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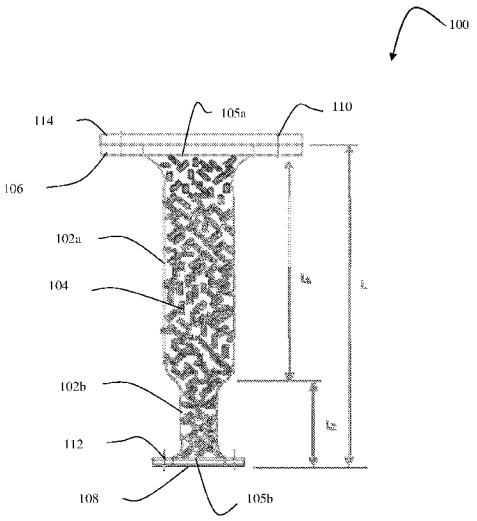

FIGURE 1

(57) Abstract: An apparatus and a method for replenishing a pressure swing adsorption system with an adsorbent is disclosed in the present disclosure. The apparatus comprises a hopper arrangement and a mechanism. The hopper arrangement is disposed about an operative top of the pressure swing adsorption system. The hopper arrangement is in fluid communication with the pressure swing adsorption system via an aperture. The hopper arrangement accommodates and selectively supplies adsorbent into the pressure swing adsorption system when the amount of the adsorbent within the pressure swing adsorption system is reduced below a predetermined threshold quantity due to adsorbent escape; and/or the purity of the target fluid emanating out of the pressure swing adsorption system is reduced below a predetermined threshold purity level. The mechanism selectively controls the flow of adsorbent into the pressure swing adsorption system.

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AN APPARATUS AND METHOD FOR REPLENISHING A PRESSURE SWING ADSORPTION SYSTEM WITH ADSORBENT

FIELD

The present disclosure relates to solid–gas adsorption and in particular to pressure swing adsorption systems.

BACKGROUND

Adsorption is a phenomenon in which molecules in fluid phase are attracted to the surface of a solid commonly called as an adsorbent. This phenomenon finds use in varied industrial applications, one being separation of individual components of a gaseous mixture, under pressure, using suitable adsorbents. An assembly effecting the separation of gases by way of adsorption under high pressure is called a Pressure Swing Adsorption (PSA) system. The adsorbents used are generally porous materials having a large surface area per unit mass. Examples of such adsorbents include carbon molecular sieves, silica and zeolites.

PSA-based processes rely on the fact that under high pressure, gas molecules tend to get attracted to the surfaces of the adsorbents. As the pressure is increased more gas is adsorbed on to the surface of the adsorbent and when the pressure is reduced, the adsorbed gas gets desorbed from the surface of the adsorbent and is recovered. As different gases tend to be attracted to different adsorbent surfaces, the PSA process offers a highly reliable method to separate gases from a mixture using a range of adsorbents.

In a typical PSA system, a multi-component gas at a high pressure is passed through multiple adsorption beds so as to adsorb all the components but one which is the least adsorbed on the adsorbent surface at a given pressure. In a bi-component mixture, the adsorbed gas is termed as affinity gas and the other component that passes unaffected is called the target gas. For example, in order to separate oxygen from a mixture of gases, the gaseous mixture is forced under high pressure into a tank filled with zeolite as the adsorbent which adsorbs all other gases sequentially with the increasing pressure while oxygen which has the least affinity for getting adsorbed on the surface of zeolites is passed forward and collected. Similarly, in order to separate nitrogen, the gaseous mixture is forced under high pressure into a tank filled with carbon molecular sieves. All gases except nitrogen get sequentially adsorbed on the surface of the adsorbent particles with the increasing pressure while nitrogen which has the least

affinity for getting adsorbed on the surface of carbon molecular sieves is passed forward and collected. When the bed reaches the limit of its capacity i.e. it gets saturated with the gases it is regenerated by reducing the pressure, thereby resulting in desorption of the gases from the surface of the adsorbents and releasing the adsorbed gaseous components. It is then ready for another cycle of such a separation process where the same steps are repeated to obtain the target gas.

