(12) UK Patent Application (19) GB (11) 2 311 025 (13) A

(43) Date of A Publication 17.09.1997

(21) Application No 9705223.7

(22) Date of Filing 13.03.1997

(30) Priority Data
(31) 9605574 (32) 16.03.1996 (33) GB

(51) INT CL[6]
B01D 53/32 , B03C 3/41

(52) UK CL (Edition O)
B1W WX

(56) Documents Cited
GB 2169819 A WO 95/04875 A1 WO 86/03553 A1
WO 84/02743 A1 US 4521229 A

(58) Field of Search
UK CL (Edition O) B1W WX , B2J JH
INT CL[6] B01D 53/32 , B03C 3/41
Online databases: WPIand CLAIMS

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(54) Treating particulate pollutants

(57) An exhaust system (400), such as for a motor vehicle, which releases emissions to atmosphere includes a corona discharge cell (408) with an ion emitter therein, whereby particulate pollutants passing through the system are electrically charged and hence more readily dispersed and precipitated in order to reduce airborne pollution.

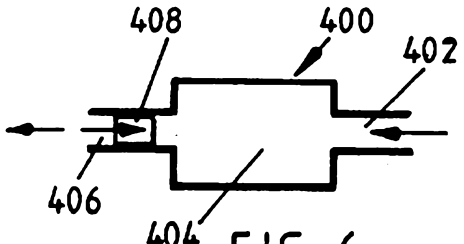

FIG. 6

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

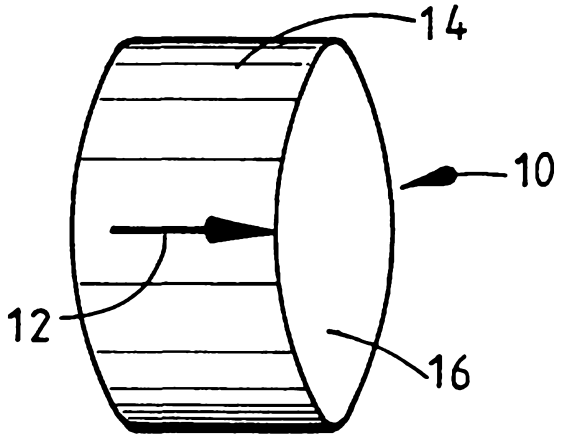

FIG.1

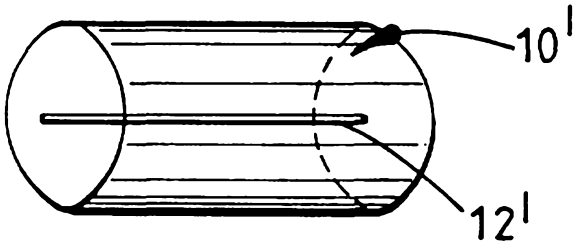

FIG.2

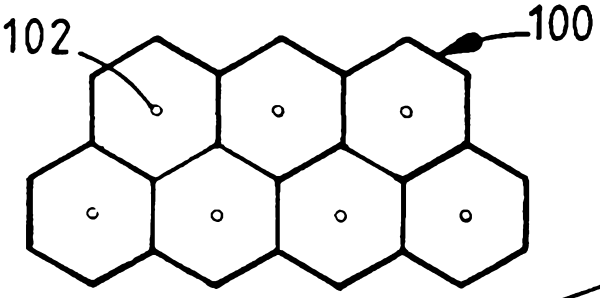

FIG.3

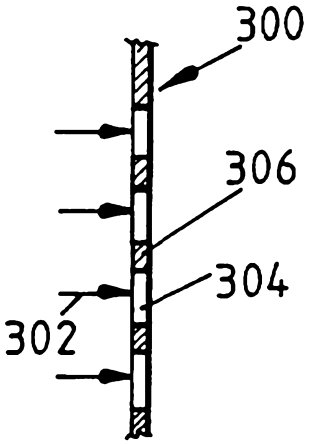

FIG.5

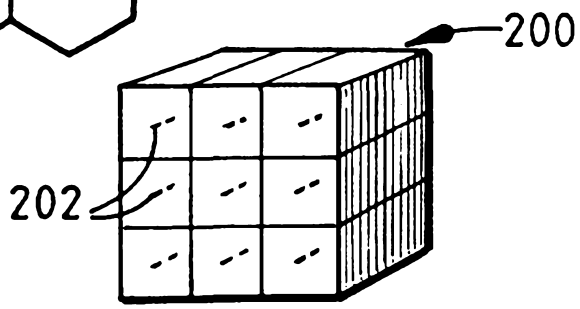

FIG.4

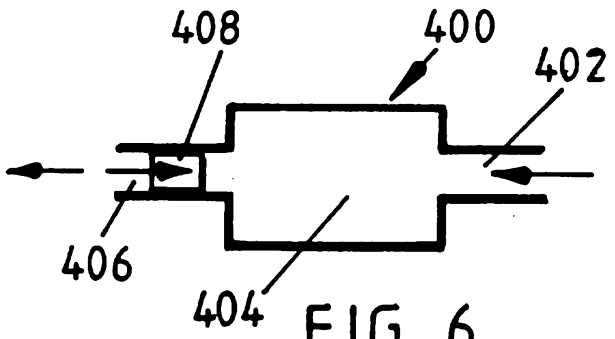
408
400
402
406
404

FIG. 6

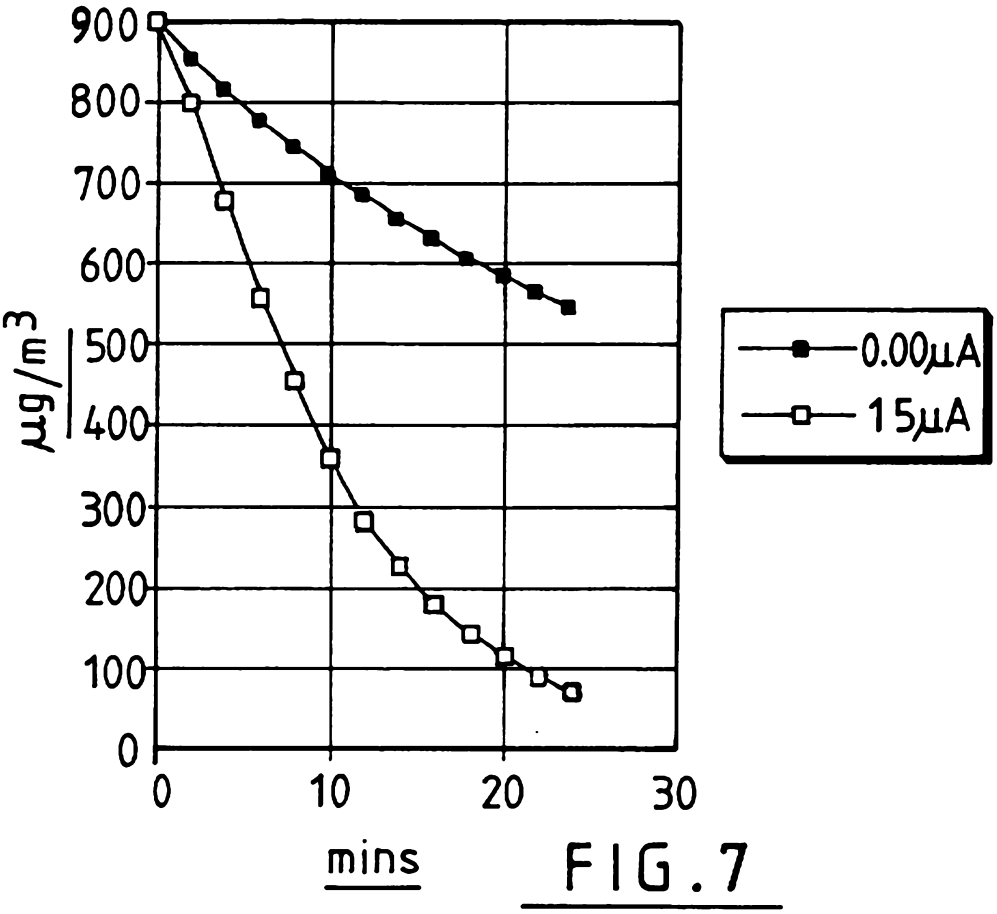
900
800
700
600
500
400
300
200
100
0
µg/m3
0
10
20
30
mins
0.00µA
15µA

FIG. 7

TITLE: Treatment of particulate pollutants.

