United States Patent [19]

Peterson

[11] **3,901,798**

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[54] **AEROSOL CONCENTRATOR AND CLASSIFIER**

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[73] Assignee: **Environmental Research Corporation,** St. Paul, Minn.

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[52] **U.S. Cl.** **209/143**
[51] **Int. Cl.²** **B07B 7/00**
[58] **Field of Search** .... 209/143, 145, 1, 210; 73/28, 29, 432 PS, 421.5 R; 55/270, 319, 434, 439, 17

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Assistant Examiner—Ralph J. Hill
Attorney, Agent, or Firm—Dorsey, Marquart, Windhorst, West & Halladay

[57] **ABSTRACT**

An aerosol sampler which concentrates and classifies airborne particles. Particles in the size range of 0.1 – 10 microns are classified according to particle size by means of the particle inertia principle. The unique design reduces particle losses and is characterized by an annular passage in the flow path of the sample.

14 Claims, 7 Drawing Figures

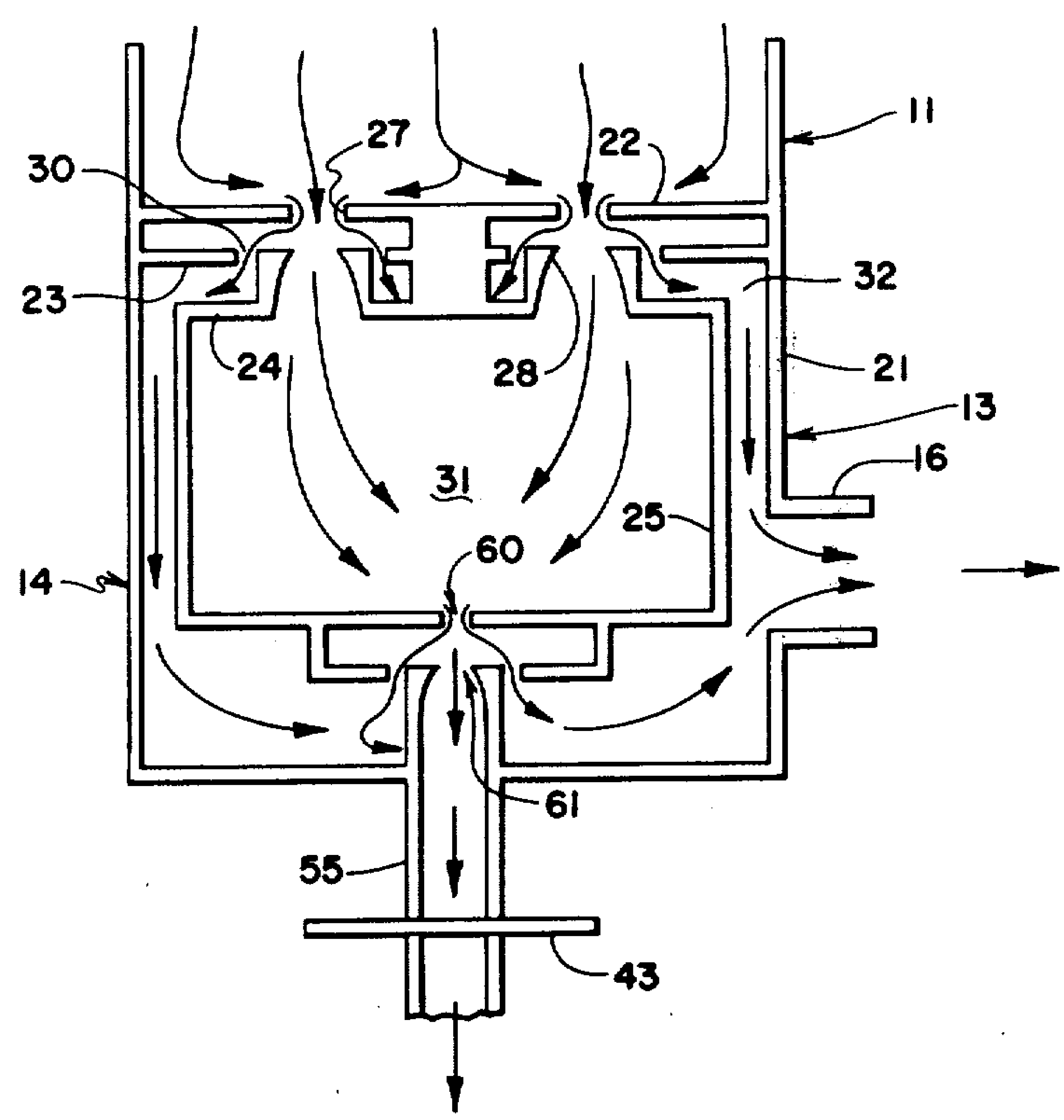

Fig. 1

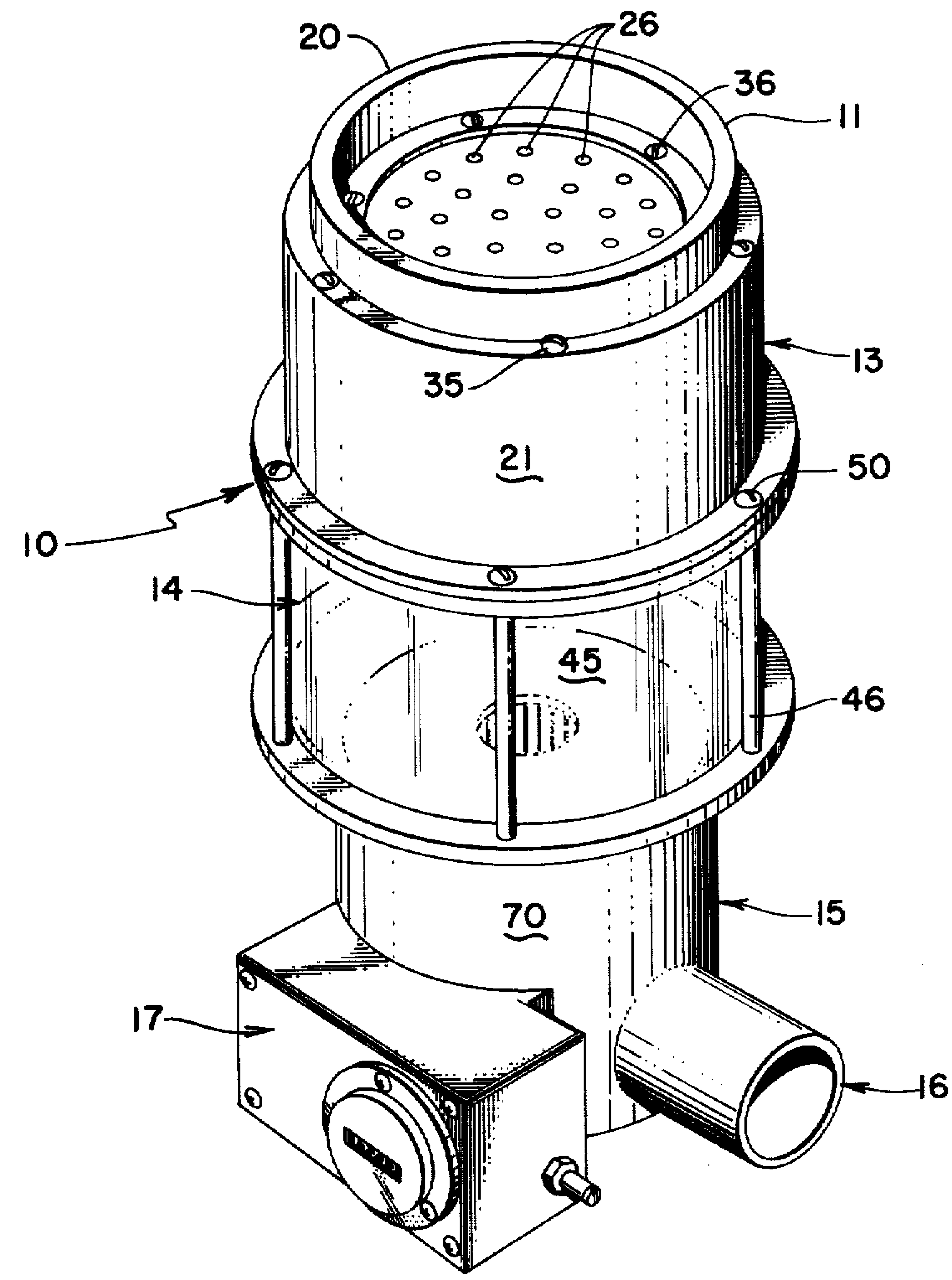
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Fig. 2

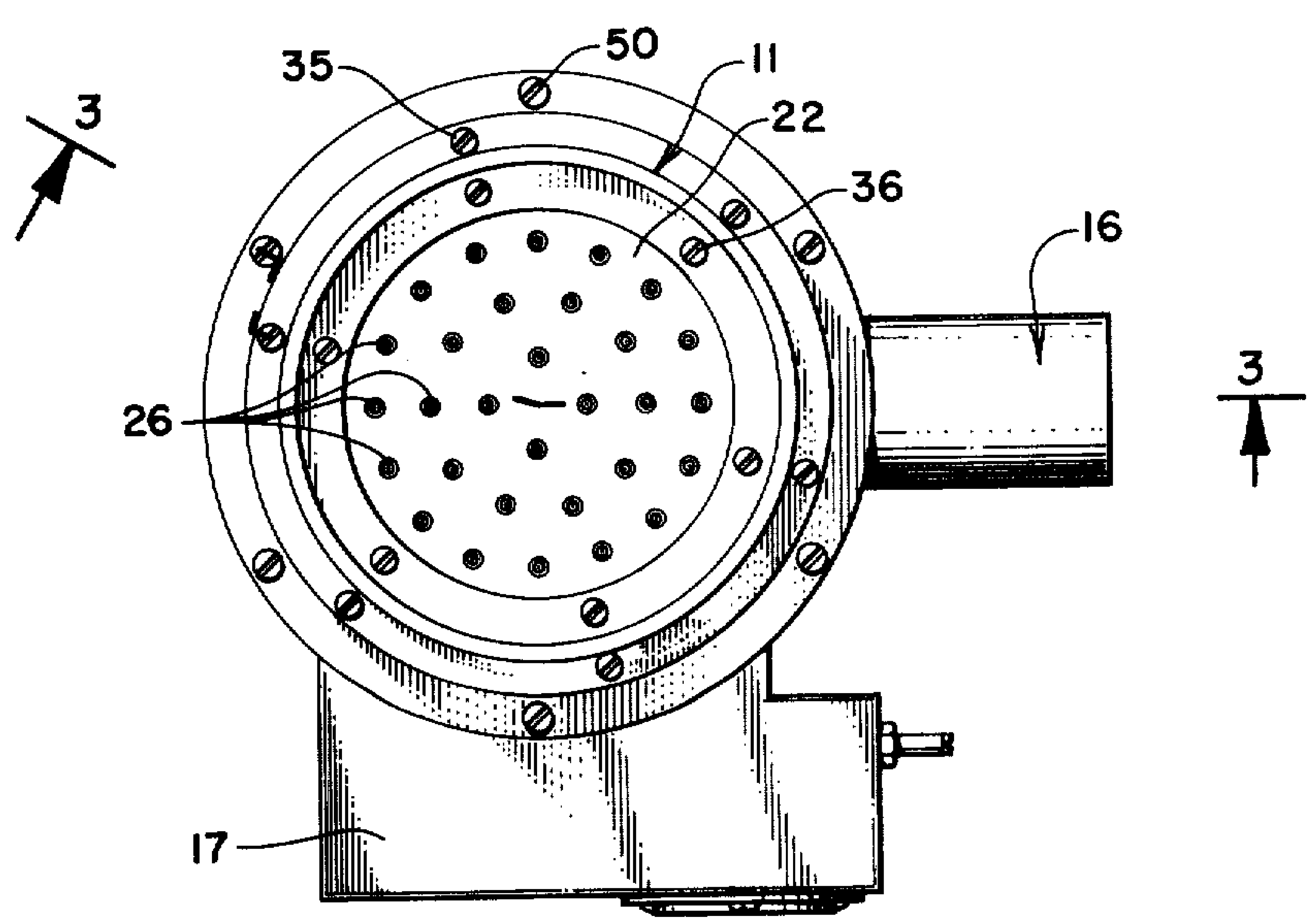
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Fig. 3

