United States
Environmental Protection
Agency

Air and Radiation

EPA 420-B-97-001
August 1997

EPA

# Emissions and Fuel Economy Effects of Vehicle Exhaust Emission Control Device

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## 1.0 Abstract

This report describes testing by EPA of the Vehicle Exhaust Emission Control Device (VEECD) retrofit device under Section 32918 Retrofit Devices (RD). This testing was conducted at the National Vehicle and Fuel Emissions Laboratory (NVFEL) in Ann Arbor, Michigan at the request of the device developer, Hawtal Whiting Environmental Ltd. of the UK since submission of the RD application, Hawtal Whiting has established a tradename, EVEL™ for the VEECD.

The VEECD is described by the developer in the international patent application as an embodiment of air bleed principle. It is intended to be retrofitted to vehicles produced without any, or with earlier-technology emission control systems. It is not compatible with newer complex engine management systems or vehicles equipped with closed-loop three-way catalytic systems. The device is designed to be inserted into the hose connecting the inlet manifold to the vacuum brake booster and, as claimed by the developer, acts to optimize the air/fuel mixture during idle and deceleration.

The developer claims (RD Application Appendix A) that the valve significantly reduces CO and HC emissions without substantially increasing $CO_2$ or NOx emissions. Incidental City Fuel economy enhancement was also claimed. Non-FTP test data obtained for 1986/87 European vehicles from two laboratories in the UK was submitted. This data (Appendix B) was analyzed using the t-test for the difference of constant speed data 30/60/85MPH) at95% confidence level and the following was concluded:

- The device appeared to reduce CO emission at low speed; however, this effect is reduced at higher constant speed.
- HC and NOx emissions did not appear to be affected by the device.
- The device seemed to have negligible effect on $CO_2$ emissions and fuel economy.

The apparent CO emission reduction warranted EPA to proceed with confirmatory testing of the VEECD device.

The developer provided two vehicles as basis for the test program. Both were 1973 model-year light-duty vehicles. One was a Dodge Dart powered by a 318 cu. in. engine; the other a Ford Mustang incorporating a base 302 cu. in. engine. Both vehicles were selected by the developer because they appeared to be close to original specification and incorporated the early-technology emission-control systems with which the VEECD is most compatible.

The agreed upon test plan sequence (Appendix C) included a comprehensive inspection and maintenance identical to that performed on in-use vehicles in EPA's Recall Program done by Vehicle Programs and Compliance Division (VPCD). Federal Test Procedures (FTP) were performed to establish the baseline tailpipe emission output of both vehicles. The VEECD was then installed on each vehicle by the developer's representative under the auspices of EPA personnel in accordance with the written instructions provided by the developer. The vehicles were again subjected to FTP testing. The third and final test consisted of a second baseline test without the VEECD.

Complete test data were collected only on the Ford because an undiagnosed engine failure in the Dodge prevented this vehicle from completing the second baseline test.

EPA concludes the following from the testing conducted on these two vehicles:

- Use of the VEECD resulted in a decrease in hydrocarbon (HC) and carbon monoxide (CO) emissions and an increase of oxides of nitrogen (NOx) and carbon dioxide ($CO_2$) emissions in both cars.

- Use of the VEECD resulted in an increase in city fuel economy in the Ford. Fuel economy in the Dodge remained the same.

## 2.0 Background

Under Section 32918 of title 49 U.S.C., EPA is required, in response to requests from certain sources, to evaluate aftermarket retrofit devices and fuel additives (collectively referred to as devices) that are claimed to improve fuel economy and emissions. EPA receives information about many of these devices that are represented by the device developer/manufacturer as offering a potential for reductions in emissions and/or an improvement in the fuel economy of conventional automobiles. EPA's VPCD is interested in evaluating such devices because of the obvious benefits the test results and analysis have for the nation. EPA invites developers of devices to submit information on the principle of operation together with available preliminary emission test data. In those cases where the developer's/manufacturer's application meets certain established program criteria, and the device shows promise in preliminary screening tests at an independent laboratory, confirmatory tests may be run at EPA's NVFEL in Ann Arbor, Michigan at the expense of the applicant. EPA is also required to evaluate devices at the request of the Federal Trade Commission and may perform such a device evaluation at the discretion of the EPA Administrator.

The conclusions drawn from EPA evaluation tests are necessarily of limited applicability. An all encompassing evaluation of the effectiveness of a device in achieving performance improvements on the many types of vehicles that are in actual use would require a large sample of test vehicles. This is not economically feasible in the evaluation projects conducted by EPA. Therefore, the conclusions from such device evaluation tests can be considered to be quantitatively valid only for the specific test cars used; however, it is reasonable to extrapolate the results from EPA tests to other types of vehicles in a directional manner; i.e., to suggest that similar results are likely to be achieved on other similar types of vehicles.

## 3.0 Introduction

This report describes EPA's testing of the VEECD air-bleed device under Section 32918. The evaluation was conducted to address claims of reduced emissions and incidental improved city fuel economy performance of this device.

## 4.0 Purpose of the Test Program

The purpose of EPA RD test program was to conduct a controlled technical evaluation of the VEECD air-bleed device in a manner that would address the developer's specific claims for significant reduction in HC and CO; with incidental reductions in fuel consumption during urban test cycles. Effect of the VEECD on power, octane requirement, cleanliness of the combustion chamber, and driveability were not evaluated. The developer made the following statements with regard to the device:

Purpose:

A mechanical device, which can be easily retrofitted to old vehicles to significantly reduce CO and HC emissions without significantly increasing $CO_2$ and Nox emissions. Incidental reduction in fuel consumption, particularly during the urban cycle is also achieved.

Applicability:

Effective on four-stroke spark ignition engines and operates with carburetor and fuel-injection systems. VEECD is not compatible with diesel engines.

Not compatible with complex engine management systems or vehicles fitted with three-way, closed loop catalytic converters. Weather and driving conditions do not adversely affect the functionality of the VEECD.

Theory of Operation:

The VEECD enhances the efficiency of the mix between air/fuel ratio in the combustion chamber and it also reduces overall friction in the non-combustion cylinders.

Construction and Operation:

VEECD is a simple mechanical "T" shaped valve. It is fitted to the vacuum brake servo line and acts to optimize the air/fuel mixture during idle and deceleration.

Specific Claims:

Significantly reduces CO and HC levels. Incidental reductions in fuel consumption, particularly in the urban cycles have been achieved.

## 5.0 Test Plan

The test plan developed by EPA and approved by the developer was as follows:

- The developer provided two test vehicles. Both were 1973 model-year light-duty vehicles. One was a Dodge Dart, the other a Ford Mustang.

- Both vehicles were subjected to inspection and maintenance identical to that performed on more recent model vehicles selected for testing in the VPCD Recall Program. Both were tuned as close to manufacturer's specifications as possible given their age and engine wear, replacing parts as necessary. The resultant air fuel ratio (AFR) was rich of stoichiometry in both vehicles.

- Baseline FTP testing was performed to establish the emissions and fuel economy of both vehicles prior to the installation of the VEECD. The FTP (Federal Register; 40 CFR Part 86; July 1, 1990) is the official EPA test procedure for determining the exhaust emissions and city fuel economy of a vehicle. The vehicles were not tested for evaporative emissions.

- A VEECD was installed in each vehicle and adjusted per developer's procedure by a developer's representative under the auspices of EPA personnel. No adjustments were made to any engine components between tests.

A second set of tests were then performed to evaluate the performance of the VEECD.

The device was removed prior to the second series of baseline tests. Again, no adjustments were made to any engine components between tests. Only the Ford completed this phase of testing. Due to an undiagnosed engine failure, the Dodge did not complete its second baseline test.

Claims other than improved city fuel economy and reduced CO and HC exhaust emissions were not specifically addressed. These other claims are in large part subjective and procedures for their evaluation are neither well defined nor routinely used by EPA. In addition, to evaluate other claims or vehicle system effects would require extensive vehicle mileage or engine out-of-vehicle operation. It should be noted however, that test technicians noted no driveability problems during the test driving cycles.

During the program, the device developer was present for all phases except the first series of baseline tests.

## 6.0 Results

The results of EPA testing can be found in Table 1. These data have been analyzed and indicate the following:

- Neither vehicle met all emission standards for which they were originally designed even though both had been tuned as close to the manufacturer's specifications as possible and certain parts replaced as necessary. The resultant air fuel ratio for both the Dodge and Ford was rich of stoichiometry at 14.4 and 18.6 respectively. Given the age and engine wear of the vehicle, this is not unusual.

- HC and CO decreased from each vehicle with installation of the VEECD.

