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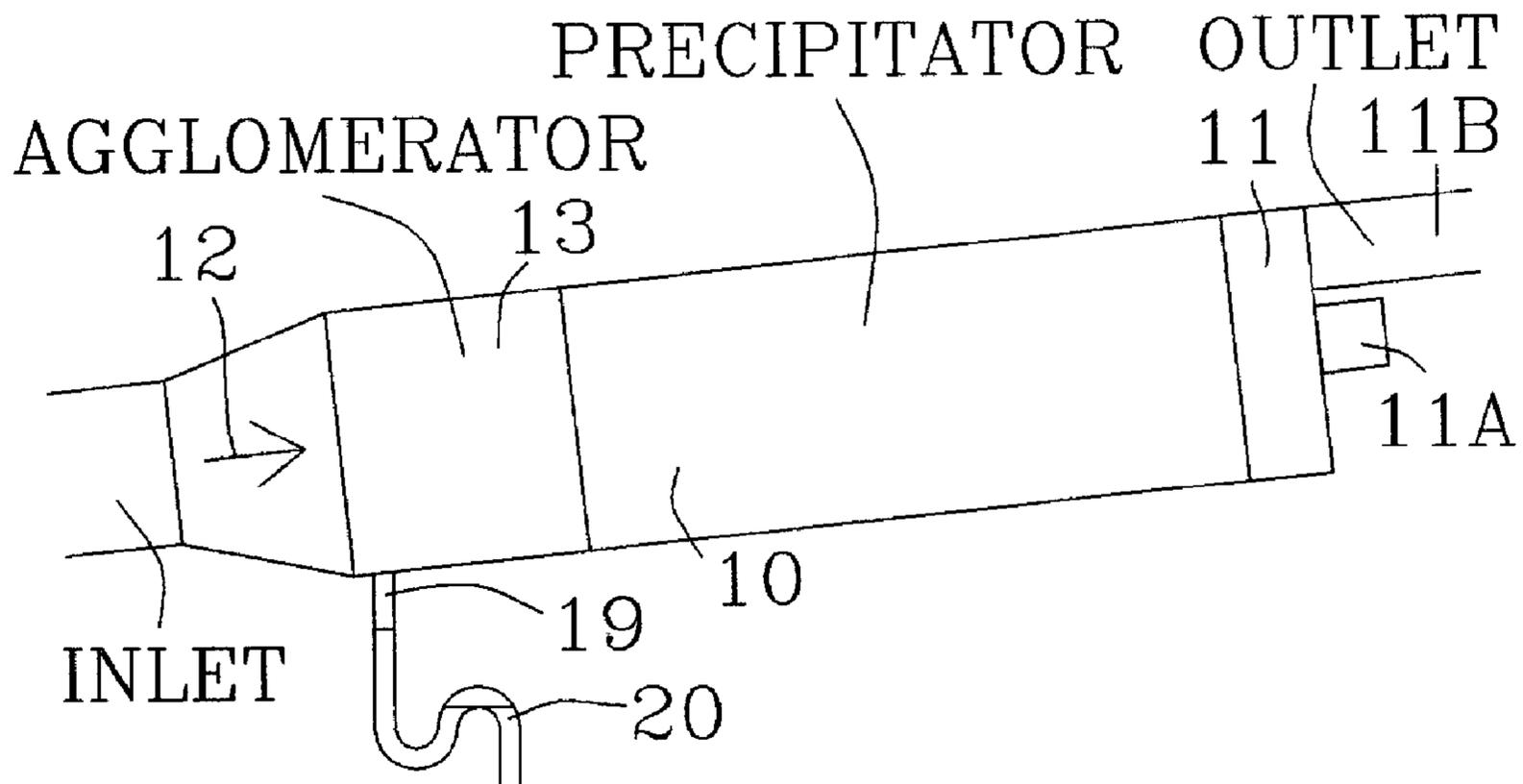
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(54) **AGGLOMERATION ET PRECIPITATION DE PARTICULES A  
PARTIR D'UN CIRCUIT GAZEUX**

(54) **PARTICLE AGGLOMERATION AND PRECIPITATION FROM A  
GASEOUS STREAM**



(57) Le rendement d'un précipitateur servant à séparer les particules liquides et solides dans un jet gazeux est amélioré lorsque les particules sont de dimension fine ou ultra-fine, c.-à-d. submicrométrique, en traitant le jet avant son arrivée dans le précipitateur pour agglomérer les particules fines en particules plus grosses. On obtient ce résultat en faisant passer le jet à travers une série de grilles. Certaines particules entraînées dans le jet heurtent la partie solide de chacune des grilles et s'agglomèrent. Par la suite une bonne partie des particules agglomérées sont entraînées de nouveau dans le jet et parviennent au précipitateur. Comme seulement une faible proportion des particules entrent en collision avec les grilles, il est normalement préférable d'utiliser un grand nombre de grilles, c.-à-d. au moins 30. Une forme améliorée de précipitateur fait appel à des feuillets plissés comme surface collectrice des particules.

