(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
01 February 2024 (01.02.2024)

(10) **International Publication Number**
WO 2024/023106 A1

(51) **International Patent Classification:**
D06M 11/79 (2006.01) ***B01J 20/32*** (2006.01)
D06M 13/507 (2006.01) ***C09K 3/32*** (2006.01)
B01J 20/10 (2006.01)

(21) **International Application Number:** PCT/EP2023/070615

(22) **International Filing Date:** 25 July 2023 (25.07.2023)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
22187285.6 27 July 2022 (27.07.2022) EP

(71) **Applicant: TECHNISCHE UNIVERSITÄT DARMSTADT** [DE/DE]; Karolinenplatz 5, 64289 Darmstadt (DE).

(72) **Inventors: STANZEL, Mathias**; Saalburgstr. 6, 60385 Frankfurt am Main (DE). **RATH, Nicole**; Friedhofstraße 7, 63179 Obertshausen (DE). **BIESALSKI, Markus**; Bleichstrasse 13, 63477 Maintal (DE). **ANDRIEU-BRUNSEN, Annette**; Schwambstr. 12, 64287 Darmstadt (DE).

(74) **Agent: FUCHS PATENTANWÄLTE PARTNERSCHAFT MBB**; Tower 185, Friedrich-Ebert-Anlage 35-37, 60327 Frankfurt am Main (DE).

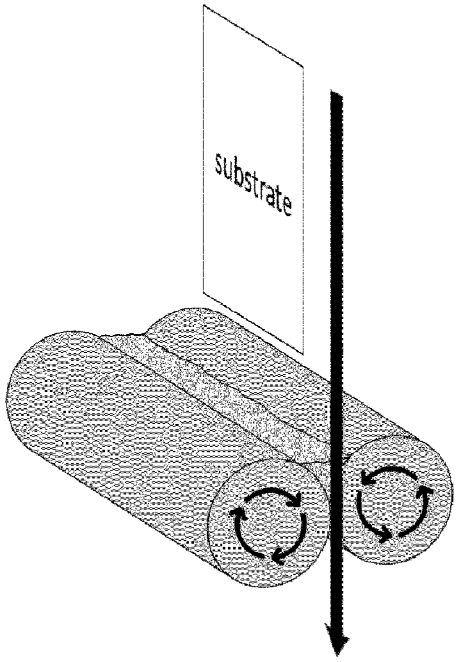
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: SILICA IMPREGNATED NON-WOVEN FABRICS, THEIR USE AND METHOD FOR THEIR MANUFACTURE

(57) **Abstract:** New uses of a silica impregnated fibrous non-woven fabric are disclosed with an oven-dry silica content of 7 - 30 wt.-% for binding nonpolar and/or oily liquids as well as hydrophobic binder fleeces and processes.

Figure 1



[Continued on next page]

Published:

- *with international search report (Art. 21(3))*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

SILICA IMPREGNATED NON-WOVEN FABRICS, THEIR USE AND METHOD FOR THEIR MANUFACTURE

The application pertains to new uses of a silica coated fibrous non-woven fabric with an oven-dry silica content of 7 - 30 wt.-% for binding nonpolar and/or oily liquids as well as the binder fleeces and processes.

Technical background of the invention

Oil binders are used to bind mineral oils from building yards, road maintenance departments and fire brigades. Prior art oil binders rely mostly on grained-powders or liquids. Basic materials are often mineral or vegetable substances (e.g., corncob granules). There are also fleeces, cubes and much more to safely absorb oil in certain situations. Also floating oil binding agents exist which are used in combination with oil barriers and oil rakes to remove mineral oils from bodies of water.

The most common area of application is the removal of leaking liquids after a traffic accident or traces of oil from cars with a ruptured oil pan. Powdery oil binding agents used for spreading and removing the oil can significantly impair the sweep ability of this mixture of oil with oil binding agent by creating a smear, so that a remaining trace of oil binding agent cannot be avoided.

Traces of oil binder must not remain to create slip resistance. When selecting the product, it is therefore important to ensure that the oil binding agent for traffic areas cannot produce dust from production to use, i.e., does not tend to form powdery components.

Other oil binding materials, such as for example fleeces, are normally only single-use and meant to be disposed after binding the oil, rendering itself toxic waste which needs to be carefully disposed.

Furthermore, especially oil binding fleeces, consist mostly of polymers (polypropylene) or other composite materials which cannot be recycled, use valuable fossil resources, and can pose an environmental problem in themselves.

On the other hand, additional applications can be envisaged for oil binding materials, for example for cleaning clothes, skin, or other household areas. Also, the chemical industry is interested in oil binders, for example for a cheap phase separation of nonpolar and polar components during industrial processes.

Thus, there is a wide need for environmentally friendly, recyclable oil binding materials.

The present invention solves the aforementioned environmental problems by providing environmentally hydrophobic binder fleeces, which can be used as oil binding fleeces and can even be recycled (both the oil-binder itself, as well as the oily or nonpolar component bound to it).

Description of the invention

In a first aspect, the present invention relates to the use of a silica coated fibrous non-woven fabric with oven-dry silica content of 7 - 30 wt.-% for binding nonpolar and/or oily liquids for at least 1 hour or more, or 2 hours or more, or 6 hours or more, or 24 hours or more, or 48 hours or more, or 3 days or more, or 1 week or more, or 1 month or more, or 1 year or more, or, in one embodiment, may be indefinitely, within the silica coated fibrous non-woven fabric.

In a first aspect, the present invention relates to the use of a silica coated fibrous non-woven fabric with oven-dry silica content of 7 - 30 wt.-%, or at least 10.5 wt.-%, and having a surface energy on both sides, which is increased as compared to the non-impregnated fibrous non-woven fabric for binding nonpolar and/or oily liquids.

As such the silica coated fibrous non-woven fabric may be used in a number of applications in which nonpolar liquids need to be absorbed, for example it may be are used to bind mineral oils from building yards, road maintenance departments and fire brigades. Since the silica coated fibrous non-woven fabric can float on water, it can be used in combination with oil barriers and oil rakes to remove mineral oils from bodies of water.

Further uses include the removal of leaking operating materials after a traffic accident or traces of oil from cars with a ruptured oil pan. One advantage in this respect is, that the inventive silica coated fibrous non-woven fabric show such a good oil-binding activity that little or no smear or remnants are created. The inventive silica coated fibrous non-woven fabric may also be used as a chemical binder for absorbing nonpolar chemicals, including for use in industry, on traffic areas or in bodies of water. As universal binders, they can be used for hazardous substances as well as for mineral oils, in one embodiment the material of the fibrous non-woven fabric is resistant to the respective chemical.

Such nonpolar chemicals may be selected from the list comprising organic oils (including natural fats and oils), mineral oils, fats, petrol/gasoline, organic solvents, alkanes, alkenes, alkines, benzene and other aromatic derivatives, ether, toluene, chloroform, diethyl ether, ethyl acetate, turpentine, etc.

Accidents involving chemicals that are transported hot and cool and solidify in the event of a leak are particularly problematic. Before these products can be picked up with oil absorbents, they must be dissolved with hot water generated at the accident site or condensate brought in. This work can usually only be managed by plant fire brigades with special equipment.

Further uses include the use of the inventive silica coated fibrous non-woven fabric for recycling of a nonpolar liquid and/or chemical as described hereinunder. Also beneficial is that the inventive silica coated fibrous non-woven fabric itself is so stable that it can be recycled several times and thus reduces the waste created.

Further uses also include as household articles, for example kitchen sponges, kitchen towels, kitchen fleeces and the like, as well as products of the personal hygiene, such as make-up removal pads, cotton swabs, towels, wet wipes, toilet paper, and the like, where at least one surface has a binding activity for nonpolar and/or oily liquids. In those areas the inventive silica coated fibrous non-woven fabrics can be used to bind nonpolar liquids, for example such as cooking oils, facial fat, earwax, cosmetics, etc. and/or can be used to apply oily crèmes or oils to the skin. Especially for baby's wet wipes with natural oils (e.g., coconut-oil, almond oil and/or olive oil) are preferred. In yet another embodiment bacterial nanocellulose (BNC) fleeces can be impregnated to bind nonpolar liquids. Such BNCs or other inventive silica coated fibrous non-woven fabrics can be used for cosmetic and/or medical purposes, for example as facemasks, Band Aid®, adhesive tape, dressing, or the like, especially when combined with nonpolar cosmetic and/or pharmaceutical compositions.

The advantage of the described use, product, and process according to the invention compared to the state of the art is an environmentally friendly, non-toxic final product (i.e., only comprising SiO_2), which also allows the technical use of the oil-binding fibrous non-woven fabric according to the invention in environmentally sensitive areas. Furthermore, the impregnation can be carried out at temperatures below 150°C (between 4 – 40°C; or ambient temperature at 20°C) and atmospheric pressure, which leads to significant energy savings.

In one first aspect, a fibrous non-woven fabric with oil-binding abilities is provided.In one embodiment, the fibrous non-woven fabric is selected from the group consisting of non-woven paper fabrics, non-woven textile fabrics, in particular non-woven cotton fabrics. In some embodiments, the non-woven textile fabric may be made of polymers, such as for example polylactic acid (PLA) or other biogenic, nonpolar or lightly polar polymeric fibers, such as for example silk fibers. As such biodegradable polymers are preferred, for example biopolyesters of synthetic or microorganism origin (e.g., polyhydroxybutyrate and polylactic acid), or agro-polymers such as polysaccharides (e.g., starches), proteins (e.g., animal-based whey or plant derived gluten), etc. In one embodiment the fibrous non-woven fabric is selected from the group comprising non-woven paper fabric, viscose (regenerated cellulose) and/or cotton and/or any combination thereof.