The extracted gases find use in various industrial applications. Nitrogen enriching PSA systems, for example, mainly cater to the needs of process units, utilities and offsite facilities in an onshore gas terminal. The growing nitrogen demand requires the development of highly efficient separation processes for nitrogen production from various feed mixtures. However, ever since the inception of this technology, the adsorption/desorption units of the PSA units have had to face continuous adsorbent attrition during operation. During operation under high pressure, as the adsorbent material turns into fine dust, it tends to escape into the ambient air during desorption phase, posing serious environmental and health concerns. Also, a bulging of the filtration systems is witnessed. To account for the loss of adsorbent material because of attrition a fresh quantity of adsorbent stock is always required to be kept on standby for replenishing the PSA. However, during replenishment of the PSA with fresh adsorbent, it is subjected to shutdown which reduces the efficiency and performance of the process. Also, the issue of particle attrition is almost always left unchecked. This amounts to huge losses in a large scale processing unit.

Therefore, there is a need for a simple and reliable apparatus for adsorbent replenishment in the pressure swing adsorption system that can eliminate dusting and attrition of the adsorbent, check undesired fluidization of the adsorbent in the adsorption system and minimize the environmental and health concerns due to adsorbent attrition.

OBJECTS

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

An object of the present disclosure is to provide an apparatus for replenishing pressure swing adsorption units.

Another object of the present disclosure is to provide an arrangement that systematically makes up for the attrition of adsorbent in a PSA unit during operation without any need to dust-off the adsorbent.

Still another object of the present disclosure is to avoid undesired fluidization of the adsorbent in the adsorption bed of the PSA unit.

A further object of the present disclosure is to maintain the purity of the resultant target gas above 99.6%.

Yet another object of the present disclosure is to cause negligible attrition of adsorbent into the environment.

Other objects and advantages of the present disclosure will be more apparent from the following description when read in conjunction with the accompanying figures, which are not intended to limit the scope of the present disclosure.

SUMMARY

An apparatus and a method for replenishing a pressure swing adsorption system with an adsorbent is disclosed in the present disclosure. The apparatus comprises a hopper arrangement **100** and a mechanism.The hopper arrangement is disposed about an operative top of the pressure swing adsorption system. The hopper arrangement **100** is in fluid communication with the pressure swing adsorption system via an aperture. The hopper arrangement **100** accommodates and selectively supplies adsorbent into the pressure swing adsorption system when

- the amount of the adsorbent **104** within the pressure swing adsorption system is reduced below a predetermined threshold quantity due to adsorbent escape; and/or
- the purity of the target fluid emanating out of the pressure swing adsorption system is reduced below a predetermined threshold purity level.

The mechanism selectively controls the flow of adsorbent into the pressure swing adsorption system.

BRIEF DESCRIPTION OF THE DRAWING

The subject matter of the present disclosure will now be explained in relation to the accompanying non-limiting drawing.

FIGURE 1 illustrates an apparatus in the form of a hopper arrangement for replenishing the adsorbent bed, in accordance with an embodiment of the present disclosure; and

FIGURE 2 illustrates the position of the hopper arrangement of **FIGURE 1** in relation to a pressure swing adsorption system.

DETAILED DESCRIPTION

An apparatus and a method for replenishing a pressure swing adsorption system with an adsorbent is disclosed herein.

The subject matter of the present disclosure overcomes the drawbacks in the state of the art by providing a continuous controlled flow of adsorbent in the fluidized adsorption bed of a PSA unit. The above mentioned objectives are fulfilled by providing a novel arrangement for adsorbent make-up in the adsorption system as disclosed herein.

As shown in **FIGURE 1**, the apparatus for adsorbent make-up in an operative configuration comprises a hopper arrangement **100** having an upper portion **102a** extending into a lower portion **102b** in an operative vertical position. The wall of the hopper arrangement **100** has a thickness sufficient to bear the load of the adsorbent **104** fed through it. The position of the apparatus **100** in relation to the pressure swing adsorption system is as shown in **FIGURE 2**. In an embodiment, the average diameter of the upper portion **102a** is more than the average diameter of the lower portion **102b** and gives the hopper an inverted bottle appearance with its neck attached to the PSA unit. The open top of the upper portion **102a** extends outwardly from the vertical at its uppermost end **105a** and has a first flange **106** attached thereto. Likewise the open bottom of the lower portion **102b** extends vertically from the vertical at its lowermost end **105b** and has a second flange **108** attached thereto. The first and the second flanges have threaded holes **110** and **112**. The first flange **106** is bolted to a dummy flange **114** from above through threaded holes **110**. In an embodiment, a total of 8 holes are provided on the first flange **106**. Further, the second flange **108** is bolted on top of an adsorption bed of a PSA unit (not shown in the figure), through threaded holes **112**.