(57) The performance of a precipitator for separating liquid or solid particles suspended in a gaseous stream is improved when the particles are fine or ultra-fine, e.g. submicron, by treating the stream before it enters the precipitator to agglomerate the fine particles into larger ones. This result is achieved by passing the stream successively through a series of screens. Some particles entrained in the stream impact on solid portions of each screen, and become agglomerated in the process. Subsequently, a large portion of the agglomerated particles are re-entrained in the stream and pass to the precipitator. Since only a small percentage of the particles impacts each screen, a relatively large number of screens is normally preferred, e.g. at least 30. An improved form of precipitator employs pleated sheets to form the surfaces on which the particles are collected.

Abstract

The performance of a precipitator for separating liquid or solid particles suspended in a gaseous stream is improved when the particles are fine or ultra-fine, e.g. submicron, by  
5 treating the stream before it enters the precipitator to agglomerate the fine particles into larger ones. This result is achieved by passing the stream successively through a series of screens. Some particles entrained in the stream impact on solid portions of each screen, and become  
10 agglomerated in the process. Subsequently, a large portion of the agglomerated particles are re-entrained in the stream and pass to the precipitator. Since only a small percentage of the particles impacts each screen, a relatively large number of screens is normally preferred, e.g. at least 30. An  
15 improved form of precipitator employs pleated sheets to form the surfaces on which the particles are collected.

PARTICLE AGGLOMERATION AND  
PRECIPITATION FROM A GASEOUS STREAM

Field of the Invention

This invention relates both to improvements in particle precipitators and to particle agglomerators designed for use with particle precipitators, as well as to the combination of a particle agglomerator and a particle precipitator. The invention has both method and apparatus aspects.

Background of the Invention

It is known in the prior art to use a particle precipitator for separating entrained particles from a turbulent gaseous flow (commonly, but not necessarily, air). The particles may be solid or liquid.

In the specific description below, one aspect of the present invention will be explained mainly in relation to the separation from a turbulent air stream of an oil mist, i.e. ultra-fine suspended oil particles, typically droplets of the order of less than 0.5 microns. Such a mist-laden air stream is typically encountered as exhaust from industrial machinery operating at high speed.

It should be understood, however, that this exemplification of the present invention in relation to the separation of oil droplets from an air stream is not intended to be limiting to the broad scope of the present invention, since the invention is also applicable to the separation (precipitation) of other suspended liquid or solid particles, e.g. dust, fumes or smoke. Such separation can be carried out by any form of precipitator, such as an electrostatic precipitator, that is capable of carrying out the desired separation of particles from a gaseous stream.

It has been found that the efficiency of a particle precipitator is significantly greater if the particles are of a

certain minimum size. The separation of submicron particles by a precipitator is less efficient or may require more expensive equipment. For example, adequate separation of submicron particles may require a multiple stage or unduly long precipitator. Hence, either an unsatisfactory result or a need for unduly expensive equipment will be experienced.

#### Summary of the Invention

An object of the present invention is to avoid these difficulties by providing a method and apparatus for increasing the size of the particles in the gaseous stream and then precipitating these increased size particles from the gaseous stream.

In accordance with one aspect of the present invention there is provided an agglomeration and precipitation device comprising in combination: (a) an agglomeration device intended to receive a turbulent gas stream containing fine suspended particles and to discharge the stream in which the major part of said fine particles has agglomerated in the form of larger particles, and (b) a precipitation device provided downstream of the agglomeration device to receive the stream coming from the agglomeration device and to separate the larger particles from the gas stream, wherein said precipitation device comprises at least one non-obstructed channel intended to convey the stream exhibiting a turbulent flow and a series of objects extending along at least one side of each channel, said objects being positioned at close intervals in the direction of flow so as to define with each other spaces which swirls coming from each channel enter, which leads to an accumulation of particles at the surface of said objects after the swirl have declined, wherein said

objects consist of at least one corrugated plate.

The agglomerator of this combination may comprise a duct with a mouth for receiving the stream and an exit for discharging the stream, and a series of screens mounted  
5 substantially parallel to each other in the duct while spaced apart along the duct between the mouth and the exit, each screen extending across the duct generally transversely of the stream so that substantially the entire stream passes through all the screens successively. Each screen has solid portions  
10 distributed across the duct for impaction by some of said particles and holes distributed across the duct for unhindered passage of the stream. The agglomerator will preferably also contain some means for discharging the agglomerated particles that are not re-entrained into the gas stream, but fall to the  
15 bottom of the unit.

In accordance with another aspect of the present invention there is provided a method of agglomerating and precipitating particles suspended in a gas stream exhibiting turbulent flow having a direction of flow, said method  
20 comprising the steps of: (a) agglomerating, in an agglomerating portion of a device, fine particles in a turbulent gas stream, containing said fine particles in a suspended form, wherein a major number of said fine particles are formed into larger particles; (b) discharging said larger  
25 particles from said agglomerating portion of said device; (c) inputting said larger particles and said gas stream into a precipitation portion of said device; (d) separating, by precipitation, said larger particles from said gas stream, said separating step comprises the steps of: (e) flowing said  
30 larger particles and said turbulent gas stream through at least one non-obstructed channel intended to convey the gas

stream exhibiting turbulent flow and a series of objects extending along at least one side of each of said at least one non-obstructed channel, said objects being positioned at close intervals in the direction of flow so as to define with each other spaces; and (f) generating swirls in said gas stream in 5 said spaces, which leads to an accumulation of said larger particles at surfaces of said objects after the swirl have declined, wherein said objects consist of at least one corrugated plate.

collection of the particles on surfaces of said objects upon decay of the eddies. According to a further aspect of the present invention, the objects on the surfaces of which the particles collect are formed from at least one pleated sheet.

