AIR POLUTION STUDY OF ENGINE TEST ENVIRONMENTS

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ABSTRACT

A study has been made of the sources and detection of air pollutants in engine test laboratories during performance tests, cubicles for exhaust gas analyser or calibration gas bottles and automobile workshop during engine tuning process. Engine design, operational mode, calibration gas concentration and laboratory ventilation were identified as variable factors that can influence the concentration of pollutants in the test environment. The investigation covered the determination of carbon monoxide (CO), nitrous fumes - NO_x (nitric oxide and nitrogen dioxide), and diesel odour intensity in these working environments.

The effects of pollutants on test operators, inconsistency of test results, inadequate ventilation in the laboratory and the existence of pollutants in automobile workshop are also discussed. Generally, it was observed that concentration levels of CO and NO_x in the laboratory, gas bottle cubicles and automobile workshop vary during the test period. High concentration levels occurred immediately after calibration, during long idling and high speed and load operation when ventilation was inadequate.

The ambient air quality standard as set by the World Health Organisation (WHO) in 1987 for CO and nitric dioxide (NO_2) for one hour exposure are compared with measured values. When ventilation was adequate, the concentration levels of the pollutants were lower than the set values.

1.0 INTRODUCTION

The exhaust gases of internal combustion engines (ICE) are recognised as the major sources of atmospheric pollution in urban areas as well as in engine test laboratories and automobile workshops. The importance of the investigation into all of the pollutants cannot be over stressed, because of the stringent environmental regulations and standards on air quality, and because of the effects of these emissions on our health.

Systematic measurement of criteria pollutants like CO, NO_2 or Nitrous fumes ($NO + NO_2 \rightarrow NO_x$), suphuric dioxide ($SO_2$), and hydrocarbon (HC) has been a feature of engine test programme in the research and development of ICE. Because of the precision measurements required by motor manufacturers, rigorous calibration of exhaust gas analysers, using concentrated pollutant gases in nitrogen, is a vital part of their test programmes. Since exhaust gas bottle cubicles and test laboratories are likely to be contaminated during analyser calibration and engine performance test respectively, monitoring of these toxic gases in those environments is usually carried out on a periodic basis with a frequency determined by test conditions.

Substantial quantities of CO would exist in the exhaust gases of spark-ignition engines, depending on the richness of the fuel-air mixture. A number of studies has been reported on the effect of CO on our health through inhalation (Lawther, 1975; Patterson et al, 1979). In hot climate conditions, the emission of NO_2 and HC from exhaust gases may take part in chemical reaction in the formation of ozone and other photochemical pollutants. It is reported (Lawther, 1975) that a concentration of 120 ppb of these pollutants can lead to increase in the frequency of asthmatic attacks, throat and nasal irritation and eye watering.

The formation of NO and CO during combustion process in ICE depends on test variables which

eventually affect the concentration of these pollutants in the laboratories. During test on diesel engines, diesel odour and smoke were recognised as nuisance in the test environments. The reduction of all these pollutants is currently a major strategy in engine development.

Monitoring of environmental pollution is carried out in urban areas by government agencies, higher institutions of learning, and independent organisations. However, investigations on air pollution in engine test laboratories and automobile workshops are scanty. The main objectives of this investigation is therefore to highlight the presence of toxic gases in engine test environment and health hazard of these gases. In particular, it is envisaged that the inexperienced engine test operators and motor mechanics will take notice of the existence of these gases in their work environments and adopt ways and means of reducing or eliminating them.

In most developed nations, the Health and Safety Act on emission of toxic gases into the atmosphere usually contains list of premises and substances which are deemed to be noxious or offensive. Every person having control of such premises of a class prescribed is expected to use the best practical means of preventing the emission into the atmosphere from the premises of noxious or offensive substances. The monitoring of these noxious substances would be more informative if automated or computer based data-logging and control systems are used. The method adopted in this investigation could only provide a partial solution to this global problem.

2.0 SOURCES AND DISPERSION

The main source of pollution of engine test environment is the crankcase blowby when adequate exhaust system is not provided or the blowby is not recirculated as shown in Figure 1. In exhaust emission measurements for certain test requirements or harmonisation of test equipment at various laboratories, crankcase blowby is not normally allowed to recirculate directly through the air cleaner. In some cases, it is exhausted into the test environment if no facilities exist for exhausting it out of the laboratory. Exhaust pipe leakage, dipstick tubes, exhaust from gas analysers and leaking calibration gas bottles are identified as other sources of pollution of the test environments.

