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(54) Title: A GAS-SOLID SEPARATOR AND A PROCESS FOR GAS-SOLID SEPARATION

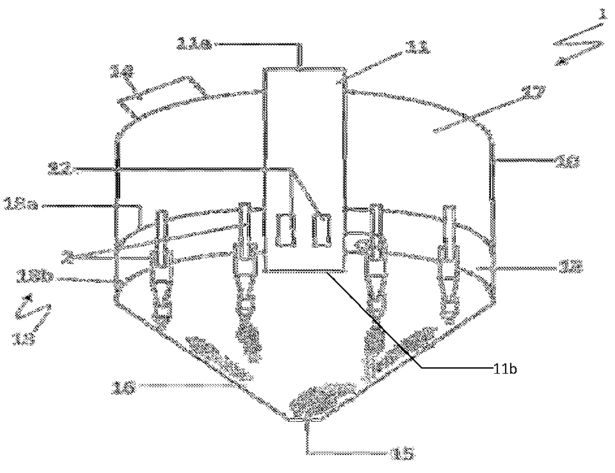

Fig. 2

(57) Abstract: A gas-solid separator comprises a housing comprises an inlet conduit configured to receive a gas-solid mixture. The inlet conduit extends in an operative downward direction inside the housing. The gas-solid separator further comprises a first outlet conduit configured to discharge cleaned gas containing minute amounts of solid particles and a second outlet conduit configured to evacuate solid particles collected in the housing. The gas-solid separator also comprises a plurality of axial swirl cone cyclones. The axial swirl cone cyclone has a cyclone body having a cylindrical portion that forms a swirl zone and a conical portion extending coaxially from the cylindrical portion that forms a vortex zone. The axial swirl cone cyclone comprises a feed inlet, a cleaned gas outlet disposed, and swirl imparters. A process for gas-solid separation is also disclosed in the present disclosure.

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A GAS-SOLID SEPARATOR AND A PROCESS FOR GAS-SOLID SEPARATION

FIELD

The present disclosure relates to the field of chemical engineering. In particular, the present disclosure relates to the field of gas-solid separation.

DEFINITIONS

FEED herein means a gas-solid mixture such that solid particles are entrained in a gas. The feed is supplied as an input to a gas-solid separator.

CLEANED GAS herein means a gas-solid mixture from which at least a portion of solid particles have been removed.

AXIAL SWIRL CONE CYCLONE herein means a cyclone separator that employs the use of two cones/conical portions, viz., vortex zone and deep leg, which are configured in the operative bottom portion of the axial swirl cone cyclone. The explanation for the terms axial, swirl, and cyclone are as follows:

AXIAL - Gas enters the axial swirl cone cyclone in an axial manner rather than tangential manner.

SWIRL - Rotational velocity is provided to the feed by swirl vanes instead of tangential entry of the feed into the axial swirl cone cyclone.

CONE - To maintain the tangential velocity constant while sending flue gases from the core of the cyclone to the top outlet of the cyclone

CYCLONE - A unit to separate solids from gas by means of centrifugal force acting on the feed.

BACKGROUND

Fluid Catalytic Cracking (FCC) processes are widely used refining processes in petroleum refineries. The FCC process is carried out to convert a high-boiling point and high-molecular weight petroleum crude oil to gasoline, olefinic gases, and other products. Petroleum crude oil is reacted with a hot catalyst for breaking it into by-products which are introduced in a reactor. In the reactor, the catalyst (spent catalyst) is separated from the by-products, and the recovered catalyst (spent catalyst) is regenerated with the help of hot air in a regenerator. The flue gas thus formed inside the regenerator is a mixture of gas formed by burning off deposition layers formed on the catalyst and the solid particles of the catalyst itself. The temperature of the flue gases, at this point, is typically in the range of 700°C-800°C, and hence there is still a lot of energy contained in the flue gases.

But the flue gases formed at this point are neither fit to be released to the atmosphere, nor can they be utilized for further use in devices like turbines for generating power. This is because the flue gas contains entrained solid catalyst particles. To remove the entrained solid catalyst particles from the flue gas, a Third Stage Separator (TSS), which is generally a gas-solid separator, is employed. The TSS recovers the catalyst particles from the flue gas thereby making the flue gas suitable for use in conjunction with a turbine or for any other application. Thereafter the flue gas can also be released into the atmosphere.

It is observed that the efficiency of gas-solid separation offered by a conventional gas-solid separator is low, thereby resulting in the entrained solid catalyst particles not being substantially removed from the flue gas even after the separation process.

Moreover, conventional cyclones used in conventional gas-solid separators involve the use of elements like stabilizer-pins and stabilizer plates or tangential slots, thus increasing the number of components inside the cyclone which become clogging prone due to small slit sizes. The increased number of components results in a complicated configuration of the cyclone, which is not desired.

Hence, in order to address the aforementioned drawbacks, there is a need for a gas-solid separator which provides significant separation of entrained solid particles from a gas.

OBJECTS

Some of the objects of the present disclosure, which at least one embodiment herein satisfies, are as follows.

It is an object of the present disclosure to ameliorate one or more problems of the prior art or to at least provide a useful alternative.

An object of the present disclosure is to provide a gas-solid separator that provides a significant separation of entrained solid particles from a gas.

Another object of the present disclosure is to provide a gas-solid separator that facilitates capturing solid particles entrained in a gas.

Another object of the present disclosure is to provide a gas-solid separator that is simplistic in design and operation and still have better separation efficiency.

Another object of the present disclosure is to provide a gas-solid separator that aids in reducing environmental pollution.