The fibrous non-woven fabric of the present invention is a fibrous non-woven fabric. In one embodiment, the fibrous non-woven fabric is selected from the group consisting of non-woven paper fabrics and non-woven textile fabrics. In one embodiment, the fibrous non-woven fabric is a non-woven paper fabric.

In one embodiment, the fibrous non-woven fabrics of the invention still maintain flexibility.

Thus, in one embodiment, the paper mentioned hereinunder is selected from the group consisting of eucalyptus paper and/or northern bleached softwood kraft (NBSK). In other embodiments cotton linters (80 g/m^2) and/or abacá (13 g/m^2). Other papers that can be used according to the invention include: Aburatorigami, Affiche paper, Albumin paper, Alfapaper, Amatl, APCO II/II (DIN 16519 T2), Watercolour paper (between 120 g/m^2 up to 850 g/m^2 , for watercolour board from approx. 150 g/m^2), copying paper, lining paper, baking paper, banana paper, banknote paper, baryta paper, bible printing paper (grammage between 25 and 60 g/m^2 ; also known as thin printing paper), illustration paper, blueprint paper, bombyzine paper, letter paper, stamp paper, book paper, coloured paper, handmade paper, buttered paper or parchment substitute, China paper, Chinese rice paper, chromo paper, down printing paper, decalcifying paper, thick printing paper, document paper, double wax paper, printing paper, duplex paper, carbonless paper (also known as carbonless paper or copy paper, grammage 30-40 g/m^2), Ice paper (ice board or alabaster paper), elephant skin, electrical insulating paper, ivory paper, ivory board (grammage from 240 to 320 g/m^2), continuous printing paper for EDP printing (DIN 672), label paper, fabriano paper, Fine papers (all wood-free and rag-containing papers according to DIN), filter paper, felt paper, flock paper (velour paper), florpost (florpost paper), photo paper, coated paper, ribbed paper or vergé paper, glass-fibre paper, Gummed paper, rag paper (at least 10% rag or cotton, hemp or flax fibre), semi-chemical paper (at least 65% semi-chemical pulp of the total fibre pulp), hemp paper, hard paper (fibre composite of paper and a phenol-formaldehyde synthetic resin (phenoplast), hard post paper (also bank post paper), high-gloss paper (one-sided cast-coated but not calendered paper), Wood-free paper (not more than 5% by weight of lignified fibres), Wood-containing paper (not less than 5% by weight of lignified fibres), Hydrographic paper, Hygienic papers (especially tissue papers), Ingres paper (hand-made or cylinder mould hand-made paper, Japan paper, potassium iodide starch paper, chancery paper (grammage of 60 and 120 g/m^2), carbon paper, Khoi paper, copying paper, corrosion protection paper (VCI paper, Volatile Corrosion Inhibitor), kraft liner, kraft paper (also: Packing paper) (grammage formerly around 130 g/m^2 , today around 80 g/m^2), Chalk paper, Crepe paper, Kitchen crepe, Art paper, Plastic fibre papers or plastic papers, Copper printing paper, Map paper, Leather paper, Light tracing paper, Blotting paper (also non-woven paper), Manila paper, Medical papers (ISO 11607, EN 868-6 , EN 868-3, and ISO 10993-5), Metallised paper, Metal-laminated paper, Medium-fine papers, Mummy paper, Natural fibre papers (these include papers made from cotton, banana, sisal, mulberry fibres, rice, maize, wheat straw paper, kudzu paper, daphne paper (Lokta, Nepal, Himalayan paper) *Daphne bholua* and *Daphne papyracea*), Non-impregnated paper (non-impregnated paper, at most with a surface treatment or pigmentation of up to 5 g/m^2), offset printing paper (also known as offset paper for short), oiled paper or waxed paper according to DIN 6730, parabaic, parchment substitute (also known as buttered paper), parchment paper, parchment substitute (also known as greaseproof paper), parchment, poster paper, plotter paper, post paper (grammage between 70 and 120 g/m^2), quartz fibre paper (filter paper containing quartz fibres), swell paper, recycled paper (any paper containing more than 25 % recovered paper before further refinement), rice paper, raw paper, saa paper (also known as siam paper), absorbent paper, SC paper, silhouette paper (or clay paper) (grammage 80-90 g/m^2), sandpaper, writing paper, typewriter paper (also known as SM paper), DIN 6730), scratch paper, swell paper, tissue paper (25 g/m^2 grammage), carbonless copy paper, also NCR paper (no carbon required), security paper, silicone paper, tension paper, spider paper, spinning paper, stone paper, straw paper, synthetic paper, ropes (or packing ropes, lift ropes), tea bag paper (mainly made of abaca fibres), directory paper (approx. 35 g/m^2), thermal paper, rotogravure paper, tracing paper, release paper, vellum paper (velin), velour paper, wasli paper, watermark paper, work printing paper, xuan paper, drawing paper (in different grammages from 60 g/m^2), newsprint, cigarette paper and combinations thereof.

The term grammage or basis weight is to be used interchangeably here.

In one embodiment, the provided non-woven paper fabric has a grammage of 10 – 1000 g/m^2. In one aspect between 10 – 55 g/m^2, or 12 – 53 g/m^2. In other aspects the grammage is between 50 – 1050 g/m^2, or 65 – 1000 g/m^2 (for example in case of wood pulp boards). In further aspects the grammage is or 65 to 150 g/m^2, or of 70 to 130 g/m^2, or of 80 to 120 g/m^2.

The fibrous non-woven fabric can be a commercially available fibrous non-woven fabric. In particularly, the non-woven paper fabric can be a commercially available non-woven paper fabric. In an alternative, the step of providing the fibrous non-woven fabric, in particularly the non-woven paper fabric, can also contain the step of the production of the fibrous non-woven fabric, in particularly the non-woven paper fabric. The production of a non-woven paper fabric may be conducted with the Rapid-Köthen method, in one embodiment in a sheet forming Rapid-Köthen plant, in one embodiment according to DIN 54358 and/or ISO 5269/2 (ISO5269-2:2004(E), „Pulps – Preparation of Laboratory Sheets for Physical Testing – Part 2: Rapid Köthen Method, 2004“).

In some embodiments, in the production of the fibrous non-woven fabric, in particularly the non-woven paper fabric, no further additives or fillers are used. In other embodiments additives such as conservation agents, bleaching agents, thickeners, plasticizers, surfactants, etc. may be used.

The oil-binding fibrous non-woven fabric of the present invention may be made of any fibrous non-woven fabric made from staple fibres (short) and long fibres (continuous long), bonded together by chemical, mechanical, heat or solvent treatment. The term “fibrous non-woven fabric” is used hereinunder to denote fabrics, such as felt, which are neither woven nor knitted. Some non-woven materials lack sufficient strength unless densified or reinforced by a backing. In one important aspect the fibrous non-woven fabric is paper.

The term “non-impregnated fibrous non-woven fabric” refers to the same fibrous non-woven fabric but not impregnated with any of the impregnation solutions disclosed in this application and/or otherwise silica treated.

The “nonpolar and/or oily liquids” may be selected from oils, fuels and any other nonpolar liquid, such as for example motor oil, diesel, heating oil, cutting oil, vegetable oil, oil-based solvents. Especially nonpolar substances can be separated from polar substances, for example oil from water surfaces. In some embodiments for example canola oil, toluene, dichloromethane and n-hexane were absorbed by the inventive silica-coated fibrous non-woven fabrics. In further embodiments even liquids, being both (slightly) polar as well as nonpolar may be absorbed.

Wherein the fibrous non-woven fabric has an oven-dry silica-content of about 4 wt.-% or more, or 5 wt.-% or more, or 6 wt.-% or more, or 7 wt.-% or more, or of about 8 wt.-% or more, or of about 9 wt.-% or more, or of about 10 wt.-% or more; up to about 30 wt.-% or less, or up to about 25 wt-% or less, or up to about 20 wt-% or less; in one aspect between 4 wt.-% to 30 wt.-%, or between 6 wt.-% to 25 wt.-%, or between 7 wt.-% to 20 wt.-%. In one aspect the air-dry or oven-dry silica content is at least 7 wt.-%.

Preferably the silica-impregnation is homogeneous in the fibrous non-woven fabric, that is the difference in air-dry or oven-dry silica-content on one side is less than 2:1 as compared to the other side, or less than 1.5:1; or less than 1.2:1.

In a further aspect, the oil absorption capacity is about 3 g/g or more, or about 5 g/g or more, or about 10 g/g or more, or about 20 g/g or more, about 25 g/g or more; in some embodiments up to about 100 g/g or less, or up to about 60 g/g or less, or up to about 55 g/g or less, or up to about 53 g/g or less; in one aspect between 3 g/g to 55 g/g, or between 5 g/g to 53 g/g, most or between 8 g/g to 50 g/g. In one aspect the oil absorption capacity content is at least 12 g/g.

In a further aspect, the water absorption capacity is reduced about 1.5 times than of the non-impregnated material, is reduced about 2 times than that of the non-impregnated material, or about 3 times than of the non-impregnated material, or about 4 times than of the non-impregnated material, or about 5 times than of the non-impregnated material; in some embodiments it is reduced up to about 30 times than of the non-impregnated material, or up to about 20 times than of the non-impregnated material, or up to about 15 times than of the non-impregnated material, or between 1.5 to 30 times, or between 3 to 20 times more than of the non-impregnated material. In one aspect the water absorption capacity is at least 10 times reduced in comparison to the non-impregnated material.

