

Mechanochemical process

Field of invention

5 The present invention relates to a mechanochemical process for decontaminating and/or eliminating problematic, synthetic, biogenic and biological materials, for digesting phosphates, for immobilizing metals and compounds thereof, for splitting carbon dioxide and carbon monoxide into the elements and for recovering valuable products.

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The present invention also relates to the use of the products resulting from the mechanochemical process.

15 Last but not least, the present invention relates to new mechanical mills for mechanochemical processes.

Prior art

20 The special physicochemical effects and mechanisms of mechanochemistry are the subject of numerous theoretical investigations such as the articles by

- V. V. Boldyrev, Mechanochemistry and mechanical activation of solids, in Russian Chemical Reviews, 75 (3) 177-189 (2006);
- 25 - P. Yu. Butygain and A. N. Streletskii, The Kinetics and Energy Balance of Mechanochemical Transformations, in Physics of the Solid State, Vol. 47, No. 5, 2005, 856-852;
- J. Fontaine et al. Tribochemistry between hydrogen and diamond-like carbon
30 films, in Surface Coatings Technology 146-147 (2001) 286-291;
- L. Takacs, Mechanochemistry and the Other Branches of Chemistry: Similarities and Differences, in Acta Physica Polonica A, Vol. 121 (2012), 3, 711-714;

- S. A. Steiner III et al., Circumventing the Mechanochemical Origins of Strength Loss in the Synthesis of Hierarchical Carbon Fibers, in *Applied Materials & Interfaces*, 2013, 4892-4903; or

- 5 - MaterialsGate Newsletter Sept. 12, 2017, Tribology: Simulation shows previously unknown friction mechanisms at the molecular level.

Furthermore, review articles give an overview of the historical development and perspectives of mechanochemistry, such as the articles by

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- S. L. James et al., Mechanochemistry: opportunities for new and cleaner synthesis, in *Chem. Soc. Rev.*, 2012, 41, 413-447, in which syntheses of inorganic materials such as alloys, oxides, halides, sulfides, nitrides and composites, cocrystals such as charge transfer cocrystals, acid-base cocrystals, ionic cocrystals and organic catalysis by cocrystallization, new forms of drugs such as pharmaceutical cocrystals and organic syntheses with carbon-carbon and carbon-X bond formation such as stoichiometric organic reactions, metal catalyzed organic reactions, organocatalytic asymmetric reactions, syntheses of ligands and host-guest systems, the synthesis of metal complexes and the synthesis of coordination polymers (MOFs) are presented;

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- P. Balaz et al., Hallmarks of mechanochemistry: from nanoparticles to technology, in *Chem. Soc. Rev.*, 42, 2013, 7571-7637; or

- Tomislav Friscic, Supramolecular concepts and new techniques in mechanochemistry: cocrystals, cages, rotaxanes, open metal-organic frameworks, in *Chem. Soc. Rev.*, 2012, 41, 3493-3510.

Mechanochemistry is also used to solve special problems and for synthesis.

- 30 For example, F. Cavalierie and F. Padella describe in the article Development of composite materials by mechanochemical treatment of post-consumer plastic waste, in *Waste Management*, 22 (2002) 913-916, that a composite can be produced from mixtures of polypropylene and polyethylene by milling in liquid carbon dioxide, which

no longer shows any incompatibility between the two polymers and which has better properties than the starting polymers.

For example, Haoliang Jia et al. describe in their article Formation of nanocrystalline
 5 TiC from titanium and different carbon sources by mechanical alloying in Journal of Alloys and Compounds, 472 (2009) 97-103, the production of nanocrystalline titanium carbide from titanium powders and various carbon sources.

Tan Xing et al. describe in their article Ball milling: a green approach for synthesis of
 10 nitrogen doped carbon nanoparticles in Nanoscale, 2013, 5, 7970-7976, an industrially applicable synthesis process for the production of nitrogen doped carbon nanoparticles.

L. Borchardt et al. describe in their article Mechano-chemistry assisted synthesis of
 15 hierarchical porous carbon applied as supercapacitors in Beilstein Journal of Organic Chemistry, 2017, 13, 1332, the production of porous carbon from plant materials for use in capacitors and electrodes.

In their article Mechanochemical surface modification of carbon fibers using a simple
 20 rubbing process in Journal of Composite Materials 0 (0) 1-8, S. Motozuka et al. describe the surface modification of carbon fibers based on polyacrylonitrile by mechanical friction.

In their article Mechanochemical polymerization - controlling a polycondensation
 25 reaction between a diamine and a dialdehyde in a ball mill in RCS Adv., 2016, 6, 64799-64802, S. Grätz and L. Borchardt describe the mechanochemical polycondensation between a diamine and a dialdehyde, which offers an attractive alternative to conventional processes.

30 In the conference report AIP Conference Proceedings, Volume 1664, Issue 1, 150008 (2015), Recycling and Processing of several typical crosslinked polymer scraps with enhanced mechanical properties based on solid state mechanochemical milling, the authors describe the milling of partially devulcanized or uncrosslinked tire rubber chips, post-vulcanized fluororubber chips and cross-linked polyethylene chips from

cable waste, by means of which they obtain material with improved processability and better mechanical properties.

5 Further examples of the usefulness of mechanochemistry in different fields emerge from the following patents.

For example, the German published patent application DE 10 2014 101 766 A1 discloses a process for recovering and, optionally, separating lanthanides as chlorides or oxides from mineral waste and residues. In this process, first, powder
10 particles are produced, which are then activated mechanochemically.

The European patent EP 1 830 824 B1 discloses a process for producing a nanoparticle composition which comprises nanoparticles of a therapeutic agent. In this case, a mixture of a precursor compound and a co-reactant is milled in a milling
15 device using a milling medium.

The American patent application US 2017/0036967 A1 discloses a process for producing fertilizers based on humic acids from lignite and leonardite in a mechanochemical reactor for highly viscous media.
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The mechanochemical production of zeolites is described in the international patent application WO/072527 A2.

The mechanochemical production of largely iron-free metal chalcogenides or arsenides from iron-free metal powders and sulfur, selenium, tellurium or arsenic is
25 disclosed in the European patent application EP 1 681 270 A2.

The European patent EP 1 303 460 B1 describes the mechanochemical synthesis of lithiated manganese dioxide from manganese dioxide and lithium salts.
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The translation of the European patent EP 0 963 825 B1, DE 699 11 502 T2, describes the mechanochemical treatment of plastics such as polyethylene terephthalate, polystyrene, polypropylene or polyethylene in the presence of liquid

carbon dioxide for the compatibilization and recycling of heterogeneous plastics, which are recovered from municipal or commercial waste.

A process for the production of peptides with the aid of proteolytic enzymes is disclosed in the German published patent application DE 42 40 545 A1, in which amino-protected amino acids as acylation components are reacted with carboxyl-protected amino acids in the presence of a substance containing water of crystallization such as $\text{Na}_2\text{CO}_3 \times 10\text{H}_2\text{O}$ by milling with one another.

10 The Japanese patent JP 3099064 B2 discloses a mechanochemical process for producing a thermoplastic composite from a non-thermoplastic, natural polymer, such as cellulose or chitin, and from 5 to 20% by weight of a synthetic thermoplastic. The resulting composite material itself is thermoplastic.

15 In the older German patent application file number 10 2018 000 418.0 with the filing date of January 20, 2017, a mechanochemical process for the production of valuable products that are free of persistent organic pollutants and other organohalogen compounds is described. They are made from waste of single-variety and non-single-variety plastics and plastic laminates that are contaminated with persistent organic
20 pollutants and/or contain other organohalogen compounds, wherein, in the mechanochemical process

(i) the waste is comminuted so that the particle size distribution is as narrow as possible,

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(ii) the comminuted waste is filled in a mill containing milling balls and further comminuted by milling,

(iii) at least one dehalogenating agent is added in a molar excess with respect to
30 the amounts of persistent organic pollutants and/or other organohalogen compounds present,

(iv) the mixture of milled comminuted waste and dehalogenating agent is milled further and the milling is ended after a preselected time,

(v) the resulting valuable products free of persistent organic pollutants and other organohalogen compounds are separated from the milling balls and the halogen-containing, water-soluble products formed are separated by washing with aqueous solvents and/or the halogen-containing, water-insoluble products formed are not washed out but rather remain as fillers in the valuable products, and

(vi) the washed valuable products after drying and the unwashed valuable products are checked to determine whether they still contain persistent organic pollutants and/or other organohalogen compounds, wherein

(vii) at least one additive is added before and/or after process step (iv).

Another problem with the recycling of plastics, in particular of non-single-variety plastics and plastic laminates, is their high content of organically bound halogens if, for example, PVC, PVDF, PTFE or chlorofluorinated thermoplastics are contained in the plastic waste.

G. Cagnetta et al. describe in their article Mechanochemical conversion of brominated POPs into useful oxybromides: a greener approach, in Sci. Rep., 2016, 6, 28394 the decomposition of brominated persistent organic pollutants through the reaction with stoichiometric amounts of bismuth oxide or lanthanum oxide with the formation of the corresponding oxybromides and amorphous carbon.

In their article Simultaneous treatment of PVC and oyster-shell wastes by mechanochemical means, in Waste Management 28 (2008) 484-488, W. Tonganmp et al. describe the dechlorination of PVC with oyster shell waste, which provides calcium chloride and organic products with double bonds.

A mechanochemical process for the reductive dehalogenation of organohalogen substances is disclosed in the German patent DE 197 42 297 C2, wherein the substance or the substance mixture is milled with the addition of elemental alkali metal, alkaline earth metal, aluminum or iron as reducing agent and ethers, polyethers, ammonia, amines, Amides, trialkylsilanes, polyalkylhydrogensiloxanes or

metal nitrides, individually or in combination as a hydrogen source, in one step. In this way, sands or soils contaminated with PCB or chlophen can be mechanochemically decontaminated.

- 5 However, not only the high organohalogen content of plastics such as PVC, but also a lower organohalogen content can cause problems when recycling plastic and plastic laminates. Even if the waste does not contain any organically bound halogens, after a long period of use of the plastics and laminates outdoors, ubiquitous persistent organic pollutants or persistent organic pollutants or POP (persistent organic
- 10 pollutants) such as organochlorine insecticides of the 1st generation such as chlordane, DDT, dieldrin or toxaphene, industrially manufactured chemicals such as PCB or by-products of manufacturing and combustion products such as chlorinated and brominated dioxins and dibenzofurans will inevitably accumulate over time. Representatives of these compound classes are also known as the "dirty dozen".
- 15 POPs are semi-volatile and can occur both in the gas phase and bound to dust particles and are distributed worldwide through long-distance transport mechanisms. Because of their lipophilicity, they bioaccumulate in the adipose tissues of animals and humans. Some of the POPs are considered endocrine disruptors or are carcinogenic and have also been linked to infertility, behavioral disorders, and
- 20 immunodeficiencies. Traces of them contaminate large-scale products such as titanium dioxide nanoparticles, which are used as color pigments in cosmetics, inks and plastics. The amounts may appear small in individual cases, but because of the amounts of titanium dioxide in question, they cannot be neglected.
- 25 (See the article by Georgios Ctistis, Peter Schön, Wouter Bakker and Gregor Luthe, PCDDs, PCDFs, and PCBs co-occurrence in TiO₂ nanoparticles, in Environmental Science and Pollution Research, DOI 10.1007/s11356-015-5628-7)

- In the article "A mini-review on mechanochemical treatment of contaminated soil:
- 30 From laboratory to large-scale", in Critical Reviews in Environmental Science and technology, August 2018, pages 1 to 51, G. Cagnetta provides an overview of mechanochemical decontamination of soils.

The German patent application DE 102 61 204 A1 discloses a process for the decontamination or detoxification of solid or liquid products contaminated with environmental toxins such as polyhalogenated compounds or organochlorine substances such as dioxins, dibenzofurans and by-products (congeners) or PCBs by means of high kinetic processes in which the contaminated products are subjected to high-kinetic ultra-fine comminution using so-called tribomaterials through multiple effects of impact or shear forces. All types of glass from Duran/Solidex to window glass are used as tribomaterials. In addition, grains of sand, granite particles or quartz porphyry particles as well as enamel as cullet particles or sodalite or ceramics can be used, if appropriate, in a mixture. In these cases the particles are up to 5 mm in size. But oxides such as silicon dioxide, calcium oxide, magnesium oxide, titanium dioxide, iron oxides, zirconium oxide or boron oxide, sulfides such as pyrite, iron sulfide and antimony sulfide, nitrides such as boron nitride and silicon nitride, carbides such as boron carbide, silicon carbide and tungsten carbide, silicides such as iron silicide and titanium silicide or silicon and boron may be used in admixture, if appropriate. The particle sizes are between 10 µm and 1 mm. In Example 3 of the patent application, 10 g of activated charcoal to which 0.17 TCDD (2,3,7,8-tetrachlorodibenzo[1,4]dioxin) and 0.23 g of congeners had been absorbed, were milled with 200 g of broken Duran glass and 2 kg of steel balls (CR 6). No toxins or volatile organic compounds could be detected after milling.

Processes for removing trace substances are known from the company publication "HUBER Technology Waste Water Solution, Vierte Reinigungsstufe: HUBER-Lösungen zur Elimination von Mikroverunreinigungen", downloaded from the Internet on December 30, 2018. These processes use activated charcoal filters, which are regenerated by washing them out. However, with continued operation of the filter, the loading of the inner surface of the activated charcoal with micropollutants increases. The process with an activated charcoal filter can also be combined with ozonization or with sand filtration of the water from the secondary clarifier.

Every year in Germany alone, millions of tons of manure, dried liquid manure, liquid manure, fermentation residues, dry ferments, sewage sludge, ferments, biowaste, water from secondary clarifiers, dry concentrates from the biological purification stages and waste and residues from chemical washers, filters and electrostatic

precipitators, waste and residues from exhaust air treatment and from air conditioning systems accumulate. They contain, among other things, nitrates, nitrites, nitrosamines, ammonium salts, ammonia, sulfur compounds, pesticides, drugs and their residues and metabolites, heavy metals and radioactive metals and their compounds, viruses, bacteria and other toxic materials.

The German legislature and the European Union are therefore applying ever stricter standards to the emission of these pollutants. Producers, waste processors and waste users have to adapt to this.

Manure and its traditional and customary utilization process, such as spreading it as farm-own fertilizer on fields and grassland with a manure tank that spreads the manure on the surface or inoculates it directly into the soil, are particularly problematic. If manure is applied in excess or at times of the year when the vegetation cannot absorb the nutrients it contains, such as in winter, the risk of nutrient leaching into deeper soil layers and of seepage or shielding and erosion in groundwater and surface water increases. Ammonium salts, nitrates and other manure ingredients can, for example, cause algal blooms and fish deaths through eutrophication in bodies of water. Last but not least, the application on the soil surface - especially when using wide spreaders - is associated with nutrient losses, wherein the easily soluble nitrogen compounds and above all ammonium salts are lost in the form of ammonia.

Manure can also contain residues from veterinary drugs, especially antibiotics. Especially in intensive animal husbandry, in which antibiotics are used on a large scale, the animals excrete a large part of the substances in the feces and urine unchanged. By spreading such manure, the drugs also get into the environment, such as the groundwater. Manure fertilization is generally forbidden for vegetable and fruit growing, as dangerous pathogens such as EHEC bacterial strains can get into the soil through animal excrement.

The liquid or solid residue that remains after the fermentation of biomass in a biogas plant is called digestate. The terms biogas slurry or fermentation product are also used. Because of their high content of nutrients, the digestate is mostly used as

agricultural fertilizer. In other recycling processes, the digestate is first dried before it is spread on agricultural land. The drying systems for the digestate are often operated with heat from the conversion of biogas into electricity. Since the digestate can still contain a certain proportion of hard-to-break carbohydrates such as cellulose and lignocellulose, it can also be of interest as fuel after drying. However, the high mineral content and the sulfur and nitrogen compounds it contains cause high levels of slag and corrosion.

Another problem area is sewage sludge. Said sewage sludge is a mixture of solids and liquids that are produced by sedimentation in wastewater treatment. In addition to water, the liquid medium contains a large number of dissolved chemical compounds. In its initial state, sewage sludge is thin and dark in color. By sedimentation (action of gravity) solids contents of about 2% to 5% are achieved.

In the case of sewage sludge, a distinction is made between raw sludge and treated sewage sludge. Sludge fields in sewage treatment plants as primary sludge in the mechanical cleaning stage or as excess sludge in the biological stage. Excess sludge consists mostly of microorganisms such as protozoa and bacteria. By aerobic and anaerobic stabilization of the raw sludge, the less odor-intensive, treated sewage sludge is obtained. The anaerobic treatment takes place in larger sewage treatment plants in digestion towers and supplies the digested sludge.

By flocculation and precipitation with auxiliary substances such as iron(III) chloride or lime, the sewage sludge is processed in such a way that it can be dewatered to a solids content of up to 35% using centrifuges and belt sieve systems, for example. Using chamber filter presses, even higher degrees of dewatering can be achieved.

The sewage sludge is rich in nutrients, as the bacteria in the biological stage use the wastewater ingredients to build up the biomass. Nitrates, which are present in up to 1300 mg/liter, phosphates and other nutrient salts are of particular importance for agriculture.

However, sewage sludge also contains substances that can be problematic for the environment and people, in particular, heavy metals that occur, among other things,

through dissolution from pipelines. Organic pollutants should also not be neglected. Sewage sludge can contain a large number of organic compounds with different properties and effects that end up in the wastewater through anthropogenic processes. These substances can be carcinogenic, mutagenic, toxic or hormonally active, for example. The Sewage Sludge Ordinance specifies limit values for the sum parameters AOX (absorbable organically bound halogens), PCB (polychlorinated biphenyls) and PCDD (polychlorinated dioxins and dibenzofurans). If such substances are present in the wastewater, there is a particular danger because they can bioaccumulate even in low concentrations after agricultural application and can enter the food chain. Due to the legal bans on the use of some weed and pest control agents that have been adopted in the meantime, some of these compounds are currently no longer detectable in sewage sludge. However, other toxic organic compounds are still present in the sewage sludge.

- As with manure, there are no known economic processes by which the heavy metals and the other toxic substances can be rendered harmless and at the same time the phosphates and the other nutrient salts can be recovered in a bioavailable form.

Another problem area is phosphorus. Phosphorus is a finite resource, the easily recoverable mineral reserves of which should be depleted in 80 to 120 years. There is an annual potential of around 70,000 t of phosphorus for recovery in German wastewater, while around 120,000 t per year are used in Germany alone. Phosphorus recycling is now mandatory for large water treatment plants with a population equivalent of 50,000 or more. The uptake of phosphorus and micronutrients such as potassium and magnesium can also be increased by nitrification inhibitors, which lengthen the ammonium phase of the nitrogen introduced into the soil.

Manure processing through incineration or pyrolysis of the manure converts the phosphate contained in it through vitrification, which means that it is no longer bioavailable and lost for fertilization.

Coals are known to bind phosphates and then make them bioavailable again to the plants. Vegetable coals and biochar are used for this purpose, as is lignite, which, however, contains many toxic polycyclic aromatic hydrocarbons (PAHs).

Another secondary source of phosphate are building materials such as phosphate-containing cements, concretes, bricks, artificial stones and grout, as well as phosphate-containing foods such as dairy products, sausage products and canned fish. However, only poorly functioning and therefore uneconomical processes are available for the recovery of phosphate in bioavailable form.

Every year, 200,000,000 t of manure and, in addition, digestate, dry ferments and concentrates from exhaust air scrubbers are spread on fields in Germany. This corresponds to 34,000,000 t/year of ammonium, 36,000,000 t/year of nitrate and 20,000,000 t/year of phosphate from manure alone.

The ammonium form of ammonia, however, is not lost via the gas phase because it is not volatile. However, its mobility is lower than that of nitrate, since it can bond ionically as a cation to the negatively charged soil particles.

In soils saturated with water and at high temperatures, denitrification to nitrous oxide (laughing gas) and nitrogen oxides NO_x, which are greenhouse gases, is favored.

Attempts are therefore currently being made to burn and/or pyrolyze manure, to destroy nitrate, to bind ammonia by drying or to use nitrification inhibitors or to sterilize manure under pressure.

Pyrolysis and incineration of manure require high energies because the water has to be evaporated. In addition, the fine dust must be retained with filters. Phosphates are lost because they vitrify and are therefore no longer bioavailable. Important nitrogen fertilizers are lost and are converted into nitrogen oxides NO_x, which are hazardous to the environment and form acids. The processes must be carried out centrally so that they can only be implemented on a large scale and involve high investments. This leads to additional transport costs and emissions. The loss of nitrogen fertilizer must be compensated for by artificial fertilizers. In and of itself, it is not the nitrates and ammonium that are the real problem, but their uneven distribution over the year and their uneven uptake by the plants and washing out. These problems are not solved by pyrolysis and incineration.

When the nitrate is destroyed using biological and chemical processes, important nitrogen fertilizers are lost, which has to be compensated for by artificial fertilizers. The processes are very costly and do not solve the problem of long-term fertilization.

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The binding of ammonia in dryers by water and acids and subsequent biological degradation is also not effective. It is true that ammonia is bound by water and/or acid during the drying of manure and biogas and can then be oxidized to form nitrates with bacteria. This liquid fertilizer can also be applied during the growing season and adapted to the needs of the plants. The disadvantage, however, is the enormous amount of energy required to evaporate 200,000,000 t of water and condense it again and bind acid. Simple calculations show that the energy requirement would correspond to twelve times the amount of natural gas that is produced in Germany. For these reasons, this solution would not make sense in terms of energy, not to mention the carbon dioxide footprint that would be associated with it.

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The reduction of fertilizer loss through nitrification inhibitors is a simple process that can be carried out in a decentralized manner. Phosphates, potassium and magnesium remain bioavailable, which ensures an improved yield and less nitrate gets into the groundwater. However, the nitrification inhibitors used are classified as hazardous to water and water-soluble, which is why they contaminate the groundwater. While nitrates can be removed from the groundwater through biological treatment, the nitrification inhibitors accumulate in the groundwater and in the food chain and therefore pose a danger in the long term.

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When filtering manure with CNF filters, the nanopores clog up directly, so that they are not permeable for manure without prior micro and nanofiltration and cannot bind the nitrate either.

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CNF binds heavy metals in the anionic form, but these must be removed from the manure together with the CNF, otherwise they will be released again in the soil when the CNF biodegrades.

Coals bind phosphates and other nutrients and release them with a delay. The problem, however, is the high production costs for activated charcoal, for example, at around € 2000.00/ton, or the high level of contamination of lignite.

- 5 Other waste containing environmentally harmful organic materials is the sludge from oil production. Here, too, no satisfactory solution has yet been found for converting this type of waste into valuable products.

10 The concentration of the greenhouse gas carbon dioxide in the earth's atmosphere has increased continuously since the industrial revolution and has now reached a critical value that leads to a noticeable warming of the earth's atmosphere. As a result, the permafrost soil, for example, is melting and the glaciers are receding as water reserves. Another consequence could be the development of methane - an even more effective greenhouse gas - from methane ice, the negative consequences
15 of which are unforeseeable.

There is therefore no lack of attempts to reduce the formation of carbon dioxide and/or to remove the carbon dioxide once it has formed from the atmosphere. However, the respective processes are expensive, complex and their success is
20 questionable. There is therefore no lack of attempts to split carbon dioxide into oxygen and carbon at comparatively low temperatures, as can be seen from the following publications:

- H. Kato et al., JOURNAL OF MATERIALS SCIENCE (1994), 29:5689,
25 "Decomposition of carbon dioxide to carbon by hydrogen-reduced Ni(II)-bearing ferrite";
- Kodama et al., Journal of Solid State Chemistry, 1995, "XRD and Mössbauer studies on oxygen deficient Ni(II)-bearing ferrite with a high reactivity for CO₂
30 decomposition to carbon";
- Kodama et al., Materials Research Bulletin, 1995, "CO₂ decomposition to carbon by ultrafine Ni(II) bearing ferrite at 300 °C";

- Masamichi Tsuji et al., Applied Catalysis A: General, Vol. 142 (1), 1996, 31-45, "Catalytic acceleration for CO₂ decomposition into carbon by Rh, Pt or Ce impregnation onto Ni(ii)-bearing ferrite";
- 5 - Chun-lei Zhang et al., Materials Chemistry and Physics, Vol. 62 (1), 2000, 52-61, "Studies on the decomposing carbon dioxide into carbon with oxygen deficient magnetite: II. The effects of magnetite on activity of decomposition CO₂ and mechanism of the reaction";
- 10 - Dorna Esrafilzadeh et al., Nature Communications 10, Article number: 865 (2019), "Room temperature CO₂ reduction to solid carbon species on liquid metals featuring atomically thin ceria interfaces".

However, these processes still require further development in order to be able to be
15 used industrially.

Furthermore, the waste from carbon fiber-reinforced plastics (CFRP) is difficult to recycle in order to recover the expensive carbon fibers for further use. For example, carbon fiber reinforced polyepoxides are treated with supercritical water or solvents to
20 release the carbon fibers. From the American patent application US 2019/0203013 A1 a work-up process is known in which the CFRPs are aerobically depolymerized. The released carbon fibers can be reused and the resulting monomers can be polymerized again. However, this is comparatively complex. In particular, the separation of the monomers is problematic in terms of safety. The process known
25 from the American patent application US 2019/0039266 A1 and the known device circumvent this problem by pyrolyzing the CFRPs, which releases the carbon fibers again - but at the cost of eliminating the plastic matrix.

It would therefore be desirable if the CFRPs could be converted directly into new
30 valuable products. However, the previously known processes and devices are not suitable for this purpose.