Patterson et al (1979) revealed that automobile engines contribute about 59% of CO emitted into the atmosphere. While concentrations as high as 10% CO and 4000 ppm NO can leak from calibration gas bottles to the test environment, gasoline engine can emit up to 7% CO during idle operation with rich fuel mixtures and 3500 ppm NO_x at high load and speed when peak combustion temperature prevails.

The disappearance of CO and NO at ambient temperature and pressure is of particular importance to the environmental pollution problem. The formation of CO_2, and NO_2 by the reaction of CO and NO respectively with atomic oxygen (O) is significant at room temperature when an ozone (O_3) source is available according to the following equations:

$$CO + O + M \underset{}{\overset{K_1'}{\rightleftharpoons}} CO_2 + M \quad (1)$$

$$NO + O + M \overset{K_2}{\rightleftharpoons} NO_2 + M \quad (2)$$

where $K_1 = 10^{7.7}$ 1^2 mol^{-2} sec^{-1}

$K_2 = 10^{10.46 \pm 1}$ 1^2 mol^{-2} sec^{-1}

The third body, M is assumed to be nitrogen (N_2). For a given residence time the rate of dispersion will depend on the gas phase thermal decomposition of ozone to produce the required atomic oxygen. However, reaction in ambient conditions without ozone is very slow. A critical review of rate coefficient for CO reaction shows a wide scatter in the published rate data. This suggests that measurements and interpretation of CO formation and disappearance in post flame and atmosphere may present formidable difficulties.

The paths of atmospheric ozone formation have been well documented. Normally, NO reacts with O_2 in the formation of NO_2 Subsequently, under the influence of solar radiation, NO_2 breaks down to NO and highly reactive O-atom. This O-atom would combine with oxygen (O_2) to form O_3. Normally, the ozone would then react again with the NO to convert it back to NO_2

Aldehydes (formaldehyde, Acetaldehyde and crotonaldehyde) and crotonic acid are known as the sources of irritating and unpleasant odoriferous compounds of diesel engine exhaust gases. The constituents may have been caused by partial oxidation or cracked fuel compounds during heterogeneous combustion in diesel engines.

3.0 AMBIENT AIR QUALITY CRITERIA

Air quality standard is provided by measurements of pollutant concentration in ambient air. The World Health Organisation (WHO), the American Environmental Protection Agency (EPA), the Health and Safety at Work Executive (HSWE) of Great Britain and similar bodies in other countries as well as the European Communities (EC) Directives recommend different air quality standards. These organisations face a difficult task in the specification of pollutants concentration and times of exposure to act as air quality criteria or standard, since different classes of people will be exposed to the specified standard at any given time. The population and the type of work place will also have to be considered, because persons exposed to hazardous gases in a certain work place are different from the population exposed to city air which may include the very old and the sick. There fore, there is no uniformity of standards set by these bodies. In some cases environmentalists, management board of companies and the work-force can influence a proposed standard.

Threshold Limit Value (TLVs) is usually time weighted concentration (TLVs-TWA) based on an eight-hour work schedule in an approximately 40 hour-working week. It is expected that repeated exposure to set limit value will not have adverse effect on the health of personnel. However, these values are not normally sharp dividing lines between "safe" and "dangerous" concentrations. For certain criteria pollutants short term exposure limits (STEL) for one hour is specified. All these limits are constantly reviewed.

4.0 SAMPLING AND ANALYTICAL TECHNIQUE

Two series of tests were conducted at different environmental sites using spark-ignition and turbocharged diesel engines. One of the test environments is located at Keltec Industrial Research Limited in London while the other is the engine test laboratory and automobile workshop of the Rivers State University of Science and Technology, Port Harcourt, Nigeria.

At the location in London, CO and NO_x emissions were measured with non-dispersive infra-red (NDIR) and chemiluminescence analysers respectively at the lowest ranges. At the university, NDIR analyser and CO detector (dragger) tubes with an associated gas extraction pump were used to measure CO emission while only NO_x detector tubes were used to measure NO emission in the absence of chemiluminescence analyser. In accordance with the measurement procedure, the detector tubes were tightly inserted into the pump and one stroke of the pump was used for CO while ten stroke were used for NO_x measurement. The total length of discoloration of the indicating layer (white to brown for CO and dark blue to grey for NO_x) is a measure of the concentration of the different species. The use of detector tubes only for NO_x measurement at the university did not adversely affect the results since the error margin in the use of analyser and detector tubes is within $\pm$ 5% which is acceptable in the ranges measurements were made. Stainless steel sampling probes were located in turn where test operators stand to adjust the engine test parameters, calibrate the exhaust analyser, and record results.

