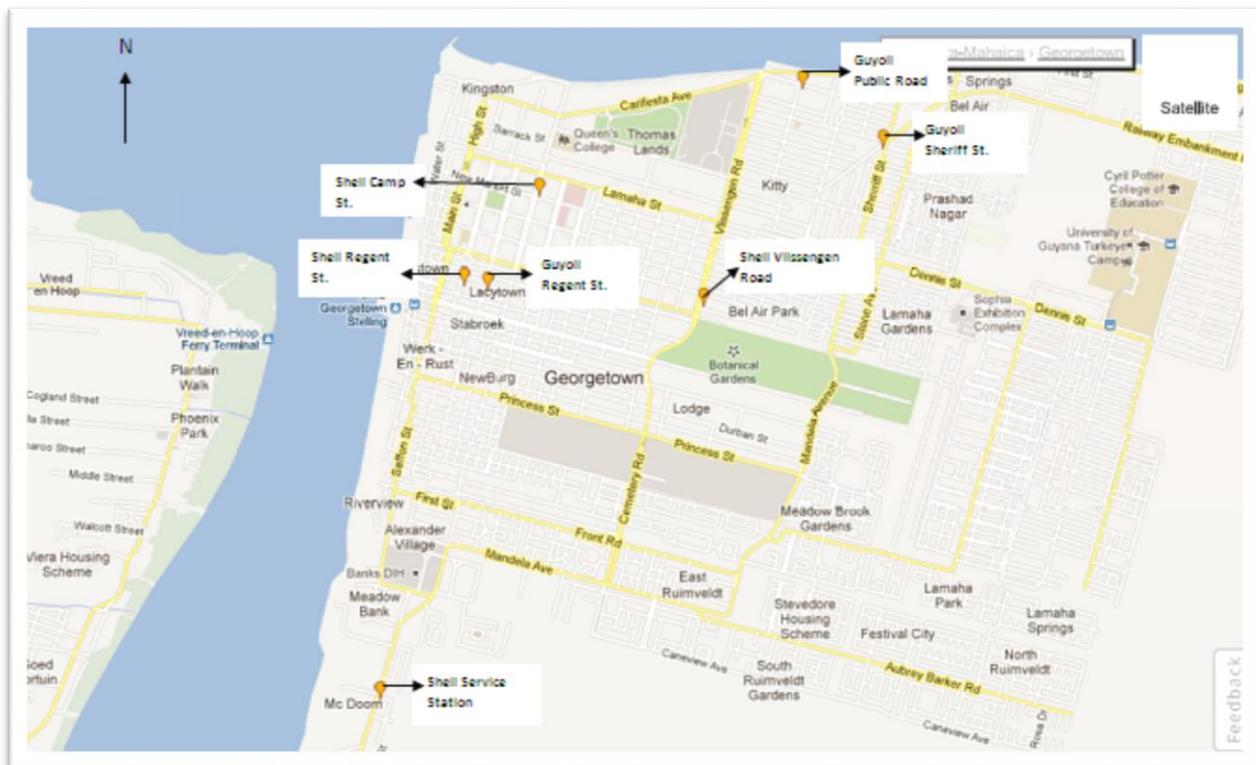

Figure 1: Location of the Service Stations, Greater Georgetown. Source: Google Earth

Experiment Design

Temperature was tested using a HACH pH meter as this had the thermometer or temperature sensor attached to it. The meter was attached to a display screen (series: HQ40d). Since the emission of benzene would be affected by temperature, it was decided that data should be obtained to determine the lowest and highest benzene concentration that the pump attendants would be exposed to. Therefore, temperature measurements were taken at the highest temperature, at the lowest temperature and at a temperature between those two.