In an embodiment, the diameter of the uppermost end **105a** of the upper portion **102a** is about 230 mm and the first flange **106** attached to the uppermost end **105a** has a diameter of about 1000 mm. Further, the diameter of the lowermost end **105b** of the lower portion **102b** is about 50 mm; while the second flange **108** attached to the lowermost end **105b** has a diameter of about 170 mm. The average diameter of the upper portion **102a** is about 4 to 5 times the average diameter of the lower portion **102b**.

In an exemplary embodiment of the present disclosure, the hopper arrangement **100** has a length **L** of about 600 mm, in which the upper portion **102a** has a length **L1** of about 460 mm or more while the length **L2** of the lower portion **102b** is 140 mm. The upper portion **102a** collects adsorbent feed **104** from the open uppermost end **105a** and delivers the same to the lower portion **102b** of the hopper arrangement **100**. The adsorbent **104** exits into the PSA through the lowermost portion **105b;** its flow into the PSA is regulated by a valve (not shown in the figure).

The mechanism for selectively controlling the flow of adsorbent comprises valves, seals, actuators and combinations thereof.

FIGURE 2 illustrates a simple pressure swing adsorption system **118** indicating the position of the hopper arrangement **100** in relation to it**.** Compressed air enters the adsorption system **118** through the inlet **119. T**he target gas exits the adsorption system **118** through the exit **120**. A ball valve **116** provides control of adsorbent flow into the pressure swing adsorption system **118**.

In operation of the pressure swing adsorption system **118**, the hopper arrangement **100** can be installed operatively above or on to the side of the PSA unit. The hopper arrangement **100** is filled with the adsorbent **104**. The adsorbent **104** is accommodated in the hopper arrangement **100** as a buffer stock for the PSA unit and to be kept ready to be delivered into the unit. When the amount of the adsorbent within the pressure swing adsorption system is reduced below a predetermined threshold quantity and/or the purity of the target fluid emanating out of the pressure swing adsorption system is reduced below a predetermined threshold purity level, the mechanism fitted at the lowermost portion **105b** is configured to open and allow the adsorbent **104** to fall into the PSA unit.

In one aspect of the present disclosure, a method for replenishing a pressure swing adsorption system with an adsorbent is disclosed. When, during the adsorption process, the adsorbent

104 present in the adsorption bed gets used up i.e. the pores of the adsorbent particles are filled with gas or the PSA unit gets filled with adsorbent dust leading to attrition and reduction in the purity level of the target component gas, the mechanism attached to the lowermost end **105b** is configured to open resulting in the flow of adsorbent **104** into the PSA unit. In an exemplary embodiment, when the purity of the target gas exiting the PSA unit drops below 99.6%, the valve is made to open and fresh adsorbent **104** is fed to the unit. In this way, a continuous flow of the adsorbent **104** to the adsorption bed is maintained.

In an exemplary embodiment, the apparatus of the present disclosure is used with a Pressure Swing Adsorption system using carbon molecular sieves as the adsorbent to separate nitrogen from air. As the purity of nitrogen which is the target gas, exiting the PSA unit drops below 99.6%, the valve attached to the lowermost portion **105b** of the hopper arrangement **100** opens and allows the adsorbent **104** from the hopper arrangement **100** to flow into the PSA system.

In another exemplary embodiment, when the adsorbent level within the PSA unit is detected to be below the threshold quantity, the valve attached to the lowermost portion **105b** of the hopper arrangement **100** opens and allows the adsorbent **104** from the hopperarrangement **100** to flow into the PSA system.

TECHNICAL ADVANCEMENTS AND ECONOMIC SIGNIFICANCE

The hopper arrangement, in accordance with the present disclosure described herein above, has several technical advantages including, but not limited to, the realization of:

- Continuous flow of adsorbent into the pressure swing adsorption unit;
- Elimination of undesirable dusting of the adsorbent; and
- Increase in the purity of the resultant target gas to above 99.6%.

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 ingredients or quantities, as the use may be in the embodiment of the disclosure to achieve one or more of the desired objects or results.

