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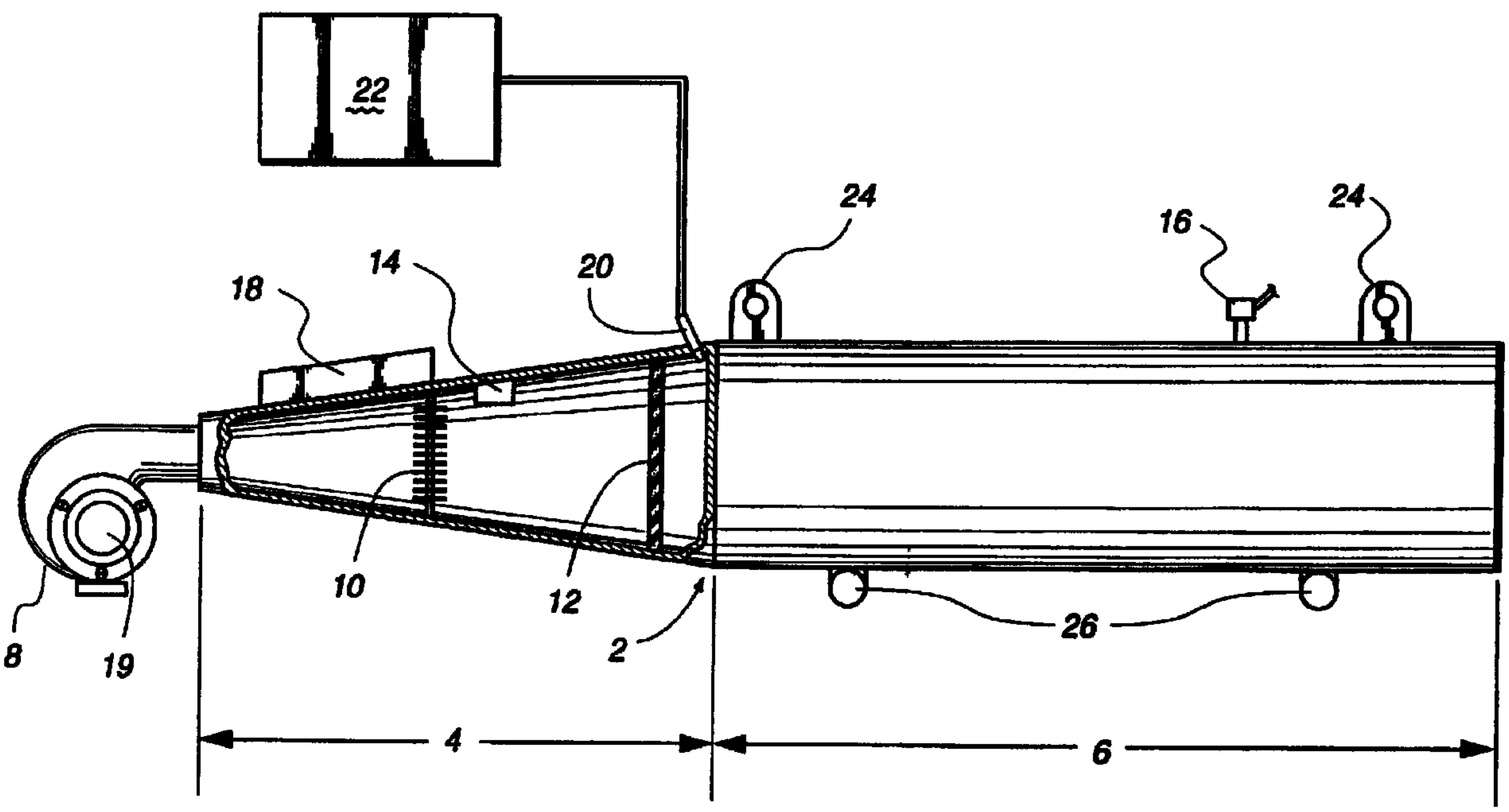
(54) Title: A METHOD AND DEVICE FOR PRODUCING AND DELIVERING AN AEROSOL FOR REMOTE SEALING AND COATING




(57) Abrégé/Abstract:
The invention is a method and device (2) for sealing leaks remotely by means of injecting a previously prepared aerosol into the enclosure being sealed. Specifically the invention is a method and device (2) for preparing, transporting, and depositing a solid phase aerosol to the interior surface of the enclosure relating particle size, particle carrier flow rate, and pressure differential, so that particles deposited there can be bridge and substantially seal each leak.

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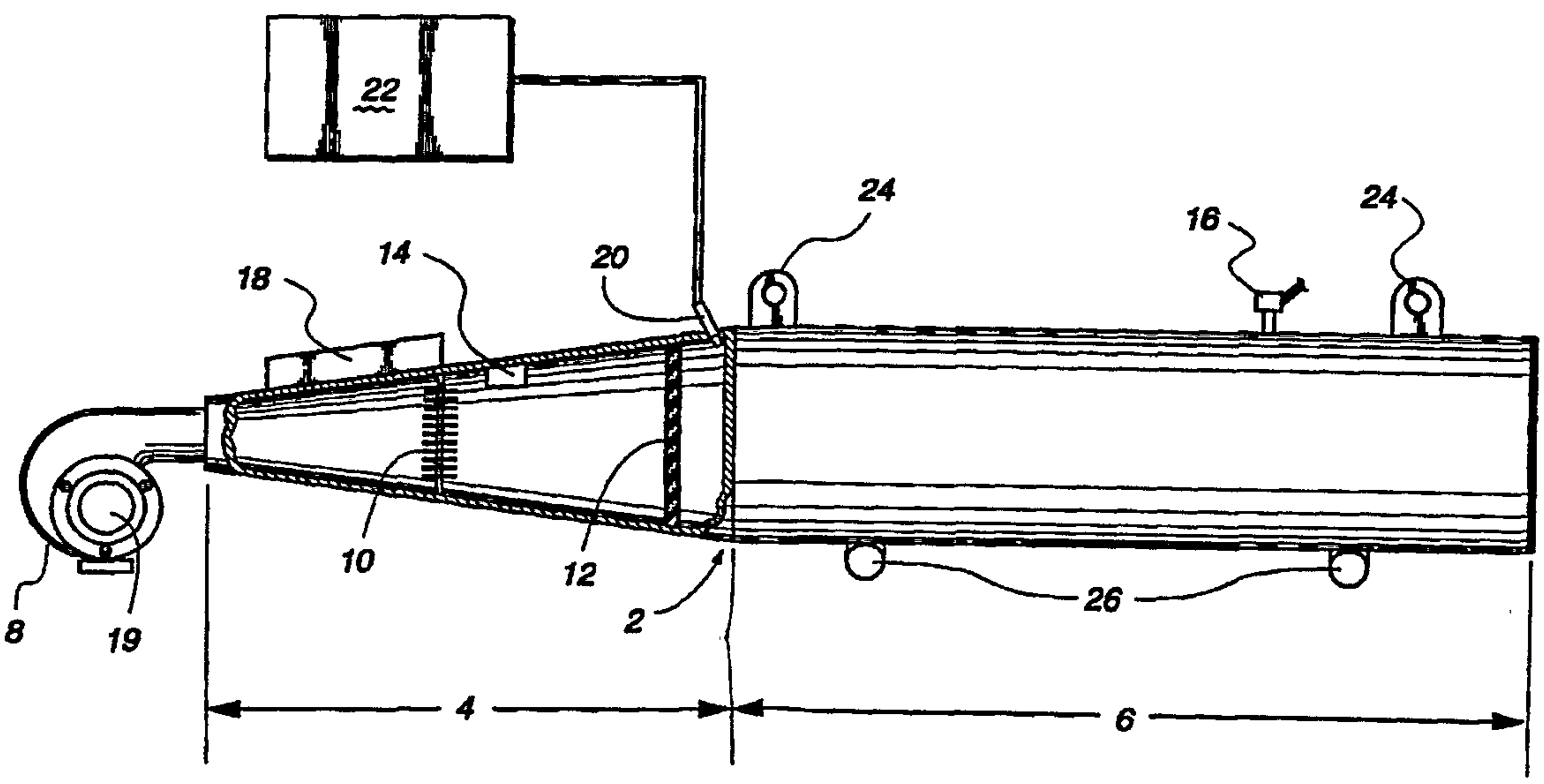


