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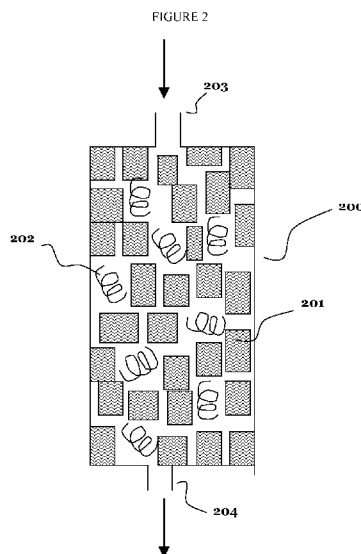
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(54) Title: PACKED ADSORBENT SYSTEMS WITH LOW FLOW RESISTANCE



(57) Abstract: A packed adsorption system having excellent adsorption capacity, yet low flow resistance is disclosed. The packed adsorption system comprises a conventional adsorbent particle and a non-adsorbent filler having internal void structure. The disclosed adsorption system offers ease and flexibility in optimizing the adsorption capacity and flow resistance for the selected end-used applications by simply adjusting the relative level of adsorbent particle and a non-adsorbent filler in the adsorption system. The disclosed adsorption system provides at least about 30% reduction in pressure drop compared to a conventional adsorption system consisting entirely of the adsorbent, at an air flow rate of about 20 cm/sec, while affording no more than about 30% reduction in adsorption capacity compared to the convention adsorption system. When desired, the non-adsorbent filler may have an internal void fraction of greater than about 0.50.



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International Patent Application For

PACKED ADSORBENT SYSTEMS WITH LOW FLOW RESISTANCE

This non-provisional application relies on the filing date of provisional U.S. Application Serial No. 61/045752 filed on April 17, 2008, which is incorporated herein by reference, having been filed within twelve (12) months thereof, and priority thereto is claimed under 35 USC § 1.19(e).

BACKGROUND OF THE DISCLOSURE

[0001] Adsorbent materials, such as activated carbon, have been widely used for removal of impurities and recovery of useful substances from fluid streams because of their high adsorptive capacity. The contaminated fluid stream is passed through the system containing packed adsorbents, wherein the contaminants are adsorbed onto the adsorbents, and consequently the level of contaminant in the fluid stream exiting the packed adsorbent system is substantially reduced. One important application is in automotive evaporative emission control, by which gasoline vapor escaping during refueling and diurnal breathing of fuel tanks is captured and recycled to the engine.

[0002] One important performance attribute of the packed adsorbent system is an adsorption capacity which, for most applications, is determined by the porosity and surface area characteristics of the adsorbent material. Another important performance attribute is the resistance of the packed adsorbent system toward the flow of the fluid that is under treatment. It is desirable to reduce the flow resistance of the packed adsorbent system as much as possible. For example, when the packed adsorbent system is used in the evaporative emission control canister for automobile, air and gasoline vapors are forced through the packed adsorbent system in the canister during refueling of the vehicle. High flow resistance of the packed adsorbent system in the canister results in an undesirable build-up of pressure in the fuel tank.

[0003] Several approaches have been explored to decrease the flow resistance of the packed adsorption bed. A simple and frequently applied approach is to increase the size of the adsorbent particles used in the packed adsorption bed. Usually, the packed adsorption system obtained from this approach has a substantially reduced adsorption capacity.

[0004] U.S. Patent No. 6,866,699 describes an emission control system with low flow resistance comprising at least two consecutive packed adsorption beds of activated carbon with comparable adsorption capacities per unit volume. The activated carbon in the first adsorption bed has larger particle size than that of the carbon in the second adsorption bed. Therefore, the flow resistance per unit bed of the first adsorption bed is lower than that of the second bed. Automotive canisters, for example, are often partitioned into larger and smaller sections for reasons of improved adsorption kinetics. However, in order to reap this kinetic benefit, the smaller section must have a significantly smaller cross sectional area. Since this smaller section must contain the smaller particles, it is this section that that will have the principal effect on flow resistance. Under these practical circumstances, the effect of reducing the flow resistance by increasing the adsorbent particle size in the larger section is relatively small.

[0005] U.S. Patent No. 6,284,705 addresses the flow resistance of the adsorbent system by using activated carbon in honeycomb shape as an adsorbent. Due to the openness of the honeycomb structure, the reported system has much lower flow resistance than the conventional packed adsorbent system. This approach requires the use of the adsorbent having honeycomb structure, which is costly because a rather complicate process is required to shape the adsorbent material into the honeycomb structure.

[0006] U.S. Patent No. 4,541,996 discloses cylindrical catalyst/adsorbent particles having internal reinforcing vanes or ribs extending from the inner wall to the center of the adsorbent particle. This configuration provides the adsorbent with large geometric surface area, yet low flow resistance because of the openings inside the adsorbent. However, like the honeycomb, these shaped adsorbent particles are quite costly. Moreover, the volumetric adsorption capacity of such shaped particles is relatively low because of the voidage inherent in the particle shape.

[0007] Accordingly, there is a need for a packed adsorbent system having excellent adsorption capacity and low flow resistance that is economical. It is desirable that such packed adsorbent system employs a conventional adsorbent material in order to minimize the production cost.

