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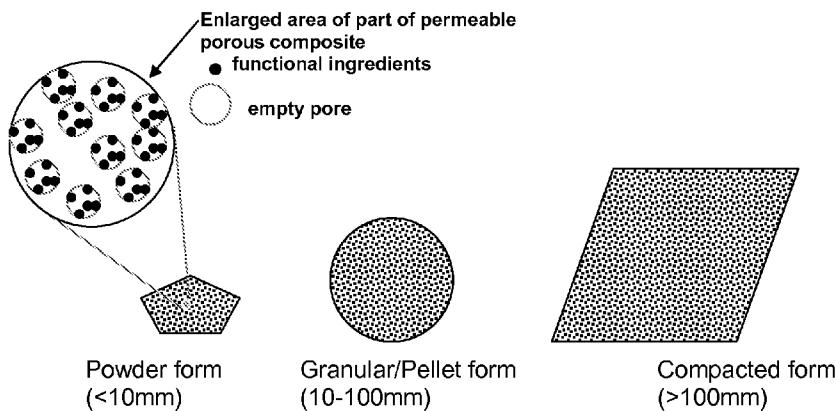
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(54) Title: PERMEABLE POROUS COMPOSITE

Figure 1



(57) **Abstract:** The present invention relates to a porous and permeable composite for treatment of contaminated fluids characterized in that said composite comprises a body of iron particles and 0.01-10% by weight of at least one functional ingredient distributed and locked in the pores and cavities of the iron body. The present invention also relates to methods of making a permeable porous composite for water treatment. The present invention also relates to use of a permeable porous composite according to any preceding claims for reducing the content of contaminants in a fluid, wherein said fluid is allowed to pass through the permeable composite.

PERMEABLE POROUS COMPOSITE

Field of the invention

The present invention concerns a composite containing iron particles and at least one functional ingredient. The particles of the functional ingredients are well distributed in a permeable porous iron body. The present 5 invention also concerns the method of making the composite, and the use of the composite for purifying fluids. The composite can be manufactured into powder form, pellet form and various other forms by using powder metallurgical processes.

Background of the invention

10 Toxic inorganic/organic substances in various water sources have to be reduced below regulated levels before the water goes into drinking water systems or is released into recipients.

15 Nitrate(NO_3^-) is the most common inorganic contaminant found in groundwater in the areas where agriculture activities occur heavily. Nitrates usually come from fertilizers, used in farming and gardening in order to provide the plants and shrubs with nutrients.

20 Other contaminants which may be generated from such activities are phosphates (PO_4^{3-}) and traces of pesticides such as atrazine. Accumulation of fertilizers is a problem as they can go through the soil and contaminate ground water systems. Both shallow water wells and deep water wells can be affected.

25 Toxic metals such as arsenic (As), chromium (Cr), whereof its oxidation state +6 (Cr^{VI}) is regarded as most harmful, lead (Pb), mercury (Hg), cadmium (Cd), selenium(Se), etc, other substances as chlorinated hydrocarbons and other organic substances, sometimes measured as Total Organic Carbon (TOC) are generated either from natural origins or from industrial or farming activities.

In order to reach acceptable levels of contaminants in drinking water, several processes are currently used.

30 Reverse osmosis is based on the process of osmosis. This involves the selective movement of water from one side of a membrane to the other. A major disadvantage of reverse osmosis is the large amount of contaminated wastewater generated, which can be as much as 50 to 90 % of the incoming water. Over time, clogging of the membrane pores occurs as iron, 35 salts and bacteria accumulate on the membrane surface. This not only

affects the performance of the reverse osmosis system, but can also cause bacterial contamination of the water. This technique is also very energy consuming.

Distillation processes are also used. The nitrate and other minerals 5 remain concentrated in the boiling tank. The disadvantages of this process include the amount of energy consumed (to boil the water), limited capacity and constant maintenance.

The ion exchange process percolates water through bead-like spherical resin materials (ion-exchange resins). Ions in the water are exchanged for 10 other ions fixed to the beads. The two most common ion-exchange methods are softening and deionization. Ion exchange techniques also generate hazardous brine waste that needs to be deposited. Deionization (DI) systems effectively remove ions, but they do not effectively remove most organics or micro-organisms. Microorganisms can attach to the resins, providing a culture 15 media for rapid bacterial growth and subsequent pyrogen generation. This technique has a low initial capital investment but a high long-term operational cost.

US patent publication No. 2007/0241063A1 describes a process for treating water contaminated with a volatile organic compound with iron powder granules containing iron, carbon and oxygen. The carbon addition to the 20 iron powder granules in US2007/0241063A1 is made during the atomization process and are not subjected to any mixing process. This is commonly known as a “pre-alloy” process in the field of powder metallurgy.

US patent No. 5534154 describes a procedure for treating contaminated 25 water by passing the water containing contaminant in solution through a permeable body of treatment material comprising particles of an adsorptive material physically mixed with particles of metal. The iron metal particles mentioned in the patent are iron fillings generally in solid granular form. The procedure requires a negative Eh voltage which in turn demands oxygen 30 exclusion.

US6827757 describes a magnetite-iron based composite with very small average particle size of 0.05 – 10 μ m.

EP1273371A2 describes an iron powder adapted to remediate selected media by dehalogenating halogenated hydrocarbons in the media comprising 35 iron powder particles and inorganic compounds. Said inorganic compounds should have a very low electric resistivity, preferably selected from

the group consisting of Ca, Ti, V and Cr. Said inorganic compounds should be present on at least a portion of the surface of each particle.

Summary of the invention

An object of the invention is to provide permeable porous composites comprising an iron body suitable for contaminant purification of fluids, especially liquids, such as water. The composites can be applied in fluid treatments such as drinking water treatment, waste water treatment such as municipal and industrial waste water treatment, and also for soil remediation. Further the permeable porous composite has functional ingredients in their free form well distributed and locked in the pores of an iron body. The term 'locked in' refers to the effect of attaching functional ingredient particles to the iron body in such a way that they will not be removed from the iron body by the fluid during the purification process. Another object of the invention is to provide the method of making the iron-based composite.

Yet another object of the invention is to provide a method for purifying liquids, such as water, from contaminants with no generation of hazardous waste products.

Yet another preferred object of the invention is to provide a product and method for reducing nitrates in water, especially water to be used as drinking water.

The present invention relates to a porous and permeable composite for treatment of contaminated fluids characterized in that said composite comprises a body of iron particles and 0.01-10% by weight of at least one functional ingredient distributed and locked in the pores and cavities of the iron body. A body of iron particles is to be interpreted as a body of particles as they are in original state or the iron particles have been formed into a different shape (an iron body).

A permeable porous composite, comprising 0.01%-10% by weight of at least one functional ingredient, preferably selected from the group consisting of carbon containing compounds, calcium containing compounds, sodium containing compounds, iron containing compounds, titanium containing compounds and aluminium containing compounds; preferably said carbon containing compounds are selected from graphite, activated carbon (AC) and coke; said iron containing compounds are selected from ferric or ferrous sulphate, ferric oxides and ferric hydroxides; said titanium containing compounds is titania; and said aluminium containing compounds are selected from alumina, activated alumina and aluminium silicates such as zeolites;

said sodium containing compound is soda; said calcium containing compounds is lime; preferably said functional ingredient is from the group of graphite, activated carbon, coke, activated alumina and zeolites, most preferably from the group of graphite, activated carbon, coke. Optionally may 5 further functional ingredients outside the mentioned group be selected, depending on the contaminant to be processed. All functional ingredients should be locked in and well distributed in the permeable porous iron body.

The present invention also relates to methods of making a permeable porous composite e.g. for water treatment. Said composite can be manufactured 10 into various forms, such as powder, chip, flake, block or pellet, using common powder metallurgical technologies.