- HC and CO were decreased by 21% and 31% respectively in the Dodge; 4% and 20% in the Ford.

- NOx emissions increased from both cars with the installation of the VEECD; 13% for the Dodge and 10% for the Ford.

- $CO_2$ emissions from both cars increased also; 6% for the Dodge, 4% for the Ford.

- No improvement in city fuel economy was seen in the Dodge; however, city fuel economy did improve by 2% in the Ford.

## 7.0 Conclusions

EPA concludes the following from the testing reported (Table 1) above.

EPA testing confirmed the trend of data and claims submitted by the developer. The VEECD showed a decrease in HC and CO emissions from two examples of vehicles incorporating older emission control system technology. Volumes of such vehicles are small in the United States so applicability of the VEECD domestically would be quite limited. However, other geographic locations where there are high volumes of vehicles with older emission control systems might benefit from VEECD usage in reducing CO and HC's provided that any $No_x$ increase does not lead to increase in ozone ($O_3$) levels. Ozone is formed in ambient air from photochemical reactions of HC's and $No_x$. A recent report[1] emphasizes the increased importance of $No_x$ in $O_3$ formation. The relative importance of HC and $No_x$ control varies from one part of a geographic location to another depending on local conditions. EPA regulates vehicle emissions of CO to meet ambient CO levels and HC and $No_x$ to meet acceptable $O_3$ levels. Therefore, based upon this very limited amount of test data from one vehicle that completed the test plan, it would seem that the use of VEECD on vehicles containing older technology emission control systems may be environmentally beneficial because of the reduction in HC and CO for areas meeting HC and CO controls. However, any $No_x$ increase must be considered since in some conditions $No_x$ emissions are more important than HC in ozone formation. Finally, the fuel economy increase seen in the Ford was not significant for a test sample of this size.

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[1]"Rethinking the Ozone Problem in Urban and Regional Air Pollution", National Research Council, 1992, National Academy Press, 2101 Constitution Ave., NW, Washington, DC 20418.

TABLE 1

TEST RESULTS FROM EPA TESTING OF TWO VEHICLES
WITH AND WITHOUT VEECD
IN RESPONSE TO DEVELOPER'S APPLICATION

| Vehicle | Test # | Date | ODO[1] | HC[2] | CO[2] | NOx[2] | $CO_2$ | MPG[3] |
|---|---|---|---|---|---|---|---|---|
| DODGE | | | | | | | | |
| Baseline | 301001 | 3/25/97 | 61474 | 3.9 | 68 | 3.1 | 511 | 14.1 |
| W/VEECD | 301002 | 4/08/97 | 61501 | 3.1 | 47 | 3.5 | 545 | 14.1 |
| % Change | | | | -21 | -31 | +13 | +6 | 0 |
| FORD | | | | | | | | |
| Baseline | 300001 | 3/25/97 | 34340 | 4.9 | 99.4 | 1.4 | 516 | 12.9 |
| W/VEECD | 300002 | 4/8/97 | 34367 | 4.3 | 73.3 | 1.7 | 550 | 13.1 |
| Baseline Retest | 300003 | 4/9/97 | 34393 | 4.1 | 84.1 | 1.7 | 542 | 12.9 |
| % Change | | | | -4 | -20 | +10 | +4 | +1.5 |
| Original Certification Standards. | | | | 3.4 | 3.9 | 3.0 | | |

Units: [1] Odometer mileage reading but not known if actual.
[2] HC, CO, Nox, CO in Grams/mile
[3] Miles per gallon

# APPENDICES

A - Application

B - Millbrook Test Data

C - Test Plan

D - Test Vehicle Descriptions

NON-CONFIDENTIAL

# EPA AFTERMARKET RETROFIT DEVICE EVALUATION APPLICATION

for Hawtal Whiting Environmental's Vehicle Exhaust Emissions Control Device

1. Title

Vehicle Exhaust Emission Control Device (VEECD)

2. Identification Information

a) Marketing Identification

No trade names exist as yet, but known internally as VEECD.

b) Inventor and Patent Protection

1. Mr. Richard Bushell,
107 Offington Lane,
Worthing,
Sussex BN13 9RW

2. Patent Application No. PCT/GB96/00999 (attached)

c) Applicant
(see attached letter from inventor)

1. Hawtal Whiting Environmental Limited
Phoenix House,
Christopher Martin Road,
Basildon,
Essex SS14 3EZ

2. Mr. Ken Tibbitt - Managing Director

3. Mr. Ken Tibbitt - Managing Director
Ms Elizabeth McNabb - Business Development Manager
Phoenix House,
Christopher Martin Road,
Basildon,
Essex SS14 3EZ
Tel (44) 1268 531155 Fax (44) 1268 273555

3. Description

a) Purpose

A mechanical device, which can be easily retro-fitted to old vehicles to significantly reduce CO and Total Hydro-Carbon (THC) emissions without significantly increasing $CO_2$ and $NO_x$ emissions. Incidental reduction in fuel consumption, particularly during the urban cycle also achieved.

b) Applicability

1. Effective on 4 stroke spark ignition (Gasoline, LPG/CNG) engines and operates with both carburettor and fuel injection systems. VEECD is not compatible with diesel (compression ignition) engines.

2. Not compatible with complex engine management systems or vehicles fitted with three way, closed loop catalytic converters. Weather and driving conditions do not adversely effect the functionality of the VEECD.

c) Theory of Operation

The VEECD enhances the efficiency of the mix between air /fuel ratio in the combustion chamber, it also reduces overall friction in the non combusting cylinders.

d) Construction and Operation

VEECD is a simple mechanical 'T' shaped valve. It is fitted to the vacuum brake servo line and acts to optimise the air/fuel mixture during idle and deceleration.

e) Specific Claims

Significantly reduces CO and THC levels. CO reductions in excess of 50% are often achieved as verified by the attached results from Millbrook Proving Grounds Emission Laboratory, an internationally recognised independent test laboratory and AEA Technology, the UK's Atomic Energy Authority based in Harwell. The tests at Millbrook were witnessed and verified by the "Vehicle Certification Agency", VCA. The VCA is the UK's national approval authority for new road vehicles. This report is also attached.

Incidental reductions in fuel consumption, particularly in the urban cycles, have been achieved. This has been verified by the attached fuel consumption certificate from Evans Halshaw (Sussex) Ltd..

f) <u>Cost and Marketing</u>

HW Environmental does not intend to sell this product directly to end-users. Our preferred method of marketing is via technology licences, thus we have not set a retail price. However we estimate that manufacturing and packaging costs will be less than US $30.

A small production run of 6000 units has been successfully produced in the UK.

4. <u>Installation</u>

Note: The VEECD is designed to be fitted by a competent engineer who has a basic knowledge of engine diagnostics using a gas analyser. The VEECD is not intended to be fitted by the car owner. The information in this section has been therefore kept to a minimum. It includes non-confidential information only. However, attached is a confidential document, for EPA use only, that covers the installation of the VEECD in more depth. This is for the EPA engineer who will be testing the unit.

a) <u>Equipment</u>

The equipment necessary to install the VEECD is non specialist with the exception of one item, a specialised tuning tool. The other tools include a pair of efficient pipe cutters, a screwdriver, and a gas emission analyser which records CO and THC gases.

b) <u>Operation</u>

The installation of the VEECD is simple. It can be fitted by any engineer who has a basic knowledge of engine diagnostics using a gas analyser which reads CO and THC gases. Prior to fitting, the vehicle's engine should be tuned to manufacturers specification.

Using a gas analyser and the specialised tuning tool provided, the VEECD can be tuned accurately to the vehicle's requirements. The reduction in CO and THC will be clearly seen as adjustment occurs.

Once the optimum setting has been achieved, the filter pad and lock ring should be fitted to the unit and the installation is then complete.

c) <u>Safety</u>

Tüv of Europe certify that the VEECD has <u>no</u> adverse effect on braking efficiency. See attached report.

d) Maintenance

Annual replacement of the filter and other minor components is recommended.

5. Effects on Emissions and Fuel Economy

b) Test Results Report attached.

| | | |
|---|---|---|
| Evans Halshaw | - Fuel Consumption Certification | - Feb 95 |
| Tüv | - Gutachillche Stellungnahme Benzinspargerät Eco System '96 | - Feb 95 |
| AEA Technology | - Emissions Fuel Consumption Tests on Miric Device | - Oct. 95 |
| Millbrook | - Eco-System effect on vehicle emissions during EPAII (urban) driving cycle and constant speeds | - Nov 95 |
| VCA | - Eco-System emissions reduction device | - Jan 96 |

6. Testing

Vehicle must be set to manufacturers recommended specification.

