(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 356 040 A2**

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: 89307864.2

(51) Int. Cl.4: **F01N 3/02**

(22) Date of filing: 02.08.89

(30) Priority: 03.08.88 GB 8818463

(43) Date of publication of application: 28.02.90 Bulletin 90/09

(84) Designated Contracting States: ES GR

(71) Applicant: LOUGHBOROUGH CONSULTANTS LIMITED
University of Technology
Loughborough LE11 3TF(GB)

(72) Inventor: Garner, Colin Peter
207 Hermitage Road
Loughborough, LE11 0PD(GB)
Inventor: Dent, John Cotton
29 Springfield Close Burton on the Wolds
Leicestershire, LE12 5AN(GB)

(74) Representative: Bardo, Julian Eason et al
Abel & Imray Northumberland House 303-306
High Holborn
London, WC1V 7LH(GB)

(54) **Apparatus and method for removing particulate matter from the exhaust gases of an internal combustion engine.**

(57) The apparatus for removing particulate matter from exhaust gases includes a filter 6 for trapping particulate matter carried by the gases. A microwave generator 8 is arranged to irradiate the upstream face 10 of the filter 6, heating and oxidising particulate matter trapped in only a region adjacent that face. The heated zone then travels through the filter 6, regenerating the whole filter.

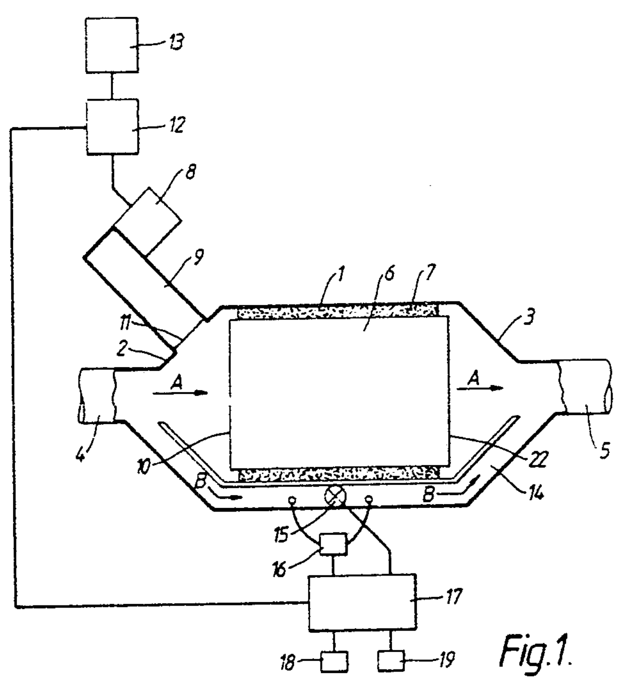

Fig.1.

EP 0 356 040 A2

Apparatus and Method for removing particulate matter from the exhaust gases of an internal combustion engine

This invention relates to an apparatus and method for removing particulate matter from the exhaust gases of an internal combustion engine.

Diesel engines are becoming increasingly popular for use in motor vehicles due to their good fuel economy and relatively safe exhaust emissions compared to petrol engines. The exhaust gases of a diesel engine do however contain considerably more particulate matter than those of a comparable petrol engine, and this particulate matter can often be seen as black smoke emitted from the exhaust pipe of a diesel-engined vehicle.

A known method of cleaning exhaust gases is to incorporate a filter into the exhaust system to trap the particulate matter. Several types of particle filter are presently available that are very effective at removing particulate matter from the exhaust gases, but which eventually become clogged as deposits of the particulate matter build up. This clogging effect restricts the flow of exhaust gases through the filter, increasing the exhaust back-pressure on the engine and reducing its efficiency. In order to restore the engine's efficiency it is necessary either to replace the filter or to clean it.

A known method of cleaning (or "regenerating") the filter in situ on the vehicle is to heat the filter to a very high temperature, whereupon the particulate matter, which is largely carbonaceous, combines with free oxygen in the exhaust gases producing mainly relatively harmless carbon dioxide gas which is passed out of the exhaust system.

Various methods for heating the filter have been proposed, including throttling the engine, using a separate fuel burner or an electrical heating element or, as disclosed in British Patent Application No. GB 2,080,140, using a microwave generator to heat the particulate matter directly. In all of these methods however a problem is providing sufficient energy to raise the particulate matter in the filter to a temperature of approximately 500 to 600°C which is necessary for rapid oxidation to take place. In addition, most of the methods proposed have been inefficient, requiring a high power input, and expensive or too large for convenient installation on most motor vehicles. It is an object of this invention to mitigate at least some of these problems.

According to the present invention there is provided an apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a chamber having a gas inlet opening towards the upstream end thereof and a gas outlet opening towards the downstream end thereof, a filter mounted within the chamber between the inlet opening and the outlet opening for trapping particulate matter carried by exhaust gases flowing through the chamber, and means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation into the chamber to irradiate the upstream end of the filter to heat and oxidise particulate matter trapped within the filter, the arrangement being such that initially particulate matter in only a region adjacent the upstream end of the filter is exposed to the full heating effect of the electromagnetic radiation.