A method for manufacturing a porous and permeable composite for treatment of contaminated fluids, comprising the steps of; mechanically 15 mixing iron particles representing an iron body with at least one functional ingredient, which is present in an amount of 0.01-10% by weight, until the functional ingredient is distributed by mechanical forces into the iron body and locked; optionally heat treating the iron body, with or without said at least one functional ingredient, at a temperature between 300 and 1200°C in an inert or reducing atmosphere; optionally compacting the iron body, with or without 20 said at least one functional ingredient, into a compacted body having a green density equal to or below 7.0g/cm³; and/or optionally sizing said iron body, with or without said at least one functional ingredient, wherein said steps can be carried out in optional order.

The present invention also relates to use of a permeable porous composite 25 according to any preceding claims for reducing the content of contaminants in a fluid, wherein said fluid is allowed to pass through the permeable composite. Said fluid may be a water containing fluid, preferably ground water, river water, industrial waste water, civic waste water and/or surface water. Said fluid may be used as drinking water after purification treatment 30 according to the present invention. Said contaminants may be selected from the group consisting of nitrate, nitrite, heavy metals, such as As, Pb, Hg, Cd, Se, Cr and hexavalent Cr, other toxic inorganic substances and toxic organic compounds; or combinations thereof; preferably nitrate and/or nitrite.

Detailed description of the present invention

35 The permeable and porous composite according to the present invention comprises a mixture of porous iron, and 0.01-10%, preferably 0.05-8%, preferably 0.1-5 % by weight of at least one functional ingredient which might

be chosen from coke, graphite, activated carbon, ferric oxides, ferric hydroxides, titania, alumina, activated alumina, zeolites, lime, soda, ferric or ferrous sulphate, preferably from the group of coke, graphite, activated carbon, activated alumina and zeolites. Depending of the pore and cavity size of the

5 permeable porous iron, the functional ingredient may have in some embodiments of the invention a particle size less than 20 µm, preferably less than 10 µm, in other embodiments the particle size of the functional ingredients may be less than 10 µm preferably less than 5 µm. The particle size being above about 0.02 µm.

10 The use of the wording "permeable" as disclosed herein is to be interpreted as a composite or a iron powder or body being constructed so that it is permeated or penetrated, especially by liquids or gases. The use of the wording "porous" as disclosed herein is to be interpreted as a composite or a iron powder or body being constructed so that it is admitting the passage of

15 gas or liquid through pores or interstices. Thus, the permeable and porous composite according to the present invention comprises the at least one functional ingredient located in pores and cavities of the composite. The iron part of the composite, the iron body, could be made of iron powder or iron particles which themselves are porous. Otherwise, the iron body, the porous

20 and permeable iron structure, is prepared using compaction and/or heat and optional sizing of iron powder or particles.

The iron particles or powder are/is mixed with the functional ingredient resulting in a composite according to the invention. Also, the iron powder can be mixed with the functional ingredient(s) before being compacted and/or

25 heat treated, optionally followed by sizing into a desired size. Alternatively, the iron powder can be compacted and/or heat treated, optionally followed by sizing into a desired size, before being mixed with the functional ingredient(s).

All functional ingredients should be locked in and well distributed in the permeable porous iron body or iron structure. The functional ingredients are

30 in free from, i.e. still in their original state, and thus not altered in any way like alloyed or coated to the iron body. Apart from obtaining a combined technical effect from the adsorptive capacity of the functional ingredient and the redox ability from the porous iron a synergetic effect is obtained when combining the porous iron with the functional ingredient locked into the pores of the iron. The

35 term functional ingredient should be interpreted as an additive which main function is to enhance the purification of fluids, by providing a synergetic effect with the iron particles. This synergetic effect is evident by the

remarkable high efficiency of the new permeable porous composite for removal of multiple contaminants for example nitrate and arsenic in combination in water. An additionally advantage with the method for reducing contaminants in fluids according to the present invention is, in contrast to 5 methods such as conventional ion exchange is that no hazardous waste is generated by the method.

In one embodiment porous iron powder particles having a particle size range between 10 mm and 10 µm, preferably between 5 mm and 20 µm and most preferably between 2 mm and 45 µm is preferably used. Finer iron powder 10 may also be used and can in these cases be turned into coarser porous particles by known methods such as compaction and sizing; heat treatment and sizing; or compaction, heat treatment and sizing. The iron powders used in these cases may have particle size range between 2 mm and 1 µm, preferably between 1 mm and 1 µm, and preferably 0.5 mm and 1 µm. Having too 15 small average particle size increases the oxidation rate of the iron particles to too high levels, meaning a loss of process efficiency. Depending on the application, i.e. type of fluid to be treated and type of contaminants, different iron powders and different functional ingredients could be chosen in order to obtain optimal efficiency. For reducing nitrate content in drinking water, chemically 20 reduced iron powder has shown to be one preferred embodiment of the present invention.

Preferably, the iron powder has a content of Fe of more than 90 % iron, preferably more than 95%. Iron powder particles used may originate directly from atomization of molten iron i.e. gas atomization and water atomization of 25 molten iron, chemical reduction of iron oxides such as CO-reduction or H2-reduction of iron oxides and thereafter being mixed with the functional ingredients optionally followed by other processes steps, such as compaction, heat treatment, sizing or combinations thereof.

The iron particles or iron powder used may be iron particles having a 30 particle size range between 10 mm and 10 µm, preferably between 5 mm and 20 µm and most preferably between 2 mm and 45 µm but is not to be interpreted as limited to these particle sizes. If the iron particles are going to be subjected to compaction and /or heat smaller particle sizes could be used e.g. between 2 mm and 1 µm, preferably between 1 mm and 1 µm, and preferably 35 0.5 mm and 1 µm. Further, in another embodiment the iron particles are preferably porous iron particles, i.e. the particles are themselves porous.

The functional ingredient is added to the iron body, i.e iron particles or iron particle structure, in an amount of with 0.01%-10% preferably 0.05-8%, preferably 0.1-5 % by weight of at least one functional ingredient. The particle size of the functional ingredients may be less than less than 20 μm , preferably 5 less than 10 μm , and in some cases also preferably less than 5 μm e.g. preferably 0.01-20 μm , preferably 0.01-10 μm , preferably 0.02-10 μm , preferably 0.02-5 μm .

Mixing of the iron powder or particles with the at least one functional ingredient is performed by mechanical mixing in such a way that the small 10 functional particles are forced into the internal porosity of the permeable iron particle structure and become locked in the structure.

Compaction of a disclosed material is done at pressures below 1000 MPa, preferably below 600 MPa, e.g. 10-1000 MPa or 20-600 MPa, to achieve a compacted density of about or less than 7.0 g/cm³ to form desired 15 shapes, such as blocks, granules or pellets. Preferably the compacted density is between 2.5-7.0 g/cm³, preferably 4-6 g/cm³ depending of type of iron powder used. The compaction process forces, if a functional ingredient is present, the free smaller functional ingredient particles to be locked inside the iron body. An iron powder having irregular shape and a porous structure can 20 provide high green strength to the permeable porous composite thus allowing lower density promoting higher permeability.

Embodiments requiring heating treatment to achieve a porous and permeable composite according to the invention would involve temperatures below 1200°C, below 1000°C, or below 800°C depending on the types iron 25 powder and functional ingredients used in a reducing or inert atmosphere. The heat treatment temperature being above 300 °C, preferably above 400°C. Temperature intervals of interest are especially 300-1200°C, 400-1200°C, 300-1000°C, 400-1000°C, 300-800°C, 400-800°C, 300-700°C, 400-700°C, 300-600°C, 400-600°C, 300-500°C and 400-500°C. The heat treatment 30 according to the present invention induces bonding between iron particles, so-called thermal bonding. If a functional ingredient is present, the heat treatment temperature should also be chosen so that the functional ingredient is kept in its original state, e.g. not diffusing into the iron structure. Also, the heat treatment process forces the free smaller functional ingredient particles 35 to become locked inside the permeable porous iron body.