[0008] It is further beneficial to have a packed adsorbent system that provides ease and flexibility in optimizing the adsorption capacity and flow resistance for the selected end-used applications.

SUMMARY OF THE DISCLOSURE

[0009] A packed adsorption system having excellent adsorption capacity, yet low flow resistance is disclosed. The packed adsorption system comprises a conventional adsorbent particle and a non-adsorbent filler having internal void structure. The disclosed adsorption system offers ease and flexibility in optimizing the adsorption capacity and flow resistance for the selected end-used applications by simply adjusting the relative volume and adsorption capacity of the adsorbent particles and the volume of the non-adsorbent filler in the adsorption system. The disclosed adsorption system provides at least about 30% reduction in pressure drop compared to a conventional adsorption system consisting entirely of the adsorbent, at an air flow rate of about 20 cm/sec, while affording no more than about 30% reduction in adsorption capacity compared to the convention adsorption system. When desired, the non-adsorbent filler may have an internal void fraction of greater than about 0.50.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 shows a schematic sectional view of a conventional packed adsorption system, wherein the system is packed entirely with adsorbent particles;

[0011] FIG. 2 shows a schematic sectional view of the disclosed packed adsorption system, wherein the system contains carbon adsorbent particles and non-adsorbent fillers having compression spring shape;

[0012] FIG. 3 shows a schematic sectional view of the packed adsorption system, containing the same volume percentage of activated carbon as the adsorption system of FIG. 2 but absence of the non-adsorbent fillers; and

[0013] FIG. 4 is a graph showing the pressure drop across the adsorbent system, at the air flow rate of 20 cm/sec, for the disclosed packed adsorbent system having different level of void fraction compared to the conventional packed adsorption system.

DETAILED DESCRIPTION OF THE DISCLOURE

[0014] The present disclosure now will be described more fully hereinafter, but not all embodiments of the disclosure are necessarily shown. While the disclosure has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof.

[0015] FIG. 1 shows a schematic sectional view of a conventional packed adsorption system 100 filled with adsorbent particles 101. A contaminated fluid stream is passed through the adsorption system 100 via an inlet 102 and an outlet 103. The fluid stream is subjected to tortuous path of packed adsorbent particles in the column 100, and the contaminants in the stream are adsorbed onto the adsorbent particles. As a result, the level of contaminants in the fluid stream exiting the adsorption system 100 is substantially reduced. The tortuous path of the packed adsorbent particles, however, imparts significant flow restriction into the adsorption system 100.

[0016] FIG. 2 shows a schematic sectional view of one embodiment of the disclosed packed adsorption system 200. A fraction of the adsorbent particles 201 in the packed adsorption system 200 is replaced with the selected non-adsorbent fillers. A contaminated fluid stream is subjected to the adsorption system 200 via an inlet 203 and an outlet 204. The open structure of fillers 202 allows the fluid stream to pass through the system 200 faster, and thereby significantly reducing the flow resistance of the system. The relative volume amount and adsorption capacity of the adsorbent particles 201 and the volume of the fillers 202 may be optimized such that the system 200 may have a similar high adsorption capacity as the adsorption system 100 in FIG. 1, yet a much lower flow resistance.

[0017] The flow restriction of a packed adsorption system may be significantly reduced by replacing a fraction of the conventional adsorbent in the system with a non-adsorbent fillers having an internal void fraction of greater than about 0.50. The internal void fraction of the non-adsorbent fillers $[VF_{(F)}]$ suitable for use in the present disclosure is determined based on the equation:

$$VF_{(F)} = 1 - [GD/PD]$$

wherein GD was the geometric density of the filler particle as determined from its external dimensions and its mass, and PD was the true density of the solid material in the filler as measured by mercury porosimetry or calculated from known material densities.

[0018] The packed adsorption system of the present disclosure comprises:

- (a) an adsorbent; and
- (b) a non-adsorbent filler characterized by an internal void fraction of greater than 0.50.

[0019] In one embodiment of the present disclosure, the non-adsorbent filler has an internal void fraction of greater than 0.70.

[0020] In one embodiment of the present disclosure, the non-adsorbent filler has an internal void fraction of greater than 0.80.

[0021] The non-adsorbent fillers may have the internal void structure such that the adsorbent particles are completely or partially excluded from intruding inside the void structure. The fillers may be uniformly distributed in the adsorption system. The fillers may have similar size and shape compared to the adsorbent particles. Examples of the non-adsorbent fillers suitable for use in the present disclosure include, but are not limited to, coils, screens, tubes, particles of agglomerated fibers, agglomerations of small particles, open cell foams, brushes, corrugated sheets, perforated hollow shapes, perforated solid shapes, and mixtures thereof.

[0022] Suitable adsorbents for the present disclosure may be any conventional adsorbents. Examples of these adsorbents include, but are not limited to, activated carbon,

zeolite, alumina, silica, carbon black, aluminosilicates, molecular sieves, particles impregnated or coated with chemically reactive agent, and mixtures thereof.