"Relatively low frequency" electromagnetic radiation is hereby defined as radiation in the R.F. or microwave frequency ranges, having a frequency of less than 10^{12}Hz.

The arrangement of the invention is such that the downstream edge of the hot region initially heated by the electromagnetic radiation subsequently travels to the downstream end of the filter.

Since particulate matter in only a small region of the filter is exposed to the full heating effect of the electromagnetic radiation, a relatively low-powered generator of electromagnetic radiation is sufficient to heat the particulate matter in that region to the temperature at which rapid oxidation takes place. Once oxidation in that region has commenced, the energy liberated by the exothermic oxidation reaction helps the hot region to spread to other parts of the filter, oxidising the remaining particulate matter, and enough energy may be liberated in this manner to cause oxidation of all the particulate matter without the addition of any further external energy. It may therefore be possible to turn the generator off, or reduce its power output, once particulate matter in the small region of the filter has been ignited, thereby saving energy. Because the region of the filter in which particulate matter is heated initially is adjacent the upstream end of the filter, the flow of oxygen-carrying exhaust gases through the filter causes a forced-convection effect which aids the movement of the hot region through the filter, and supplies oxygen to assist the oxidation process. Further, because the hot region travels through the filter in a controlled manner, the heat produced by the exothermic reaction of the particulate matter may be regulated, thereby reducing the risk of damage to the filter matrix by melting or cracking.

The apparatus may be installed in the exhaust system of a vehicle engine or a stationary internal-combustion engine.

The chamber and the filter may be substantially cylindrical and coaxial with one another.

The means for generating electromagnetic radiation may be a microwave generator.

The apparatus may include an exhaust gas by-pass for reducing, in use, the flow of exhaust gases through the filter, and a by-pass valve for regulating the flow of exhaust gases through the by-pass. By reducing the flow of exhaust gases through the filter during the initial heating period the particulate matter can be raised more quickly to the temperature at which rapid oxidation takes place. Restoring the full flow of exhaust gases through the filter after the initial heating period produces a forced-convection effect and supplies oxygen to assist the oxidation process in downstream parts of the filter. The by-pass may extend from a point upstream of the filter to a point downstream of the filter.

The by-pass may be formed as a jacket surrounding the cylinder, thereby helping further to heat the filter.

The apparatus may include a control device for controlling operation of the generator means and the by-pass valve, thereby regulating the oxidation process and helping to prevent damage to the filter. Advantageously, the apparatus includes means for sensing the amount of particulate matter in the filter, an output of said means being connected to an input of the control device. The sensing means may include a pressure transducer, or alternatively the sensing means may be arranged to sense the electrical load on the generator of electromagnetic radiation, or the electromagnetic field in the chamber.

The flow of exhaust gases through the filter may be substantially rectilinear and in a direction parallel to the longitudinal axis of the filter.

The means for generating electromagnetic radiation may be arranged to irradiate the whole of the upstream end of the filter with a substantially uniform intensity, thereby reducing the risk of damaging the filter due to uneven heating.

The filter may include a reflective shield for reflecting transmitted radiation towards the upstream end of the filter, thereby enhancing the localised heating effect.

The apparatus advantageously includes means for sensing the temperature of the particulate matter trapped in the filter. The temperature-sensing means preferably includes means for measuring the electrical load on the radiation generator, or the electromagnetic field in the chamber.

The apparatus may include an inlet for admitting a gas other than exhaust gases to the upstream end of the gas chamber. The other gas may for example be ambient air, oxygen or nitrogen. The inlet may include means for urging the other gas into the chamber. The apparatus may include means for regulating the flow of the other gas into the chamber.

The apparatus may include means for disrupting the field pattern of the microwave energy in the chamber.

According to the present invention there is further provided an apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a filter for trapping particulate matter carried by the exhaust gases, means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation to irradiate the filter, and means for measuring the electrical load on the radiation generator to determine the amount of particulate matter in the filter.

The present invention yet further provides an apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a filter for trapping particulate matter carried by the exhaust gases, means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation to irradiate the filter, and means for measuring the electrical load on the radiation generator to determine the temperature of the particulate matter in the filter.

The present invention yet further provides an apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a filter for trapping particulate matter carried by the exhaust gases, means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation to irradiate the filter, and means for measuring the electromagnetic field in the chamber to determine the temperature of the particulate matter in the filter.

The present invention yet further provides a method of removing particulate matter from the exhaust gases of an internal combustion engine, in which the gases are passed through a filter, trapping particulate matter carried by the exhaust gases and periodically an upstream end of the filter is irradiated with electromagnetic radiation of relatively low frequency as herein defined, causing particles trapped in a region of the filter to heat up, the downstream edge of the heated region being initially adjacent the upstream end of the filter and subsequently travelling to the downstream end of the filter.

The filter is advantageously irradiated with microwave radiation.

The flow of exhaust gases through the filter may be reduced for at least part of the time that the filter is irradiated. The full flow of exhaust gases through the filter may be restored after an initial heating period.

Advantageously, the amount of particulate matter trapped in the filter is sensed and the periodic irradiation of the filter is controlled in dependence on the sensed amount of material. The flow of exhaust gases through the filter may also be controlled in dependence on the sensed amount of material. The amount of particulate matter may be sensed by measuring the gas pressure difference across the filter, or alternatively by measuring the electrical load on the generator of electromagnetic radiation, or the electromagnetic field in the chamber.