DESCRIPTION

This invention concerns treatment of particulate pollutants.

Smoke and other exhaust emissions from fuel engines contain high amounts of particulate pollutants. These can remain in the air for long periods adversely affecting air quality. This is a major problem in towns and cities due to high densities of road traffic. The problem is not limited to exhaust emissions from motor vehicles but arises from any plant, machinery, engine or generator wherein solid, liquid or gaseous fuel is consumed creating exhaust emissions containing particulate matter.

There could be a vast improvement in air quality in spite of these exhaust emissions if the length of time that the particulate matter remains in air circulation could be reduced. Filtering of such emissions to remove particulate matter is not particularly effective, as filters become clogged and so lose efficiency.

An object of this invention is to provide means for treating exhaust emissions containing particulate pollutants, whereby the length of time that such pollutants spend in air circulation is reduced.

Accordingly the present invention proposes that exhaust emissions be subjected to ionization treatment, whereby particulate pollutants become charged and hence are more readily dispersed and precipitated.

In a preferred embodiment of the invention exhaust systems producing particulate pollutants are provided with means for electrically

charging exhaust emissions, such as one or more corona discharge cells.

A preferred corona cell has a passageway for exhaust emissions and an ion emitter or electrode associated therewith. The passageway preferably has an associated ion collector surface for attracting ionised air molecules whilst charged pollutant particles may pass through the passageway. The collector surface may form at least a part of a passageway wall.

In one preferred embodiment the corona cell comprises a tube having at least a part of its inner surface of conductive material and an ion emitter or electrode therein. The tube may be of any suitable cross section and is preferably connected to earth. For the tube to be conductive, it may have on its inner surface a conductive coating or layer, which may extend over the whole of the tube or only part thereof, such as in the form of a band or strip.

In other preferred embodiments an array of such corona cells may be provided. Hexagonal section tubes are preferred for making up an array of corona cells in a honeycomb arrangement.

In another preferred embodiment, an array of corona cells may be provided by an apertured plate having a conductive surface and an ion emitter for each aperture.

The ion emitters used in the invention may be of any suitable type to produce a corona discharge when subjected to a high voltage. Needle emitters may be used in the invention but wires, filaments or bunches of same may be used.

The invention will now be further described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 shows schematically a corona cell;

Figure 2 shows schematically another form of corona cell;

Figures 3 to 5 show schematically arrays of corona cells;

Figure 6 shows schematically a motor vehicle exhaust system of the invention; and

Figure 7 is a graph showing smoke concentration against time with and without the effect of a corona cell.

Referring to Figure 1 of the accompanying drawings, a corona cell 10 comprises a corona discharge electrode 12 in a tube 14. The inner surface 16 of the tube is of conducting material and is held at a different voltage to the corona electrode. Typically the conducting material is earthed whilst the electrode has a voltage of $\pm$ 3000 to $\pm$ 20,000 volts applied thereto. An operating current of 1 to 50, typically 15μA, is desirable. The tube 14 is cylindrical and the electrode is a needle on the central axis of the tube.

As shown in Figure 2 of the accompanying drawings, the electrode of a corona cell 10′ may be a thin wire 12′.

The corona cells operate by ionizing air molecules which in turn charge dirt particles passing through the cell due to the corona discharge from the electrode or ion emitter. Charged air molecules have high mobility and are attracted to the conductive surface of the cell where they are discharged to earth. The lower mobility dirt particles pass through the cell in

their charged state.

Figures 3 to 5 show arrays of corona cells 100, 200 and 300 respectively with electrodes 102, 202, 302 respectively. The cells of Figure 3 are hexagonal in section so that a close packed array is possible as with Figure 4 where the cells are square in section.