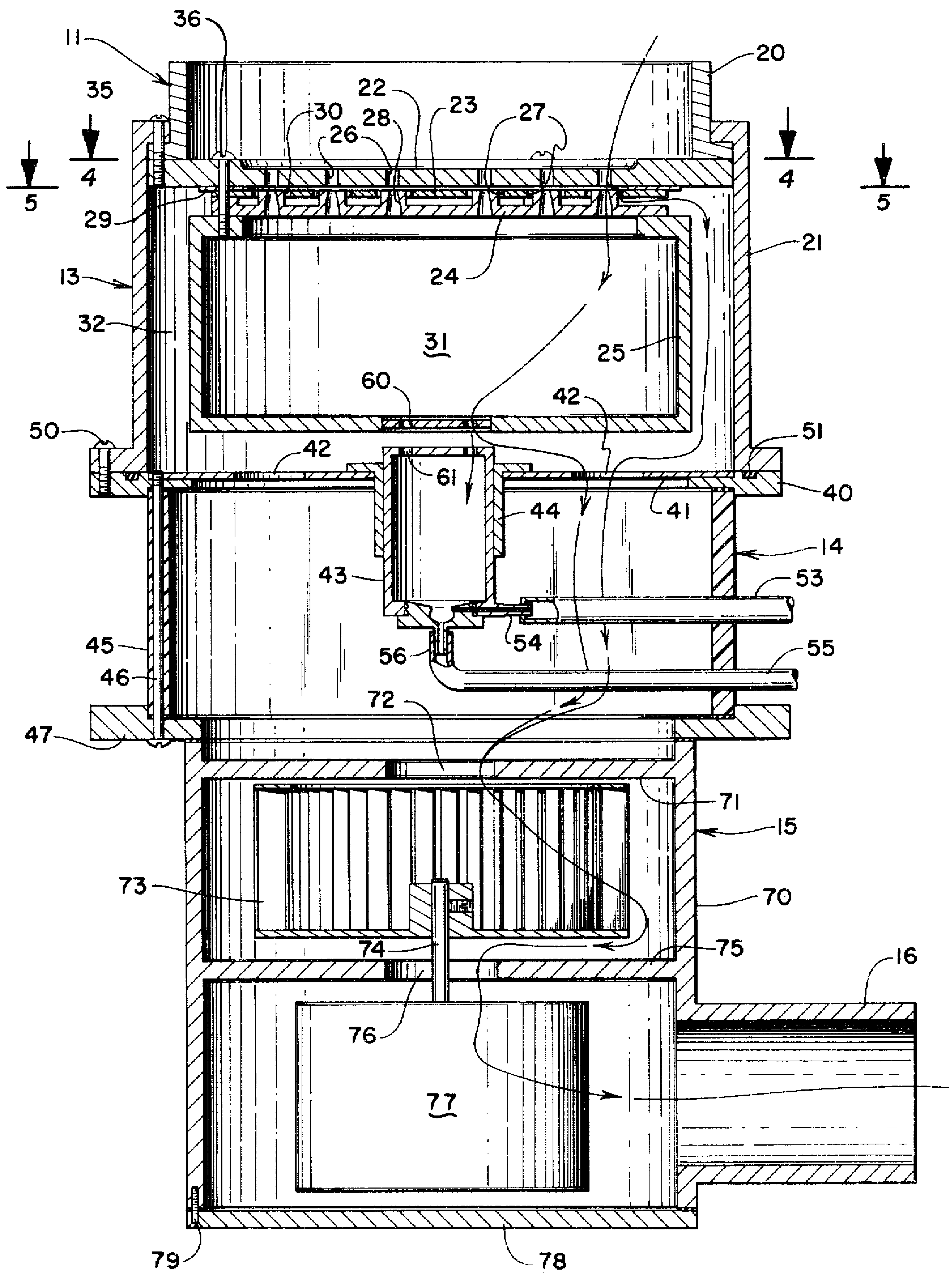
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Fig. 4