In this respect it needs to be understood that the hydrophobicity of the non-woven fabric is increased and for commercial applications it needs to be below the threshold of a water capacity of 3 g/g or less.

Thus, in a further embodiment, the water absorption capacity may be less than 3.0 g/g (water/material), or less than 2.8 g/g (water/material), or less than 2.7 g/g (water/material), or less than 2.6 g/g (water/material), or less than 2.5 g/g (water/material), or less than 2.25 g/g (water/material), or less than 2.0 g/g (water/material). In one embodiment the water absorption capacity may be between 1.0 and 3.0 g/g, or between 1.25 and 2.8 g/g, or between 1.5 and 2.7 g/g.

It has been found that especially for certain commercial applications a water absorption capacity of 3 g/g or less is preferred, since in real-life applications, such as for example when recovering an oil slick on the sea, the nonwoven fabrics are exposed to an aqueous environment for many hours and otherwise absorb too much water and become unsuitable for oil binding and/or even lose their floating capabilities.

In a further aspect, the roughness defined by ISO 25178 of the fibrous non-woven fabric remains the same after silica coating. This is important, since otherwise the oil-absorption may be negatively affected.

In a further aspect, the surface energy of the silica impregnated fibrous non-woven fabric may be increased at least 1.1 –fold, or at least 1.2-fold, or at least 1.3-fold, or at least 1.5-fold, or at least 2-fold, or at least 2.5-fold, or at least 3-fold as compared to the non-impregnated fibrous non-woven fabric. In another embodiment the surface energy is not increased more than 5-fold or less, or more than 4.5-fold or less, or more than 4-fold or less. Thus, the surface energy of the silica impregnated fibrous non-woven fabric may be increased between 1.1 – 5-fold, or between 1.5 to 4-fold as compared to non-impregnated fibrous non-woven fabric.

In yet a further aspect, the recovery of the silica impregnated fibrous non-woven fabric is at least 90% after binding the nonpolar and/or oily liquid and subsequent immersing in ethanol to remove the nonpolar. In one embodiment, the recovery rate may be at least 95%, at least 98%, or at least 99% and up to 100%, i.e., between 90% and 100%, or between 95% and 99%, or between 96% and 98%.

In yet a further aspect, the swelling capacity of the fibres in the silica impregnated fibrous non-woven fabric is 20 wt.-% or less. Without being bound to theory it seems that the swelling capacity of the fibres in water in the fibrous non-woven fabric is reduced by the silica treatment and this effect adds to the improved oil binding capability. Thus, in one aspect the swelling capacity of the oil binding fibrous non-woven fabric after silica-impregnation is about 20% or less when immersed in water as measured by air drying or oven drying, or about 10% or less, or about 5% or less, or about 2% or less, or about 1% or less as compared to the non-impregnated fibrous non-woven fabric. Experimentally, this method is exceedingly simple - the fibre samples, fully swollen and containing excess water, are dried very slowly, and weighed periodically. It is shown that for a time the moisture is lost at a nearly constant rate. Eventually, however, the drying rate changes and thereafter steadily diminishes. It is believed that this change occurs only after all nonswelling water external to the fibre has evaporated. The moisture regain at this point of transition in the desiccation rate is considered to be indicative of the maximum water-holding capacity of the cellulose - i.e., the swelling capacity.

In yet a further embodiment, water contact angle on the surface of the silica impregnated fibrous non-woven fabric may be above 90°, or above 100°, or above 110° on at least one, on both sides. The preferred contact angle may be up to 120°, and in certain cases even up to 150° in case of superhydrophobic surfaces. A usual surface of the silica impregnated fibrous non-woven fabric according to the present invention shows a contact angle of between 90° to 120°.

In a further aspect, the present invention relates to an impregnating solution comprising a silicon component for reducing the water binding capabilities of fibrous non-woven fabric resulting in an environmentally friendly and non-toxic final product, in particular paper and board; comprising the following compounds in weight-%:

Compound	**wt.-%**
silicon component, such as tetraethyl orthosilicate (TEOS)	2 - 20
H_2O	0 – 10 (ad 100 wt.-%)

alcohol (e.g., EtOH, MeOH)	75 - 90
catalyst (e.g., HCl, NaOH)	0.001 – 0.05

Instead of alcohol other organic solvents may also be used, however, they are usually more expensive and/or not environmentally friendly.

Thus, in a most preferred aspect, the present invention also pertains to an impregnation mixture comprising the following compounds in weight-%:

Compound	**wt.-%**
silicon component, such as tetraethyl orthosilicate (TEOS)	5 - 18
H_2O	1 – 10 (ad 100 wt.-%)
alcohol (e.g., EtOH, MeOH)	75 - 90
catalyst (e.g., HCl, NaOH)	0.01 – 0.04

Thus, in a more preferred aspect, the present invention also pertains to an impregnation mixture comprising the following compounds in weight-%:

Compound	**wt.-%**
silicon component, such as tetraethyl orthosilicate (TEOS)	about 9.3
H_2O	about 8
alcohol (e.g., EtOH, MeOH)	about 82.6
catalyst (e.g., HCl, NaOH)	about 0.03

Thus, in a more preferred aspect, the present invention also pertains to an impregnation mixture comprising the following compounds in weight-%:

Compound	**wt.-%**
silicon component, such as tetraethyl	about 17.1

orthosilicate (TEOS)	
H_2O	about 7.4
alcohol (e.g., EtOH, MeOH)	about 75.5
catalyst (e.g., HCl, NaOH)	about 0.03

In yet a further aspect, the fibrous non-woven fabric is impregnated with a mixture comprising the relative amounts of 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)): 0-30 alcohol (e.g., EtOH or MeOH): 0-10 H_2O: 0.001 catalyst (i.e., acidic or basic catalyst, e.g., HCl or NaOH).

In yet a further aspect, the fibrous non-woven fabric is impregnated with a mixture comprising the relative amounts of 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)): 1-30 alcohol (e.g., EtOH or MeOH): 1-10 H_2O: 0.001 catalyst (i.e., acidic or basic catalyst, e.g., HCl or NaOH).

In yet a further aspect, the fibrous non-woven fabric is impregnated with a mixture comprising the relative amounts of 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)): 10-30 alcohol (e.g., EtOH or MeOH): 2-10 H_2O: 0.01 catalyst (i.e., acidic or basic catalyst, e.g., HCl or NaOH).

In yet a further aspect, the fibrous non-woven fabric is impregnated with a mixture comprising the relative amounts of 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)): 15-25 alcohol (e.g., EtOH or MeOH): 3-7 H_2O: 0.01 catalyst (i.e., acidic or basic catalyst, e.g., HCl or NaOH).

In yet a further aspect, the fibrous non-woven fabric is impregnated with a mixture comprising the relative amounts of 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)): 20 alcohol (e.g., EtOH or MeOH): 5 H_2O: 0.01 catalyst (i.e., acidic or basic catalyst, e.g., HCl or NaOH).

Further compositions can be found in the example section.

In yet another aspect the present invention also pertains to a fibrous non-woven fabric obtained by impregnating the fibrous non-woven fabric with one or more of the mixtures disclosed hereinunder.

In certain preferred embodiments, the impregnating solution consists of the silicon component. In other words, the portion of the silicon component in the impregnating solution is 100% by weight.

Thus, in particularly, the impregnating solution may be pure silane. In other preferred embodiments, the impregnating solution contains in addition to the silicon component still at least one further component, for example a solvent component such as for example an alcohol or water and/or an acid component.

In one embodiment, the portion of the silicon component in the impregnating solution may be in a range of 5% by weight to 100% by weight, or 10% by weight to 99% by weight, or 20% by weight to 98% by weight, or 40% by weight to 97% by weight, or 60% by weight to 96% by weight, or 80% by weight to 95% by weight. Via the portion of the silicon component the extent of the water repellent properties of the surfaces of the fibrous non-woven fabrics can be adjusted in a targeted manner. Higher portions of silicon component are connected with more hydrophobic surface properties.

In one embodiment, the silicon component is selected from the group consisting of tetraethyl orthosilicate (TEOS), tetramethyl orthosilicate, polydimethoxysiloxane, 1,2-bis(triethoxysilyl)ethane, silicon tetraacetate, (3-Aminopropyl)triethoxysilane, (3-Aminopropyl)trimethoxysilane, *N*-[3-(Trimethoxysilyl)propyl]ethylenediamine, [3-(2-Aminoethylamino)propyl]trimethoxysilane, N-(2-Aminoethyl)-3-aminopropyltrimethoxysilane, 3-(2-Aminoethylamino)propyldimethoxymethylsilane, Bis[3-(trimethoxysilyl)propyl]amine, Methyltrimethoxysilane, Methyltriethoxysilane, Dimethyldimethoxysilane, Dimethyldiethoxysilane, Trimethylmethoxysilane, Trimethylethoxysilane, (polydimethylsiloxane), and mixtures of two or more thereof. Particularly preferable is the component TEOS. TEOS is a common basic chemical which is not expensive and readily available.In one embodiment, the component is pre-condensed (i.e., still liquid). The term "*pre-condensed*" means that only oligomers have already been formed, but that the material is not yet completely polymerized.

In one embodiment, the impregnating solution contains solvents in a portion which is in a range of 0 to 98% by weight, or of 0.1 to 50% by weight, or of 0.2 to 20% by weight, or of 0.5 to 10% by weight, or of 1 to 5% by weight.In one embodiment, the solvent is selected from the group consisting of water, alcohol (e.g., ethanol, methanol, isopropanol, etc.) and mixtures of two or more thereof. In one embodiment, the solvent is ethanol.