(57) Abstract

The invention is a method and device (2) for sealing leaks remotely by means of injecting a previously prepared aerosol into the enclosure being sealed. Specifically the invention is a method and device (2) for preparing, transporting, and depositing a solid phase aerosol to the interior surface of the enclosure relating particle size, particle carrier flow rate, and pressure differential, so that particles deposited there can be bridge and substantially seal each leak.

# A METHOD AND DEVICE FOR PRODUCING AND DELIVERING AN AEROSOL FOR REMOTE SEALING AND COATING

The invention described herein was made with U.S. Government support between the U.S. Department of Energy and the University of California for operation of Lawrence Berkeley National Laboratory. The U.S. Government retains certain rights in this invention.

## FIELD OF THE INVENTION

The present invention relates to a method and device for producing and delivering an aerosol for remote sealing and coating. More specifically the invention relates to sealing leaks from the inside of enclosures or applying an even coating to the inside surface of those enclosures remotely by means of injecting an aerosol into the enclosure to be sealed.

## BACKGROUND OF THE INVENTION

There is a substantial need for methods of remote sealing and coating. Research has shown that the energy savings potential of sealing duct leaks is on the order of 20% of the furnace or air conditioner energy use (Modera, M.P. (1993 - Energy and Buildings, 20:65-75). During the past five years, research has quantified the impacts of residential duct system leakage on HVAC energy consumption and peak electricity demand. A typical California house with ducts located in the attic or crawlspace wastes approximately 20% of heating and cooling energy through leaks and draws approximately 0.5 kW more electricity during peak cooling periods. Besides, given that 25% to 75% of the leaks are not accessible, conventional technologies such as using duct tape or mastic are often not satisfactory.

Encapsulants for duct systems have been previously disclosed and some of those have been applied by introducing a fog into the duct system.

Shinno teaches sealing and coating a pipe through the application of a mist to the interior surface of the pipe [U.S. Patent No. 4,327,132 Method for Lining of Inner Surface of a Pipe (April 27, 1982)]. This patent discusses the use of a multiple component epoxy based mist which is applied with a rapid air stream and then dried in place with the same rapid air stream. It also discusses the withdrawal and revival

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of residual paint exhausted from the pipe outlet. The Shinno patent calls for multiple gas flows, one to atomize the liquid to be applied and another to blow the mist down the pipe. Shinno also calls for mixture velocities of between 30 meters/second and 100 meters/second.

Koga teaches a method and apparatus for generating a plastic mist for deposition upon the interior surface of a pipe [U.S. Patent No. 4,454,173 Method for Lining Pipes in a Pipeline (June 12, 1984) and U.S. Patent No. 4,454,174 Method for Lining Pipes of a Pipeline (June 12, 1984)]. These patents confine themselves to the delivery of a plastic mist to the interior pipe surface. The Koga patents describe the use of a compressor and a vacuum generator to carry the mist through the pipeline. Additionally, these patents teach the use of low air pressure at one stage and high air pressure at another. In the Koga patent a heater is used to maintain the plastic in a liquid form.

Hyodo et al. teaches a method for sealing pipes which comprises feeding an aerosol type sealant into a pipe in the form of a foam [U.S. Patent No. 4,768,561 Process for Sealing Pipes (September 6, 1988)]. The sealant disclosed is one containing an aqueous resin selected from the group consisting of emulsions and latexes as a main component and being added with a propellant such as Freon 12/Freon 114.

SUMMARY OF THE INVENTION

The present invention is a method and device for remotely sealing and coating an enclosure from within. It allows for precise control of where the encapsulant material is deposited and is capable of effectively sealing leaks remotely from within an enclosure even where a complex network of bends, tees, and wyes is involved.

A method according to the invention recites the use of aerosol sealants, the versatility of this technique is that it can be used effectively in enclosure with bends and bifurcations without significantly affecting sealing performance.

The method involves blowing an aerosol through an enclosure or duct system to seal the leaks from the inside, the principle being that the aerosol particles deposit in the cracks of the ductwork as they try to escape because of the pressure differential from blowing. However, merely introducing an aerosol with randomly sized particles does not result in a seal. A technique according to the invention utilizes a better understanding of aerosol transport in an ADS (air distribution system) as well as particle deposition in the leaks to provide quantifiable sealing performance.

An aerosol-based technique is used to significantly reduce the leakiness of air distribution systems (ADS). An aerosol made out of a liquid suspension of a vinyl polymer can plug 16 $cm^2$ of Effective Leakage Area in a branch of a residential duct system in less than 30 minutes. In a small scale duct system the Effective Leakage Area of a typical duct can be reduced by about 80% in 20 minutes (see Table 1, below).

Using an aerosol to seal leaks from within an enclosure or to apply an even coating along the interior surface of an enclosure requires careful preparation of the aerosol and control of the flow through the enclosure. In the case of leak sealing, the pressure within the enclosure must also be controlled in order for the aerosol to deposit at the leaks.