An embodiment of the invention will now be described by way of example with reference to the accompanying drawings, of which:

Figure 1 is a diagrammatic longitudinal cross-section through an apparatus for removing particulate matter from the exhaust gases of an internal combustion engine,

Figure 2 is a diagrammatic longitudinal cross-section through a part of the apparatus, and

Figure 3 is a diagrammatic representation of an alternative arrangement of the apparatus.

As shown in Figure 1, the apparatus includes a substantially cylindrical chamber 1 having upstream and downstream frusto-conical end walls 2 and 3 respectively. The chamber 1, which may be made of stainless-steel, is mounted in-line in the exhaust system of an internal combustion engine, for example a diesel engine, with an exhaust-gas inlet pipe 4 connected to an opening in the centre of the upstream end wall 2 and an exhaust-gas outlet pipe 5 is similarly connected to an opening in the centre of the downstream end wall 3. Exhaust gases flow through the chamber 1 in the direction indicated by the arrows A.

Situated coaxially within the chamber 1 is a cylindrical filter 6 for removing particulate matter from exhaust gases flowing through the chamber. A sealing mat 7, for example of the type sold under the trade mark INTERAM extends around the circumference of the filter 6, sealing the gap between the filter and the cylindrical wall of the chamber 1.

A microwave generator 8 in the form of a magnetron is connected via a waveguide 9 to an off-centre aperture in the upstream end wall 2, and is arranged to direct microwave energy, which may be of frequency 2450 MHz, into the chamber 1, to irradiate the upstream face 10 of the filter 6. A screen 11 of ceramic, glass or other low-loss dielectric material, which is substantially transparent to the microwaves, is provided towards that end of the waveguide 9 which is remote from the magnetron 8, to prevent exhaust gases entering the waveguide and damaging the magnetron. The magnetron 8 is connected via a switching unit 12 to an electrical power supply 13.

A by-pass exhaust pipe 14 is connected in parallel with the chamber 1 between the exhaust gas inlet pipe 4, at a point just upstream of the chamber, and the exhaust gas outlet pipe 5 at a point just downstream of the chamber. Located within the by-pass pipe 14 is a by-pass valve 15 which is normally closed to prevent exhaust gases flowing through the by-pass pipe 14. Connected to the by-pass pipe 14 on either side of the valve 15 is a differential pressure transducer 16 which senses the difference between the exhaust gas pressures in the chamber 1 on either side of the filter 6. The output of the pressure transducer 16 is connected to a control device 17, which is connected also to the outputs of transducers 18 and 19 for detecting the engine load and speed respectively. Outputs of the control device 17 are connected to the by-pass valve 15, to control opening and closing of the valve, and the magnetron switching unit 12.

Figure 2 is a diagrammatic longitudinal cross-section through a part of the filter 6. The filter 6 is a conventional ceramic honeycomb monolith filter (for example of the type manufactured by Corning and NGK), and consists of a series of parallel channels 20 which extend longitudinally through the filter from the upstream face 10 to the downstream face 22, and which are separated by thin, porous ceramic walls 21. The upstream and downstream ends of the channels 20 are blocked alternately by plugs of high temperature cement 23 so that, as indicated by the arrows A, exhaust gases enter the channels which are open at their upstream ends and pass through the porous walls 21 to leave the filter via the channels which are open at their downstream ends. The pores in the walls 21 are small enough to trap the particles carried by the exhaust gases, and the exhaust gases are therefore filtered by a process of interception, the trapped particulate matter accumulating as a deposit 24 on the walls of those channels 20 which are open at their upstream ends.

In normal operation, when the internal combustion engine is running, the by-pass valve 15 is closed, causing the exhaust gases to flow through the filter 6 in the chamber 1, before exiting through the outlet pipe 5. As described above, particulate matter carried by the exhaust gases, such as carbon or soot, is trapped by the filter 6, so that exhaust gases leaving the chamber are cleaner than those entering it.

Since the filter 6 provides a certain amount of resistance to the flow of exhaust gases through it, a pressure difference is created between the upstream and downstream ends of the chamber 1, and is sensed by the differential pressure transducer 16. The magnitude of the pressure difference depends on the engine load, the engine speed, and the amount of particulate matter 24 deposited on the porous walls 19 of the filter 6, the pressure difference increasing as more particulate matter is deposited. Eventually, the back-pressure of exhaust gases created by the increasing resistance to flow caused by deposits of particulate matter in the filter has an adverse effect on the efficiency of the internal combustion engine, and it becomes necessary to regenerate, or clean, the filter.

The regeneration process is activated by the control device 17, which compares the output of the pressure transducer 16 with the signals representing the engine speed and the engine load, and from these values assesses the amount of particulate matter in the filter. When the amount exceeds a predetermined limit, the control device 17 opens the by-pass valve 15, allowing exhaust gases to pass around the filter 6 (as indicated by the arrows B), and turns the magnetron 8 on. Microwave energy generated by the magnetron 8 is guided by the waveguide 9 through the screen 11 and into the chamber 1 to irradiate the upstream face 10 of the filter 6.