20th January, 1997

**NON-CONFIDENTIAL**

# EPA AFTERMARKET RETROFIT DEVICE EVALUATION APPLICATION

**For Hawtal Whiting Environmental's**
**Vehicle Exhaust Emissions Control Device**

## PATENT APPLICATION

**PATENT APPLICATION:- PCT/GB96/00999**

**INTERNATIONAL PUBLICATION:- WO 96/34194**

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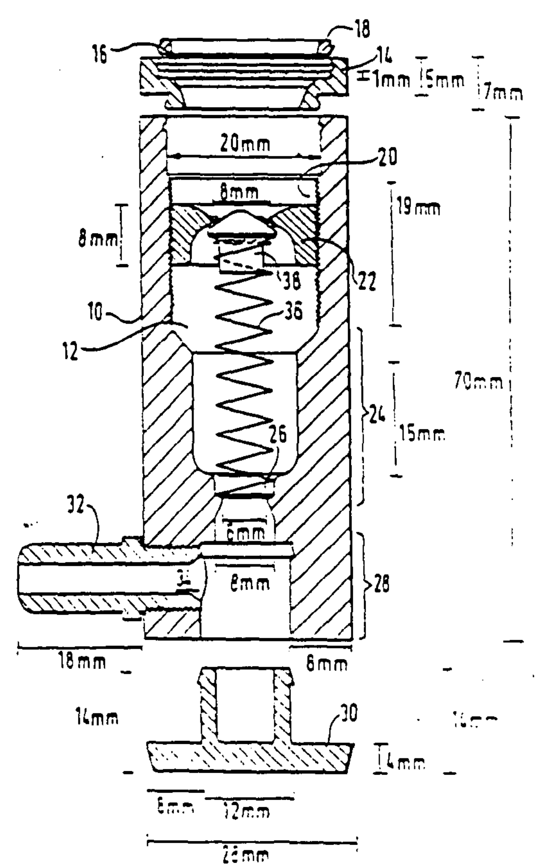
(54) Title: AUTOMATIC VALVE FOR THE INLET MANIFOLD OF AN INTERNAL COMBUSTION ENGINE

(57) Abstract

An automatic bleed valve is disclosed, suitable for attachment to the inlet manifold of an internal combustion engine in order to provide an effective embodiment of the "air bleed" principle. Small amounts of inlet air are allowed into the inlet manifold at periods of high vacuum (low pressure) present during deceleration. The valve closure (38) is biassed by a biassing means (36), e.g. a compressing spring, which acts on the face of the closure disposed away from the seat (22). Other aspects provide for a valve seat which is adjustable in position relative to the closure, a closure and seat of different plastics materials, and a closure with a conical aspect, preferably paired with a seat with a complementary contact portion.



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# AUTOMATIC VALVE FOR THE INLET MANIFOLD OF AN INTERNAL COMBUSTION ENGINE

The present invention relates to an automatic bleed valve. It is especially suitable for attachment to the inlet manifold of an internal combustion engine.

The principle of "air bleed" has been known for many years. This principle states that allowing a small amount of additional air into the inlet manifold of an internal combustion engine at times of particularly low pressure (high vacuum), for example during moments of acceleration or deceleration of the engine, will allow significantly more efficient fuel burning within the engine. This should, in theory, reduce the emission of pollutants such as carbon monoxide (CO) and unburnt hydrocarbons (HC). However, to the knowledge of the inventor, no commercially useful embodiment of this principle has been produced. This is essentially because the reaction time of a bleed air supply must be extremely small in order to keep up with the variations in vacuum in the inlet manifold. As an example, the period for which air must be supplied is of the order of tens of milliseconds.

Early examples of this principle can be found in GB496409 from 1937 and GB690635 from 1950. Such devices do not appear to have become common in the field.

GB 2129869 and GB 2213875 propose arrangements in which a ball bearing-based non-return valve is arranged to supply bleed air to the inlet manifold. The ball bearing is biased towards a valve seat by a spring. However, the response time of these versions are lower than desirable, and in addition the CO and HC reductions achieved are disappointing, even taking into account the lower response time.

In recent times, attention has been directed to computer based engine management systems (EMS). These are essentially microprocessors supplied with data from a number of sensors distributed around the engine. The EMS notes this data and compares it with preset data and/or algorithms and actively manages certain variables in order to optimise the fuel burning characteristics. However, such a system will inevitably be reactive in that an imbalance must first be detected and then corrected after it has existed for a certain period. Thus, the efficiency of such systems is inherently limited by their processing times.

Recent attention has therefore been directed to providing ever better response times for an existing EMS.

The present invention provides a working, useful embodiment of the air bleed principle. To do so, it proposes a number of departures from the existing arrangements.

The present invention therefore provides, in its first aspect, an air inlet valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure, the seat and the closure having complementary-formed conical mating surfaces, the closure being biassed toward the seat by a biassing means acting on the face of the closure disposed away from the seat.

It is preferred if, in this arrangement, the biassing means is disposed in the lee of the valve closure thereby to limit disturbance of airflow over the closure.

A suitable biassing means is a compression spring. In that case, it is preferred if the compression spring alone supports the valve closure. This can facilitate placing the spring in the lee of the closure, and generally reduces the number of parts within the potential airflow path of the valve.

In its second aspect, the present invention provides an air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat member and a valve closure element biased towards the valve seat member, the seat member and closure element being enclosed within a housing, wherein the valve seat member is locatable within that housing in any one of a plurality of positions displaced longitudinally with respect to the biassing of the valve closure element.

Thus, the strength of biasing of the valve closure can be varied, together with the internal volume behind the valve arrangement. This allows the arrangement to be tuned to a particular engine. Whilst the ideal air fuel ratio is 14.7 to 1, an individual engine may be set to run at anywhere between 10 to 1 and 12 to 1, to provide for smooth and robust running. The exact ratio for which a particular engine is set will generally differ from the next engine in line. Thus, the exact pressure in the inlet manifold which corresponds to normal running, sharp acceleration, and sharp deceleration will vary from engine to engine. By this aspect of the present invention, the inlet valve can thus be tuned to reflect this.

Preferably, the valve seat is moveable longitudinally by rotation of a screw thread arrangement. Ideally, the screw threads will be external of the seat and internal within a cylindrical bore in the housing. Suitably, the seat can be disc-shaped. Thus, the adjustment screw can be securely enclosed within the housing. This prevents tampering and enables the vendor of the article to provide a guarantee. Preferably, the housing is sealed against tampering, for example by use of a snap ring retainer for a porous lid. Snap rings are known *per se* and cannot be removed without damage to and hence sacrifice of the ring.

A fine pitched screw thread is preferred, to allow more precise adjustment. A preferred maximum pitch is 30μm.

These aspects allow embodiments of the present invention to achieve reductions in CO and HC pollutants that are closer to those predicted from the theoretical application of the air bleed principle, and significantly better than the ball bearing design.

The present invention also, independently, provides a tool suitable for adjustment of such a preferred valve seat.

This tool, which is according to the third aspect of the present invention, comprises an elongate engagement portion extending from a handle, a tip of the engaging portion having means for inter-engagement with the valve seat, and a longitudinal flow passage running internally of the engagement portion from the tip thereof to an outlet displaced from the tip of the elongate portion. Thus, the tool can be used to engage and rotate the valve seat whilst still allowing passage of air through the valve, via the flow passage. Preferably, the passage is narrower in cross-section than the aperture of the valve seat, to provide a venturi acceleration of the air passing therethrough. This should give an audible effect when air is passing which will be detectable by an engineer tuning the device, to aid such tuning. Alternatively, or in addition, the outlet of the internal passage can be located in the vicinity of the handle, so at to allow a thumb or other digit to be placed near the outlet to sense air flow directly.

In a particularly preferred version, the tip of the elongate portion includes a sealing means for sealing against the valve seat.

The engagement means can be a simple projection or pair of projections on the tip of the elongate portion which engage in corresponding recess(es) on a face of the valve seat, or vice versa.

In its fourth independent aspect, the present invention provides an air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure element biased toward the valve seat and a flow passage leading from the valve seat to a connection port for communication with the inlet manifold, wherein the cross-sectional area of the flow passage at a point intermediate the connection port and valve seat is less than the cross-sectional area of the flow passage at points both upstream and downstream of that intermediate point.

Thus, the flow passage provides a form of "venturi". It has been found by the inventor that such an arrangement surprisingly provides a much quicker transmission of the inlet manifold pressure to the valve seat and closure. Thus, the bleed valve will react very much more quickly than otherwise.