[0023] The activated carbon used in the present disclosure may be derived from various carbon precursors. These include, but are not limited to, wood, wood dust, wood flour, cotton linters, peat, coal, coconut, lignite, carbohydrates, petroleum pitch, petroleum coke, coal tar pitch, fruit pits, fruit stones, nut shells, nut pits, sawdust, palm, vegetables such as rice hull or straw, synthetic polymer, natural polymer, lignocellulosic material, and combinations thereof. Furthermore, the activated carbon may be produced using a variety of processes including, but are not limited to, chemical activation, thermal activation, and combinations thereof. U.S. Patent No. RE 31,093 teaches a chemical activation of wood-based carbon with phosphoric acid to improve the carbon's decolorizing and gas adsorbing abilities. U.S. Patent No. 4,769,359 teaches a method of producing activated carbon by treating coal cokes and chars, brown coals or lignite with a mixture of NaOH and KOH and heating to at least 500°C in an inert atmosphere.

[0024] The disclosed packed adsorption system has a void fraction in its bed of at least 25% higher than the void fraction of the convention adsorption system consisting entirely of the adsorbent particles. In one embodiment, the disclosed packed adsorption system has a void fraction in its bed of at least 40% higher than the void fraction of the convention adsorption system consisting entirely of the adsorbent particles. In one embodiment, the disclosed packed adsorption system has a void fraction in its bed of at least 45% higher than the void fraction of the convention adsorption system consisting entirely of the adsorbent particles.

[0025] The void fraction of the adsorption system $VF_{(S)}$ is calculated from the known volumes of the adsorbent particles, known volume of the non-adsorbent filler, and their respective individual void fractions according to the following equation:

$$VF_{(S)} = \frac{\text{Void Volume of the Adsorption System } [VV_{(S)}]}{\text{Actual Volume of the Adsorption System}}$$

[0026] The void volume of the adsorption system $VV_{(S)}$ is calculated according to the following equation:

$$VV_{(S)} = VV_{(F)} + VV_{(A)} + VV_{(A-F)}$$

wherein $VV_{(F)}$ is the filler void volume; $VV_{(A)}$ is the void volume between the adsorbent particles; and $VV_{(A-F)}$ is the void volume between the adsorbent and the filler particles.

[0027] The filler void volume $VV_{(F)}$ is calculated according to the following equation:

$$VV_{(F)} = VF_{(F)} \times \text{Volume of the Non-adsorbent filler.}$$

[0028] The void volume between the adsorbent particles $VV_{(A)}$ is calculated according to the following equation:

$$VV_{(A)} = VF_{(A)} \times \text{Volume of the system packed entirely with the adsorbent particles}$$

wherein $VF_{(A)}$ is the void fraction of the adsorption system packed with the adsorbent particles that was determined as following:

$$VF_{(A)} = 1 - AD / PD$$

wherein AD is the apparent density of the system as determined by dividing the weight of the adsorption system by the volume of the system, and PD is the particle density as determined by mercury porosimetry at a pressure appropriate for filling between the particles in a pore size range of about 35 to 50 microns, depending on the sample particle size, without intrusion into the particles.

[0029] The void volume between the adsorbent and the filler particles is calculated according to the following equation:

$$VV_{(A-F)} = VF_{(A-F)} \times \text{Volume of the filler}$$

[0030] The void fraction between the adsorbent and the filler particles $VF_{(A-F)}$ is assumed to be the same as that for packing the adsorbent particles with other adsorbent particles $VF_{(A-A)}$. This is a good approximation when the volume of the filler is significantly less than the volume of the adsorbent.

[0031] The percentage increase in the void fraction of the disclosed packed adsorption system compared to that of the control adsorption system packed entirely with the

adsorbents (i.e., the system of FIG. 1) is calculated according to the following equation:

$$\% \text{ Increase in the Void Fraction} = [\text{VF}_{(S)} - \text{VF}_{(A)}] \times 100 / \text{VF}_{(A)}$$

[0032] The disclosed packed adsorption system shows at least a 30% reduction of the pressure drop across the system, at an air flow rate of about 20 cm/sec, compared to the convention adsorption system packed entirely adsorbent particles. In one embodiment, the disclosed packed adsorption system shows at least a 40% reduction of the pressure drop across the system, at an air flow rate of about 20 cm/sec, compared to the convention adsorption system packed entirely adsorbent particles.

[0033] While the disclosed packed adsorption system provides a substantial reduction in pressure drop compared to the conventional adsorption system consisting entirely of the adsorbent, its adsorption capacity may be about the same as that of the conventional adsorption system. As a fraction of the adsorbent particles in the disclosed adsorption system is replaced with the non-adsorption fillers to reduce the pressure drop, one skilled in the arts would expect a reduction in adsorption capacity of the disclosed adsorption system. This occurs in the disclosed adsorption system, but such a loss in adsorption capacity may readily be compensated by using an adsorbent with a higher adsorption capacity. Furthermore, it has been found experimentally that the efficiency of regeneration in the working capacity tests may be improved by using the non-adsorbent fillers, and that the adsorption capacity of the adsorbents in the disclosed adsorption system may be significantly increased on a per volume basis.

[0034] The disclosed adsorption system may be used in various applications. These include, but are not limited to, evaporative emission control systems for automobiles, solvent recovery systems, gas purification systems, and gas separation systems.