The different dielectric properties of the ceramic filter 6 and the trapped particulate matter make them react differently to the incident microwave energy. The ceramic material of the filter 6 is substantially transparent to the microwaves and the microwave energy is therefore able to pass through the filter with little attenuation, producing very little heating effect in the filter. The bipolar molecules of the particulate matter are however excited into vibration by the alternating electric field of the microwaves, and the particulate matter therefore absorbs the microwave energy, becoming heated by it.

Since only the upstream face 10 of the filter 6 is irradiated, the microwave energy is absorbed almost entirely by particulate matter in a small region close to that face, the rapid attenuation of the microwave energy by the particulate matter substantially preventing it penetrating further into the filter 6. The actual size of the small region depends on, amongst other things, the concentration of particulate matter in the filter. However, by way of example, with a heavily loaded filter, most of the incident microwave energy may be absorbed by particulate matter within a quarter of the gas path-length from the upstream face of the filter. The particulate matter in that small region is therefore heated rapidly to a very high temperature.

During the initial heating period, the by-pass valve 15 is held open allowing most of the relatively cool exhaust gases to pass through the by-pass pipe 14 without cooling the filter 6. Since the flow path through the filter is not positively closed, some of the exhaust gas will continue to pass through the filter, but the flow-rate through the filter will be very much reduced. This allows the particulate matter in the heated region to reach a temperature of approximately 500 to 600 °C, at which temperature a rapid exothermic reaction takes place, in which it combines with oxygen in the small amount of exhaust gas still flowing through the filter, liberating heat and producing relatively harmless carbon dioxide gas which passes through the porous walls 21 of the filter and out of the exhaust system.

As the particulate matter near to the upstream face 10 of the filter 6 is oxidised, the microwave energy is able to penetrate further into the filter and this, together with the energy liberated by the exothermic reaction of the particulate material, causes the downstream edge of the hot region to travel through the filter to the downstream face 20. In order to encourage the heated region to travel through the filter, the by-pass valve 15 is at this stage closed, causing all the oxygen-carrying exhaust gases to flow through the filter 6 and producing a forced-convection effect which drives the heated region through the filter. At the same time, the increased supply of oxygen from the increased flow of exhaust gases encourages the exothermic reaction to proceed more rapidly, liberating heat at a faster rate and thereby causing the temperature to rise still further.

Provided the initial temperature of the particulate matter is in excess of approximately 500 to 600 °C and there is sufficient free oxygen in the exhaust gases, the oxidisation reaction becomes self-sustaining, allowing the magnetron to be turned off if desired after the initial heating period, or to be used at reduced power, for example by pulse-width modulation. Modulated use of the by-pass valve 15, possibly in conjunction with the magnetron 8, enables the regeneration process to be regulated, preventing damage to the filter 6 from excessive temperatures, and permits extremely rapid regeneration of the filter with the minimum input of energy.

Figure 3 shows an alternative arrangement of the apparatus, in which the waveguide 9 is positioned along the longitudinal axis of the chamber 1 and the exhaust inlet pipe 4 is offset so that exhaust gases from the engine 25 enter the chamber through the upstream frusto-conical wall 2. The axial arrangement of the waveguide 9 helps to ensure that the front face 10 of the filter 6 is heated evenly by microwave energy from the magnetron 8.

An inlet pipe 26 for ambient air is connected to the exhaust inlet pipe 4 upstream of the point where it enters the chamber 1. The air inlet pipe 26 is provided with a fan 27 and a valve 28 for controlling the flow of air therethrough. The by-pass pipe 14 extends from a point on the exhaust gases inlet pipe 4 upstream of the connection with the air inlet pipe 26 to the outlet pipe 5. A valve 15 is provided at the upstream end of the by-pass pipe 14 to control the flow of exhaust gases through the by-pass. A further valve 29 is provided in the exhaust gas inlet pipe 4 between the connection points of the by-pass pipe 14 and the air inlet pipe 26 for controlling the flow of exhaust gases to the filter 6.

During normal operation of the apparatus, the by-pass valve 15 and the air inlet valve 28 are closed and the exhaust inlet valve 29 is open, so that all the exhaust gases flow through the filter 6, trapping ay particulate matter in the gases.

When it is necessary to regenerate the filter, the by-pass valve 15 is opened and the exhaust inlet valve 29 is closed, causing the exhaust gases to by-pass the filter 6, and the magnetron 8 is switched on. The microwave energy irradiates the front face 10 of the filter pre-heating a small zone of the filter adjacent that face. In the absence of any relatively cool gases flowing through the filter, the particulate matter in the small zone adjacent the front face 10 of the filter 6 soon reaches a temperature of 500 - 600°C, at which temperature the air inlet valve 28 is opened and the fan 27 is activated to force ambient air through the filter causing rapid oxidation of the particulate matter. As with the arrangement described above, the energy liberated by the exothermic oxidation reaction causes the heated zone to travel rapidly through the filter, regenerating the entire filter.

By using a separate inlet to provide ambient air rather than relying on free oxygen in the exhaust gases the reaction is made far more predictable and easy to control. The steps of the regeneration process may be modulated as necessary and the preheating and full regeneration steps may be repeated several times before normal operation is recommenced. It is also possible to pump other gases, such as oxygen or nitrogen through the filter to increase or decrease the oxidation rate or to cool the filter.