In order to determine the time at which measurements should be taken, data on temperature variation throughout the day was needed. This information was obtained from the Hydrometerological Office of the Ministry of Agriculture, Guyana. The data set on temperature obtained dated from the 19 April 2012 to 27 April 2012. From this data set it was determined that the lowest temperature for Georgetown fell between 05:00hrs and 06:00hrs, and that the highest temperature fell between 12:00hrs and 14:00hrs. A median temperature was found to be between 10:00hrs and 11:00hrs. Thus, the time intervals chosen for taking measurements were 05:00-06:00hrs, 10:00-11:00hrs, and 12:30-13:30 hrs.

It was decided that temperature measurements would be taken for three days at each service station. During each time interval, three measurements would be taken. The vehicles temperatures that were measured included cars, pickups and mini-buses. Temperature measurements were only taken at five of the seven gas stations because the gasoline damaged the protective plastic covering the thermometer. Before the measurements of temperature were taken, the general environmental conditions of each service station were recorded. The environmental conditions (e.g. windy, overcast) at each time of testing were also recorded.

Verbal consent to measure the temperature was sought from the customers that were refuelling their vehicles during the testing intervals. Once they agreed, the tank was opened and the thermometer was immediately placed in the vehicle tank i.e. before refuelling commenced. The temperature and time were then recorded.

Calculation of Benzene Emission Factor

In 1986, a study by Laing (United States (US) Environmental Protection Agency) developed an empirical relationship between benzene refuelling emissions and fuel/ temperature conditions. His report on the study presented the results of an Environmental Protection Agency test program designed to characterize benzene refuelling emissions. The study also examined several other available benzene refuelling emission studies to form a combined data base (Laing, 1986, p. 1). A relationship between benzene refuelling emissions and three significant parameters was then developed by fitting a multivariate linear regression model these combined data.

According to Laing (1986, p. 5), "the relationship has several important uses such as the estimation of a national benzene rate." In order to estimate a total emission factor for benzene during refuelling a spillage factor must be taken into account. This prediction equation (model) used to calculate the benzene emission factor for this research was as follows:

E$_r$ = (0.038 * %Bz) – (1.60 x 10^{-4} * T$_D$) – (4.24 x 10^{-4} * ΔT)

Where;
E_r = Emission rate in grams benzene/ gallon (important to note here is the type of gallon used in the equation)
%Bz = Liquid fuel benzene concentration (% wt.), expressed as a percent not a decimal fraction
T_D = Dispensed fuel temperature (°F)
ΔT = Difference between fuel tank temperature and dispensed fuel temperature (°F).
The benzene concentration obtained from the certificate of quality was in %v. Therefore there had to be a conversion from %v to %wt. This was done using the following conversion:
%wt. = %v (A in B) x density A/ density B (at 15 °C); where A= benzene and B= gasoline
The density (kg/L) of the gasoline at 15 °C was also obtained from the certificate of quality.
The model (Laing, 1986) required the temperature to be in °F, but the temperature was measured in °C during data collection. This was converted to °F using a "Convert.exe" computer programme based on the formula °F= (°C*5/9) + 32.

Considerations and Limitations
- The model does not take into consideration the fuel delivery rate
- The model does not take into consideration the vehicle fuel system configuration
- Measurements were taken at atmospheric pressure
- The liquid gasoline and the gasoline vapour were assumed to be the same temperature due to limitation with equipment as the temperature sensor was too big to go into the vehicle tank.

Calculation of an Estimated Benzene Exposure
The exposure concentration was calculated using a Gaussian model of atmospheric dispersion which determines exposure. It is a mathematical model of atmospheric dispersion that tries to simulate the behaviour of the plume emitted from the ground level point source, or in chimneys with specific height. The model chosen calculates concentration in the air from a ground level source.

The estimated benzene exposure concentration at 0.5m =
$C(x,0,0)= Q/\pi \, u \, \sigma_y \, \sigma_z$
Where;
Q= emission rate in g/s
u= wind speed in m/s
σ_y= 3.05m, normal deviation in direction y
σ_z= 0.035m, normal deviation in direction z
(Source: Wark and Warner, 2001, p. 161)

Considerations and Limitations
- The flow rate was not measured but was obtained from the head offices of the service stations.