In its fifth independent aspect, the present invention relates to an air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure element biased toward the valve seat, wherein the valve closure is conical in external section, the inclusive angle of the cone being between 55 and 125°, preferably 75 to 105°, more preferably 85 to 95°, and wherein the seat is correspondingly formed to provide a measure of sealing against the closure element.

Such an inclusive angle has been found to enable swift response of the valve closure element in terms of the translational distance required to open the valve to a sufficient extent, whilst being sufficiently narrow to minimise the disturbance to air flow across the closure element.

More preferably, the valve closure element is free floating with respect to the valve seat. One way of achieving this to support the valve closure element via the biasing means only.

By these preferred arrangements, the valve closure element becomes self centring. This notably improves the sealing when closed, which is of great benefit in this context. Failure to close promptly and properly may cause an increase in fuel consumption, in certain circumstances.

In its sixth independent aspect, the present invention provides an air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure element biased toward a valve seat, wherein the closure and seat are of a different plastics material. Plastics material is advantageous in this circumstance because the resultant lower weight of the closure element reduces the inertia of that element and thereby increases the reaction speed. A suitable plastics material for one of the element is nylon 66, and it is particularly preferred if the seat is formed of this material. However, the use of identical plastics materials for both the seat and closure has been found to result in unacceptably high rates of wear.

A particularly suitable material for the closure element is a PTFE/acetal mixture. The PTFE component is preferably between 90 and 98%, balance acetal. A particularly preferred composition is about 96% PTFE and about 4% acetal. This material is preferred because the PTFE gives an especially low friction surface which increases the reaction speed, whilst the acetal ensures that the element has a sufficient strength.

Such a low friction surface for the valve gives surprisingly better response times. It is thought that this is because it reduces the tendency of the valve closure to "stick" temporarily whilst travelling to the closed position. In extreme circumstances, it is possible for the valve closure to sit in an open position, held in place by friction alone. Such a situation can lead to increased fuel consumption.

A preferred opening pressure for the valve of all the above aspects is 14 inches of Mercury. Clearly, many of the valves encompassed by the above aspects will be adjustable in respect of the pressure at which they open, in which case it is preferred that they are capable of adjustment so as to open at that pressure.

In the case of relatively large engines, it has been found by the inventor that further improvements in emissions reduction can be obtained by providing two such valves in parallel, with one valve opening at a higher pressure than the other. This means that at very high vacuum levels, larger volumes of air can be supplied correspondent with the higher demands of a larger engine. Suitable pressures are between 13 and 17 inches for one valve and upwards of 16 inches for the second, subject to it being greater than that for the first valve.

The present invention also relates to an internal combustion engine comprising an air inlet bleed valve communicating with the volume enclosed by the inlet manifold, wherein the air inlet bleed valve is in accordance with at least one of the above aspects. It also relates to a vehicle incorporating such an internal combustion engine.

Embodiments of the present invention will now be described by way of example, with reference to the accompanying Figures in which:-

Figure 1 is partially exploded cross-sectional view of an embodiment of the present invention;

Figure 2 is a detailed view of the valve closure element of Figure 1;

Figure 3 is cross-sectional view of a tool according to an aspect of the present invention;

Figure 4 is a sectional view of Figure 3 along the lines IV-IV of Figure 3;

Figure 5 is a partially exploded cross-sectional view of a further embodiment of the present invention; and

Figures 6a and 6b are plan views of the shutter of Figure 5 in the open and closed positions respectively.

Referring to Figure 1, this shows a bleed valve according to the present invention, along with dimensional information for the relevant parts illustrated. It can be seen that the valve comprises a generally cylindrical body portion 10 which has an internal passage 12 extending along the length of the body portion 10. Within the passage 12 are, in sequence, a filter housing 14 at the open end of the passage 12 which holds a filter 16 by sandwiching it between a ledge on filter housing 14 and a retaining circlip 18, an internally threaded portion 20 within which is held a valve seat 22, a progressively narrowing region 24 culminating in an internal ledge 26, and a progressively widening portion 28 in the outlet of which is inserted a closure element 30 which seals the passage 12. A communication tube 32 is engaged within a tapped bore 34 leading to the passage 12. Thus, the tube 32 provides an outlet within the passage 12.

The valve seat 22 has an external screw-thread which engages with the threaded portion 20 of the passage 12.

The threaded portion 20 is greater in longitudinal extent than the height of the valve seat 22, and therefore rotation of that valve seat 22 within the screw-thread will cause the longitudinal position of the valve seat 22 to alter. The pitch of the screw thread is 13/16 thousandths of an inch, or 20μm.

A spring 36 lies within the passage 12 and rests at one end on the ledge 26, where it is held in a tight fit within the progressively narrowing portion 24. The spring 36 is 12mm long. At its other end, the spring supports a valve closure element 38, shown in more detail in Figure 2. This has a cylindrical portion 40 which is a snug fit inside the spring 36, and a cone-shaped portion 42 which fits within the aperture of the valve seat 22. In the embodiment shown, the base of the cone 42 is wider than the cylindrical portion 40, but this is not essential. It would however be necessary to provide a simple lip onto which the end of the spring 36 could abut to prevent the valve closure element falling into the spring. What is necessary is that the cone portion 42 is able to provide a measure of sealing against the valve seat 22.

On the top (outer) surface of the valve seat 22 are a pair of recesses (not shown) for engagement with the tool illustrated in Figures 3 and 4. The use and purpose of this will be described later.

In use, the tube 32 is connected to the inlet manifold of an internal combustion engine, and sudden increases in the vacuum (decreases in pressure) in the inlet manifold above a predetermined magnitude will be transmitted to the passage 12 and result in the bleed valve opening slightly to allow additional bleed air. It has been found by the inventor that the progressive narrowing of the passage 12 to a minimum diameter, in this example at the ledge 26, provides a venturi effect which speeds the reaction time of the device. The exact mechanism for this is not yet known, but it is believed to lie in the creation of a form of vortex within the flow passages.

The exact pressure at which an individual engine will benefit from bleed air will vary according to the engine, and is generally not precisely predictable. However, this embodiment can be tuned to a particular engine by rotating the valve seat 22 and thereby displacing it upwards or downwards as illustrated. This will both vary the volume within the passage 12 behind the valve, and the pretensioning of the spring 36 when closed. Both of these will vary the reaction characteristics of the valve and allow it to be tuned to a particular engine. It is preferred if the valve is set to open at about 14 inches of Mercury or greater.

The valve closure element 38 has an inclusive angle (in this embodiment) of 115.4°. This is particularly suitable for a high performance engine. In a normal family car, an inclusive angle of about 90° would be more appropriate. Essentially, the precise angle is a trade-off between the distance which the valve closure element 38 must travel (and hence the reaction time) and the effect of the obstruction on the air flow rate.

The valve seating is a complementary shape to the valve closure element, slightly tapered at its outer side to aid air flow.

The filter 16 is necessary since the unit will be installed under the bonnet of a vehicle. A suitable form of filter is crushed steel wool, which is a commercially available form of filter. Sintered ceramic filters are also possible, but steel wool is preferred due to its lesser resistance to air flow.

A notable advantage of the arrangement illustrated is that the circlip 18 and filter 16 prevent unauthorised access to the internal parts of the valve. Thus, once the valve has been tuned to a particular engine (which will of course necessitate removal of the filter 16 to gain access to the valve seat 22), the unit can be sealed until its next service, allowing the imposition of a warranty.

The materials selected for the various parts are significant. The body 10, tube 32, closure element 30, and filter holder 14 and circlip 18 are all structural parts and can be made from, for example, aluminium. This however is not particularly vital so long as the parts can be manufactured to necessary tolerances. In the case of aluminium, an anodising finish is preferred for corrosion reasons.

However, the valve seat 22 and valve closure element 38 must react very quickly to changing pressures behind and be of a wear-compatible material. Thus, a low density material is preferred for the valve closure element 38 in order to reduce its weight, and this suggests plastics material. This also implies plastics material for the valve seat 22, for wear reasons, but it has been found by the inventor that the use of Nylon 66 for both materials results in a higher wear rate than preferred.

In this embodiment, therefore, the valve seat 22 is of Nylon 66, whilst the valve closure element is of a commercially available mix of 94% PTFE and 4% acetal. This combination is preferred because one material is a polar polymer, whilst the other is non-polar. Hence they are incompatible and will not fuse at the microscopic level.

As mentioned above, for large engines it can be beneficial if two such valves are connected in parallel. A suitable arrangement is for the outlet 32 of one valve to connect with the internal space 12 of the other. One valve is then set to open at a higher pressure that the other, for example 13 to 17 inches of Mercury for one and 16 inches or greater (but in any case greater that the first) for the second. This the allows a greater volume flow of air at particularly high vacuum levels in order to satisfy the higher demands of a larger engine.