Various modifications of the apparatus are possible and some of these will now be described.

The control device 17 may be designed to activate the regeneration process at predetermined intervals of time or vehicle mileage instead of relying on the output of a pressure transducer.

Alternatively, the mass of particulate matter in the filter 6 may be assessed by sensing the electrical load on the magnetron 8, and the regeneration process activated when the mass exceeds a predetermined value. Since the electrical load on the magnetron 8 depends on the dielectric load that is being heated, and the dielectric load is in turn determined largely by the amount of particulate material in the filter 6, by measuring a suitable parameter in the electrical supply to the magnetron the mass of particulate material trapped by the filter can be ascertained. Suitable electrical parameters for measurement include the magnetron power or current consumption. A control circuit for measuring one or more of these parameters may be incorporated in the electrical power supply for the magnetron, and the magnetron may operated periodically or continuously at a very low power level in order to assess the mass of particulate matter in the filter, to determine whether regeneration is necessary. The regeneration process may therefore take place automatically whenever the mass of particulate matter trapped by the filter exceeds a predetermined level.

Alternatively, the dielectric load may be ascertained by sensing the electromagnetic field in the chamber, for example by measuring the voltage standing wave ratio (VSWR) or the reflection coefficient.

A similar technique may be used to determine when, during the initial heating period, the temperature of the particulate material has reached a sufficiently high temperature for rapid oxidation to take place, indicating that the by-pass valve 15 may be closed to encourage forced-convection. In this case, the VSWR, the reflection coefficient or one of the electrical parameters mentioned above, is measured and recorded before the heating process is initiated, and is measured again at regular intervals during the heating process. Since the dielectric properties of the particulate matter vary with temperature, by comparing the initial recorded value for the chosen electrical parameter with the values taken during heating, the temperature of the particulate matter can be determined. An electrical circuit for measuring particulate temperature may be incorporated in the control device 17.

The apparatus may include different types and shapes of filters. For example, instead of a ceramic monolithic filter, a foam or fibre filter, manufactured from a ceramic or other low-loss dielectric material may be used, and the flow of exhaust gases through the filter may be radial instead of axial. In any case, however, it will be the upstream face of the filter which is irradiated to heat particulate matter in a small region adjacent that face.

It is possible to use materials other than stainless steel for the chamber 1. Although stainless-steel has good thermal and mechanical stability, for improved electrical efficiency a non-magnetic material of high electrical conductivity such as copper, brass or aluminium may be preferred.

If a material of very high electrical conductivity is used, it may be desirable to provide a terminating load to prevent the magnetron overloading if there is very little particulate matter in the chamber. The load may be introduced by manufacturing the filter from a slightly "lossy" dielectric material, or by providing a separate terminating load in the chamber 1, downstream of the filter 6.

The efficiency of the chamber 1 may be improved by the provision of tuning plates or fins. For example, a continuous circular fin may be attached to the inner surface of the chamber 1 in the vicinity of the upstream face 10 of the filter 6, to ensure that the face is evenly heated right up to the periphery of the face.

Alternatively, uniform heating of the front face of the filter may be ensured by embedding small pieces of wire in the filter around its periphery to act as aerials which increase the concentration of microwave energy in their vicinity, or by impregnating parts of the filter with a material that preferentially absorbs microwave energy, so that those parts are heated directly by the microwaves.

Further, a mode stirrer device, comprising for example a rotating metal plate, may be provided in the chamber or the waveguide to disrupt the microwave field shape, preventing the concentration of microwave energy in any one spot. The mode stirrer device may be mechanically or electrically driven or, if located within the chamber, may be rotated by the flow of gases therethrough. As a further measure against uneven heating of the front face of the filter, either the filter or the waveguide may be rotated or oscillated during use.

The localised heating of a small region of the filter may be enhanced by providing a metallic shield in the filter adjacent its upstream face matrix just downstream of the upstream face 10, to reflect transmitted microwaves back into that region. A shield of this sort may be particularly useful with other types of filter medium, such as a ceramic fibre-mesh filter or a ceramic foam filter.

Different types of waveguide may be incorporated in the apparatus. The waveguide 9 should be of suitable size and shape to ensure that the microwaves are transmitted efficiently, but may be straight or curved and, if it is desired to mount the magnetron 8 remotely from the chamber 1, in order to provide insulation from heat or vibration, it may be of considerable length. Alternatively, the waveguide may amount to little more than an extension of the chamber 1. The waveguide 9 may also be adjustable for tuning purposes. A tapered waveguide or applicator may be used to provide a divergent beam of microwaves and, in order to produce more uniform heating, the waveguide may be mounted on the axis of the chamber 1 instead of off-centre. Further, if it is desired to heat different regions of the chamber 1 a split waveguide or more than one microwave source may be provided, which sources may be actuated alternately to reduce power consumption.

The waveguide screen 11 may be located at various positions in the waveguide 9. For example, the screen may be positioned adjacent to the magnetron 8, away from the hot exhaust gases. The screen 11 may alternatively be positioned at a microwave nodal point, so that any particulate matter adhering to it is cleaned off during the regeneration process, or at an antinode for maximum waveguide efficiency. In order to distribute the microwaves more evenly within the chamber, the screen may be in the form of a diverging lens, causing the microwaves to spread out as they pass through it.