Since no chemical or physical methods have been developed to measure diesel odour, the operators used their sense of smell to determine the intensity and quality of the odour during the operation of the diesel engine. According to AAronson et al (1970), neither the diesel odour problem nor the potential health hazards associated with any carcinogens which may be present in diesel exhaust can be evaluated until the chemical composition of diesel exhaust is qualitatively determined.

Table 1. CO and NO_x concentrations in exhaust gases of the gasoline and turbocharged diesel engines at idle and full load operating conditions.

Emission	Gasoline Engine	Turbocharged Diesel Engine
	IDLE OPERATION	
	800 rev/min	650 rev/min
CO ppm	32,500	300
NO_x	425	350
AIR-FUEL Ratio	13	50
	FULL LOAD OPERATION	
	450 Rev/min; 75Nm	1800 Rev/min; 540 Nm
CO ppm	15,000	500
NO_x	3,250	2,500
AIR-FUEL Ratio	13.5	27

5.0 DISCUSSION OF RESULTS

The measured concentration levels of CO and NO_x for the various operating conditions are presented in Figure 2 in the form of bar charts. The height of each bar represents the level of concentration at idle or full load operation of the gasoline or diesel engine with and without ventilation. The ambient air quality guidelines of WHO (1987) for CO and NO_x for one hour exposure as reported by Kiely, G (1996) are also presented for comparison with the test results.

It was observed that when the WHO standards were compared with the results of the two engines, higher CO and NO_x levels existed in the laboratory at full load and idle conditions when ventilation fans were switched off. When the fans were switched on and the test repeated, all the pollutants were significantly lower, in some cases, there was no indication of pollutants in the environments. It was difficult to obtain reputability of results from the calibrating gas bottle cubicles and the exhaust analyser environment due to air-motion and the chemistry of the species. However, the presence of pollutants in these environments was established.

CO level in the bonnets of two different designs of saloon car during engine tuning in the automobile workshop was investigated. It was observed that the mechanics who work on vehicles with rear-mounted engines are exposed to higher CO level than those who specialise on vehicles with engines in the front bonnets. This is due to the proximity of the exhaust outlet and blowby to the mechanics in the process of tuning or adjustment while the engine is idling. The measured pollutants levels were also inconsistent here since the CO and No_x levels in the exhaust would depend on the model, size and age of the vehicles. In the diesel engine laboratory, all the test operators agreed that the diesel odour during high load operation and inadequate ventilation was very offensive but could not determine the intensity or quality of the odour.

This work has revealed through observation that operators test results can be inconsistent by as much as 15% towards the tail end of engine test run. The average time for a full load test of about ten sets of data is usually 1.5 hours, while that of part load test with emission measurement can last up to 2.5 hours. As shown in Fig. 3, the percentage carboxyl haemoglobin (COHb) in the blood stream of the operators would have reached 10% and above, with inadequate ventilation resulting in headache and reduced mental activity. The inconsistency in recording test results would therefore be high. However, the level of COHb in the blood stream of the operators would depend on the initial concentration emanating from high, light or low level of cigarette smoking, the duration of exposure and the degree of ventilation. From measurements, it was observed that some brands of cigarette smoke contain up to 75 ppm CO. Though smoking is not normally allowed in engine test environment, operators either smoke or are exposed to cigarette fumes in rest rooms and canteens immediately after of before test operations.

Lawther (1975) revealed that the nervous system is very sensitive to hypoxia. Therefore, the perception and performance of test operators exposed to certain levels of CO should be related to hypoxia. Their intellect and senses become dull without realising it; hence their ability to judge properly becomes questionable. This would give rise to reduced performance

on jobs that require skill and concentration. It was observed that operators' performance improved when they became aware that their performance pattern was being monitored. However, the time normally required to complete a test run increased by about 10%.

6.0 CONCLUSION

This investigation has revealed that concentration of noxious and offensive pollutants exist in engine test laboratories and automobile workshop and the level can be higher than the air quality standard of WHO (1987) when ventilation in these places is inadequate.

Test operators and motor mechanics are exposed to CO, NO_x and offensive diesel odour when working in a test environment that has inadequate ventilation. Uncertainties involving dispersion and atmospheric reactions however prevented any definite conclusion to be drawn concerning the levels of CO and NO_x in these environments; therefore, adequate ventilation must be ensured at all times.