Figures 3 and 4 show two cross-sections of a tool suitable for tuning the previously described valve. The tool comprises a handle 50 from which extends an elongate portion 52 which is sufficiently narrow to extend into the interior of the passage 12 at its outer end. At the tip of the elongate portion 52 is an O-ring seal 54, and within the O-ring seal are a pair of projections 56a and 56b. Between the projections 56a and 56b is the opening of an internal flow passage 58 which communicates with opening 60 at the junction between the handle 50 and elongate portion 52. In use, the filter 16 and circlip 18 are removed, and the tool is inserted into the passage 12. The projections 56a and 56b engage in corresponding recesses on the outer surface of the valve seat 22, and the O-ring 54 seals against the valve seat 22. At this stage, the engine is running. The operator can rotate handle 50, which adjusts the vertical position of the valve seat 22 in the manner previously described. During this time, all air being taken by the valve will be drawn through the passage 58 due to the O-ring 54. Since the passage 58 is narrower than the passage 12, a "sucking" noise will be heard as the valve opens, which will aid the operator in tuning the valve. Since the outlet 60 is at the edge of the handle 50, an operator can place a finger or other digit close to or nearly over the opening 60 to provide further confirmation of air flow.

Figure 5 shows a further embodiment of the invention. In this embodiment, many parts are common to the first embodiment, shown in Figure 1, and like reference numerals are used to denote like parts. There are however a number of significant differences which are as follows.

The biasing spring 36 which biases the valve closure element of 38 toward the valve seat 22 is seated in a ledge 62 which is movable along the axis of the spring under control of a servo motor 64. That servo is controlled by a programmable controller 66 which is fed with engine running information, for example from an engine management system, by cables 68. Thus, the valve tension is continuously adjustable within limits and this will enable the vacuum pressure at which the valve opens to be adjusted during operation of the engine.

This enables the unit to be tuned during running of the engine to setting which correspond to the type of use. For example, different demands are placed on the engine at idle, urban and cruise conditions and the unit can react to different driving conditions detected via the data arriving in cables 68. The programmable controller 66 will contain pre-recorded settings corresponding to different conditions.

It has been found that if the spring ledge 62 is moved so as to decrease the tension in the spring 36 at a time when the valve is opened, the reduced tension combined with the established airflow through the valve can mean that the valve does not then properly close of its own accord. Hence, in this embodiment, a shutter 70 is provided. The shutter 70 is under the control of a servo 72 which is in turn actuated by an interface unit 74. In this embodiment, the shutter 70 is a three leaf blade shutter, and is shown in its open and closed positions in Figures 6a and 6b respectively.

Thus, immediately before the spring ledge 62 is moved, the shutter servo 72 acts to close the shutter 70, which prevents any further airflow and causes the pressures either side of the valve to equalise and hence closes the valve. The spring seat 62 is then adjusted to the correct position by its servo 64. The shutter is then opened and operation resumes.

The shutter 70 and servo 72 are arranged such that in the event of an electrical or electronic failure within the system, the shutter 70 closes, taking the unit out of action and thus having no effect on the engine. This "fail safe" action prevents faults in the unit affecting the engine in a detrimental fashion.

With the shutter in place, it is clearly impossible to adjust the valve seat 22 using the tool shown in figures 3 and 4. Thus, coarse adjustment of the valve is only possible during assembly, and leaving fine adjustment to be carried out via the servo 64. This acts as a further means to prevent tampering with the unit by the user which might invalidate a warranty.

In a preferred form of the invention, the embodiments of Figure 1 or Figure 5 are combined with a water injection means which acts to inject water into the fuel air mixture during periods of acceleration i.e. low vacuum. Such water injection is known to be beneficial to the engine performance during periods of acceleration, and thus a combined system will be beneficial during both acceleration and deceleration (during which the high vacuum causes the valve to open).

It will be appreciated by those skilled in the art that the above described embodiments are purely exemplary of the present invention, and that many modifications could be made whilst remaining within the scope of the present invention. For example, the closure element 30 could be formed integrally with the body portion 10, as could the outlet tube 32 or the filter holder 14. Alternatively, or in addition, a secondary filter could be added before the filter 16 to provide an element of prefiltration and alleviate clogging of the filter 16. This might be desirable in dusty countries. Equally, the precise dimensions given are illustrative only and other dimensions could be selected although the present inventor has found that those dimensions shown give good results. Tests of the device illustrated achieved an 80% CO reduction and up to 70% HC reduction.

The device can be manufactured as a discrete unit, as illustrated, which is suitable for retro-fitting to existing vehicles or fitting during assembly. Equally, the device can be physically incorporated into the inlet manifold as an integral part thereof.

CLAIMS

1. An air inlet valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure, the seat and the closure having complementary-formed conical mating surfaces, the closure being biassed toward the seat by a biassing means acting on the face of the closure disposed away from the seat.

2. An air inlet valve according to claim 1 wherein the biassing means is disposed in the lee of the valve closure thereby to limit disturbance of airflow over the closure.

3. An air inlet valve according to claim 1 or claim 2 wherein the biassing means is a compression spring.

4. An air inlet valve according to claim 3 wherein the compression spring alone supports the valve closure.

5. An air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat member and a valve closure element biased towards the valve seat member, the seat member and closure element being enclosed within a housing, wherein the valve seat member is locatable within that housing in any

one of a plurality of positions displaced longitudinally with respect to the biassing of the valve closure element.

6. An air inlet bleed valve according to claim 5 wherein the valve seat is moveable longitudinally by rotation of a screw thread arrangement.

7. An air inlet bleed valve according to claim 6 wherein the screw threads are external of the seat and internal within a cylindrical bore in the housing.

8. An air inlet bleed valve according to any one of claims 5 to 7 wherein the seat is disc-shaped.

9. An air inlet bleed valve according to any one of the preceding claims wherein the housing is sealed against tampering.

10. An air inlet bleed valve according to claim 9 wherein the sealing is by use of a snap ring retainer for a porous lid.

11. An air inlet bleed valve according to any one of claims 6 to 8, or 9 to 10 as dependent on claims 6 to 8 wherein the screw thread has a pitch of 30μm or less.

12. An air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure element biased toward the valve seat, wherein the valve closure is conical in external section, the inclusive angle of the cone being between 55 and 125°.

13. An air inlet bleed valve according to claim 12, wherein the inclusive angle of the cone is between 70 and 100°.

14. An air inlet bleed valve according to claim 13 wherein the inclusive angle of the cone is between 85 and 95°.

15. An air inlet bleed valve according to any one of claims 12 to 14 wherein the seat has a contact region with the closure, which region is tapered with a substantially corresponding angle.

16. An air inlet bleed valve according to any one of claims 12 to 15 wherein the valve closure element is free floating with respect to the valve seat.

17. An air inlet bleed valve according to claim 16 wherein a biassing means both biases the valve closure element toward the valve seat and supports the valve closure element.

18. An air inlet bleed valve according to claim 17 wherein the biasing means is a spring.

19. An air inlet bleed valve for the inlet manifold of an internal combustion engine, comprising a valve seat and a valve closure element biased toward a valve seat, wherein the closure and seat are of a different plastics material.

20. An air inlet bleed valve according to claim 19, wherein one of the seat and closure are of nylon 66.

21. An air inlet bleed valve according to claim 20 wherein the seat is formed of Nylon 66.

22. An air inlet bleed valve according to any one of claims 19 to 21 wherein the closure element is a PTFE/acetal mixture.

23. An air inlet bleed valve according to claim 22 wherein the mixture comprises between 90 and 98% PTFE, balance acetal and inevitable impurities.

24. An air inlet bleed according to claim 23 wherein the PTFE component is substantially equal to 96%.

25. An air inlet bleed valve for an engine manifold substantially as any one described herein with

reference to the accompanying drawings.

26. An air inlet bleed valve according to any preceding claim which is adapted to open at an internal pressure of about 14 inches of Mercury or greater.

27. An air inlet arrangement comprising two air inlet valves, each being according to any preceding claim, each being adapted for connection to the inlet manifold of an internal combustion engine, one inlet valve being adapted to open at a first vacuum pressure, the second being adapted to open at a second vacuum pressure, the second vacuum pressure being higher than the first vacuum pressure.