5 Brief Description of the Drawings

Figure 1 shows an overall arrangement of an agglomerator and a precipitator;

10 Figure 2 shows a fragmentary, cut-away, side view of an agglomerator according to an embodiment of the present invention, such agglomerator being adapted to be mounted at the input end of a particle precipitator;

Figure 3 is a fragmentary, cut-away, plan view of part of the agglomerator of Figure 2;

Figure 4 is a view taken on the line 4-4 in Figure 2;

15 Figure 4A shows a fragment of a variant of Figure 4;

Figure 5 is a fragmentary, cut-away, perspective view of a collector element in a modified form of precipitator according to another embodiment of the invention;

20 Figure 6 is a cut-away, end view of the precipitator of Figure 5;

Figure 7 is a cut-away, underside view of the precipitator of Figures 5 and 6; and

Figure 8 is an enlarged fragment of a collector element in this precipitator.

25 Detailed Description of the Preferred Embodiments

The particle precipitator 10 shown in Figures 1 and 2 may be the particle precipitator described below with reference to Figures 5 to 8. Alternatively, it may be any other precipitator capable of separating solid or liquid particles from a turbulent  
30 air stream 12 sucked into the system by a fan 11 or by any other means. The fan has a motor 11A and an outlet 11B.

In advance of the precipitator 10 there is located an agglomerator 13, the function of which is to increase the size of the particles entrained or suspended in the air stream 12, so that collector surfaces of the precipitator 10 can perform more effectively in separating them from the stream.

The system shown in Figure 1 is assumed to be designed for the separation of liquid particles from the gaseous stream, e.g. from a mist, for which reason it is inclined to the horizontal and is fitted with a liquid trap 20. The liquid collected in the system (mainly, but not exclusively, in the bottom of the precipitator) flows down on the bottoms of both the precipitator and the agglomerator, to enter the drain 19 and hence the trap 20 which serves as an external collector for the liquid while preventing air from being sucked into the system at this location. Typical liquid levels in the drain 19 and trap 20 are shown.

When the system is designed for separating solid particles, e.g. dust, these latter features are modified, as is explained below in relation to figures 6 and 7.

As shown in Figures 2 and 3, the agglomerator 13 may consist of a tubular duct 14 of rectangular cross-section (specifically, in an example, 34 cm long, 46 cm wide and 30 cm high) forming a tunnel between a mouth connected to the inlet for the gaseous stream and an exit connected to the precipitator 10. Situated in this duct 14 is a spaced apart series of screens 15, each of which extends fully across the duct in both directions perpendicular to the air stream 12 so that substantially all the air stream must pass successively through all these screens. In practice, a small amount of the stream may pass around the edge of the screens.

As shown in Figure 4, which is not to scale, a typical screen 15 consists of two sets of transverse strands 16 forming a mesh, the strands being made of an appropriate material, such as

polyester, fiberglass or metal. In a typical example each strand 16 is approximately 1 mm thick, the strands being spaced apart from each other by approximately 5 mm. The ratio of the spacing between the strands to the thickness of the strands can be in the range of ten to five. A convenient method of forming this assembly when the screens 15 are made of a flexible material is to employ a very long strip of such material and thread it over top and bottom rods 17 and 18 that extend across the duct 14. The diameter of these rods will determine the spacing between the individual screens 15, which spacing can conveniently be within the range of approximately 5 mm to 1 cm. If the screens are placed much closer together than this, their function, as explained below, will not be fully achieved, since they will not act fully as separate screens. If they are placed further apart, while they will function effectively, they will cause the apparatus to be unnecessarily long.

With the turbulent air stream 12 assumed to be carrying submicron oil mist particles entering the mouth of the agglomerator 13, it has been found experimentally that a few of the particles will separate from those portions of the air stream that pass on each side of each strand 16, such separated particles impacting directly on the strands. At each screen 15 only a small fraction of the incoming mist particles will impact on the strands, because most of the particles will pass unhindered with the air stream through the holes between the strands. Assuming that a fraction  $y$  of the incoming mist particles impacts on the solid portions (strands) of the first screen, the remaining fraction  $(1 - y)$  will pass through the holes. Turbulence will mix the mist particles that have passed with the stream through the holes to a substantially uniform distribution before they reach the second screen. Additionally, if found useful, the strands can be staggered between adjacent screens to ensure that there are strands located directly in the

path of the particles that have passed with the stream through the holes of the previous screen. At the second screen the same fraction  $y$  of the remaining fraction  $(1 - y)$  will impact on the strands. The fraction remaining (transmitted through the holes) after the second screen is thus  $(1 - y) - y(1 - y) = (1 - y)^2$ . After passing through  $n$  screens the fraction of the original oil mist particles remaining in the air stream will be  $(1 - y)^n$ . A typical value for  $y$  will be 0.04, i.e. 4%. If  $n = 60$ , for example, the fraction of particles remaining after the stream has passed through the last screen of the series will be 0.96 to the power 60, which is approximately 0.09. Thus, a fraction of about 9% of the original mist particles will remain in the air stream exiting the agglomerator, while about 91% will have impacted on one or other of the screens.