An acid-catalyzed mechanochemical process is known from the article by S. Amirjyayer et al., Understanding the Mechanocatalytic Conversion of Biomass: A

Low-Energy One-Step Reaction Mechanism by Applying Mechanical Force, Angewandte Chemie International Edition, Vol. 58, Issue 16, with which celluloses can be broken down into low molecular weight sugars. It is not known to what extent this process can be used for the industrial production of salable valuable products.

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Overall, prior art processes are poorly or not at all suited for decontaminating or eliminating of problematic, synthetic, biogenic and biological materials, for immobilizing metals, for digesting phosphates, for separating carbon dioxide and carbon monoxide into the elements and for recovering valuable products.

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Object of the present invention

The present invention was based on the object of finding a widely applicable process that enables natural, synthetic, biological and biogenic materials to be

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decontaminated and/or eliminated in a simple manner, and metals to be immobilized so that they can be safely stored, to digest phosphates and make them bioavailable again, to split carbon dioxide and carbon monoxide into their elements, so that a carbon dioxide sink is created, and to recover valuable products such as complete fertilizers or the allotropes of carbon such as graphene, carbon nanotubes, carbon nanocones and activated charcoal. In particular, however, activated charcoal is to be obtained, which can be fed back into the process or used for the production of terra preta or as a carbon dioxide sink.

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Solution according to the invention

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Accordingly, the object of the present invention was achieved using the mechanochemical process for decontaminating and/or eliminating problematic, synthetic, biogenic only and biological materials, for digesting phosphates, for immobilizing metals and compounds thereof, for splitting carbon dioxide and carbon monoxide into the elements and for recovering valuable products according to independent patent claim 1, and the mechanochemical mill according to independent patent claim 20. Advantageous embodiments and uses can be found in the dependent claims referring back to the independent claims.

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Advantages of the present invention

With regard to the prior art, it was surprising and not foreseeable for the person skilled in the art that the object on which the present invention was based could be achieved using the mechanochemical process according to the invention. In particular, it was surprising that the mechanochemical process according to the invention no longer had the disadvantages of the prior art, but that it was extremely broadly applicable and made it possible, in a simple manner, to decontaminate and/or eliminate synthetic, biological and biogenic materials, to immobilize and detoxify metals and compounds thereof, so that they can be safely stored or used as catalysts, to digest phosphates and make them bioavailable again, to split carbon dioxide and carbon monoxide into oxygen and elemental carbon and to recover valuable products such as complete fertilizers or the allotropes of carbon such as graphene and carbon nanotubes, carbon nanocones and activated charcoal. In particular, however, activated charcoal could be recovered, which could be fed back into the mechanochemical process. This made it possible to reduce the carbon dioxide footprint, as biomass could be permanently converted into coal. In addition, because of the coal, the fertilizers produced were able to intensify the activation of microorganisms in the soil. In addition, it was even possible to use lignite for the mechanochemical process according to the invention.

In particular, it was surprising that in the mechanochemical process no polycyclic aromatic hydrocarbons (PAH; PAH), nitrosamines, tars and other harmful substances were formed and no brominated and/or chlorinated dioxins, dibenzofurans and toxic lipophilic compounds generating radical oxidative stress (ROS) were formed due to the presence of chlorides and bromides. In addition, drug residues, toxins of all kinds, biocides, viruses, bacteria, algae, poisonous plants and parts thereof, as well as poisonous animals and parts thereof, could be destroyed and eliminated. It was the particular advantage that the mechanochemical process according to the invention converted organic materials of any kind into carbon, in particular activated charcoal, which could, for example, be returned to the fourth purification stage of sewage treatment plants or could be used for battery storage. With plastics and increased proportions of sand or cement, new masonry sand and masonry cement could be produced. In particular, the masonry cements no longer showed any cement

efflorescence and/or cement residue. In addition, the cement could be used as a source of phosphate and as a raw material for the manufacture of fertilizers. Anatas and diamonds could occur as by-products. The pulverulent products of the mechanochemical process according to the invention could be processed directly into granules and pellets.

The pulverulent products of the mechanochemical process according to the invention could be used for the production of release agents for plastic molding from membranes of fuel cells, for the recycling of plastics from electronic materials and the production of pure plastics by bacteria.

Furthermore, the mechanochemical process according to the invention could serve to convert thermosets into thermoplastics and/or activate thermosets on their surface through the formation of reactive radical centers and/or functional groups, so that they served as graft bases for the graft copolymerization.

It was also surprising that explosives and pyrotechnic materials could also be disposed of without problems using the mechanochemical process according to the invention.

Overall, the implementation of the mechanochemical process according to the invention required comparatively little energy, lower costs and lower transport costs and contributed to protecting the phosphate reserves.

Detailed description of the invention

The present invention relates to a mechanochemical process which is carried out using mechanical mills. Customary and known mechanical mills can be used for the process according to the invention. Examples of suitable mechanical mills are ball mills, hammer mills, pinned disk mills, jet mills, vibration mills, shaking mills, horizontal mills, attritors and planetary mills. For example, the mechanical mill described in the German published patent application DE 195 04 540 A, Figures 1a to 4b, can be used.

The means for agitating the milling elements in an energy-rich mass flow together with the material to be milled can, in addition to the attritors according to the aforementioned German published patent application, have different shapes, which are preferably symmetrical with respect to the at least one, in particular one, drive shaft. These agitation means preferably consist of metals, alloys, ceramics and with ceramics and coated metals and alloys.

For example, the power transmission can take place through planar striking wings that have at least two striking ends that are arranged symmetrically relative to the drive shaft so that no imbalance occurs. The striking wings can be arranged on the drive shaft with a gap between them and/or to align with one another, and preferably have circular holes in the area of their ends.

However, planar striking disks can also be used which preferably have a circular circumference and preferably have circular, oval, elliptical and/or elongated holes curved parallel to the circumference, which are preferably arranged in a circle and preferably at the same distance from one another. The striking disks can be arranged on the drive shaft in such a way that the holes are arranged with a gap between them and/or to align with one another.

The planar striking disks can, however, also have raised webs on their surface, which are arranged symmetrically and extend in a straight line and/or preferably curved in the direction of rotation from the drive shaft to the circular edge. The beginnings and the ends of the webs are preferably arranged at the same distance from one another. Preferably, at least four of these webs are used. In a further embodiment, these webs are arranged on the two opposite sides of the planar striking disks. The webs can have a quadrangular, a triangular or a semicircular cross-section. The striking disks can be arranged on the drive shaft in such a way that the webs are arranged with a gap between them and/or to align with one another.

The power transmission to the milling elements can, however, also take place by means of striking fans arranged symmetrically to the drive shaft. They are formed by a ring that surrounds the drive shaft and at least two striking fans radiating from this ring. In a further embodiment, the ring widens on at least two surfaces arranged

symmetrically to the drive shaft, each of which merges into at least two outwardly radiating striking fans. Preferably, the edges are curved and are located on an imaginary circle around the entire arrangement. Thus, it can be n-fold single striking fans or n-fold multiple striking fans, where $n = \text{at least } 2$.

5

In a further embodiment, the striking fans can have raised webs on one side or on two opposite sides, which raised webs are arranged symmetrically to one another and extend from the drive shaft to the respective edge of the striking fans. The webs can have triangular, quadrangular or semicircular profiles.

10

In yet another embodiment, these webs can extend parallel to the curved edges of the striking fans.

Preferably, the agitation means described above are spaced apart by at least the width of a milling element. The width of the agitation means seen in the transverse direction to the drive shaft is preferably 0.1 to 8 times the width of the respective milling elements. On the drive shaft, the agitation means can be arranged parallel to one another or offset.

Instead of the agitation means described above, it is also possible to use striking clubs which are arranged symmetrically with respect to the drive shaft and which have striking elements which are connected to the ring surrounding the drive shaft by straight or curved rods of equal length or of different lengths. The striking elements can be cuboid, shovel-shaped, spherical or drop-shaped elements or ellipsoids. So that there is no imbalance when turning, they preferably have the same weight.

The drive shafts themselves can be spline shafts, hollow shafts, power take-off shafts, worm shafts, tapered shafts, conical shafts or triangular shafts.

Instead of the arrangements of a drive shaft and the agitation means described above arranged around it, at least two counter-rotating rollers arranged parallel to one another in the longitudinal direction of the milling chamber can be used. The material to be milled is milled in the area where the rollers touch.

In one embodiment, the rollers are arranged obliquely to the longitudinal axis of the milling chamber, which results in additional torsion of the material to be milled.

5 In yet another embodiment, the roller rotates against an abrasion surface, so that the milling takes place in the area of contact between the roller and the abrasion surface.

In further embodiments, the surfaces of the rollers and the abrasion surfaces can have structures such as, for example, teeth, nipples and/or depressions.

10 In a still further embodiment, the striking effect and the fitting joint can be improved by resilience of the roller surface. This resilience can be achieved by virtue of the fact that the rollers as a whole are arranged in a resilient manner with respect to one another. However, individual points on the roll surface can also be configured to be separately resilient. This can be achieved, for example, in that the rollers have
15 depressions in the area of their surface in which balls are arranged which are pressed out of the depressions by coil springs. The depressions can have a larger clear width than the radius of the ball, so that the material to be milled that gets into the depressions trickles out of the depressions again as the rollers continue to rotate.

20 The milling chamber in which the agitation means are arranged, is preferably of tubular design and preferably has a circular circumference. If the rollers described above are used, the milling chamber can also be delimited by two opposite, parallel, straight walls which extend at a distance over the width of the rollers and which are connected by two opposite curved walls.

25

In the longitudinal direction, i.e. viewed along the drive shaft, the circumference of the milling chamber can constrict at least once, so that at least two spherical milling chambers are arranged one behind the other and connected to one another by a circular opening are formed as a result. The dimensions of the agitation means are
30 then adapted to the course of the walls in the individual milling chambers, so that the agitation means are also the largest at the largest diameter of the spherical milling chambers, with their dimensions decreasing to the left and to the right, following the rounding of the milling chambers.

The mechanical mills can be powered directly by the energy supplied by wind turbines, water turbines and tidal power plants.

5 Repulsion motors have proved to be successful for the smooth start-up of large mechanical mills. These motors can then be throttled in their power output during the subsequent continuous operation.

A combination of a powerful motor for starting up, which is switched off after starting, and a weaker motor for continuous operation can also be used.

10

In addition, gas turbines and internal combustion engines powered by fossil fuels or fuels obtained from biotechnology can be used.

15 Asynchronous motors, DC motors (commutator motors), AC and three-phase motors, rotating field and traveling field machines, three-phase asynchronous machines, slip-ring motors, three-phase synchronous machines, cascade machines, stepper motors, brushless DC motors, linear motors, AC motors, capacitor motors, shaded-pole motors, synchronous motors, single-phase asynchronous motors, reluctance motors, magnetic motors, transverse flux machines, commutator machines, direct current
20 motors, universal motors (for direct and alternating current), permanently excited direct current motors, electrically excited (separately excited) direct current motors, series motors, shunt machines, compound motors, ball bearing motor, unipolar motors, homopolar motors, and Barlow's wheels.

25 Preferably, electric motors according to the international patent application WO 2017/055246A2 are used. These motors comprise at least one electrical machine component with at least one winding for generating a magnetic field, which winding comprises at least one waveguide, which has a jacket and an inner cavity through which a coolant can be routed, the winding having two ends at which an electrical
30 operating voltage is connected and wherein

- the waveguides are round tube-shaped and have an outer diameter in a range of 3 mm,
- the ends of the winding each serve as a coolant inlet or coolant outlet, and

- the ends of the winding are connected to a connector comprising a coolant inlet and/or a coolant outlet, multiple waveguide connections for connecting waveguides, a manifold through which the coolant is fed into at least one waveguide, and/or a collecting channel into which the coolant emerging from at least one waveguide flows and is routed to the coolant outlet of the connector.

Electric motors of this type are sold by Dynamic E Flow GmbH, Kaufbeuren, Germany, under the capcooltech® brand. The types HC and LC are preferably used.

- However, motors driven by compressed air can also be used, which are particularly useful in explosion-proof areas.

The milling can take place at a temperature of the milling elements and the material F to be milled from -273 °C to +1200 °C. The temperatures in the so-called hotspots and in the plasmas can be up to 15,000 °C.

The duration of the milling can vary widely and can therefore be perfectly adapted to the task at hand. The milling time is preferably from 0.5 minutes to 1000 hours, more preferably from 10 minutes to 500 hours, particularly preferably from 10 minutes to 100 hours and in particular from 10 minutes to 50 hours.

The milling can be carried out in the presence of at least one, in particular one, inert substance. Examples of suitable inert substances are gaseous, liquid and solid nitrogen, gaseous, liquid and solid carbon dioxide under conditions under which it is not split into the elements, and sulfur hexafluoride and the gaseous, liquid and solid noble gases neon, argon, krypton and xenon and gaseous and liquid helium.

Preferably, a plasma is present during milling in the interior of the mills, i.e. in the milling chamber. The plasma can be generated by generating triboplasma by means of gas discharge, hotspots, electrostatic charging, emission of exoelectrons, triboluminescence, crystal lattice defects, shredding, dislocations, crystal lattice vibrations, fracture formation, cutting processes, compressions, sanding, drilling, grinding, abrasion, high pressures, friction, metastable states and hotspots due to the collision of the solids and/or the friction of the solids against each other as well as

catalytically active and/or piezoelectric particles and coatings on the milling elements and/or the walls of the milling chamber and/or on the agitation means and/or in the milling chamber of the mechanical mills, focused laser radiation, electron radiation, radioactive radiation, X-rays, UV radiation, IR radiation, microwave radiation, ultrasound, chemical and nuclear reactions, electrostatic fields, electromagnetic fields, direct voltage, capacitive electrical excitation, wire explosions, gas discharges, electric arcs, spark discharges, vacuum spark discharges, cyclotron resonance, capacitive glass tube discharge and the pinch effect.

10

The radiation can be radiated into the milling chamber through mechanically stable, scratch-resistant, radiation-permeable windows, via the drive shaft and/or the agitation means.

15 In addition, IR radiation and UV radiation, preferably with specific wavelengths that stimulate bonds, can be used.

Through acoustophoresis or battery aggregation, in particular through standing ultrasonic waves, the material to be milled can be changed during milling in order to open up new mechanochemical process paths. The resulting nanoparticles and microparticles of the material to be milled can be aggregated again in order to react mechanochemically in a new way.

Preferably, the plasma is generated by piezoelectric particles. Preferably, piezoelectric particles are selected from the group consisting of carbon, quartz, glass barium titanate (BTO), lead zirconate titanate (PZT), lead magnesium niobate (PMN), gallium orthophosphate, berlinite, tourmaline, seignette salt, piezoelectric thin layers of zinc oxide, aluminum nitride, silicon nitride, silicon carbide, aluminum oxide, zirconium oxide and titanium nitride, polyvinylidene fluoride (PVDF) and ferroelectric, polycrystalline ceramics. In particular, carbon, quartz and glass are used.

In a particular embodiment, the piezoelectric particles or materials can be applied to the surfaces of the milling elements, the walls, the drive shafts and/or the agitation means and/or introduced into the milling chambers of the mechanical mills.

The catalytically active particles and/or the coatings can also be applied to the milling elements, the drive shafts, the walls of the milling chamber and/or to the agitation means and/or introduced into the milling chamber of the mechanical mills.

5

Preferably, the catalytically active particles from the group consisting of metals, metal alloys, metal compounds and microporous materials are used.

The metals used can be

10

Actinium, symbol: Ac, atomic number: 89

Aluminum, symbol: Al, atomic number: 13

Americium, symbol: Am, atomic number: 95

Antimony, symbol: Sb, atomic number: 51

15

Arsenic, symbol: As, atomic number: 33

Astatine, symbol: At, atomic number: 85

Barium, symbol: Ba, atomic number: 56

Berkelium, symbol: Bk, atomic number: 97

Beryllium, symbol: Be, atomic number: 4

20

Bismuth, symbol: Bi, atomic number: 83

Lead, symbol: Pb, atomic number: 82

Bohrium, symbol: Bh, atomic number: 107

Boron, symbol: B, atomic number: 5

Cadmium, symbol: Cd, atomic number: 48

25

Cesium, symbol: Cs, atomic number: 55

Calcium, symbol: Ca, atomic number: 20

Californium, symbol: Cf, atomic number: 98

Cerium, symbol: Ce, atomic number: 58

Chromium, symbol: Cr, atomic number: 24

30

Cobalt, symbol: Co, atomic number: 27

Copernicium, symbol: Cn, atomic number: 112

Curium, symbol: Cm, atomic number: 96

Darmstadtium, symbol: Ds, atomic number: 110

Dubnium, symbol: Db, atomic number: 105

- Dysprosium, symbol: Dy, atomic number: 66
Einsteinium, symbol: Es, atomic number: 99
Iron, symbol: Fe, atomic number: 26
Erbium, symbol: Er, atomic number: 68
5 Europium, symbol: Eu, atomic number: 63
Fermium, symbol: Fm, atomic number: 100
Flerovium, symbol: Fl, atomic number: 114
Francium, symbol: Fr, atomic number: 87
Gadolinium, symbol: Gd, atomic number: 64
10 Gallium, symbol: Ga, atomic number: 31
Germanium, symbol: Ge, atomic number: 32
Gold, symbol: Au, atomic number: 79
Hafnium, symbol: Hf, atomic number: 72
Hassium, symbol: Hs, atomic number: 108
15 Holmium, symbol: Ho, atomic number: 67
Indium, symbol: In, atomic number: 49
Iodine, symbol: I, atomic number: 53
Iridium, symbol: Ir, atomic number: 77
Potassium, symbol: K, atomic number: 19
20 Carbon, symbol: C, atomic number: 6
Copper, symbol: Cu, atomic number: 29
Lanthanum, symbol: La, atomic number: 57
Lawrencium, symbol: Lr, atomic number: 103
Lithium, symbol: Li, atomic number: 3
25 Livermorium, symbol: Lv, atomic number: 116
Lutetium, symbol: Lu, atomic number: 71
Magnesium, symbol: Mg, atomic number: 12
Manganese, symbol: Mn, atomic number: 25
Meitnerium, symbol: Mt, atomic number: 109
30 Mendelevium, symbol: Md, atomic number: 101
Molybdenum, symbol: Mo, atomic number: 42
Moscovium, symbol: Mc, atomic number: 115
Sodium, symbol: Na, atomic number: 11
Neodymium, symbol: Nd, atomic number: 60

- Neptunium, symbol: Np, atomic number: 93
- Nickel, Symbol: Ni, atomic number: 28
- Nihonium, symbol: Nh, atomic number: 113
- Niobium, symbol: Nb, atomic number: 41
- 5 Nobelium, symbol: No, atomic number: 102
- Oganesson, symbol: Og, atomic number: 118
- Osmium, symbol: Os, atomic number: 76
- Palladium, symbol: Pd, atomic number: 46
- Phosphorus, symbol: P, atomic number: 15
- 10 Platinum, symbol: Pt, Atomic number: 78
- Plutonium, symbol: Pu, atomic number: 94
- Polonium, symbol: Po, atomic number: 84
- Praseodymium, symbol: Pr, atomic number: 59
- Promethium, symbol: Pm, atomic number: 61
- 15 Protactinium, symbol: Pa, atomic number: 91
- Mercury, symbol: Hg, atomic number: 80
- Radium, symbol: Ra, atomic number: 88
- Rhenium, symbol: Re, atomic number: 75
- Rhodium, symbol: Rh, atomic number: 45
- 20 Roentgenium, symbol: Rg, atomic number: 111
- Rubidium, symbol: Rb, atomic number: 37
- Ruthenium, Symbol: Ru, atomic number: 44
- Rutherfordium, symbol: Rf, atomic number: 104
- Samarium, symbol: Sm, atomic number: 62
- 25 Scandium, symbol: Sc, atomic number: 21
- Seaborgium, symbol: Sg, atomic number: 106
- Selenium, symbol: Se, atomic number: 34
- Silver, symbol: Ag, atomic number: 47
- Silicon, symbol: Si, atomic number: 14
- 30 Strontium, symbol: Sr, atomic number: 38,
- Tantalum, symbol: Ta, atomic number: 73
- Technetium, symbol: Tc, atomic number: 43
- Tellurium, symbol: Te, atomic number: 52
- Tennesine, symbol: Ts, atomic number: 117

Terbium, symbol: Tb, atomic number: 65

Thallium, symbol: Tl, atomic number: 81

Thorium, symbol: Th, atomic number: 90

Thulium, symbol: Tm, atomic number: 69

5 Titanium, symbol: Ti, atomic number: 22

Uranium, symbol: U, atomic number: 92

Vanadium, symbol: V, atomic number: 23

Hydrogen, symbol: H, atomic number: 1

Tungsten, symbol: W, atomic number: 74

10 Ytterbium, symbol: Yb, atomic number: 70

Yttrium, symbol: Y, atomic number: 39

Zinc, symbol: Zn, atomic number: 30

Tin, symbol: Sn, atomic number: 50

Zirconium, symbol: Zr, atomic number: 40.

15

When using reactive metals such as alkali and alkaline earth metals and radioactive metals, the appropriate customary and known precautionary measures must be taken.

20 The following metal alloys can be used:

Aluminum alloys:

25 - Alloys with copper, magnesium, silicon or manganese as the main alloy element.

- Duralumin is a wrought alloy made from aluminum, copper, magnesium, manganese and silicon

- Partinium

- Aluminum-manganese alloy

30 - Aluminum-magnesium alloy

- Hydronalium: trade name for a cast aluminum alloy with 3-12% magnesium

- Aluminum-silicon alloy, mainly as a cast alloy

- Silumin: brand name for a range of hypoeutectic to eutectic aluminum

- silicon casting alloys.

- Aluminum-lithium alloy (are particularly light.)
- Aluminum-zinc-magnesium alloy
- Titanal

5 **Lead alloys:**

- Hard lead consists of lead and antimony
- Shot is an alloy of lead, arsenic and antimony.
- Tin solder is a lead-tin alloy. For some time now, tin alloys containing copper or silver have also been used.
- Sodium-lead alloys are used as drying agents and in the manufacture of tetraethyl lead.

Bismuth alloys:

- Rose's metal is made up of bismuth, lead, and tin
- Wood's metal is made up of bismuth, lead, tin, and cadmium
- Lipowitz metal,
- Orion metal,
- Quick solder,
- Darcot metal
- Cobalt alloys
- Stellites are hard alloys made from 20 - 68% cobalt. Other essential components in different amounts are chromium, tungsten, nickel, molybdenum and, in some cases, up to 2.5% carbon.
- Vitallium is a metal alloy made from cobalt, chrome and molybdenum (see chrome-cobalt-molybdenum alloy)

Iron alloys:

- Steel is a collective term for plastically deformable iron-carbon alloys and a maximum of 2.06 percent carbon
- Cast iron is a collective term for non-plastically deformable iron-carbon alloys and at least 2.06% C (usually around 4% percent carbon.)

- Iron-nickel alloy
- Invar consists (mainly) of iron and nickel.
- Kovar consists (mainly) of iron, nickel and cobalt.
- Ferro alloy

5

Aluminum alloy:

- Devarda's alloy

10 **Gallium alloy:**

- Galinstan is a eutectic alloy of gallium, indium and tin.

Gold alloys:

15

- Titanium gold: alloy: 99% gold, 1% titanium, is mainly used in the manufacture of wedding rings and in medical technology. In terms of color, it is comparable to 750 yellow gold, but a little grayer.

20

- Colored gold (general) is an alloy of gold, silver (to lighten the yellow and to improve the mechanical workability) and copper (for the "noble" intense gold color or for the red tint).
- Yellow gold: the proportion of silver corresponds to that of copper.
- Red gold: the proportion of silver is significantly lower than that of copper (also known locally as Turkish gold).

25

- Russian gold: slightly lighter red gold with the unusual gold content of 583.
- Pale gold: the proportion of silver is much higher than that of copper.
- Green gold: gold with predominantly or exclusively silver. Small amounts of cadmium are often added to intensify the green tone, but this has been prohibited throughout the EU since 2011.

30

- White gold and gray gold are alloys of gold, with platinum, palladium or silver. But there are also white gold alloys with cobalt, chromium, manganese-germanium and other metals. Nickel was also used in the past.

- Electrum is an alloy of gold and silver that was already known in ancient times. The term is also used for amber. Since 1920, electron has been the protected name for a magnesium alloy from the then IG Farbenindustrie, Griesheim plant.
- Normmetall or Norm-Metall (in Switzerland also: guarantee metal) is an alloy containing gold with less than 333% gold content.
- Hard gold: gold produced by electroplating with small proportions (a few atomic%) of cobalt, nickel or iron.

Copper alloys:

10

- Bronzes or brasses, with tin determining the bronzes and zinc determining the brass.
- Bronze (real bronze) is an alloy that consists only of copper and tin.
- Aluminum bronze is an alloy that can consist of copper and aluminum as well as parts of nickel and iron.
- Brass is an alloy of copper and zinc, widely used as a rolling and wrought material with an admixture of lead, also aluminum.

15

- Copper-rich brass is called tombak
- Lead bronze is an alloy of copper, tin and lead.

20

- Isabellin is an alloy of copper, nickel and manganese, primarily for thermally resistant wires (heating conductor alloy)

- Constantan is a comparable alloy of copper, nickel and manganese.
- Nickelin is a comparable alloy of copper, nickel and manganese.
- Nickel silver (alpaca, pakfong) is an alloy of copper, nickel and zinc.

25

- Gunmetal is an alloy made of copper, tin, zinc and lead used for fittings, among other things.
- Beryllium copper made from copper and beryllium was especially used for non-sparking tools in mining.
- White copper is a light-colored copper-arsenic alloy.

30

Magnesium alloys:

- Electron is a name that was protected in the 1920s for a magnesium alloy.