Sizing of a disclosed iron material into particles before an addition of the at least one functional ingredient preferably results in a particles size

range between 10 mm and 10 μm , preferably between 5 mm and 20 μm and most preferably between 2 mm and 45 μm .

The mixing step may be performed in an ordinary mixer, such as a Z-blade mixer, cone mixer, ribbon mixer or high speed mixer for a period of time 5 between 0.5 min och 8 hours, preferably 1 minute to 5 hours or 30 min to 3 hours. Compaction may be performed in any suitable compaction equipment such as a ordinary uniaxial press at a pressure below 1 000 MPa or in high velocity compaction machine. Heat treatment may be performed in a batch oven or a continuous mesh belt furnace at a temperature of 300-1200°C for a 10 period between 5 minutes and 24 hours, e.g. 30 min to 18 hours, 1-12h, 2-8h. Sizing or gently grinding may be performed in any suitable equipment giving a particle size between 10 mm and 10 μm , preferably between 5 mm and 20 μm and most preferably between 2 mm and 45 μm .

(1) In one embodiment of the present invention chemically reduced 15 porous iron particles having a particle size range between 10 mm and 10 μm are mechanically mixed with at least one functional ingredient. The particle size of the functional ingredients may be less than 10 μm , preferably less than 5 μm . The mechanical mixing is performed in such a way that the small particles are forced into the internal porosity of the porous iron particles, such 20 as sponge-like reduced iron powder, and become locked in the structure.

(2) In another embodiment of the present invention, iron powder particles, having particle size range between 2 mm and 1 μm , preferably between 1 mm and 1 μm , and preferably 0.5 mm and 1 μm , are subjected to 25 heat treatment at 300-1200°C, depending on particle size, the types iron powder and functional ingredients, in a reducing or inert atmosphere. After heat treatment the resulting powder cake is sized into porous iron powder with desired size. The heat treated and sized powder is then mechanically mixed with 0.01-10% by weight of at least one functional ingredient. The particle size of the functional ingredients may be less than 10 μm , preferably 30 less than 5 μm . The mechanical mixing is performed in such a way that the small functional particles are forced into the internal porosity of the iron particles, and become locked in the structure.

(3) In yet another embodiment iron particles having a particle size 35 range between 10 μm and 10 mm are mixed with 0.01-10% by weight of at least one functional ingredient. The particle size of the functional ingredients being less than 20 μm , preferably less than 10 μm . Said mixture is to subjected to be compaction at pressures below 1000 MPa, preferably below 600

MPa, to achieve a compacted density between 2.5-7.0 g/cm³, preferably 4-6 g/cm³ depending of type iron powder used, into desired shapes such as blocks, granules or pellets. The compacted composite may alternatively be sized into desired size. The compaction process forces the free smaller

5 functional particles to be locked inside the porous iron body. An iron powder having irregular shape and a porous structure can provide high green strength to the permeable porous composite thus allowing lower density promoting higher permeability.

(4) In yet another embodiment iron particles having a particle size 10 range above between 10 mm and 10 µm, preferably between 5 mm and 20 µm and most preferably between 2 mm and 45 µm are mixed with 0.01%-10%, preferably 0.1-5 % by weight of at least one functional ingredient. The particle size of the functional ingredient being less than 20 µm, preferably less than 10 µm. Said mixture is subjected to heat treatment at 300-1200°C in a 15 reducing or inert atmosphere. After heat treatment the resulting powder cake is sized into desired size. The heat treatment process forces the free smaller particles to be locked inside the porous iron powder.

(5) In yet another embodiment iron particles having a particle size 20 range above between 10 mm and 10 µm are mixed with 0.01%-10% by weight of at least one functional ingredient. The particle size of the functional ingredient being less than 20 µm, preferably less than 10 µm. Said mixture is subjected to powder compaction at pressures below 1000 MPa to achieve a compacted density of less than 7.0 g/cm³ to form desired shapes, such as blocks, granules or pellets. The compaction process forces the free smaller 25 particles to be locked inside the iron body. Said compact is then subjected to heat treatment at 300-1200°C, depending on the particle size, types iron powder and functional ingredients used, in a reducing or inert atmosphere. The heat treatment temperature should be also chosen so that the functional ingredient is kept in its original state, e.g. not diffusing into the iron structure. 30 The compacted and heat treated composite may alternatively be sized into desired size.

(6) In an alternative embodiment iron particles having a particle size 35 range between 2 mm and 1 µm, preferably between 1 mm and 1 µm, and preferably 0.5 mm and 1 µm is subjected to compaction at pressures below 1000 MPa to achieve a compacted density between than 2.5-7.0 g/cm³, or 4-6 g/cm³ depending of type iron powder used, to form desired shapes, such as blocks, granules or pellets. The compacted body being then sized into

particles having a particles size range between 10 mm and 10 μm . The sized material are mechanically mixed with 0.01%-10% by weight of at least one functional ingredient. The particle size of the functional ingredient may be less than 10 μm , preferably less than 5 μm . The mechanical mixing is performed 5 in such a way that the small functional particles are forced into the internal porosity of the porous iron particles and become locked in the structure.

(7) In an alternative embodiment iron particles having a particle size range between 2 mm and 1 μm , preferably between 1 mm and 1 μm , and 10 preferably 0.5 mm and 1 μm is subjected to compaction at pressures below 1000 MPa to achieve a compacted density between than 2.5-7.0 g/cm³, or 4-6 g/cm³ depending of type iron powder used, to form desired shapes, such as blocks, granules or pellets. The compacted body is subjected to heat treatment at 300-1200°C, depending on the particle size, types iron powder 15 and functional ingredients used, in a reducing or inert atmosphere. The heat treated material being then sized into particles having a particles size range between 10 mm and 10 μm , preferably between 5 mm and 20 μm , and most preferably between 2 mm and 45 μm . The sized material are mechanically mixed with 0.01%-10% by weight of at least one functional ingredient. The 20 particle size of the functional ingredient may be less than 10 μm , preferably be less than 5 μm . The mechanical mixing is performed in such a way that the small functional particles are forced into the internal porosity of the porous iron particles and become locked in the structure.

In yet another embodiment a method for producing a porous and 25 permeable composite involves a H₂-reduced iron powder (porous particles) having a particle size range between 45 μm and 850 μm in size, and having a Fe-content of at least 90% by weight of the iron powder which is mechanically mixed with a functional ingredient chosen from graphite and/or activated carbon, wherein the functional ingredient is locked into the pores of the porous iron particles. The composite comprises a body of H₂-reduced iron 30 powder of porous particles having a particle size range between 45 μm and 850 μm in size and having a Fe-content of at least 90% by weight of the iron powder, and the functional ingredient is chosen from graphite and/or activated carbon.

In another embodiment of the invention a method for reducing the 35 content of contaminants in fluids is disclosed comprising the steps of obtaining a permeable porous composite as described above and allowing the

contaminated fluid to pass through the permeable composite thus reducing the content of the contaminants.

The permeable porous composite could be placed inside a container connected to the supply system of the fluid to be treated. Such containers

5 could be placed serial or parallel and connected to additional containers containing other known substances for reducing the content of harmful substances in the fluid. The composite according to the invention preferably has a specific surface area above 0.2, preferably above 0.5 and most preferably above 1 m²/g as measured by BET (Brunauer, Emmett and Teller, 1938).

10 The permeable porous composite according to the present invention should have a permeability, expressed as porosity ranging from 11 to 68 %, preferably 23-50 %, regardless of embodiment.

In one embodiment of the present invention the permeable porous composite consists of a mixture of porous iron, and 0.01%-10%, preferably 15 0.1-5 % by weight of at least one functional ingredient.