The waveguide 9 may be fitted with a water cooling jacket or with external fins for air cooling.

The microwave generator 8 may be a magnetron, klystron or some other device. Although an operating frequency of 2450 MHz is suggested above as microwave generators of that frequency are readily available, any relatively low-frequency electromagnetic radiation may of course be used, either in the R.F. or microwave frequency ranges and having a frequency of less than 10^{12}Hz. Means for cooling the microwave generator may be provided.

Although provision of a by-pass pipe 14 enables very high temperatures to be achieved with a relatively low-powered magnetron, if a higher-powered magnetron is provided the by-pass pipe may be omitted, thereby producing a simpler apparatus. If provided, the by-pass valve 15 cculd be electrically, pneumatically or servo-operated, and could be mechanically latched in either the open or closed position. If it is desired to increase the gasflow through the filter 6 when the valve 15 is open, a restriction could be permanently provided in the by-pass pipe 14. To provide a further heating effect on the filter 6 the by-pass pipe 14 could be formed as a jacket surrounding the chamber 1.

By providing suitable catalysts in the chamber 1, the temperature to which the particulate matter must be heated to produce a rapid, self-sustaining reaction may be reduced to less than 600 °C, for example to a temperature in the range 250 to 400 °C.

In order to prevent the release of particulate matter into the environment during the regeneration process, two or more filter systems may be provided in parallel, to be regenerated alternately, so that the exhaust gases ar filtered continuously. Ambient air may be used as the oxygen source. Alternatively, a small, non-regenerative filter may be provided in the by-pass pipe 14, or the by-pass pipe 14 could be arranged to allow exhaust gases to by-pass only a part of the filter, for example being reintroduced to the filter mid-way along its length, to ensure that all exhaust gases pass through the filter even when the by-pass is in use.

Although the escape of microwave energy from the system is unlikely unless exhaust pipe diameters greater than approximately 60 mm are used, in order to reduce this possibility still further, crosswires, axial plates or perforated metal sheeting may be fitted to reflect the energy back into the chamber. In addition a "g"-switch may be provided to turn-off the apparatus in the event of an impact of a magnitude likely to cause damage.

Claims

1. An apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a chamber having a gas inlet opening towards the upstream end thereof and a gas outlet opening towards the downstream end thereof, a filter mounted within the chamber between the inlet opening and the outlet opening for trapping particulate matter carried by exhaust gases flowing through the chamber, and means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation into the chamber to irradiate the upstream end of the filter to heat and oxidise particulate matter trapped within the filter, the arrangement being such that initially particulate matter in only a region adjacent the upstream end of the filter is exposed to the full heating effect of the electromagnetic radiation.

2. An apparatus according to claim 1, in which the chamber and the filter are substantially cylindrical and coaxial with one another.

3. An apparatus according to any preceding claim, including an exhaust gas by-pass for reducing, in use, the flow of exhaust gases through the filter, and a by-pass valve for regulating the flow of exhaust gases through the by-pass.

4. An apparatus according to claim 3, including a control device for controlling operation of the generator means and the by-pass valve.

5. An apparatus according to claim 4, including means for sensing the amount of particulate matter in the filter, an output of said means being connected to an input of the control device.

6. An apparatus according to any preceding claim, in which the flow of exhaust gases through the filter is substantially rectilinear and in a direction parallel to the longitudinal axis of the filter.

7. An apparatus according to any preceding claim, in which the means for generating electromagnetic radiation is arranged to irradiate the whole of the upstream end of the filter with a substantially uniform intensity.

8. An apparatus according to any preceding claim, including means for sensing the temperature of the particulate matter trapped in the filter.

9. An apparatus according to any preceding claim, including an inlet for admitting gas other than exhaust gases to the upstream end of the chamber.

10. An apparatus according to claim 9, in which the inlet includes means for urging the other gas into the chamber.

11. An apparatus according to claim 9 or claim 10, including valve means for regulating the flow of the other gas into the chamber.

12. An apparatus according to any preceding claim including means for disrupting the field pattern of the microwave energy in the chamber.

13. An apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a filter for trapping particulate matter carried by the exhaust gases, means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation to irradiate the filter, and means for measuring the electrical load on the radiation generator to determine the amount of particulate matter in the filter.

14. An apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a filter for trapping particulate matter carried by the exhaust gases, means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation to irradiate the filter, and means for measuring the electrical load on the radiation generator to determine the temperature of the particulate matter in the filter.

15. An apparatus for removing particulate matter from the exhaust gases of an internal combustion engine, including a filter for trapping particulate matter carried by the exhaust gases, means for generating electromagnetic radiation of relatively low frequency as herein defined and directing the electromagnetic radiation to irradiate the filter, and means for measuring the electromagnetic field in the chamber to determine the temperature of the particulate matter in the filter.

16. A method of removing particulate matter from the exhaust gases of an internal combustion engine, in which the gases are passed through a filter, trapping particulate matter carried by the exhaust gases and periodically an upstream end of the filter is irradiated with electromagnetic radiation of relatively low frequency as herein defined, causing particles trapped in a region of the filter to heat up, the downstream edge of the heated region being initially adjacent the upstream end of the filter and subsequently travelling to the downstream end of the filter.