In one embodiment, the impregnating solution contains water in a portion which is in a range of 0 to 20% by weight, or of 0.5 to 10% by weight, or of 1 to 5% by weight.

In one embodiment, the impregnating solution contains an acidic or basic catalyst, in one embodiment acid, for example HCl (37 wt%) in a portion of 0.001 to 0.2% by weight, or of 0.005 to 0.1% by weight, or of 0.01 to 0.05% by weight. As basic catalyst NaOH may be used.

In one embodiment, the impregnating solution according to the present invention consists of at least 95% by weight, or at least 98% by weight, or at least 99% by weight, or at least 99.9% by weight, or at least 99.99% by weight of alcohol (e.g. ethanol, methanol, isopropanol, etc.), water, silicon component and HCl. It is a special advantage of the method according to the present invention that no further components are required in the impregnating solution. In one embodiment, the impregnating solution even consists of at least 95% by weight, or at least 98% by weight, or at least 99% by weight, or at least 99.9% by weight, or at least 99.99% by weight of ethanol, silicon component and HCl.

In one embodiment, the impregnated fibrous non-woven fabric comprises a silicon component (e.g., silica or aminosilica or organosilica) in a portion of 0.1 to 30% by weight, or of 0.5 to 10% by weight, or of 1 to 5% by weight, or of 1.5 to 7.5% by weight. he impregnated fibrous non-woven fabric consists of the fibre component (in particularly paper) and the impregnating component (SiO_2).

Preferably, the impregnated fibrous non-woven fabric comprises the fibre component in a portion of 90 to 99.9% by weight, or of 92.5 to 99.8% by weight, or of 95% by weight to 99.5% by weight.

The fibrous non-woven fabric of the invention may be any fleece or non-woven cloth, or nanostructured network made of natural material (i.e., of animal, bacterial or plant origin), such as cotton, wool, wood (e.g., wood pulp board), cellulose (e.g., paper), bacterial nanocellulose (BNC, especially for cosmetic and medical purposes), or the like.

In yet a further aspect, the fibrous non-woven fabric is made of paper and/or cotton. In one embodiment, the form of an oil or fuel binding fleece comes in sizes of about 410 x 510 mm, however, it may also be formed as a part of an oil barrier or as a filter.

Preferably, the impregnated fibrous non-woven fabric of the invention consists of the fibre component (e.g., paper) and the impregnating component (e.g., SiO_2). The fibrous non-woven fabric may contain further components, or however in a portion of at most up to 50% by weight, such as for example 0 to 30% by weight, or up to 25% by weight, or up to 10% by weight, or up to 5% by weight, or up to 2% by weight, or up to 1% by weight, or less than 0.5% by weight. These further components may in particularly be inorganic and/or organic fillers.

In one embodiment, the portion of the fibre component and the impregnating component in the fibrous non-woven fabric of the present invention is at least 50% by weight, or at least 75% by weight, or at least 90% by weight, or at least 95% by weight, or at least 98% by weight, or at least 99% by weight. In one embodiment, the impregnated fibrous non-woven fabric of the invention consists of the fibre component and the impregnating component.

In a further embodiment the specific surface area determined by BET is about ± 10%, or about ± 5%, or about ± 2% as compared to the non-impregnated fibrous non-woven fabric. The “B.E.T.” or “BET” (Brunauer–Emmett–Teller) theory aims to explain the physical adsorption of gas molecules on a solid surface and serves as the basis for an important analysis technique for the measurement of the specific surface area of materials. It is defined and measured according to DIN ISO 9277. The inventive improved fibrous non-woven fabric shows a similar surface and pore distribution and size as non-impregnated fibrous non-woven fabric, thereby having the beneficial effect that the oil retention remains the same, whereas the water retention is significantly reduced.

In yet a further aspect, the fibrous non-woven fabric is used as an oil binder for absorption and optionally recovery of a nonpolar and/or oily liquids on a surface or in a polar liquid (e.g., water). For the recovery normally an alcohol (such as ethanol or methanol) may be used to solubilize and wash-out the nonpolar liquid from the fibrous non-woven fabric which then can be re-used for further binding of new nonpolar components. In another embodiment instead of the alcohol a surfactant (e.g., in a mixture of water and surfactant in form of a washing solution) may be used. Since the recovery of the fibrous non-woven fabric is well over 90%, it can be re-used several times, or at least 5 times, or at least 10 times, or at least 20 times; in one embodiment even up to 80 times, or even up to 90 times, or even up to 100 times.

In yet a further aspect, the fibrous non-woven fabric is used as an oil binder on a water surface, for example after an oil accident in the sea, in a lake, in a river, in the environment, on a street, after a car accident, in a garage.

In another aspect the invention pertains also to a silica impregnated fibrous non-woven fabric for the uses described herein impregnated with silica, for example by using a mixture comprising the relative amounts of 1 silicon component (e.g. tetraethyl orthosilicate (TEOS)) : 10-30 alcohol (e.g. EtOH or MeOH) : 2-10 H_2O : 0.01 catalyst (i.e. acidic or basic catalyst, e.g. HCl or NaOH) with an increased free surface energy as compared to non-impregnated fibrous non-woven fabrics, for example in case of cellulose of more than 64 $mN * m^{-1}$. This is insofar surprising, since cellulose surfaces do have a rather reduced surface energy of about 60 $mN * m^{-1}$. However, the impregnation solution in combination with the drying steps explained hereinunder result in an increased free surface energy.

In another aspect the invention pertains also to a method for producing the silica impregnated fibrous non-woven fabric of the invention for the use as described hereinunder, comprising the steps:

a. Mixing a sol comprising 1 tetraethyl orthosilicate (TEOS) : 20 EtOH : 5 H2O : 0.01 HCl

b. Stirring the sol for 24 h at room temperature (20 °C)

   i. coating a fibrous non-woven fabric from natural fibres by immersion of the fibrous non-woven fabric into the impregnating solution using a size press for bilateral coating, with a speed of 5 m/min at a roll pressure of 0.5 - 1.0 bar; or

   ii. using some process to impregnate fibrous non-woven fabric, for example

      a. either a spray apparatus for coating at an air pressure of 1.0 – 2.0 bar; or

      b. dipping the impregnate fibrous non-woven fabric for up to 5 minutes in the impregnation solution; or

      c. using a size press;

c. Placing the freshly impregnated fibrous non-woven fabric in a pre-heated oven at 160 °C for 15 min at atmospheric pressure;

d. Cooling the silica-impregnated fibrous non-woven fabric down to ambient temperature (20 °C);

e. Thereby obtaining the silica impregnated fibrous non-woven fabric.

In one embodiment, the removal of the fibrous non-woven fabric from the impregnating solution is conducted at a time point 0.1 to 10 seconds, or 0.1 to 30 seconds after the completion of the immersion of the fibrous non-woven fabric into the impregnating solution.

In one embodiment household articles, such as kitchen sponges, kitchen towels, kitchen tissues, and/or cosmetic pads or swabs may be impregnated only on one preferred side of the fibrous non-woven fabric in order to create an oil-binding ability on just one side and/or area of the article. In such a case coating by spraying the impregnation solution is preferred.

In another aspect the invention pertains also to a method for producing the silica impregnated fibrous non-woven fabric of the invention for the use as described hereinunder, comprising the steps:

   a. mixing a sol comprising 1 tetraethyl orthosilicate (TEOS) : 20 EtOH : 5 H2O : 0.01 HCl and fibres of a fibrous non-woven fabric in a bath so that the impregnation mixture is distributed evenly on the fibres for up to 30 minutes;

b. extracting the fibrous non-woven fabric from the bath;
c. placing the freshly impregnated fibrous non-woven fabric in a pre-heated oven at 160 °C for 15 min at atmospheric pressure;
d. cooling the silica-impregnated fibrous non-woven fabric down to ambient temperature (20 °C);
e. thereby obtaining the silica impregnated fibrous non-woven fabric.

In another aspect the invention pertains also to a method for recycling a nonpolar liquid from a polar liquid as well as the silica-impregnated fibrous non-woven fabric, comprising the steps of:

a. obtaining a silica-impregnated fibrous non-woven fabric as described hereinunder;
b. placing it in a mixture of nonpolar and polar liquids, or placing it at the surface of a nonpolar liquid so that the nonpolar liquid is absorbed by the silica-impregnated fibrous non-woven fabric;
c. placing the silica-impregnated fibrous non-woven fabric with the bound nonpolar liquid in a cleansing bath comprising an alcohol (e.g., ethanol and/or methanol), surfactant, water, and/or (organic) solvent; and/or a mixture thereof;
d. waiting for between 1 and 24 hours until the cleansing bath (comprising an alcohol (e.g. ethanol and/or methanol), surfactant, water, and/or (organic) solvent; and/or a mixture thereof), has displaced the nonpolar liquid from the silica-impregnated fibrous non-woven fabric;
    a. extracting the nonpolar liquid from the cleansing bath solution by conventional methods, such as distillation, precipitation, etc.;
    b. thereby obtaining the recycled nonpolar liquid for the next application;

and

    a. drying the silica-impregnated fibrous non-woven fabric in a pre-heated oven at 160 °C for 15 min at atmospheric pressure;
    b. cooling the silica-impregnated fibrous non-woven fabric down to ambient temperature (20 °C);

c. thereby obtaining the recycled silica impregnated fibrous non-woven fabric for the next application.