EXPERIMENTAL

[0035] Adsorbents

[0036] The activated carbon pellet BAX 1500 commercially available from MeadWestvaco Corporation was used as the adsorbent in the tested adsorption system. The carbon pellets had a nominal diameter of 2 mm and length of 1 to 5 mm.

[0037] Non-Adsorbent Fillers

[0038] Several types of non-adsorbent fillers were tested: wire compression springs, chips made from wire screen, fiber plugs. The wire coil fillers were of a similar size and shape and were selected from available compression springs to have an inside diameter and a pitch that would exclude penetration by the pellet particles. The screen wire chip filler were cut from 28 Mesh-screen that had been folded into a shallow “V” shape. The chips were nominally square, measuring about 3 to 6 mm on a side, and about 1 mm thick. The fiber plug fillers were punched from a ¼” thick household scrubbing pad with a ⅛”-drive punch.

[0039] The void fractions of the non-adsorbent fillers were as shown in TABLE 1.

TABLE 1

Non-Adsorbent Filler	Geometric Density (g/ml)	Material Density (g/ml)	Void Fraction VF _(F)
Wire Coils	1.31	7.8	0.83
Wire Chips	1.14	7.6	0.85
Fiber Plugs	0.097	1.28	0.92

[0040] Packed Adsorption Systems

[0041] The adsorption system had an inside diameter of about 40 mm and contained a bed of activated carbon pellets and non-adsorbent fillers that was 356 mm deep. This was a representative of a core through a typical automotive evaporative emission control canister. The activated carbon and filler particles were fed into the vessel from separate vibrating feeders. The adsorbent beds were packed by dropping the particles into the vessel at a total rate of about 55 ml/min to insure consistent packing.

[0042] The pressure drop across the adsorbent beds was measured at several air flow rates equivalent to linear velocities of 5 to 20 cm/sec. This is the range of flow rates typically encountered, for example, in evaporative emission control applications. Pressure taps above and below the bed allowed the measurement of differential pressure across the bed during the flow of gas. A Dwyer electronic pressure gauge was used to measure the differential pressure to 0.01 inches water column.

[0043] The packed adsorption systems containing different types of non-adsorbent fillers and at different volume percentages of the fillers were tested: coil fillers at 21% by volume, coil fillers at 30% by volume, chip fillers at 26% by volume, and fiber plug fillers at 20% by volume. Percentage by volume was the volume of the fillers per the total volume of the adsorbent bed. For example, the adsorbent bed containing 21% filler would consist of 21% volume of the filler and 79% volume of the activated carbon. The volume of fillers was calculated by subtracting the measured volume of carbon from the total bed volume. The conventional adsorption system packed entirely with the activated carbon as shown in FIG. 1 was used as control.

[0044] TABLE 2 shows the pressure drop of the tested packed adsorption systems. TABLE 3 shows the percentage reduction of pressure drop in the disclosed packed adsorption systems, comparing to the control system. The packed adsorption systems of the present disclosure exhibited about 50% reduction of the pressure drop compared to the control conventional packed adsorption system.

TABLE 2

Flow Rate (cm/sec)	Pressure Drop (inches WC)				
	Control (FIG. 1)	21% Coils	30% Coils	26% Chips	20% Fiber Plug
5	0.96	0.53	0.40	0.43	0.53
10	1.99	1.12	0.82	0.89	1.12
15	3.23	1.81	1.33	1.44	1.82
20	4.55	2.55	1.88	2.02	2.54

TABLE 3

Flow Rate (cm/sec)	Reduction in Pressure Drop Compared to Control (%)				
	Control (FIG. 1)	21% Coils	30% Coils	26% Chips	20% Fiber Plug
5	0	45	58	55	45
10	0	44	59	55	44
15	0	44	59	55	44
20	0	44	59	56	44

[0045] To further investigate the effect of non-adsorbent fillers on the pressure drop, the packed adsorption system as showed in FIG. 3 was tested. The adsorption system of FIG. 3 had the same volume percentage of activated carbon in the total adsorption system as the system shown in FIG. 2, except for the absence of non-adsorbent fillers. For example, the adsorption system of FIG. 3 having 21% void would consist of 21% volume of void space and 79% volume of activated carbon. The pressure drops across the adsorbent system of FIG. 3 were measured at several air flow rates, and compared to those of the adsorbent system of FIG. 2 having the same percentage volume of the activated carbon (i.e., consist of 21% volume of filler and 79% volume of activated carbon) at the same air flow rate.

TABLE 4

Flow Rate (cm/sec)	Reduction in Pressure Drop (%)				
	Control (FIG. 3)	21% void	30% void	26% void	20% void
5	0	33	44	43	34
10	0	33	46	44	32
15	0	33	46	44	33
20	0	33	45	44	33

[0046] TABLE 4 shows that the adsorption system of FIG. 3 having the same

volume percentage of activated carbon as in the system of FIG. 2 did not provide as much reduction in pressure drop. For example, the disclosed system of FIG. 2 having 21% volume coil fillers showed about 45% reduction in the pressure drop at the air flow rate of 5 cm/sec; whereas, the comparative system of FIG. 3 having 21% volume of void space exhibited only about 30% reduction in the pressure drop at the same air flow rate. This shows that the use of non-adsorbent fillers provides more beneficial reduction in the pressure drop than simply using lower amount of the adsorbent materials in the adsorption system.