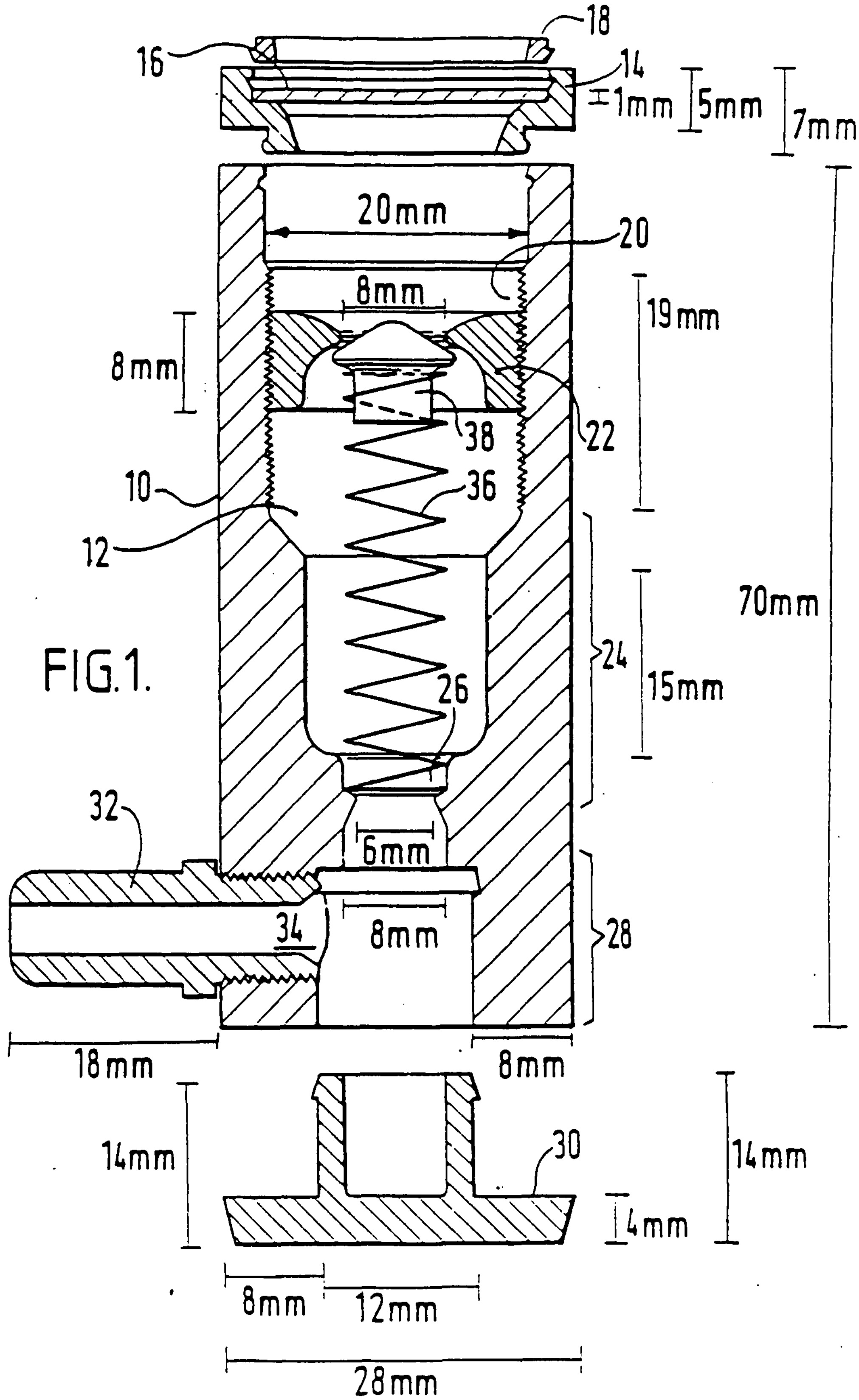
28. An air inlet arrangement according to claim 27 wherein the first vacuum pressure is between 13 and 17 inches of Mercury and the second vacuum pressure is greater than larger of 16 inches of Mercury and the first vacuum pressure.

29. An air inlet arrangement according to claim 27 or claim 28 wherein the outlet of the first or second inlet valve is connected to the interior of the second or first inlet valve respectively at a point downstream of the valve seat and valve closure.

30. An internal combustion engine comprising an air inlet

bleed valve according to any one of claims 1 to 25 or an air inlet arrangement according to any one of claims 27 to 29, the valve or arrangement communicating with the volume enclosed by the inlet manifold.

31. A vehicle incorporating an internal combustion engine according to claim 30.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15mm
26
32
6mm
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30
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4mm
8mm
12mm
28mm

FIG.1.

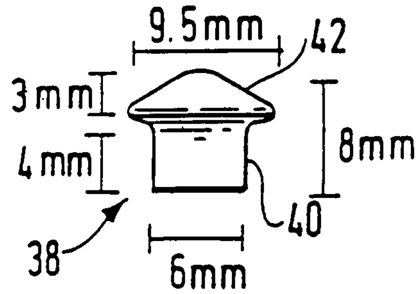


FIG.2.

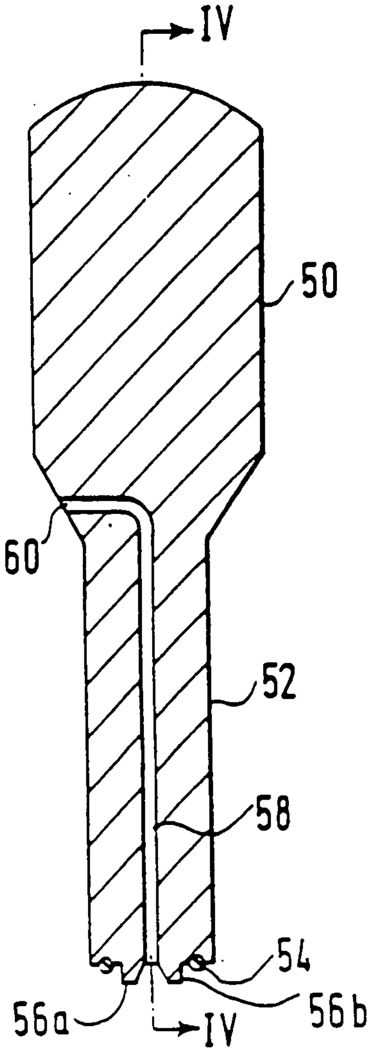


FIG.3.

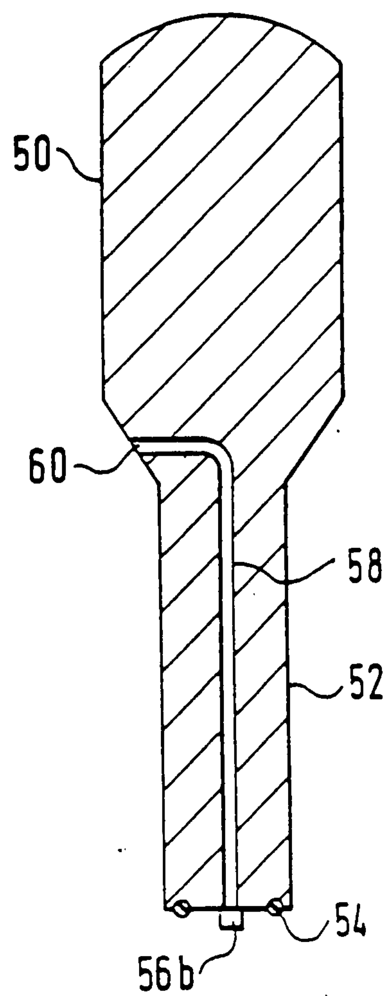


FIG.4.