Another object of the present disclosure is to provide a process for gas-solid separation.

Another object of the present disclosure is to provide gas-solid separator that facilitates lower damage of downstream equipment like turbine blades.

Yet another object of the present disclosure is to provide a gas-solid separator that is cost effective and has an extended service life.

Other objects and advantages of the present disclosure will be more apparent from the following description, which is not intended to limit the scope of the present disclosure.

SUMMARY

The present disclosure envisages a gas-solid separator defined by a housing. The gas-solid separator comprising an inlet opening configured on an operative top plate of the housing for introducing a gas-solid mixture therein. A bottom opening is configured in an operative bottom portion of the housing for evacuating solid particles therefrom. A first plate and a second plate are configured within the housing to separate the housing into a first zone, a second zone, and a third zone. An inlet conduit fitted in the inlet opening for feeding the gas-solid mixture to the second zone. The gas-solid separator further comprises a plurality of axial swirl cone cyclones fitted within the housing and configured to transverse the first, second, and third zones. Each axial swirl cone cyclone is defined by a body that has a first opening configured to be in communication with the second zone for receiving the gas-solid mixture. At least one swirl imparter is disposed within the cyclone and configured to impart swirling motion to the gas-solid mixture. A second opening of the body is in communication with the third zone for evacuating solid particles from the axial swirl cone cyclone into the third zone. A third opening of the axial swirl cone cyclone is configured to receive a cleaned gas within the axial swirl cone cyclone, and a fourth opening in communication with the first zone for emitting the cleaned gas from the cyclone into the first zone. The gas solid separator further comprises an outlet opening configured in the first zone for leading cleaned air outside the gas-solid separator.

A process for gas-solid separation using the gas-solid separator is also disclosed in the present disclosure.

BRIEF DESCRIPTION OF ACCOMPANYING DRAWING

A gas-solid separator of the present disclosure will now be described with the help of accompanying drawing, in which:

Fig. 1 illustrates a front sectional view of a gas-solid separator in accordance with an embodiment of the present disclosure;

Fig. 2 illustrates a schematic diagram of a gas-solid separator of Fig. 1;

Fig. 3 illustrates a sectional top view of the gas-solid separator of Fig. 1;

Fig. 4 illustrates a schematic view of an axial swirl cone cyclone that is used in the gas-solid separator of Fig. 1, in accordance with the present disclosure; and

Fig. 5 illustrates a schematic view of the formation of a natural duct due to the swirling action of the feed within the axial swirl cone of Fig. 4.

DETAILED DESCRIPTION

The disclosure will now be described with reference to the accompanying embodiments which do not limit the scope and ambit of the disclosure. The description provided is purely by way of example and illustration.

The embodiments herein and the various features and advantageous details thereof are explained with reference to the non-limiting embodiments in the following description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein. The examples used herein are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

The description of the specific embodiments will so fully reveal the general nature of the embodiments herein that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein.

The gas-solid separator 1 of the present disclosure is now described with reference to Fig. 1, Fig. 2, and Fig. 3. The gas-solid separator 1 has a housing 10. The housing 10 has an operative top plate and an operative bottom portion. An inlet opening is configured on the operative top plate of the housing 10 to introduce a gas-solid mixture therein. The inlet opening is configured to receive an inlet conduit 11, is formed on the operative top plate of the housing 10. More specifically, the inlet conduit is fitted in the inlet opening for feeding the gas-solid mixture therein. An outlet opening 14 is also formed on the operative top of the housing 10 and configured for leading the cleaned gas outside the gas-solid separator. A bottom opening 15 is configured in the operative bottom portion of the housing 10 which facilitates the removal/evacuation of solid particles collected in the housing 10.

The housing 10 further comprises a plurality of plates 18. The plates 18 are disposed horizontally in the housing 10 in an axially spaced configuration. In an embodiment, the plurality of plates 18 comprises a first plate 18a and a second plate 18b. In an embodiment, the plurality of plates 18 is of carbon steel. The plurality of plates 18 divide the housing 10 in three zones, viz., a cleaned gas collecting zone 17 (also referred to as first zone), a flue gas-solid common feed header zone 13 (also referred to as second zone), and a common catch zone 16 (also referred to as third zone). More specifically, the common catch zone 16 (third zone) is defined in the portion operatively below the second plate 18b. The cleaned gas collecting zone 17 (first zone) is defined in a portion operatively above the first plate 18a. The flue gas-solid common feed header zone 13 (second zone) is defined in a portion operatively between the first plate 18a and the second plate 18b. The cleaned gas collecting zone 17 is adapted to receive the cleaned gas containing minute amounts of entrained solid particles. The solid particles that are separated from the feed are collected in the common catch zone 16. The flue gas-solid common feed header zone 13 is adapted to receive the feed via the inlet conduit 11. More specifically, the inlet conduit 11 feeds the gas-solid mixture to the flue gas-solid common feed header zone 13. The first plate 18a prevents the mixing of the cleaned gas collected in the cleaned gas collecting zone 17 and the feed that is introduced in the flue gas-solid common feed header zone 13. The second plate 18b prevents the mixing of the feed introduced in the flue gas-solid common feed header zone 13 and the solid particles present in the common catch zone 16. The plurality of plates 18 is also configured to support a plurality of axial swirl cone cyclones 2. The manner in which the plurality of plates 18 supports the axial swirl cone cyclones 2 has been described in the subsequent sections of the present disclosure. The plurality of axial swirl cone cyclones 2 is disposed within the housing 10 such that the feed is received inside the plurality of axial swirl cone cyclones 2.