One embodiment of the invention is to apply the composite to drinking water treatment, waste water (municipal and industrial) treatment and soil remediation. The permeable porous composite according to the invention is designed for optimal treatment of nitrates and nitrites and toxic inorganic and 20 organic contaminants.

No direct hazardous waste products are generated when using the permeable porous composite according to the invention for water treatment.

The generated by product, i.e. the used porous composite, can be used in other industries, for instance as raw material for the steel industry.

25 The composite according to the invention demonstrates greater and more consistent performance in removal of nitrate and other contaminants during water treatment and results in no direct hazardous waste.

Drawings

Figure 1 shows a schematic drawing of permeable porous composites according to the invention and different shapes, which the composite could be made into.

Figure 2 shows a schematic drawing of a column used for evaluating the performance of the permeable porous composite according to the invention.

35 Figure 3 shows a schematic drawing of an apparatus used for evaluating permeability of the permeable porous composite according to the invention. Using minimal air pressure to assist water to overcome the surface ten-

sion of water on the composite in order to determine the max. (min.) permeable density (porosity). The composite was compacted into different density (porosity). Measurement of the amount of water passed through the composite by time under pressure or no pressure.

5 Figure 4: Examples of production methods according to the invention
 Figure 5: Picture of porous iron particle
 Figure 6: Picture of solid iron particle
 Figure 7: Picture showing functional ingredients (here activated carbon (AC) particles) in free form locked into the pores of porous iron particales
 10 through mechanically mixing process. The porous iron particle structure have a lighter colour than the encased AC particles.

Examples

The following materials were used as functional materials;

15 Table 1

Name	Main constituent % by weight	Average particle size D50, μm	Specific surface area (BET) m^2/g
Activated carbon, AC	95.4 % C	3.8	680
Graphite A	99.4 % C	2.71	250
Graphite B	99.0 % C	5.5	10
Ferric oxide	99.1 % Fe_2O_3	0.75	5

Used functional ingredients

Example 1

A sample of natural occurring water, ground water from Martinsberg, PA, USA, was used. Chemical analysis is shown in table 2. The test was performed by pumping the water into a column having a test material, as shown in figure 3. The empty bed contact time, EBCT, was 25 minutes. The effluent water was analyzed with regards to contaminants after certain time intervals. The content of contaminants at 0 hours is equal to the content in the non treated water (influent).

Table 2

Nitrate (as N) [mg/l]	22.7
pH	7.33
Alkalinity [mg/l]	220
Acidity [mg/l]	<1.0
Total hardness [mg/l]	531
Conductivity [mS/cm]	2680

Different materials were tested as permeable materials referring to their ability to reduce nitrate concentration in the solution. The following

5 materials were tested;

Material 1; A commercial available activated carbon granular, AC, 0.6 x 2.4 mm size having a specific surface area of 600 m²/g as measured by BET method.

10 Material 2; A commercial available solid non porous atomized iron powder, having a particle size less than 200µm, having a carbon content of less than 0.1% by weight dissolved in the iron matrix, and a specific surface area of less than 0.1 m²/g as measured according to BET.

15 Material 3; A commercial available solid non porous iron aggregate having a carbon content of 3% by weight dissolved in the iron matrix, a specific surface area of 1.2 m²/g as measured according to BET and a size of 0.3 x 5 mm.

20 Material 4; A permeable porous composite according to the present invention having a specific surface area of 2.7 m²/g as measured according to BET. The composite being produced by mixing graphite A with a porous hydrogen reduced iron powder having a particle size between 10-850 µm, mean particle size of about 250 µm for a period of 30 min until the graphite was forced into the pores of the iron powder. The amount of graphite A in said composite was 1% by weight of the composite.

25 Material 5: A permeable porous composite according to the present invention having a specific surface area of 6.7 m²/g as measured according to BET. The composite being produced by activated alumina with a porous hydrogen reduced iron powder having a particle size between 10-850 µm, mean particle size of about 250 µm for a period of 30 min until the alumina was forced into the pores of the iron powder. The amount of activated 30 alumina in said composite was 4% by weight of the composite.

Material 6: A permeable porous composite according to the present invention having a specific surface area of 2.0 m²/g as measured according to BET. The composite being produced by zeolite with a porous hydrogen reduced iron powder having a particle size between 10-850 µm, mean particle size of about 250 µm for a period of 30 min until the zeolite was forced into the pores of the iron powder. The amount of zeolite in said composite was 4% by weight of the composite.

The test was continuously conducted during a period of 72 hours for each material. The following table shows the concentration of nitrate ions in effluent for each material. The concentration of nitrate was measured by an ion selective electrode and expressed as nitrogen content in mg/l.

Table 3

Hours	Material 1 – comparative example		Material 2 – comparative example		Material 3 – comparative example		Material 4 – permeable porous composite – according to the invention (graphite A)		Material 5 – permeable porous composite – according to the invention (activated alumina)		Material 6 – permeable porous composite – according to the invention (Zeolite)	
	mg/l	% reduction	mg/l	% reduction	mg/l	% reduction	mg/l	% reduction	mg/l	% reduction	mg/l	% reduction
0	22.4	0	22.4	0	22.4	0	22.4	0	22.6	0	22.6	0
3	12.3	45.1	21.0	6.3	22.8	0	3.6	83.9	16.8	25.7	21.3	5.8
6	15.6	30.4	22.5	0	22.4	0	1.9	91.5	13.1	42.0	19.7	12.8
9	18.4	17.9	22.9	0	22.0	1.8	1.2	94.6	12.4	45.1	12.3	45.6
12	20.2	4.6	22.6	0	22.1	1.3	0.9	96.0	3.6	84.1	7.6	66.5
24	21.3	4.9	21.7	3.1	21.8	2.7	1.2	94.6	2.6	88.3	6.5	71.3
28	22.1	1.3	22.4	0	20.4	8.9	0.9	96.0	2.2	90.1	5.0	77.8
32	21.5	4.1	21.4	4.5	20.0	10.7	0.7	96.9	1.8	91.9	2.9	87.2
48	22.4	0	22.3	0.4	19.2	14.3	0.9	96.0	2.0	91.3	2.2	90.1
52	22.4	0	21.6	3.6	16.7	25.4	1.1	95.1	1.7	92.5	2.0	91.3
56	22.4	0	21.9	2.2	16.3	27.2	1.9	91.5	1.7	92.5	1.9	91.8
72	22.4	0	22.0	1.8	13.0	41.9	1.8	92.0	1.8	91.9	1.8	91.9

As can be seen from table 3 above the permeable porous composites according to the invention are able to reduce the nitrate content during the whole test period and above 90 % from between 3 to 48 hours of running, depending on the functional ingredient used. Material 1 reduces the nitrate 5 concentration with about 18-45% up to 9 hours. Material 2 shows hardly any reducing effect and material 3 reduces the nitrate content less than 50 % during the test period and only start to work after a substantial time period.

Example 2

Various permeable porous composites according to the invention, were 10 tested according to the method described in example 1, with regards to their nitrate reducing ability. The water to be used was taken from the same source. The permeable porous composites were prepared by mixing different functional ingredients with a porous iron powder obtained by hydrogen reduction of iron oxides and having a particle size between 10-850 μm , mean 15 particle size of about 250 μm for a period of 30 minutes until the functional ingredient was well distributed and locked into the pores of the permeable porous iron.

In composite 1 1% by weight of AC was used as functional ingredient. The specific surface area of composite 1 was 5.7 m^2/g as measured by BET.

20 In composite 2 2% by weight of AC was used as functional ingredient. The specific surface area of composite 2 was 12.8 m^2/g as measured by BET.

In composite 3 1% by weight of graphite A was used as functional ingredient. The specific surface area of composite 3 was 2.7 m^2/g as measured by BET.

25 In composite 4 2% by weight of graphite B and 3% by weight of ferric oxide, Fe_2O_3 were used as functional ingredients. The specific surface area of composite 1 was 0.6 m^2/g as measured by BET.

