Vehicle cabin air quality monitor using gas sensors for improved safety

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Abstract - A vehicle cabin air quality monitor using carbon monoxide (CO) and oxygen (O_2) gas sensors has been designed, developed and on-road tested. The continuous monitoring of oxygen and carbon monoxide provides added vehicle safety as alarms could be set off when dangerous gas concentrations are reached, preventing driver fatigue, drowsiness, and exhaust gas suicides. CO concentrations of 30 ppm and oxygen levels lower than 19.5% were experienced whilst driving.

A. Introduction

Cabin air quality in automobiles, planes and other confined spaces has gained much interest [1-3]. The adverse health effects caused by high carbon monoxide, nitrogen dioxide and discomfort caused by suspended particulate matter such as dusts, fumes, mists, and smokes has instigated innovative automobile features, such as vehicle cabin air quality control integrated to the Heating, Ventilation and Air Conditioning (HVAC) system.

The target gases of interest are exhaust pollutants that are likely to cause discomfort, induce poor hand-eye coordination, fatigue, and drowsiness, decreasing the drivers awareness and increasing the probability of a collision. Exhaust pollutants such as CO, NO_x, and hydrocarbons are known to contribute to various adverse health effects such as headaches, nausea, dizziness, and irritation to the eyes and respiratory tract [4,5]. The Australian National Occupational Health and Safety Commission (NOHSC) exposure standard for CO levels is 30 ppm time weighted average over an 8 hour period [6].

However, not only are exhaust emissions a health hazard but so too is our natural breathing process in a confined environment. In the course of breathing, we exhale carbon dioxide which in an indoor environment such as a vehicle cabin, can displace oxygen, leaving the environment oxygen deficient. Adverse human health effects may manifest due to the high carbon dioxide and low oxygen concentrations, the situation being exaggerated when vehicle occupants choose to operate the HVAC system in the "recycle" mode aiming to prevent outdoor-polluted air entering. A study on fatal single vehicle crashes highlights it is more likely to have windows closed, the heater on, and less likely to have fresh air and less and air conditioning fitted [7]. The Occupational Safety and Health Administration (OSHA), U.S. Department of Labor has issued its final rules on Confined Spaces (29 CFR 1910.146). It states a "hazardous atmosphere" is one which has an atmospheric oxygen concentration below 19.5% [8].

Another issue concerning vehicle cabin air quality are motor vehicle exhaust gas suicides caused by carbon monoxide poisoning. In Australia there were 509 motor vehicle exhaust gas suicides in 1995, representing 22% of total suicides [9]. Many deaths are also

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attributed to fatal unintentional carbon monoxide poisoning in and around motor vehicles. A study of U.S. deaths found that 57% of unintentional CO poisoning deaths occurred in automobiles [10]. By incorporating a system with CO and O_2 gas sensors it is believed that the safety of vehicles can be dramatically increased, and deaths caused by carbon monoxide poisoning prevented.

B. Experimental

A microprocessor controlled system incorporating CO and O_2 gas sensors was developed. The system was calibrated to O_2 certified gas bottles balanced with N_2, the O_2 sensor has an accuracy of 1% and a resolution of 0.1%. The CO element was calibrated to a commercially available analyser with a 10% accuracy and a 1 ppm resolution. The system continuously monitored the air quality every second and the data were recorded on a PC via an RS-232 interface. An Australian manufactured Toyota Camry (1997, 2.2 litre) sedan vehicle was used for the on-road tests and a Ford Falcon (1996, 4.0 litre) sedan vehicle was used for the simulation suicide experiment.

The oxygen concentration was analysed in various driving conditions. As the HVAC settings influences the fresh air intake into the vehicle cabin, as does the average speed of the vehicle, thus four main tests were devised. The system was tested when in city and freeway driving conditions, in both cases the HVAC system were set to "recycle" then to "fresh air" mode. The carbon monoxide and oxygen concentration were analysed during a simulated suicide attempt. A hose of 30 mm diameter was connected to the exhaust outlet of the vehicle and then directed into the vehicle cabin.