In Figure 5, the cells 300 are provided by apertures 304 through a conductive plate 306. The area of the plate surrounding each aperture of the plate acts as a collecting surface for ionized air molecules, whilst charged dirt particles pass through the apertures.

It is envisaged that one or more corona cells or an array of corona cells of the types described will be included in exhaust systems, for example, of motor vehicles, as shows schematically in Figure 6 of the accompanying drawings. A conventional motor vehicle exhaust system 400 has an inlet 402 from the engine, a silencer box 404 and an outlet 406 in sequence. In the outlet is situated a corona cell 408, such as of the type shown in any one of Figures 1 to 5. The corona cell is powered from the motor vehicle's own battery. The stream of gas/particles passing through the exhaust system also passes through the corona cell where the particles are charged. The charged particles are then either drawn to earth and hence deposited on, for example, the road surface more quickly than hitherto and/or their rate of dispersion is enhanced due to the mutually repulsive electrical forces between the charged particles. Thus, air quality may be improved by the speedier dispersal amd precipitation of airborne particulate pollutants.

The following experiments were carried out to evaluate the present

invention.

In the first experiment a room having a volume of 5.2m^3 was fed with smoke from burning of a standard incense powder and the concentration of smoke particles measured over a period of time, firstly with no corona cell operating in the room and secondly with a corona cell operating. A fan was used to blow the smoke through the corona cell. The smoke density in the room was measured using an infrared scattering aerosol mass density monitor.

The corona cell was a tube of length 100mm and diameter 100mm with a conducting earthed inner surface and an axially located needle ion emitter i.e. of the type shown in Figure 1 of the accompanying drawings. The cell was operated at 15μA. The smoke particles do deposit on surfaces over a period of time and as can be seen from the graphs of Figure 7 with no corona cell operating, there is a gradual decrease in the airborne smoke particle density. But even after 20 minutes the density was still well over half of the initial density.

However, with the corona cell operating in the room, the deposition of smoke particles onto surfaces of the room is much quicker so that after 20 minutes the smoke particle density was almost down to 1/9 of its initial value.

The increased rate of deposition is believed to be due to the electrical charging of smoke particles by the corona cell. As the smoke particles pass through the corona cell, they are charged by collisions with faster moving ionized air molecules. Ionized air molecules in the cell,

because of their greater mobility are drawn to the conductive surface of the cell before they can escape and are discharged. The heavier less mobile charged smoke particles are able to escape from the corona cell without being discharged but are drawn to earth or dispersed onto surfaces more quickly due to their electrostatic charge than if they were uncharged.

In a second experiment smoke from burning of a standard incense powder was blown through the same room and the concentration of smoke particles measured at the inlet and at the outlet to the room, firstly, with no corona cell operating in the room and secondly with a corona cell operating. The room contained a homogenising fan to ensure substantially even distribution of smoke particles within the room.

The smoke was blown into the room at a rate of $50m^3/hr$ at a fixed concentration of $1000\mu g/m^3$ and the smoke concentration measured at the outlet to the room using an infrared scattering aerosol mass density monitor.

Without the corona cell operating the outlet smoke concentration was measured at $800\mu g/m^3$. From this measurement, the deposition rate of smoke particles could be calculated as follows:

inlet concentration x flow rate -

outlet concentration x flow rate

= amount deposited

= 1000 x 50 - 800 x 50 = 10mg/hr

However, the real rate of deposition is proportional to the concentration of smoke at the time i.e.

$$\frac{dm}{dt} = K_u \times \text{outlet concentration}$$

wherein $\frac{dm}{dt}$ is the amount of deposition per hour and

K_u is the rate constant of deposition with no corona cell operating.

Thus, $10 = K_u \times 800$

$K_u = 0.0125$

Repeating the experiment with a corona cell of the type used in the first experiment operating at 15μA, the outlet concentration was found to 150$\mu g/m^3$.

Using the same formulae the new rate constant (K_c) was calculated as 0.283. Accordingly, the rate constant of deposition of smoke particles with the corona cell operating was over 20 times greater than without.

By the same token, it can be seen that by incorporating a corona cell into exhaust systems, deposition and dispersal of smoke particles may be achieved at much faster rates than occurs with natural deposition, whereby air quality may be improved, as smoke particles overall will spend less time in the air.