The present invention represents a dramatic breakthrough in the technology because it is capable of both remotely sealing and coating an enclosure from within. Not only useful for sealing and coating ducts and other enclosures, this technology is also applicable to filling voids in buildings and other cavities for increased structural integrity, sound proofing, and insulation. The sealing and coating method and device described in this application offer significant advantages over the conventional technology.

It is an object of the present invention to provide a method and device which is capable of sealing a plurality of leaks from within an enclosure.

It is another object of the present invention to provide a method and device which can seal leaks without having to be directed towards specific openings.

It is a further object of the present invention to provide a device which can be easily transported.

It is a further object of the present invention to provide a device which is safe and easy to use.

In accordance with an aspect of the present invention, there is provided a method for remotely sealing an enclosure from within, said method comprising the steps of: a) creating a selected flow rate of a fluid within the enclosure from a fluid injection location to and through leaks in said enclosure and providing a particular pressure within the enclosure and a particular differential pressure across the leaks; b) monitoring the pressure within the enclosure; c) controlling the flow rate of step a) in response to the monitored pressure of step b) to maintain said particular pressure and differential pressure; and d) injecting particles from a particle injection location into said enclosure with said particles having a size range, such that a substantial portion of said particles in said size range are transported by said fluid through said enclosure until said particles reach a location at or adjacent to said leaks with said particles substantially retaining their shape and adhering to an interior surface of the enclosure and to each other at impact locations adjacent to the leaks to build up a bridge of particles to span between the boundaries of each of said leaks.

In accordance with another aspect of the present invention, there is provided a device for remotely sealing and coating an enclosure from within comprising: a) a primary body being comprised of a hollow structure divided into a preparation end and a delivery end, b) a fan connected to the preparation end of the primary body, c) an airheater disposed between said fan and the delivery end of the primary body, d) a filter disposed between said airheater and the delivery end of the primary body, e) a thermostat located within the primary body, f) a pressure switch located within the primary body, g) a control mechanism connecting said fan, the pressure sensor, said airheater and the thermostat, h) an injection nozzle set into the primary body between the filter and the delivery end of the primary body, i) an aerosol source connected to said injection nozzle.

In accordance with yet another aspect of the present invention, there is provided a method for remotely applying a uniform coating to the walls of an enclosure by means of turbulent diffusion of aerosol particles, comprising the steps of: a) choosing a desired distance from an injection point to which the coating should be delivered; b) preparing an aerosol of particles of a particular size range; c) generating a fluid flow from said injection point to pressurize said enclosure that results in an enclosure flow which results in wall deposition dominated by turbulent diffusion for the chosen particle sizes; and d) introducing the particles into the fluid flow, wherein a deposition velocity of the particles is determined by means of the following equations:

$$V_e = \begin{cases} \frac{1}{2\pi}\left[(\pi + 2\gamma)V_d + 2V_g \cos\gamma\right] \\ \qquad if \quad |V_d| < |V_g|, \\ \qquad \quad where\ \gamma = \arcsin\left(\frac{V_d}{V_g}\right); \\ V_d, \\ \qquad if \quad |V_d| \geq |V_g| \end{cases}$$

$$V_d = V_* U \sqrt{f/2}$$

$$V_* = 6.9 \times 10^{-4} \tau_*^2 \qquad if \quad \tau_* \leq 15$$

$$V_* = 0.16/\tau_*^{0.086} \qquad if \quad \tau_* > 15$$

$$V_g = g\,\tau$$

so as to result in $V_d \geq V_g$ and a penetration efficiency corresponding to the chosen coating distance from the injection point of the enclosure, where the penetration efficiency is defined as:

$$P = \exp\left(-\frac{4V_e L}{UD}\right) = \exp\left(-\frac{4V_e L}{\nu \mathrm{Re_D}}\right).$$

In accordance with yet another aspect of the present invention, there is provided a method for sealing leaks in a fluid enclosure comprising the steps of: a) pressurizing the enclosure using a fluid flowing at a particular fluid flow rate from a fluid injection location to and through leaks in said enclosure and providing a particular differential pressure across the leaks; b) providing particles; c) introducing said particles into said fluid flowing from said fluid injection location; wherein said particles substantially retain their shape and adhere to the enclosure wall and to each other at impact at locations adjacent to the leaks to build up a bridge of particles to span between the boundaries of each of said leaks.

In accordance with yet another aspect of the present invention, there is provided a seal of a leak opening in an enclosure comprising: particles which substantially retain their shape and adhere to an enclosure wall and each other at locations adjacent to a leak opening in the enclosure wall, where the particles as a result of their adherence to each other at locations adjacent to said leak opening form a bridge of particles establishing a seal spanning between the boundaries of said leak.

These and other objects and features of the invention will become fully apparent when the following detailed description of the invention is read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cutaway side view of a device for implementing the method of the present invention.

Figure 2 is a graph of an example of Penetration efficiency plotted versus flowrate for various particle sizes;

Nomenclature

$C_m$ mass concentration of the aerosol [kg/m$^3$]

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| | |
|---|---|
| $D$ | duct diameter [m] |
| $d(\ )$ | differential [-] |
| $d_p$ | particle diameter [m] |
| $\frac{dU}{dy}$ | velocity gradient of the approaching flow [$s^{-1}$] |
| $e$ | duct wall thickness [m] |
| $f$ | Friction factor [-] |
| $g$ | acceleration of gravity [$m/s^2$] |
| $h$ | leak-width [m] |
| $i$ | index [-] |
| $L$ | duct length [m] |
| $P$ | penetration [-] |
| $Q$ | flow rate [$m^3/s$] |
| $Re_s$ | slot Reynolds number $\frac{v_s h}{\nu}$ [-] |
| $Re_D$ | duct Reynolds number $\frac{U D}{\nu}$ [-] |
| $Re_p$ | particle Reynolds number (based on relative velocity) [-] |
| $S$ | particle-to-air density ratio [-] |
| $SE$ | sealing efficiency [-] |
| $Stk$ | Stokes number $\frac{\tau v_s}{y_s} = \frac{S\,Re}{18}\left(\frac{d_p}{h}\right)^2\sqrt{\frac{\alpha}{2}}$ [-] |



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$t$ time [s]

$t_i$ i-th characteristic sealing time [s]

$t_{res}$ residence time in the separation zone $t_{res} \sim \frac{y_s}{V_s}$ [s]

$U$ Average velocity in the duct [m/s]

$U_s$ velocity upstream of the slot at $y = y_s$ [m/s]