The concentration of nitrate was measured by an ion selective electrode and expressed as nitrogen content in mg/l.

Table 4

Hours	Composite 1 – according to the invention		Composite 2 – according to the invention		Composite 3 – according to the invention		Composite 4 – according to the invention	
	N mg/l	% reduction						
0	22.4	0	22.4	0	22.4	0	22.7	0
3	13.1	41.5	12.0	46.4	13.6	39.3	21.4	5.7
6	11.8	47.3	9.8	56.3	1.9	91.5	20.4	10.1
9	7.8	65.2	5.7	74.6	1.2	94.6	19.6	13.7
12	1.7	92.4	1.3	94.2	0.9	96.0	17.6	22.5
24	1.6	92.9	1.0	95.5	1.2	94.6	9.6	57.7
28	2.2	90.2	1.5	93.3	0.9	96.0	7.3	67.8
32	2.2	90.2	1.2	94.6	0.7	96.6	6.5	71.4
48	2.5	88.8	1.0	95.5	0.9	96.0	4.1	81.9
52	2.1	90.6	0.9	96.0	1.1	95.1	4.1	81.9
56	2.2	90.2	1.7	92.4	1.9	91.5	6.3	72.2
72	1.3	94.2	1.0	95.5	1.8	92.0	9.1	59.9

As can be seen from table 4 the permeable porous composites 1-3 has a capacity of removal of nitrate with more than 90 % after 9-12 hours. Composite 4 reduces the nitrate content to a level of about 70 % after 32 hours and up to 56 hours of testing.

Example 3

This example shows the ability for a permeable porous composite according to the invention to reduce multiple contaminants in ground water. The test was performed according to example 1 with the exception that 10 Arsenic, As, phosphate, PO_4^{3-} , and hexavalent chromium, Cr^{VI} , was added, spiked, to the water prior to testing.

The permeable material was the permeable porous composite no 2 used in example 2.

The concentration of nitrate was measured by an ion selective electrode and expressed as nitrogen content in mg/l. The concentration of phosphate and hexavalent Cr was measured by a colometric method and the concentration of arsenic by atomic absorption analyzer, AAS. The concentration of phosphate was expressed as P mg/l. Also concentrations of As and Cr is expressed in mg/l.

Table 5

Hours	Nitrate		As mg/l		PO ₄ ³⁻		Cr ^{VI}	
	(N) mg/l	% reduction	mg/l	% reduction	(P) mg/l	% reduction	mg/l	% reduction
0	23.1	0	1.260	0	0.285	0	0.273	0
3	5.01	78.3	0.007	99.4	0.064	77.5	0.031	88.6
6	2.30	90.0	0.007	99.4	0.053	81.4	0.021	92.3
9	1.44	93.8	0.002	99.8	0.053	81.4	0.027	90.1
12	1.46	93.7	0.003	99.8	0.048	83.2	0.023	91.6
24	0.49	97.9	0.006	99.5	0.058	89.6	0.013	95.2
28	0.61	97.4	0.009	99.3	0.061	78.6	0.012	95.6
32	0.80	96.5	0.008	99.4	0.059	79.3	0.011	96.0
48	1.00	95.7	0.007	99.4	0.073	74.4	0.014	94.9

As can be seen from table 5 the permeable porous composite according to the invention has the capacity of removal multiple combinations of contaminants.

Example 4

This example shows the ability for a permeable porous composite according to the invention, composite 2 in example 2, to reduce multiple contaminants in ground water compared to material 3 in example 1.

The test was performed according to example 1 with the exception that Arsenic, As was added, spiked, to the water prior to testing.

The concentration of nitrate was measured by an ion selective electrode and expressed as nitrogen content in mg/l and the concentration of arsenic was measured by AAS.

Table 6

Hours	Non porous iron powder + 3% graphite - comparative example				Composite 2 - according to the invention			
	Nitrate (N) mg/l	% reduction	As mg/l	% reduction	Nitrate (N) mg/l	% reduction	As mg/l	% reduction
0	22.5	0	5.300	0	23.0	0	5.400	0
3	21.1	6.2	0.022	99.6	3.9	83.0	0.014	99.7
6	20.8	7.6	0.013	99.8	3.0	87.0	0.007	99.9
9	21.1	6.2	0.020	99.6	4.5	80.4	0.083	98.5
12	22.5	0	0.033	99.4	3.6	84.3	0.024	99.6
24	18.1	19.6	0.458	91.4	3.0	87.0	0.019	99.6
28	22.0	2.2	0.460	91.3	2.7	88.3	0.011	99.8

As is evident from table 6 the permeable porous composite according to the invention has in the long run a higher capacity of removal of arsenic as compared to the comparative example. After 24 hours the ability for the com-

5 parative material to reduce As is going down whereas such tendency is not noticed for the composite according to the invention. The capacity for removal of nitrate is about 80-90% for the inventive material whereas the non porous iron powder having a carbon content of 3% by weight dissolved in the iron matrix removes nitrate to a limited extent.

10 Example 5

This example shows how to determine the degree of locking for a permeable porous composite according to the invention.

A porous iron powder was mixed with different functional ingredients, 2 % by weight of AC, 1% by weight of graphite A and 2 % by weight of graphite B, respectively, for 20 minutes. Standard sieve analysis were performed 15 on the permeable porous composite and content of carbon was measured in the different fractions. When the finer functional ingredient is well distributed and locked into the pores of the porous iron the relative content of functional ingredient in the different fractions shall be as close as possible to the percentage 20 of total material in the fractions. By dividing the content of functional

material in a sieve interval with the total content of functional ingredient, a measure of degree of distribution and locking is obtained. In order to achieve a sufficient distribution and locking of the functional ingredient this measure, relative distribution shall be between 1.50 and 0.50 for intervals containing

5 more than 5 % by weight of the permeable porous composite. Furthermore, the amount of functional material in the finer fraction, less than 0.075 mm, shall not exceed 30 %, preferably not exceed 20 % of the total amount of functional material.

The porous iron powder used had a Fe content of minimum 97% by weight, a carbon content below 0.1 % by weight, an apparent density of 1.3 g/cm³. 46.8 % by weight was above 0.250 mm, 30.9 % by weight above 0.150 mm, 13.8 % by weight above 0.075 mm and the rest, 8.5 % by weight below 0.075 mm.

The following table 7 shows the sieve analysis of the different permeable porous composite and also the content of carbon in the different sieve fractions.

Table 7

	Added 2 % AC				Added 1% graphite A				Added 1% graphite B			
	% by weight of comp	% C by weight	Distrib. of C in fractions %	Relative distrib. of C	% by weight of comp	% C by weight	Distrib. of C in fractions %	Relative distrib. of C	% by weight of comp	% C by weight	Distrib. of C in fractions %	Relative distrib. of C
Total	100	1.91	100.0	1	100	0.98	100	1	100	1.99	100.0	1
+0.250 mm	48.6	1.59	40.5	0.83	47.6	0.88	42.7	0.89	47.3	1.55	36.9	0.78
+0.150 mm	28.5	2.06	30.7	1.08	27.7	0.96	27.2	0.98	29.4	2.23	32.9	1.12
+0.075 mm	14.2	2.36	17.5	1.23	14.2	1.15	16.8	1.18	14.9	2.54	19.0	1.28
-0.075 mm	8.7	2.48	11.3	1.30	10.5	1.24	13.3	1.27	8.4	2.65	11.2	1.33

Example 6 - Preparation of the permeable porous composite

This example shows how various types of iron powders can be used for production of the permeable porous composite, depending on the method of preparation. Iron powders used and method of production shall be chosen 5 so that the permeable porous composite will have less than 20 % by weight below 75µm, preferably less than 10 % by weight below 75 µm as finer porous iron particles may easily be transported away by the flow of water. As functional ingredient 2% of AC was used.