- Wind speed data was used to find an average wind speed for Greater Georgetown due to equipment limitation. Average wind speed for Greater Georgetown (u) = 8.2m/s (Hydrometerological Office).
- The model calculates atmospheric concentration from an emission source at ground level along a horizontal distance of 0.5m. This distance was chosen because it is assumed that pump attendants will most likely operate within this distance from the pumps. In this instance the ground level can be considered as 1m high. This height was chosen because according to CAPCOA (1997, p. 13) for refuelling emissions, the release height was chosen to be one meter. This is the same height as most car nozzle receptors.
- The values for σ_y and σ_z were calculated via extrapolation.

Results and Discussion

Figures 2 and 3 show the variation benzene emission factor throughout the day. The average emission factor for the Shell service stations was 0.02763 g benzene/ gallon, and for Guyoil it was 0.03501 g benzene/ gallon.
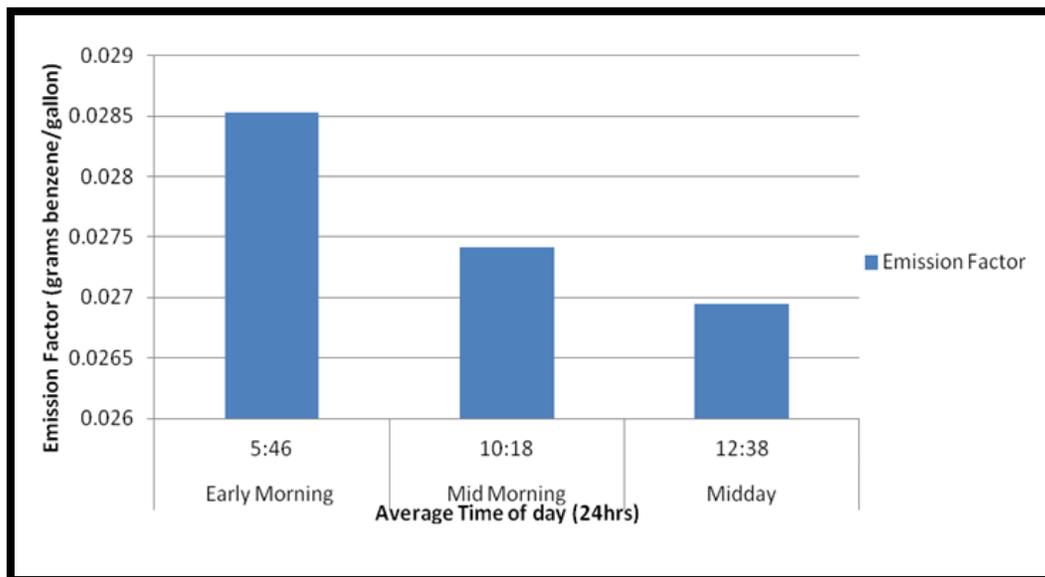

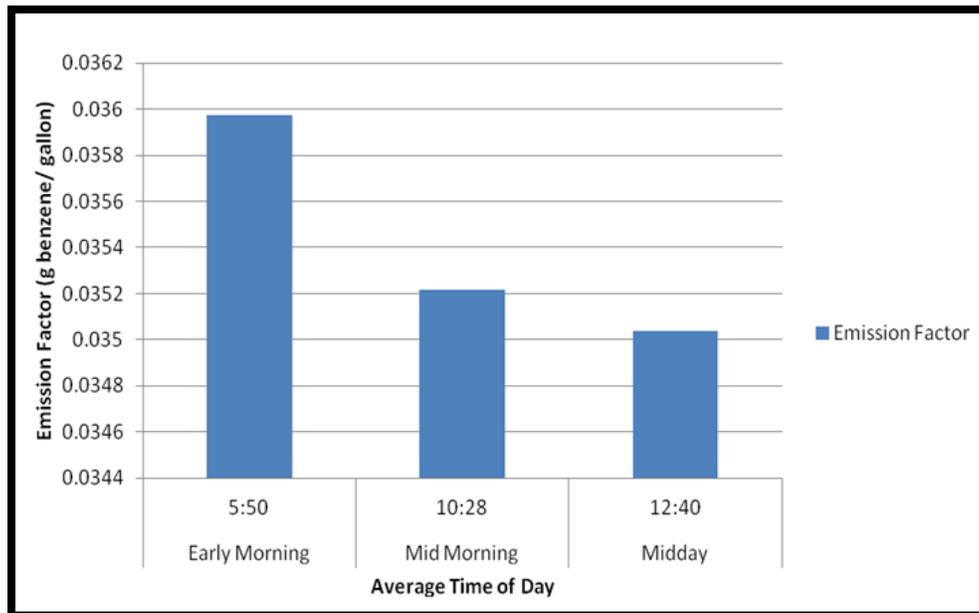Figure 2: Benzene Emission Factor for Shell Service Stations