$u$ velocity along x [m/s]

$\vec{u}$ velocity vector [m/s]

$V_d$ turbulent diffusion velocity [m/s]

$V_e$ Effective mean deposition velocity at the wall [m/s]

$V_g$ Gravitational settling velocity $V_g = g\,\tau$ [m/s]

$V_*$ Dimensionless deposition velocity [-]

$\mathrm{V}$ velocity along y [m/s]

$\mathrm{V}_r$ Radial velocity of the particle [m/s]

$\mathrm{V}_s$ Bulk velocity through the slot; here $\sqrt{\frac{1}{C_p}\,\frac{2\Delta P}{\rho_f}}$ [m/s]

$w$ thickness of the seal [m]

$w_r$ Relative velocity of the particle

$$w_r = \left\| \vec{u}_p - \vec{u}_f \right\| \text{ [m/s]}$$

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$x$ horizontal coordinate [m]

$y$ vertical coordinate [m]

$y_s$ height of the dividing suction streamline [m]

Greek symbols:

$\alpha$ dimensionless velocity gradient of the approaching flow $\frac{h}{v_s}\frac{dU}{dy}$ [-]

$\Delta P$ pressure differential across the slot [Pa]

$\gamma$ Angle [rd]

$\eta$ deposition efficiency [-]

$\nu$ kinematic viscosity of the fluid of interest $[m^2/s]$

$\rho$ density $[kg/m^3]$

$\tau$ particle relaxation time [s]

$\tau_*$ Dimensionless particle relaxation time [-]

Subscripts and superscripts:

$f$ pertaining to the fluid of interest

$0$ at t = 0, at the beginning of the experiment

$D$ pertaining to duct

$p$ pertaining to particle

$ref$ at the reference pressure differential

$s$ pertaining to slot

$seal$ pertaining to particle build up

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- average value

* dimensionless quantities

Abbreviations:

ADS Air Distribution System

ELA Effective Leakage Area [$m^2$]

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a method and device for the remote sealing and/or coating of a structure from within. Specifically the invention includes a method for preparing, transporting, and remotely depositing an aerosol along the interior surface of an enclosure and/or depositing the aerosol in any leaks or openings in that enclosure so as to seal those leaks or openings. The invention also includes a device capable of performing the method.

The Method

There are four steps to the general method of the present invention. First, an aerosol is prepared (for example from a liquid suspended solid). Second, a carrier (fluid) flow is generated. Third, the aerosol is introduced into the carrier flow. Fourth, the aerosol laden carrier flow is used to pressurize the enclosure to be sealed.

The most critical aspect of preparing the aerosol for the leak sealing aspect of the subject invention is that it must be appropriately sized and substantially solidified prior to reaching the leaks to be sealed. The aerosol must be sized small enough to travel to the leaks prior to leaving the carrier flow through gravitational settling and be large enough to leave the air stream and deposit along the leak boundaries once the leak is reached. When used for sealing, the particles must be sticky and they must substantially hold their shape so that they can build up on one another when they impinge upon the interior surface of the enclosure.

In one embodiment of the present invention, this preparation is accomplished by either 1) drying the air prior to the injection of a liquid-suspended solid aerosol or 2) heating the incoming airflow prior to aerosol injection. When using a liquid base for the sealant aerosol, two means for the controlling the size of the aerosol particles are the type of injection nozzle used and the degree of dilution of the liquid suspension. Alternatively, it is possible that a solid phase aerosol could be used directly.

The most important variables affecting the transport and deposition of the aerosol are, the duct (i.e., enclosure) flow rate, the size of the particle, and the duct pressure. These variables affect the rate and efficiency with which sealing (all three

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variables) and coating (flowrate and size) occur. They also determine how far down the duct (or pipe) a particle will travel prior to gravitational settling.

These variables can be calculated once a particular sealing efficiency has been chosen. Sealing efficiency is the product of penetration efficiency $(P)$ and deposition efficiency $(\eta)$.

$$[\text{Sealing efficiency}] = (P)\ (\eta)$$

$$P = \exp\left(-\frac{4V_e L}{v \mathrm{Re}_D}\right) = \exp\left(-\frac{4V_e L}{UD}\right)$$

$$\eta \sim \frac{\tau v_s^2}{y_s}\frac{e}{v_s h} = Stk\frac{e}{h}$$

Stokes number is defined by:

$$Stk = \frac{S\,\mathrm{Re}}{18}\left(\frac{d_p}{h}\right)^2\sqrt{\frac{\alpha}{2}} = \frac{\tau c v}{y}$$

Calculations were performed using the models for the velocity caused by turbulent diffusion $(V_d)$ experimentally-derived correlations (see Anand, N.K. and Mc Farland, A.R. *American Industrial Hygiene Association, 50:* 307-312) were used to determine the turbulent diffusion velocity $(V_d)$:

$$V_d = V_* U\sqrt{f/2}$$

$$V_* = 6.9 \times 10^{-4}\,\tau_*^2 \qquad for \quad \tau_* \le 15$$

$$V_* = 0.16/\tau_*^{0.086} \qquad for \quad \tau_* > 15$$

$$\tau_* = \frac{\tau U}{D} f Re_D$$

where the friction factor $f$ is given by the Blasius equation:

$$f = \frac{0.316}{4\mathrm{Re}_D^{0.25}}$$

The effective mean deposition velocity Ve can be assessed:

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$$V_e = \begin{cases} \frac{1}{2\pi}\left[(\pi + 2\gamma) V_d + 2V_g \cos\gamma\right], \\ \quad if \quad |V_d| < |V_g|, \\ \quad\quad where \;\; \gamma = \arcsin\left(\frac{V_d}{V_g}\right); \\ V_d, \\ \quad if \quad |V_d| \geq |V_g| \end{cases}$$

From the point of view of coating, as can be understood from a close examination of Figure 2, the greater the turbulent diffusion velocity ($V_d$) as compared to the gravitational settling velocity ($V_g$), the more even particle deposition is in a cross-section of the duct of interest.