The inlet conduit 11 has a first operative end 11a and a second operative end 11b. The first operative end 11a of the inlet conduit is configured to receive the feed, and the second operative end 11b of the inlet conduit 11 is sealed. The inlet conduit 11 is disposed in inlet opening of the housing 10 such that its first operative end 11a protrudes out of the housing 10 and its second operative end is extended in an operative downward direction within the housing 10. In an embodiment, the inlet opening is configured centrally on the operative top plate of the housing 10, and the inlet conduit 11 is received therewithin. The inlet conduit 11 has a plurality of feed distributor openings 12, which are formed proximal to the second operative end 11b (also referred to as operative bottom end) thereof and are in fluid communication with the flue gas-solid common feed header zone 13. The feed is introduced inside the flue gas-solid common feed header zone 13 via the plurality of feed distributor openings 12, of the inlet conduit 11.

The optimal ranges of some of the dimensions of the gas-solid separator 1, so far described with reference to Fig. 1, are tabulated in table 1. Table 1 also illustrates a range of the number of axial swirl cone cyclones that can be disposed within the gas-solid separator 1.

TABLE 1:

Part	Parameter	Minimum	Maximum	Preferable Range
Housing 10	Diameter(D), m Height, m	4 0.4D	12 1D	6-8 0.5D-0.7D
Inlet conduit 11	Diameter, m	0.2D	0.2D	0.2D
Axial swirl cone cyclones 2	Number of cyclones.	2	500	100-200

Fig. 4 illustrates a schematic view of an axial swirl cone cyclone 2 that is disposed in the gas-solid separator 1 in accordance with the present disclosure. The axial swirl cone cyclone 2 is defined by a cyclone body 29 that has a cylindrical portion and a truncated conical portion extending coaxially from the cylindrical portion. The cylindrical portion defines a swirl zone (zone 20) and the conical portion defines a vortex zone 21. A deep leg 22, having cross-sectional area slightly greater than the cross-sectional area of the vortex zone outlet, is disposed at an operative bottom end of the vortex zone 21. In an embodiment, the deep leg 22 has a deep leg base 23 extending therefrom, wherein the deep leg base 23 has a conical configuration. The deep leg base 23 prevents the gas flow inside the cyclone from the bottom of the common catch zone 16. The axial swirl cone cyclone 2 has a first opening 24, formed on the operative upper end 20a of the swirl zone 20, which is configured to be in communication with the second zone 13 for receiving the gas-solid mixture. A cleaned gas outlet 26, that defines a third opening 26a and a fourth opening 26b, is disposed concentrically with the first opening 24 such that the cleaned gas outlet 26 defines an annular space between the first opening 24 and the cleaned gas outlet 26. A plurality of swirl imparters 27 are disposed in said annular space operatively below the first opening 24, and a second opening 25 is formed in an operative end of the deep leg 22 to facilitate the removal/evacuation of the solid particles collected in the axial swirl cone cyclone into the third zone 16.

As seen in Fig. 4, the axial swirl cone cyclones 2 are supported on the first plate 18a and the second plate 18b. More specifically, holes are configured on the first plate 18a and the second plate 18b, which facilitate the holding of the axial swirl cone cyclone 2. The holes configured on the first plate 18a have cross-sectional dimensions that complement the cross-sectional dimensions of the cleaned gas outlet 26, so that the cleaned gas outlet 26 can be received and supported therewithin. The holes configured on the second plate 18b have cross-sectional dimensions that complement the cross-sectional dimensions of the swirl zone 20, so that the swirl zone 20 can be received and supported therewithin.

The optimal range of some of the dimensions of the axial swirl cone cyclone 2, so far described with reference to Fig. 2, are tabulated in table 2. Table 2 also illustrates the number of swirl imparters that can be configured within the axial swirl cone cyclone 2.

TABLE 2:

Part	Parameter	Minimum	Maximum	Preferable Range
Swirl zone 20	Inlet diameter(D), Height, m	50mm 1D	500mm 6D	200-300mm 2-3D
Vortex Zone 21	Inlet Dia, m Outlet Dia, m Height, m	1D 0.2D 1D	6D 0.8D 6D	2-3D 0.4-0.6D 2-3D
Deep legs 22	Diameter, m Height, m	0.2D 1D	0.8D 4D	0.4-0.6D 2-3D
Deep leg base 23	Inlet dia, m Outlet dia, m Height, m	0.2D 0.1D 0.3D	0.8D 0.4D 0.7D	0.4-0.6D 0.15-0.25D 0.4-0.5D
Second opening 25	Tube dia, m Tube height, m	0.1D 0.5	0.4D 3D	0.15-0.25D 1-2D
Cleaned gas outlet 26	Tube diameter, m Tube height, m	0.2D 3D	0.8D 8D	0.3-0.6D 0.4-8D
Swirl imparters 27	Number of vanes	4	12	6-10

The process for separation of solid particles from a gas-solid mixture is now described in the following sections. Firstly the gas-solid mixture is introduced in into the flue gas-solid common feed header zone 13 of the gas-solid separator 1. The plurality of axial swirl cone cyclones 2 is provided and disposed within the gas-solid separator 1. The axial swirl cone cyclone comprises a cleaned gas outlet 26, a swirl zone 20, swirl imparters 27, and a vortex zone 21, such that the swirl zone 20 is in fluid communication with the flue gas-solid common feed header zone 13, and the swirl zone is adapted to receive the gas-solid mixture. The swirl imparters 27 are configured to impart a swirling motion to the gas-solid mixture for facilitating the separation of the solid particles from the gas-solid mixture to obtain a substantially cleaned gas. The solid particles are collected in a common catch zone 16 of the gas-solid separator 1. The third opening 26a of the cleaned gas outlet 26 receives the cleaned gas, and the cleaned gas is allowed to exit the axial swirl cone cyclone via the fourth opening 26b and gets collected into the cleaned gas collecting zone 17, or the first zone 17, of the gas-solid separator 1 and discharged therefrom via the first outlet opening 14 of the gas-solid separator 1.