[0047] The presence of open structured fillers in a packed bed decreases flow resistance and pressure drop across the bed by increasing the open space or void space between the carbon particles. Thus, the filler particles contribute their own void space to the void space of the mixture and pressure drop should be reduced in proportion to the volume of filler and the void fraction of that filler.

[0048] TABLE 5 and FIG. 4 show the pressure drop across the packed adsorption system at the air flow rate of 20 cm/sec for the adsorption system containing the non-adsorbent fillers of different void fraction.

TABLE 5

Filler	% Volume of Filler	Void Fraction of the Adsorption System	%Increase in Void Fraction Compared to the Control	Pressure Drop (inches WC)
Control (FIG. 1)	0	$VF_{(C)} = 0.37$	0%	4.58
Coils	21	$VF_{(S)} = 0.54$	46%	2.55
	30	$VF_{(S)} = 0.62$	68%	1.88
Chips	26	$VF_{(S)} = 0.59$	59%	2.02
Plugs	20	$VF_{(S)} = 0.55$	49%	2.28

[0049] Adsorption Capacity of the Adsorption System

[0050] The adsorption capacity of the packed adsorption system was determined using the following procedure: An air stream containing 50% by volume of butane was subjected through the packed adsorption system at a linear velocity of 5 cm/sec. The breakthrough of butane through the adsorption system was monitored with a Rosemount Model 800 infrared hydrocarbon analyzer. Very sharp breakthrough profiles were observed, and the influent butane mixture flow was terminated when the effluent level reached 5%. The system was weighed to determine the amount adsorbed, and then purged with 150 bed volumes of air in 20 minutes. The system was weighed again at the end of purge, and the weight loss recorded was as Working Capacity. Five or six adsorb/purge cycles were run in immediate succession for each sample, and the steady state capacity obtained over the last three cycles was averaged to yield the reported capacity value.

[0051] The control adsorption system was conventional packed adsorption system packed entirely with activated carbon adsorbents. The working capacities of the disclosed adsorption systems containing the selected non-adsorbent fillers were determined and compared to that of the control system of FIG. 1.

TABLE 6

	Working Capacity of the Packed Adsorption Systems			
	Capacity (gm/L Bed)	Capacity (% of Control)	Carbon Volume (% of Control)	Capacity (gm/L Carbon)
Control (FIG. 1)	47.6	100.0	100.0	47.6
21% Springs	43.5	91.4	79	55.1
30% Springs	39.1	82.0	70	55.8
26% Chips	40.2	84.4	74	54.3

[0052] TABLE 6 shows that the loss of adsorption capacity as a result of displacing the activated carbon adsorbents by the selected non-adsorbent fillers was not directly proportional to the amount of the displacement. For example, the disclosed adsorbent system containing 21% volume of the coil fillers had a carbon volume of about 79% of that of the control system. However, its working capacity was about 91% of the control. In fact, the adsorption capacity per liter of the disclosed packed adsorbent system actually increased by about 14% to 17%. Based on the present data, one skilled in the arts would recognize that it is possible to match the performance of vessels containing carbon with a nominal BWC of about 13 gm/dL, while decreasing the pressure drop by about 60%.

[0053] While the disclosure has been described by reference to various specific embodiments, it should be understood that numerous changes may be made within the spirit and scope of the inventive concepts described. It is intended that the disclosure not be limited to the described embodiments, but will have full scope defined by the language of the following claims.

We Claim:

1. A packed adsorption system, comprising:
 - (c) an adsorbent; and
 - (d) a non-adsorbent filler having an internal void fraction of greater than about 0.50.
2. The system of Claim 1, wherein the non-adsorbent filler has the internal void fraction of greater than about 0.70.
3. The system of Claim 1, wherein the non-adsorbent filler comprises a member selected from the group consisting of coils, screens, tubes, particles of agglomerated fibers, agglomerations of small particles, open cell foams, brushes, corrugated sheets, perforated hollow shapes, perforated solid shapes, and mixtures thereof.
4. The system of Claim 1, wherein the adsorbent comprises a member selected from the group consisting of activated carbon, zeolite, alumina, silica, carbon black, aluminosilicates, molecular sieves, particles impregnated or coated with chemically reactive agent, and mixtures thereof.
5. The system of Claim 4, wherein a precursor of the activated carbon comprises at least one material selected from the group consisting of wood, wood dust, wood flour, cotton linters, peat, coal, coconut, lignite, carbohydrates, petroleum pitch, petroleum coke, coal tar pitch, fruit pits, fruit stones, nut shells, nut pits, sawdust, palm, vegetable, synthetic polymer, natural polymer, lignocellulosic material, and combinations thereof.
6. The system of Claim 1, characterized by:
 - (a) at least about 30% reduction in pressure drop at an air flow rate of about 20 cm/sec compared to an adsorption system consisting entirely of the adsorbent; and
 - (b) no more than about 30% reduction in adsorption capacity compared to the adsorption system consisting entirely of the adsorbent.
7. The system of Claim 6, characterized by at least about 40% reduction in pressure drop at an air flow rate of about 20 cm/sec compared to the adsorption system consisting entirely

of the adsorbent.