As for the deposition efficiency ($\eta$), in the case of particle deposition in a two-dimensional slot from a transverse stream (which is representative of the deposition phenomenon that occurs in many leaks encountered in air-distribution systems and can be used to approximate sealing of annular joint leaks and circular holes), it may be determined as follows:

$$\eta \sim \frac{\tau v_s^2}{y_s}\frac{e}{v_s h} = \frac{\tau v_s}{y_s}\frac{e}{h} = Stk\frac{e}{h}$$

where the symbols are listed in the Nomenclature and $V_S$ and $y_S$ can be calculated with the following equations:

$$v_s = 0.6\sqrt{\frac{2\,\Delta P}{\rho_f}}$$

$$y_s = D\sqrt{50.63\frac{Re_s}{Re_D^{\frac{7}{4}}}}$$



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The theoretical limits of such an analysis are approximated by the following:

$$\mathrm{Re}_p \sim Stk \frac{v_s d_p}{v} << 1$$

$$\mathrm{Stk} \sim \frac{\tau}{t_{res}} << 1$$

$$\frac{\tau v_s}{e} >> 1$$

There is more than one set of flow rates, particle sizes, and duct pressures that wiil satisfy these equations. For the sealing aspect of the present invention the solid aerosol particle can measure between 1 and 100 microns. In its preferred range the particle size should measure between 2 and 40 microns in diameter with a most preferred range of between 3 and 15 microns in diameter. Flow rates can range from 20 - 20,000 cubic meters per hour. In residential duct work the preferred range for flow rates is between 100 and 5000 cubic meters per hour with a most preferred range of between 200 and 600 cubic meters per hour. In commercial duct work the preferred range for flow rate is between 500 and 5000 cubic meters per hour. There is an upper limit on duct pressure established by the structural integrity of the enclosure to be sealed.

With regards to sealing leaks, particle deposition is achieved by "building up a bridge," between the boundaries formed by a leak in the enclosure. In one embodiment, the particulate sealant material is suspended in a liquid base. A solid phase aerosol is formed by removing the liquid during the aerosol injection. One example of a suitable material is to suspend vinyl plastics in water for use as an aerosol. Specifically, an aerosol is generated from a liquid suspension of an acetate-acrylate vinyl polymer and then dried in order to obtain solid sticky particles. Regardless of the material chosen, it is critical that the particles retain their shape on impact with the leak boundaries. If the particles are too deformable, they will tend to spread over the leak boundaries preventing any particle build up spanning the leaks.

In the actual practice of the above described method the duct flow rate and the pressure within the enclosure must be maintained to minimize the loss of sealant material. In practice the pressure and flow rate must be maintained above a minimum value.

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The preparation of the enclosure to be sealed typically includes closing intentional openings in the enclosure. For example, the vents in a heating system would be closed. Another possible step in the preparation of the enclosure would be the introduction of bag filters to keep up the velocity within the system. In the real world it would also be necessary to isolate any objects within the enclosure that might be sensitive to coating.

In the sealing application, closing intentional openings and using a gas as the carrier makes it possible for the invention to provide immediate feedback on the air-tightness of the enclosure being sealed. This is accomplished by monitoring the carrier flow and the enclosure pressure during the sealing process.

General Coating Concept

By means of the knowledge disclosed in this application, aerosol injection can be optimized to coat the inside of enclosures rather than buildup preferentially at the leaks in those enclosures. This is accomplished by operating in a regime of aerosol transport that is turbulent-diffusion dominated, and does not require the use of "limited-slip" particles (i.e., particles that will build-up). This can be understood by examining the equations for penetration efficiency, P, and deposition velocity, $V_e$. The deposition velocity is made up of two components, the gravitational settling velocity, $V_g$, and the turbulent diffusion velocity, $V_d$. As the air flowrate is increased, the velocity and Reynolds number of the flow through the enclosure is increased, which increases the turbulent diffusion velocity, $V_d$. By increasing the turbulent diffusion velocity, wall deposition becomes dominated by turbulent diffusion, and therefore becomes uniform. By contrast, at low flowrates (i.e., velocities and Reynolds numbers) wall deposition occurs principally by means of gravitational settling, and therefore is concentrated at the bottom of the enclosure.

In addition, because the aerosol does not need to span any gaps for the coating application, the constraint that the particles be "limited-slip" (i.e., that they do not flow appreciably after contact) is relaxed. In fact, some particle flow is beneficial in this application, as it will result in a more uniform coating.

Figure 2 illustrates the regimes of operation for the particular application of an air duct. At low air flow rates the removal of particles from the airstream occurs principally by gravitational settling, which results in deposition on the bottom of the duct, and therefore a low penetration. As the air flow is increased, the wall deposition is decreased due to the fact that the particles are moving more quickly through the duct, and therefore travel further before falling to the bottom, corresponding to a high penetration. To preferentially deposit particles at the leaks, particle sizes and flowrates that maximize enclosure penetration efficiency while maintaining a reasonable deposition efficiency are chosen. As the air flow rate is increased further, the removal at walls begins to increase due to the increase in turbulent diffusion to the walls at higher Reynolds numbers, resulting once again in a low penetration. It is this third regime that results in relatively uniform coating on the interior walls of the duct.

A plot of the Effective Leakage Area versus time documents a large reduction in the leakage area. The time history of the Leakage reduction provides documentation of the sealing process. Documentation of leakage area reduction can be presented to third party auditors to quantify the effectiveness of sealing and subsequent energy saving as a result of using the particles to seal remote leaks. The ELA curve will be different for different duct systems, even duct systems which are ostensibly constructed identically. Identical curves have a very low probability of occurring.

A Device

One aspect of the present invention is a device for carrying out the method described above. Figure 1 illustrates one embodiment of the present invention. The device is made up of a primary body 2 being comprised of a hollow structure divided into a preparation end 4 and a delivery end 6. In one embodiment the primary body 2 is cylindrical in shape with the preparation end 4 tapering into a truncated cone.

A fan 8 is connected to the preparation end 4 of the primary body 2 The fan 8 produces an airflow through the hollow portion of the primary body 2 and exits at the delivery end 6 of the primary body 2. The air flow produced is the carrier flow into which the solid phase aerosol will be injected and the used to pressurize the enclosure to be sealed. An airheater 10 placed between the fan 8 and the delivery end 6 of the primary body 2 heats the incoming airflow. In another embodiment the use of a desiccant could be substituted for the airheater 10. A filter 12 is fitted between the airheater 10 and the delivery end 6 of the primary body 2 to reduce any particulate impurities prior to injecting the aerosol and insure that aerosol particles do not come in contact with the heater 10.

A thermostat 14 is located within the primary body 2. A pressure switch 16 is located within the primary body 2. In the present embodiment the switch 16 is located in the delivery end 6 of the primary body 2. A control mechanism 18 connecting the fan 8, pressure switch 16, airheater 10, and thermostat 14 in conjunction with those parts controls the temperature and velocity of the carrier flow.

A flow measurement sensor 19 is connected to the inlet of the fan 8. In one embodiment, the pressure difference across an orifice plate is measured with a pressure transducer. The flow through the unit is proportional to the square root of the pressure differential across the orifice plate.