Definitions

The term “air dry” is a term well-known in the field for describing additives added to a porous material such as a fibrous non-woven fabric. When describing the portion of an additive in “air dry” porous material such as fibrous non-woven fabric, it refers to the state of the material with less than 10 wt.% of residual moisture (e.g., water). This state can be achieved by drying the fibrous non-woven fabric by drying at SATP-conditions („Standard Ambient Temperature, Pressure “), i.e., T = 298,15 K (25 °C); pressure (p) = 101.300 Pa = 1013 hPa = 101,3 kPa = 1,013 bar. “Oven dry” is defined as the state of porous material such as a fibrous non-woven fabric without any residual moisture, i.e., 0 wt.% residual moisture. This may be achieved for example by drying the material in a preheated oven at 160 °C for 15 minutes at pressure (p) = 101.300 Pa but may also be achieved by other drying schemes which dries the material until no shift in weight can be measured.

Thus, “air dry” is the general term for a residual moisture in the porous material, such as a fibrous non-woven fabric, of less than 10%, e.g., between 0% and 10%, whereas “oven dry” is the specific case with a residual moisture of 0% in the porous material, such as a fibrous non-woven fabric.

The term “oily liquid” refers herein to a type of liquid that exhibits the properties of being greasy, viscous, and having a smooth or slippery texture. It typically has a high viscosity, meaning it flows slowly and is resistant to pouring. Oily liquids are composed of molecules that do not readily mix with water, known as hydrophobic molecules. These hydrophobic molecules tend to be nonpolar or have low polarity, which gives rise to their oily nature. Oily liquids can be derived from various sources, both natural and synthetic. Examples of natural oily liquids include various types of plant and vegetable oils (such as olive oil, coconut oil, and sunflower oil), animal fats (such as butter or lard), and petroleum-based oils (such as mineral oil). Synthetic or man-made oily liquids can include lubricating oils, hydraulic fluids, and various industrial oils.

Short description of the figures

Figure 1: Schematic illustration of the bilateral coating process using a size press.

Figure 2: Photograph of water contact angle measurements of 2 µL water droplets on silica impregnated sponge cloth (left) and cellulose swab (right) showing hydrophobic surface

properties on both sides of the samples.

Figure 3: Thermogravimetric analysis of silica impregnated sponge cloth (solid line) and silica impregnated cellulose swabs (dotted line).

Figure 4: SEM micrographs of sponge cloth and cellulose swab (top row) and silica impregnated sponge cloth and silica impregnated cellulose swab (bottom row) at a magnification of 150 and 2000 respectively.

Figure 5: a) Absorption capacities of sponge cloths, cellulose swabs, and cotton non-woven before (white, dark grey, and white filled with diagonal lines bars respectively) and after silica coating (light grey, black, and white filled with horizontal lines bars respectively) for the solvents water, canola oil, toluene, dcm, n-hexane. b) Recovery of silica impregnated sponge cloths and cellulose swabs after solvent absorption and subsequent immersing in ethanol to remove the solvents.

Figure 6: Sponge cloths consisting of viscose and cotton were coated with silica as described hereinunder. The sponge cloths were coated using a size press and subsequently dried in a preheated oven at 160 °C for 15 minutes. The adsorption capacities of the coated sponge cloths were further determined gravimetrically after immersing 3x3 cm pieces in water for 1 hour. Sponge cloths with a water absorption capacity of less than 3 g/g were achieved at a silica-content of about 7 wt-% or more.

Experimental Section

Reagents

All chemicals and solvents were purchased from Merck Millipore and Thermo Fisher Scientific and used as received unless otherwise stated. Cellulose swabs were purchased from B. Braun SE and sponge cloths were purchased from Carl Roth.

Silica Coating

For silica coating of fabrics from natural fibres, a coating sol with following molar ratios was prepared:

1 Tetraethyl orthosilicate (TEOS) : 20 EtOH : 5 H_2O : 0.01 HCl

The components of the sol were mixed, stirred for 24 h at room temperature, and used for silica coating of fabrics from natural fibres using a size press for bilateral coating or spray apparatus for unilateral coating. Using the size press, the samples were impregnated with a speed of 5 m/min at a roll pressure of 0.5 - 1.0 bar. Using the spraying apparatus, an air pressure of 1.0 – 2.0 bar was used. Freshly impregnated substrates were placed in a pre-heated oven at 160 °C for 15 min at atmospheric pressure before cooling down to ambient temperature.

Contact angle determination

Contact angle measurements were carried out using a OCA35 model from DataPhysics® Instruments GmbH with the Program SCA-Software 4.5.2 Build 1052. All samples were measured at three positions and the average value was calculated with standard deviation. A water drop volume of 2 µL was used for static contact angle measurements with a dosing rate of 0.5 µL/s.

Thermogravimetric Analysis (TGA)

TGA was performed using a TGA 1 Mettler-Toledo. The samples were heated from 25 °C to 600 °C with a heating rate of 10 K/min under constant air flow of 30 mL/min.

Scanning Electron Microscopy (SEM)

SEM micrographs were recorded using a Zeiss EVO 10 SEM operated at an acceleration voltage of 10 kV. Prior to measurements, the samples were sputter impregnated with a platinum/palladium layer of 10 nm.

Solvent absorption capacity

Sponge cloths were cut into 3 x 3 cm pieces. Cellulose swabs with a dimension for 4 x 5 cm were used as received. For determination of the solvent absorption capacity, the samples are firstly weighed in the dry state. Then, the sample pieces were immersed in the solvents water, canola oil, toluene, dichloromethane (dcm), and n-hexane, respectively, for 2 min. Subsequently, the sample is removed from the solvent and the solvent was allowed to drip off before weighing the samples in the wet state. All samples were measured three times and the average value was calculated with standard deviation. The sorption capacity is calculated according to

$$Ca(g/g) = (m_t - m_0)/m_0$$

with m_0 as the mass of the sample before solvent absorption, and m_t the mass of the sample after solvent absorption.

Determination of recovery. After weighing the samples in the wet state, the samples are placed in a beaker containing ethanol for 10 min to release the solvent and to recover the samples. Then, the samples were dried at ambient environment, before weighing again. The recovery is calculated according to

$R(\%) = (Ca-m_r-m_0) * 100/Ca$

with m_r as the mass of the sample after solvent extraction and drying.

Determination of wetting behavior

Water contact angle measurements were performed after silica coating of sponge cloths and cellulose swabs. Photographs of water droplets on both sides of the silica impregnated samples are depicted in Figure 1. All samples showed hydrophilic surface properties before silica coating; hence, no water contact angles could be determined due to instant infiltration of the water droplets in the samples. After silica coating, hydrophobic surfaces with contact angles above 90° are observed on both sides of sponge cloths and cellulose swabs.

Determination of silica content

The silica content of silica impregnated sponge cloths and cellulose swabs is determined via TGA. Thereby, the silica content can be determined from the plateau of the TGA curves at 550 °C, since silica is stable up to 1700 °C, whereas natural organic fibres are totally combusted. Comparing the values between 550 °C and 600 °C before and after silica coating allows to take the natural ash content of the substrates into account. Furthermore, the weight loss occurring till 150 °C can be assigned to physically adsorbed water and is considered in the calculation to determine the silica content with respect to oven-dry samples. TGA curves of silica sponge cloths and silica impregnated cellulose swabs, as well as the calculated silica contents are depicted in Figure 2.

Morphological analysis

Sponge cloth and cellulose swabs were investigated with respect to their morphology before and after silica coating using SEM (Figure 4). Silica impregnated sponge cloths as well as silica impregnated cellulose swabs do not show morphological differences on the micrometre scale compared to non-impregnated sponge cloths and cellulose swabs. This can be explained due to the low silica amount as deduced from TGA.

Determination of solvent sorption capacity

The sorption capacities of sponge cloths and cellulose swabs were determined before and after silica coating for the solvents water, canola oil, toluene, dcm, and n-hexane (Figure 5a). According to the determined absorption capacities, water absorption is drastically reduced due to silica coating for both sponge cloths and cellulose swabs. In contrast to this, the absorption capacities for the solvents canola oil, toluene, dcm, and n-hexane are only slightly reduced due to silica coating. Hence, silica impregnated sponge cloths and cellulose swabs can be used as selective oil absorber for oil-water-separation, e.g., selective oil absorption on water or wet surfaces. It is noteworthy that no directed transport of fluid is demonstrated and no application of silica sponge cloths or cellulose swabs as asymmetric membranes in oil-water-separation is encompassed by this invention.

Furthermore, the absorbed solvents are eliminated from silica impregnated sponge cloths and cellulose swabs by simply immersing in ethanol, thus replacing the absorbed solvents with ethanol. Thereby, removed solvents such as canola oil can be regained as resource and the absorbing sponge cloths and cellulose swabs can be recovered for further oil/solvent absorption after drying at ambient conditions (Figure 5b).

Roughness and Surface Energy

Our investigations of the oil absorbent fleeces in terms of roughness and surface energy resulted in the following:

- roughness according to ISO 25178 (device “Sensofar PLu Neox®”):

20LF80KF_virgin: SA = 5,088 +- 0,41 µm; SZ = 69,797 +- 13,38 µm

20LF80KF_SiO_2: SA = 5,179 +-1,098 µm; SZ = 61,78 +- 7,02 µm

Swab (cotton)_virgin: SA = 28,778 µm; SZ = 573,87 µm

Swab (cotton)_SiO_2: SA = 23,671 µm; SZ = 318,7 µm

The roughness does not seem to change due to a silica coating; deviations are within the error range of the method used.

Surface energy determined with a binary system of water and ethylene glycol according to Zhang et al., Langmuir 2019, 35, 12317-

water-ethylene glycol:

20LF80KF-SiO_2: $\gamma s,d$= 154.09, $\gamma s,p$=24.05 γs=**178.14 mN/m**

water-ethylene glycol:

20LF80KF-virgin: $\gamma s,d$=12.10, $\gamma s,p$=52.61 γs= **64.7 mN/m**

Surprisingly, the surface energy increases with silica coating and approaches the surface energy of clean glass (300-500 mN/m). This contrasts with earlier report where silica coatings decreased the surface energy.