The operation of the gas-solid separator 1 will now be described, in further detail, with reference to Fig. 1 through Fig. 5. The feed (gas-solid mixture) is introduced in the gas-solid separator 1 via the inlet conduit 11. The inlet conduit 11 is in fluid communication with the flue gas-solid common feed header zone 13. The feed is introduced inside the flue gas-solid common feed header zone 13 via the plurality of feed distributor openings 12, formed on the inlet conduit 11 near the second operative end 11b of the inlet conduit 11. A plurality of the axial swirl cone cyclones 2 is supported on the plurality of plates 18, such that the feed inlet 24 of the axial swirl cone cyclone 2 is in fluid communication with the flue gas-solid common feed header zone 13 and the cleaned gas outlet 26 is in fluid communication with the cleaned gas collecting zone 17.

The feed enters the axial swirl cone cyclone 2 via the first opening 24. The swirl imparters 27 impart a swirling motion to the feed, and as the feed advances operatively downwards inside the swirl zone 20, the angular velocity, with which the feed is moving in a spiral motion, increases. As the angular velocity increases, the centrifugal force associated with the feed also increases. As the feed enters the vortex zone 21, the spiral motion keeps the solid particles separate from the cleaned gas upflowing while dragging solid particles towards bottom of the axial swirl cone cyclone. This process prevents the solid re-entraining in the cleaned gas which is channelized towards outlet of the cyclone. The motion of the solid particles slows down, and the solid particles tend to fall down inside the deep leg 22, where gas velocity decreases due to increase in flow area, and the separated particles tend to fall in common catch zone 16.

Meanwhile, the angular velocity of the cleaned gas, formed inside the vortex zone 21 after the separation of the solid particles from the feed, also decreases. The decreased angular velocity of the cleaned gas results in the formation of a natural duct 30 (seen in Fig. 5) inside the vortex zone 21 (denoted by arrows inside the vortex zone 21). The cleaned gas thus formed inside the vortex zone 21 exits the vortex zone 21, along the direction of arrow 31, through the natural duct 30 and enters the swirl zone 20, wherefrom it enters the cleaned gas outlet 26 and is ultimately collected in the cleaned gas collecting zone 17 in the housing 10.

All the axial swirl cone cyclones 2 in the plurality of the axial swirl cyclones operate in this manner, and the solid particles collected in the deep legs 22 of all the axial swirl cone cyclones 2 are then received in the common catch zone 16 and removed therefrom via the second aperture 15 that is formed on the operative bottom of the housing 10. The cleaned gas, containing minute amounts of solid particles, discharged from the axial swirl cone cyclones 2 is collected in the cleaned gas collecting zone 17, and subsequently discharged through the first outlet opening 14 of the gas-solid separator 1.

Table 3 illustrates the minimum, maximum, and the preferable ranges of the different operating parameters, for the dimensional specifications and other specifications illustrated in Table 1 and Table 2, of the gas-solid separator 1.

TABLE 3:

Operating Parameter	**Minimum**	**Maximum**	**Preferable Range**
Flue Gas Flow Rate	300 kNm^3/hr	450 kNm^3/hr	350-425 kNm^3/hr
Particle Diameter	$1x10^{-6}$ m	$200x10^{-6}$ m	1-100 $x10^{-6}$ m
Particle Concentration in the Flue Gas	$50mg/Nm^3$	$1000mg/Nm^3$	$400-700mg/Nm^3$
Bottom flow	1%	8%	3%
Operating Temperature,	600 °C	800 °C	675-725 °C
Operating Pressure, barg	2 barg	4 barg	2.5-3.5 barg

For the preferable range, proposed configuration of the gas-solid separator can give an overall separation efficiency beyond 80%, and the clean gas can have emission levels below 50mg/Nm^3. Within specific range, a maximum separation efficiency of 86% was obtained.

The operation of the plurality of axial swirl cone cyclones 2, and the plurality of plates 18 inside the housing 10 of the gas-solid separator 1 of the present disclosure, facilitate in the obtainment of a separation efficiency that is significantly improved as compared with the conventional separators. As the separation efficiency is increased, a higher amount of solid particles entrained in the feed are captured. These particles can be recovered and are prevented from being released directly into the atmosphere. This results in reduced environmental pollution.

All the openings in the gas-solid separator 1 of the present disclosure have a diameter of at least 80mm. Such a configuration of openings results in reduced clogging and choking of the solid particles inside the openings.

Furthermore, the configuration of the axial swirl cone cyclone 2, that is to be used in the gas-solid separator 1, is such that it comprises a very small number of different components, unlike the conventional cyclones which have elements like stabilizer-pins and stabilizer plates. The reduced number of components in the axial swirl cone cyclone 2 of the present disclosure has resulted in a significantly reduced cost and a significantly simple operation. The less number of components and the simplified operation of the axial swirl cone cyclone 2 results in an extended service life of the axial swirl cone cyclone 2, and ultimately an extended service life of the gas-solid separator 1 of the present disclosure. Moreover, with such a simple configuration, the axial swirl cone cyclone 2 of the present disclosure can also be retro-fitted in existing gas-solid separators with minimal modification.