If crankcase blowby is not recirculated, exhaust pipe leakage will still remain the main source of pollution in test environment. The CO from the exhaust emissions of motor vehicles would increase the COHb of operators and motor mechanics, if the exhaust gases are not adequately piped out of the laboratory or workshop.

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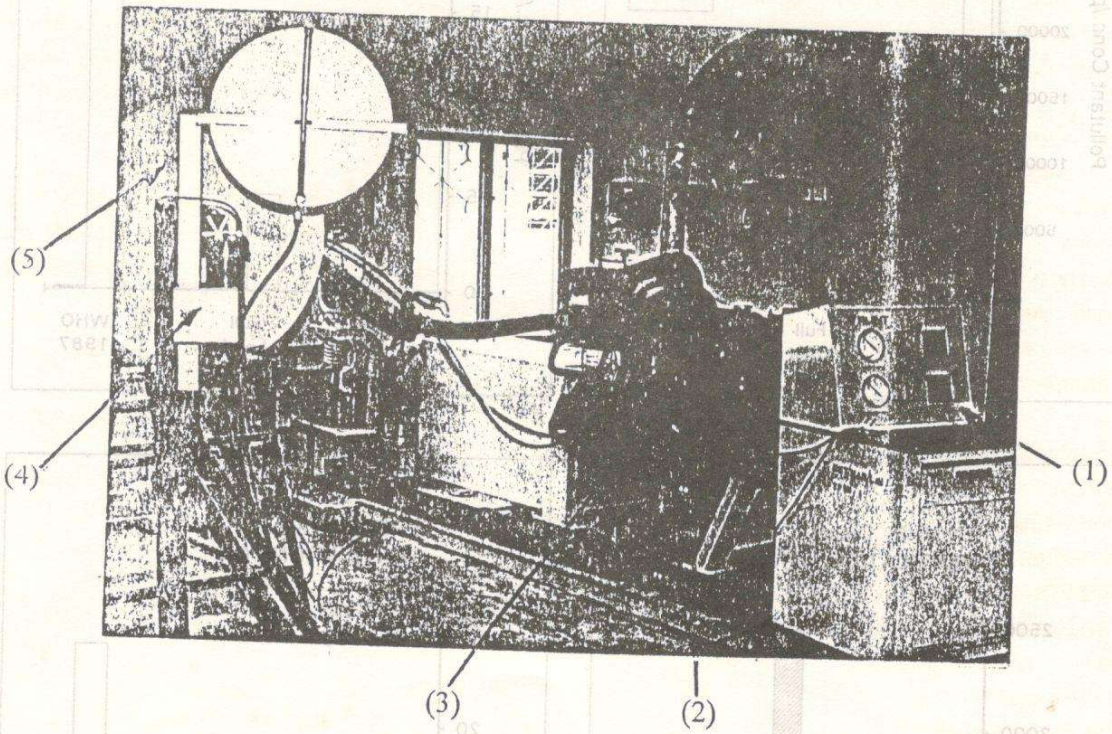
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1. control console
2. diesel engine
3. crankcase blowby
4. fuel measuring unit
5. air measurement drum