After impaction, most of the impacted particle material tends to become re-entrained in the air stream. However, it has been found that this re-entrained material consists of new particles that are larger than the original particles. In other words, the original individual fine particles have become agglomerated into larger particles. Some of these agglomerated particles remain in the agglomerator by falling to the floor of the unit, forming a bulk liquid that flows into the trap to form part of the total collected particles. An important consideration for this function to occur is that the gaseous stream passing through the agglomerator should be in turbulent flow.

In an experiment conducted with an oil mist generated by a nebulizer, it was measured that about 80% by weight of the mist particles entering the agglomerator were smaller than 0.5 microns. When this mist was passed directly into a precipitator that was one meter long (with the agglomerator removed), only about 40% by weight of the particles were separated from the air stream. However, when the agglomerator was located between

the incoming mist and the same precipitator, the latter separated approximately 93% by weight of the mist particles from the air stream. Theory predicts that this same stream performance (93% collection) could have been achieved by a precipitator alone  
5 (without the agglomerator), if the length of the precipitator had been increased to five meters. While the agglomerator alone is a very poor collector of submicron particles, the synergistic combination of the phenomena taking place in the agglomerator and the precipitator acting together provides a method of achieving  
10 the desired high performance in separating fine particles without the need to use a longer precipitator.

To demonstrate this synergism, assume the particle agglomerator collected the mist with an overall fractional efficiency  $a$  and the precipitator collected the same mist with an  
15 overall fractional efficiency  $b$ . Then, in the absence of synergism, the fractional efficiency  $E$  of the combined system agglomerator plus precipitator would be  $E = 1 - (1 - a)(1 - b)$ . As has been shown, the actual fractional efficiency  $E'$  of the combined system agglomerator plus precipitator is much greater  
20 than  $E$ , i.e.  $E' \gg E$ . Not only does this show the existence of synergism, but it also shows the physical reason for it, which is that the mist leaving the agglomerator and entering the precipitator is not the same mist as entered the agglomerator, but it is a much greater particle size mist, which is recovered  
25 with a much higher fractional efficiency  $b' > b$  by the precipitator than the original mist would have been. Hence  
 $1 - (1 - a)(1 - b') \gg 1 - (1 - a)(1 - b)$ . The particle size distribution of the original mist has been determined to be 80% by weight under 0.5 micron, whereas the mist leaving the  
30 agglomerator has a mean particle size of about 4 micron. The measured efficiencies involved are  $E' = 0.93$ ,  $b' = 0.9$ ,  $b = 0.4$ , and  $a = 0.3$ , whence  $E = 0.58$ . It is thus evident that  $E' \gg E$ .

In the mathematical examples above it was assumed that 60 screens were used, and in the actual experiment referred to above 57 screens were used. The choice of the number of screens will be a compromise between improved performance (more screens) and economy (fewer screens). In a case where some loss of performance is tolerable, or, if the size of the incoming particles is larger than submicron but nevertheless fine in the sense of being undesirably small for separation directly by the precipitator, a smaller number of screens can be used. The number of screens will preferably not normally be less than 30, but even this number may go as low as ten or even lower when either a lesser performance is acceptable or the value of  $y$  can be increased, or the apparatus is dealing with a mist containing significantly larger initial droplets. Thus there can be circumstances in which only a relatively small number of screens would be useful. There is really no maximum, although anything over 100 would normally be uneconomical in relation to the advantage gained. The preferred range will normally be 30 to 80.

While each screen 15 has so far been described as being in the form of a meshlike structure formed of mutually perpendicular strands, it is also possible to employ any other structure, such as a plate with holes punched in it, that achieves the same effect, namely provides a large number of distributed solid portions for impaction of some of the particles, while leaving holes for the gaseous stream and the remaining particles entrained therein to pass through. While the use of a plate with punched holes may increase the pressure loss experienced by the gaseous stream, it may, on the other hand, increase the value of  $y$  and hence reduce the number of screens needed, which in turn will have a desirable effect on the pressure drop.

It is to be understood that the reference to "screens" in the appended claims is intended to include not only meshlike structures but also non-meshlike structures, such as a punched

plate 16A shown in Figure 4A, provided that the alternative serves a like purpose of providing a distributed area of solid portions for the particles to impact against and open spaces for the gaseous stream to pass through unhindered. In the interest of minimizing the pressure drop, the area of the solid portions will normally be a portion less than 50% of the total cross section of the duct.

Several long-term tests have been run with an oil mist input. At the end of these tests the screens in the agglomerator, as well as the particle collector elements in the precipitator, were found to be soaked with oil. The flow rate used was 1000 cubic meters per hour, and the air stream velocity was seven meters per second. Very satisfactory separation of the oil droplets was obtained with an acceptable pressure loss of only five centimetres of water column.

The screens will preferably be oriented generally vertically, with the gaseous stream flowing generally horizontally. However, these requirements are not rigid and some deviation from them will still allow the agglomerator to function effectively. Indeed, the tilting of the system to provide for run off of the collected liquid into the trap will represent some deviation from a truly horizontal orientation, and, as indicated below, the degree of tilt may be increased, e.g. 15°, when solid particles are being collected. Normally, there would be no advantage in varying from a gaseous stream that flows generally horizontally and screens that are mounted generally vertically.