C. Results

Figs. 1 and 2 show the concentration profile of O_2 over a 15 minute period whilst driving under the specified conditions. It is clearly evident that as the HVAC system is on "recycle" or "fresh" mode, the O_2 concentration depletes. In the case of city driving as shown in Fig. 2 O_2 depletes below 19.5%, this case being considered a "hazardous atmosphere" by OSHA [4].

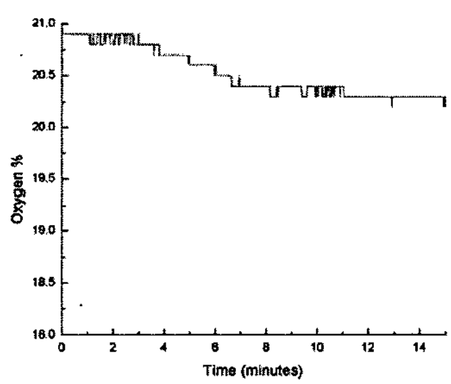

Fig. 1: Vehicle cabin oxygen profile whilst city driving with the HVAC set on the "fresh" air mode.

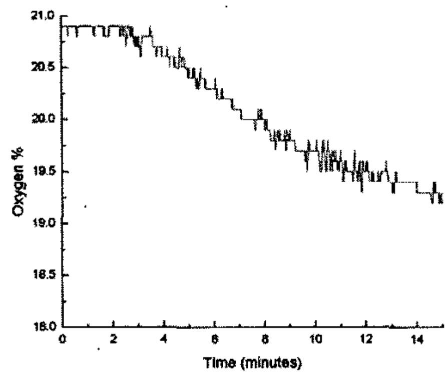

Fig. 2: Vehicle cabin oxygen profile whilst city driving with the HVAC set on the "recycle" air mode.

The freeway driving profiles displayed similar characteristics to those of the figures shown. However, as Table 1 indicates, in the case of the HVAC being set on "recycle" mode, the O_2 concentration is higher. This could be attributed to the high speed of the vehicle, forcing fresh air into the cabin via the HVAC system, door seals, window seals or outlet ventilation slots which exist at the rear of most vehicles.

Table 1: O_2 concentration dependence on vehicle speed and driving scenario.

Driving Scenario	Average Vehicle Speed	Lowest O_2 Detected
City – Recycle	32 km/h	19.2 %
City – Fresh	20 km/h	20.2 %
Freeway - Recycle	58 km/h	19.8 %
Freeway - Fresh	60 km/h	20.2 %

The simulated suicide attempt reached undetectable levels, greater than 600 ppm within several seconds of the experiment. However, the exhaust fumes displace the oxygen within the vehicle cabin. The oxygen concentration exponentially declined to 7% after 30 minutes. Therefore, not only does a passenger or suicide victim suffer from CO poisoning, but the effect is amplified with the dramatic decrease in O_2 concentration. Such a rapid change in CO and O_2 concentrations can be used as a gas signature to trigger the system to set alarms, such as a dash board warning light, or in extreme cases like a suicide attempt, shut down the engine when the vehicle is stationary. It is recommended that alarms trigger when the O_2 concentration reaches 19.5 % and CO levels exceed 30 ppm. Extreme action should be taken when a rapid increase in CO concentration past 600 ppm is detected, which may indicate a suicide attempt.

D. Conclusions

Vehicle safety can be improved by introducing a vehicle cabin air quality monitor to control the HVAC system and to further provide appropriate warning if poor cabin air quality exists. The sensors should be mounted as central in the vehicle as possible. Sensors should not be located in front of passengers where exhaled gas and humidity may not reflect the average air quality of the cabin. Sensors chosen for such a system must be highly durable and withstand vibration, long term degradation, electromagnetic interference (EMI), electrostatic discharge (ESD) and other toxic substances which may poison the gas sensors. Poor cabin air quality commonly exists within vehicles. By providing an alarm to passengers, a simple remedy such as opening the window replenishing fresh air into the cabin, provides a safe driving environment.

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