Figure 3: Benzene Emission Factor for Guyoil Service Stations

The estimated occupational exposure of pump attendants to benzene in gasoline during refuelling was determined to be 1.5 mg/m^3 for Shell pump attendants and 0.4 mg/m^3 for Guyoil pump attendants. In addition, results show that with a higher emission rate the exposure is lower (Guyoil) and with a lower emission the exposure is higher (Shell). This result indicates that the benzene emission factor during refuelling does not directly correspond to exposure concentration (i.e. a higher emission factor does not result in higher occupational exposure). There are other factors that would influence benzene exposure during vehicle refuelling. Based on the calculations, this result can be attributed to the flow rate of the gasoline during refuelling, which depends on the model of the dispensing pumps the service stations use.

The gasoline pumps at Shell service stations dispense gasoline at a higher rate (8-10 gallons/ minute) than the pumps at Guyoil service stations (2 gallons/minute) due to their different specifications or because they use different pump models, and so the pump attendants at the Shell service stations were exposed to a higher concentration of benzene than the ones at Guyoil service stations. This results because a greater volume of gasoline could be pumped in a minute. Therefore, it may be assumed that if Guyoil were to change the model of their dispensing pumps to one with a flow rate similar to that of Shell, then Guyoil pump attendants would be exposed to a higher benzene concentration during vehicle refuelling.

The occupational exposure determined for pump attendants in Greater Georgetown were well within the permissible exposure limit (8hr Time Weighted Average) set by the countries in the developed world e.g. the U.S. Occupational Safety and Health Administration which set a limit of

1ppm or 3.2mg/m^3 (Figure 4). As such the pump attendants at Shell and Guyoil service stations were not exposed to dangerous levels of benzene based on these results.
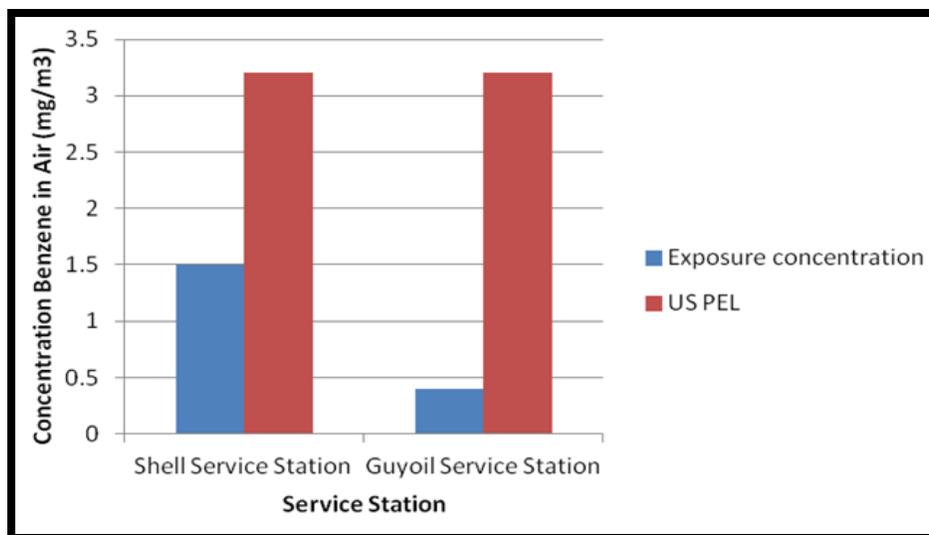