Nickel based alloys:

- Plessite consists of intergrown kamacite (beam iron) and taenite (band iron) and occurs in nickel-iron meteorites
- 5 - Chronine refers to alloys made of nickel and chromium.
- Monel is an alloy of nickel, copper, iron and manganese.
- Inconel and incoloy are alloys made of nickel, chromium and up to 5% iron that are heat-resistant up to 800 °C.
- Superalloy is an alloy of nickel, iron and molybdenum.

10

Mercury alloys:

- Silver amalgam
- Gold amalgam, as a compound of mercury with gold, is not a dedicated alloy,
- 15 but merely an environmentally harmful intermediate stage in gold extraction

Silver alloys:

- Sterling silver: alloy with 925/1000 silver that is alloyed with copper or other
- 20 materials. This alloy is mostly used to make coins, jewelry and cutlery.
- Vermeil: silver that has been fire-gilded.
- Niello (tula silver): (mainly used in the Middle Ages for works of art and tableware) is made with silver, copper, lead, sulfur and ammonium chloride.
- Tibet silver: alloy with a very low silver content of 250/1000.

25

Tungsten alloys or Composites:

Tungsten is one of the refractory metals which, due to their high melting point (SMWungsten = 3422 °C), can only be alloyed with other metals with difficulty and is

30 therefore sintered to give composite materials such as, e.g. hard metals for machining materials.

- Widia, the protected name for a hard metal consisting of tungsten, cobalt, carbon and titanium.

- A tungsten-silver composite is also misleadingly referred to as a sweat-cooling alloy.
- The real alloys, on the other hand, include tungsten-molybdenum alloys, high-density tungsten alloys with the alloy components nickel, copper, iron, and molybdenum in varying compositions.
- As an alloying element with a proportion of a few percent by weight, tungsten is usually a component of both high-quality steels (see also list of alloying elements) and wire alloys used for lighting purposes (e.g. the Osram® brand as a contraction of osmium and tungsten).

10

Zinc alloy:

- Zamak alloy
- Fine zinc - cast alloys are mainly used for pressure die-cast parts, including those in investment casting.
- Titanium zinc is a zinc alloy that is preferred for galvanizing and has a very low copper and titanium content.
- Alzen (ZnAl35), also Alzeen, are brand names for zinc-aluminum alloys.

15

20 **Tin alloys:**

- Britannia metal is an alloy of 90-95% tin with up to 9% antimony and one percent copper. According to "Gießereilexikon" (formerly) used for household goods and decorative objects ("false bronzes").
- Pewter is an alloy of tin, copper and/or lead.
- Tin solder is a lead-tin alloy. For some time now, tin alloys containing copper or silver have also been used.
- "Potin gris" is a historical, French bronze (copper alloy with a proportion of tin).

25

30 **Intermetallic compounds:**

- Zintl phases.
- Laves phases.
- Hume-Rothery phases.

Magnetic and magnetizable alloys:

- Alloys of iron with at least one metal selected from the group consisting of ruthenium, osmium, cobalt, rhodium, iridium, nickel, palladium, platinum, copper, silver, gold, zinc, cadmium, scandium, yttrium, lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium oxide, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, tungsten, manganese, rhenium, aluminum, gallium, indium, thallium, germanium, tin, lead, antimony and bismuth; examples of suitable metal alloys are soft magnetic metal alloys such as Permalloy® based on nickel and iron, nickel-iron-zinc alloys or Sendust based on aluminum, silicon and iron; $RE_{i-y}La_y Fe_{100-v-w-x-z}Co_wM_zB_x$, where RE is a rare earth metal from the group cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium oxide, terbium oxide, dysprosium, holmium, erbium, thulium, ytterbium and lutetium, and M is a metal from the group titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum and tungsten and $v = 5-15$, $w \geq 5$, $x = 9-30$, $y = 0.05-0.5$ and $z = 0.1-5$; the above-mentioned metals and metal alloys can contain at least one further metal and/or non-metal selected from the group consisting of lithium, sodium, potassium, rubidium, cesium, beryllium, magnesium, calcium, strontium, barium, boron, carbon, silicon, nitrogen, phosphorus, arsenic, oxygen, sulfur, selenium, tellurium, fluorine, chlorine, bromine and iodine, or are contained in non-stoichiometric amounts. A particularly suitable material of this type is NdFeB.
- Examples of suitable catalytic metal compounds are the borides, oxides, sulfides, selenides, tellurides, carbides, silicides, germanides, nitrides, phosphides, arsenides, antimonides, fluorides, chlorides, bromides and iodides, coordination compounds with organic and/or inorganic ligands, isopoly acids and heteropoly acids (polyoxometalates; POM) as well as covalent organic metal organyls, sandwich compounds and carbenes.

In particular, hematite, non-stoichiometric hematites, ferrites, nickel ferrites, nickel salts and polyoxometalates (POMs) are used.

Examples of suitable POMs are known from the international patent application WO 2016/116259 A1, page 14, line 32, to page 23, line 17, and in particular from Table 1, "Summenformeln von geeigneten POM".

- 5 Examples of suitable microporous materials are zeolites and metal-organic framework compounds (metal-organic frameworks; MOFs). Zinc-modified zeolites are used in particular.

By milling the catalytically active particles, nanoparticles and microparticles are
10 generated and/or the surfaces of the drive shafts, walls, milling elements, agitation means and/or rollers are repeatedly activated, which increases the catalytic effects. The metals and metal alloys are also repeatedly generated anew through the reduction with the aid of the carbonaceous materials present. This can result in new active centers on the catalysts due to torsion and lattice structural defects and they
15 can be supplied with electrons for redox reactions through piezoelectric properties.

The milling elements or milling balls consist of a high and low temperature resistant, impact resistant, abrasion resistant material with a high hardness and a very high melting point. Suitable milling elements consist, for example, of aluminum oxide,
20 steatite, porcelain, zirconium oxide, glass, flint stone, steels, chromium steels, tungsten carbide, silicon carbide, silicon nitride, boron nitride or boron carbide, or they contain these materials.

The milling elements can have any diameter, depending in particular on the size and
25 construction of the mill, the type of acceleration, for example by rotating the mill wall, by rotating or vibrating the container surrounding the milling chamber, by centrifugal forces, by compressed air, by impacts or by electrostatic and/or magnetic attraction as well as the materials to be milled. The diameters can therefore be optimally adapted to the particular task in an advantageous manner. The diameters are
30 preferably from 0.5 cm to 10 cm.

The milling elements can be spheres or ellipsoids or have irregular shapes, so that there are different contact options per collision. In addition, the milling elements can have smooth or roughened surfaces or have cup-shaped depressions such as a golf

ball, in which case material to be milled can accumulate in the cups. The surface of the milling elements can have a layer of the material to be milled or be doped with it.

Preferably, milling balls are used as milling elements.

5

If, on the other hand, the rollers described above are used for milling the material to be milled, none of the milling elements described above are used. The rollers, which can be solid or hollow, are preferably constructed from the same hard materials as the milling elements.

10

The mechanochemical process according to the invention is used for decontaminating, eliminating, regenerating, immobilizing, digesting and/or converting natural, synthetic, biogenic and biological materials or materials to be milled into valuable products, for immobilizing metals and compounds thereof, for digesting
15 phosphates, for splitting carbon dioxide and carbon monoxide into the elements and recovering valuable products. Said materials preferably contain phosphates, in particular vitreous phosphates, which can be recovered again in bioavailable form using the mechanochemical process according to the invention.

20 In the first process step of the mechanochemical process according to the invention, at least one, in particular one, suspension or pasty mixture, at least one, in particular one, finely divided solid mixture and/or at least one, in particular one, gas is provided as material to be milled.

25 In the context of the present invention, a solid material or a solid mixture is regarded as finely divided if it consists of particles with a mean particle size d_{50} of 1 nm to 2 cm.

The at least one finely divided solid mixture, which is either suspended or is present as a paste or as a finely divided solid powder, preferably contains at least one
30 material which contains or consists of at least one, in particular one, phosphate.

Preferably, the at least one material is selected from the group consisting of natural, synthetic, biogenic and biological materials that are contaminated, ecologically problematic and worrying, harmful, intensely smelling, toxic, combustible, oxidizing,

radioactive and/or explosive, mixtures and waste as well contaminated mineral coals, biochars, activated charcoals and carbon suppliers.

Preferably, the materials are selected from the group consisting of dried manure,
 5 liquid manure, fermentation residues, dry ferments, sewage sludge, ferments, composts, biowaste, vegetable waste, leaves, sawn timber, construction timber, mash, pomace, food industry waste, biotechnological waste, genetic engineering waste, animal waste, waste from metal extraction, radioactive waste, waste from
 10 carbon fiber-reinforced plastics (CFRP), celluloses, hemicelluloses, liginocelluloses, celluloses, hemicelluloses and/or liginocelluloses-containing biomasses and waste, high-molecular-weight proteins and structural proteins, dry concentrates of the biological purification stages of sewage treatment plants, chemical washers and filters, waste water, residues of exhaust air treatment, nitrogen compounds, sulfur compounds, phosphorus compounds, polycyclic aromatic hydrocarbons (PAHs),
 15 volatile organic compounds (VOCs), reactive gases, medical products, hormones, micropollutants, phosphate-containing building materials, phosphate-containing body components, phosphate-containing food and feed, other phosphate sources, synthetic and natural, intensely smelling substances, synthetic and natural toxins, biocides, pyrotechnic materials, explosives, viruses, bacteria, mycoplasmas, prions, algae,
 20 poisonous plants and parts thereof and poisonous animals and parts thereof.

In particular, the nitrogen compounds are selected from the group consisting of ammonia, aliphatic amines, cycloaliphatic amines, olefinically unsaturated amines, aromatic amines, saturated, unsaturated and aromatic heterocyclic amines and the
 25 ammonium compounds thereof, amides, amine oxides, ammine complexes, azo compounds, carbodiimides, hydrazines, hydrazones, hydrazide hydrazones, guanidines, ureas, biurets, triurets, semicarbazides, carbodiazones, carbazidic acid derivatives, isosemicarbazides, imines, isocyanides, N-hydroxy compounds, carboxamides, carboxylic acid hydrazides, imide, hydrazone, hydroximic and
 30 hydroxamic acids, nitrates, nitrites, nitrides, nitriles, nitroso compounds, nitrosyl compounds, nitro compounds, tetrazenes and urethanes. In particular, the nitrogen compounds are nitrates, nitrites and nitrosamines.

In particular, the sulfur compounds are selected from the group consisting of the allotropes of sulfur, hydrogen sulfide, thiols, sulfides, sulfur halides, sulfoxides, sulfones, sultones, sulfuric acid esters, sulfonic acids, sulfonic acid esters, sulfur-nitrogen compounds and sulfonium compounds.

5

In particular, the phosphorus compounds are selected from the group consisting of phosphorus allotropes, phosphines, phosphonium compounds, phosphites, phosphates, phosphonates, phosphorus halides and phosphazenes, but in particular phosphates.

10

In particular, the fluids are selected from the group consisting of industrial solvents and residues of industrial solvents, in particular solvents from the paint industry, the automotive industry, chip production and industrial low-molecular and high-molecular organic synthesis.

15

In particular, the volatile organic compounds (VOC) are selected from the group consisting of aldehydes and ketones such as ethanal, propionaldehyde, thioaldehyde, butyraldehyde, heptanal, methyl ethyl ketone, cyclohexanone and formaldehyde, alkanes and cycloalkanes such as hexane, heptane, octane, nonane, decane, cyclohexanone and methylcyclohexane, aromatics such as benzene, toluene, ethylbenzene, xylene, cresol and styrene, phenols such as phenol and cresol, volatile halogenated hydrocarbons (LHKW), such as partially and fully chlorinated hydrocarbons, fluorinated hydrocarbons and chlorofluorocarbons, such as trifluorochloromethane, carbon tetrachloride, carbon tetra fluoride, chloroform, trichloroethane, tetrachloroethane and dichlorobenzene.

25

In particular, the reactive gases, which are not mentioned above, are selected from the group consisting of methane, ethane, propane, butane, ethylene, propylene, hydrocyanic acid, dicyan, phosgene, acetylene, vinyl fluoride, vinyl chloride, vinylidene chloride, vinylidene fluoride, nitrogen trifluoride, tetrafluorohydrazine, cis- and trans-difluorodiazine, sulfur tetrafluoride and carbon monoxide.

30

Under the right conditions, carbon dioxide is also a reactive gas.

In particular, the PAHs are selected from the group consisting of pentals, indene, naphthalene, azulene, heptalene, biphenylene, asymmetrical indacene, symmetrical indacene, acenaphthylene, fluorene, phenals, phenanthrene, anthracene, acephenanthrylene, aceanthrylene, triphenylene, pyrene, chrysene, naphthacene, pleiades, picene, perylene, pentaphene, pentacene, tetraphenylene, hexaphene, hexacene, rubicene, coronene, trinaphthylene, heptaphene, heptacene, octacene, ovalene, superphenalene, benzo[a]anthracene, benzob[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene and benzo[ghi]perylene.

10

In particular, the medical products are selected from the group consisting of the drugs, including hormones, that are listed in the "GELBEN LISTE Pharmaindex" and the "Roten Liste", drugs not approved for human use, veterinary drugs, drugs in the research stage, in development and in clinical testing as well as their wastes and metabolites thereof.

15

In particular, the micropollutants are selected from the group consisting of medical products, industrial chemicals and hormones in concentrations from µg/liter to ng/liter and microplastics. In particular, the phosphate-containing building materials are selected from the group consisting of phosphate-containing cements, concretes, bricks, artificial stones, stones, boards, composite materials with wood and annular gap mortar.

20

In particular, the other sources of phosphate are selected from the group consisting of detergents, anti-corrosion agents, teeth, tooth meal, bones, bone meal, apatite and hydroxyapatite.

25

In particular, the phosphate-containing foods and feeds are selected from the group consisting of dairy products, sausage products, lemonades, ready meals, canned fish and phosphate-containing feeds for animals.

30

In particular, the intensely smelling substances are selected from the group consisting of synthetic, organic and inorganic nitrogen, sulfur, selenium, tellurium, phosphorus

and arsenic compounds, animal-based, sympathetic and antipathic fragrances and plant-based, sympathetic and antipathic fragrances.

5 In particular, the synthetic toxins are selected from the group consisting of warfare agents, potassium cyanide, beryllium, selenium, tellurium, thallium, white phosphorus, arsenic, arsenic compounds, cadmium, mercury, mercury compounds, polonium, plutonium and polyhalogenated aromatics, dioxins and dibenzofurans.

10 In particular, the natural toxins are selected from the group consisting of vegetable, animal, fungal and bacterial toxins and algae toxins.

In particular, the biocides are selected from the group consisting of pesticides, herbicides, virucides against viruses, bactericides against bacteria, acaricides against mites, algaecides against algae, fungicides against fungi, insecticides against insects,
15 microbicides against germs, molluscicides against snails, nematocides against roundworms (nematodes), rodenticides against rodents, avicides against birds and piscicides against fish.

20 In particular, the pyrotechnic materials are selected from the group consisting of fireworks and theatrical fireworks and the oxidizing agents, fuels and auxiliaries used therein.

In particular, the explosives are selected from the group consisting of chlorates, perchlorates, xenon oxides, organic and inorganic nitrogen halogen compounds,
25 peroxides, nitric acid esters, nitro compounds, nitramines, nitrosamines, high-energy nitrogen compounds, initiating explosives and low-smoke powders. Examples of such explosives are described, for example, in the textbook by Thomas M. Klapötke, Chemistry of High-Energy Materials, Walter de Gruyter, Berlin/New York, 2011.

30 In particular, the poisonous plants and the parts thereof are selected from the group consisting of the plants monkshood, poison parsley, common arum, deadly nightshade, angel's trumpet, brunfelsia, boxwood, Chaerophyllum temulum, water hemlock, autumn crocus, hemlock, spotted hemlock, lily of the valley, cyclamen, February daphne, datura, alpine delphinium, common foxglove, dieffenbachia, basket

ferns, wallflower, Californian poppy seeds, spindle tree, poinsettia, rubber tree, gloriosa superba, ivy, stinking hellebore, Christmas rose, acanthus, hyacinth, henbane, holly, iris, laburnum, bleeding heart, oleander, tobacco, paris, snap bean, bracken, apricot, cherry laurel, buttercup, rhubarb, castor-bean plant, rhododendron, robinia, elder, bittersweet, potato, Ignatius bean, tansy, luckynut, ongaonga, white veratrum, Chinese wisteria, tomato, eggplant, yew tree, and taxus plants.

In particular, the poisonous animals and parts thereof are selected from the group consisting of sponges, anthozoae, hydrozoans, scyphozoans, polychaetes, snails, cephalopods, insects, arachnids, fish, amphibians, reptiles, birds and mammals.

Examples of structural proteins are keratin of the hair, nails, hooves and horns of mammals, of the feathers of birds and scales of reptiles, collagen of the connective tissue and the extracellular matrix of all tissue animals, elastin, fibrillar (fibrous) structural proteins such as myosin and tropomyosin, which cause contraction of the muscle cells (these are usually referred to as movement proteins), fibrous silk proteins from insects (fibroin and sericin) or spiders (spidroin 1 and spidroin 2), arthropodin and sclerotin (phenol-tanned arthropodin), in addition to chitin, the main component of the body shell (cuticle) of arthropods, centrioles and microtubules of most living organisms and microfilaments of the cytoskeleton of most living organisms.

Preferably, the carbon-supplying materials are selected from the group consisting of the above-described plant materials as well as husks, wood chips, sawdust, hay, grass, grain, awns, silage, nutshells, bark, dried leaves and needles and natural fibers such as seed fibers such as cotton (CO), Kapok (KP), poplar fluff, acon, bamboo fibers, nettle fibers, hemp fibers (HA), jute (JU), kenaf, linen (LI), hops, ramie (RA) and hemp, hard fibers such as pineapple, caroa, curaua, henequen, New Zealand flax, sisal (SI) and coconut (CC) and fibers made from natural polymers such as cellulosic fibers such as viscose (CV), modal (CMD), lyocell (CLY), cupro (CUP), acetate (CA) and triacetate (CTA).

In addition, the at least one preferably phosphate-containing material contains at least one type of carbon selected from the group consisting of pure, finely divided mineral

coal, pure, finely divided biochar, pure, finely divided activated charcoal, contaminated, finely divided mineral coal, contaminated, finely divided biochar, contaminated, finely divided activated charcoal, finely divided lignite and pure and contaminated finely divided carbon suppliers and from the aforementioned moistened materials.

The at least one, in particular a finely divided solid mixture can furthermore contain at least one solid, finely divided or, in the case of the at least one suspension, at least one dissolved, emulsified or suspended additive that differs materially from the materials described above. Preferably, the at least one additive is added from the group consisting of inorganic and organic salts, acids, bases, oxides, reducing agents, oxidizing agents, water vapor, superheated steam, zeolites and sheet silicates. Examples of suitable inorganic and organic salts are the lithium, sodium, potassium, magnesium and calcium salts of hydrochloric acid, sulfuric acid, nitric acid, nitrous acid, acetic acid, propionic acid, butyric acid, benzoic acid, benzenesulfonic acid and benzenephosphonic acid. Examples of suitable acids are those mentioned above. Examples of suitable bases are lithium, sodium, potassium, magnesium and calcium hydroxide. Examples of suitable oxides are the iron oxides, aluminum oxide, gallium oxide, indium oxide, silicon oxide, sands, germanium oxide, tin oxide, lead oxide, antimony oxide and bismuth oxide. Examples of suitable reducing agents are hydrogen, lithium aluminum nitride, sodium borohydride, sodium sulfite, sodium dithionite and sodium thiosulfate. Examples of suitable oxidizing agents are oxygen, hydrogen peroxide and organic peroxides, sodium percarbonate, potassium permanganate, potassium dichromate and the halogens.

The oxidizing agents mentioned have the advantage that they can provide coals G with functional groups that improve adsorption and chemisorption and open up new reaction paths.

Sodium chloride, potassium chloride and sheet silicates are used in particular.

The sheet silicates are preferably nanoparticles and/or microparticles with a mean particle size d_{50} of 1 nm to <1000 μm , preferably 10 nm to 900 μm , in particular 300

nm to 1000 nm, particularly in particular 650 ± 200 nm, very particularly in particular 650 ± 150 nm and in particular 650 ± 100 nm.

The elemental composition and the structure of the layered silicate micro- and/or

5 nanoparticles can also vary very widely. For example, the division of silicates into the following structures is known:

- island silicates
 - group silicates
 - ring silicates
 - 10 - chain and band silicates
 - transition structures between chain and sheet silicates
 - sheet silicates
 - framework silicates.
- 15 Sheet silicates are silicates whose silicate ions consist of layers of corner-linked SiO_4 tetrahedra. These sheets and/or double sheets are not further linked to one another. The technically important clay minerals found in sedimentary rocks are also sheet silicates. The layered structure of these minerals determines the shape and properties of the crystals. They are usually tabular to leafy with good to perfect cleavage parallel
- 20 to the layers. The number of rings that make up the silicate sheets often determines the symmetry and shape of the crystals. Water molecules, large cations and/or lipids can be embedded between the layers.

Examples of suitable sheet silicates are shown in Table 1 below. The list is exemplary

25 and not exhaustive.

Table 1: Molecular formulae of suitable sheet silicates ^{a)}

No.	Type	Molecular formula
1	Martinite	$(\text{Na}, \text{Ca})_{11}\text{Ca}_4(\text{Si}, \text{S}, \text{B})_{14}\text{B}_2\text{O}_{40}\text{F}_2 \cdot 4(\text{H}_2\text{O})$
2	Apophyllite-(NaF)	$\text{NaCa}_4\text{Si}_8\text{O}_{20}\text{F} \cdot 8\text{H}_2\text{O}$

3	Apophyllite-(KF)	$(K,Na)Ca_4Si_8O_{20}(F,OH) \cdot 8H_2O$
4	Apophyllite-(KOH)	$KCa_4Si_8O_{20}(OH,F) \cdot 8H_2O$
5	Cuprorivaite	$CaCuSi_4O_{10}$
6	Wesselsite	$(Sr,Ba)Cu[Si_4O_{10}]$
7	Effenbergerite	$BaCu[Si_4O_{10}]$
8	Gillespite	$BaFe^{2+}Si_4O_{10}$
9	Sanbornite	$BaSi_2O_5$
10	Bigcreekite	$BaSi_2O_5 \cdot 4H_2O$
11	Davanite	$K_2TiSi_6O_{15}$
12	Dalyite	$K_2ZrSi_6O_{15}$
13	Fenaksite	$KNaFe^{2+}Si_4O_{10}$
14	Manaksite	$KNaMn^{2+}[Si_4O_{10}]$
15	Ershovite	$K_3Na_4(Fe,Mn,Ti)_2[Si_8O_{20}(OH)_4] \cdot 4H_2O$
16	Paraershovite	$Na_3K_3Fe^{3+}_2Si_8O_{20}(OH)_4 \cdot 4H_2O$
17	Natrosilite	$Na_2Si_2O_5$
18	Kanemite	$NaSi_2O_5 \cdot 3H_2O$
19	Revdite	$Na_{16}Si_{16}O_{27}(OH)_{26} \cdot 28H_2O$
20	Latiumite	$(Ca,K)_4(Si,Al)_5O_{11}(SO_4,CO_3)$
21	Tuscanite	$K(Ca,Na)_6(Si,Al)_{10}O_{22}(SO_4,CO_3,(OH)_2) \cdot H_2O$
22	Carletonite	$KNa_4Ca_4Si_8O_{18}(CO_3)_4(OH,F) \cdot H_2O$
23	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
24	Ferripyrophyllite	$Fe^{3+}Si_2O_5(OH)$
25	Macaulayite	$(Fe^{3+},Al)_{24}Si_4O_{43}(OH)_2$
26	Talc	$Mg_3Si_4O_{10}(OH)_2$
27	Minnesotaite	$Fe^{2+}_3Si_4O_{10}(OH)_2$
28	Willemseite	$(Ni,Mg)_3Si_4O_{10}(OH)_2$
29	Pimelite	$Ni_3Si_4O_{10}(OH)_2 \cdot 4H_2O$
30	Kegelite	$Pb_4Al_2Si_4O_{10}(SO_4)(CO_3)_2(OH)_4$
31	Aluminoseladonite	$K(Mg,Fe^{2+})Al[(OH)_2]Si_4O_{10}]$
32	Ferroaluminoseladonite	$K(Fe^{2+},Mg)(Al,Fe^{3+})[(OH)_2]Si_4O_{10}]$
33	Seladonite	$K(Mg,Fe^{2+})(Fe^{3+},Al)Si_4O_{10}(OH)_2$
34	Chromseladonite	$KMgCr[(OH)_2]Si_4O_{10}]$
35	Ferroseladonite	$K(Fe^{2+},Mg)(Fe^{3+},Al)[(OH)_2]Si_4O_{10}]$
36	Paragonite	$NaAl_2(Si_3Al)O_{10}(OH)_2$