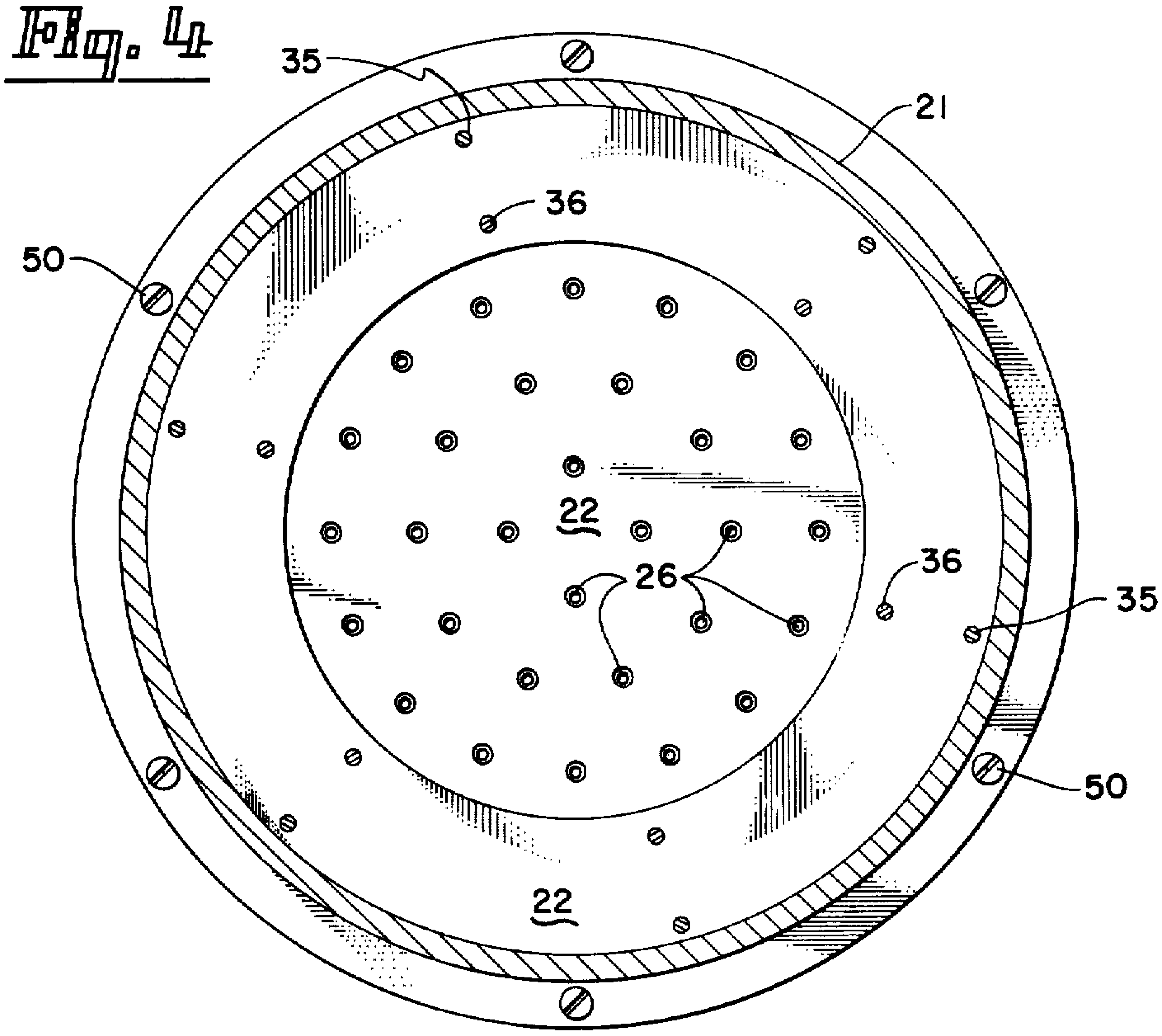

Fig. 5

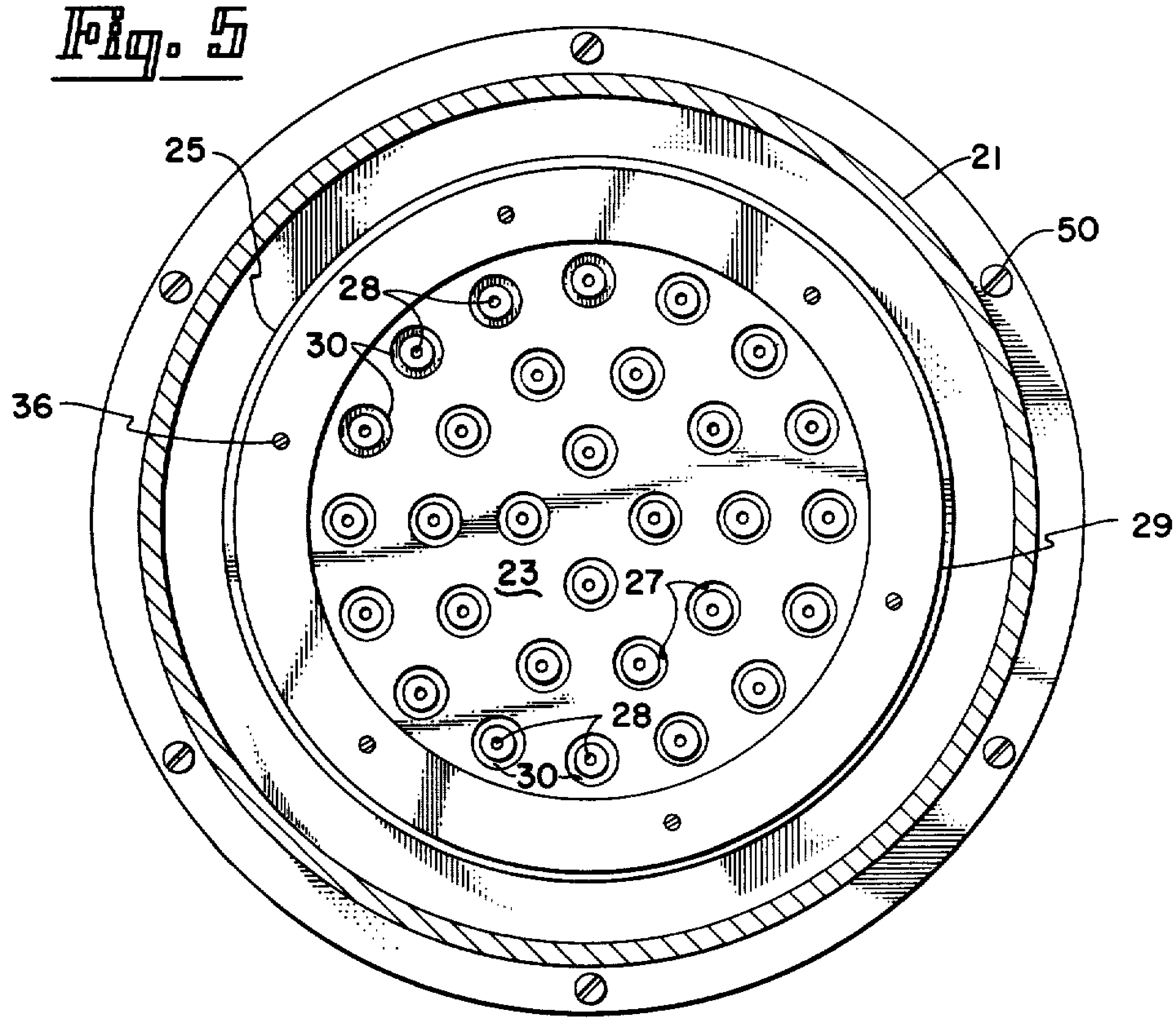

Fig. 6

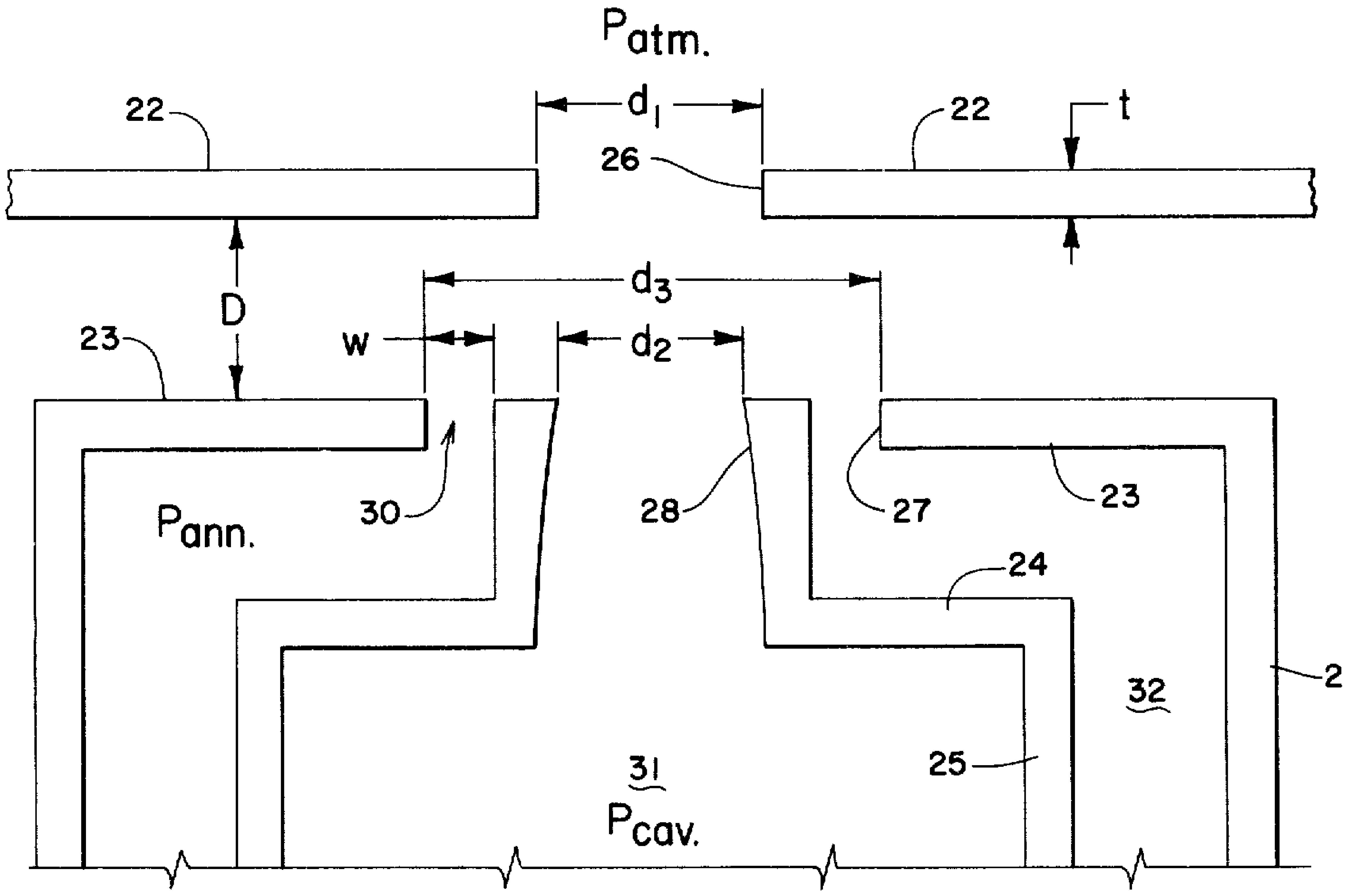