Different types of permeable porous composites were prepared by;

10 (1) compacting an iron powder into TRS (Traverse Rupture Strength) bars followed by sizing, gently grinding into desired size, thereafter mixed with the functional ingredient, - CSM

(2) compacting an iron powder into TRS bars followed by heat treatment in an atmosphere of nitrogen followed by sizing, grinding into desired size,

15 thereafter mixed with the functional ingredient, - CHSM

(3) mixing the functional ingredient with an iron powder compacting the mixture into TRS bars followed by sizing, gently grinding into desired size, - MCS

(4) mixing the functional ingredient with an iron powder, compacting the

20 mixture into TRS bars followed by heat treatment in an atmosphere of nitrogen followed by sizing, grinding into desired size, - MCHS

After compaction, green density, porosity and green strength were measured. Green strength were also measured after heat treatment. Thereafter the samples were sized into desired size, particle size distribution 25 and apparent density were measured on the obtained sized powder.

Green density (GD) was measured by dividing the weight of the sample with the calculated volume.

Green strength (GS), expresses the strength of the porous structure of the composite made, was measured according to ASTM B 312- ISO 3995

30 Porosity was measured based on green density measurements and the specific density (the density without the porosity) of the material.

Apparent density (AD) was measured using a Hall Flow meter.

Specific surface area (SSA) was measured according to the BET method.

Table 8. Preparation of different types of composites and their efficiency in nitrate reduction

Process step	Production method	1- CSM	3- MCS	2- CHSM	4- MCHS	2- CHSM	4- MCHS	2- CHSM	4- MCHS
Raw iron material	Iron powder	Porous	Porous	Porous	Porous	Porous	Porous	Non porous	Non porous
% Fe	min 97	min 97	min 97	min 97	min 98	min 98	min 99	min 99	min 99
% C	max 0.1	max 0.1	max 0.1	max 0.1	max 0.1	max 0.1	max 0.1	max 0.1	max 0.1
AD g/cm ³	1.3	1.3	1.8	1.8	2.4	2.4	3	3	3
+0.850 mm %wt	0	0	0	0	0	0	0	0	0
+0.250 mm %wt	46.8	46.8	0	0	0	0	0	0	0
+0.150 mm %wt	30.9	30.9	4.9	4.9	1.3	1.3	7.6	7.6	7.6
+0.075 mm %wt	13.8	13.8	50.2	50.2	45.3	45.3	37.2	37.2	37.2
-0.075 mm %wt	8.5	8.5	44.9	44.9	53.4	53.4	55.2	55.2	55.2
SSA m ² /g	0.23	0.23	0.2	0.2	0.12	0.12	0.05	0.05	0.05
Mixing process	%AC	0	2	0	2	0	2	0	2
	Time min	0	20	0	20	0	20	0	20

Compaction - process & material	Compaction Pressure psi/MPa	25000/ 172	25000/ 172	30000/ 206	30000/ 206	30000/ 206	30000/ 206	30000/ 206
	GD g/cm ³	4.68	4.42	4.96	4.86	5.42	5.35	5.76
	Porosity %	40.5	43.8	37.0	38.2	31.1	32.0	26.8
	GS psi/N/mm ²	4300/ 30.1	3810/ 26.7	1500/ 10.5	1100/ 7.7	1600/ 11.2	580/ 4.1	900/ 6.3
	Heat treatment - process & material	Temperature °C	21	21	538	900	538	900
Sizing process	GS after heat treatment psi/N/mm ²	4300/ 30	3810/ 26	3960/ 27.7	4660/ 32.6	3120/ 21.8	990/ 6.9	2890/ 20.2
	Grinding	yes	yes	yes	yes	yes	yes	yes
Mixing process	%AC	2	0	2	0	2	0	2
	Time min	20	0	20	0	20	0	20
Final product - Sized material	composite	porous	porous	porous	porous	porous	porous	porous
	%C	2	2	2	2	2	2	2
	AD g/cm3	1.29	1.37	1.56	1.48	1.98	1.88	2.78
	+0.250 mm %wt	72	68	73.4	91.1	51.9	63.7	66.2

24

Table 8 shows that permeable porous composites according to the present invention may be produced according to various methods.

For example non porous iron powder can be turned into a permeable porous composite having a porosity above 25%, giving sufficient permeability 5 to the contaminated fluid or liquid. For example non porous iron powder can also be turned into a porous iron powder or structure.

Finer iron powder can also be used for producing the permeable porous composite with a particle size distribution substantially less than 20 % by weight being less than 75 μm . If more than 20 % by weight of the 10 permeable porous composite is less than 75 μm the composite will be less effective as the finer fraction tends to be carried away by the liquid.

In order not to disintegrate after processing it is believed that the green strength of the compacted material should exceed 500 psi, a criterion which is fulfilled by all examples of example 6.

15 **Example 7**

This example shows how the minimum required porosity for the permeable porous composite was measured. Three different iron powders, suitable to be used for producing the permeable porous composite, and two different permeable porous composites according to the invention was tested.

20 The test equipment as according to Figure 3.

The iron powders and the composites were compacted into different green densities. The permeable porous composites were manufactured according to embodiment (3) disclosed earlier.

25 The materials to be tested were placed in the column and water was passed. The amount of water penetrating through the test material was measured as ml water after 5 minutes.

30 The following table 9 shows that the porosity of the permeable porous composite has to be more than about 11 %. This is evident by test 1 and 2. At a porosity of 9.7 % no water passes through the composite at any applied pressure (test 2). At a porosity of 12.8 % water passes through the composite at a minimal pressure of 5 psi (0.03 MPa), thus the porosity needed has to be above about 11 %.

Table 9

		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Iron powder		Non porous	Non porous	Porous	Porous	Porous	Porous
	% Fe	min 99	min 99	min 98	min 97	min 97	min 97
	% C	max 0.1					
	AD g/cm ³	3	3	2.4	1.3	1.3	1.3
	+0.850 mm %wt	0	0	0	0	0	0
	+0.250 mm %wt	0	0	0	46.8	46.8	46.8
	+0.150 mm %wt	7.6	7.6	1.3	30.9	30.9	30.9
	+0.075 mm %wt	37.2	37.2	45.3	13.8	13.8	13.8
	-0.075 mm %wt	55.2	55.2	53.4	8.5	8.5	8.5
	SSA m ² /g	0.05	0.05	0.12	0.23	0.23	0.23
	mixing	no	no	no	no	1% AC	1% graphite A
Compacted material	density, g/cm ³	6.86	7.11	5.96	4.77	4.94	5.00
	porosity, %	12.8	9.7	24.3	39.4	37.2	36.5
Permeability test	time, min	5.0	5.0	5.0	5.0	5.0	5.0
	air pressure, psi/MPa	ml water after 5 minutes					
	0/0	0	0	0	0	0	0
	5/0.034	1	0	3	2	2	2
	10/0.069	2	0	5	4	4	4
	20/0.138	3	0	11	9	6	7