The discovery that concentration of aerosols and smoke particles reduces far more rapidly in the atmosphere when electrically charged leads to the conclusion that air pollution due to motor vehicle exhausts in cities could be very effectively and cheaply reduced by placing a corona cell at an appropriate point in the tail pipe of every vehicle.

The production of toxic aerosols by motor vehicle exhausts is by far and away the most significant contributing factor to urban air pollution in developed countries, where smoke free fuels are mandatory. Any method by which such aerosol emissions can be reduced, and/or its rate of precipitation

once emitted increased, would greatly reduce the pollution levels in cities.

The discovery that charging aerosols or smoke particles with negative ions greatly increases their rate of precipitation and dispersal suggests that the universal charging of exhaust gases from motor vehicles would greatly decrease the extent and impact of air pollution in cities. In certain areas, such as Los Angeles, where the air quality is very hazardous and a definite threat to life, this could improve mortality rates very considerably.

The connection between the increased rate of precipitation/dispersal of aerosol and the decreased concentration of pollutants is considered in detail below. The density of atmospheric pollution moving with a drift (or wind) velocity $\underline{v}$ at each point $\underline{x}$ in the city or region under consideration, at a time "t", recognising that both ρ and $\underline{v}$ will, in general, depend on position and time

$$\rho = \rho(\underline{x}, t), \underline{v} = (x,t)$$

where, obviously, both $\underline{x}$ and $\underline{v}$ are vector quantities with three components,

$$\underline{x} = (x, y, z) \text{ and } \underline{v} = (v_x, v_y, v_z).$$

The distribution of atmospheric pollution in space and variations in time may depend on the sources of such pollution, and on various possible ongoing processes that may eliminate it (referred to as 'sinks').

The fundamental equation for the density ρ is the standard continuity equation of fluid dynamics, including usual terms to describe possible sources and sinks of the pollution. This differential equation simply states that the dynamic rate of change of density ρ at any given point is

equal to the local sum of source minus sink terms.

$$(\partial\rho / \partial\rho\ ) + \text{Div.}(\underline{V}\ \rho\ ) = \Sigma \text{ Sources} - \Sigma \text{ Sinks.}$$

The source under consideration is motor vehicle exhaust emissions, while sinks include spontaneous precipitation (quite slow, but continuous) rain induced precipitation (highly time dependent: occasional, but large), ion induced precipitation (potentially large and continuous), and natural destruction due to chemical reactions and UV light. The prime focus will be on the first term ($\partial\rho / \partial t$), since this describes the rate of change of pollution density ρ, and therefore any decrease. Specifically, we want to see how its magnitude is influenced by the presence or absence of the other terms in different situations.

In a typical real life situation, the first term also depends to some small extent on changes in overall atmospheric density: for example, changes in atmospheric pressure, temperature, or humidity, all of which produce small overall changes in density, but percentage-wise, relatively small changes in pollution levels. These, we shall therefore neglect. The second-term, Div. ($\underline{V}\rho$) refers to net effects of mass transfer in and out of the region being considered (such as those due to wind or local air drift). On the right side of the equation, the possible sources and sinks have been detailed above. Though apparently complex, the equation can be simply seen to be saying that:

the intrinsic rate of change of local pollution density, ($\partial\rho / \partial t$), is equal to:

the increase due to source(s) of pollution (in this case, car

exhausts), minus decreases due to 'sinks' of the pollution (such as precipitation), minus changes due to mass transfer such as wind.

which makes good intuitive sense.

Let us now consider how to apply this equation to a city in very general terms. First we shall make certain simplifying assumptions which apply to specific situations, and then generalise back to more complex cases. Consider, for example, the situation where the pollution in a city is constant, a 'steady state', where the sources and sinks are in balance. The intrinsic rate of change is zero, and the first term ($\partial\rho / \partial t$) can be neglected. In this case the equation becomes:

$$\Sigma \text{ Sources} - \Sigma \text{ Sinks} = \text{Mass transfer terms } \Delta.(\underline{V}.\rho)$$

As a second level of simplification, consider what happens when we treat a whole city and where, as is the case in the San Bernadino Valley, east of Los Angeles, there is often no significant air flow in or out of the valley for days at a time, we can legitimately assume we are dealing with a closed system. Now, since there is no mass flow in or out of the overall system, the mass flows only cause local variations in density ρ, we can, with certain supplementary conditions (see below), neglect the mass transfer terms, as they will not affect our conclusion.