An injection nozzle 20 is set into the primary body 2 between the filter 12 and the delivery end 6 of the primary body 2. A liquid suspension of aerosol is delivered to the injection nozzle 20 from an aerosol source 22. In one embodiment the aerosol source 22 is comprised of an air compressor, a pressure regulator, and a liquid storage tank. The best results will be obtained where the injection nozzle and aerosol source produce a monodisperse aerosol. If a dry aerosol source is used, the airheater 10 can be eliminated.

A pair of handles 24 are attached to the primary body 2 of the device to aid with transportation and handling of the device. Additionally, a set of feet 26 are attached to the bottom of the primary body 2 to stabilize the unit and aid in positioning the device.

In actual use the delivery end 6 is connected to an opening in the enclosure to be sealed. The fan 8 generates a carrier flow which is pulled through the flow measurement sensor 19, heated by the airheater 10, and then passed through the filter 12 to remove impurities. Aerosol is injected from the aerosol source 22 through the injection nozzle 20 into the preparation end 4 of the device. The aerosol is carried by the carrier flow generated by the fan 8 and out the delivery end 6 of the device. The liquid in the aerosol evaporates off and the carrier flow with the remaining solid phase aerosol is used to pressurize the enclosure to be sealed.

The pressure differential between the interior of the enclosure and the outside atmosphere causes the particles of the solid phase aerosol to find the leaks in the enclosure. When the aerosol impinges on the interior boundaries of the leaks, it sticks where it makes contact. Through this process a "bridge" is built up between the boundaries formed by a leak in the enclosure.

As leaks are sealed the pressure in the enclosure rises. The rise in pressure acts as feed back to the device and the pressure switch 16 in conjunction with the control mechanism 18 turns off the device once pressure reaches a level indicating that the leaks are sealed.

Example 1

Experiments were conducted using a device similar to the embodiment described herein. It has been found that use of the method and device of the present invention can seal 16 $cm^2$ Effective Leakage Area (ELA) in an enclosure in less than 30 minutes. The results in Table 1 provide a proof-of-concept of the of the sealing of an enclosure with aerosols. Table 1 illustrates typical results.

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TABLE 1 - ELA Reduction After Aerosol Injection

| # | Initial Flow Rate [$m_3$/h] | Ending Pressure [Pa] | Liquid Flow Rate [cc/min] | Duration [min] | ELA before Injection [$cm^2$] | Precision in initial ELA measure-ment (in %) | ELA Reduction (in %) |
|---|---|---|---|---|---|---|---|
| 1 | 40 | 60 | 5.7 | 50 | 16.4 | 3.0 | 34 |
| 2 | 70 | 96 | 10 | 25 | 16.4 | 3.0 | 18 |
| 3 | 60 | 135 | 6 | 20 | 16.4 | 3.0 | 84 |
| 4 | 50 | 210 | 5 | 30 | 16.4 | 3.0 | 95 |
| 5 | 50 | 205 | 5 | 30 | 16.4 | 3.0 | 82 |
| 6 | 40 | 210 | 410 | 30 | 16.4 | 3.04 | 94 |
| 7 | 40 | 209 | 4 | 30 | 16.4 | 3.0 | 94 |
| 8 | 30 | 18 | 3 | 30.4 | 16.4 | 3.0 | 29 |
| 9 | 60 | 105 | 6 | 30 | 16.4 | 3.0 | 94 |
| 10 | 40 | 10 | 4 | 30 | 36.1 | 2.4 | 37 |
| 11 | 50 | 15 | 5 | 30 | 26.3 | 2.7 | 42 |

In the Experiments(#) 1-11 summarized in Table 1, an in-line heater was used to lower the water content of the aerosol particles prior to aerosol injection.

From Table 1, it can be seen that the ELA of the Enclosure can be reduced by more than 90% in 20 to 45 minutes. In addition, the initial air flow rate can be lowered down to 40 cubic meters/hour per branch, and still provides sufficient aerosol penetration and significant ELA reduction (see experiments 6 and 7). According to our experiments, plugging an equivalent of 16 $cm^2$ will occur in about 30 minutes. Larger initial leaks require more time for sealing (see experiments 10 and 11).

Example 2

The graph shown in Figure 2 illustrates Penetration efficiency as a function of flow rate and particle size. This example was carried out using the method of the present invention in a duct having a 15 cm diameter and a length of 10 meters. The ridge in the plots represents the conditions under which the maximum penetration results from a balance of turbulent diffusion velocity $V_d$ to the walls of the duct and gravitational settling velocity $V_g$ for a particular particle size travelling through the duct.

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CLAIMS:

1. A method for remotely sealing an enclosure from within, said method comprising the steps of:

a) creating a selected flow rate of a fluid within the enclosure from a fluid injection location to and through leaks in said enclosure and providing a particular pressure within the enclosure and a particular differential pressure across the leaks;

b) monitoring the pressure within the enclosure;

c) controlling the flow rate of step a) in response to the monitored pressure of step b) to maintain said particular pressure and differential pressure; and

d) injecting particles from a particle injection location into said enclosure with said particles having a size range, such that a substantial portion of said particles in said size range are transported by said fluid through said enclosure until said particles reach a location at or adjacent to said leaks with said particles substantially retaining their shape and adhering to an interior surface of the enclosure and to each other at impact locations adjacent to the leaks to build up a bridge of particles to span between the boundaries of each of said leaks.

2. The method according to claim 1, wherein enclosure sealing efficiency is the product of a penetration efficiency (P) and a deposition efficiency ($\eta$), where the variables P and $\eta$ are dependent on said particle size range, said fluid flow rate and said pressure differential across the leaks with there being a range of sealing efficiency values that result in the leak being substantially sealed.

3. The method as recited in claim 1, wherein said particles are in a size range between 1 and 100 microns in diameter.

4. The method as recited in claim 3, wherein said particles are in a size range between 2 and 40 microns in diameter.

5. The method as recited in claim 4, wherein said particles are in a size range between 3 and 15 microns in diameter.

6. The method as recited in claim 1, wherein the fluid flow rate generated is between 20 and 20,000 cubic meters per hour.

7. The method as recited in claim 6, wherein the fluid flow rate generated is between 100 and 5,000 cubic meters per hour.

8. The method as recited in claim 7, wherein the fluid flow rate generated is between 200 and 600 cubic meters per hour.

9. The method as recited in claim 1, wherein the particles are a solid phase aerosol with step d) comprising the steps of:

e) diluting a sealant suspended in a carrier liquid;

f) injecting the sealant suspended in the carrier liquid into the fluid flow; and

g) reducing the degree of saturation of the vapor phase of the carrier liquid in the fluid flow.