Figures 5 to 8 show details of those aspects of a precipitator that represent variations on the constructions disclosed in the prior art. The theory underlying the particle separating performance of the precipitator of Figures 5 to 8 nevertheless remains essentially the same as that set out the prior art.

In Figures 5 to 8 the precipitator 10 has a casing 21, forming a tunnel extending from a mouth that receives the gaseous stream from the agglomerator or directly from an intake if no agglomerator is necessary because of the relatively large size of the entrained particles, to an exit connected to the fan.

In order to provide as extensive a disclosure as possible the precipitator of Figures 5 to 8 is shown as one designed for the separation of solid particles, without an agglomerator attached to it. The basic construction is nevertheless equally applicable to the separation of liquid particles, subject only to the adoption of a suitable liquid collecting arrangement, such as the discharge channels and trap 20, to replace the dust collecting arrangement shown in Figures 5 to 8.

The collector elements that extend along the casing 21 take the form of pleated sheets 22, preferably of metal. The pleated sheets 22 extend all the way from the top of casing 21 to within a short distance from the bottom of the casing, leaving a clearance through which the collected dust can pass through opening 30 and slot 25 into the hopper 26. In Figure 5 only the beginning of one pleated sheet 22 is shown for simplicity. There will in practice be a plurality of such sheets side by side, e.g. the three shown in Figures 6 and 7, positioned across the casing 21 while spaced apart to allow channels 23 for the gaseous stream located between adjacent sheets and between the sheets and the casing. Since this embodiment of the invention is designed for collecting dust and dust does not flow as readily as a liquid, the casing 21 is given an increased tilt, e.g. at least 15°, to the horizontal 29, and a vibrator 28 is connected to it to make the dust flow down its floor. When the dust that has been collected by the pleated sheets 22 falls to the bottom of the casing 21, some of it would spread out into the open channels 23 if not restrained, and would be subject to re-entrainment in the

gaseous stream. To avoid this result the bottoms of the sheets 22 are enclosed within troughs 24. At the lower (input) end of the casing 21, these troughs 24 have opening 30 communicating with a slot 25 that extends across the casing floor and communicates with a hopper 26 (omitted from Figure 5 for simplicity) that acts as an external collector for receiving the dust and conveying it away. If an agglomerator is used, it may conveniently be housed in the same casing 21, or a casing of the same cross section as 21, as in the case of mist collection shown in Fig. 1. In this case at the inlet end of the agglomerator there is a slot 25 rather than a hole to discharge the dust. In the case of dust collection there is also a clearance left between the screens and the floor of the agglomerator. A baffle 27 is located at the upper (output) end of the casing 21 to cause the gaseous stream to exit from the casing at a level above its floor and hence minimize any tendency to re-entrain dust that has fallen to the floor.

To minimize the re-entrainment of dust particles that have been separated from the stream by the pleated sheets, but have not yet fallen into the troughs, the pleating should be tight, i.e. should be at a small angle. In other words the depth of each pleat in the direction  $d$  (Figure 8) should be substantially greater than the pitch  $p$ . A desirable ratio for  $d$  to  $p$  would be about four. While this ratio can be varied to suit individual circumstances, it will be kept appreciably greater than one for the best performance.

Claims:

1. An agglomeration and precipitation device comprising in combination:

(a) an agglomeration device intended to receive a  
5 turbulent gas stream containing fine suspended particles and to discharge the stream in which the major part of said fine particles has agglomerated in the form of larger particles, and

(b) a precipitation device provided downstream of the  
10 agglomeration device to receive the stream coming from the agglomeration device and to separate the larger particles from the gas stream, wherein said precipitation device comprises at least one non-obstructed channel intended to convey the stream exhibiting a turbulent flow and a series of objects extending  
15 along at least one side of each channel, said objects being positioned at close intervals in the direction of flow so as to define with each other spaces which swirls coming from each channel enter, which leads to an accumulation of particles at the surface of said objects after the swirl have declined,  
20 wherein said objects consist of at least one corrugated plate.

2. The agglomeration and precipitation device as claimed in claim 1, wherein the folds of each of said at least one corrugated plate have a depth that is greater than the pitch between the folds.

25 3. The agglomeration and precipitation device as claimed in claim 1, wherein said depth is approximately four times as great as said pitch.

4. The agglomeration and precipitation device as claimed in claim 1, wherein each of said at least one corrugated plate is positioned substantially vertically so as to allow the particles accumulated at the surface thereof to fall to the bottom of a casing containing said plate(s) and thus defining said channel(s).

5. The agglomeration and precipitation device as claimed in claim 4, wherein the bottom of the casing is inclined to the horizontal in order to favor the flow of the particles fallen from the surface of the corrugated plate(s) towards an end of said bottom, then into an external collector.

6. The agglomeration and precipitation device as claimed in claim 5, wherein said particles are liquid and said external collector comprises a liquid trap.

7. The agglomeration and precipitation device as claimed in claim 5, wherein said particles are solid and said external collector comprises a hopper.

8. The agglomeration and precipitation device as claimed in claim 7, comprising a cup which extends along the bottom of the casing and which contains the lower parts of said corrugated plates, wherein a small free space is provided between the lower ends of said corrugated plates and the bottom of the casing in order to collect the solid particles fallen from the surface of the plates and to guide them below said corrugated plates through an opening provided in the cup so as to drive them towards a particle discharge slot situated at the end of the casing bottom.