8. The system of Claim 6, characterized by no more than about 20% reduction in adsorption capacity compared to the adsorption system consisting entirely of the adsorbent.
9. A packed adsorption system comprising an adsorbent and a non-adsorbent filler having an internal void structure, and characterized by:
 - a. a void fraction of at least about 25% higher than a void fraction of an adsorption system consisting entirely of the adsorbent;
 - b. at least about 30% reduction in pressure drop across the system at an air flow rate of about 20 cm/sec compared to the adsorption system consisting entirely of the adsorbent; and
 - (c) no more than about 30% reduction in adsorption capacity compared to the adsorption system consisting entirely of the adsorbent.
10. The system of Claim 9, characterized by a void fraction of at least about 40% higher than a void fraction of the adsorption system consisting entirely of the adsorbent;
11. The system of Claim 9, characterized by at least about 40% reduction in pressure drop across the system at an air flow rate of about 20 cm/sec compared to the adsorption system consisting entirely of the adsorbent.
12. The system of Claim 9, characterized by no more than about 20% reduction in adsorption capacity compared to the adsorption system consisting entirely of the adsorbent.
13. The system of Claim 9, wherein an internal void fraction of the non-adsorbent particle is greater than about 0.50.
14. The system of Claim 13, wherein an internal void fraction of the non-adsorbent particle is greater than about 0.70.
15. The system of Claim 9, wherein the non-adsorbent filler comprises a member selected

from the group consisting of coils, screens, tubes, particles of agglomerated fibers, agglomerations of small particles, open cell foams, brushes, corrugated sheets, perforated hollow shapes, perforated solid shapes, and mixtures thereof.

16. The system of Claim 9, wherein the adsorbent comprises a member selected from the group consisting of activated carbon, zeolite, alumina, silica, carbon black, aluminosilicates, molecular sieves, particles impregnated or coated with chemically reactive agent, and mixtures thereof.
17. The system of Claim 16, wherein a precursor of the activated carbon comprises at least one material selected from the group consisting of wood, wood dust, wood flour, cotton linters, peat, coal, coconut, lignite, carbohydrates, petroleum pitch, petroleum coke, coal tar pitch, fruit pits, fruit stones, nut shells, nut pits, sawdust, palm, vegetable, synthetic polymer, natural polymer, lignocellulosic material, and combinations thereof.
18. A packed adsorption system, comprising an adsorbent and a non-adsorbent filler having an internal void fraction of greater than about 0.50, and characterized by:
 - (a) at least about 30% reduction in pressure drop at an air flow rate of about 20 cm/sec compared to an adsorption system consisting entirely of the adsorbent; and
 - (b) no more than about 30% reduction in adsorption capacity compared to the adsorption system consisting entirely of the adsorbent.
19. The system of Claim 18, wherein the non-adsorbent filler has the internal void fraction of greater than about 0.70.
20. The system of Claim 18, wherein the non-adsorbent filler comprises a member selected from the group consisting of coils, screens, tubes, particles of agglomerated fibers, agglomerations of small particles, open cell foams, brushes, corrugated sheets, perforated hollow shapes, perforated solid shapes, and mixtures thereof.
21. The system of Claim 18, wherein the adsorbent comprises a member selected from the

group consisting of activated carbon, zeolite, alumina, silica, carbon black, aluminosilicates, molecular sieves, particles impregnated or coated with chemically reactive agent, and mixtures thereof.

22. The system of Claim 21, wherein a precursor of the activated carbon comprises at least one material selected from the group consisting of wood, wood dust, wood flour, cotton linters, peat, coal, coconut, lignite, carbohydrates, petroleum pitch, petroleum coke, coal tar pitch, fruit pits, fruit stones, nut shells, nut pits, sawdust, palm, vegetable, synthetic polymer, natural polymer, lignocellulosic material, and combinations thereof.
23. The system of Claim 18, characterized by at least about 40% reduction in pressure drop at an air flow rate of about 20 cm/sec compared to the adsorption system consisting entirely of the adsorbent.
24. The system of Claim 18, characterized by no more than about 20% reduction in adsorption capacity compared to the adsorption system consisting entirely of the adsorbent.