10. The method as recited in claim 9, wherein step g) includes the step of:

h) drying the vapor phase of the carrier liquid in said fluid flow.

11. The method as recited in claim 9, wherein step g) includes the step of:

h) heating the vapor phase of the carrier liquid in said fluid flow.

12. The method as recited in claim 1, wherein step a) to aid in pressurizing the enclosure comprises the steps of:

e) closing any intentional openings in the enclosure; and

f) isolating or removing coating-sensitive structures from the interior of the enclosure.

13. The method as recited in claim 12, wherein step a) to further aid in pressurizing the enclosure comprises the additional step of:

g) using a filter at an intentional opening of said enclosure to reduce internal pressure and increase fluid flow velocities.

14. The method as recited in claim 12, wherein step a) to further aid in pressurizing the enclosure comprises the additional step of:

g) inducing turbulence in the enclosure to help keep particles suspended in the airflow.

15. The method as recited in claim 9, wherein the solid phase aerosol is suspended in water.

16. The method as recited in claim 9, wherein the fluid of step a) is air.

17. A device for remotely sealing and coating an enclosure from within comprising:

a) a primary body being comprised of a hollow structure divided into a preparation end and a delivery end,

b) a fan connected to the preparation end of the primary body,

c) an airheater disposed between said fan and the delivery end of the primary body,

d) a filter disposed between said airheater and the delivery end of the primary body,

e) a thermostat located within the primary body,

f) a pressure switch located within the primary body,

g) a control mechanism connecting said fan, the pressure sensor, said airheater and the thermostat,

h) an injection nozzle set into the primary body between the filter and the delivery end of the primary body,

i) an aerosol source connected to said injection nozzle.

18. The device as recited in claim 17, wherein a flow measurement apparatus is connected to said fan.

19. The device as recited in claim 18, wherein the pressure switch is a remote unit located within the enclosure to be sealed.

20. The device as recited in claim 18, wherein the injection nozzle is an ultrasonic nozzle.

21. The device as recited in claim 18, wherein the aerosol source comprises an air compressor, a pressure regulator, and a liquid storage tank.

22. A method for remotely applying a uniform coating to the walls of an enclosure by means of turbulent diffusion of aerosol particles, comprising the steps of:

a) choosing a desired distance from an injection point to which the coating should be delivered;

b) preparing an aerosol of particles of a particular size range;

c) generating a fluid flow from said injection point to pressurize said enclosure that results in an enclosure flow which results in wall deposition dominated by turbulent diffusion for the chosen particle sizes; and

d) introducing the particles into the fluid flow, wherein a deposition velocity of the particles is determined by means of the following equations:

$$V_e = \begin{cases} \frac{1}{2\pi}\left[(\pi + 2\gamma)V_d + 2V_g \cos\gamma\right], \\ \quad if \quad |V_d| < |V_g|, \\ \quad\quad where\ \gamma = \arcsin\left(\frac{V_d}{V_g}\right); \\ V_d, \\ \quad if \quad |V_d| \geq |V_g| \end{cases}$$

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$$V_d = V_* U \sqrt{f/2}$$

$$V_* = 6.9 \times 10^{-4} \tau_*^2 \quad if \quad \tau_* \leq 15$$

$$V_* = 0.16/\tau_*^{0.086} \quad if \quad \tau_* > 15$$

$$V_g = g\,\tau$$

so as to result in $V_d \geq V_g$ and a penetration efficiency corresponding to the chosen coating distance from the injection point of the enclosure, where the penetration efficiency is defined as:

$$P = \exp\left(-\frac{4V_e L}{UD}\right) = \exp\left(-\frac{4V_e L}{\nu \mathrm{Re_D}}\right).$$

23. A method for sealing leaks in a fluid enclosure comprising the steps of:

a) pressurizing the enclosure using a fluid flowing at a particular fluid flow rate from a fluid injection location to and through leaks in said enclosure and providing a particular differential pressure across the leaks;

b) providing particles;

c) introducing said particles into said fluid flowing from said fluid injection location;

wherein said particles substantially retain their shape and adhere to the enclosure wall and to each other at impact at locations adjacent to the leaks to build up a bridge of particles to span between the boundaries of each of said leaks.

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24. The device as recited in claim 17 wherein the aerosol source provides

particles which substantially retain their shape and adhere to an enclosure wall and each other at locations adjacent to a leak opening in the enclosure wall, where the particles as a result of their adherence to each other at locations adjacent to said leak opening form a bridge of particles establishing a seal spanning between the boundaries of said leak.

25. The method as recited in claim 22 wherein the particles substantially retain their shape and adhere to an enclosure wall and each other at locations adjacent to a leak opening in the enclosure wall, where the particles as a result of their adherence to each other at locations adjacent to said leak opening form a bridge of particles establishing a seal spanning between the boundaries of said leak.