9. The agglomeration and precipitation device as claimed in claim 8, comprising a vibrator intended to favor transfer of the solid particles towards the external collector.

10. A method of agglomerating and precipitating particles suspended in a gas stream exhibiting turbulent flow having a direction of flow, said method comprising the steps of:

(a) agglomerating, in an agglomerating portion of a device, fine particles in a turbulent gas stream, containing said fine particles in a suspended form, wherein a major number of said fine particles are formed into larger particles;

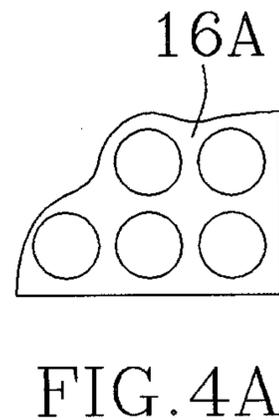
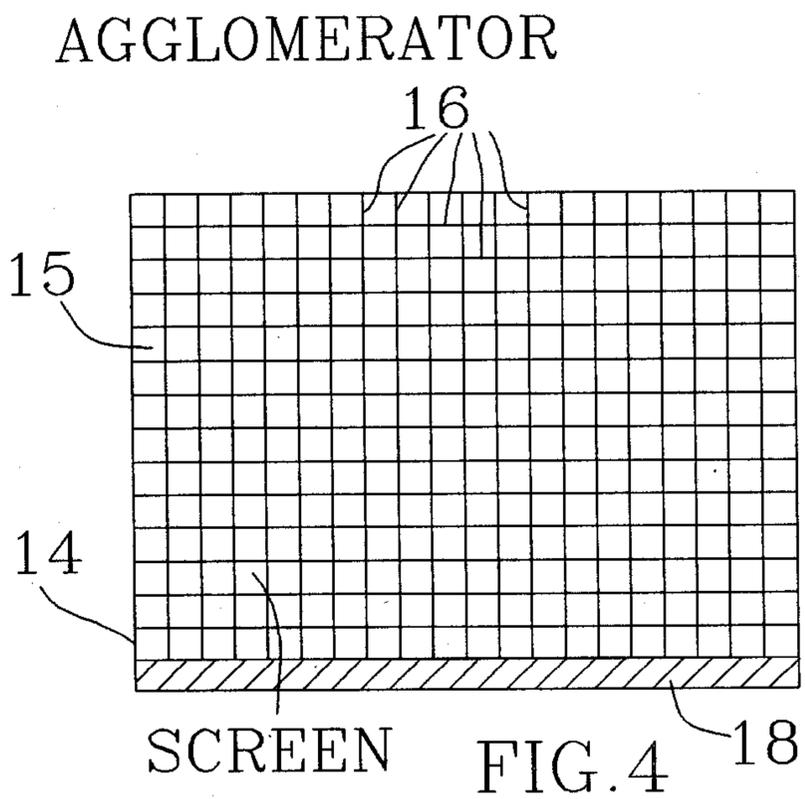
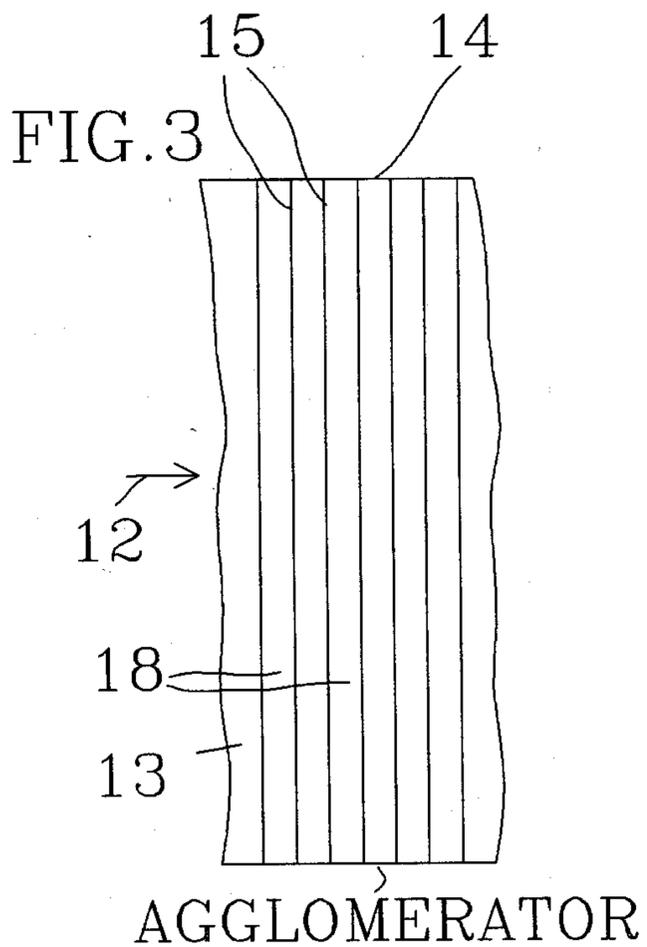
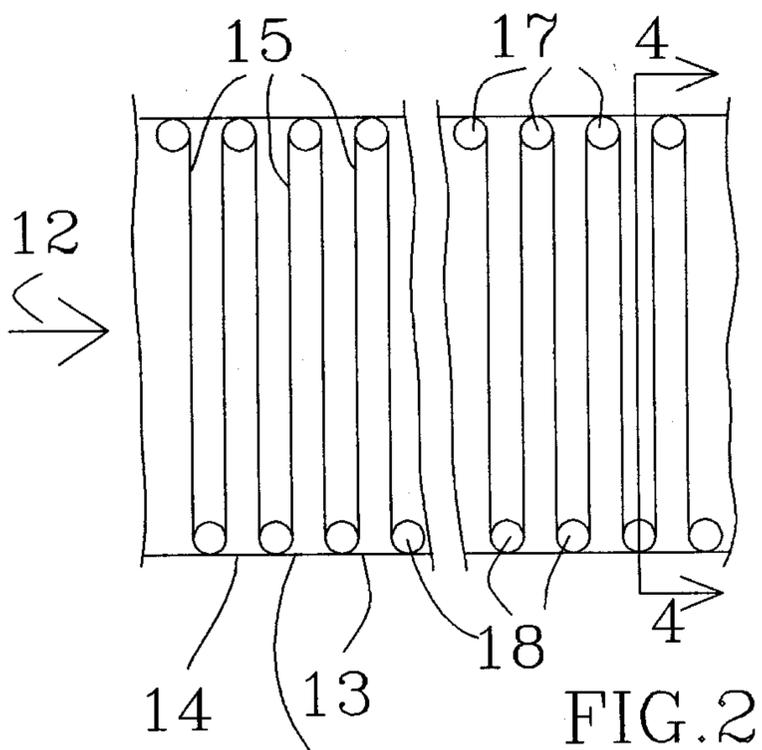
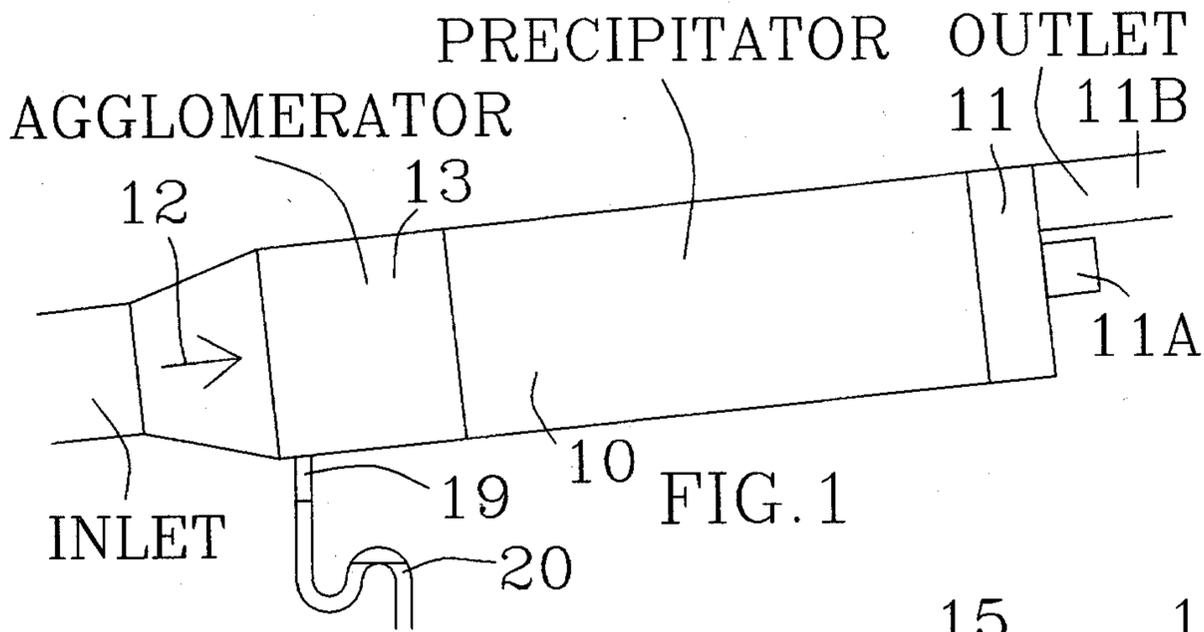
(b) discharging said larger particles from said agglomerating portion of said device;