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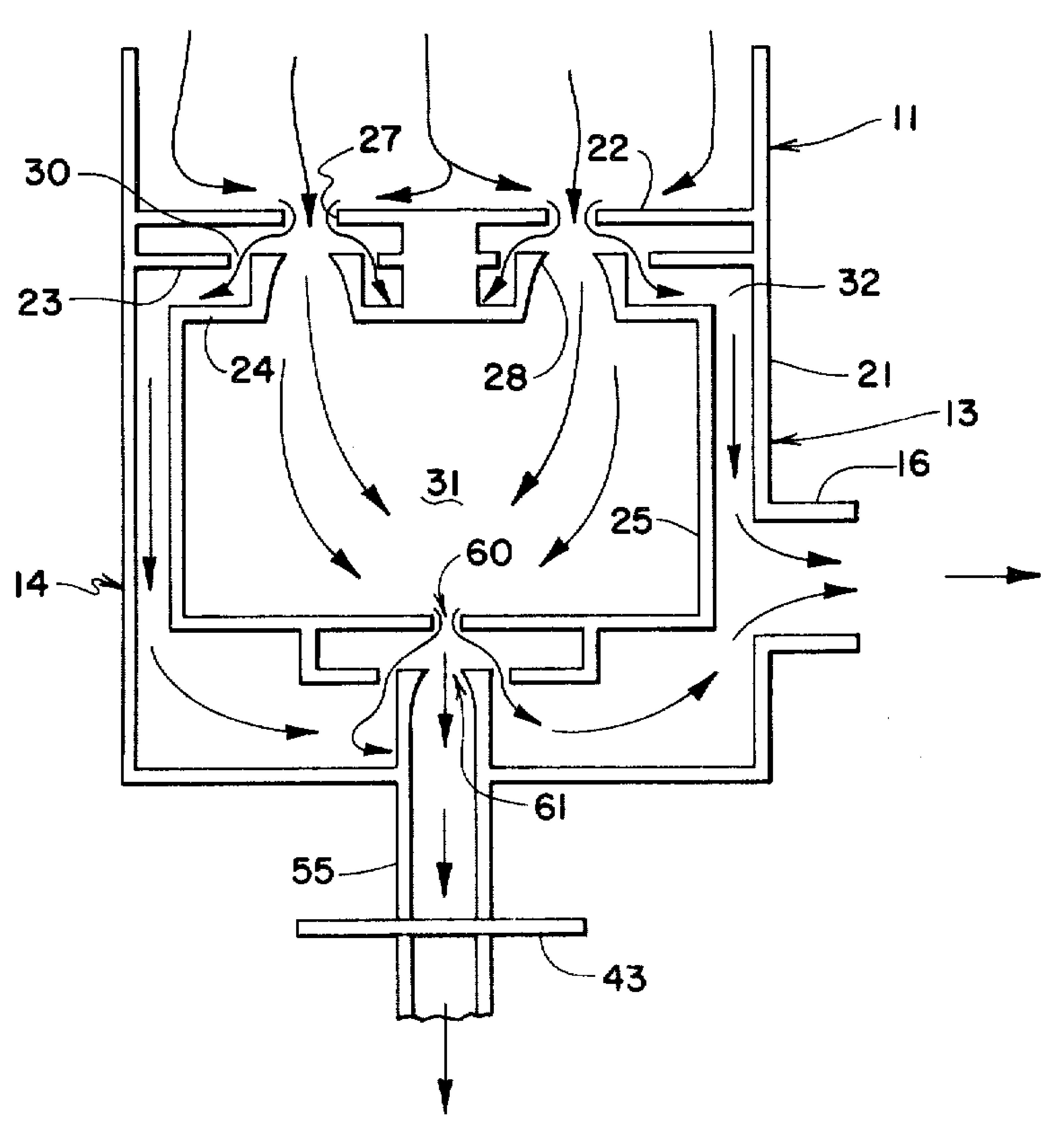
Fig. 7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AEROSOL CONCENTRATOR AND CLASSIFIER