Accordingly, the hydrophobic treatment cannot be explained by the classic route, namely the increase in roughness and/or the reduction in surface energy.

Without being bound to theory, the effect of the silica coating in terms of hydrophobicity may be explained by the fact that the fibres are "vitrified" and thus no longer absorb water or swelling with water is prevented (cf. water absorption capacity before and after silica coating), in combination with the intrinsic roughness of natural fibres.

Adsorption capacity of silica coated sponge cloths in dependence of the silica content

Sponge cloths consisting of viscose and cotton were coated with silica as described hereinunder. The sponge cloths were coated using a size press and subsequently dried in a preheated oven at 160 °C for 15 minutes.

The adsorption capacities of the coated sponge cloths were further determined gravimetrically after immersing 3x3 cm pieces in water for 1 hour. Results are depicted in figure 6.

The water absorption capacity below a silica content of about 7 wt% is above 3 g/g (water/material) and not suited for the purposes of the claimed oil-absorbing non-woven fabrics since it is not hydrophobic enough. A silica content of more than 30 wt% is not favoured due to economic considerations. In this respect, it needs to be understood that the oil retention capacity is not so much due to an increase in lipophilicity, but due to a reduction in hydrophobicity of the non-woven fabric, which needs to be below the threshold of a water capacity of 3 g/g or less.

Claims

1. Use of a silica impregnated fibrous non-woven fabric with oven-dry silica content of 7 - 30 wt.-% and having a surface energy on both sides, which is increased as compared to the non-impregnated fibrous non-woven fabric for binding nonpolar and/or oily liquids.

2. The use according to claim 1, wherein the silica impregnated fibrous non-woven fabric of claim 1, has at least one additional feature selected from:

    a. an oven-dry silica content of at least 10.5 wt.-%;

    b. an oil absorption capacity of at least 3 g/g;

    c. a water absorption capacity of less than 3 g/g;

    d. a roughness as defined by ISO 25178 which remains the same as compared to the non-impregnated fibrous non-woven fabric;

    e. a retention of nonpolar and/or oily liquids for at least 1 hour within the silica impregnated fibrous non-woven fabric;

    f. the water absorption capacity is reduced at least 1.5-times as compared to the non-impregnated fibrous non-woven fabric;

    g. a swelling capacity of the fibres in the silica impregnated fibrous non-woven fabric of 20 wt.-%, or less;

    h. a contact angle on the surface of the silica impregnated fibrous non-woven fabric of above 90° on both sides; and/or

    i. a porosity which is the same as compared to the non-impregnated fibrous non-woven fabric.

3. The use according to any of the previous claims, wherein the recovery of the silica impregnated fibrous non-woven fabric after binding the nonpolar and/or oily liquid and subsequent immersing in ethanol to remove the nonpolar and/or oily liquid is at least 90%.

4. The use according to any of the previous claims, wherein the swelling capacity of the fibres in the silica impregnated fibrous non-woven fabric is 10 wt.-%, or less.

5. The use according to any of the previous claims, wherein the fibrous non-woven fabric is impregnated with 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)) : 1-30 alcohol (e.g., EtOH) : 1-10 H_2O : 0.001-0.02 acidic or basic catalyst (e.g., HCl).

6. The use according to any of the previous claims, wherein the fibrous non-woven fabric is made of paper, viscose (regenerated cellulose), a biodegradable polymer and/or cotton.

7. The use according to any of the previous claims as an oil binder for absorption and optionally recovery of a nonpolar and/or oily liquids on a surface or in a polar liquid (e.g., water).

8. The use according to any of the claims 1 to 8 as a nonpolar and/or oil liquid binder in an environment selected from the sea, a lake, a river, a street, a garage and/or in a household environment.

9. A silica impregnated fibrous non-woven fabric for the use in any of the claims 1 to 8, characterized by a surface energy of the silica impregnated fibrous non-woven fabric, which is increased as compared to the non-impregnated fibrous non-woven fabric; and having a surface energy which is increased as compared to the non-impregnated fibrous non-woven fabric.

10. A silica impregnated fibrous non-woven fabric of claim 9, having at least one additional feature selected from:

    a. an oven-dry silica content of at least 10.5 wt.-%;

    b. an oil absorption capacity of at least 3 g/g;

    c. a water absorption capacity of less than 3 g/g;

    d. an roughness as defined by ISO 25178 which remains the same as compared to the non-impregnated fibrous non-woven fabric;

    e. a retention of nonpolar and/or oily liquids for at least 1 hour within the silica impregnated fibrous non-woven fabric;

    f. the water absorption capacity is reduced at least 1.5-times as compared to the non-impregnated fibrous non-woven fabric;

    g. a swelling capacity of the fibres in the silica impregnated fibrous non-woven fabric of 20 wt.-%, or less;

h. a contact angle on the surface of the silica impregnated fibrous non-woven fabric of above 90° on at least one side; and/or

i. a porosity which is the same as compared to the non-impregnated fibrous non-woven fabric.

11. A method for producing the silica impregnated fibrous non-woven fabric of claims 9 or 10 for the use in any of the claims 1 to 8, comprising the steps:

a. Mixing a sol comprising 1 silicon component (e.g., tetraethyl orthosilicate (TEOS)) : 10-30 alcohol (e.g., EtOH) : 2-10 H_2O : 0.005-0.02 acidic or basic catalyst (e.g., HCl);

b. Stirring the sol for 24 h at room temperature (20°C)

   i. coating a fibrous non-woven fabric from natural fibres using a size press for bilateral coating, with a speed of 5 m/min at a roll pressure of 0.5 - 1.0 bar; or

   ii. using a spray apparatus for unilateral coating at an air pressure of 1.0 – 2.0 bar

c. Placing the freshly impregnated fibrous non-woven fabric in a pre-heated oven at 160 °C for 15 min at atmospheric pressure;

d. Cooling the silica-impregnated fibrous non-woven fabric down to ambient temperature (20 °C);

e. Thereby obtaining the silica impregnated fibrous non-woven fabric.