17. A method according to claim 16, in which the flow of exhaust gases through the filter is reduced for at least part of the time that the filter is irradiated.

18. A method according to claim 17, in which the full flow of exhaust gases through the filter is restored after an initial heating period.

19. A method according to any one of claims 16 to 18, in which the amount of particulate matter trapped in the filter is sensed and the periodic irradiation of the filter is controlled in dependence on the sensed amount of material.

20. A method according to claim 19 when dependent on claim 17, in which the flow of exhaust gases through the filter is also controlled in dependence on the sensed amount of material.

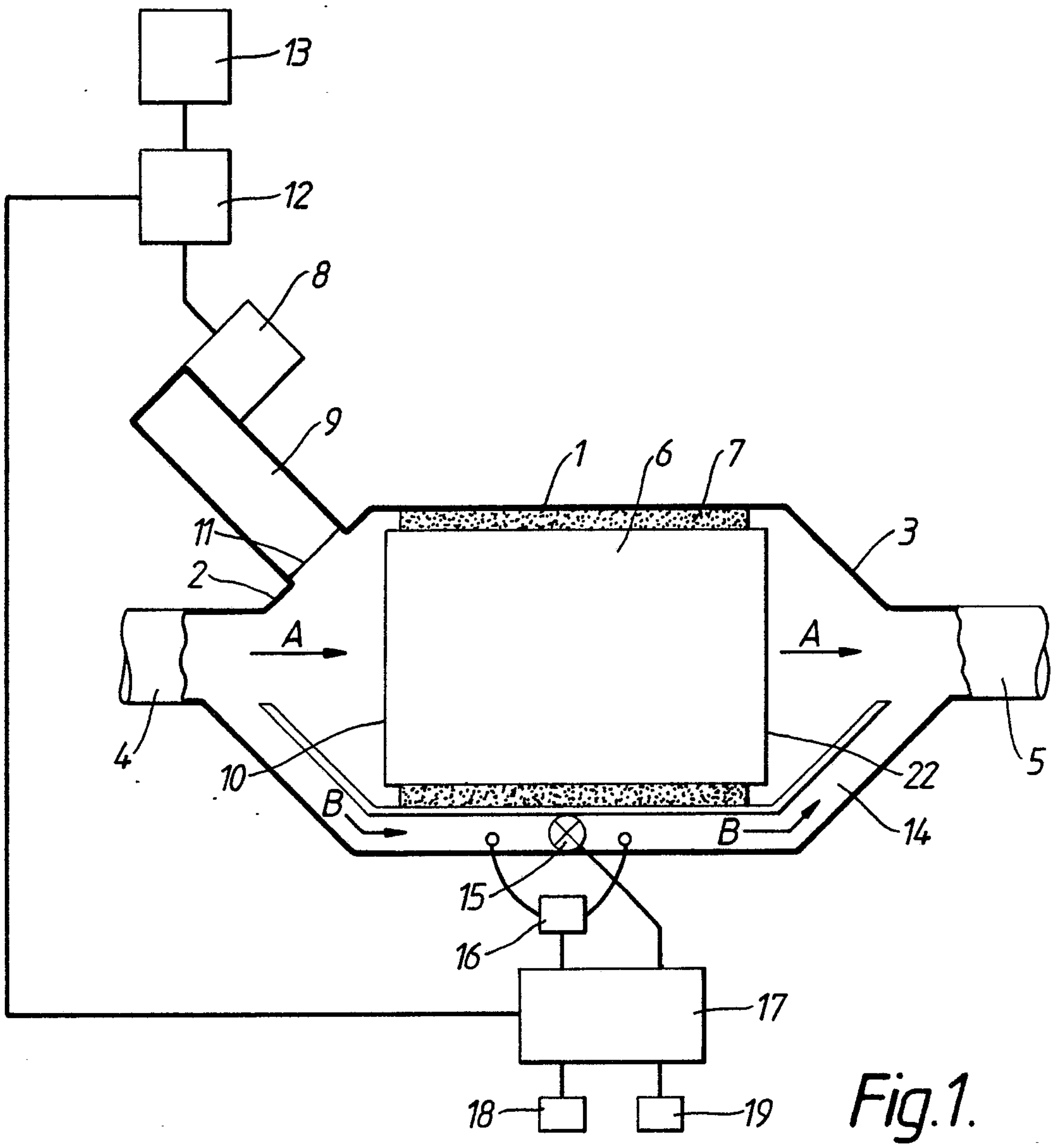
13
12
8
9
1
6
7
11
2
3
A
A
4
5
10
22
B
B
14
15
16
17
18
19

Fig.1.