BACKGROUND OF THE INVENTION

The invention pertains to the field of analyzing particle laden (or polluted) air by measuring the concentration, size and size distribution of the suspended particles. It is useful in the detection of biological or radioactive particles suspended in the atmosphere, in the detection of biological contamination in hospitals, in the analysis of smoke stack emissions, in monitoring ambient conditions for pollution, and in classification of pigments according to particle size. In general the invention is useful in any field which requires the sampling, concentrating, or classifying according to particle size, of nonfibrous airborne particles within the size range of 0.1 – 10 microns.

The invention operates on the principle of particle inertia. Air with suspended particles is caused to flow along a path, and a portion of the airstream is deflected. The smaller particles with less mass and inertia negotiate the turn and continue along the deflected path. The larger particles (above the cutpoint) with greater mass and inertia fail to negotiate the turn and continue along the original direction of the airstream. Particles are thus separated or classified according to particle size.

The effect and persistence of particulate matter in the atmosphere is primarily dependent upon particle size. Reduction in atmospheric visibility, for example, is largely due to particles in the size range of 0.1 – 1 microns. Where synergistic action has been observed with toxic gases, indications are that the effect is more pronounced when the particles are submicron in size. Particulates of definable particle size enhance atmospheric reactions and transformations of pollutant gases, exert an influence on radiation transfer of solar energy to the earth's surface, and may be responsible for inadvertent weather modification by nucleating cloud formation. Accordingly, air quality and source emission standards will likely be expressed in terms of the size of emitted particles and, consequently, means for measuring and classifying particles according to particle size will be required.

The principle of particle inertia has been used in prior art devices. The cascade impactors described by Hounam and Sherwood[1], and by Connor[2], for example, utilize this principle. In these, as well as other prior art devices, particle wall losses are significant, that is, 40–45% particle loss or 55–60% efficiency is not uncommon when comparing what comes out with what goes in. In addition in prior art devices there is substantial particle bounce-off from the collected surfaces which distorts the particle size distribution of the sample collected. Moreover, the limited quantity of particle mass which can be collected prior to particle reentrainment is another limitation of prior art devices, and the collection surface upon which the particles are collected in prior art devices is not readily amenable to a variety of analysis techniques including beta-attenuation, culturing, microscopic examination, and other methods.

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2. Connor, W. D., "An Inertial Type Particle Separator for Collecting Large Samples," *Journal of the Air Pollution Control Association*, 16: p. 35 (January 1966)

SUMMARY OF THE INVENTION

The primary advantage of the present invention is that particle losses are reduced to 15–20%, that is, the sampler operates at an efficiency in the range of 80–85%. In addition the present invention promotes efficient impingement and concentration of particles of various sizes into a given classification, that is, a more precise cutpoint for particles of various sizes results. The present invention also facilitates removal of the sample onto a defined filter media or area for analysis.

The invention is characterized by an annular passage disposed about and in the plane of a second orifice concentrically located in spaced relationship downstream from a first orifice.

More particularly, the invention may be summarized as apparatus for classifying airborne particles according to particle size including a first plate which defines a first orifice. A second plate spaced from the first plate defines a second orifice larger than and substantially concentrically disposed with respect to the first orifice. The second orifice is downstream from the first. Tubular means, also downstream from the first orifice, disposed substantially in the plane of the second orifice, directed toward, substantially the size of, and substantially concentrically disposed with respect to the first orifice, defines a third orifice and an annular passage between the second orifice and tubular means. This annular passage is the critical element in the present invention and distinguishes it from prior art devices. A pressure gradient, decreasing in pressure from the first orifice to the annular passage and third orifice is provided to induce flow through the first orifice and the third orifice and the annular passage. In the embodiment shown the first orifice, the third orifice, and the annular passage are circular.

The invention may be practiced in a plurality of stages. For this purpose, second stage classification apparatus may be disposed in the airstream that passes through the third orifice in the first stage. Additional stages may also be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the preferred embodiment showing the intake section, the first stage section, the second stage section, and the blower section.

FIG. 2 is a top view of the aerosol sampler shown in FIG. 1.

FIG. 3 is a vertical sectional view of the present invention taken on the line 3—3 of FIG. 2.

FIG. 4 is a horizontal sectional view taken on the line 4—4 of FIG. 3.

FIG. 5 is a horizontal sectional view taken on the line 5—5 of FIG. 3.

FIG. 6 is an enlarged, schematic, vertical sectional view of the classification zone of the present invention. The relative size and relationship of the critical elements is shown.

FIG. 7 is an enlarged, schematic, vertical sectional view similar to FIG. 6 and shows a second stage classification section.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The general nature of the present invention may be readily understood with reference to FIG. 1. Ambient air to be concentrated and classified enters the aerosol sampler **10** at intake section **11.** The sample passes downwardly through first stage section **13** in which fractionation occurs and then through second stage section **14** in which further fractionation occurs. The sample fraction is collected in second stage section **14.** The balance and major volumetric portion of the airstream passes through blower section **15,** and exits from the apparatus at exhaust cylinder **16.** Timer **17** serves to record the length of time of operation of the apparatus or the length of time over which the sample is collected. The classification of particles in the airstream is brought about between intake section **11** and exhaust cylinder **16** in a manner described in detail below.