37	Boromuskovite	$\text{KAl}_2(\text{Si}_3\text{B})\text{O}_{10}(\text{OH},\text{F})_2$
38	Muskovite	$\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH},\text{F})_2$
39	Chromphyllite	$\text{K}(\text{Cr},\text{Al})_2[(\text{OH},\text{F})_2 \text{AlSi}_3\text{O}_{10}]$
40	Roscoelithe	$\text{K}(\text{V},\text{Al},\text{Mg})_2\text{AlSi}_3\text{O}_{10}(\text{OH})_2$
41	Ganterite	$(\text{Ba},\text{Na},\text{K})(\text{Al},\text{Mg})_2[(\text{OH},\text{F})_2 (\text{Al},\text{Si})\text{Si}_2\text{O}_{10}]$
42	Tobelithe	$(\text{NH}_4,\text{K})\text{Al}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_2$
43	Nanpingite	$\text{CsAl}_2(\text{Si},\text{Al})_4\text{O}_{10}(\text{OH},\text{F})_2$
44	Polyolithionite	$\text{KLi}_2\text{AlSi}_4\text{O}_{10}(\text{F},\text{OH})_2$
45	Tainiolithe	$\text{KLiMg}_2\text{Si}_4\text{O}_{10}\text{F}_2$
46	Norrishite	$\text{KLiMn}^{3+}_2\text{Si}_4\text{O}_{12}$
47	Shirokshinite	$\text{KNaMg}_2[\text{F}_2 \text{Si}_4\text{O}_{10}]$
48	Montdorite	$\text{KMn}_{0.5}^{2+}\text{Fe}_{1.5}^{2+}\text{Mg}_{0.5}[\text{F}_2 \text{Si}_4\text{O}_{10}]$
49	Trilithionite	$\text{KLi}_{1.5}\text{Al}_{1.5}[\text{F}_2 \text{AlSi}_3\text{O}_{10}]$
50	Masutomilithe	$\text{K}(\text{Li},\text{Al},\text{Mn}^{2+})_3(\text{Si},\text{Al})_4\text{O}_{10}(\text{F},\text{OH})_2$
51	Aspidolithe-1M	$\text{NaMg}_3(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2$
52	Fluorophlogopite	$\text{KMg}_3(\text{AlSi}_3)\text{O}_{10}\text{F}_2$
53	Phlogopite	$\text{KMg}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{F},\text{OH})_2$
54	Tetraferriphlogopite	$\text{KMg}_3[(\text{F},\text{OH})_2 (\text{Al},\text{Fe}^{3+})\text{Si}_3\text{O}_{10}]$
55	Hendricksite	$\text{K}(\text{Zn},\text{Mn})_3\text{Si}_3\text{AlO}_{10}(\text{OH})_2$
56	Shirozulithe	$\text{K}(\text{Mn}^{2+},\text{Mg})_3[(\text{OH})_2 \text{AlSi}_3\text{O}_{10}]$
57	Fluorannit	$\text{KFe}_3^{2+}[(\text{F},\text{OH})_2 \text{AlSi}_3\text{O}_{10}]$
58	Annite	$\text{KFe}_3^{2+}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH},\text{F})_2$
59	Tetraferriannite	$\text{KFe}_3^{2+}(\text{Si}_3\text{Fe}^{3+})\text{O}_{10}(\text{OH})_2$
60	Ephesite	$\text{NaLiAl}_2(\text{Al}_2\text{Si}_2)\text{O}_{10}(\text{OH})_2$
61	Preiswerkite	$\text{NaMg}_2\text{Al}_3\text{Si}_2\text{O}_{10}(\text{OH})_2$
62	Eastonite	$\text{KMg}_2\text{Al}[(\text{OH})_2 \text{Al}_2\text{Si}_2\text{O}_{10}]$
63	Siderophyllite	$\text{KFe}_2^{2+}\text{Al}(\text{Al}_2\text{Si}_2)\text{O}_{10}(\text{F},\text{OH})_2$
64	Anandite	$(\text{Ba},\text{K})(\text{Fe}^{2+},\text{Mg})_3(\text{Si},\text{Al},\text{Fe})_4\text{O}_{10}(\text{S},\text{OH})_2$
65	Bityite	$\text{CaLiAl}_2(\text{AlBeSi}_2)\text{O}_{10}(\text{OH})_2$
66	Oxykinoshitalithe	$(\text{Ba},\text{K})(\text{Mg},\text{Fe}^{2+},\text{Ti}^{4+})_3(\text{Si},\text{Al})_4\text{O}_{10}\text{O}_2$
67	Kinoshitalithe	$(\text{Ba},\text{K})(\text{Mg},\text{Mn},\text{Al})_3\text{Si}_2\text{Al}_2\text{O}_{10}(\text{OH})_2$
68	Ferrokinoshitalithe	$\text{Ba}(\text{Fe}^{2+},\text{Mg})_3[(\text{OH},\text{F})_2 \text{Al}_2\text{Si}_2\text{O}_{10}]$
69	Margarite	$\text{CaAl}_2(\text{Al}_2\text{Si}_2)\text{O}_{10}(\text{OH})_2$
70	Chernykhite	$\text{BaV}_2(\text{Si}_2\text{Al}_2)\text{O}_{10}(\text{OH})_2$

71	Clintonite	$\text{Ca}(\text{Mg}, \text{Al})_3(\text{Al}_3\text{Si})\text{O}_{10}(\text{OH})_2$
72	Wonesite	$(\text{Na}, \text{K},)(\text{Mg}, \text{Fe}, \text{Al})_6(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH}, \text{F})_4$
73	Brammallite	$(\text{Na}, \text{H}_3\text{O})(\text{Al}, \text{Mg}, \text{Fe})_2(\text{Si}, \text{Al})_4\text{O}_{10}[(\text{OH})_2, \text{H}_2\text{O}]$
74	Illite	$(\text{K}, \text{H}_3\text{O})\text{Al}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{H}_2\text{O}, \text{OH})_2$
75	Glaukonite	$(\text{K}, \text{Na})(\text{Fe}^{3+}, \text{Al}, \text{Mg})_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2$
76	Agrellite	$\text{NaCa}_2\text{Si}_4\text{O}_{10}\text{F}$
77	Glagolevite	$\text{NaMg}_6[(\text{OH}, \text{O})_8 \text{AlSi}_3\text{O}_{10}]\cdot\text{H}_2\text{O}$
78	Erlianite	$\text{Fe}^{2+}_4\text{Fe}^{3+}_2\text{Si}_6\text{O}_{15}(\text{OH})_8$
79	Bannisterite	$(\text{Ca}, \text{K}, \text{Na})(\text{Mn}^{2+}, \text{Fe}^{2+}, \text{Mg}, \text{Zn})_{10}(\text{Si}, \text{Al})_{16}\text{O}_{38}(\text{OH})_8\cdot n\text{H}_2\text{O}$
80	Bariumbannisterite	$(\text{K}, \text{H}_3\text{O})(\text{Ba}, \text{Ca})(\text{Mn}^{2+}, \text{Fe}^{2+}, \text{Mg})_{21}(\text{Si}, \text{Al})_{32}\text{O}_{80}(\text{O}, \text{OH})_{16}\cdot 4\text{-}12\text{H}_2\text{O}$
81	Lennilenapeite	$\text{K}_{6-7}(\text{Mg}, \text{Mn}, \text{Fe}^{2+}, \text{Fe}^{3+}, \text{Zn})_{48}(\text{Si}, \text{Al})_{72}(\text{O}, \text{OH})_{216}\cdot 16\text{H}_2\text{O}$
82	Stilpnomelane	$\text{K}(\text{Fe}^{2+}, \text{Mg}, \text{Fe}^{3+}, \text{Al})_8(\text{Si}, \text{Al})_{12}(\text{O}, \text{OH})_{27}\cdot 2\text{H}_2\text{O}$
83	Franklinphillite	$(\text{K}, \text{Na})_{1-x}(\text{Mn}^{2+}, \text{Mg}, \text{Zn}, \text{Fe}^{3+})_8(\text{Si}, \text{Al})_{12}(\text{O}, \text{OH})_{36}\cdot n\text{H}_2\text{O}$
84	Parsettensite	$(\text{K}, \text{Na}, \text{Ca})_{7.5}(\text{Mn}, \text{Mg})_{49}\text{Si}_{72}\text{O}_{168}(\text{OH})_{50}\cdot n\text{H}_2\text{O}$
85	Middendorffite	$\text{K}_3\text{Na}_2\text{Mn}_5\text{Si}_{12}(\text{O}, \text{OH})_{36}\cdot 2\text{H}_2\text{O}$
86	Eggletonite	$(\text{Na}, \text{K}, \text{Ca})_2(\text{Mn}, \text{Fe})_8(\text{Si}, \text{Al})_{12}\text{O}_{29}(\text{OH})_7\cdot 11\text{H}_2\text{O}$
87	Ganophyllite	$(\text{K}, \text{Na})_x\text{Mn}^{2+}_6(\text{Si}, \text{Al})_{10}\text{O}_{24}(\text{OH})_4\cdot n\text{H}_2\text{O} \{x = 1\text{-}2\}\{n = 7\text{-}11\}$
88	Tamaite	$(\text{Ca}, \text{K}, \text{Ba}, \text{Na})_{3\text{-}4}\text{Mn}^{2+}_{24}[(\text{OH})_{12}\{(\text{Si}, \text{Al})_4(\text{O}, \text{OH})_{10}\}_{10}]\cdot 21\text{H}_2\text{O}$
89	Ekmanite	$(\text{Fe}^{2+}, \text{Mg}, \text{Mn}, \text{Fe}^{3+})_3(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2\cdot 2\text{H}_2\text{O}$
90	Lunijianlaite	$\text{Li}_{0.7}\text{Al}_{6.2}(\text{Si}_7\text{AlO}_{20})(\text{OH}, \text{O})_{10}$
91	Salitite	$\text{Na}_{0.5}\text{Li}_{0.5}\text{Al}_3[(\text{OH})_5 \text{AlSi}_3\text{O}_{10}]$
92	Kulkeite	$\text{Na}_{0.35}\text{Mg}_8\text{Al}(\text{AlSi}_7)\text{O}_{20}(\text{OH})_{10}$
93	Aliettite	$\text{Ca}_{0.2}\text{Mg}_6(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4\cdot 4\text{H}_2\text{O}$
94	Rectorite	$(\text{Na}, \text{Ca})\text{Al}_4(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4\cdot 2\text{H}_2\text{O}$
95	Tarasovite	$(\text{Na}, \text{K}, \text{H}_3\text{O}, \text{Ca})_2\text{Al}_4[(\text{OH})_2 (\text{Si}, \text{Al})_4\text{O}_{10}]_2\cdot \text{H}_2\text{O}$
96	Tosudite	$\text{Na}_{0.5}(\text{Al}, \text{Mg})_6(\text{Si}, \text{Al})_8\text{O}_{18}(\text{OH})_{12}\cdot 5\text{H}_2\text{O}$
97	Corrensite	$(\text{Ca}, \text{Na}, \text{K})(\text{Mg}, \text{Fe}, \text{Al})_9(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_{10}\cdot n\text{H}_2\text{O}$
98	Brinrobertsite	$(\text{Na}, \text{K}, \text{Ca})_{0.3}(\text{Al}, \text{Fe}, \text{Mg})_4(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4\cdot 3.5\text{H}_2\text{O}$
99	Montmorillonite	$(\text{Na}, \text{Ca})_{0.3}(\text{Al}, \text{Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_2\cdot n\text{H}_2\text{O}$
100	Beidellite	$(\text{Na}, \text{Ca}_{0.5})_{0.3}\text{Al}_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2\cdot 4\text{H}_2\text{O}$
101	Nontronite	$\text{Na}_{0.3}\text{Fe}^{2+}_3(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2\cdot 4\text{H}_2\text{O}$
102	Volkonskoite	$\text{Ca}_{0.3}(\text{Cr}^{3+}, \text{Mg}, \text{Fe}^{3+})_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2\cdot 4\text{H}_2\text{O}$

103	Swinefordite	$(\text{Ca}, \text{Na})_{0.3}(\text{Al}, \text{Li}, \text{Mg})_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH}, \text{F})_2 \cdot 2\text{H}_2\text{O}$
104	Yakhontovite	$(\text{Ca}, \text{Na}, \text{K})_{0.3}(\text{CuFe}^{2+}\text{Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$
105	Hectorite	$\text{Na}_{0.3}(\text{Mg}, \text{Li})_3\text{Si}_4\text{O}_{10}(\text{F}, \text{OH})_2$
106	Saponite	$(\text{Ca} _2, \text{Na})_{0.3}(\text{Mg}, \text{Fe}^{2+})_3(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
107	Ferrosaponite	$\text{Ca}_{0.3}(\text{Fe}^{2+}, \text{Mg}, \text{Fe}^{3+})_3[(\text{OH})_2 (\text{Si}, \text{Al})\text{Si}_3\text{O}_{10}] \cdot 4\text{H}_2\text{O}$
108	Spadaite	$\text{MgSiO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}$
109	Stevensite	$(\text{Ca} _2)_{0.3}\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$
110	Sauconite	$\text{Na}_{0.3}\text{Zn}_3(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
111	Zinksilite	$\text{Zn}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
112	Vermiculite	$\text{Mg}_{0.7}(\text{Mg}, \text{Fe}, \text{Al})_6(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4 \cdot 8\text{H}_2\text{O}$
113	Rilandite	$(\text{Cr}^{3+}, \text{Al})_6\text{SiO}_{11} \cdot 5\text{H}_2\text{O}$
114	Donbassite	$\text{Al}_{2.3}[(\text{OH})_8 \text{AlSi}_3\text{O}_{10}]$
115	Sudoite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$
116	Klinochlore	$(\text{Mg}, \text{Fe}^{2+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$
117	Chamosite	$(\text{Fe}^{2+}, \text{Mg}, \text{Fe}^{3+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH}, \text{O})_8$
118	Orthochamosite	$(\text{Fe}^{2+}, \text{Mg}, \text{Fe}^{3+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH}, \text{O})_8$
119	Baileychlore	$(\text{Zn}, \text{Fe}^{2+}, \text{Al}, \text{Mg})_6(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_8$
120	Pennantite	$\text{Mn}^{2+}_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$
121	Nimite	$(\text{Ni}, \text{Mg}, \text{Fe}^{2+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$
122	Gonyerite	$\text{Mn}^{2+}_5\text{Fe}^{3+}(\text{Si}_3\text{Fe}^{3+}\text{O}_{10})(\text{OH})_8$
123	Cookeite	$\text{LiAl}_4(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$
124	Borocookeite	$\text{Li}_{1-1.5}\text{Al}_{4-3.5}[(\text{OH}, \text{F})_8 (\text{B}, \text{Al})\text{Si}_3\text{O}_{10}]$
125	Manandonite	$\text{Li}_2\text{Al}_4[(\text{Si}_2\text{AlB})\text{O}_{10}](\text{OH})_8$
126	Franklinfurnaceite	$\text{Ca}_2(\text{Fe}^{3+}\text{Al})\text{Mn}^{3+}\text{Mn}_3^{2+}\text{Zn}_2\text{Si}_2\text{O}_{10}(\text{OH})_8$
127	Kämmererite(Var.v. Klinochlore)	$\text{Mg}_5(\text{Al}, \text{Cr})_2\text{Si}_3\text{O}_{10}(\text{OH})_8$
128	Niksergievite	$(\text{Ba}, \text{Ca})_2\text{Al}_3[(\text{OH})_6 \text{CO}_3 (\text{Si}, \text{Al})_4\text{O}_{10}] \cdot 0.2 \text{H}_2\text{O}$
129	Surite	$\text{Pb}_2\text{Ca}(\text{Al}, \text{Mg})_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2(\text{CO}_3, \text{OH})_3 \cdot 0.5 \text{H}_2\text{O}$
130	Ferrisurite	$(\text{Pb}, \text{Ca})_{2-3}(\text{Fe}^{3+}, \text{Al})_2[(\text{OH}, \text{F})_{2.5-3} (\text{CO}_3)_{1.5-2} \text{Si}_4\text{O}_{10}] \cdot 0.5 \text{H}_2\text{O}$
131	Kaolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
132	Dickite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
133	Halloysite-7Å	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
134	Sturtite	$\text{Fe}^{3+}(\text{Mn}^{2+}, \text{Ca}, \text{Mg})\text{Si}_4\text{O}_{10}(\text{OH})_3 \cdot 10 \text{H}_2\text{O}$

135	Allophane	$\text{Al}_2\text{O}_3 \cdot (\text{SiO}_2)_{1.3-2} \cdot (\text{H}_2\text{O})_{2.5-3}$
136	Imogolithe	$\text{Al}_2\text{SiO}_3(\text{OH})_4$
137	Odinite	$(\text{Fe}^{3+}, \text{Mg}, \text{Al}, \text{Fe}^{2+}, \text{Ti}, \text{Mn})_{2.4}(\text{Si}_{1.8}\text{Al}_{0.2})\text{O}_5(\text{OH})_4$
138	Hisingerite	$\text{Fe}_2^{3+}\text{Si}_2\text{O}_5(\text{OH})_4 \cdot 2\text{H}_2\text{O}$
139	Neotokite	$(\text{Mn}, \text{Fe}^{2+})\text{SiO}_3 \cdot \text{H}_2\text{O}$
140	Chrysotile	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
141	Klinochrysotile	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
142	Maufite	$(\text{Mg}, \text{Ni})\text{Al}_4\text{Si}_3\text{O}_{13} \cdot 4\text{H}_2\text{O}$
143	Orthochrysotil	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
144	Parachrysotil	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
145	Antigorite	$(\text{Mg}, \text{Fe}^{2+})_3\text{Si}_2\text{O}_5(\text{OH})_4$
146	Lizardite	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
147	Karyopilite	$\text{Mn}^{2+}_3\text{Si}_2\text{O}_5(\text{OH})_4$
148	Greenalithe	$(\text{Fe}^{2+}, \text{Fe}^{3+})_{2-3}\text{Si}_2\text{O}_5(\text{OH})_4$
149	Berthierine	$(\text{Fe}^{2+}, \text{Fe}^{3+}, \text{Al})_3(\text{Si}, \text{Al})_2\text{O}_5(\text{OH})_4$
150	Fraipontite	$(\text{Zn}, \text{Al})_3(\text{Si}, \text{Al})_2\text{O}_5(\text{OH})_4$
151	Zinalsite	$\text{Zn}_7\text{Al}_4(\text{SiO}_4)_6(\text{OH})_2 \cdot 9\text{H}_2\text{O}$
152	Dozyite	$\text{Mg}_7(\text{Al}, \text{Fe}^{3+}, \text{Cr})_2[(\text{OH})_{12} \text{Al}_2\text{Si}_4\text{O}_{15}]$
153	Amesite	$\text{Mg}_2\text{Al}(\text{SiAl})\text{O}_5(\text{OH})_4$
154	Kellyite	$(\text{Mn}^{2+}, \text{Mg}, \text{Al})_3(\text{Si}, \text{Al})_2\text{O}_5(\text{OH})_4$
155	Cronstedtite	$\text{Fe}_2^{2+}\text{Fe}^{3+}(\text{SiFe}^{3+})\text{O}_5(\text{OH})_4$
156	Karpinskite	$(\text{Mg}, \text{Ni})_2\text{Si}_2\text{O}_5(\text{OH})_2$
157	Népouite	$(\text{Ni}, \text{Mg})_3\text{Si}_2\text{O}_5(\text{OH})_4$
158	Pecoraite	$\text{Ni}_3\text{Si}_2\text{O}_5(\text{OH})_4$
159	Brindleyite	$(\text{Ni}, \text{Mg}, \text{Fe}^{2+})_2\text{Al}(\text{SiAl})\text{O}_5(\text{OH})_4$
160	Carlosturanite	$(\text{Mg}, \text{Fe}^{2+}, \text{Ti})_{21}(\text{Si}, \text{Al})_{12}\text{O}_{28}(\text{OH})_{34} \cdot \text{H}_2\text{O}$
161	Pyrosmalithe-(Fe)	$(\text{Fe}^{2+}, \text{Mn})_8\text{Si}_6\text{O}_{15}(\text{Cl}, \text{OH})_{10}$
162	Pyrosmalithe-(Mn)	$(\text{Mn}, \text{Fe}^{2+})_8\text{Si}_6\text{O}_{15}(\text{OH}, \text{Cl})_{10}$
163	Brokenhillite	$(\text{Mn}, \text{Fe})_8\text{Si}_6\text{O}_{15}(\text{OH}, \text{Cl})_{10}$
164	Nelenite	$(\text{Mn}, \text{Fe}^{2+})_{16}\text{Si}_{12}\text{As}^{3+}_3\text{O}_{36}(\text{OH})_{17}$
165	Schallerite	$(\text{Mn}^{2+}, \text{Fe}^{2+})_{16}\text{Si}_{12}\text{As}^{3+}_3\text{O}_{36}(\text{OH})_{17}$
166	Friedelite	$\text{Mn}^{2+}_8\text{Si}_6\text{O}_{15}(\text{OH}, \text{Cl})_{10}$
167	Mcgillite	$\text{Mn}^{2+}_8\text{Si}_6\text{O}_{15}(\text{OH})_8\text{Cl}_2$
168	Bementite	$\text{Mn}_7\text{Si}_6\text{O}_{15}(\text{OH})_8$

169	Varenneseite	$\text{Na}_8(\text{Mn}, \text{Fe}^{3+}, \text{Ti})_2[(\text{OH}, \text{Cl})_2(\text{Si}_2\text{O}_5)_5] \cdot 12\text{H}_2\text{O}$
170	Naujakasite	$\text{Na}_6(\text{Fe}^{2+}, \text{Mn})\text{Al}_4\text{Si}_8\text{O}_{26}$
171	Manganonaujakasite	$\text{Na}_6(\text{Mn}^{2+}, \text{Fe}^{2+})\text{Al}_4[\text{Si}_8\text{O}_{26}]$
172	Spodiophyllite	$(\text{Na}, \text{K})_4(\text{Mg}, \text{Fe}^{2+})_3(\text{Fe}^{3+}, \text{Al})_2(\text{Si}_8\text{O}_{24})$
173	Sazhinit-e(Ce)	$\text{Na}_2\text{CeSi}_6\text{O}_{14}(\text{OH}) \cdot n\text{H}_2\text{O}$
174	Sazhinite-(La)	$\text{Na}_3\text{La}[\text{Si}_6\text{O}_{15}] \cdot 2\text{H}_2\text{O}$
175	Burckhardtite	$\text{Pb}_2(\text{Fe}^{3+}\text{Te}^{6+})[\text{AlSi}_3\text{O}_8]\text{O}_6$
176	Tuperssuatsiaite	$\text{Na}_2(\text{Fe}^{3+}, \text{Mn}^{2+})_3\text{Si}_8\text{O}_{20}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
177	Palygorskite	$(\text{Mg}, \text{Al})_2\text{Si}_4\text{O}_{10}(\text{OH}) \cdot 4\text{H}_2\text{O}$
178	Yofortierite	$\text{Mn}^{2+}_5\text{Si}_8\text{O}_{20}(\text{OH})_2 \cdot 7\text{H}_2\text{O}$
179	Sepiolithe	$\text{Mg}_4\text{Si}_6\text{O}_{15}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$
180	Falcondoite	$(\text{Ni}, \text{Mg})_4\text{Si}_6\text{O}_{15}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$
181	Loughlinitite	$\text{Na}_2\text{Mg}_3\text{Si}_6\text{O}_{16} \cdot 8\text{H}_2\text{O}$
182	Kalifersite	$(\text{K}, \text{Na})_5\text{Fe}_7^{3+}[(\text{OH})_3 \text{Si}_{10}\text{O}_{25}]_2 \cdot 12\text{H}_2\text{O}$
183	Minehillite	$(\text{K}, \text{Na})_{2-3}\text{Ca}_{28}(\text{Zn}_4\text{Al}_4\text{Si}_{40})\text{O}_{112}(\text{OH})_{16}$
184	Truscottite	$(\text{Ca}, \text{Mn})_{14}\text{Si}_{24}\text{O}_{58}(\text{OH})_8 \cdot 2\text{H}_2\text{O}$
185	Orlymanite	$\text{Ca}_4\text{Mn}_3^{2+}\text{Si}_8\text{O}_{20}(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
186	Fedorite	$(\text{Na}, \text{K})_{2-3}(\text{Ca}, \text{Na})_7[\text{Si}_4\text{O}_8(\text{F}, \text{Cl}, \text{OH})_2](\text{Si}_4\text{O}_{10})_3 \cdot 3.5\text{H}_2\text{O}$
187	Reyerite	$(\text{Na}, \text{K})_4\text{Ca}_{14}\text{Si}_{22}\text{Al}_2\text{O}_{58}(\text{OH})_8 \cdot 6\text{H}_2\text{O}$
188	Gyrolithe	$\text{NaCa}_{16}\text{Si}_{23}\text{AlO}_{60}(\text{OH})_8 \cdot 14\text{H}_2\text{O}$
189	Tungusite	$\text{Ca}_{14}\text{Fe}_9^{2+}[(\text{OH})_{22}](\text{Si}_4\text{O}_{10})_6]$
190	Zeophyllite	$\text{Ca}_4\text{Si}_3\text{O}_8(\text{OH}, \text{F})_4 \cdot 2\text{H}_2\text{O}$
191	Armstrongite	$\text{CaZr}(\text{Si}_6\text{O}_{15}) \cdot 3\text{H}_2\text{O}$
192	Jagoite	$\text{Pb}_{18}\text{Fe}^{3+}_4[\text{Si}_4(\text{Si}, \text{Fe}^{3+})_6][\text{Pb}_4\text{Si}_{16}(\text{Si}, \text{Fe})_4]\text{O}_{82}\text{Cl}_6$
193	Hyttisjöite	$\text{Pb}_{18}\text{Ba}_2\text{Ca}_5\text{Mn}_2^{2+}\text{Fe}_2^{3+}[\text{Cl}](\text{Si}_{15}\text{O}_{45})_2 \cdot 6\text{H}_2\text{O}$
194	Maricopaite	$\text{Ca}_2\text{Pb}_7(\text{Si}_{36}, \text{Al}_{12})(\text{O}, \text{OH})_{99} \cdot n(\text{H}_2\text{O}, \text{OH})$
195	Cavansite	$\text{Ca}(\text{VO})\text{Si}_4\text{O}_{10} \cdot 4\text{H}_2\text{O}$
196	Pentagonite	$\text{Ca}(\text{VO})\text{Si}_4\text{O}_{10} \cdot 4\text{H}_2\text{O}$
197	Weeksite	$(\text{K}, \text{Ba})_2[(\text{UO}_2)_2 \text{Si}_5\text{O}_{13}] \cdot 4\text{H}_2\text{O}$
198	Coutinhoite	$\text{Th}_{0.5}(\text{UO}_2)_2\text{Si}_5\text{O}_{13} \cdot 3\text{H}_2\text{O}$
199	Haiweeite	$\text{Ca}[(\text{UO}_2)_2 \text{Si}_5\text{O}_{12}(\text{OH})_2] \cdot 6\text{H}_2\text{O}$
200	Metahaiweeite	$\text{Ca}(\text{UO}_2)_2\text{Si}_6\text{O}_{15} \cdot n\text{H}_2\text{O}$
201	Monteregianite-(Y)	$\text{KNa}_2\text{YSi}_8\text{O}_{19} \cdot 5\text{H}_2\text{O}$
202	Mountainite	$\text{KNa}_2\text{Ca}_2[\text{Si}_8\text{O}_{19}(\text{OH})] \cdot 6\text{H}_2\text{O}$