In this case, that of a closed steady rate system, the resulting equations are exceedingly simple, and the results of the proposed changes are quite conclusive. The general equation reduces to:

$$\Sigma \text{ Sources} - \Sigma \text{ Sinks} = 0$$

or,

Auto Emission Rates = Total Precipitation Rate

Because of the nature of the terms, this equation turns into a condition on the value for the density ρ in the steady state. This is because the rates of precipitation of the pollution are obviously proportional to the density of the pollution, and this will remain the case whatever the variation of the pollution density throughout the city, whether it be a Bell curve, or a square function, with constant density within the city limits and zero outside, as in the case, for example, of air trapped in a valley. In general, it will remain true for all processes linearly dependent on ρ.

Here the Emission Rate should be considered as a 24 hour, or even weekly, average, while the precipitation rate should be considered as the sum of the "Natural" Rate, plus the possible "induced" Rate. In a normal, complex situation of varying densities, emissions and precipitation or absorption rates, combined with mass transfer over a closed system, this result may be regained by integrating over the closed system, and time averaging over whatever cyclic time period (daily, weekly, or even annually) is considered appropriate for the problem under consideration. Obviously, for auto pollution, the emissions reach highs during rush hours and lows in the early hours of the morning, so 24 hour diurnal averaging is essential. If steady state conditions last more than six days, variations of traffic density at weekends, as opposed to weekdays, would also have to be taken into account. The results of the complex integrations will, however, be the same as for our simplifying assumptions.

We can then write the natural and induced precipitation rates, ρ_n

and ρ_i as:

$$\rho_n = f_n \text{ and } \rho_i = f_i\rho$$

and arrive at the simple equation:

$$E = f_n\rho + f_i\rho = (f_n + f_i)\rho$$

Solving this for the density ρ yields.

$$= E/(f_n + f_i)$$

(Although this may have been derived by time and space-averaging, it will still be true when ρ is not constant and different points have widely differing values, provided the stated assumptions (i.e. mass transfer rates etc. ρ) remain valid).

This equation allows us to justify, very generally, the very important overall result that pollution density will be reduced by turning on an induced precipitation, increasing the proportionality factor from f_n, the natural rate, to the vastly increased one, $(f_n + f_i)$. This follows because equation states is that if the rate of precipitation of pollution is increased by a given factor, then the mean density of pollution will be decreased by the same factor

$$\text{i.e. as } f_n \rightarrow (f_n + f_i) = n \times f_n$$

then the density changes as:

$$\rho_1 = E/f \rightarrow \rho_2 = E/(f_n + f_i) = E/n \times f_n = \rho_1 \times (1/n)$$

i.e. then the pollution density is decreased by a similar factor of n as stated above.

However, as long as all these processes are linear in the density, the method of analysis remains valid. Processes that invalidate it are non-

linear (self-interactions of the pollution of different kinds): for example, collisions between droplets that cause them to coalesce and so to come down more quickly; or else, chemical reactions between pollutants, or possible catalytic processes, where the presence of one pollutant catalyses the destruction of others. We shall assume, for want of information to the contrary, that all these can be neglected.

The effects of local motions are easily taken into account by returning to the fundamental equation in the steady state form

$$\Sigma \text{ Sources} - \Sigma \text{ Sinks} = \text{Mass transfer terms } \Delta . \underline{V}$$

noting that the Mass Transfer Terms (MTT's) account for a certain percentage of the local dispersion of pollution, so that it is removed from areas close to the sources (e.g. motorways, 'turnpikes', and main roads), and spread over areas of lesser concentration. The result is that locally the effects of induced precipitation will produce a smaller percentage reduction in regions of high concentration of pollutants, since Mass Transfer effects are also decreasing pollution levels.