The detailed design and construction of the present invention may be readily understood with reference primarily to FIGS. **2–6.** With reference first to FIG. **3,** intake section **11** includes flow containment collar **20** which is generally cylindrical and flanged at one end. With continued reference to FIG. **3,** first stage section **13** includes cylindrical housing **21** which is internally flanged at its upper edge and externally flanged at its lower edge. Nozzle orifice plate **22,** guide plate **23,** separation plate **24,** and first stage collecting cavity housing **25** complete the basic elements in first stage section **13.** Nozzle orifice plate **22** defines a series of spaced orifices **26** shown in both FIGS. **3** and **4.** Orifices **26,** which constitute the first orifice in the path of the airstream, are radially disposed about the vertical axis of sampler **10** and, in the preferred embodiment shown, number 30. A similar number of orifices **27** are provided in guide plate **23.** These orifices **27** are larger than and concentrically disposed with respect to nozzle orifices **26,** and are spaced downstream therefrom. Orifices **27** constitute the second orifice in the path of the airstream. A similar number of tubular or third orifices **28** are defined by separation plate **24** as best seen in FIG. **3.** The third orifices **28** are spaced from first orifices **26,** downstream therefrom, and are disposed concentrically with respect thereto in the plane of second orifices **27.** The wall of tubular orifices **28** is sufficiently thin so that the outside diameter of the tubular portion is less than the diameter of the second orifices **27.** Thus, an annular passage **30** is formed between second orifice **27** and the outer wall of third or tubular orifice **28.** This annular passage **30** may be seen with reference to FIGS. **3, 5** and **6** and characterize the invention.

First stage collection cavity housing **25** has an open top surface and defines air cavity **31** which serves as a confinement area for that portion of the airstream and fractionated airborne particles which pass through each third orifice **28.** First stage collecting cavity **25,** together with first stage cylindrical housing **21,** defines an annular cavity **32** which serves as a confinement area for that portion or fraction of the airstream and airborne particles which pass through each annular passage **30.**

Intake section **11** is mounted to first stage section **13** by means of screws **35.** Nozzle orifice plate **22,** gasket **29,** guide plate **23,** and separation plate **24,** are held in the requisite relationship and connected to first stage collection cavity housing **25** by means of screws **36.**

Second stage section **14** begins with mounting plate **40** and separation plate **41** which defines large unrestricted passages **42.** Sample collector **43,** sample collector mounting sleeve **44,** and second stage cylindrical housing **45** are also provided in second stage section **14.** Cylindrical housing **45,** formed from rigid transparent material, is mounted to separation plate **41** and mounting plate **40** by means of screws **46** which extend through lower separation plate **47** and are threaded into mounting plate **40.** Second stage section **14** is mounted to first stage section **13** by means of mounting plate **40** which is mounted and sealed to the lower flange of first stage cylindrical housing **21** by means of screws **50** and O-ring **51.**

Liquid or culture medium input tube **53** extends through second stage cylindrical housing **45** and connects with sample collector **43** at mounting tube **54.** Sample collection tube **55** extends from downwardly projecting mounting tube **56** of sample collector **43** and outwardly through second stage cylindrical housing **45,** as best seen in FIG. **3.**

The second stage concentration and classification occurs at secondary orifices **60** disposed in the bottom plate portion of first stage collection cavity housing **25.** Concentrically disposed second stage orifices **61** in the upper portion of the sample collector **43,** along with annular passage **32,** serve to classify the airstream further, that is, accomplish a secondary classification, as the once fractionated airstream from air cavity **31** passes through orifices **60** and is further concentrated and classified. A portion of the stream passes into annular cavity **32** and through large unrestricted passages **42,** while the other portion passes through orifices **61** into sample collector **43.** It may be noted at this point that the secondary concentration and classification shown in FIG. **3** does not include the characteristic annular passage described above in connection with the first stage classification. While not shown, a similar secondary classification structure could be provided in the second stage and, moreover, such an arrangement is shown schematically in FIG. **7.**

With continued reference to FIG. **3,** blower section **15** includes cylindrical blower housing **70,** under separation plate **71** which defines a centrally disposed unrestricted passage **72,** squirrel cage **73** keyed to drive shaft **74,** intermediate separation plate **75** which defines unrestricted passage **76,** motor **77,** and bottom plate **78.** Bottom plate **78** is mounted to cylindrical blower housing **70** by means of the screws **79.** Exhaust cylinder **16,** formed integrally with cylindrical blower housing **70,** completes blower section **15.** A conventional timer **17** (shown in FIG. **1**) is mounted to blower housing **70** to record the length of time over which the sample is collected.

The relative size of the critical parts of the invention may be best understood with reference to FIG. **6.** The same reference numerals used in describing the preferred embodiment of FIGS. **1–5** are applied to the corresponding elements shown schematically in FIG. **6.** With reference to FIG. **6,** the distance, D, between first plate **22** and second plate **23** should be 0.3 – 3 times the diameter, d_1, of first orifice **26.** The width, w, of annular passage **30** should be equal to or less than one-half the diameter, d_1, of first orifice **26.** The diameter, d_2, of third orifice **28** should be equal to or slightly less than the diameter, d_1, of first orifice **26.** The diameter of second orifice **27,** and the wall thickness of tubular orifice **28,** should be such that the area of the annular passage **30** is 0.6 – 1 times the area of third orifice **28.** The thickness, t, of first plate **22** should be less than the diameter, d_1, of first orifice **26.** For a concentration ratio (by volume) of 8:1, the area of annular passage **30** should be 0.8 times the area of third orifice **28.** For fractionation of particles in the size range of 0.1 – 10 microns, the diameter, d_1, of first orifice **26** should be in the range of 0.2 – 0.5 inches.