203	Rhodesite	$\text{KHCa}_2\text{Si}_8\text{O}_{19} \cdot 5\text{H}_2\text{O}$
204	Delhayelithe	$\text{K}_7\text{Na}_3\text{Ca}_5\text{Al}_2\text{Si}_{14}\text{O}_{38}\text{F}_4\text{Cl}_2$
205	Hydrodelhayelithe	$\text{KCa}_2\text{AlSi}_7\text{O}_{17}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$
206	Macdonaldite	$\text{BaCa}_4\text{Si}_{16}\text{O}_{36}(\text{OH})_2 \cdot 10\text{H}_2\text{O}$
207	Cymrite	$\text{Ba}(\text{Si},\text{Al})_4(\text{O},\text{OH})_8 \cdot \text{H}_2\text{O}$
208	Kampfite	$\text{Ba}_{12}(\text{Si}_{11}\text{Al}_5)\text{O}_{31}(\text{CO}_3)_8\text{Cl}_5$
209	Lourenswalsite	$(\text{K},\text{Ba})_2(\text{Ti},\text{Mg},\text{Ca},\text{Fe})_4(\text{Si},\text{Al},\text{Fe})_6\text{O}_{14}(\text{OH})_{12}$
210	Tianshanite	$(\text{Na},\text{K})_{9-10}(\text{Ca},\text{Y})_2\text{Ba}_6(\text{Mn}^{2+},\text{Fe}^{2+},\text{Ti}^{4+},\text{Zn})_6(\text{Ti},\text{Nb})$ $[(\text{O},\text{F},\text{OH})_{11} \text{B}_2\text{O}_4 \text{Si}_6\text{O}_{15}]_6$
211	Wickenburgite	$\text{Pb}_3\text{CaAl}[\text{Si}_{10}\text{O}_{27}] \cdot 3\text{H}_2\text{O}$
212	Silhydritee	$\text{Si}_3\text{O}_6 \cdot \text{H}_2\text{O}$
213	Magadiite	$\text{Na}_2\text{Si}_{14}\text{O}_{29} \cdot 11\text{H}_2\text{O}$
214	Strätlingite	$\text{Ca}_2\text{Al}[(\text{OH})_6\text{AlSiO}_2(\text{OH})_4] \cdot 2.5 \text{H}_2\text{O}$
215	Vertumnite	$\text{Ca}_4\text{Al}_4\text{Si}_4\text{O}_6(\text{OH})_{24} \cdot 3\text{H}_2\text{O}$
216	Zussmanite	$\text{K}(\text{Fe}^{2+},\text{Mg},\text{Mn})_{13}(\text{Si},\text{Al})_{18}\text{O}_{42}(\text{OH})_{14}$
217	Coombsite	$\text{K}(\text{Mn}^{2+},\text{Fe}^{2+},\text{Mg})_{13}[(\text{OH})_7 (\text{Si},\text{Al})_3\text{O}_3 \text{Si}_6\text{O}_{18}]_2$

a) cf., Mineralienatlas, mineral class VIII/H - phyllosilicates, Strunz 8 systematics

5 In particular, bentonite from the group of montmorillonites

$((\text{Na},\text{Ca})_{0.3}(\text{Al},\text{Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O})$ is used. Bentonite is a mixture of different clay minerals and contains montmorillonite as the main component. Sodium bentonite can absorb an amount of water many times its own dry weight. Furthermore, calcium bentonite can absorb fats and/or oils.

10

The sheet silicate micro- and/or nanoparticles described above are functionalized, not functionalized, aggregated, not aggregated, agglomerated, not agglomerated, supported and/or not supported. For example, they can be functionalized, agglomerated and supported. But they can also not be functionalized and aggregated.

15

They can have a catalytic effect and/or support dehalogenation.

The material to be milled contains at least one, in particular one, fluid, at least one, in particular one, solution, at least one, in particular one, suspension, at least one, in particular one, finely divided, solid mixture and/or at least one, in particular one, reactive gas. The above-mentioned materials contain problematic, synthetic, biogenic and biological materials, phosphates, metals and/or compounds thereof and/or carbon dioxide and/or carbon monoxide.

In addition, the material to be milled contains the coals and/or carbon suppliers described above.

The at least one, in particular one, suspension can also be in the form of a paste which contains at least one, in particular one, finely divided solid mixture and/or components thereof. The components of the at least one, in particular a solid, finely divided mixture can also be provided separately from one another.

The at least one, in particular one, suspension or paste can contain a continuous aqueous and/or a continuous organic liquid phase. Preferably, an aqueous phase is used which can contain water-miscible, protic and/or aprotic polar organic solvents. In particular, the aqueous phase does not contain any organic solvents.

At least one of the solvents described above is used as the at least one, in particular one, fluid.

At least one solvent in which at least one of the above-described materials is dissolved in a molecularly disperse manner is used as the at least one, in particular one, solution.

The at least one reactive gas can be present as a gas, as a condensed fluid and/or as a frozen solid.

In a second or third process step, the material to be milled is metered continuously or discontinuously to at least one, in particular a mechanical, mill. Alternatively, the components of the material to be milled can be metered in successively or

simultaneously, continuously or discontinuously, to the at least one, in particular one, mechanical mill.

In a fourth process step, the material to be milled is finely milled at constant and/or
 5 variable speed of rotation using the milling elements described above, which are
 moved using the agitation means described above, after which, in a fifth process step,
 the at least one, in particular one, resulting milled suspension of at least one
 pulverulent product or the at least one, in particular one, pulverulent product is
 separated continuously or discontinuously from the milling elements in a fifth process
 10 step and discharges it from the milling chamber.

"Variable speed of rotation" means that the speed of rotation in the course of the
 milling increases up to a limit value or decreases from a preselected value or
 increases at least once and then decreases again.

15

The milled products can be metered continuously or discontinuously into at least one
 further mechanical mill or a cascade of mills.

In a sixth process step, the at least one, in particular one, milled, finely divided solid
 20 product is separated from the at least one, in particular one, milled suspension,
 whereby at least one digested, bioavailable, water-soluble material, in particular at
 least one phosphate, is converted into the liquid, in particular aqueous medium,
 preferably dissolved in molecularly disperse form.

25 Alternatively, the at least one digested, bioavailable, water-soluble material present or
 still present in the at least one finely divided, solid product, in particular at least one
 phosphate, is left in the at least one product until it is further used, for example as a
 fertilizer.

30 Furthermore, the at least one washed, finely divided, solid product made of activated
 charcoal is returned to the first process step and/or used in some other way as a
 sales product.

The at least one, in particular one, finely divided solid product can be washed out by washing out, decanting, distillation, chromatography, extraction, magnetic separation, filtration, sedimentation and/or centrifugation.

- 5 The at least one, in particular one, finely divided solid product that is recovered as described above, can also contain at least one further, in particular at least two further, bioavailable material(s) soluble in liquid, in particular aqueous, media, which are left in or washed out from the at least one, in particular one, product until it is further used. Preferably, these bioavailable materials are selected from the group
- 10 consisting of lithium, sodium and potassium salts as well as magnesium and calcium salts, in particular sulfates.

In addition, the at least one, in particular one, solid, finely divided product can contain at least one immobilized metal selected from the group consisting of main group

15 elements, heavy metals and radioactive metals and compounds thereof. The main group elements are in particular beryllium, arsenic, antimony, bismuth, aluminum, gallium, germanium, selenium, tellurium, thallium and lead. The heavy metals are the transition metals, especially precious metals such as rhodium, iridium, palladium, platinum, silver and gold, and the lanthanides. The radioactive metals are in particular

20 the actinides. The compounds are the oxides, hydroxides, acids, salts, complexes or organometallic compounds of these elements and metals.

It is a particular advantage of the process according to the invention that toxic and/or carcinogenic metal compounds such as chromates or dichromates are reduced in the

25 course of the process according to the invention, for example to form chromium (III) or to the zero-valent metals such as chromium (0) and thereby detoxified and immobilized.

At least one, in particular one, washed-out, solid, finely divided product is the valuable

30 product activated charcoal, which can be returned to the first process step. This is a particular advantage of the mechanochemical process according to the invention, because it enables the provision of expensive fresh activated charcoal to be minimized.

In addition, the at least one solid, finely divided product that has not been washed out can be a valuable phosphate-containing fertilizer.

Furthermore, the at least one immobilized metal and/or the at least one immobilized metal compound can be at least one material that can be safely stored or dumped, or at least one heterogeneous catalyst.

When the at least one immobilized metal is at least one of the noble metals mentioned above, it can be easily recovered by burning the activated charcoal.

10

In a further particularly preferred embodiment of the mechanochemical process according to the invention, the weight ratio of the fluids, the solutions, the suspensions, the finely divided solid mixtures and/or the gases or the materials mentioned plus at least one additive to pure, finely divided mineral coal, biochar or activated charcoal, contaminated, finely divided, mineral coal, biochar or activated charcoal, finely divided lignite or pure or contaminated, finely divided carbon suppliers as well as from the above-mentioned, moistened materials in the material to be milled is 0.01 to 10^{12} , preferably 0.1 to 10^8 , particularly preferably 1.0 to 10^6 and in particular 1.0 to 10^4 .

20

It is a very important advantage of the mechanochemical process according to the invention that it serves to reduce or eliminate ammonia, ammonium salts, nitrates, nitrites and nitrosamines and/or to simultaneously generate bioavailable phosphates and activated charcoals. For this purpose, the mechanochemical process according to the invention is carried out in particular with dried manure, liquid manure, fermentation residues, dry ferments, sewage sludge, ferments, biowaste, vegetable waste, animal waste, dry concentrates of the biological purification stages of sewage treatment plants, chemical washers and filters, waste water and residues of the exhaust air treatment.

30

This demonstrates the particular advantage of the mechanochemical process according to the invention, namely that the nitrogen compounds are all converted into elemental nitrogen without NO_x or nitrous oxide being produced. The elimination takes place very quickly, so that the mechanochemical process according to the

invention can be ended after a comparatively short time, for example after 100 minutes.

In particular, the mechanochemical process according to the invention is carried out in the course of at least a fourth purification stage of sewage treatment plants.

The process according to the invention can, however, be applied much more broadly, as the following examples show.

10 **The processing of manure, biomass from biogas plants, liquid manure and sewage sludge in the mechanical mills using activated charcoal**

Scientific studies show that activated charcoal absorbs the following substances well to very well:

15

- Particles or suspended matter that are larger than the pores of the filter, such as fibers, suspended matter.
- Bacteria and parasites that are larger than the pores of the filter.
- Chlorine and chlorine compounds.

20

- Organic compounds (chemical compounds based on carbon) such as, for example, pesticides and pesticide residues, herbicides, insecticides, drug residues, hormones and hormone-like substances.

25

- Certain heavy metals such as lead and copper, selenium, cadmium, trace elements from biogas plants, uranium as an accompanying substance from phosphate.
- Ozone, superoxide, oxidizing agents.

The substances that activated charcoal block filters cannot or hardly absorb include:

30

- Organic and inorganic particles or suspended matter that are smaller than the pores of the filter.
- Dissolved salts: natural minerals such as calcium and magnesium ions, nitrate, nitrite, ammonium, etc.

Manure, biomass, liquid manure, sewage sludge contain in different concentrations:

- Water.
- Water-soluble cations: potassium, sodium, calcium, magnesium.
- 5 - Water-soluble ions: chloride, nitrate, nitrite, phosphate, sulfate, ammonium.
- Dissolved gases; ammonia, hydrogen sulfide, methane, carbon dioxide, carbon monoxide.
- Organic compounds: humic acids, pesticides, drugs and residues, hormones, PAHs, amides, proteins.
- 10 - Solid components: suspended matter, particles, fibers, sand.
- Chlorine and chlorine compounds from cleaning agents and contamination.
- Bacteria, cryptosporidia, giardia.

There are different processes of working up manure:

15

- **Separation with press screws**

- Press screws have a medium energy requirement. In them, the manure is pressed against a surrounding sieve with a screw. The thin phase goes through the sieve, the solid phase is pressed out against a mechanical resistance. With the change in
- 20 resistance - for example the opening area - the degree of separation can be influenced. Press screws can separate from the raw manure
- 25 percent of the weight,
50 percent of the dry matter,
30 percent of the nitrogen, and
25 up to 40 percent of the phosphate.

- **Separation with centrifuges**

- Centrifuges have a higher energy requirement, but separate more phosphate. The
- 30 solid and liquid phases are separated in a rapidly rotating drum. With this technology, not only fibrous materials, as in press screws, but also fine materials are included in the solid phase. This means that nutrients are enriched in this phase. Centrifuges separate:

15 percent of the weight,
 60 percent of the dry matter,
 20 percent of nitrogen, and
 up to 70 percent of the phosphate.

5

- **Multi-stage manure separators**

Multi-stage separators with two centrifuges are not only very expensive, they also have extremely high energy consumption. To do this, they extract:

10 30 percent of the weight,
 90 percent of the dry matter,
 50 percent of the nitrogen, and
 up to 95 percent of the phosphate.

15 - **Mobile manure separators**

In addition to permanently installed separators, various mobile versions are available. These devices can be brought flexibly to different locations by forklift, on car or heavy-duty trailers or on trucks. This means that the smaller quantities of manure from
 20 smaller companies, for example from contractors can be treated with well-utilized technology.

- **Mechanochemical work up**

25 Depending on the nutrient balance, the solid phases can be processed further or mechanochemically worked up. The mechanochemical work-up pursues the following goals:

- To convert nitrates and ammonium, which are shown as nitrogen here,
 30 together with organic nitrogen to atmospheric nitrogen.
- The phosphate remains water-soluble or is returned for this purpose and thus made bioavailable.
- Dry matter, which consists of cellulose, hemicellulose, lignin, humic acid, proteins, amines, tissue residues, bacteria, sludge, fibers and PAHs bound thereto,

are processed into coal or, depending on the running time of the mechanical mill, converted into short-chain biomolecules beforehand. These have nutritional value for fungi, bacteria, and animals. The material can be fed into the biogas plants to convert the nutrients into methane. In combination, the nitrogen content has been reduced at the same time.

- **The activated charcoal clarification**

In an activated charcoal block filter, three different principles complement each other in their effect:

- **The mechanical effect of the activated charcoal**

The activated charcoal, like a sieve, holds back all particles that are larger than its pores. This mechanical effect filters, for example, bacteria, cryptosporidia (single-cell parasites), giardia (small intestine parasites), suspended particles and sand, rust particles, asbestos fibers, etc. In order to achieve even finer and more reliable particle filtration than would be possible with pure activated charcoal filters, some filter inserts also use a second filter stage in the form of a hollow fiber membrane. Even

- **The catalytic effect**

Certain substances that are smaller than the pores of the filter can be converted by the activated charcoal with its catalytic effect. These substances are then no longer in their original form. The catalytic effect eliminates the unpleasant taste of chlorinated water, for example. Activated charcoal is very efficient in terms of its catalytic effect, since it is used up only to a small extent in the process. With the catalytic effect, for example, the following are removed from the water: chlorine, CFCs and CFCs.

- **The adsorptive effect**

The activated charcoal can absorb certain substances that are smaller than the pores of the filter with its adsorptive effect. During adsorption, the substances attach to the activated charcoal and stick. The forces that cause this adhesion are not chemical

bonds, but “Van der Waals forces”, which act in a similar way to magnetic forces on various substances.

Activated charcoal has the greatest adsorption power of all known substances and is therefore particularly suitable as a filter medium.

“Van der Waals forces” are very strong, but only act at a very short distance. The proximity to the contact surface and the speed at which the water flows past it is therefore crucial for the adsorptive effect. The finer an activated charcoal filter and the slower the water flows through it, the better the adsorptive filtering. This is where an advantage of particularly small activated charcoal comes into play, because it has comparatively fine pores and slows down the flow of water.

With its adsorptive effect, an activated charcoal filter can bind organic substances and inorganic substances that are undesirable for human consumption in water, such as, for example, lead, copper, pesticides, herbicides, fungicides, hormone residues, drug residues as well as odor and taste-impairing substances.

- **The mechanochemical work-up of the loaded activated charcoal**

The activated charcoal is pressed out, briefly pre-dried and then mechanochemically processed with a mechanical mill and recycled so that it can be circulated. The separated water can also be reused. The mechanochemical work-up aims at:

- Converting nitrates and ammonium together with organic nitrogen to atmospheric nitrogen.
- Making small particles with phosphate, which are water-insoluble and therefore not available to plants, bioavailable again.
- Processing dry matter, which consists of cellulose, hemicellulose, lignin, humic acid, proteins, amines, tissue residues, bacteria, sludge, fibers and PAHs, back into coal or, depending on the running time of the mechanical mill, to convert it into short-chain biomolecules beforehand. They have nutritional value for fungi, bacteria, and animals. The material can advantageously be fed into the biogas plants to convert the nutrients into methane. In combination, the nitrogen content is reduced at the same time.
- Binding heavy metals and reuse them as auxiliary materials in the activated charcoal for biomass systems. In this way they do not end up in the field or in nature.

In particular, heavy metals such as uranium, cadmium, lead, copper and cobalt no longer find their way into nature.

- Digesting herbicides, fungicides, hormone residues and drug residues to form coal.

5 - Chlorine, CHCs, CFCs, PCBs and dioxins are converted to non-toxic chlorides and coal.

- The water that is left after the activated charcoal filtering can be separated into clean water and nutrients using conventional desalination systems.

- The activated charcoal can always be recycled.

10

- **The mechanochemistry in the desalination of water**

In all cases, the desalinated water is not suitable for direct use as drinking water. In addition, such low-salt waters are corrosive for ferrous materials, since no lime-rust
 15 protective layer can be formed. Subsequent addition of calcium hydrogen carbonate therefore increases the carbonate hardness content in the water again. Calcium hydrogen carbonate is produced by a reaction of calcium hydroxide (milk of lime) with carbon dioxide (CO₂).

20 The following section lists the usual processes in the order of their economic importance. The process of multi-stage flash evaporation (MSF) is most widespread and is used on a large industrial scale. In addition to these processes, solar seawater desalination processes are also used to a lesser extent.

25 - **The multi-stage flash evaporation**

This is a thermal process with the abbreviation "MSF" (Multi Stage Flash Evaporation). It is the most commonly used process for seawater desalination. The earlier used method was the multi-effect distillation.

30

In this process, the salty water supplied is heated to a temperature of 115 °C using the waste heat from a caloric power plant, and in rare cases also from a nuclear power plant. The salt water heated in the so-called brine heater evaporates in downstream pressure reduction stages under vacuum. The water vapor is deposited

as condensate within these stages on pipes filled with cooling liquid and is removed as salt-free water. The water, which is increasingly enriched with salt as a result of the evaporation process, is also called brine and is cooled in a downstream heat exchanger to the condensation temperature (approx. 40 °C) of the steam of the fresh water supplied. It then serves as a cooling liquid in the pipelines. The pipes themselves are continuously cleaned of crystallizing salt with sponge rubber balls. Finally, fresh salt water is fed to the brine and the mixture is heated up again by the waste heat from the gas turbine. The entire process thus represents a closed cycle. The excess of the salt concentrating in the cycle is returned to the sea.

10

Large-scale plants, such as the Jabal Ali power plant and seawater desalination plant, the world's largest seawater desalination plant, desalinate 2.135 million cubic meters of seawater every day. Usually, up to 500,000 cubic meters of drinking water are recovered from the seawater every day with this process. Similar quantities are also produced by the oil-fired power plants in the region. The energy consumption is 23-27 kWh/m³.

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- **Reverse osmosis**

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In reverse osmosis, the solution is pressed under high pressure through a semipermeable membrane made of polyamide, PTFE or sulfonated copolymers with a pore diameter of 0.5 to 5 nm to overcome the osmotic pressure. This membrane acts like a filter and only lets certain ions and molecules through. A separation of the original solution is thus obtained. The membrane filter can hold back salts, bacteria, viruses, an oversupply of lime and toxins such as heavy metals.

25

The osmotic pressure increases with increasing salt concentration, so the process would come to a standstill at some point. To counteract this, the concentrate is discharged. Since the crystallization of the salt or the minerals (precipitation) in the membranes must be prevented, the use of reverse osmosis only makes sense up to a certain maximum concentration of the reflux. Depending on the salt concentration, due to the high pressure, even in optimal systems, an energy consumption of between 2 and 4 kWh per cubic meter of drinking water must be expected.

30

The membranes of a reverse osmosis system are not maintenance-free. The formation of deposits, caused by mineral deposits (scaling), biological substances (biofouling) or colloidal particles, reduces the permeation of the water molecules through the membranes. To counteract this, the membranes must be rinsed with chemical cleaners. Anti-scaling agents such as polyphosphoric acid and polymaleic acid as well as biocides and chlorine against bacterial deposits are common. These cleaning agents or rinsing water are not environmentally friendly and must be separated or treated before being returned to the sea.

- 10 The drinking water treatment systems can be equipped with additional pre-filters depending on the type of water pollution. Coarse material can be separated up to a particle size of 20 micrometers. An additional activated charcoal filter separates organic substances such as pesticides. UV irradiation can also be used downstream, which represents an additional level of safety against germs. A plant that works according to this principle is the Mossel Bay seawater desalination plant in South Africa.

At every stage of reverse osmosis, mechanochemical processing with activated charcoal offers a solution that is better than reverse osmosis:

20

- Before microfiltration, the activated charcoal is used as a preliminary stage to microfiltration in order to protect the membrane from dirt and particles. This will reduce the buildup and clogging.
- Common macromolecules are retained at the ultrafiltration stage. Most of this has already happened due to the activated charcoal, so that the ultrafiltration membrane is a guard membrane that is less clogged and lasts much longer. This applies in particular to cellulose, hemicellulose, lignin, humic acids, proteins and metabolites.
- Nanofiltration retains dissociated salts, divalent and higher-valent salts, cations and anions such as sulfates, phosphates and alkaline earth metals as well as sugars. It is particularly important that phosphates can be separated here and worked-up cleanly together with alkaline earth metals.
- In reverse osmosis, monovalent and undissociated salts are retained. This creates a highly enriched solution and suspension that contains a lot of ammonium

and nitrate as well as chlorides, bromides and alkali metal cations. These salts can be thickened separately or sold as fertilizer concentrate or, if there is an oversupply, simply converted mechanochemically into atmospheric nitrogen after drying. This would then increase the concentration of cations that are not destroyed, such as potassium in the mechanical mill.

The activated charcoal as a prefilter is mechanochemically recycled after drying.

- **Membrane distillation**

In the membrane distillation process, a microporous membrane is used that only allows water vapor to pass through, but retains liquid water. On one side of the membrane there is warm salt water and on the other side a colder surface. The countercurrent operation of the system ensures that there is a temperature difference over the entire length of the membrane. The resulting difference in water vapor partial pressure causes water molecules to move from the warm to the cold side of the membrane.

- **Experimental techniques**

In the following section, various experimental processes for desalination are listed, some of which are also used in smaller plants.

- **Plastic evaporation hoses**

As part of a European CRAFT project, the French research center CEA/GRETH has developed a seawater desalination plant in which the metal components have largely been replaced by polymers. This has the advantage that plastics corrode much less and are therefore more resistant than metals. By using plastic, the process can run under normal conditions at 100 °C and 1 bar. The device achieves a drinking water production rate of 100 l/h. Since the water is heated to 100 °C, it is largely sterile and only contains small amounts of salt.

- **Freezing process**

When salt water cools down, ice crystals are formed that are free of salts. However, the technical difficulties essentially consist in separating the ice crystals from the mother liquor. The mother liquor has to be washed off the ice crystals. In turn, there is a considerable need for fresh water, which has made this process fail in practice.

- **Electrodialysis**

Electrodialysis is only economical when the salt content is very low. The energy costs are in a linear relationship to the salt content. The procedure is therefore often only worthwhile for brackish water.

- **Ion power**

Salt water is fed into four basins. In basin 1, the salt concentration is increased (e.g. through solar evaporation). The resulting concentrated brine in basin 1 is connected via selective polystyrene membranes, which block Na^+ ions towards basin 2 and Cl^- ions towards basin 3, resulting in an excess of Na^+ or Cl^- ions in basins 1 and 2, respectively. These two basins are connected to the fourth basin by membranes. The ions diffuse from this fourth basin to compensate for ions in basins 2 and 3. The water in basin 4 is thus NaCl-free. If other salts have to be removed, other ion filters must also be used. A pilot plant was built in Canada with environmental subsidies. The Siemens group operates a pilot plant in Singapore.

The advantage is the low energy consumption, provided that the evaporation in basin 1 is caused by the sun. With the exception of sodium and chloride, the mineral content is retained, so that no other minerals have to be added for use as drinking water. Additional ion filters are required for other purposes.

- **Bio-fuel cell**

Research on bio-fuel cells for desalination of weakly salt-containing waters is carried out at the University of Queensland, Tsinghua University and the Oak Ridge National

Laboratory, USA, among others. Practical use is also being considered for brackish water.