TECHNICAL ADVANCEMENTS AND ECONOMIC SIGNIFICANCE

The gas-solid separator 1, in accordance with the present disclosure described herein above has several technical advantages including but not limited to the realization of a gas-solid separator that:

- provides a high efficiency of gas-solid separation;

- has simple and efficient design
- has a plurality of axial swirl cone cyclones;
- has reduced clogging;
- facilitates capturing solid particles entrained in a gas;
- aids in reducing the environmental pollution;
- is cost effective and exhibits extended service life;
- facilitates lower damage of downstream equipment such as turbine blades

Throughout this specification the word “comprise”, or variations such as “comprises” or “comprising”, will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

The use of the expression “at least” or “at least one” suggests the use of one or more elements or mixture or quantities, as the use may be in the embodiment of the disclosure to achieve one or more of the desired objects or results.

Any discussion of documents, acts, materials, devices, articles or the like that has been included in this specification is solely for the purpose of providing a context for the disclosure. It is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the disclosure, as it existed anywhere before the priority date of this application.

Claims:

1. A gas-solid separator having a housing, said gas-solid separator comprising:
    - an inlet opening configured on an operative top plate of said housing for introducing a gas-solid mixture therein;
    - a bottom opening configured in an operative bottom portion of said housing for evacuating solid particles therefrom;
    - a first plate and a second plate configured within said housing to separate said housing into a first zone, a second zone, and a third zone;
    - an inlet conduit fitted in said inlet opening for feeding the gas-solid mixture to said second zone;
    - a plurality of axial swirl cone cyclones fitted within said housing and configured to transverse said first, second, and third zones, wherein each axial swirl cone cyclone is defined by a body having:
        - a first opening configured to be in communication with said second zone for receiving said gas-solid mixture;
        - at least one swirl imparter configured to impart swirling motion to the gas-solid mixture;
        - a second opening in communication with said third zone for evacuating solid particles from said axial swirl cone cyclone into said third zone;
        - a third opening for receiving cleaned gas within said axial swirl cone cyclone;
        - a fourth opening in communication with said first zone for emitting the cleaned gas from said cyclone into said first zone; and
    - an outlet opening configured in said first zone for leading clean air outside said gas-solid separator.
2. The gas-solid separator as claimed in claim 1, wherein said inlet conduit is in fluid communication with said second zones via a plurality of feed distributor openings configured proximal to operative bottom end of said inlet conduit.
3. The gas-solid separator as claimed in claim 1, wherein the diameter of said housing ranges from 4m to 12m.
4. The gas-solid separator as claimed in claim 3, wherein ratio of the diameter of said inlet conduit to the diameter of said housing is 0.2:1.

5. The gas-solid separator as claimed in claim 1, wherein said body of said axial swirl cone cyclone has a cylindrical portion defining a swirl zone, and a conical portion extending from said cylindrical portion defining a vortex zone.
6. The axial swirl cone cyclone as claimed in claim 5, wherein a deep leg is disposed at an operative bottom end of said vortex zone for collecting solid particles entrained in the gas-solid mixture, and said deep leg is in fluid communication with said third zone.
7. The axial swirl cone cyclone as claimed in claim 5, wherein the ratio of the diameter of said swirl zone to the height of said swirl zone ranges from 1:1 to 1:6.
8. The axial swirl cone cyclone as claimed in claim 5, wherein the ratio of the diameter of said swirl zone to the inlet diameter of said vortex zone ranges from 1:1 to 1:6.
9. The axial swirl cone cyclone as claimed in claim 5, wherein the ratio of the diameter of said swirl zone to the outlet diameter of said vortex zone ranges from 1:0.2 to 1:0.8.
10. The axial swirl cone cyclone as claimed in claim 5, wherein the ratio of the diameter of said swirl zone to the height of said vortex zone ranges from 1:1 to 1:6.
11. The axial swirl cone cyclone as claimed in claim 6, wherein the ratio of the diameter of said swirl zone to the inlet diameter of said deep leg ranges from 1:0.2 to 1:0.8.
12. The axial swirl cone cyclone as claimed in claim 6, wherein the ratio of the diameter of said swirl zone to the height of said deep leg ranges from 1:1 to 1:4.
13. The axial swirl cone cyclone as claimed in claim 1 or claim 5, wherein the ratio of the diameter of said swirl zone to the diameter of said third opening or said fourth opening ranges from 1:0.3 to 1:0.8.
14. The axial swirl cone cyclone as claimed in claim 5, wherein the ratio of the diameter of said swirl zone to the height of a cleaned gas outlet, defining said third opening and said fourth opening, ranges from 1:3 to 1:8.
15. A process for separation of solid particles from a gas-solid mixture, said process comprising the following steps:
    - introducing the gas-solid mixture into a second zone;
    - providing a plurality of axial swirl cone cyclones disposed within said gas-solid separator, each of said axial swirl cone cyclone comprising a cleaned

gas outlet, a swirl zone having a first opening, swirl imparters, and a vortex zone, such that said swirl zone is in fluid communication with said second zone and said swirl zone is adapted to receive said gas-solid mixture;

- allowing said swirl imparters to impart a swirling motion to said gas-solid mixture facilitating the separation of said solid particles from said gas-solid mixture to obtain a cleaned gas ;
- collecting said solid particles in a third zone of said gas-solid separator; and
- allowing said cleaned gas to exit said axial swirl cone cyclone via said cleaned gas outlet and get collected in a cleaned gas collecting zone of said gas-solid separator and discharged therefrom via a first outlet opening of said gas-solid separator.