This can be seen as follows. Rewrite the above equation as:

$$\Sigma \text{ Sources} = \Sigma \text{ Sinks} + \text{MTT's}$$

and note that for a given air flow regime, the amount of reduction of pollution produced by the MTT's is proportional to the concentration of pollutants ρ. Also the sinks of pollution can be assumed, as before, to be proportional to ρ. Thus, the density ρ factorises out of the right hand side and the equation becomes

$$\rho = (\Sigma \text{ Sources})/(f_n + \text{MTT})$$

$$\rho = (\Sigma \text{ Sources})/((f_n + f_i) + \text{MTT})$$

for the cases of natural precipitation and ion induced precipitation respectively. Because of the Mass Transfer effects, it is now clear that the percentage reduction of density ρ will be less in these regions than for the case where it is absent. In local regions far from the actual sources of pollution, the Mass Transfer terms (i.e. air drift and wind) act as the local source of pollution, and the previous conclusions still hold: namely that the effect of the induced precipitation will be to reduce the concentration of pollutants by a factor $f_n/(f_n + f_i)$.

Our conclusions about the effectiveness of induced precipitation and dispersal in reducing pollution in the presence of air flow (Mass Transfer) are therefore that: the concentrations are less reduced close to the actual sources, and also in regions of strong through flow, but equally reduced in those places where such air flows dissipate, and where natural precipitation was the only method of elimination.

CLAIMS

1. An exhaust system capable of producing emissions to atmosphere containing particulate pollutants the system having means for electrically charging emissions therefrom, whereby particulate pollutants become charged and hence more readily dispersed and precipitated.

2. An exhaust system as claimed in claim 1, wherein the charging means comprises one or more corona discharge cells.

3. An exhaust system as claimed in claim 2, wherein the or each corona discharge cell has a passageway for exhaust emissions and an ion emitter or electrode associated therewith.

4. An exhaust system as claimed in claim 3, wherein the passageway has an associated ion collector surface for attracting ionized air molecules, whilst charged particulate pollutants may pass through the passageway.

5. An exhaust system as claimed in claim 4, wherein the collector surface forms at least part of a passageway wall.

6. An exhaust system as claimed in any one of claims 2 to 5, wherein the corona discharge cell comprises a tube having at least a part of its inner surface of conductive material and an ion emitter or electrode therein.

7. An exhaust system as claimed in claim 6, wherein the tube is connected to earth.

8. An exhaust system as claimed in 6 or 7, wherein the tube has on its inner surface a conductive coating or layer.

9. An exhaust system as claimed in claim 8, wherein the conductive coating or layer extends over part of the tube.

10. An exhaust system as claimed in 8 or 9, wherein the conductive coating or layer in the form of a band or strip.

11. An exhaust system as claimed in any one of claims 1 to 4 comprising an apertured plate having a conductive surface and an ion emitter for each aperture.

12. An exhaust system as claimed in any one of claims 1 to 11, wherein the ion emitter is a needle emitter.

13. An exhaust system as claimed in any one of claims 1 to 11, wherein the ion emitter is a wire or filament or a bunch or wires or filaments.

14. An exhaust system producing particulate pollutants substantially as hereinbefore described with reference to and as illustrated in any one of Figures 1 to 6 of the accompanying drawings.

The Patent Office

17.

Application No: GB 9705223.7 **Examiner:** John Warren
Claims searched: 1-14 **Date of search:** 13 June 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): B1W (WX); B2J (JH)

Int Cl (Ed.6): B01D 53/32; B03C 3/41

Other: ONLINE Databases: WPI and CLAIMS

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2 169 819 A	BOSCH - see especially Page 2 lines 67-92	1-5
X	WO 95/04875 A1	CRAVERO - see Figure 1 and Page 3 lines 1-31	1-5,12,13
X	WO 86/03553 A1	BOSCH - see Figure 1, 2a, 2b, electrodes 14,15, 20 and 22	1-6,11, 13
X	WO 84/02743 A1	BRØNNUMS - see Claim 1	1,2
X	US 4 521 229	COMBUSTION ENGINEERING - see Claim 1, electrode pins 52	1-5,12

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.