- **The mechanochemical work-up in the desalination of water**

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The salts contain alkaline cations, alkaline earth cations, cations such as ammonium, anions such as chloride and bromide as well as fluoride, nitrogen anions such as nitrite and nitrate, phosphates and residues of heavy metals. The mechanochemical work-up aims at:

10

- Immobilizing residues of heavy metals on activated charcoal.
- Converting ammonium, nitrate and nitrite partially or completely into atmospheric nitrogen in the thickened mass, which contains all of the above cations and anions. This results in a fertilizer that contains a lot of potassium and phosphate but little or no nitrogen.

15

- If there is no demand for pure ammonium and nitrate as fertilizer, it is possible to convert these substances cheaply on site into atmospheric nitrogen,
- For specific versions, see the explanations on reverse osmosis.

20

- **Detoxification of carcinogenic compounds**

- It is known that the compounds of hexavalent chromium such as potassium dichromate are carcinogenic. Using the mechanochemical process according to the invention, it is possible to reduce the hexavalent chromium to trivalent chromium and in some cases to metallic chromium. Chromium is then no longer a carcinogen in these oxidation states.

25

Work-up of nitrate and ammonium from the groundwater and drinking water with activated charcoal

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- Because of the lower concentration, activated charcoal can be used to bind nitrate,

- Functionalized activated charcoal can also be used with CaCl_2 , iron such as metallic iron and Fe (III), magnetic iron particles, copper, palladium, tin, indium and other metals.

5 - The advantages of mechanochemical work-up

- During the mechanochemical work-up, the particles are comminuted, which adds nano-effects.

10 - When used as a filter, iron can be washed out, but if it is still present, it can be reactivated by reduction.

- The same applies to nanoparticles and compounds of copper, palladium etc. These can be further comminuted and recovered together with the coal.

- This provides the option of converting the bound nitrate into nitrogen and activated charcoal even if the activated charcoal is not functionalized.

15 - The same applies also to many activated and functionalized activated charcoals, which can then be reactivated, with the nitrate being broken down at the same time.

- In this way, the activated charcoal can be mechanochemically re-functionalized or post-functionalized or refreshed and reused.

20

The mechanochemical splitting of carbon dioxide and carbon monoxide into oxygen and carbon allotropes

25 The starting point is the binding of carbon dioxide or carbon monoxide to activated charcoal or microporous materials such as zeolites in combination with activated charcoal and the subsequent mechanochemical conversion of carbon dioxide into carbon and oxygen. This means that the goal of an inexpensive carbon dioxide sink that can be implemented permanently and on a large scale and can be mobile can be achieved anywhere. The effect can be increased if bases such as ammonia or

30 alkaline solutions are available for binding. It is then a matter of chemisorption. The salts of carbon dioxide such as sodium carbonate or other salts that result from the separation of carbon dioxide can also be broken down. The adsorption of carbon dioxide can be intensified by OH groups in the coal and by a certain residual moisture that can be associated therewith. Partially pyrolyzed activated charcoal or coal has

also proven to be advantageous, since it has more OH groups and therefore binds carbon dioxide more easily. Tribochemical catalysts such as glass, quartz or rock, reducing catalysts, oxidizing catalysts, mixed catalysts or metal catalysts, as listed above, can be used as catalysts.

5

Special embodiments are the carbon dioxide conversion with a membrane, in low-temperature systems with the condensation of carbon dioxide, with the introduction of dry ice or with the low-temperature separation of carbon dioxide, with metal catalysts and metal alloys with carbon, with organometallic catalysts or with homogeneous catalysts.

10

When converting carbon dioxide with a membrane, a gas-permeable membrane is used that is permeable to oxygen and impermeable to carbon dioxide. By sucking off the oxygen, the equilibrium can be shifted so that a permanent conversion takes place. AIRCO offers a membrane that separates the substances as they flow through hollow fibers due to the different diffusion speeds.

15

In the low-temperature system with the condensation of carbon dioxide, carbon dioxide is condensed in the reactor at $-78.5\text{ }^{\circ}\text{C}$. The reactor is cooled to temperatures below the sublimation point of carbon dioxide of $-78.5\text{ }^{\circ}\text{C}$. As a result, the amounts of carbon dioxide in the milling chamber are higher than through adsorption on the coal alone. The reactor can be cooled, for example, via a double-walled reactor which is cooled with liquid nitrogen or helium. The cooling liquid can be combined with a throttle pressure release as in a refrigerator. Also, thermoelectric elements or Peltier elements can be used. The oxygen remains gaseous because it only becomes liquid at $-183\text{ }^{\circ}\text{C}$.

20

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The dry ice is introduced in pieces or as a slush, optionally mixed with coal. Or the coal is already in the milling room. The dry ice can also be present alone in the milling chamber and convert into coal in the course of milling. However, the presence of activated charcoal is preferred because it accelerates the reaction.

30

In the case of the low-temperature separation of carbon dioxide, the milling chamber contains a cold finger, which is preferably designed as a knocking finger or separator

and on which carbon dioxide is separated at -78.5°C . Alternatively, the milling chamber can be combined with a corresponding separate system. The oxygen remains in the gas phase and can be pumped out or separated by membranes.

- 5 In the same way, carbon monoxide can be split into the elements. The process according to the invention is thus also available for eliminating this toxic gas.

In a further embodiment of the mechanochemical process according to the invention, the carbon dioxide and the carbon monoxide are not only milled with activated
10 charcoal, but with any biomass and/or carbon-supplying materials. For example, compressed gaseous carbon dioxide can be injected into the biomass together with the exhaust gas from biogas plants and the resulting material to be milled can be converted mechanochemically into activated charcoal.

- 15 This means that the methane slip in biogas plants and generally in other methane and/or natural gas-powered plants such as gas engines can also be eliminated effectively, because the slip gases are converted into carbon and no longer get into the atmosphere, where they would act as particularly strong greenhouse gases. In this way, the emission of greenhouse gases can also be effectively prevented by the
20 mechanochemical process according to the invention.

The binding of noxae such as ammonia, amines, fine dust, ultra-fine dust, mercury, carbon dioxide, carbon monoxide, hydrogen sulfide and other sulfur compounds from the air of stables, sewage treatment plants, biogas plants and closed waste dumps,
25 among others, to activated charcoal is achieved through a suitable impregnation of the activated charcoal, which significantly increases and improves its adsorption capacity so that it can be used with advantage for the economical removal of poorly absorbable contaminations in gases. The noxae are then no longer exclusively bound by adsorption, but also by chemical sorption or catalytically. The activated charcoals
30 are functionalized with potassium iodide, potassium carbonate, phosphoric acid, caustic soda, potassium hydroxide, sulfur, sulfuric acid and silver and are uniformly and homogeneously impregnated.

The activated charcoal loaded with noxae can then be recycled and reactivated using the mechanochemical process according to the invention.

Another advantageous application of the mechanochemical process according to the invention is the separation and sifting of activated charcoal with different grain sizes. For this purpose, gases, in particular air or inert gases such as nitrogen, are blown through a first pipe into the milling chamber of a mechanical mill using a blower, a fan or a compressor, and the finely divided, pulverulent activated charcoal particles are discharged through a second pipe from the milling chamber and agglomerated in the gas phase by acoustophoresis, as is known, for example, from international patent application WO 2017/153038. The agglomerated activated charcoal particles are then blown into a cyclone, in which they are separated from the gas phase. A bypass, which fluidly connects the first and second pipes to one another, ensures that a stronger gas stream flows through the cyclone than through the milling chamber.

In a particularly advantageous embodiment, the mechanical mill for mechanochemical processes according to the invention comprises at least one rotatable or stationary mechanochemical reactor, waveguide or milling chamber, which contains a plurality of the above-described milling elements in a drum with at least one inlet for the material to be milled and at least one outlet for the milled product.

The drum of the rotatable mechanochemical reactor and waveguide has a disk-shaped vertical drum wall which is connected in its center to a rotatable drive shaft that can be driven by a motor.

In contrast, the drum of the stationary mechanochemical reactor and waveguide has agitation means for mixing the milling elements and the material to be milled. The agitation means are arranged to be rotatable along the longitudinal axis of the drum and are rotated by a rotatable drive shaft that can be driven by a motor and passes through the disk-shaped vertical drum wall.

The vertical drum wall of both the stationary and the rotatable mechanochemical reactor and waveguide, which is opposite the disk-shaped vertical drum wall, is formed by an impact-resistant grid or window that is permeable to electromagnetic

radiation and/or corpuscular radiation which separates the mechanochemical reactor, the milling chamber and the waveguide, respectively, and prevents the milling elements and the material to be milled from damaging the at least one radiation source.

5

Preferably, focused laser radiation, electron radiation, radioactive radiation such as alpha radiation, neutron radiation and gamma radiation, X-rays, UV radiation, IR radiation, microwave radiation and ultrasound and the corresponding radiation sources are used. In particular, microwave radiation is used.

10

The radiation sources can be permanently connected to the mechanochemical reactor, milling room and waveguide, respectively, or arranged separately therefrom.

The materials from which the mechanical mill is built depend, among other things, on the type of radiation used. In particular, when using microwave radiation, the grid, the inner walls of the mechanochemical reactor and waveguide, the milling elements and the agitation means must be made of a material that does not cause electrical short circuits. Examples of suitable materials for the inner walls and agitation means are impact-resistant, scratch-resistant and high-temperature-resistant plastics and ceramics. Preferably, the milling elements are also made of ceramic such as porcelain. For the other parts of the mechanical mill that are not irradiated, metals such as stainless steel can be used.

An electric motor, in particular one of the internally cooled electric motors described above, is preferably used for the drive.

The mechanochemical process according to the invention and the mechanical mill according to the invention are explained in more detail below with the aid of examples and figures. The examples and figures are not limiting, but are intended to specify the mechanochemical process according to the invention and the mechanochemical device according to the invention.

Figures 1 to 24 are schematic representations which are intended to illustrate the essential features of the mechanochemical process according to the invention and its use according to the invention. Some of the figures are not true to scale:

- 5 Figure 1 a mechanical mill 1 according to the invention with a rotating drum 1.5 for milling of material to be milled under irradiation with microwave radiation;

- Figure 2 a mechanical mill 1 according to the invention with a stationary drum 1.5 with attritor 1.4 for milling material to be milled under irradiation with microwave
10 radiation 2.1;

- Figure 3 a flow diagram of the mechanochemical process for decontaminating contaminated, phosphate-containing biomass and for recovering phosphate in a bioavailable form;

- 15 Figure 4 a flow diagram of the mechanochemical process for recovering regenerated activated charcoal from moist and contaminated activated charcoal and sludge of the 4th clarification stage;

- 20 Figure 5-1 (a) top view of the true-to-scale surface of striking disk 1.4.2, (b) true-to-scale side view of striking disk 1.4.2, and (c) a perspective illustration of striking disk 1.4.2;

- Figure 5-2 (a) top view of the true-to-scale surface of striking disk 1.4.2, (b) true-to-scale side view of striking disk 1.4.2, and (c) a perspective illustration of striking disk
25 1.4.2;

- Figure 6 (a) top view of the true-to-scale surface of striking disk 1.4.2, (b) true-to-scale side view of striking disk 1.4.2 and (c) perspective illustration of striking disk
30 1.4.2;

- Figure 7 (a) top view of the true-to-scale surface of striking disk 1.4.2 with striking webs 1.4.2.4, (b) true-to-scale side view of striking disc 1.4.2, (c) profile of a striking web 1.4.2.4, and (d) a perspective illustration of striking disc 1.4.2;

Figure 8 (a) top view of the true-to-scale surface of striking disk 1.4.2 with the striking webs 1.4.2.4, (b) true-to-scale side view of striking disc 1.4.2, (c) profile of a striking web 1.4.2.4, and (d) a perspective illustration of striking disc 1.4.2;

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Figure 9 (a) top view of the true-to-scale surface of striking disk 1.4.2 with striking webs 1.4.2.4, (b) true-to-scale side view of striking disc 1.4.2, (c) profile of a striking web 1.4.2.4, and (d) a perspective illustration of striking disc 1.4.2;

10 Figure 10 (a) top view of the true-to-scale surface of striking fan 1.4.3 with striking webs 1.4.2.4, (b) true-to-scale side view of striking fan 1.4.2, and (c) a perspective illustration of striking fan 1.4.2;

Figure 11 (a) top view of the true-to-scale surface of fan 1.4.3 with striking webs 15 1.4.2.4, (b) true-to-scale side view of striking fan 1.4.2, (c) profile of a striking web 1.4.2.4, and (d) a perspective illustration of striking fan 1.4.2;

Figure 12 top view of the true-to-scale surface of striking fan 1.4.3 with striking webs 1.4.2.4, (a) and (b) true-to-scale side views of striking fan 1.4.2, (c) profile of a 20 striking web 1.4.2.4, and (d) perspective illustration of striking fan 1.4.2;

Figure 13 (a) top view of the true-to-scale surface of double striking fan 1.4.3 with mountain and valley profiles 1.4.3.2, and U-shaped gaps 1.4.3.3, (b) and (d) true-to-scale side views of double striking fan 1.4. 3, (c) section through mountain and valley 25 profile 1.4.3.2, and (e) perspective illustration of double striking fan 1.4.3;

Figure 14 top view of a striking club 1.4.4 with symmetrically arranged striking elements 1.4.4.3;

30 Figure 15 top view of a striking wing 1.4.5;

Figure 16 top view of a further embodiment of striking wing 1.4.5;

Figure 17 milling by two counter-rotating rollers 1.4.6;

Figure 18 milling with two counter-rotating rollers 1.4.6 with surface structures 1.4.6.2;

5 Figure 19 milling with a roller 1.4.6 and an abrasion surface 1.4.6.3;

Figure 20 milling with two counter-rotating rollers 1.4.6 inclined to each other at a certain angle 1.4.6.5;

10 Figure 21 milling with two counter-rotating rollers 1.4.6 with resilient surfaces 1.4.6.6;

Figure 22 drum 1.5 comprising several milling chambers 1.1.1;

15 Figure 23 flow diagram of a reverse osmosis plant; and

Figure 24 grain sizes of the KS comprising a mechanochemical mill 1, an acoustophoresis device 7 for agglomerating activated charcoal particles G, and a cyclone 8 for separating the agglomerated activated charcoal particles from the gas
20 phase.

In Figures 1 to 24, the reference symbols have the following meaning:

	1	Mechanical mill, milling unit
25	1.1	Mechanical reactor, waveguide, milling chamber
	1.1.1	Spherical section-shaped milling chamber
	1.1.2	Circular constriction
	1.2	Milling elements
	1.3	Material F to be milled
30		
	1.4	Agitation means
	1.4.1	Attritor
	1.4.2	Striking disc
	1.4.2.1	Feedthrough for drive shaft 3

	1.4.2.2	Striking hole
	1.4.2.3	Edge
	1.4.2.4	Striking web
	1.4.3	Striking fan
5	1.4.3.1	Ring around drive shaft 3
	1.4.3.2	Mountain and valley profile
	1.4.3.3	U-shaped gap
	1.4.4	Striking club
	1.4.4.1	Ring around drive shaft 3
10	1.4.4.2	Connecting web
	1.4.4.3	Striking body
	1.4.5	Striking wing
	1.4.5.1	Striking end
	1.4.6	Rotating roller
15	1.4.6.1	Direction of rotation
	1.4.6.2	Jags
	1.4.6.3	Abrasion surface
	1.4.6.4	Axis of rotation
	1.4.6.5	Angle of inclination
20	1.4.6.6	Roller surface
	1.4.6.7	Depression
	1.4.6.8	Spring
	1.4.6.9	Ball
25	1.5	Drum
	1.5.1	Inlet for material F to be milled F; 1,3
	1.5.2	Outlet for milled product I
	1.5.3	Disc-shaped, vertical drum wall
	1.5.3.1	Feedthrough through 1.5.3
30	1.5.4	Drum wall opposite 1.5.3
	1.5.5	Grid, radiation-permeable window
	1.5.5.1	Opening
2		Electromagnetic radiation, corpuscular radiation

	2.1	Microwave radiation
	3	Drive shaft
	3.1	Direction of rotation
	4	motor
5		
	5	Fan
	5.0	Suction
	5.1	Sucked-in gas
	5.2	Gas stream blown into milling chamber 1.1 of 1
10	5.2.1	Gas stream blown into the bypass BP
	5.2.2	Control valve in gas line 5.5 for gas stream 5.2
	5.2.3	Control valve in gas line 5.5.1 in bypass BP for gas stream 5.2.1
	5.3	Gas stream loaded with milled material F to be milled
	5.3.1	Control valve in gas line 5.6 for gas stream 5.3
15	5.4	Gas stream with agglomerated particles 9.1
	5.5	Gas line from fan 5 to mechanical mill 1
	5.5.1	Gas line in bypass BP OH ups A
	5.6	Gas line from mechanical mill 1 to bypass BP, acoustophoresis unit 7 and cyclone 8
20	5.7	Cyclone 8 exhaust gas
	6	Permeable protective grids
	7	Acoustophoresis unit
	7.1	Ultrasonic source
	7.2	Standing wave
25	8	Cyclone
	8.1	Exhaust pipe
	8.2	Solids outlet
	9	Pulverulent solid I
	9.1	Agglomerated particles
30	A-A	Section line
	CC	Section line
	D	Diameter of striking disc 1.4.2
	d	diameter of passage 1.4.2.1 for drive shaft 3
	DS	Dissociated acids, divalent salts

	EWS	Monovalent salts
	F	Material to be milled
	H ₂ O	Water
	KS	Grain size sifter
5	MF	Microfiltration
	MM	Macromolecules
	NF	Nanofiltration
	R	Radius
	RO	Reverse osmosis
10	SP	Suspended particles
	SW	Salt water
	T	Thickness
	UDS	Undissociated Acids
	UF	Ultrafiltration
15	UO	Reverse osmosis
	X	Enlarged section
	ZU	Sugar

In the following text, the following suffixes have the following meaning:

20	A	Problematic, synthetic, biogenic and biological materials
	B	Phosphates
	C	Metals and compounds thereof
	D	Carbon dioxide, carbon monoxide
	E	Valuable products
25	F	Material to be milled, fluid, solution, suspension, finely divided solid mixture, reactive gas
	G	coal, carbon suppliers
	H	Suspension of a pulverulent product I
	I	Puwerulent product, sifted product I
30	K	Catalytically active particles
	Q	Piezoelectric particles
	Y	Weight ratio of (A, B, C and/or D and possibly Z) to G
	Z	Additive

Examples 1 to 3 and Comparative Experiment V1

The milling units 1 with attritors 1.4.1 described in the German published patent application DE 195 04 540 A1 were used for the milling experiments of Examples 1 to 3 and of Comparative Experiment V1. 2000 steel balls weighing 1 g each were used as milling elements 1.2. The weight ratio of the weight of material F to be milled : weight of steel balls 1.2 was 1:10. The milling experiments were carried out under ambient air at atmospheric pressure.

- 10 An electric motor 3 according to international patent application WO 2017/055246A2 was used to drive milling unit 1 with attritors 1.4.1. Said motor comprises an electrical machine component with at least one winding for generating a magnetic field, which winding comprises at least one waveguide, which has a jacket and an inner cavity through which a coolant can be routed, the winding having two ends at which an
- 15 electrical operating voltage is connected and wherein
- the waveguides are round tube-shaped and have an outer diameter in a range of 3 mm,
 - the ends of the winding each serve as a coolant inlet or coolant outlet, and
 - the ends of the winding are connected to a connector comprising a coolant
- 20 inlet and/or a coolant outlet, multiple waveguide connections for connecting waveguides, a manifold through which the coolant is fed into at least one waveguide, and/or a collecting channel into which the coolant emerging from at least one waveguide flows and is routed to the coolant outlet of the connector.
- 25 Motors 3 of this type are sold by Dynamic E Flow GmbH, Kaufbeuren, Germany, under the capcooltech® brand. The types HC and LC were used.

Mixtures containing potassium nitrate A were provided as material F to be milled for Examples 1 to 3. The mixture of Comparative Experiment V1 did not contain any

30 potassium nitrate A. Each of the mixtures F was milled for 480 minutes at a speed of attritors 1.4.1 of 1250 revolutions/min. Samples weighing 0.5 g were taken at 0 minutes (blank sample), after 60 minutes, after 120 minutes, and after 480 minutes and eluted with 50 ml of deionized water. The respective nitrate content A was then

measured according to DIN EN ISO 10304-1, and the ammonium content A was measured according to DIN EN ISO 11732.

Table 1 gives an overview of the mixtures F and the results of the measurements.

5

Table 1: Examples 1 to 3 and Comparative Experiment V1

No.	Material F to be milled composition	Milling time h	Ammonium A mg/liter	Nitrate A mg/liter
V1	2% by weight ammonium chloride A 49% by weight carbon G 49% by weight quartz sand Q	0	84.9	<1
”	”	60	20.7	<1
”	”	120	10.8	<1
”	”	480	9.5	<1
1	2% by weight potassium nitrate A 49% by weight carbon G 49% by weight quartz sand Q	0	<1	163
”	”	60	<1	87.4
”	”	120	<1	29.6
”	”	480	<1	28.1
2	2% by weight potassium nitrate A 2% by weight ammonium chloride A 48% by weight carbon G 48% by weight quartz sand Q	0	67.1	129
”	”	60	19.7	67.5
”	”	120	7.9	31.4
”	”	480	5.8	26.5
3	2% by weight potassium nitrate A	0	91.8	177

	2% by weight Ammonium chloride A 2% by weight Trisodiumphosphate B 47% by weight Coal G 47 % by weight Quartz sand Q			
”	”	60	22.7	78.5
”	”	120	8.5	36.2
”	”	480	8.1	43.5

It was found that the majority of ammonium A and nitrate A had already been eliminated after 60 to 120 minutes of milling.

5

Examples 4 to 6 and Comparative Experiment V2

The milling of fermentation residues A - Influence of the material compositions

The milling experiments were carried out essentially as described in Examples 1 to 3 and the Comparative Experiment V1. Table 2 gives an overview of the material compositions of the material F to be milled. The weight ratio of milling element 1.2 to material F to be milled was 50:1 in all cases. The number of revolutions was 1250 rpm in all cases. After milling times of 0, 1, 2 and 3 hours, 0.5 g of each of the finely divided pulverulent products I was eluted with 50 ml of distilled water pursuant to DIN 38414-4 DIN EN 12457-4. The respective concentrations of ammonium ions A were determined in mg/liter pursuant to DIN EN ISO 11732. The results can also be found in Table 2

15

Table 2: The milling of fermentation residues A - influence of the material compositions

20

Example ^{a)}	Fermentation residue	Quartz sand	Activated carbon	KCl	Milling time in air	Ammonium
Comparative Example ^{b)}	F (g)	Q (g)	G (g)	Z (g)	(h)	A
V2	25	25	–	–	0	21.1
”	25	25	–	–	1	10.8
”	25	25	–	–	2	11.6

„	25	25	–	–	3	9.1
4	25	25	25	–	0	25.1
„	25	25	25	–	1	3.12
„	25	25	25	–	2	4.43
„	25	25	25	–	3	2.6
5	25	–	25	–	0	11.3
„	25	–	25	–	1	4.19
„	25	–	25	–	2	3.25
„	25	–	25	–	3	1.55
6	25	25	25	25	0	11.3
„	25	25	25	25	1	4.19
„	25	25	25	25	2	3.25
„	25	25	25	25	3	1.55

- a) Example
b) Comparative experiment

- 5 The experimental results show that the decrease in ammonium ions A in the samples with activated charcoal G or quartz Q and activated charcoal A was significantly greater than in the sample without activated charcoal.

Example 7

10

The mechanochemical degradation of medicament A as a model for the 4th purification stage of sewage treatment plants

- 15 Quartz sand Q and activated charcoal G (Example 7, Experiments numbers 1 to 4 and 13 to 16), quartz sand Q alone (Example 7, Experiments numbers 9 to 12 and 21 to 24) and activated charcoal G alone (Example 7, Experiments 5 to 8 and 17 to 20) were each mixed with a mixture A consisting of 2 tablets propofol, 1 tablet loratidine, 2 tablets Ibufam and one tablet ACC. The resulting mixtures F were triturated dry once and 150 ml of distilled water was poured over a portion thereof, then allowed to soak
20 for 48 hours and then dried at room temperature under a water jet vacuum for 2 hours. The samples F were then milled under air and under argon atmosphere. The

milling experiments were carried out as described in Examples 4 to 6. Table 3 gives an overview of the experimental conditions used.

Table 3: The mechanochemical degradation of drugs

5

Example 7 Experiment No.	Quartz sand Q (g)	Activated charcoal G (g)	Milling time (min)	RPM
1	20	20	30	1100
2	20	20	60	1100
3	20	20	120	1100
4	20	20	180	1100
5	0	40	30	1100
6	0	40	60	1100
7	0	40	120	1100
8	0	40	180	1100
9	40	0	30	1100
10	40	0	60	1100
11	40	0	120	1100
12	40	0	180	1100
13	20	20	30	800
14	20	20	60	800
15	20	20	120	800
16	20	20	180	800
17	0	40	30	800
18	0	40	60	800
19	0	40	120	800
20	0	40	180	800
21	40	0	30	800
22	40	0	60	800
23	40	0	120	800
24	40	0	180	800

The results of the experiments can be summarized as follows:

1 The degradation of drug A with activated charcoal G alone was faster than that with quartz sand Q alone.

5 2. After a longer milling time (about 2 hours), the effect of quartz sand Q was stronger than that of activated charcoal G, so adding a small amount of quartz sand Q was advantageous.

3. The decrease followed the natural logarithm, with all compounds having been
10 degraded after 60 minutes.

4. Propofol A was degraded significantly more slowly than the other drugs A.

5. A significant difference between the soaked mixtures F and the dry-mixed
15 mixtures F could not be determined. However, there was a certain trend that the soaked mixtures F degraded somewhat more quickly.