CLAIMS

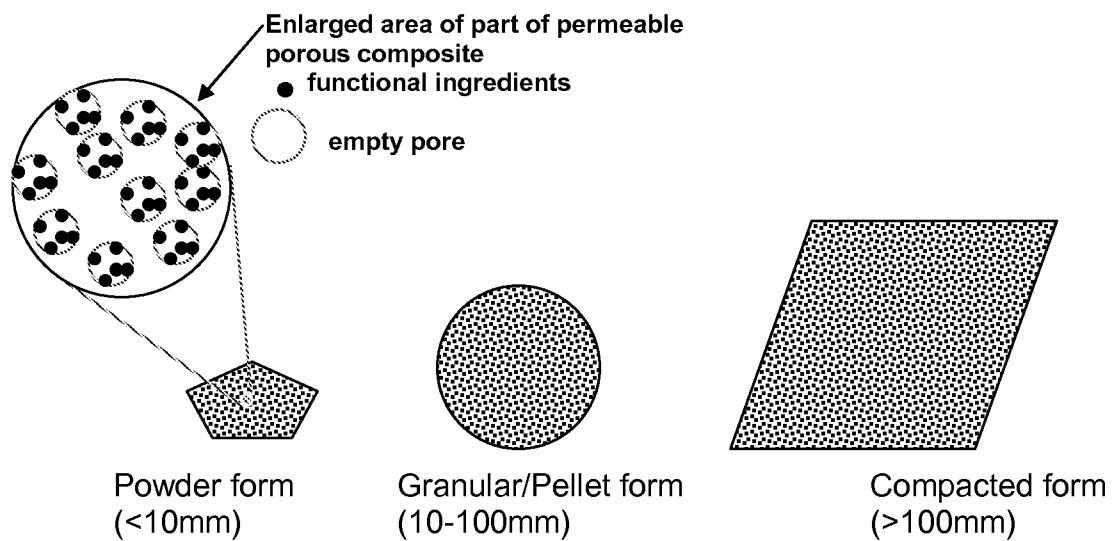
1. A porous and permeable composite for treatment of contaminated fluids characterized in that said composite comprises a body of iron particles and 5 0.01-10% by weight of at least one functional ingredient, selected from the group consisting of carbon containing compounds, calcium containing compounds, sodium containing compounds, iron containing compounds, titanium containing compounds and aluminium containing compounds, in free form, distributed and locked in the pores and cavities of the iron body, 10 wherein the iron particles have a particle size range between 10 µm and 10 mm.
2. A composite according to claim 1, wherein the iron powder particles have a particle size range between 20 µm and 5 mm and preferably between 45 µm and 2 mm; or 1 µm to 2 mm, preferably 1 µm to 1 mm and preferably 1 15 µm to 0.5 mm.
3. A composite according to claim 1 eller 2, wherein said carbon containing compounds are selected from graphite, activated carbon and coke; said iron containing compounds are selected from ferric or ferrous sulphate, ferric oxides and ferric hydroxides; said titanium containing compound is 20 titania; said sodium containing compound is soda; said calcium containing compounds is lime; and said aluminium containing compounds is selected from alumina and aluminium silicates such as zeolites; preferably from the group of graphite, activated carbon, coke, activated alumina and zeolites.
4. A composite according to any of the preceding claims, wherein the at 25 least one functional ingredient has a particle size below 20 µm, preferably 0.01-20 µm, preferably 0.01-10 µm, 0.02-10 µm, preferably 0.02-5 µm.
5. A according any of the preceding claims, wherein the iron particles has a content of Fe of more than 90 % iron, preferably more than 95% and/or said iron powder is manufactured from chemical reduction of iron oxides or atomi- 30 zation of molten iron.
6. A composite according to any of the preceding claims, wherein said composite has a specific surface area above 0.2, preferably above 0.5 and most preferably above 1 m²/g as measured by BET.
7. A composite according to any of the preceding claims, wherein the total 35 amount of the at least one functional ingredient is between 0.05-8 % by weight, preferably between 0.1-5% by weight.

8. A composite according to any of the preceding claims, wherein the iron particles are porous.
9. A composite according to any of the preceding claims, wherein said composite comprises a body of H₂-reduced iron powder of porous particles having a particle size range between 45 µm and 850 µm in size and having a Fe-content of at least 90% by weight of the iron powder, and the functional ingredient is chosen from graphite and/or activated carbon.
10. A method for manufacturing a porous and permeable composite for treatment of contaminated fluids, comprising the steps of:
 - 10 mechanically mixing iron particles, having a particle size range between 10 µm and 10 mm, representing an iron body with at least one functional ingredient, selected from the group consisting of carbon containing compounds, calcium containing compounds, sodium containing compounds, iron containing compounds, titanium containing compounds and aluminium containing compounds, in free form, which is present in an amount of 0.01-10% by weight, until the functional ingredients is distributed by mechanical forces into the iron body and locked;
 - 15 optionally heat treating the iron body, with or without said at least one functional ingredient, at a temperature between 300 and 1200°C in an inert or reducing atmosphere;
 - 20 optionally compacting the iron body, with or without said at least one functional ingredient, into a compacted body having a green density equal to or below 7.0 g/cm³; and/or
 - 25 optionally sizing said iron body, with or without said at least one functional ingredient,
- wherein said steps can be carried out in optional order.
11. Method according to claim 10, wherein the optional compaction is done at pressures below 1000 MPa, preferably below 600 MPa, e.g. 10-1000 MPa or 20-600 MPa.
- 30 12. Method according to claim 10 or 11, wherein the optional heat treatment is carried out at 300-1200 °C, preferably 400-1200 °C, 300-1000 °C, 400-1000 °C, 300-800 °C, 400-800 °C, 300-700 °C, 400-700 °C, 300-600 °C, 400-600 °C, 300-500 °C or 400-500 °C.
- 35 13. Method according to any of the preceding claims, wherein the iron particles are H₂-reduced porous iron powder particles having a particle size range between 45µm and 850µm in size, and having a Fe-content of at least 90% by weight of the iron powder, which are mechanically mixed with a

functional ingredient chosen from graphite and/or activated carbon, wherein the functional ingredient is locked into the pores of the porous iron particles.

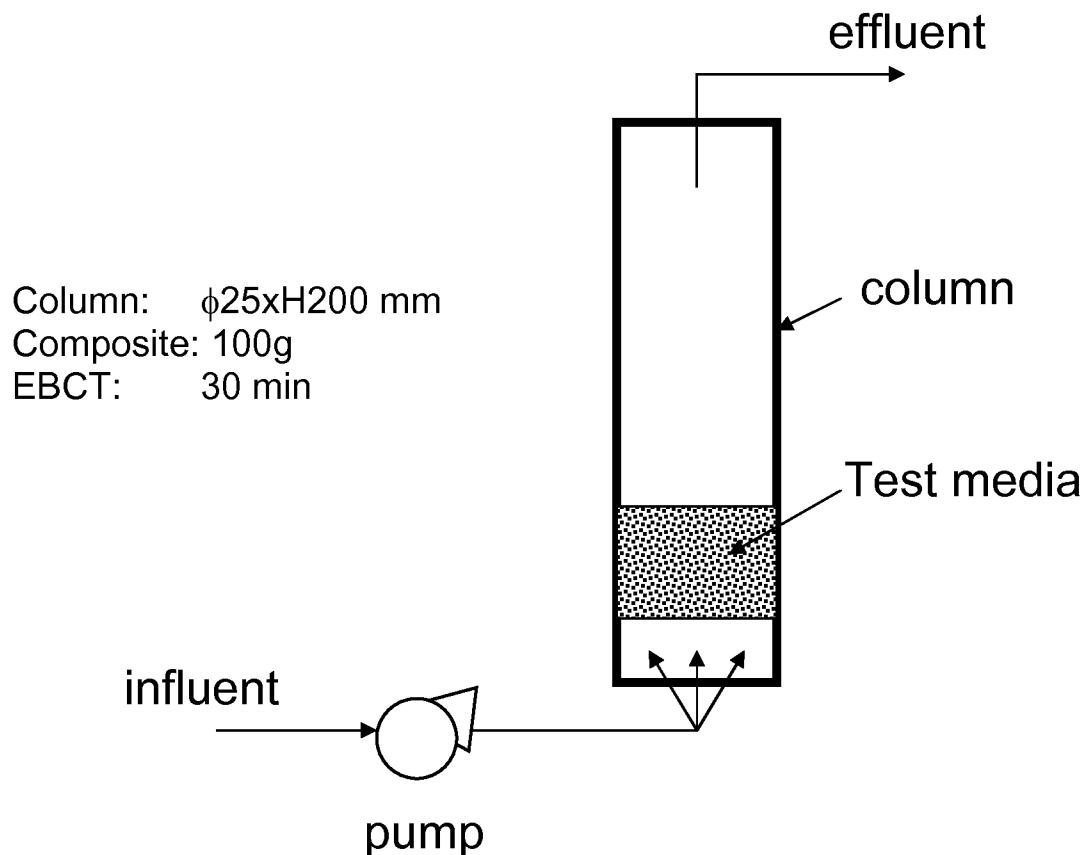
14. Use of a composite according to claims 1-9 for reducing the content of contaminants in a fluid, wherein said fluid is allowed to pass through the
5 permeable composite.
15. Use of a composite according to claims 1-9 for reducing the content of contaminants in a fluid, wherein said fluid is a water containing fluid, preferably ground water, river water, industrial waste water, civic waste water and/or surface water.
- 10 16. Use of a composite according to claims 1-9 for reducing the content of contaminants selected from the group consisting of nitrate, nitrite, heavy metals, such as As, Pb, Hg, Cd, Se, Cr and hexavalent Cr, other toxic inorganic substances and toxic organic compounds; or combinations thereof; preferably nitrate and/or nitrite.
- 15 17. Use of a composite according to claims 1-9 wherein said fluid is to be used as drinking water.