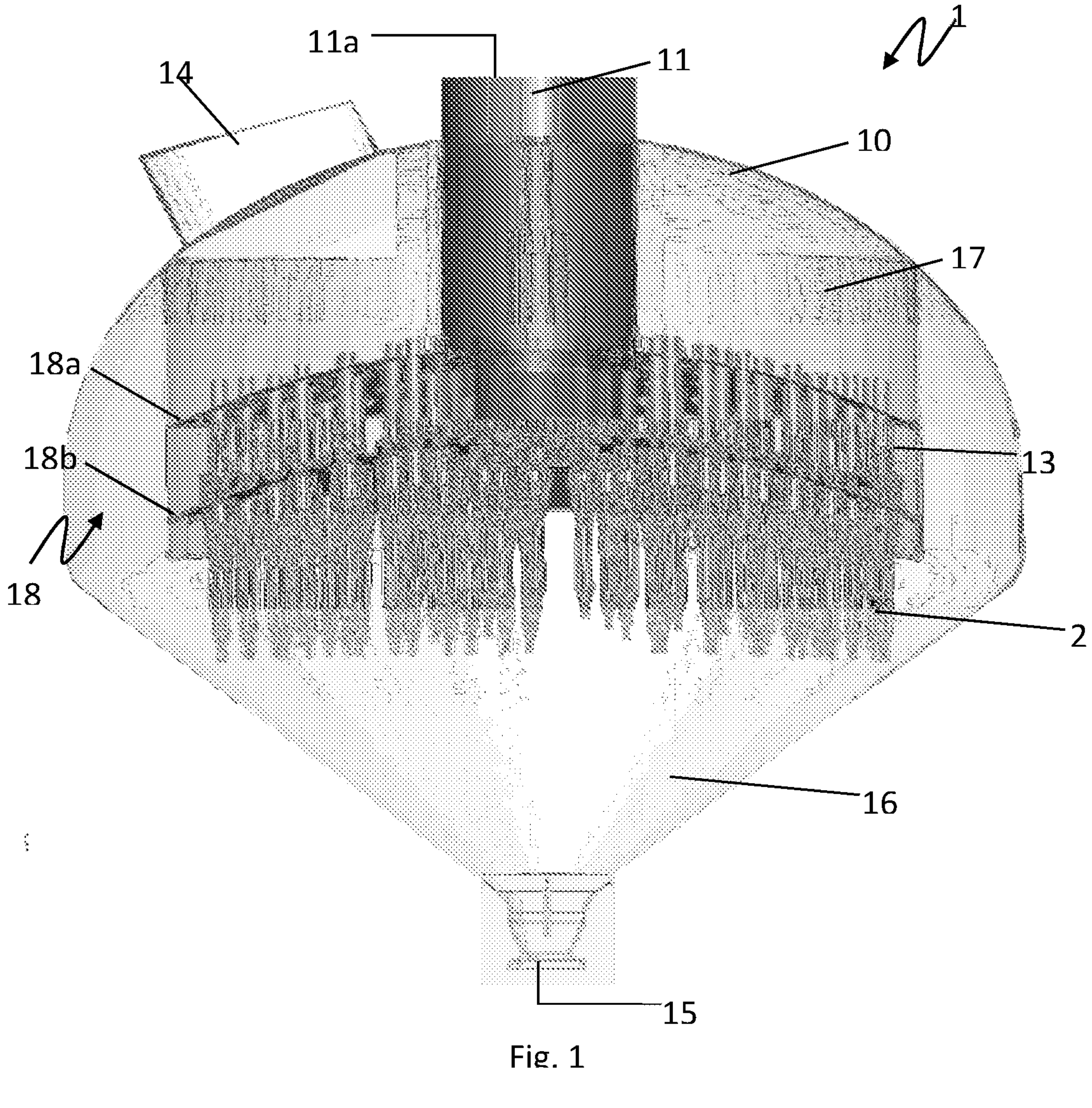

Fig. 1

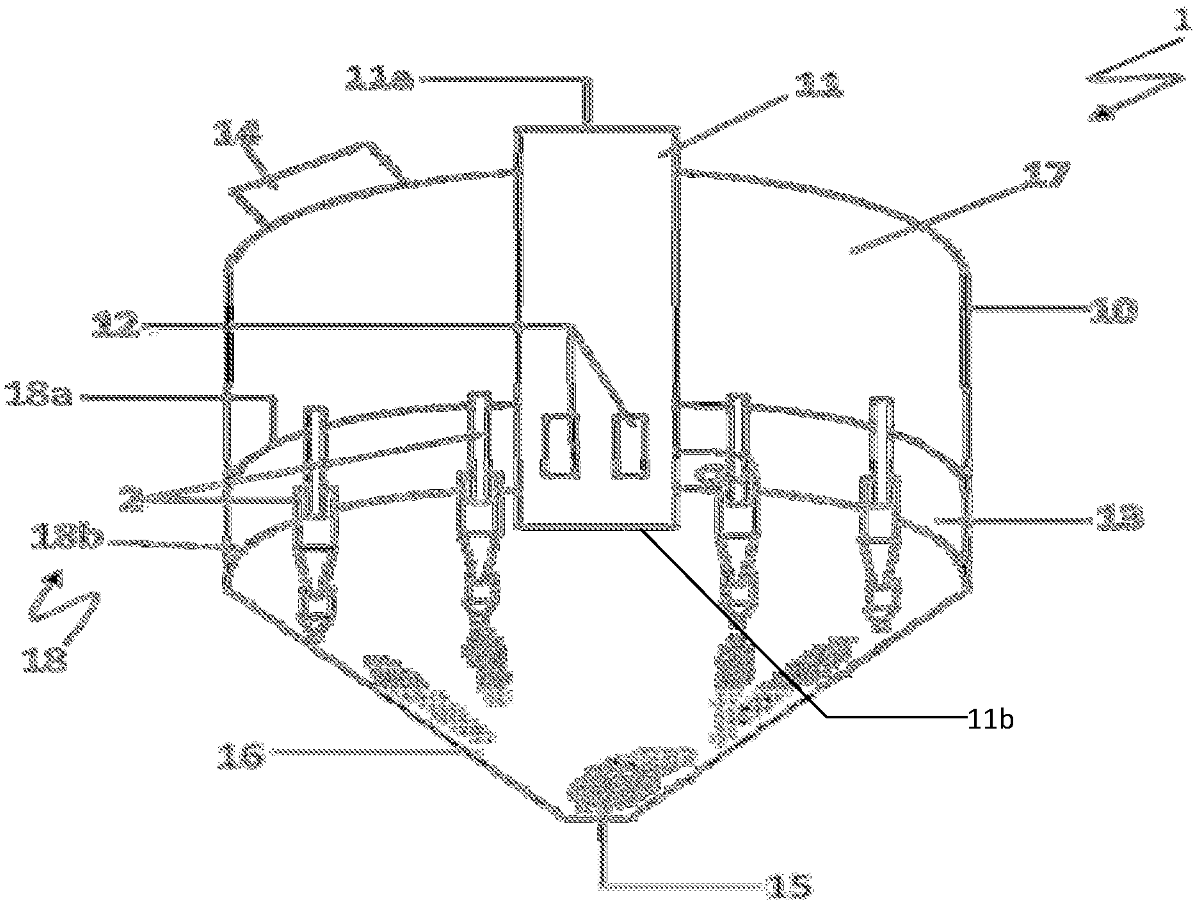

Fig. 2

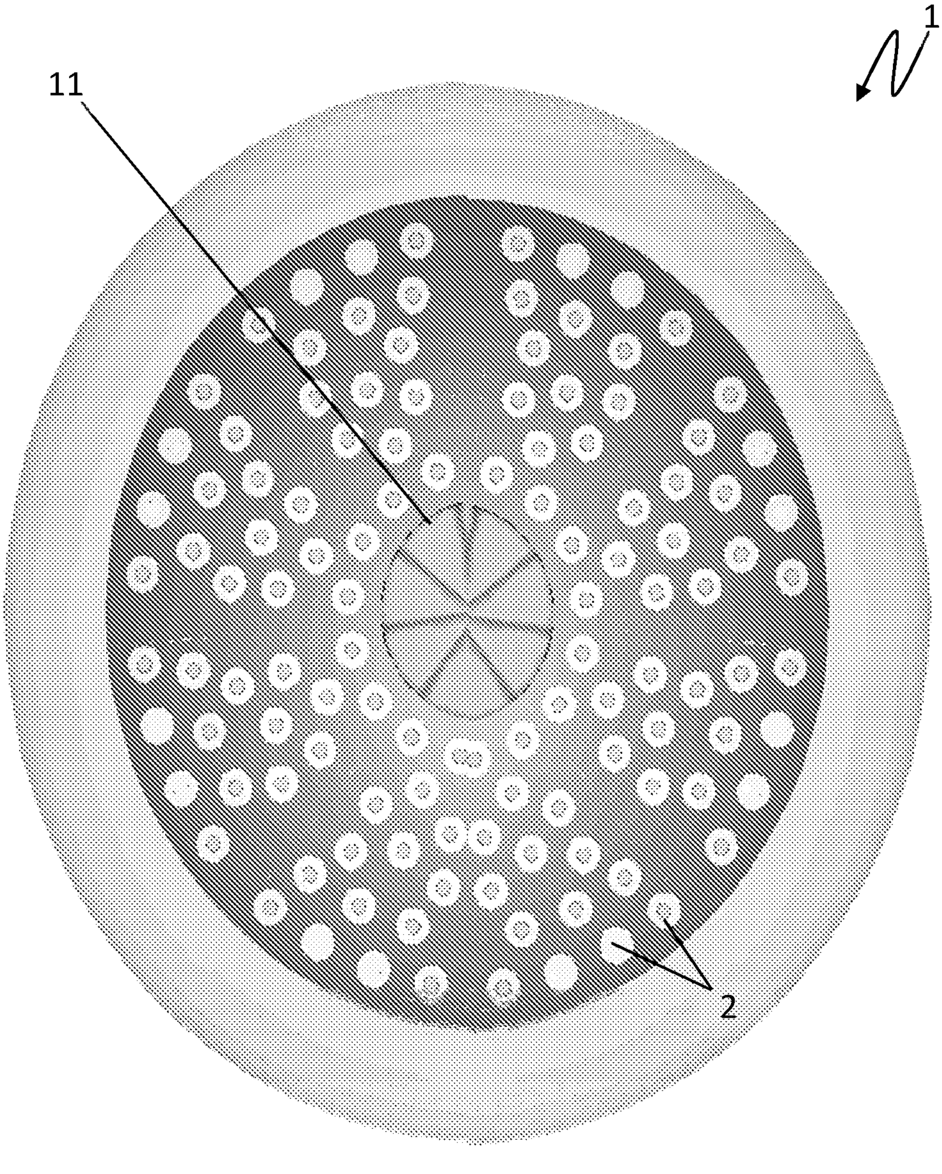

Fig. 3

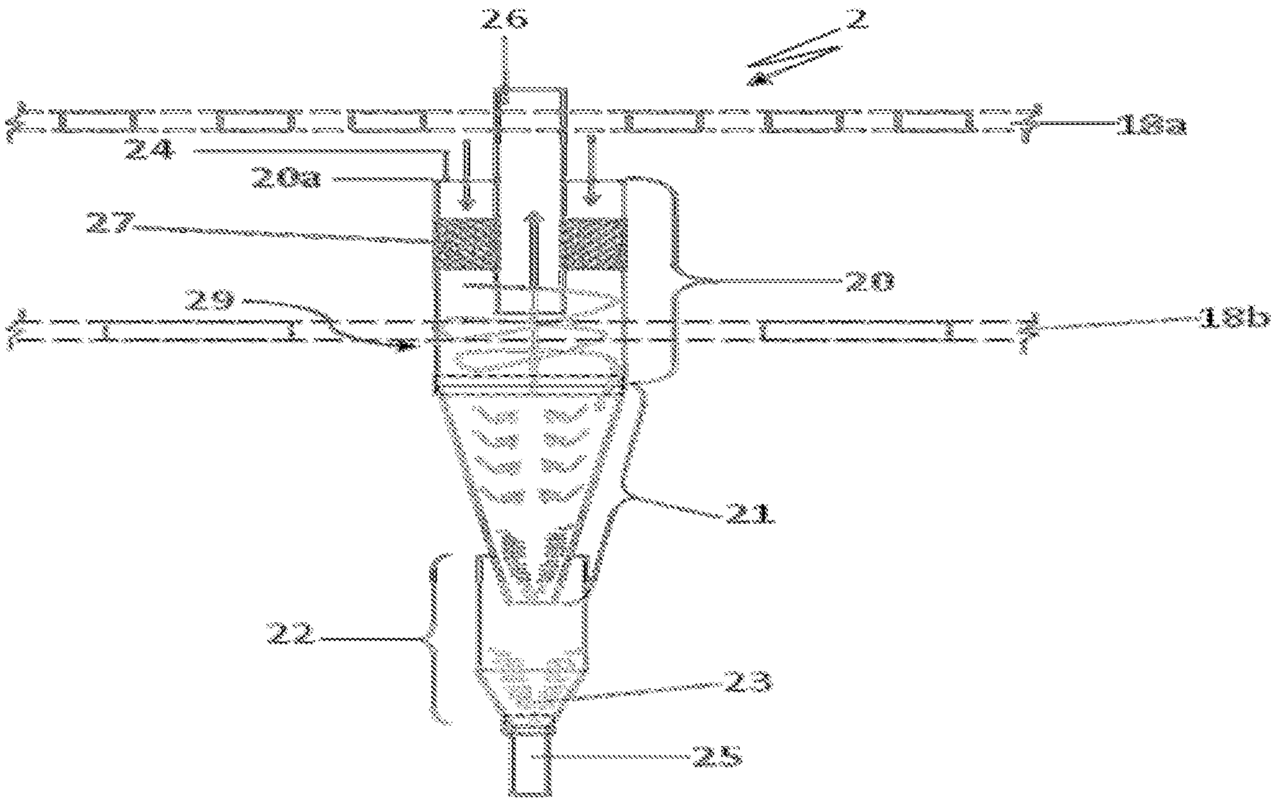

Fig. 4

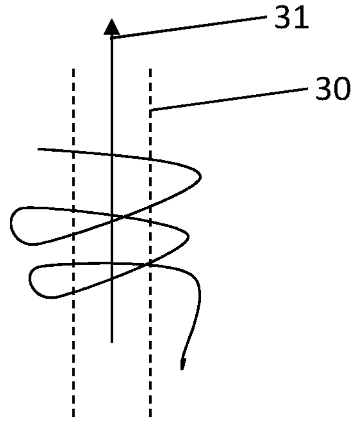

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2015/057790

A. CLASSIFICATION OF SUBJECT MATTER
B01D45/12,B04C5/06 Version=2016.01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01D, B04C, C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

IPO Internal Database, Patseer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3415042 A (WILSON J G) 10 Dec 1968, Abstract, figure 2, col 3, line 54 - col 4, line 34	1-15
Y	WO 0238279 A1 (SHELL INT RESEARCH) 16 May 2002, Abstract, page 2, line 24 - page 3, line 6, figure 1	1-15
Y	EP 0360360 A2 (SHELL INT RESEARCH) 28 March 1990, Abstract, col 2, line 18 - col 3, line 7, figure 1	1-15
Y	Buell Refinery Cyclones Publication, 2008,"Diplegs & Valves" (available online at http://www.buellrefinery.com/diplegs1.htm), Figure 3 & 4	6,11,12
A	US 5643537 A (RATERMAN M F et al.) 1 July, 1997, Abstract, claim 7, figure 3, col 4, line 59 - line 63.	1-15

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27-01-2016	27-01-2016

Name and mailing address of the ISA/	Authorized officer
Indian Patent Office Plot No.32, Sector 14,Dwarka,New Delhi-110075 Facsimile No.	Dr.Debasish Banerjee Telephone No. +91-1125300200

Citation	Pub.Date	Family	Pub.Date
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