6. The speed of rotation was a crucial factor. The degradation of drugs F was twice as fast at 1100 RPM as the degradation at 800 RPM.
20

7. No difference could be found between the milling under inert gas Z and under air.

Example 8

25

The recovery of phosphate B from the 4th purification stage of a sewage treatment plant.

Granulated loaded activated charcoal G from a basin of the 4th purification stage was
30 roughly purified once in a water bath. It was then dried in a commercially available drying system at elevated temperature and under reduced pressure. The dried activated charcoal G was continuously introduced into a mechanical mill 1 with a drum 1.5 with a volume of 900 liters. Mechanical mill 1 contained 1000 steel balls 1.2 of 5 mm diameter, which were prevented by a protective grid 6 from exiting drum 1.5.

The dried activated charcoal G was introduced through the protective grid 6 at the upper opening (1.5.1, inlet for material F to be milled) and separated again centrally by means of a cyclone 8. About 100 kg of coal G ran through mechanochemical mill 1 in 1 hour. Alternatively, the process could be carried out discontinuously as a batch process with the same amounts.

The number of revolutions of the mill 1 was 1100 RPM. The milled material F to be milled with the reactivated activated charcoal G was pressed discontinuously or continuously into pellets G in a commercially available pelletizing system. These pellets were again entered into the basin of the 4th purification stage. A loss of activated charcoal G could not be observed here. Sand contamination did not interfere with the process.

The soluble phosphates B present could be eluted in a separate wash cycle before or after the activated charcoal G was pelletized.

Example 9

The processing of manure A into activated charcoal G

1000 kg of manure A, which contained nitrates A, ammonium A, phosphates B and heavy metals C, were dried using a commercially available digestate dryer. This left 80 kg of dry matter as material F to be milled. The drying was carried out at an elevated temperature, and escaping ammonia A was bound with sulfuric acid, as described in German patent application DE 10 2016 004 162 A1. The resulting ammonium sulfate A could be processed further together with the dry matter F. The dry matter F and the ammonium sulfate A were pre-milled in a separate mechanical mill 1. Then they were continuously introduced together with half the amount of activated charcoal G into a mechanical mill 1 with a drum 1.5 of a volume of 900 liters from above through a protective grid 6 which prevented the milling elements 1.2 from exiting. 1000 kg of steel balls 1.2 of 5 mm diameter were used as milling elements 1.2. The material F to be milled was separated again centrally by means of a cyclone 8. About 100 kg of dry material F ran through the mechanical mill 1 in 1 hour and were milled at a constant speed of 1100 RPM.

The resulting solid, finely divided product I contained significantly fewer nitrate ions A and ammonium ions A than the starting products F. In addition, the heavy metals C were immobilized.

5

In addition or as an alternative to coal G, sheet silicates Z such as bentonite or montmorillonite could be introduced to immobilize the heavy metals C.

10

The solid, finely divided product I was pressed in a commercially available pelletizing system and used as an alternative E to terra preta as phosphate fertilizer E and coal fertilizer E, which promoted humus formation and microbial growth.

15

Alternatively, the phosphate B could also be removed from the pellets G. The remaining material was excellent as a substitute for activated charcoal G to bind VOCs (volatile organic compounds) as a filler for panel production and as a substitute for wood and sand.

Example 9

20

The recovery of iridium C from spent Nafion membranes A

25

500 kg of spent Nafion membranes A were shredded and dry mixed with 100 kg of activated charcoal G and 20 kg of solid caustic soda Z and pre-milled. The mixture F was then continuously introduced into a mechanochemical mill 1 as described in Examples 8 and 9 and milled for 2 hours at a speed of 1100 RPM. The finely divided solid powder I separated using a cyclone 8 was eluted with water, whereby the resulting sodium fluoride I was washed out. Remaining powder I contained the immobilized iridium C. Said Iridium C was recovered by incinerating powder I.

30

Example 10 to 14

The mechanochemical processing of biomass A, the elimination of nitrates A and ammonium A and the recovery of phosphate B

Biomass A, quartz sand Q and activated charcoal G were mixed together in various amounts. Sodium nitrate A, ammonium chloride A and vitreous ultraphosphate B were added in varying amounts to the mixtures. The resulting mixtures F were triturated dry. 150 ml of distilled water were poured over a portion thereof, soaked for 48 hours, then dried at room temperature under a water jet vacuum for 2 hours and then milled. In parallel, the dry mixed mixtures F were milled. All experiments were carried out once in an atmosphere of air and once in an atmosphere of argon Z. The devices 1 described in Examples 1 to 3 were used for this purpose. In all cases, after 30 minutes, 60 minutes, 120 minutes and 180 minutes, samples I were taken from the resulting milled mixtures F in each case and eluted with distilled water. The solutions were then analyzed.

Tables 4 to 8 give an overview of the materials used and their proportions.

Table 4: Mechanochemical milling of biomass A with the additives sodium nitrate A, ammonium chloride A and ultraphosphate B in an atmosphere of air and in an atmosphere of argon Z

Ex. 10 exp. no.	Quartz sand Q [g]	Activated carbon G [g]	Biomass A [g]	NaNO ₃ A [g]	NH ₄ Cl A [g]	Ultra- phosphate B [g]	Milling time [min]	RPM
1	30	30	30	5	5	5	30	1100
2	30	30	30	5	5	5	60	1100
3	30	30	30	5	5	5	120	1100
4	30	30	30	5	5	5	180	1100
5	0	45	45	5	5	5	30	1100
6	0	45	45	5	5	5	60	1100
7	0	45	45	5	5	5	120	1100
8	0	45	45	5	5	5	180	1100
9	45	0	45	5	5	5	30	1100
10	45	0	45	5	5	5	60	1100
11	45	0	45	5	5	5	120	1100
12	45	0	45	5	5	5	180	1100

13	30	30	30	5	5	5	30	800
14	30	30	30	5	5	5	60	800
15	30	30	30	5	5	5	120	800
16	30	30	30	5	5	5	180	800
17	0	45	45	5	5	5	30	800
18	0	45	45	5	5	5	60	800
19	0	45	45	5	5	5	120	800
20	0	45	45	5	5	5	180	800
21	45	0	45	5	5	5	30	800
22	45	0	45	5	5	5	60	800
23	45	0	45	5	5	5	120	800
24	45	0	45	5	5	5	180	800

Table 5: Mechanochemical milling of biomass A with the additives ammonium chloride A and ultraphosphate B in an atmosphere of air and in an atmosphere of argon A

5

Ex. 11 exp. no.	Quartz- sand Q [g]	Activated carbon G [g]	Biomass A [g]	NH₄Cl A [g]	Ultra- phosphat B [g]	Milling time [min]	RPM
1	30	30	30	7.5	7.5	30	1100
2	30	30	30	7.5	7.5	60	1100
3	30	30	30	7.5	7.5	120	1100
4	30	30	30	7.5	7.5	180	1100
5	0	45	45	7.5	7.5	30	1100
6	0	45	45	7.5	7.5	60	1100
7	0	45	45	7.5	7.5	120	1100
8	0	45	45	7.5	7.5	180	1100
9	45	0	45	7.5	7.5	30	1100
10	45	0	45	7.5	7.5	60	1100
11	45	0	45	7.5	7.5	120	1100
12	45	0	45	7.5	7.5	180	1100

13	30	30	30	7.5	7.5	30	800
14	30	30	30	7.5	7.5	60	800
15	30	30	30	7.5	7.5	120	800
16	30	30	30	7.5	7.5	180	800
17	0	45	45	7.5	7.5	30	800
18	0	45	45	7.5	7.5	60	800
19	0	45	45	7.5	7.5	120	800
20	0	45	45	7.5	7.5	180	800
21	45	0	45	7.5	7.5	30	800
22	45	0	45	7.5	7.5	60	800
23	45	0	45	7.5	7.5	120	800
24	45	0	45	7.5	7.5	180	800

Table 6: Mechanochemical milling of biomass A with the additives sodium nitrate A and ultraphosphate B in an atmosphere of air and in an atmosphere of argon Z

Ex. 12 exp. no.	Quartz sand Q [g]	Activated carbon G [g]	Biomass A [g]	NaNO₃ A [g]	Ultra- phosphate B [g]	Milling time [min]	RPM
1	30	30	30	7.5	7.5	30	1100
2	30	30	30	7.5	7.5	60	1100
3	30	30	30	7.5	7.5	120	1100
4	30	30	30	7.5	7.5	180	1100
5	0	45	45	7.5	7.5	30	1100
6	0	45	45	7.5	7.5	60	1100
7	0	45	45	7.5	7.5	120	1100
8	0	45	45	7.5	7.5	180	1100
9	45	0	45	7.5	7.5	30	1100
10	45	0	45	7.5	7.5	60	1100
11	45	0	45	7.5	7.5	120	1100
12	45	0	45	7.5	7.5	180	1100

13	30	30	30	7.5	7.5	30	800
14	30	30	30	7.5	7.5	60	800
15	30	30	30	7.5	7.5	120	800
16	30	30	30	7.5	7.5	180	800
17	0	45	45	7.5	7.5	30	800
18	0	45	45	7.5	7.5	60	800
19	0	45	45	7.5	7.5	120	800
20	0	45	45	7.5	7.5	180	800
21	45	0	45	7.5	7.5	30	800
22	45	0	45	7.5	7.5	60	800
23	45	0	45	7.5	7.5	120	800
24	45	0	45	7.5	7.5	180	800

Table 7: Mechanochemical milling of biomass A with the additives sodium nitrate A and ammonium chloride A in an atmosphere of air and in an atmosphere of argon Z

5

Ex. 14 exp. no.	Quartz sand Q [g]	Activated carbon G [g]	Biomass A [g]	NaNO₃ A [g]	NH₄Cl A [g]	Milling time [min]	RPM
1	30	30	30	7.5	7.5	30	1100
2	30	30	30	7.5	7.5	60	1100
3	30	30	30	7.5	7.5	120	1100
4	30	30	30	7.5	7.5	180	1100
5	0	45	45	7.5	7.5	30	1100
6	0	45	45	7.5	7.5	60	1100
7	0	45	45	7.5	7.5	120	1100
8	0	45	45	7.5	7.5	180	1100
9	45	0	45	7.5	7.5	30	1100
10	45	0	45	7.5	7.5	60	1100
11	45	0	45	7.5	7.5	120	1100
12	45	0	45	7.5	7.5	180	1100

13	30	30	30	7.5	7.5	30	800
14	30	30	30	7.5	7.5	60	800
15	30	30	30	7.5	7.5	120	800
16	30	30	30	7.5	7.5	180	800
17	0	45	45	7.5	7.5	30	800
18	0	45	45	7.5	7.5	60	800
19	0	45	45	7.5	7.5	120	800
20	0	45	45	7.5	7.5	180	800
21	45	0	45	7.5	7.5	30	800
22	45	0	45	7.5	7.5	60	800
23	45	0	45	7.5	7.5	120	800
24	45	0	45	7.5	7.5	180	800

Table 8: Mechanochemical milling of biomass with the additives sodium nitrate and ammonium chloride in an atmosphere of air and in an atmosphere of argon Z.

Ex. 14 exp. no.	Quartz sand Q [g]	Activated carbon G [g]	Biomasse A [g]	NaNO₃ A [g]	NH₄Cl A [g]	Milling time [min]	RPM
1	30	30	30	7.5	7.5	30	1100
2	30	30	30	7.5	7.5	60	1100
3	30	30	30	7.5	7.5	120	1100
4	30	30	30	7.5	7.5	180	1100
5	0	45	45	7.5	7.5	30	1100
6	0	45	45	7.5	7.5	60	1100
7	0	45	45	7.5	7.5	120	1100
8	0	45	45	7.5	7.5	180	1100
9	45	0	45	7.5	7.5	30	1100
10	45	0	45	7.5	7.5	60	1100
11	45	0	45	7.5	7.5	120	1100
12	45	0	45	7.5	7.5	180	1100

13	30	30	30	7.5	7.5	30	800
14	30	30	30	7.5	7.5	60	800
15	30	30	30	7.5	7.5	120	800
16	30	30	30	7.5	7.5	180	800
17	0	45	45	7.5	7.5	30	800
18	0	45	45	7.5	7.5	60	800
19	0	45	45	7.5	7.5	120	800
20	0	45	45	7.5	7.5	180	800
21	45	0	45	7.5	7.5	30	800
22	45	0	45	7.5	7.5	60	800
23	45	0	45	7.5	7.5	120	800
24	45	0	45	7.5	7.5	180	800

The following general tendencies can be derived from the experimental results of Examples 10 to 14.

5

1. The degradation of the biomass A and the nitrogen-containing compounds A proceeded faster with activated charcoal G than with quartz sand Q.

2. After about 2 hours, however, the effect of quartz sand Q was stronger than that of activated charcoal G, so it was advisable to add small amounts of quartz sand Q to the mixtures.

3. The decrease in nitrogen-containing compounds A followed the natural logarithm, with all nitrogen-containing compounds A having been degraded after 60 minutes.

4. A significant difference in the degradation of nitrogen-containing compounds A between soaked mixtures F and the dry-prepared mixtures F could not be determined. There was only a certain trend that the soaked mixtures F showed faster degradation.

5. The number of revolutions was the crucial factor. For example, the degradation of the nitrogen-containing compounds A is twice as fast at 1,100 RPM as the degradation at 800 RPM.

6. A difference between the rate of degradation when milling in an atmosphere of air and the rate of degradation when milling in an atmosphere of argon was not found.

7. The ultraphosphate B could be converted into bioavailable, water-soluble phosphate B by milling.

10

8. The different amounts of sodium nitrate A and ammonium chloride A had no influence on the degradation rates.

Example 15

15

Elimination of nitrates A and ammonium A and immobilization of trace elements C in carbon G and the reuse of coal G in biogas plants

10,000 kg of manure A, which contained nitrates A, ammonium A, phosphates B as well as traces of arsenic C and heavy metals C, were gradually dried using a commercially available digestate dryer. A total of 800 kg of dry matter F remained. The drying was carried out at an elevated temperature, and the escaping ammonia A was bound with sulfuric acid, as described in German patent application DE 10 2016 004 162 A1. The resulting ammonium sulfate A could be processed further together with the dry matter F. The dry matter F and the ammonium sulfate A were pre-milled in a separate mechanical mill 1. Then they were continuously introduced together with half the amount of activated charcoal G, 50 kg of bentonite Z, and 10 kg of N,N,N',N'-ethylenediamine tetra (methylene phosphonic acid) into a mechanical mill 1 with a drum 1.5 of a volume of 900 liters from above through a protective grid 6 which prevented the milling elements 1.2 from exiting. 1000 kg of steel balls 1.2 of 5 mm diameter were used as milling elements 1.2. The material F to be milled was separated again centrally by means of a cyclone 8. About 100 kg of dry material F ran through the mechanical mill 1 in 1 hour and were milled at a constant speed of 1100 RPM.

The resulting solid, finely divided product I contained significantly fewer nitrate ions A and ammonium ions A than the original dry matter F. In addition, arsenic C, heavy metals C and compounds C thereof were immobilized in coal G, bentonite Z and chelate complexing agent Z and could no longer get into the groundwater, which was a major benefit.

The water-soluble phosphate B was washed out of the solid, finely divided product I, and the resulting solution could be used as liquid fertilizer E.

The washed product I could be returned to the biogas plant as dry matter or in a moist state in any form in order to increase methane formation.

Example 16

The mechanochemical processing of manure A and the elimination of nitrates A in the presence of catalytically active iron particles K.

Manure containing 200 mg/l nitrate ions was dried in the usual and known manner. 100 parts by weight of dried manure A, 34 parts by weight of quartz sand Q, 34 parts by weight of activated charcoal G and 2 parts by weight of catalytic iron particles K were mixed with one another and milled as described in Examples 1 to 3. After 30 minutes, 60 minutes, 90 minutes, 120 minutes, 180 minutes and 240 minutes, samples I were taken from the material F to be milled and eluted with distilled water. The respective nitrate content A was then determined. It was 180 mg/l, 120 mg/l, 90 mg/l, 50 mg/l, 36 mg/l, 21 mg/l and 11 mg/l, respectively.

The example demonstrated that the mechanochemical process according to the invention was exceptionally well-suited for the elimination of nitrates A in biomasses.

Example 17

The mechanochemical immobilization of carcinogenic hexavalent chromium

A material F to be milled was prepared from 50 parts by weight of activated charcoal G, 50 parts by weight of quartz sand and 10 parts by weight of potassium dichromate C and milled as described in Examples 1 to 3. After 120 minutes, samples were taken from the pulverulent product I. The samples I were eluted with water and it was checked whether water-soluble chromium salts C were still present. However, the concentrations were below the detection limits of the customary and known methods for determining chromium C. For comparison, the chromium content of the pulverulent product I was analyzed in the customary and known manner. Almost the entire original amount of chromium C was found. Thus, the original amount of hexavalent chromium C was almost completely immobilized. The small missing amounts of chromium C had apparently been taken up by the materials in cavity 1.1 of mechanical mill 1.

Examples 18 and 19

Mechanical mills for carrying out mechanochemical processes

The mechanical mill 1 for mechanochemical processes comprised at least one rotatable (Example 18; Figure 1) or stationary (Example 19; Figure 2) also mechanochemical reactor and waveguide 1.1, which a large number of balls made of technical ceramics as milling elements 1.2 in a technical ceramics-lined drum 1.5 made of stainless steel with at least one inlet 1.5.1 for the material F to be milled 1.3 and at least one outlet 1.5.2 for the milled product I.

The drum 1.5 of the rotatable mechanochemical reactor and waveguide 1.1 of Example 18 (Figure 1) had a disk-shaped vertical drum wall 1.5.3 which was connected in its center to a rotating drive shaft 3 driven by a motor 4.

Drum 1.5 of the stationary mechanochemical reactor and waveguide 1.1 of Example 19 (Figure 2) had an attritor 1.4 made of stainless steel and coated with technical ceramics, for mixing milling elements 1.2 and material to be milled 1.3. The attritor was arranged to be rotatable along the longitudinal axis of drum 1.5 and was rotatable by a rotatable drive shaft 3 guided through passage 1.5.3.1 through the disk-shaped vertical drum wall 1.5.3 and which was drivable by a motor 4.

Both in mechanical mill 1 of Example 18 (Figure 1) and in the mechanical mill (1) of Example 19 (Figure 2), drum wall 1.5.4 opposite disk-shaped vertical drum wall 1.5.3 consisted of removable, scratch-resistant and impact-resistant grid 1.5.5 made of ceramic that is permeable for electromagnetic radiation and/or corpuscular radiation 2.1, which separated the mechanochemical reactors and waveguides 1.1 from the microwave generators 2.

The microwave generators 2 were firmly connected to mechanochemical reactors and waveguides 1.1 by means of flanges. Openings 1.5.5.1 in the grids 1.5.5 were round and formed a pattern. The grids 1.5.5 with round openings 1.5.5.1 could be replaced by grids 1.5.5 with openings 1.5.5.1 with 3-cornered, 4-cornered, 5-cornered, 6-cornered and slot-shaped outlines.

Drum 1.5 of Example 19 (Figure 2) could also have the shape shown in Figures 1a, 1b, 2a and 3a of the German published patent application DE 195 04 540 A1, only that it had at least one grid 1.5.5 on drum wall 1.5.4 opposite drive 4; 3 and the drum wall 1.5.3.

The motors 4 used were electric motors from Dynamic E Flow GmbH, Kaufbeuren, Germany, under the capcooltech® brand, type HC and type LC.

Example 20

Embodiments of agitation means 1.4 in mechanochemical mills 1

Mechanochemical mills 1 according to Example 19 were provided which, instead of attritors 1.4.1, contained further embodiments of agitation means 1.4.

Agitation means 1.4 according to Figures 5-1 (a), (b) and (c) were striking disks 1.4.2, each with a circular edge 1.4.2.3. Striking disks 1.4.2 each had a centrally arranged passage 1.4.2.1 for drive shaft 3. Six equally sized striking holes 1.4.2.2 were arranged symmetrically around passage 1.4.2.1. Striking disks 1.4.2 according to

Figures 5-2 (a), (b) and (c) differ from striking disks 1.4.2 according to Figures 5-1 a), (b) and (c) only in that they had four instead of six striking holes 1.4.2.2.

5 Striking disks 1.4.2 according to Figures 6 (a), (b) and (c) had three elongated striking holes 1.4.2.2 curved parallel to edge 1.4.2.3, that are arranged symmetrically in a circle.

Striking disks 1.4.2 could be arranged on drive shaft 3 in such a way that striking holes 1.4.2.2 were arranged to align with one another or with a gap between them.
10 Striking disks 1.4.2.1 could, however, also be arranged in such a way that, alternately, two or more were arranged to align with one another and then two or more had a gap between them.

On one of their opposite surfaces 1.4.2.4, striking disks 1.4.2 of Figures 7 (a), (b) and
15 (c) had six symmetrically arranged striking webs that were convexly curved in the direction of rotation with a triangular profile. Striking webs 1.4.2.1 each extended from passage 1.4.2.1 to edge 1.4.2.3. In a further embodiment, striking webs 1.4.2.4 could be arranged on both surfaces.

20 Striking disks 1.4.2 of Figures 8 (a), (b) and (c) differed from striking disks 1.4.2 in that striking webs 1.4.2.4 were arranged in a straight line and had a quadrangular profile. Striking disks 1.4.2 of Figures 9 (a), (b) and (c) differ from those of Figures 8 (a), (b) and (c) only in that striking webs 1.4.2.4 had a triangular profile.

25 These striking disks 1.4.2 could also be arranged on drive shaft 3 in such a way that striking webs 1.4.2.4 were arranged to align with one another or with a gap between them. Striking disks 1.4.2.1 could, however, also be arranged in such a way that, alternately, two or more were arranged to align with one another and then two or more had a gap between them.

30

Agitation means 1.4 of Figures 10 (a), (b) and (c), which are arranged symmetrically to drive shafts 3, each had two striking fans 1.4.3 radiating from a ring 1.4.3.1 surrounding passage 1.4.2. Two striking webs 1.4.2.4 with a quadrangular profile were arranged radially on each of the surfaces of the two striking fans 1.4.3. Striking

fans 1.4.3 of Figures 11 (a), (b) and (c) differ from those of Figures 10 (a), (b) and (c) only in that striking webs 1.4.2.4 had a triangular profile.

5 Striking fans 1.4.3 of Figures 12 (a), (b), (c) and (d) arranged symmetrically to drive shafts 3 each had a mountain and valley profile 1.4.3.2 extending parallel to edges 1.4.2.3 which consisted of two valleys and two mountains each.

10 In agitation means 1.4 of Figures 13 (a), (b), (c) and (e), ring 1.4.3.1 widened symmetrically and transitioned into two pairs of two radiating striking fans 1.4.3, separated from each other by a U-shaped gap 1.4.3.3 in each case. The four striking fans also each had a mountain and valley profile 1.4.3.2 extending parallel to edges 1.4.2.3.

15 These striking fans 1.4.3 could also be arranged on drive shaft 3 in such a way that they were arranged to align with one another or with a gap between them. Striking fans 1.4.3 could also be arranged in such a way that, alternately, two or more were arranged to align with one another and then two or more had a gap between them.

20 Striking club 1.4.4 of Figure 14 had three connecting webs 1.4.2.4 with a round cross section radiating symmetrically from ring 1.4.4.1 encompassing drive shaft 3, at the ends of which a spherical striking element 1.4.4.3 was attached. Striking clubs 1.4.4 could be arranged on drive shaft 3 in such a way that they were to align with one another or had a gap between them. However, they could also be arranged in such a way that, alternately, two or more were arranged to align with one another and then
25 two or more had a gap between them. In other embodiments, connecting webs 1.4.2.4 could also have a quadrangular, oval or trapezoidal cross section or a flattened cross section as the cross section through a knife blade.

30 Planar striking wing 1.4.5 of Figure 15 had an S-shape, in the two striking ends 1.4.5.1 of which striking holes 1.4.2.2 were arranged. Planar striking wing 1.4.5 of Figure 16 had a more pronounced S-shape without striking holes 1.4.2.2. Striking wings 1.4.5 could be arranged on the drive shaft in such a way that they were arranged to align with one another or had a gap between them. They could, however,

also be arranged in such a way that, alternately, two or more were arranged to align with one another and then two or more had a gap between them.

Instead of agitation means 1.4 and milling elements 1.2 described above, mechanical mills 1 could also be operated with rollers 1.4.6 rotating in the opposite direction of rotation 1.4.6.1. The milling then took place in the roller gap. In the configuration according to Figure 17, two parallel rollers were arranged in milling chamber 1.1. In the configuration according to Figure 18, the surfaces of the two rollers 1.4.6 had interlocking teeth 1.4.6.2. In the configuration according to Figure 19, roller 1.4.6 rotated against an abrasion wall 1.4.6.3, the milling taking place in the gap between roller 1.4.6 and abrasion wall 1.4.6.3. In the configuration of Figure 20, axes of rotation 1.4.6.4 of the two parallel rollers 1.4.6 intersected at an angle 1.4.6.5, which resulted in an additional torsion of the material F to be milled.

The rollers 1.4.6 of Figure 21 rotating in opposite direction of rotation 1.4.6.1 had a resilient surface 1.4.6.6. Said surface was formed by symmetrically arranged depressions 1.4.6.7, in which springs 1.4.6.8 pushed the balls 1.4.6.9 out of the depressions 1.4.6.7. The milling of the material F to be milled then took place in the contact area between two balls 1.4.6.9 when the rollers 1.4.6 were rotated. The balls 1.4.6.9 had a smaller diameter than the clear width of the depressions 1.4.6.7, so that the material F to be milled that had entered the depressions 1.4.6.7 could trickle out again when the rollers 1.4.6 were in a suitable position.