Figure 4: Calculated Occupational Exposure Concentration at Shell and Guyoil Service Stations and the US Permissible Exposure Limit

However, their health may still be at risk since the literature does suggest statistically significant associations between working as a pump attendant for at least one year and an increased risk of acute myeloid leukaemia, AML, (e.g. Terry *et al.*, 2005 and Lynge *et al.*, 1997). It is important to note that even though benzene is the primary compound in gasoline or petroleum associated with the risk of AML, exposure to multiple compounds in gasoline can contribute to an increased risk of AML specifically (Terry *et al.*, 2005). As Lan *et al.* (2004) indicated immune suppression can occur at exposure levels below 1ppm and so pump attendants may be more susceptible to infections than a non-exposed group of persons. Male pump attendants in particular may be susceptible to benzene's damaging effects as Xing *et al.* (2010) indicated that men who were exposed to less than 1ppm air benzene had statistically significant elevated rates of sperm aneuploidy. This factor has implications for the viability, development and health of their children.

It is important to consider safeguarding pump attendants against benzene exposure, even though the exposure concentration was found to be within U.S. permissible exposure limits. The reason for this is that these results are only a theoretical approximation. The benzene concentration varies in the gasoline imported in different shipments, and so pump attendants may be exposed to higher or lower concentrations than those determined in this research at different times throughout the year.

The emission factor calculated for benzene may be inaccurate because the actual temperature of the liquid gasoline was not measured because of an equipment limitation. It is possible that a lower temperature was measured because of cooler air rushing into the vehicle tank when it was opened. Also a technical error could have occurred because the equipment (temperature sensor)

could not accurately measure the temperature in the vehicle fuel tank as well as that of the dispensed fuel. This too could have resulted in an inaccurate calculation for the emission factor. Lack of a spillage factor for Guyana, resulting in the use of the U.S. EPA (Laing, 1986) spillage factor would also cause the emission factor calculated to be inaccurate. Because the emission factor calculated may have been inaccurate, the occupational exposure calculated would also have been inaccurate to some degree as its value was dependent on the emission factor calculated (i.e. when determining Q).

The estimated exposure may also be inaccurate because the actual wind speed in each service station was not measured because of the technical limitation of equipment; instead an average wind speed for Georgetown was used. It is likely that the wind speed around the pump islands in the gas stations are not this high due to vehicles in the service station blocking the wind. The physical environment may also contribute to reducing the wind speed especially in commercial areas that have buildings with more stories. A higher wind speed would result in a lower occupational exposure, and so the estimated occupational exposure may be underestimated.

Conclusion

The occupational exposure to benzene was found to be 1.5mg/m^3 for Shell service station pump attendants and 0.4mg/m^3 for Guyoil service station pump attendants. This was found to be within the PEL of 3.2mg/m^3 set by the US Occupational Safety and Health Administration. These results are a theoretical approximation of what pump attendants in Greater Georgetown may be exposed to, and is only specific for the liquid benzene concentrations in the liquid gasoline during time period in which the research was done. Precautionary measures should still be taken because the literature suggests that the health of pump attendants (working for at least one year) is at risk. Therefore installation of Stage II vapour recovery systems should be considered.

There needs to be more research done to investigate occupational exposure to benzene. More accurate methods, such as those presented in the literature, should be used. Most methods use activated charcoal to absorb benzene from the air in the service station followed by gas chromatography/mass spectrometry analysis to determine the concentration of benzene to which pump attendants are exposed. There also needs to be accurate collection of data when mathematical or computer models are used.

Acknowledgements

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