Figure 1



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Figure 2



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Figure 3

Column: $\phi 25 \times H200$ mm
Composite: $\phi 25 \times H20$ mm
water: 100 ml
air pressure: 0 and 0.035 MPa

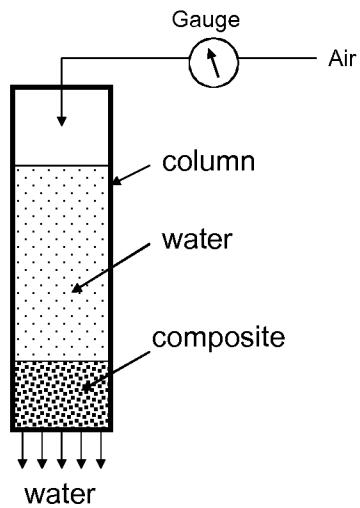


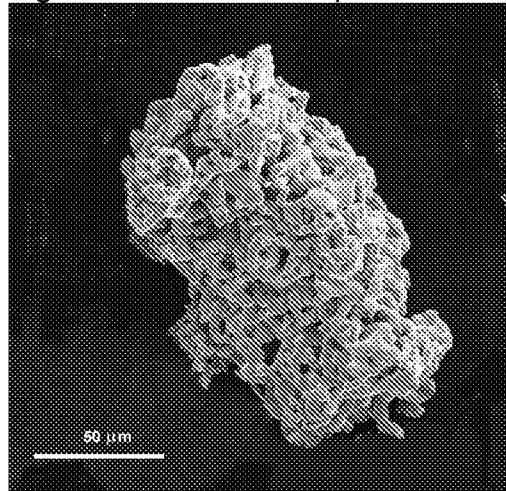
Figure 4. Examples of embodiments according to the invention

Method	Process Steps
(1)	<p>Mixing [Chem. Reduced Fe-powder (10mm-10µm) + Functional ingredient (<20µm, pref. <10µm)]</p>
(2)	<p>Heat treatment [Fe-powder (2mm-1 µm, pref. 1mm-1µm, most pref. 0.5mm-1µm), 300-1200°C] ↓ Sizing [to coarser porous powder] ↓ Mixing [Porous Fe- powder +Functional ingredient (<10µm, pref. <5µm)]</p>
(3)	<p>Mixing [Fe-powder (10mm-10µm) +Functional ingredient (<20µm, pref. <10µm)] ↓ Compaction [<1000MPa, pref. <600MPa to compacted body (blocks, granules, pellets) (2.5-7g/cm³, pref. 4-6g/cm³)] ↓ Sizing (optional) [to desired size]</p>
(4)	<p>Mixing [Fe-powder (10mm-10µm, pref.5mm-20µm, most pre. 2mm-45µm) +Functional ingredient (<20µm, pref. <10µm)] ↓ Heat treatment [300-1200°C] ↓ Sizing [to desired size]</p>

(5)	<p>Mixing [Fe-powder (10mm-10µm) +Functional ingredient (<20µm, pref. <10µm)] ↓ Compaction [<1000MPa, pref. <600MPa to compacted body (blocks, granules, pellets) <7g/cm³] ↓ Heat treatment [300-1200°C] ↓ Sizing (optional) [to desired size]</p>
(6)	<p>Compaction [Fe-powder (2mm-1 µm, pref. 1mm-1µm, most pref. 0.5mm-1µm), <1000MPa to compacted body (blocks, granules, pellets) (2.5-7g/cm³, or 4-6g/cm³)] ↓ Sizing [to particles 10mm-10µm] ↓ Mixing [Sized material +Functional ingredient (<10µm, pref. <5µm)]</p>
(7)	<p>Compaction [Fe-powder (2mm-1 µm, pref. 1mm-1µm, most pref. 0.5mm-1µm), <1000MPa to compacted body (blocks, granules, pellets) (2.5-7g/cm³, or 4-6g/cm³)] ↓ Heat treatment [300-1200°C] ↓ Sizing [to particles 10mm-10µm, pref. 5mm-20µm, most pref. 2mm-45µm] ↓ Mixing [Sized material +Functional ingredient (<10µm, pref. <5µm)]</p>

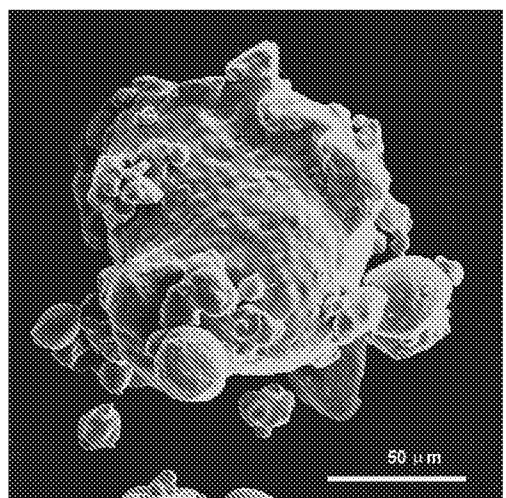
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Figure 5 : Porous iron particle



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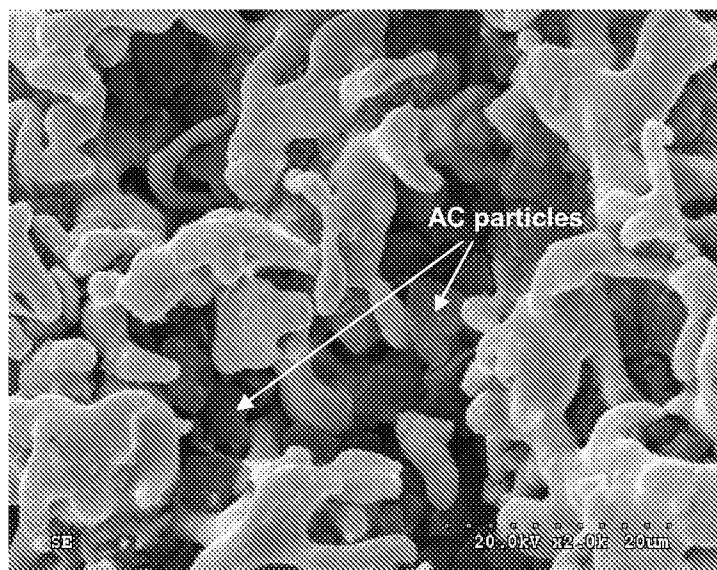
Figure 6: Solid iron particle



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Figure 7: Functional ingredients (here activated carbon (AC) particles) in free form locked into the pores of porous iron particales through mechanically mixing process



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