Figures

Figure 1

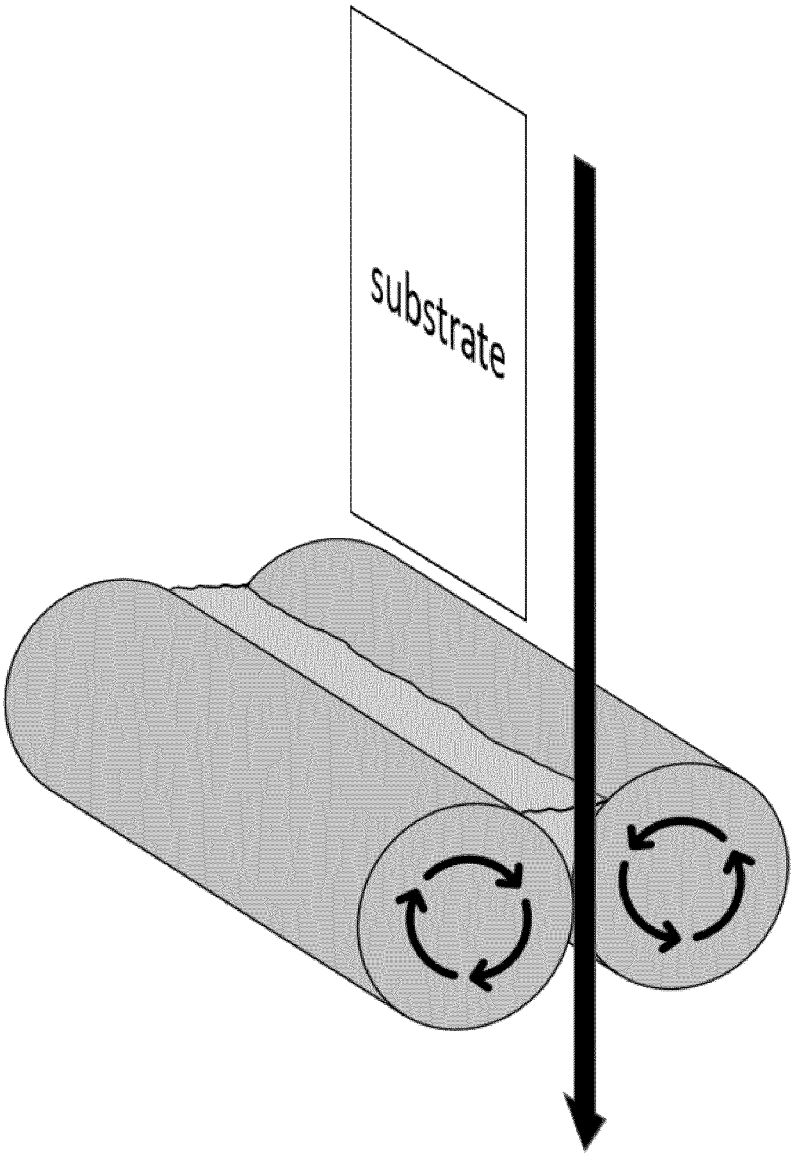


Figure 2

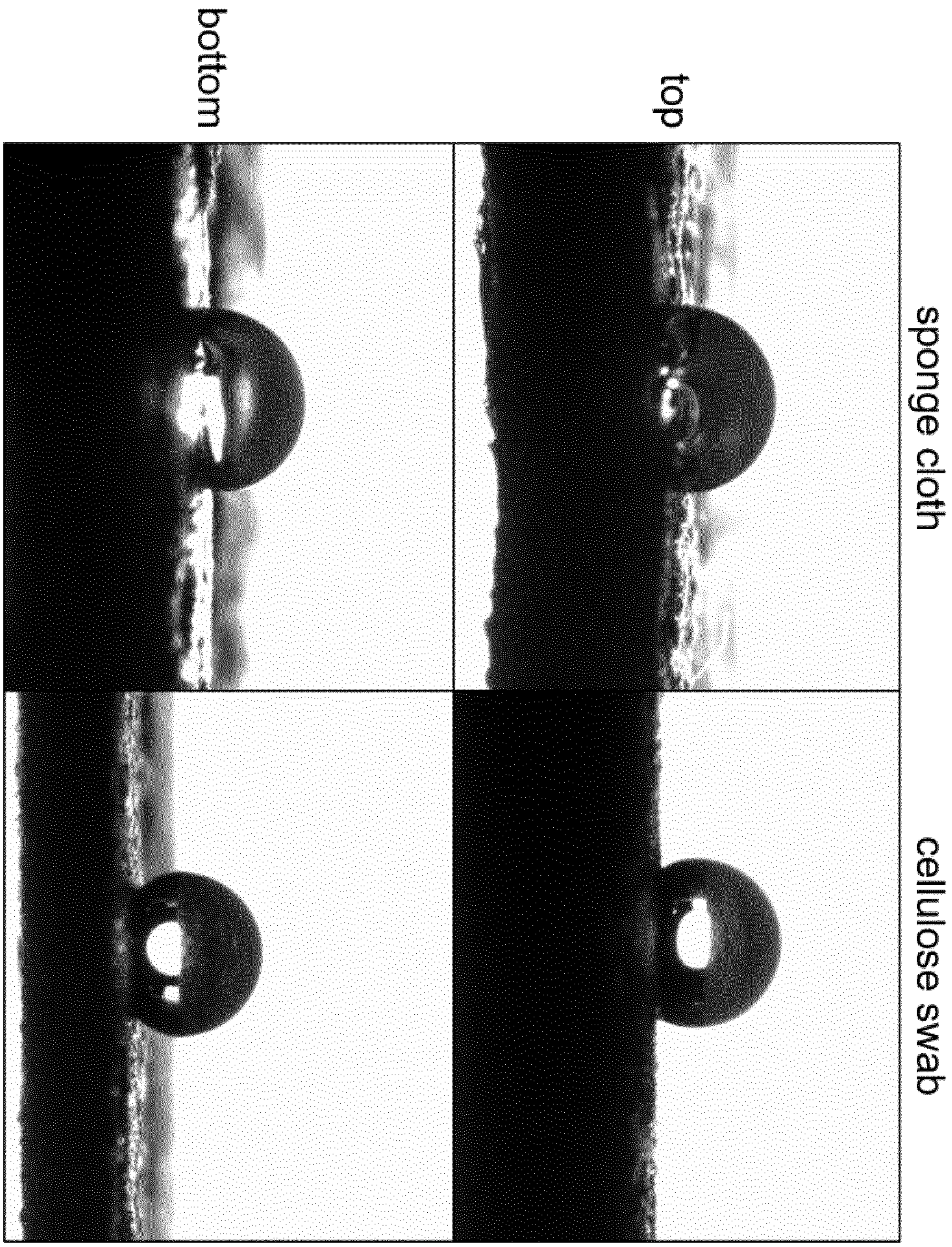
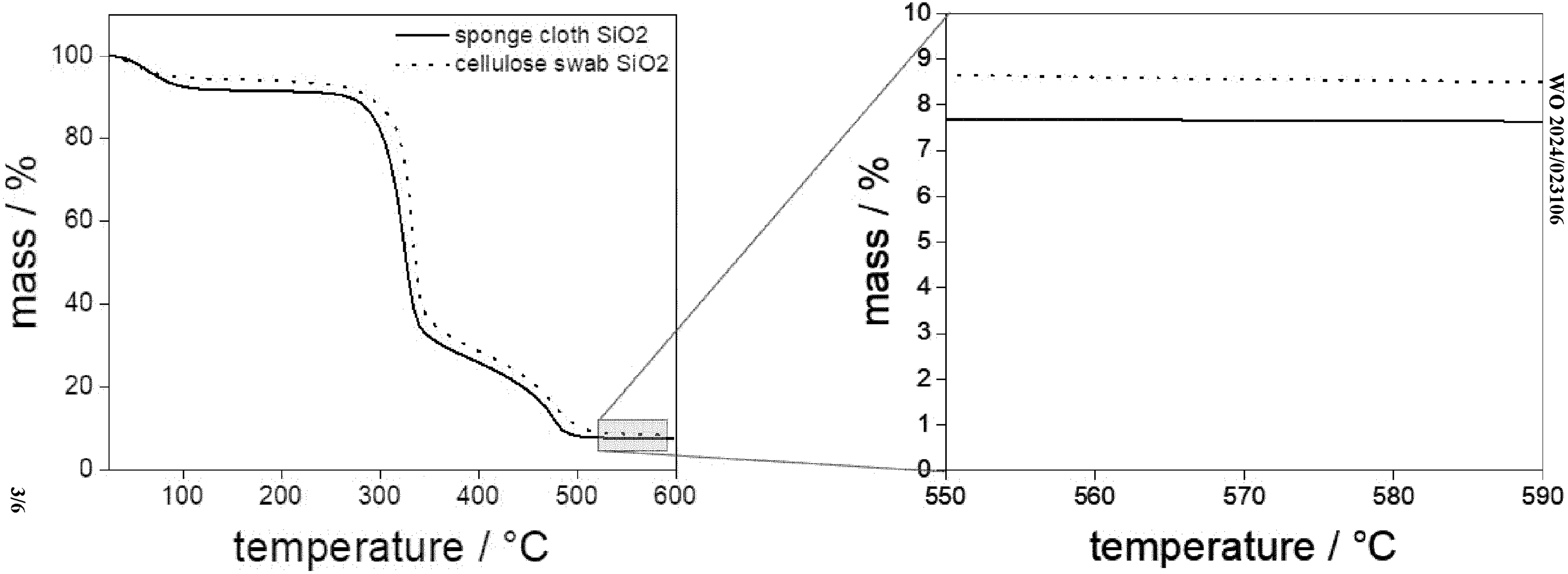
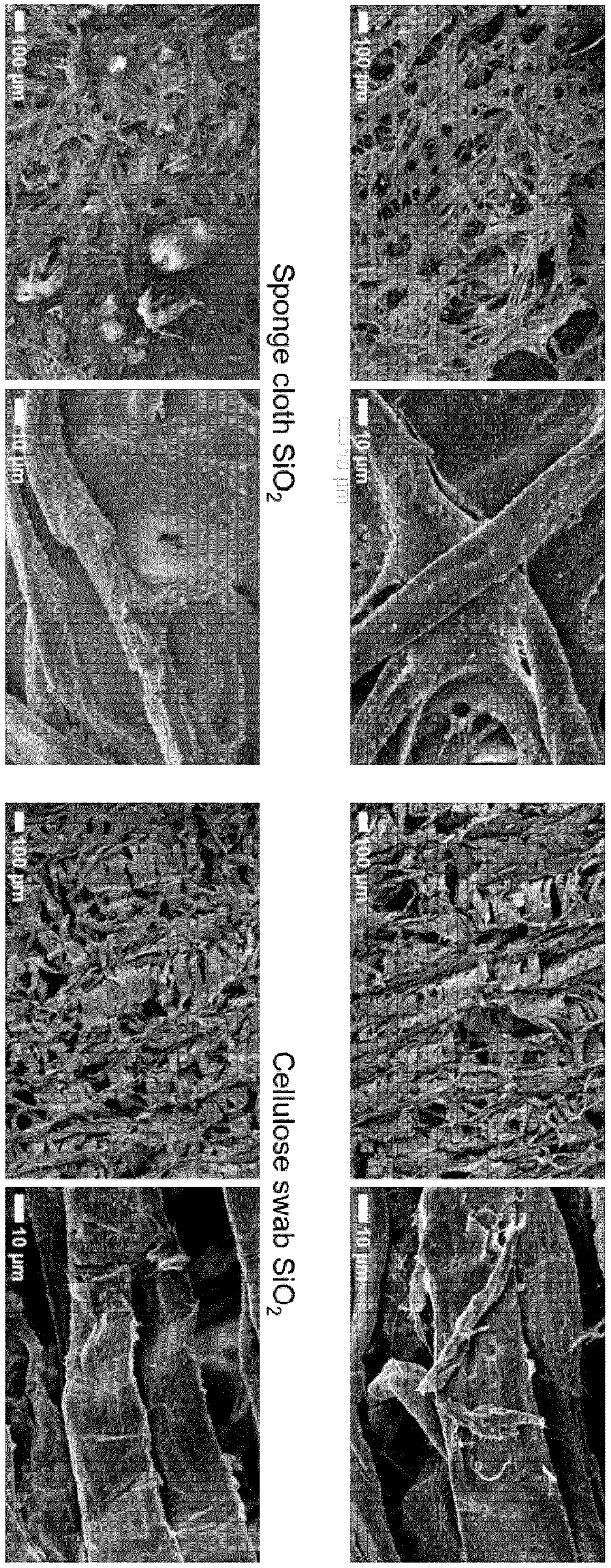


Figure 3



Sample	Silica content air-dry / %	Silica content oven-dry / %
Sponge cloth SiO2	7.1	7.7
Cellulose swab SiO2	8.4	8.9