Example 21

Embodiments of milling chamber 1.1 of mechanical mills 1

Instead of a drum 1.5, in which the milling chamber 1.1 had the shape of a straight cylinder, a milling chamber 1.1 could also be used, that at least two consecutively arranged spherical section-shaped milling chambers 1.1.1 which are formed by at least one circular constriction 1.1.2. The drive shaft 3 extended centrally through the spherical section-shaped milling chambers 1.1.1 and the circular constrictions 1.1.2. The dimensions of the agitation means 1.4 were adapted to the periodically changing

diameter of the milling chambers 1.1.1. This configuration made it possible to improve the mixing of the material F to be milled.

Example 22

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Mechanochemical process for decontaminating contaminated, phosphate-containing biomass A; B and for recovering phosphate B in bioavailable form

The mechanochemical process is explained in more detail using the flow diagram in Figure 4.

The moist, noxae-loaded, phosphate-containing biomass A; B was dried. The resulting dry matter A; B or the solids of biomass A; B were sieved and pre-milled. The water obtained during drying, which contained ammonia A and ammonium A, was subjected to osmosis or distillation, so that solid ammonium salts E were formed. Said salts could be used as ammonium fertilizers (valuable product E). Ammonium salts A together with the solids of biomass A; B could also be transferred to a mechanical mill and subjected therein to mechanochemical milling in the presence of plasma. This resulted in a noxae-free or noxae-reduced biomass A; B containing immobilized heavy metals C and destroyed bacteria A and viruses A; as well as coal G and phosphates B. This mixture I could be granulated and pelletized and used as phosphate fertilizer E with coal G and non-toxic inorganic and organic components Z. Mixture I could also be milled, so that pulverulent phosphate fertilizer E with coal G and non-toxic inorganic and organic components Z was formed. Water-soluble, bioavailable phosphate B could be extracted from powder I and pellets I and used as liquid fertilizer E. This left coal G with non-toxic organic and inorganic components Z behind.

Example 22

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The regeneration of activated charcoal G for the return to the 4th purification stage

Moist, loaded activated charcoal G and sludge A from the 4th purification stage were washed out. As a result, washed-out, moist, loaded activated charcoal G; A was obtained which was dried so that a washed out, dry, loaded activated charcoal G was obtained.

5

In a further embodiment, moist, loaded activated charcoal G; A and sludge A were dried directly, so that a dry, loaded activated charcoal G; A with sand Q and organic contaminations A was obtained as a result.

- 10 The two dry masses could each be sieved individually, or combined and then sieved, so that sieved, dry, loaded activated charcoal G; A was obtained.

Dry, loaded activated charcoal G; A with sand Q and organic contaminations A, washed out, dry, loaded activated charcoal G; A and sieved, dry, loaded activated charcoal G; A could each individually or together be subjected to a mechanochemical processing with milling elements 1.2 and plasma in a mechanical mill 1. In all cases, the result was a milled, regenerated activated charcoal G, which may also contain contaminations A; C due to fibers and mineral and metallic components. This activated charcoal was sieved to separate the heavy metals C. If necessary, the heavy metals C could also be separated using magnets. The resulting milled, sieved and regenerated activated charcoal G could be granulated and pelletized, and the granules and pellets could be returned to the 4th purification stage.

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Example 22

The radical graft copolymerization of a mixture of ethylene and propylene on mechanochemically treated, thermosetting clearcoat - proof of concept

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A mechanical mill 1 according to Examples 1 to 3 was used for the milling. The metal surfaces thereof were coated with a layer of aluminum oxide ceramic according to Example 16 (Figure 2) and instead of steel balls 1.2, balls made of said aluminum oxide ceramic were used (see Ulrike Wiech in the company brochure of Ceram Tec-ETEC GmbH, Lohmar, think ceramics TECHNISCHE KERAMIK, pages 211 and 212, 3.4.4.2 Mahlen und Brechen). The weight ratio of milling elements 1.2 to material F to

be milled was 20:1. Inlet 1.5.1 for material F to be milled comprised an evacuable lock into which material F to be milled was poured. The lock was then evacuated. After a pressure of 0.01 mbar had been reached, the lock was filled with argon up to a pressure of 1.0 bar. The material F to be milled was then dropped from the lock into the argon-filled milling chamber 1.1 of the mechanochemical reactor and waveguide 1.1. Outlet 1.5.2 for milled product P comprised a tangential cyclone separator 8.

A mixture of 70 g of powdered, thermally cured automobile series clearcoat A according to Table II-2.5: Automobilserienklarlack, page 142 of the textbook by Bodo Mueller and Ulrich Poth, Lackformulierungen und Lackrezeptur, das Lehrbuch für Ausbildung und Praxis, Vincentz Verlag, 2003, 3 g of activated charcoal G and 2 g of quartz sand Q were used as material F to be milled. The material F to be milled was milled under argon for 2 hours with an attritor speed of 1100 RPM to a fineness of a mean particle size $d_{50} = 500$ nm. During the milling, the waveguide 1.1 was irradiated through grid 1.5.5 with microwaves 2.1, which were generated using a microwave generator 2. After milling had ended, the resulting product I was flushed with argon from mechanochemical reactor 1.1 into tangential cyclone separator 8 and there separated under argon from the gas phase, transferred under inert conditions into a suitably dimensioned fluidized bed reactor of the usual and known design and whirled up with argon. The inert gas atmosphere was displaced by a gas mixture of ethylene and propylene in a molar ratio of 1:1. The gas mixture was pumped in a circle from below through the fluidized bed reactor and the pressure drop resulting from the graft copolymerization on the particles of milled product I was compensated for by additional metering in the gas mixture. When a pressure drop could no longer be observed, the graft copolymerization was terminated by flushing the fluidized bed reactor with argon and the resulting graft copolymer was discharged. This was a finely divided, free-flowing black powder with a mean particle size of $d_{50} = 1.5$ μm .

Example 23

The use of the mechanochemical process according to the invention in the production of drinking water H_2O

Figure 23 shows schematically the production of drinking water H_2O from salt water and/or dirty water SW by reverse osmosis UO and membrane filtration.

Before microfiltration MF, the activated charcoal G was used as a preliminary stage for microfiltration in order to protect membrane MF from dirt and particles SP. This has reduced the buildup and clogging.

Common macromolecules MM were retained at the ultrafiltration stage. However, the majority of macromolecules MM had already been removed by activated charcoal G, so that ultrafiltration membrane UF was a guard membrane that was less clogged and lasted much longer. This was especially true for cellulose, hemicellulose, lignin, humic acids, proteins and metabolites.

The subsequent nanofiltration retained the nanofiltration membrane NF dissociated salts and divalent and higher-valent salts DS as well as cations and anions such as sulfates DS, phosphates B and alkaline earth metals C as well as sugars ZU. It was particularly important that phosphates B could be separated here and processed cleanly together with alkaline earth metals C.

In the final reverse osmosis RO, monovalent and undissociated salts EWS; UDS were withheld. This resulted in a highly enriched solution or suspension that contains a lot of ammonium A and nitrate A as well as chlorides, bromides and alkali metal cations C. These salts C could be thickened separately or sold as fertilizer concentrate E or, if there was an oversupply, simply converted mechanochemically into atmospheric nitrogen after drying. This made it possible to increase the concentration of cations C that were not destroyed, such as potassium C, in the mechanical mill.

The activated charcoal as a prefilter was mechanochemically recycled after drying and used again as a prefilter.

Overall, this process enabled the production of pure water effectively and efficiently due to the pre-filtration and the mechanochemical reprocessing of the activated charcoal.

Example 24

The binding of noxae A using impregnated activated charcoals G and the reprocessing of the loaded impregnated activated charcoals G

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The exhaust air filters of cattle stables, digestion towers, biogas plants and closed waste disposal sites were equipped with multi-layer impregnated activated charcoal filters A. The individual layers were impregnated with potassium iodide, carbon dioxide, carbon monoxide, hydrogen sulfide and other sulfur compounds. This significantly increased the adsorption capacity of activated charcoal G, because noxae A such as ammonia, amines, fine dust, ultrafine dust, arsenic and mercury were not only bound by adsorption, but also by chemical sorption or catalyzed reactions. Activated charcoals G impregnated with potassium iodide were particularly effective in this regard.

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Impregnated activated charcoals G loaded with noxae A could then be recycled and reactivated using the mechanochemical process according to the invention.

Example 25

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The sorting of activated charcoal particles G with a particle size of 1 μm to 3 μm

A further advantageous application of the mechanochemical process according to the invention was the sorting, the separation and sorting of activated charcoal particles G with a mean particle size d_{50} of 1 μm to 3 μm in the device according to Figure 24.

For this purpose, using a fan 5, purified, dried nitrogen 5.1 was sucked in through a suction pipe 5.0 and blown as a gas stream 5.2 through a first pipe 5.5 into milling chamber 1.1 of a mechanical mill 1. Before entering milling chamber 1.1, gas 5.2 flowed through a gas-permeable protective grid 6, which prevented milling balls 1.2 from entering pipe 5.5 during the operation of mechanical mill 1. Gas flow 5.2, viewed in the direction of flow, was regulated using a control valve 5.2.2 immediately before entering the milling chamber 1.1.

The finely divided, pulverulent activated charcoal particles G were discharged from the milling chamber 1.1 with the gas stream 5.3 with a mean particle size $<1\ \mu\text{m}$ through a further protective grid 6 via a second pipe 5.6. Gas flow 5.3 was regulated by a control valve 5.3.1.

5

In the further course of pipe 5.6, gas flow 5.3 was combined with a gas stream 5.2.1 routed through a bypass BP with a pipe 5.5.1 and regulated using a control valve 5.2.3. The combined gas streams 5.3; 5.2.1 were routed into an acoustophoresis unit 7 according to the international patent application WO 2017/153038, in which finely divided activated charcoal particles G were agglomerated by means of standing ultrasonic waves 7.2, which were generated by mutually opposing ultrasonic sources 7.1, so that they had the desired mean particle size d_{50} . The exiting gas stream 5.4 with agglomerated activated charcoal particles G was blown, via gas feed line 5.6, into cyclone 8 in which agglomerated activated charcoal particles G; 9.1 were separated from the gas phase (exhaust gas 5.7) which was discharged via exhaust gas line 8.1, and discharged as a pulverulent solid 9 via solids outlet 8.2.

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A major advantage of this device was that bypass BP, which fluidly connected gas line 5.5 and gas line 5.6, ensured that a stronger gas stream 5.4 flowed through cyclone 8 than through milling chamber 1.1.

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Example 26

The mechanochemical elimination of the slip of organic gases and carbon dioxide in the exhaust gases from biogas plants and gas engines

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The slip of organic gases F and carbon dioxide D, in particular the methane slip F in biogas plants and in gas engines operated with methane and/or natural gas, could be effectively and efficiently eliminated by mechanochemically converting the slip gases into carbon using the mechanochemical process according to the invention in the presence of activated charcoal G, and thus no longer entered the atmosphere, where they would have acted as particularly strong greenhouse gases. Thus, not only could the emission of greenhouse gases be effectively prevented by the mechanochemical

30

process according to the invention, but the resulting coal G could be used again for milling.

Examples 27 and 28

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The splitting of carbon dioxide into the elements - proof of concept

Example 27: Carbon dioxide labeled with ¹³C on normal activated charcoal

10 20 g of activated charcoal with a typical isotope ratio of 98.9% C-12 and 1.1% C-13 was gassed with C-13-labeled carbon dioxide (Sigma Aldrich 364592-1L EU, 99 atom-% C-13) up to saturation in a mechanical mill with a volume of 1 l for 12 hours at room temperature. The activated charcoal was first dried at 110 °C for 12 hours and then degassed under reduced pressure. The negative pressure was a high vacuum of
15 10⁻³ hPa (mbar).

The coal was then mixed with 5% by weight silicon dioxide and treated mechanochemically at 1200 RPM at room temperature in a mechanical mill with a milling chamber of 1 l with 1250 g of chrome steel balls of 5 mm diameter. The C-13
20 content of the activated charcoal was then determined by means of mass spectrometry. The measurements indicated that 3.4% C-13 was present. This means that $3.4 \times 100/3.854 = 88.2\%$ **C-13** had been incorporated into the activated charcoal during the milling.

25 Calculation:

1 liter of C-13 CO₂ contained 0.04461 mol of C-13 CO₂

0.04461 mol contained $n \times M = m$, $m = 2.0076$ g, with a molar mass of $M = 45$ g/mol (O-16 99%)

Of this, 13/45 parts would have been converted into coal with 100% conversion. That
30 would have been 0.579 g of C-13.

A theoretical conversion of 100% would have resulted in:

20 g activated charcoal AK with 98.9% C-12, and 1.1% C-13

yielded 19.780 g 0.220 g

0.579 g AK with 1% C-12 and 99% C-13

yielded	0.006 g	0.573 g
sum:	19.786 g of C-12 and	0.793 g of C-13
total sum	19.786 g + 0.793 g = 20.579 g	
of which	96.146% C-12 and 3.854% C-13	

- 5 Previously, the mass ratio in the AK = 98.9 C-12 / 1.1% C-13
After 100% adsorption and conversion, the ratio in the AK would have been 96.146% C-12 / 3.854% C-13.

Example 28: Carbon dioxide labeled with 13-C on activated charcoal loaded with ammonia

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20 g of activated charcoal with a typical isotope ratio of 98.9% C-12 and 1.1% C-13 was gassed with C-13-labeled carbon dioxide (Sigma Aldrich 364592-1L EU, 99 atom-% C-13) and the stoichiometrically equivalent amount of ammonia up to saturation in a mechanical mill with a volume of 1 l for 12 hours at room temperature. The activated charcoal was first dried at 110 °C for 12 hours and then degassed under reduced pressure. The negative pressure was a high vacuum of 10⁻³ hPa (mbar).

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- 20 The coal was then mixed with 5% by weight silicon dioxide and treated mechanochemically at 1200 RPM at room temperature in a mechanical mill with a milling chamber of 1 l with 1250 g of chrome steel balls of 5 mm diameter. The C-13 content of the milled coal was then determined by means of mass spectrometry. The measurements indicated that 3.4% C-13 was present. This means that 3.6 x
25 100/3.854 = **93.4% C-13** had been incorporated into the activated charcoal.

Calculation:

1 liter of C-13 CO₂ contained 0.04461 mol of C-13 CO₂

0.04461 mol contained $n \times M = m$, $m = 2.0076$ g, with a molar mass of $M = 45$ g/mol
(O-16 99%)

30

Of this, 13/45 parts would have been converted into coal with 100% conversion. That would have been 0.579 g of C-13.

A theoretical conversion of 100% would have resulted in:

20 g of AK with 98.9% C-12 and 1.1% C-13

yielded 19.780 g of C-12 and 0.220 g C-13

0.579 g of AK with 1% C-12 and 99% C-13

yielded 0.006 g 0.573 g

sum: 19.786 g of C-12 and 0.793 g of C-13

5 total sum 19.786 g + 0.793 g = 20.579 g

of which 96.146% C-12 and 3.854% C-13

Previously, the mass ratio of the AK = 98.9 C-12 / 1.1% C-13

After 100% adsorption and conversion, the ratio in the AK would have been 96.146% C-12 / 3.854% C-13.

10

Conclusion:

In the presence of ammonia, the incorporation of C-13 into the activated charcoal was significantly increased. The incorporation of C-13 into the activated charcoal was

15 evidence that the carbon dioxide had been split into the elements.

Claims

1. A mechanochemical process for decontaminating and/or eliminating problematic, synthetic, biogenic and biological materials A, for digesting phosphates B, for immobilizing metals and compounds C thereof, for splitting carbon dioxide D into elements and for recovering valuable products E, **characterized in that**
 - (I) as material F to be milled, at least one fluid F, at least one solution F, at least one suspension F, at least one finely divided solid mixture F and/or at least one reactive gas F, containing
 - at least one material A, B, C and/or D, and
 - at least one material G, selected from the group consisting of pure, finely divided, mineral coal, partially pyrolyzed coal, biochar and activated charcoal, contaminated or impregnated, finely divided mineral coal, partially pyrolyzed coal, biochar and activated charcoal, finely divided lignite and pure and contaminated or impregnated, finely divided carbon suppliers, as well as from the above-mentioned, moistened materials G,

are provided or alternatively, the components F and G are provided separately from one another,
 - (II) the at least one fluid F, the at least one solution F, the at least one suspension F, the at least one finely divided solid mixture F and/or the at least one reactive gas F are filled continuously or discontinuously into the milling chamber (1.1) of at least one mechanical mill (1) or alternatively
 - (III) the components A, B, C and/or D and G of the material F to be milled are filled into the milling chamber (1.1) of the at least one mechanical mill (1) one after the other or at the same time, continuously or discontinuously, and
 - (IV) are finely milled therein by milling elements (1.2) moved by agitation means (1.4), or by rollers (1.4.6) at constant and/or variable speed of rotation, after which
 - (V) the resulting at least one suspension H of at least one pulverulent product I and/or the at least one pulverulent product I are/is separated continuously or discontinuously from the milling elements (1.2) or the rollers (1.4.6) and is discharged from the milling chamber (1.1), and
 - (VI) the at least one finely divided, solid product I is separated from the suspension H, as a result of which at least one digested, bioavailable, soluble material passes into the liquid medium as valuable product E, or

(VII) the at least one digested, bioavailable, soluble material E present or still present in the at least one finely divided, solid product I is washed out with at least one liquid medium or is left in the at least one product I as valuable product E until it is further used, and/or

5 (VIII) the at least one washed, finely divided, solid product I from activated charcoal G is returned to process step (I) and/or is used as valuable product E elsewhere, and/or

(IX) the at least one finely divided, solid product I, which contains at least one immobilized metal C and/or at least one compound C thereof, is stored until it is re-
10 used as a valuable product E or disposed of, and/or

(X) the resulting elemental nitrogen and/or oxygen are/is separated.

2. The mechanochemical process according to claim 1, **characterized in that**

- the at least one digested, liquid media-soluble material E is selected from the
15 group consisting of lithium, sodium and potassium salts and magnesium and calcium salts I and bioavailable phosphates B; I, and/or

- the at least one immobilized material C is selected from the group consisting of main group elements, transition metals, lanthanides and actinides C and compounds C thereof.

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3. The mechanochemical process according to claim 1 or 2, **characterized in that** the at least one solid, finely divided product I is at least one valuable product E selected from the group consisting of activated charcoals G, which are returned to process step (I) or used otherwise, of at least one phosphate-containing fertilizer E, which is applied to agricultural land, and of at least one safely storable material E
25 containing at least one immobilized metal C and/or at least one of compounds C thereof, or of at least one heterogeneous catalyst E based on at least one immobilized metal C and/or at least one of compounds C thereof.

30 4. The mechanochemical process according to any one of claims 1 to 3, **characterized in that** a plasma is present during the milling in the milling chamber (1.1) of the mills (1).

5. The mechanochemical process according to claim 4, **characterized in that** the plasmas are generated by generating triboplasma by means of gas discharge, hotspots, electrostatic charging, emission of exoelectrons, triboluminescence, crystal lattice defects, shredding, dislocations, crystal lattice vibrations, fracture formation, cutting processes, compressions, sanding, drilling, grinding, abrasion, high pressures, friction, mister a tablet number yes real nerve crisis foaming can cause everything metastable states and hotspots due to the collision of the solids and/or the friction of the solids against each other as well as catalytically active and/or piezoelectric particles and coatings on the milling elements (1.2) and/or the walls of the milling chamber (1.1) and/or on the agitation means (1.4) and/or in the milling chamber (1.1) of the mechanical mills (1), focused laser radiation, electron radiation, radioactive radiation, X-rays, UV radiation, IR radiation, microwave radiation, ultrasound, chemical and nuclear reactions, electrostatic fields, electromagnetic fields, direct voltage, capacitive electrical excitation, wire explosions, gas discharges, electric arcs, spark discharges, vacuum spark discharges, cyclotron resonance, capacitive glass tube discharge and the pinch effect.

6. The mechanochemical process according to claim 5, **characterized in that**

- the piezoelectric particles and/or the coatings on the milling elements (1.2), the drive shafts (3), the walls of the milling chamber (1.1) and/or on the agitation means (1.4) and/or in the milling chamber (1.1) of the mechanical mills (1) are selected from the group consisting of carbon, quartz, glass barium titanate (BTO), lead zirconate titanate (PZT), lead magnesium niobate (PMN), gallium orthophosphate, berlinite, tourmaline, seignette salt, piezoelectric thin layers of zinc oxide, aluminum nitride, silicon nitride, silicon carbide, aluminum oxide, zirconium oxide and titanium nitride, polyvinylidene fluoride (PVDF) and ferroelectric, polycrystalline ceramics, and
- the catalytically active particles and/or the coatings on the milling elements (1.2), the walls of the milling chamber (1.1), the drive shafts (3) and/or on the agitation means (1.4) and/or in the milling chamber (1.1) of the mechanical mills (1) are selected from the group consisting of metals, metal alloys, metal compounds and microporous materials.

7. The mechanochemical process according to any one of claims 1 to 6, **characterized in that** the at least one material A is selected from the group

consisting of natural, synthetic, biogenic and biological materials that are ecologically problematic, intensely smelling, toxic, combustible, oxidizing, radioactive, carbon supplying and/or explosive, mixtures thereof and waste thereof, as well as contaminated mineral coals, biochars, activated charcoals and carbon suppliers.

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8. The mechanochemical process according to any one of claims 1 to 7, **characterized in that** the milling of the at least one material F to be milled is carried out at a temperature of the milling elements (1.2) and of the at least one material F to be milled of -273 °C to +1,200 °C.

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9. The mechanochemical process according to claim 8, **characterized in that** the temperatures in the hotspots and in the plasmas are up to 15,000 °C.

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10. The mechanochemical process according to any one of claims 1 to 9, **characterized in that** the weight ratio (Y) = (A, B, C and/or D) : (G) in the material F to be milled is 0.01 to 10^{12} .

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11. Use of an electric motor, comprising an electric machine component with at least one winding for generating a magnetic field which comprises at least one waveguide which has a jacket and an inner cavity through which a coolant can be routed, the winding having two ends, to which an electrical operating voltage is connected, and wherein

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- the waveguides are formed to be round tubular and have an outer diameter in a range from 1 mm to 4 mm,
 - the ends of the winding each serve as a coolant inlet or coolant outlet, and
 - the ends of the winding are connected to a connector comprising a coolant inlet and/or a coolant outlet, several waveguide connections for connecting waveguides, a manifold through which the coolant is fed into at least one waveguide, and/or a collecting channel into which the coolant emerging from at least one waveguide flows and is routed to the coolant outlet of the connector,
- as a drive for mechanical mills for mechanochemical processes.

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12. A mechanical mill (1), comprising at least one rotatable or stationary mechanochemical reactor and waveguide (1.1) containing a rotatable or stationary

drum (1.5) with a milling chamber (1.1) with at least one inlet (1.5.1) for the material to be milled (F; 1.3), at least one outlet (1.5.2) for the milled product I and a plurality of stationary or rotatable agitation means (1.4), wherein

- the drum (1.5) of the rotatable mechanochemical reactor and waveguide (1.1) has a disk-shaped vertical drum wall (1.5.3) which is connected in its center to a rotatable drive shaft (3) which can be driven by a motor (4), and
- the drum (1.5) of the stationary mechanochemical reactor and waveguide (1.1) has agitation means (1.4) rotatable by means of a drive shaft (3) for mixing the milling elements (1.2) and the material to be milled (1.3) or rotatable rollers (1.4.6) oriented in the longitudinal direction of the drum (1.5), the drive shaft (3) being driven by a motor (4) and being guided through the disc-shaped vertical drum wall (1.5.3) through the passage (1.5.3.1),
- the agitation means (1.4) are selected from the group consisting of striking disks (1.4.2), striking fans (1.4.3), striking clubs (1.4.4) and striking wings (1.4.5) having striking holes (1.4.2.2), striking webs (1.4.2.4), mountain and valley profiles (1.4.3.2), connecting webs (1.4.4.2) and striking elements (1.4.4.3) that are arranged symmetrically to the drive shaft (3), and wherein
- the rotatable rollers (1.4.6) can be rotated in opposite directions of rotation (1.4.6.1) and their axes of rotation (1.4.6.4) are parallel to one another or have an angle of inclination (1.4.6.5) or can be rotated against an abrasion surface (1.4.6.3).

13. The mechanochemical mill (1) according to claim 14, **characterized in that** the mill (1) has an agitation means (1.4) of the same type and/or at least two different types of agitation means (1.4), wherein the agitation means (1.4) selected from of the group consisting of striking disks (1.4.2), striking fans (1.4.3), striking clubs (1.4.4) and striking wings (1.4.5) having striking holes (1.4.2.2), striking webs (1.4.2.4), mountain and valley profiles (1.4.3.2), connecting webs (1.4.4.2) and striking elements (1.4.4.3) that are arranged symmetrically to the drive shaft (3), are arranged to align with one another and/or with a gap between them in the direction of the drive shaft (3).

14. The mechanical mill (1) according to claim 12 or 13, **characterized in that** the drum wall (1.5.4) opposite the disk-shaped vertical drum wall (1.5.3) of both the stationary and the rotatable mechanochemical reactor and waveguide (1.1) is formed

from impact-resistant grid or window (1.5.5) permeable for electromagnetic radiation and/or corpuscular radiation (2.1), which separates the mechanochemical reactor and waveguide (1.1) from the at least one radiation source (2).

- 5 15. The mechanochemical mill (1) according to any one of claims 12 to 14,
characterized in that the milling chamber (1.1) has at least two consecutively
arranged spherical section-shaped milling chambers (1.1.1) which are formed by at
least one circular constriction (1.1.2), wherein the drive shaft (3) extends centrally
through the spherical section-shaped milling chambers (1.1.1) and the circular
10 constrictions (1.1.2) and the dimensions of the agitation means (1.4) are adapted to
the periodically changing diameter of the milling chambers (1.1.1).