FIGURE 1

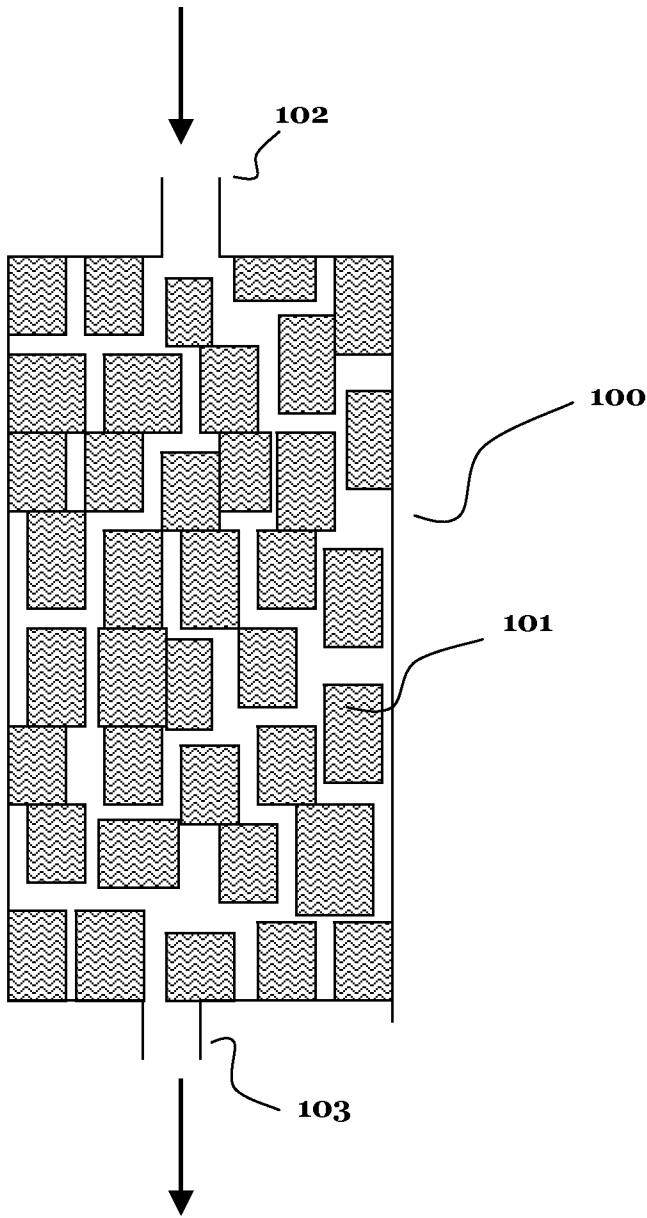


FIGURE 2

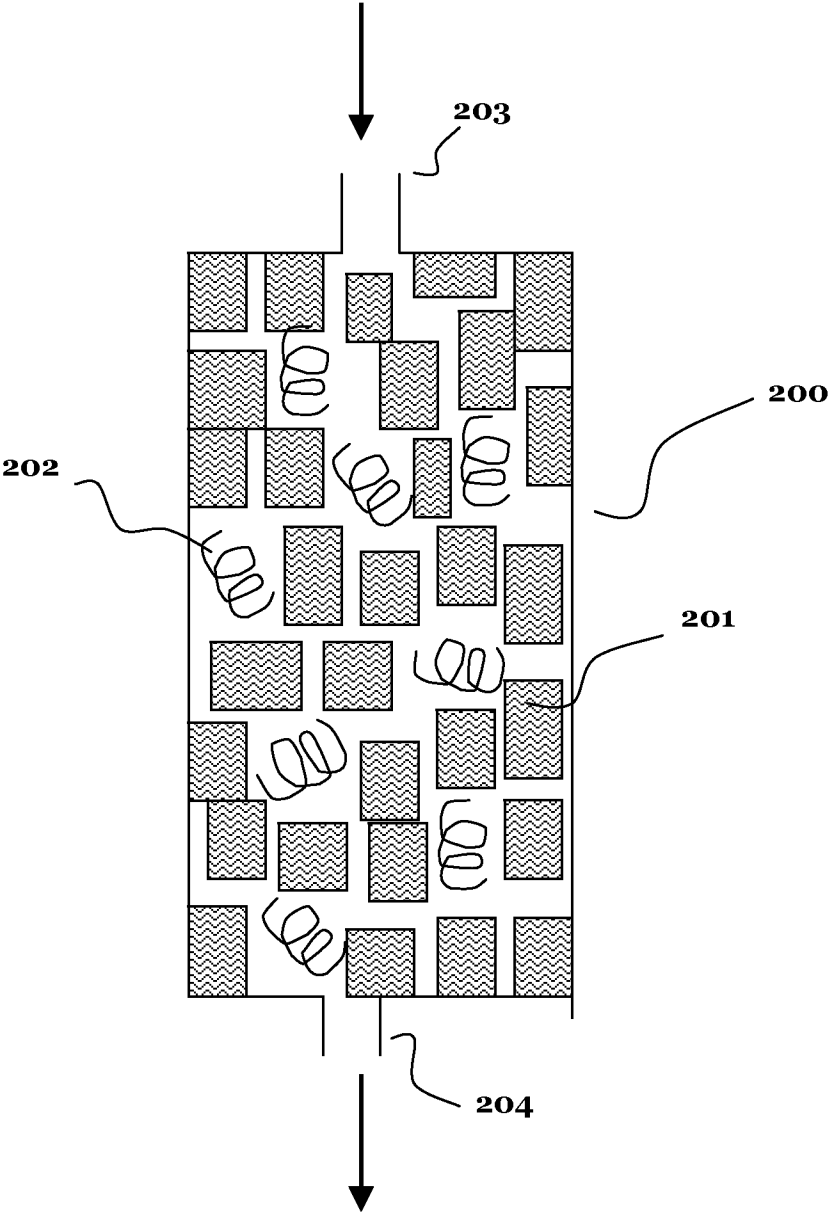
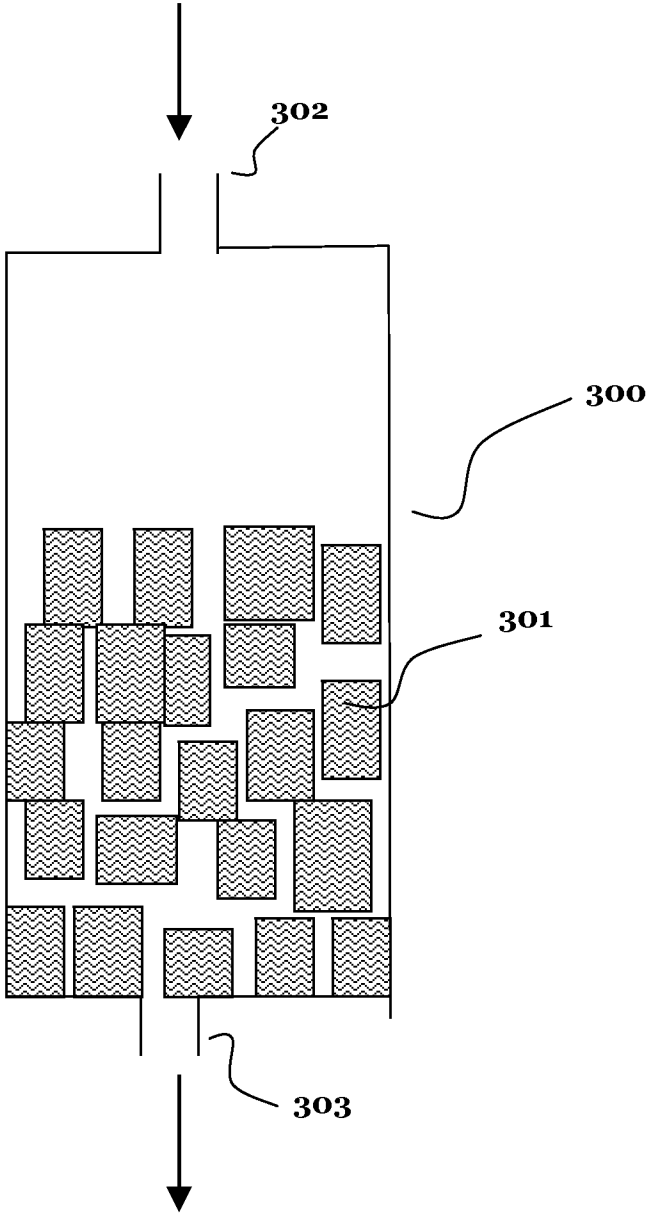
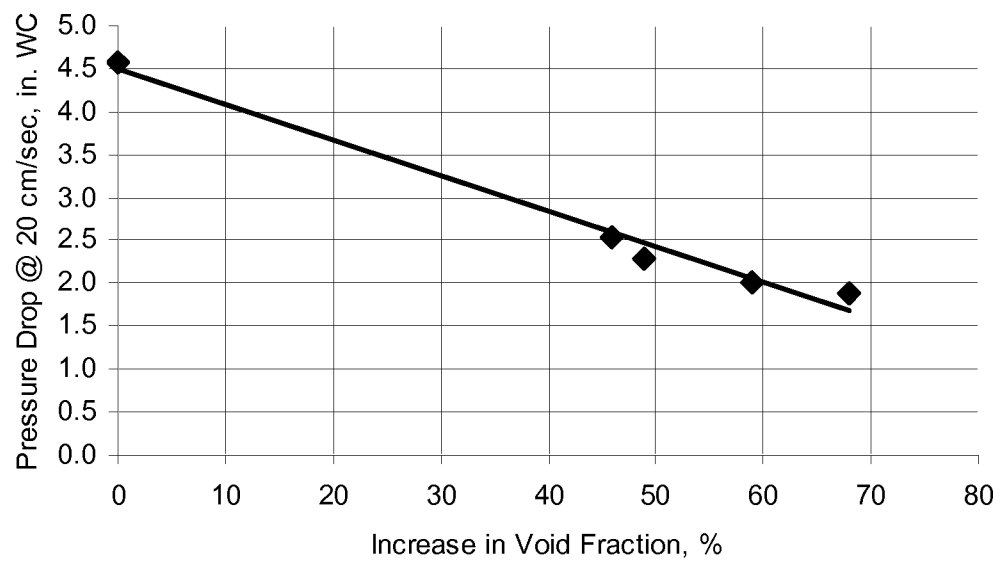


FIGURE 3



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FIGURE 4



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/041002

A. CLASSIFICATION OF SUBJECT MATTER

INV. B01D53/04 B01J19/30 C01B31/08 B01J20/20

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 B01J

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 234 326 A (BAILEY ALAN ET AL) 18 November 1980 (1980-11-18) columns 1-2 figure 4 table 1	1-24
X	US 6 540 815 B1 (HILTZIK LAURENCE H [US] ET AL) 1 April 2003 (2003-04-01) column 1, lines 11-13 column 2, lines 5-30 column 3, lines 51-60 column 4, lines 8-15 column 9, line 56 - columns 10-37 example 1 table 1 claims 8,9,15,16	1-24

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

29 July 2009

Date of mailing of the international search report

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PCT/US2009/041002

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No

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