For a 50% cutpoint of 1.5 microns[1], the diameter, d_1, of first orifice **26** should be 0.136 inches. The pressure, P_{ann}, in annular passage **30** and annular cavity **32** should be 16–18 inches of water less than atmospheric pressure, P_{atm}. The pressure, P_{cav}, in third orifice **28** and first stage collection cavity **31** should be only slightly less than atmospheric, that is, 0.1 – 0.2 inches of water less than atmospheric, P_{atm}. Under the foregoing conditions, the velocity of the airstream passing through first orifice **26** is approximately 6,200 centimeters per second. The volumetric through-put is about 35 cfm. Those skilled in the art may choose a blower and motor of appropriate size and capacity to achieve these conditions.

1. A 50% cutpoint of 1.5 microns means that 50% of the 1.5 micron sized particles pass from first orifice **26** directly through third orifice **28** into first stage collection cavity **31**, and 50% of the 1.5 micron particles pass through annular passage into annular cavity **32.** Particles larger than 1.5 microns pass directly through third orifice **28** in increasing percentages above 50% and through annular passage **30** in decreasing percentages below 50%. The percentage of particles in a size range greater than 1.5 microns flowing through third orifice **28** increases with the increase in particle size, and the percentage of particles smaller than 1.5 microns which pass through annular passage **30** increases as particle size decreases.

The operation of the invention may be best understood with reference to FIG. **7.** A two stage classifier is shown schematically in FIG. **7** and the elements or components are assigned reference numerals identical to the numerals assigned to the corresponding elements or components shown or described in connection with the preferred embodiment in FIGS. **1–5.** Due to the pressure gradient referred to above in the description of the preferred embodiment, ambient air, that is, the air to be sampled, is drawn into intake section **11** and into orifices **27.** At this point fractionation occurs. A portion of the airstream, that is, approximately 80–90% by volume of the airstream, is deflected and passes through annular passage **30** into annular cavity **32.** The balance of the airstream, that is, 10–20% by volume, passes directly from first orifice **27** through third orifice **28** and into first stage collecting cavity **31.** The difference in volume when comparing the volume of the airstream passing through annular passage **30** with the volume passing through third orifice **28** is due to the substantial difference between the pressure in annular cavity **32** and first stage collection cavity **31.** In other words, the pressure gradient from first orifice **27** to annular passage **30** and annular cavity **32** is substantial, whereas the pressure gradient between first orifice **27** and third orifice **28** is slight. Fractionation occurs as the airstream is deflected from a path directly from first orifice **27** through third orifice **28** with a substantial portion passing through annular passage **30.** At this point particles above the cutpoint continue along a path without deflection and in first stage collection cavity **31.** Particles below the cutpoint negotiate the turn, due to their smaller mass and inertia, and pass through annular passage **30** and enter annular cavity **32.** Further fractionation occurs at second stage orifice **60.** The nature of the classification in the second stage is identical to that in the first. The fraction of air in annular cavity **32** resulting from both first and second stage classification is discharged through exhaust cylinder **16.** The sample fraction is collected on sample collector **43** and analyzed. Analysis may be carried out by beta-attenuation, by culturing the sample, and by other means known to those skilled in the art.

I claim as my invention:

1. Apparatus for classifying airborne particles according to particle size which comprises:

a first plate defining a first orifice;

a second plate spaced from the first plate and defining a second orifice larger than and substantially concentrically disposed with respect to the first orifice;

tubular means defining a third orifice disposed substantially in the plane of the second orifice, directed toward, substantially the size of, and substantially concentrically disposed with respect to the first orifice, to thereby define an annular passage between the second orifice and the tubular means;

means for establishing communication between said first orifice, on the one hand, and said third orifice and said annular passage, on the other hand;

an outlet for returning air passing through said annular passage to the atmosphere;

means for establishing communication between said annular passage and said outlet; and

collecting means communicating with the third orifice for collecting the particles passing therethrough.

2. The apparatus of claim **1** and means for providing a pressure gradient decreasing in pressure from the first orifice to the annular passage and the third orifice.

3. The apparatus of claim **1** wherein the first orifice is substantially circular.

4. The apparatus of claim **3** wherein the spacing between the first plate and the second plate of 0.3 – 3 times the diameter of the first orifice.

5. The apparatus of claim **4** wherein the distance between the annular passage and the third orifice is equal to or less than one-half the diameter of the first orifice.

6. The apparatus of claim **5** wherein the area of the annular passage is 0.6 – 1 times the area of the first orifice.

7. The apparatus of claim **6** wherein the thickness of the first plate is less than or equal to the diameter of the first orifice.

8. The apparatus of claim **1** and secondary stage classifying means comprising:

a secondary first plate defining a secondary first orifice disposed in the path of the particles after passage through the third orifice and prior to entrance into the collecting means;

means for establishing communication between said third orifice and said secondary first orifice;

a secondary second plate spaced from the secondary first plate and defining a secondary second orifice larger than and substantially concentrically disposed with respect to the secondary first orifice; and

secondary tubular means defining a secondary third orifice communicating with the collecting means and disposed substantially in the plane of the secondary second orifice, directed toward, substantially the size of, and substantially concentrically disposed with respect to the secondary first orifice to thereby define a secondary annular passage between the secondary second orifice and the secondary tubular means;

means for establishing communication between said secondary first orifice, on the one hand, and said secondary third orifice and said secondary annular passage, on the other hand; and

means for establishing communication between said secondary annular passage and said outlet.

9. The apparatus of claim **8** and means for providing a pressure gradient decreasing in pressure from the first orifice to the annular passage and the third orifice, from the third orifice to the secondary first orifice, and from the secondary first orifice to the secondary annular passage and the secondary third orifice.

10. The apparatus of claim **9** wherein the secondary first orifice is substantially circular.

11. The apparatus of claim **10** wherein the spacing between the secondary first plate and the secondary second plate is 0.3 – 3 times the diameter of the secondary first orifice.

12. The apparatus of claim **11** wherein the distance between the secondary annular passage and the secondary third orifice is equal to or less than one-half the diameter of the first orifice.

13. The apparatus of claim **12** wherein the area of the annular passage is 0.6 – 1 times the area of the secondary first orifice.

14. The apparatus of claim **13** wherein the thickness of the secondary first plate is less than or equal to the diameter of the secondary first orifice.

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