Figure 1: Diesel Engine test bed installation

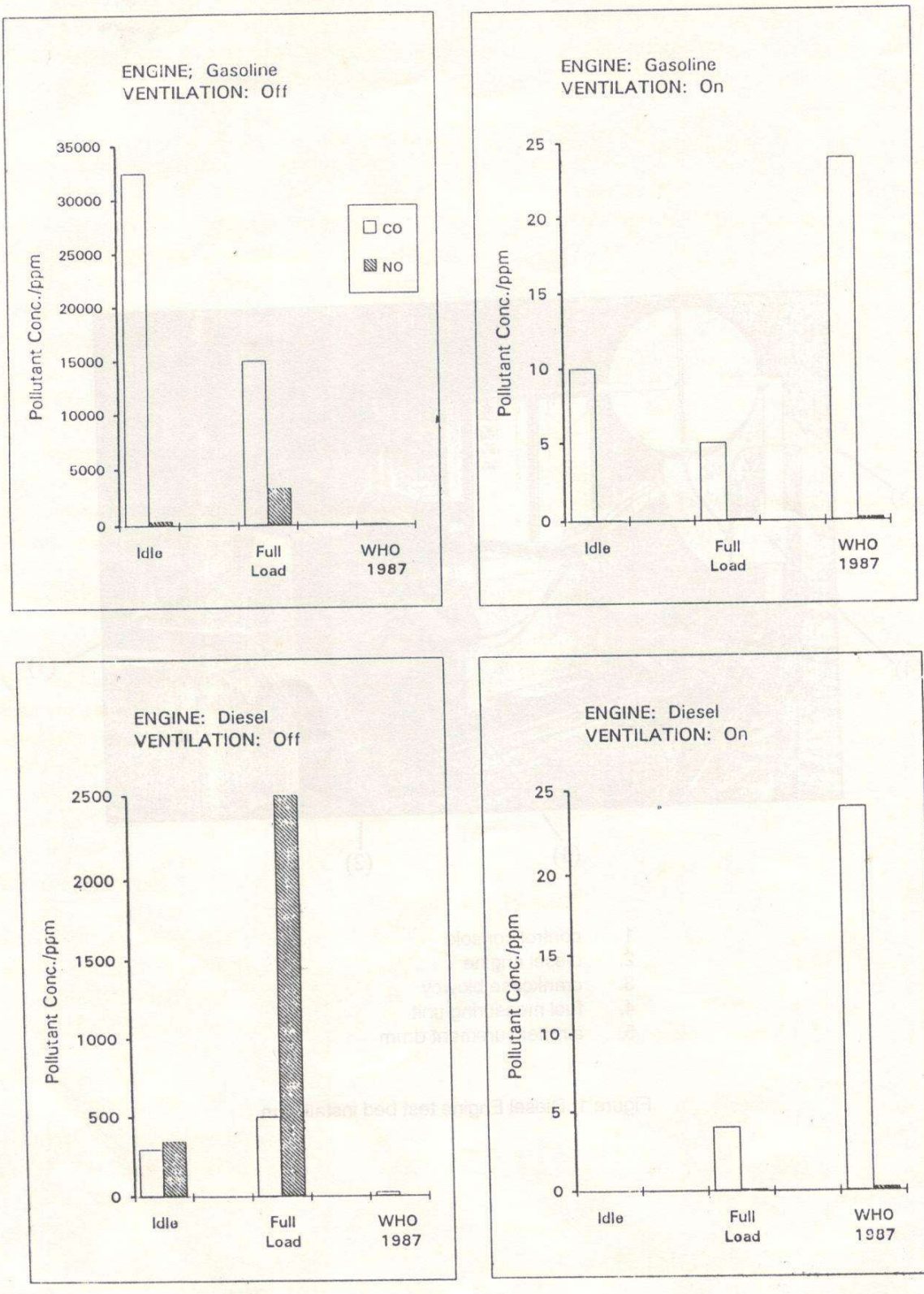


Figure 2: CO and NO Concentrations in the Engine Test Laboratory at Throttle Lever Position

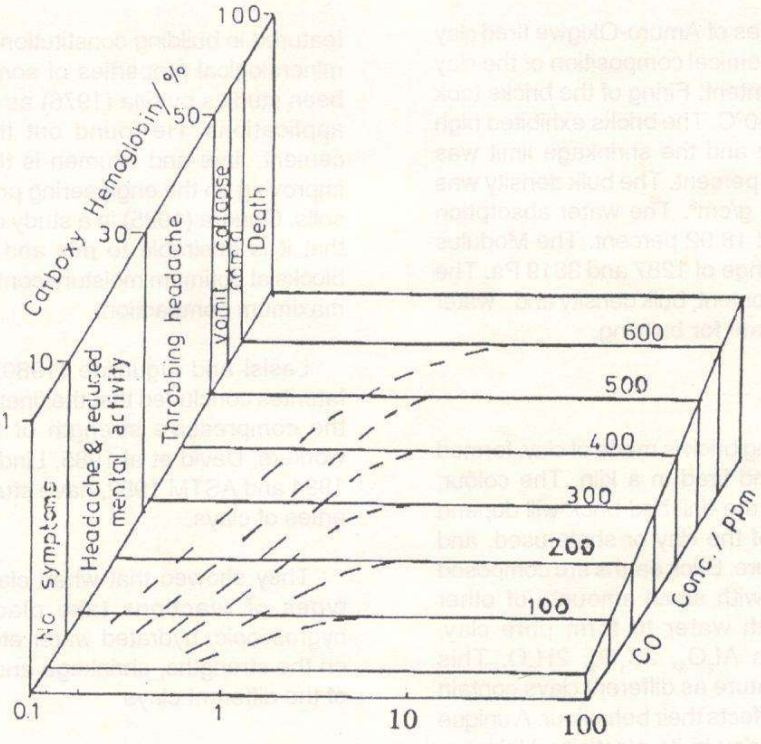


Figure 3: Toxicity of carbon monoxide