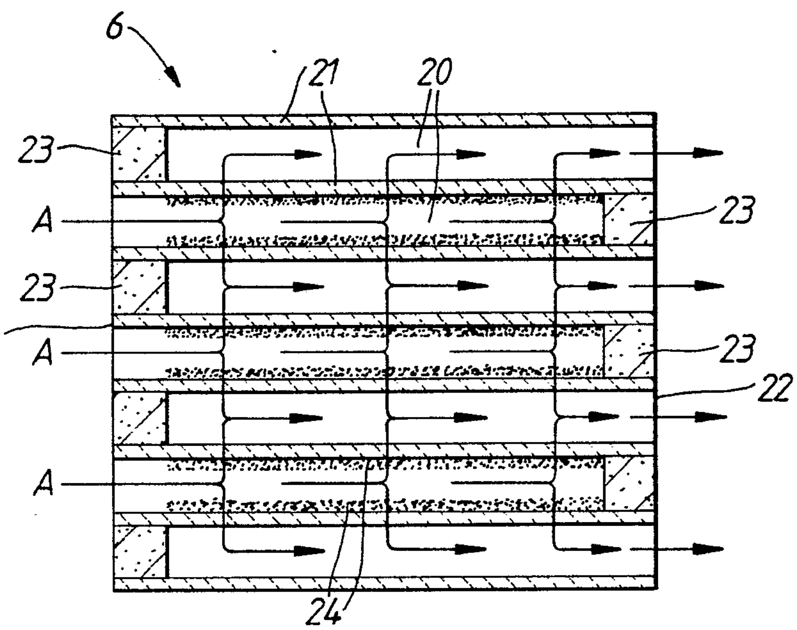
6
21
20
23
A
23
23
10
A
23
22
A
24

Fig.2.

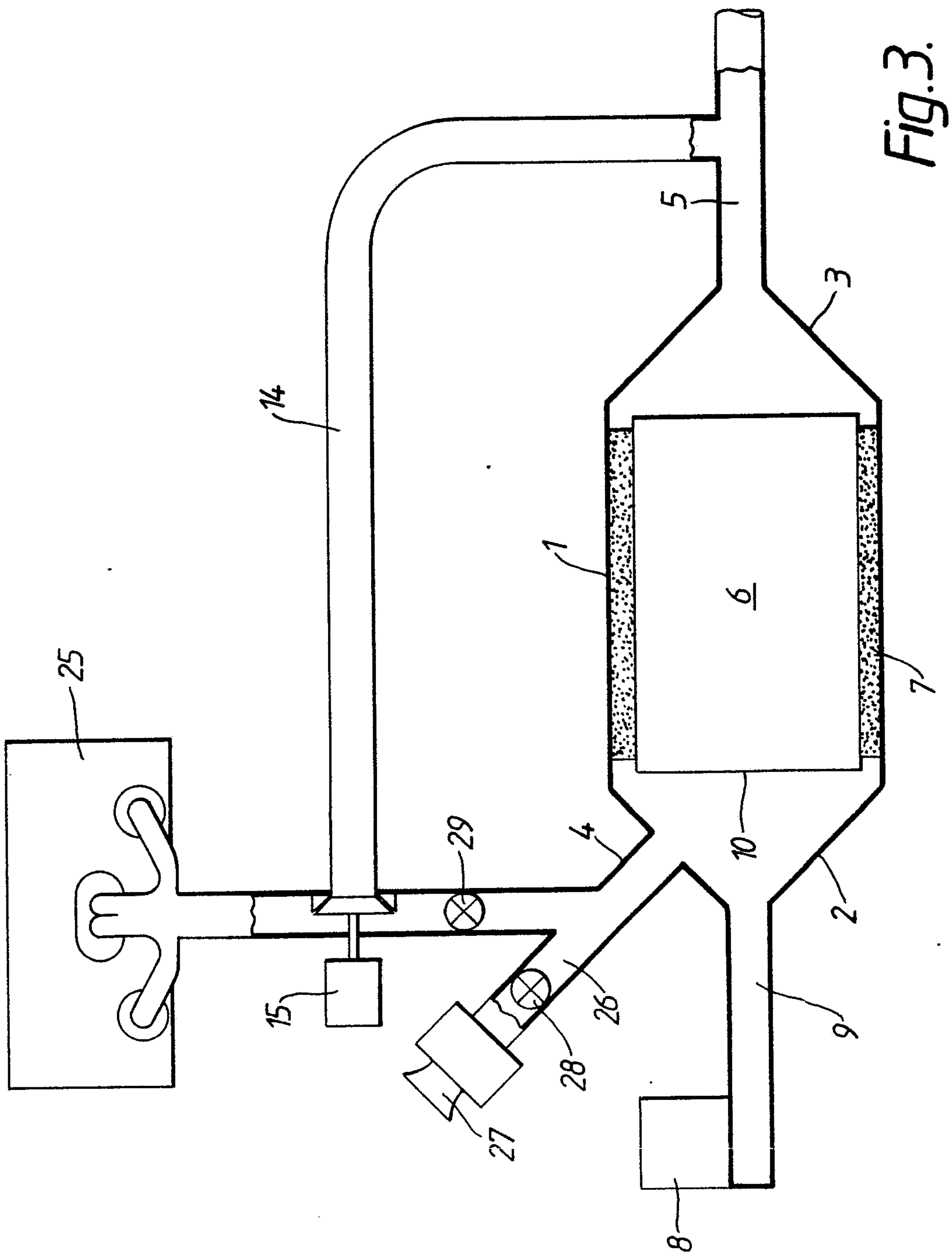

Fig.3.