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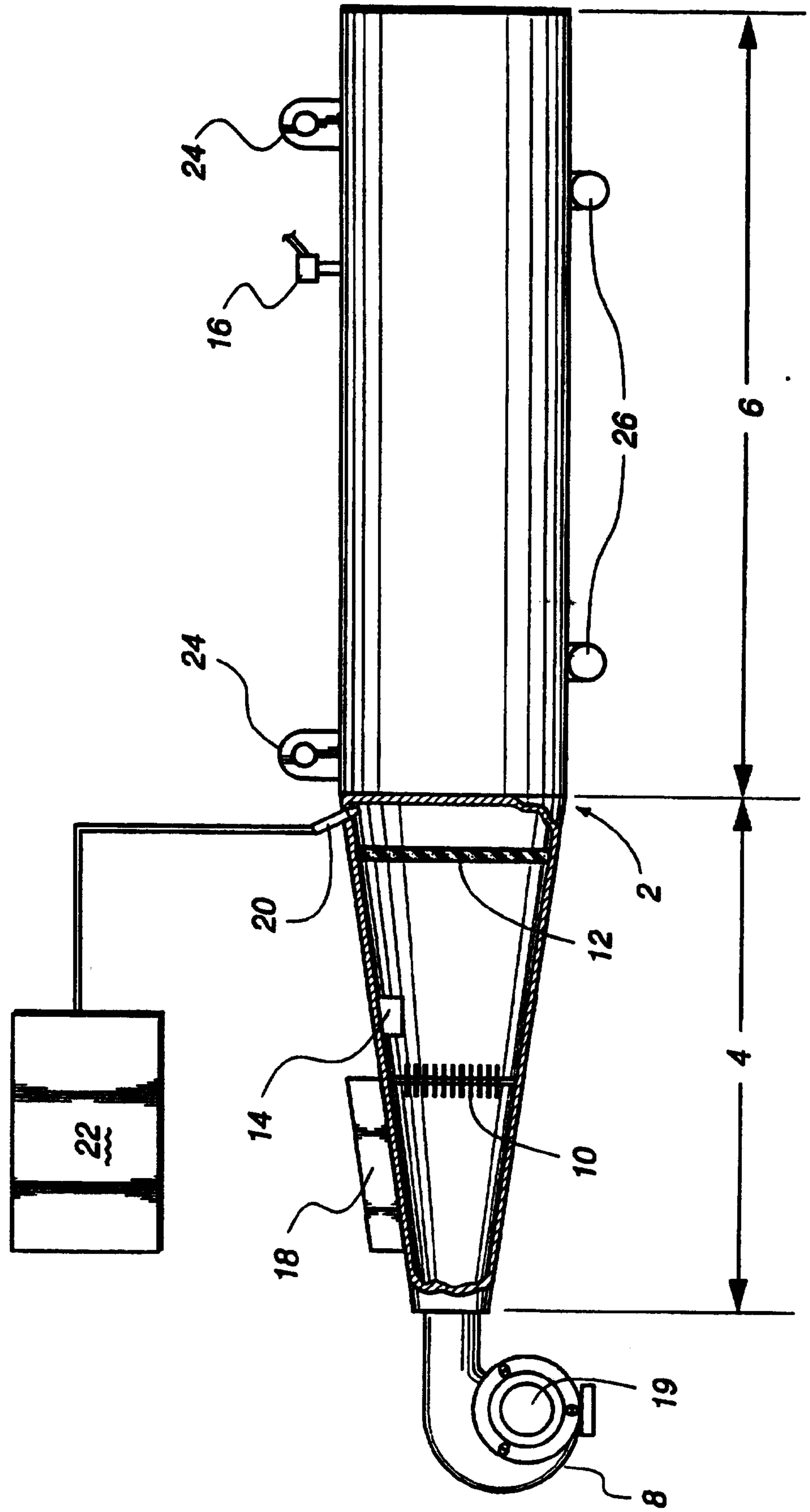
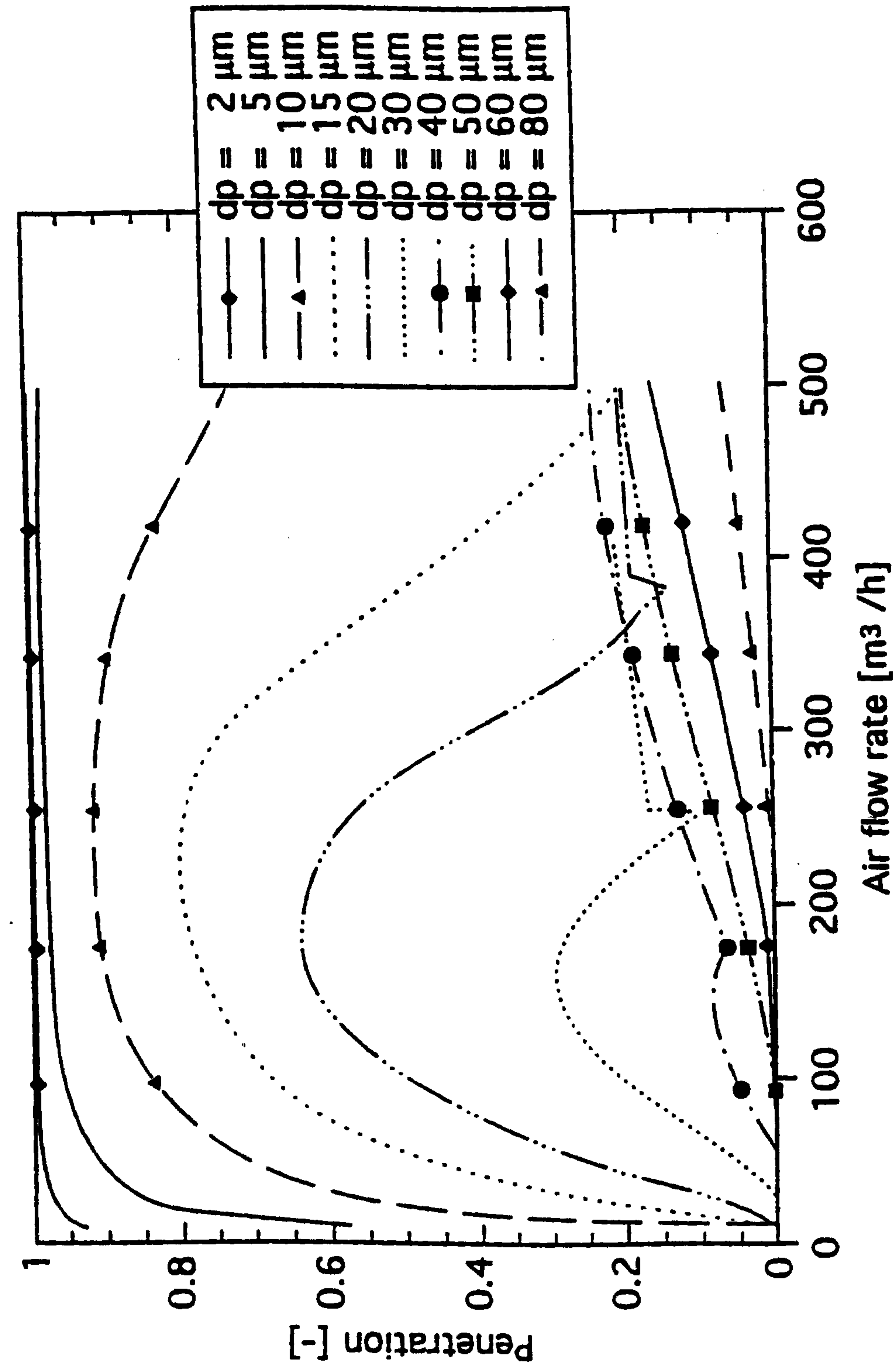
PATENT AGENTS

1/2 FIGURE 1



2/2 FIGURE 2


dp = 2 µm
dp = 5 µm
dp = 10 µm
dp = 15 µm
dp = 20 µm
dp = 30 µm
dp = 40 µm
dp = 50 µm
dp = 60 µm
dp = 80 µm
Penetration [-]
0
0.2
0.4
0.6
0.8
1
Air flow rate [m3 /h]
0
100
200
300
400
500
600


22
24
24
16
14
20
18
10
12
2
8
19
26
4
6