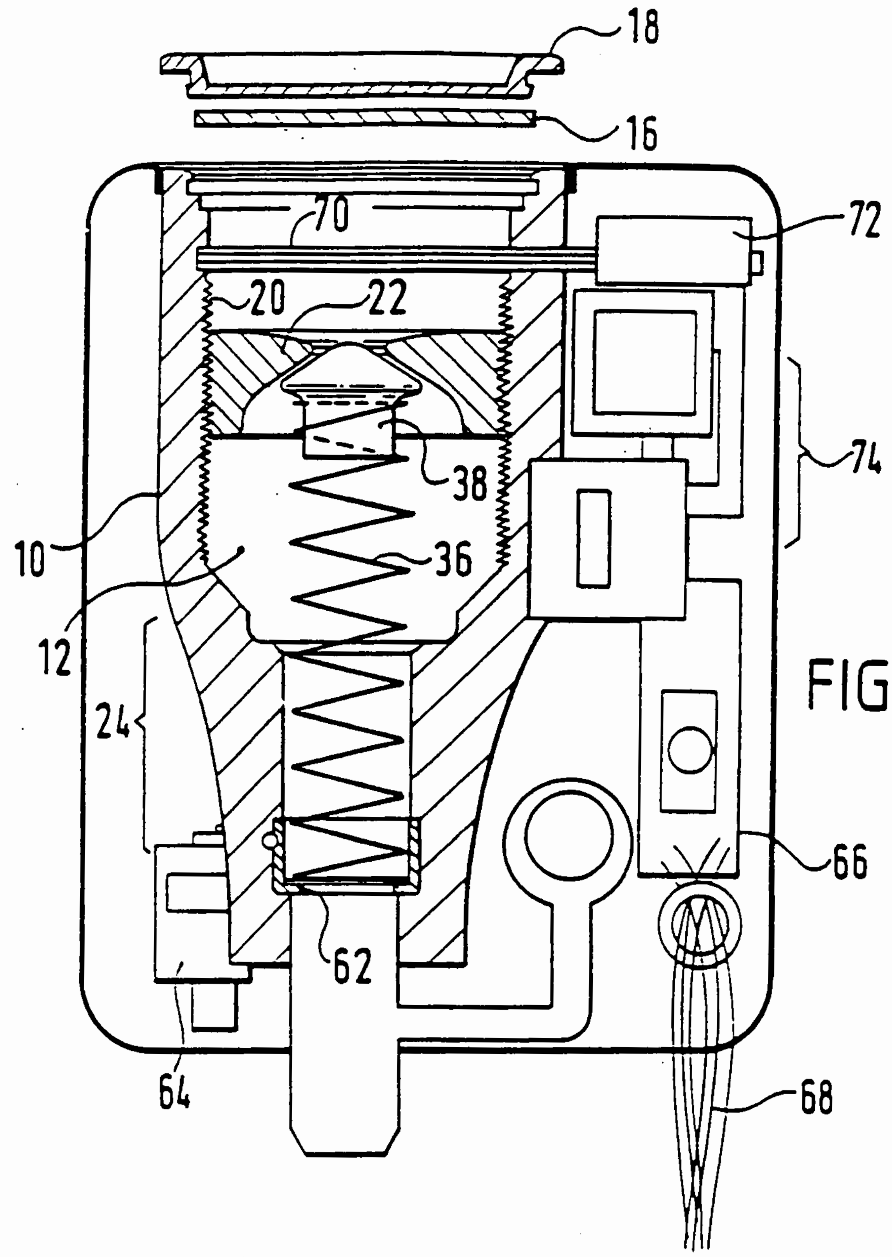


FIG.5.

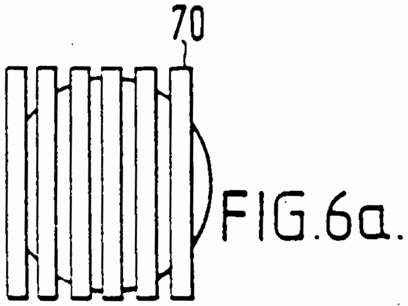


FIG.6a.

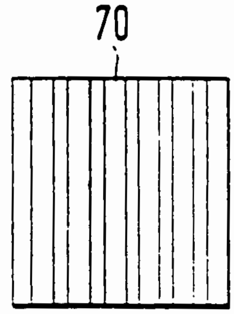


FIG.6b.

## APPENDIX B

## Millbrook Test Data

**Data Set A**

Vehicle Configuration--Stock

| | Units | HC | CO | Nox | CO2 | Units | Fuel Used |
|---|---|---|---|---|---|---|---|
| Phase 1 | gm | 5.623 | 24.627 | 17.433 | 1068.2 | litre/100km | 8.24 |
| Phase 2 | gm | 7.105 | 44.039 | 13.049 | 1258.9 | litre/100km | 9.21 |
| Combined | g/km | 1.062 | 5.729 | 12.543 | 194.2 | litre/100km | 8.75 |

Vehicle Configuration--With Device

| | Units | HC | CO | Nox | CO2 | Units | Fuel Used |
|---|---|---|---|---|---|---|---|
| Phase 1 | gm | 5.598 | 12.360 | 17.330 | 1075.7 | litre/100km | 8.20 |
| Phase 2 | gm | 5.901 | 16.678 | 12.337 | 1288.3 | litre/100km | 9.12 |
| Combined | g/km | 0.963 | 2.440 | 2.485 | 198.0 | litre/100km | 8.68 |

Vehicle Configuration--Stock

| | Units | HC | CO | Nox | CO2 | Units | Fuel Used |
|---|---|---|---|---|---|---|---|
| Phase 1 | gm | 5.335 | 19.913 | 17.223 | 1052.2 | litre/100km | 8.14 |
| Phase 2 | gm | 6.450 | 37.599 | 12.267 | 1251.3 | litre/100km | 9.10 |
| Combined | g/km | 0.989 | 4.827 | 2.475 | 193.3 | litre/100km | 8.64 |

**Data Set B**

Vehicle Configuration--Stock

| 30 mph | Sample# | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 782.0 | 3716.0 | 747.0 | 14.32 | 5.23 |
| | 2 | 783.0 | 3881.0 | 755.0 | 14.35 | 5.20 |
| | 3 | 789.0 | 3944.0 | 753.0 | 14.35 | 5.19 |
| | 4 | 781.0 | 3979.0 | 732.0 | 14.35 | 5.19 |
| | 5 | 779.0 | 3908.0 | 742.0 | 14.34 | 5.18 |
| | 6 | 780.0 | 3741.0 | 762.0 | 14.34 | 5.19 |
| | **Avg.** | **782.3** | **3861.5** | **748.5** | **14.34** | **5.20** |

Vehicle Configuration--With Device

| 30 mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel (1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 767.0 | 1641.0 | 743.0 | 14.11 | 5.12 |
| | 2 | 733.0 | 1742.0 | 762.0 | 14.15 | 5.12 |
| | 3 | 709.0 | 1677.0 | 771.0 | 14.14 | 5.07 |
| | 4 | 712.0 | 1576.0 | 781.0 | 14.17 | 5.03 |
| | 5 | 686.0 | 1633.0 | 736.0 | 14.18 | 5.07 |
| | 6 | 681.0 | 1682.0 | 747.0 | 14.22 | 5.11 |
| | **Avg.** | **714.7** | **1658.5** | **756.7** | **14.16** | **5.09** |

Vehicle Configuration--Stock

| 30 mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel (1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 717.0 | 3554.0 | 730.0 | 14.33 | 5.16 |
| | 2 | 669.0 | 3532.0 | 689.0 | 14.26 | 5.18 |
| | 3 | 677.0 | 3640.0 | 684.0 | 14.32 | 5.16 |
| | 4 | 702.0 | 3797.0 | 722.0 | 14.29 | 5.14 |
| | 5 | 690.0 | 3633.0 | 698.0 | 14.29 | 5.16 |
| | 6 | 699.0 | 3738.0 | 722.0 | 14.39 | 5.15 |
| | **Avg.** | **692.3** | **3649.0** | **707.5** | **14.31** | **5.16** |

**Data Set C**

Vehicle Configuration--Stock

| 60 mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 646.0 | 1505.0 | 3485.0 | 13.76 | 6.62 |
| | 2 | 646.0 | 1604.0 | 3496.0 | 13.81 | 6.61 |
| | 3 | 642.0 | 1575.0 | 3520.0 | 13.78 | 6.57 |
| | 4 | 638.0 | 1442.0 | 3542.0 | 13.70 | 6.52 |
| | 5 | 647.0 | 1527.0 | 3571.0 | 13.80 | 6.51 |
| | 6 | 654.0 | 1625.0 | 3608.0 | 13.78 | 6.49 |
| | **Avg.** | **645.5** | **1546.3** | **3537.0** | **12.77** | **6.55** |

Vehicle Configuration--With Device

| 60 mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 659.0 | 1237.0 | 3542.0 | 13.90 | 6.55 |
| | 2 | 657.0 | 1357.0 | 3578.0 | 13.96 | 6.59 |
| | 3 | 658.0 | 1420.0 | 3601.0 | 13.99 | 6.53 |
| | 4 | 654.0 | 1410.0 | 3632.0 | 13.99 | 6.53 |
| | 5 | 647.0 | 1446.0 | 3625.0 | 13.99 | 6.52 |
| | 6 | 638.0 | 1394.0 | 3661.0 | 13.95 | 6.50 |
| | **Avg.** | **652.2** | **1380.3** | **3606.5** | **13.96** | **6.54** |