(c) inputting said larger particles and said gas stream into a precipitation portion of said device;

(d) separating, by precipitation, said larger particles from said gas stream, said separating step comprises the steps of:

(e) flowing said larger particles and said turbulent gas stream through at least one non-obstructed channel intended to convey the gas stream exhibiting turbulent flow and a series of objects extending along at least one side of each of said at least one non-obstructed channel, said objects being positioned at close intervals in the direction of flow so as to define with each other spaces; and

(f) generating swirls in said gas stream in said spaces, which leads to an accumulation of said larger particles at surfaces of said objects after the swirl have declined, wherein said objects consist of at least one corrugated plate.



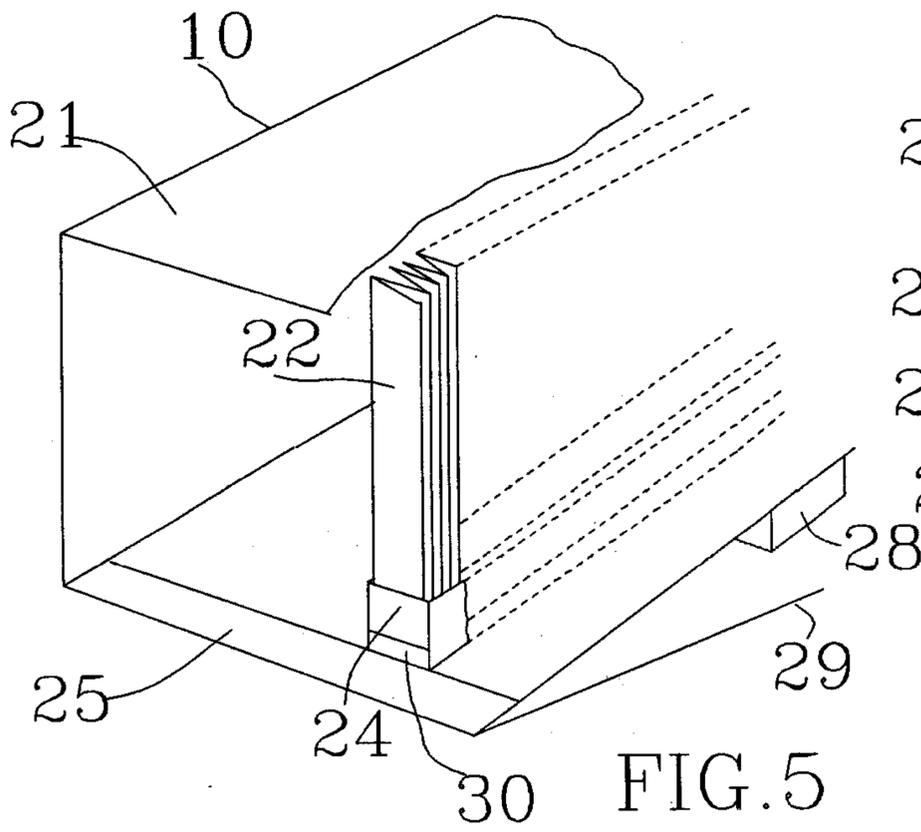


FIG. 5

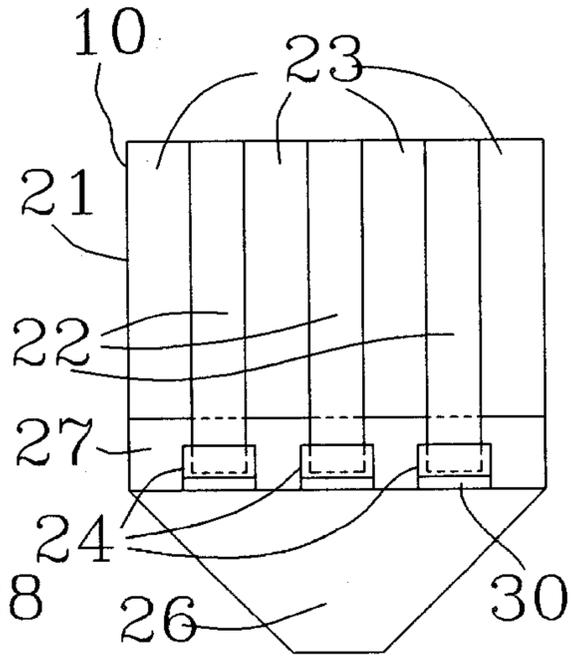


FIG. 6

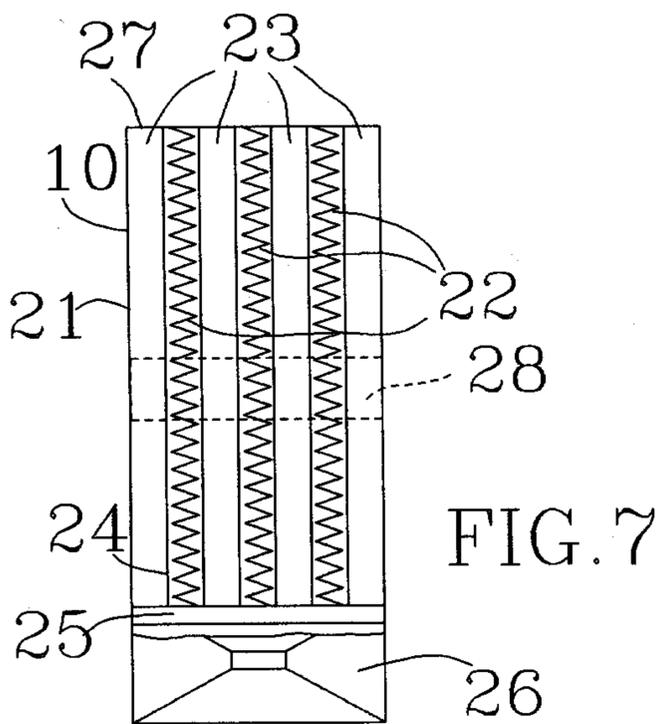


FIG. 7

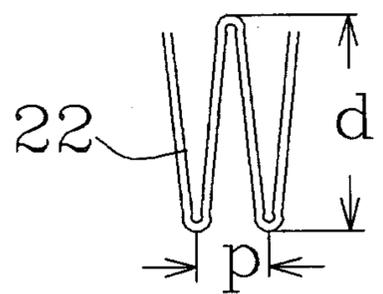


FIG. 8