The embodiments herein and the various features and advantageous details thereof are explained with reference to the non-limiting embodiments in the description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein.

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.

The numerical values mentioned for the various physical parameters, dimensions or quantities are only approximations and it is envisaged that the values higher/lower than the numerical values assigned to the parameters, dimensions or quantities fall within the scope of the disclosure, unless there is a statement in the specification specific to the contrary.

CLAIMS

1. An apparatus for replenishing a pressure swing adsorption system with an adsorbent **104**, said apparatus comprising:
   - a hopper arrangement **100** disposed about an operative top of said pressure swing adsorption system, said hopper arrangement being in fluid communication with said pressure swing adsorption system via an aperture, said hopper arrangement adapted to accommodate and selectively supply adsorbent into said pressure swing adsorption system when
     - the amount of said adsorbent **104** within said pressure swing adsorption system is reduced below a predetermined threshold quantity due to adsorbent escape; and/or
     - the purity of the target fluid emanating out of said pressure swing adsorption system is reduced below a predetermined threshold purity level;
   - a mechanism for selectively controlling the flow of adsorbent into said pressure swing adsorption system.

2. The apparatus as claimed in claim 1, wherein said hopper arrangement comprises:
   - an upper portion **102a**, comprising an open top, extending into a lower portion **102b**, comprising an open bottom, in an operative vertical configuration; wherein the average diameter of said upper portion **102a** is more than average diameter of said lower portion **102b**;
   - a first flange **106** attached to said open top of said upper portion **102a** of the hopper; and
   - a second flange **108** attached to said open bottom of said lower portion **102b** of the hopper, wherein the second flange **108** is adapted to be fitted to a complementary flange of the pressure swing adsorption system.

3. The apparatus as claimed in claim 1, wherein the average diameter of the upper portion is 4 to 5 times greater than the average diameter of the lower portion.

4. The apparatus as claimed in claim 1, wherein the mechanism for selectively controlling the flow of adsorbent consists of a combination of valves, seals and actuators.

5. A method for replenishing a pressure swing adsorption system with an adsorbent **104**, said method comprising the following steps:
   - providing an apparatus comprising:
     - a hopper arrangement **100** disposed about an operative top of said pressure swing adsorption system, said hopper being in fluid communication with said pressure swing adsorption system via an aperture, said hopper arrangement **100** adapted to accommodate and selectively release adsorbent **104** into said pressure swing adsorption system to make-up spent adsorbent; when
       - the amount of said adsorbent **104** within said pressure swing adsorption system is reduced below a predetermined threshold quantity due to adsorbent escape; and/or
       - the purity of the target fluid emanating out of said pressure swing adsorption system is reduced below a predetermined threshold purity level.