Vehicle Configuration--Stock

| 60 mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 635.0 | 1330.0 | 3567.0 | 13.81 | 6.50 |
| | 2 | 642.0 | 1458.0 | 3598.0 | 13.88 | 6.51 |
| | 3 | 642.0 | 1465.0 | 3634.0 | 13.90 | 6.51 |
| | 4 | 647.0 | 1519.0 | 3672.0 | 13.88 | 6.50 |
| | 5 | 645.0 | 1525.0 | 3659.0 | 13.86 | 6.48 |
| | 6 | 642.0 | 1469.0 | 3668.0 | 13.81 | 6.45 |
| | **Avg.** | **642.2** | **1461.0** | **3633.0** | **13.86** | **6.49** |

**Data Set D**

Vehicle Configuration--Stock

| 85mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 414.0 | 2157.0 | 3543.0 | 14.30 | 11.31 |
| | 2 | 340.0 | 2183.0 | 3502.0 | 14.40 | 11.38 |
| | 3 | 313.0 | 2291.0 | 3447.0 | 14.50 | 11.56 |
| | 4 | 292.0 | 2320.0 | 3431.0 | 14.50 | 11.43 |
| | 5 | 278.0 | 2266.0 | 3449.0 | 11.40 | 11.44 |
| | 6 | 278.0 | 2271.0 | 3488.0 | 14.50 | 11.25 |
| | Avg. | 319.2 | 2248.0 | 3476.0 | 14.47 | 11.39 |

Vehicle Configuration--With Device

| 85mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 440.0 | 2016.0 | 3541.0 | 14.36 | 11.28 |
| | 2 | 334.0 | 1998.0 | 3563.0 | 14.40 | 11.27 |
| | 3 | 302.0 | 2013.0 | 3531.0 | 14.40 | 11.18 |
| | 4 | 284.0 | 2014.0 | 3546.0 | 14.39 | 11.11 |
| | 5 | 270.0 | 1894.0 | 3584.0 | 14.36 | 11.11 |
| | 6 | 264.0 | 1847.0 | 3607.0 | 14.37 | 10.81 |
| | **Avg.** | **309.0** | **1963.0** | **3562.0** | **14.38** | **11.13** |

Vehicle Configuration--Stock

| 85mph | Sample # | HC(ppm) | CO(ppm) | Nox(ppm) | CO2(%) | Fuel(1/100k) |
|---|---|---|---|---|---|---|
| | 1 | 393.0 | 1968.0 | 3557.0 | 14.32 | 10.93 |
| | 2 | 347.0 | 1941.0 | 3615.0 | 14.33 | 10.89 |
| | 3 | 316.0 | 2025.0 | 3570.0 | 14.34 | 11.00 |
| | 4 | 303.0 | 2051.0 | 3585.0 | 14.34 | 10.93 |
| | 5 | 285.0 | 1902.0 | 3625.0 | 14.34 | 10.81 |
| | 6 | 273.0 | 1917.0 | 3613.0 | 14.33 | 10.75 |
| | **Avg.** | **319.5** | **1967.3** | **3594.2** | **14.33** | **10.89** |

**Data Set E (VCA)**

Vehicle Configuration--Stock

| Speed | HC (ppm) | CO (ppm) | Nox (ppm) | $CO_2$ (%) |
|---|---|---|---|---|
| 48 km/hr | 783 | 3966 | 752 | 14.39 |
| 96 km/hr | 648 | 1757 | 3601 | 14.02 |
| 137 km/hr | 285 | 2349 | 3468 | 14.58 |

Vehicle Configuration--With Device

| Speed | HC (ppm) | CO (ppm) | Nox (ppm) | $CO_2$ (%) |
|---|---|---|---|---|
| 48 km/hr | 679 | 1642 | 746 | 14.00 |
| 96 km/hr | 633 | 1395 | 3651 | 13.82 |
| 137 km/hr | 271 | 1911 | 3594 | 14.43 |

Vehicle Configuration--Stock

| Speed | HC (ppm) | CO (ppm) | Nox (ppm) | $CO_2$ (%) |
|---|---|---|---|---|
| 48 km/hr | 694 | 3719 | 720 | 14.35 |
| 96 km/hr | 635 | 1572 | 3658 | 13.98 |
| 137 km/hr | 278 | 2002 | 3597 | 14.45 |

## APPENDIX C

## TEST PLAN APPLICABLE TO EACH VEHICLE TESTED

1. Test Fuels

EPA tests are generally run on Indolene HO or, if warranted, commercial unleaded gasoline. Indolene HO is an unleaded fuel with a research octane of about 96. Indolene fuel is special in the sense that its production characteristics are closely controlled. The fuel specifications must fall within certain limits set by EPA. Tight control of fuel quality eliminates the fuel as a source of test variability in vehicle certification tests. There is no reason to expect that the emission characteristics from a vehicle running on Indolene fuel would be significantly different from the emission characteristics when running on a summer grade of commercial pump gasoline.

2. Vehicle Inspection and Checkout

Upon receipt, the odometer reading will be recorded and the vehicle will be checked and adjusted to ensure that it is operating in accordance with vehicle manufacturer's specifications. The following checks, maintenance and adjustments will be performed:

a. Fuel

Drain fuel. Pressure check fuel system. Fill tank with test fuel.

b. Parts (check and/or change)

| | |
|---|---|
| Engine oil | Change (engine warm). Use oil meeting vehicle manufacturers viscosity specifications and latest SAE service specification. |
| Oil filter | Change. Use OEM part |
| Air filter | Change. Use OEM part |
| Fuel filter | Check |
| Distributor Cap | Check |
| Rotor | Check |
| Ignition wires | Check |
| Spark plugs | Change. Use OEM parts<br>Perform compression check here |
| PCV filter | Check |
| PCV valve | Check |
| Engine coolant | Check |
| Transmission fluid | Check |

| | |
|---|---|
| EGR | Check |
| Tires | Check |

c. <u>Computer</u>
Check for and record any fault codes. Correct cause(s) of any codes present.

d. <u>Engine Condition</u>

| | |
|---|---|
| Compression | Check and record. |

e. <u>Settings</u> (if adjustable)

| | |
|---|---|
| Curb idle | Check and adjust if not within manufacturer specifications. Record manufacturer specifications as received setting, and reset level. |
| Ignition timing | Check and adjust if not within manufacturer specifications. Record manufacturer specifications as received setting, and reset level. |

3. <u>Initial Check of Emissions and Fuel Economy</u>

After vehicle inspection and checkout, the vehicle will be stabilized on the test fuel by testing the vehicle at least one time over the standard test sequence of a Federal Test Procedure (FTP) and Highway Fuel Economy Test (HFET). All testíng will be performed on a water-break dynamometer.

4. <u>Baseline Tests</u>

Valid FTP and HFET procedures will be performed on the test vehicle after baseline stabilization. All tests will be conducted on a water-brake chassis dynamometer. Vehicle driveability will be noted.

5. <u>Device Installation</u>

a. The device will be installed in accordance with the written installation instructions provided.

b. The installation will be performed by EPA contractor personnel with the applicant's representative observing, if desired.

6. Device Testing - Immediate Effects

Valid FTP and HFET procedures will be performed on the test vehicle after device installation. All tests will be conducted on a water-brake chassis dynamometer. Vehicle driveability will be noted.

7. The device will be removed and the vehicle returned to its original configuration. Valid FTP and HFET procedures will again be performed.

8. Data Analysis

The test results will be analyzed to determine if there is a statistically significant difference between the data sets (vehicle with and without the device).

NOTE ON TESTING

a. FTP and HFET are to be performed in accordance with EPA procedures applicable to the model year vehicle undergoing testing, except that evaporative emissions are not measured during heat build.

b. The same driver and dynamometer should be used to test the vehicle whenever possible. Driveability should be evaluated during testing. Written driveability comments will be noted.

Approved: Hawtal Whiting Environmental Ltd.

By: [signature]

Date: 24-2-97

**Appendix D**

**Test Vehicle Description**

| Make/Model | Dodge Dart | Ford Mustang |
|---|---|---|
| Model Year | 1973 | 1973 |
| Vehicle ID | LH23G3G248856 | F3F04F110384F |
| Type | 2 dr. Coupe | 2 dr. Coupe |
| Initial Odometer* | 61,458 miles | 34,325 miles |
| Fuel Metering | Carburetion | Carburetion |
| Emission Control System | EGR | EGR |
| Transmission | Automatic | Automatic |
| Tires | P215/65R15 | P205/70R14 |
| Test Parameters: | | |
| Inertia Weight | 3,625 lbs. | 3,500 lbs. |
| Dyno hp | 12 hp | 12.3 hp |

*Odometer mileage reading but not known if actual.