Figure 4



Sponge cloth

Cellulose swab

Sponge cloth SiO_2

Cellulose swab SiO_2

Figure 5

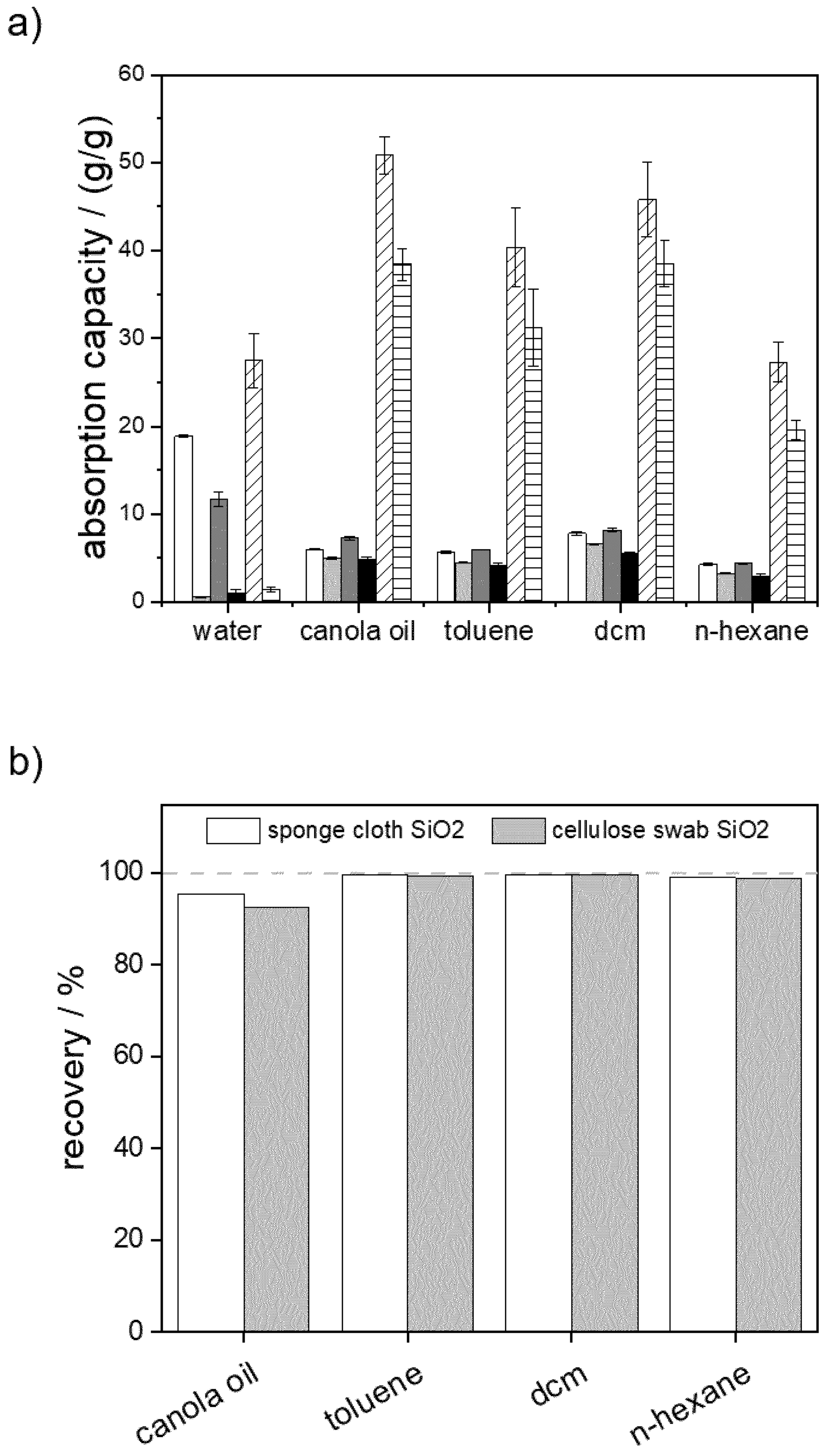
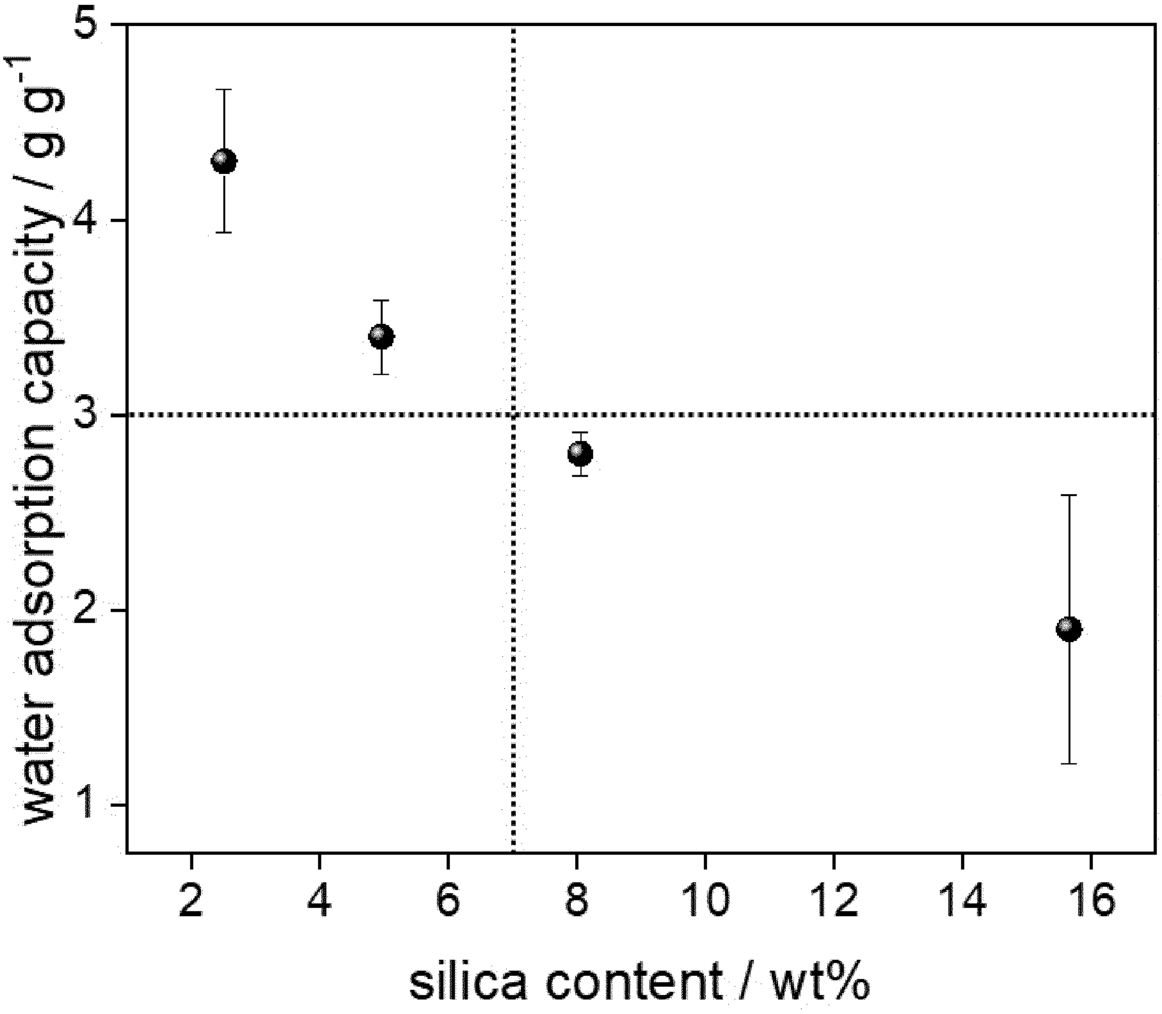

a)
absorption capacity / (g/g)
0
10
20
30
40
50
60
water
canola oil
toluene
dcm
n-hexane
b)
sponge cloth SiO2
cellulose swab SiO2
recovery / %
0
20
40
60
80
100
canola oil
toluene
dcm
n-hexane

Figure 6


water adsorption capacity / g g^{-1}
1
2
3
4
5
silica content / wt%
2
4
6
8
10
12
14
16

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/070615

A. CLASSIFICATION OF SUBJECT MATTER

INV. D06M11/79 D06M13/507 B01J20/10 B01J20/32 C09K3/32
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

D06M B01J C09K F16D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 3 009 558 A2 (CENTI CT DE NANOTECNOLOGIA E MATERIAIS TECNICOS FUNCIONAIS E INTELIGEN) 20 April 2016 (2016-04-20) paragraphs [0001], [0006], [0009], [0016], [0021] -----	1-11
X	US 2022/034041 A1 (NAU MAXIMILIAN [DE] ET AL) 3 February 2022 (2022-02-03) paragraphs [0017], [0069], [0076] -----	1-3,5-11
X	CN 106 480 711 A (UNIV TIANJIN TECHNOLOGY) 8 March 2017 (2017-03-08)	1-10
A	paragraphs [0071], [0072] -----	11

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search 11 October 2023	Date of mailing of the international search report 19/10/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Blas, Valérie

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/070615

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 3009558 A2	20-04-2016	NONE	
US 2022034041 A1	03-02-2022	CN 112840073 A	25-05-2021
		DE 102018124255 A1	02-04-2020
		EP 3655575 A1	27-05-2020
		US 2022034041 A1	03-02-2022
		WO 2020069943 A1	09-04-2020
CN 106480711 A	08-03-2017	NONE	