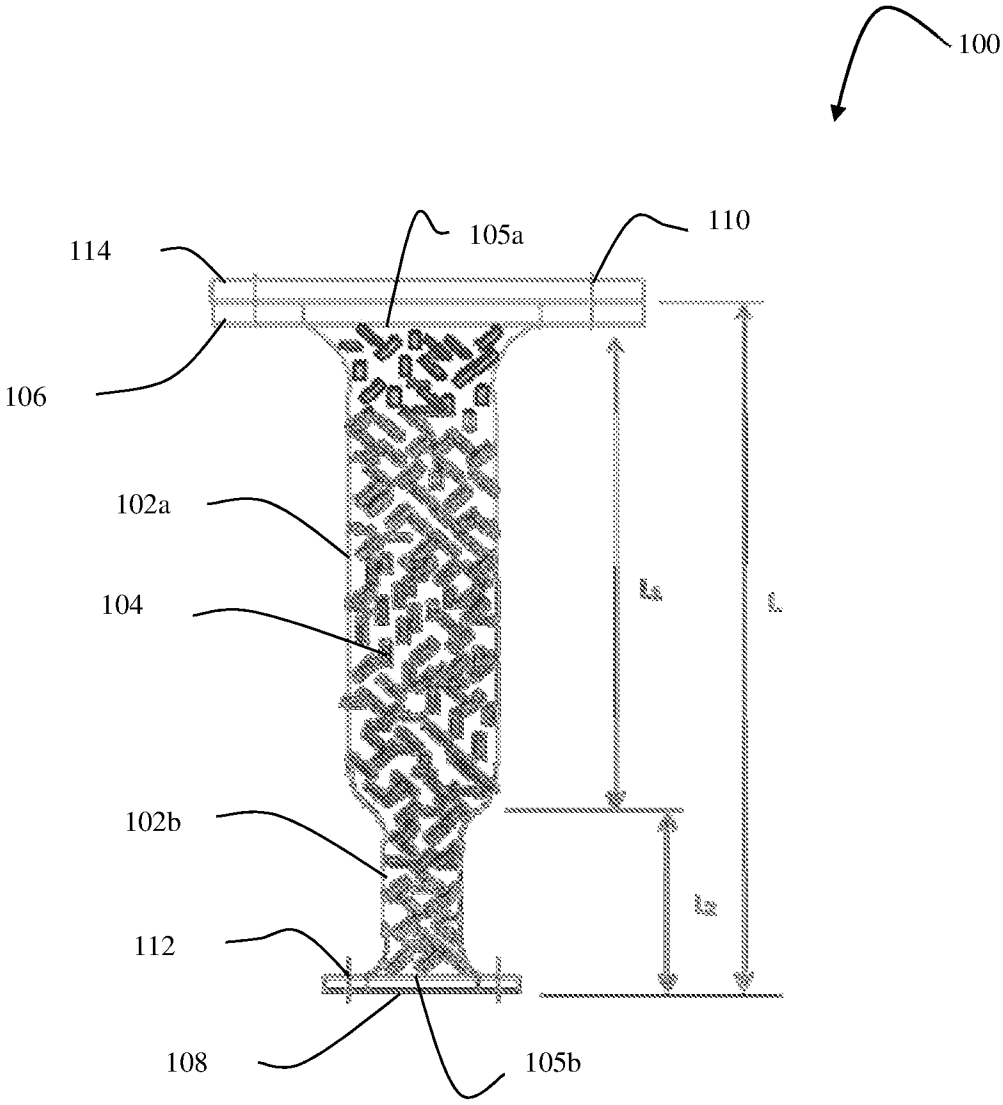

FIGURE 1

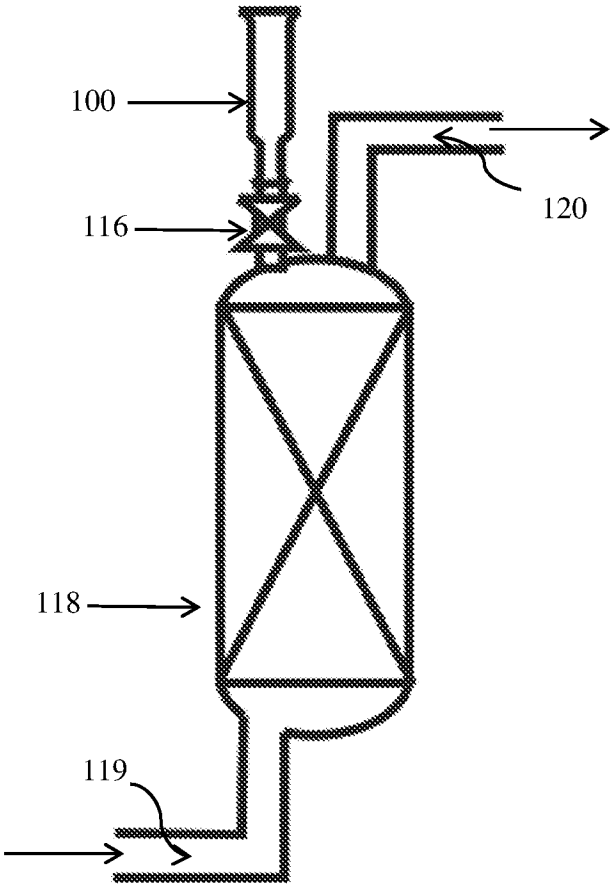

FIGURE 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2015/054422

A. CLASSIFICATION OF SUBJECT MATTER
B01D53/04,B01D53/053,C01B3/56,C10K1/32 Version=2015.01

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)

B01D53

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)

PatSeer, IPO Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP2004066096 (A) published on 4 March, 2004 Abstract	1-5
Y	US2014/0003186 A1 published on 2 January, 2014 para. 16-17, 39-40, Fig. 1	1-5

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

* Special categories of cited documents:

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US 2014/0003186 A1	02-01-2014	US 2008273418 A1	06-11-2008