SPIRAL HEAT EXCHANGER WITH ANTI-FOULING PROPERTIES

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ABSTRACT

The invention relates to a spiral heat exchanger comprising a spiral body formed by at least one spiral sheet wound to form the spiral body forming at least a first spiral-shaped flow channel for a first medium and a second spiral-shaped flow channel for a second medium, wherein the spiral body is enclosed by a substantially cylindrical shell being provided with connecting elements communicating with the first flow channel and the second flow channel. At least a part of the spiral heat exchanger is provided with a coating comprising silicon oxide, SiO₂.
SPIRAL HEAT EXCHANGER WITH ANTI-FOULING PROPERTIES

TECHNICAL FIELD

[0001] The present invention refers generally to spiral heat exchangers allowing a heat transfer between two fluids at different temperature for various purposes. Specifically, the invention relates to a spiral heat exchanger which has been coated for improving anti-fouling properties and has in some embodiments been given predetermined, structural properties for ensuring that the coating remains on the product when the product is used.

BACKGROUND ART

[0002] Spiral heat exchangers are generally formed by winding two metal sheets around one another so as to delimit two separate passages. The two flat sheets are welded together at a respective end, wherein the welded joint will be comprised in a center portion of the sheets. The two sheets are wound around one another to form the spiral element of the sheets so as to delimit two separate passages or flow channels. Distance members, having a height corresponding to the width of the flow channels, may be arranged on one or both of the sheets.

[0003] Two inlet/outlet channels are formed in the center of the spiral element. The two channels are separated from each other by the center portion of the sheets. A shell is welded onto the outer periphery of the spiral element. The side ends of the spiral element are processed, wherein the spiral flow channels may be laterally closed at the two side ends in various ways. Typically, a cover is attached to each of the ends. The covers may include connection pipes extending into the center and communicating with a respective one of the two flow channels. At the radial outer ends of the spiral flow channels a respective header is welded to the shell or the spiral element forming an outlet/inlet member to the respective flow channel.

[0004] Such a spiral heat exchanger is described for example in U.S. Pat. No. 5,505,255. In this case, the spiral heat exchanger is formed by winding two metal sheets each having protrusions on one of their faces.

[0005] In many industrial processes fouling of heat transfer equipment is of concern. In order to keep a satisfying performance of the equipment regular service and cleaning is necessary to remove build up of deposits on the heat transfer surfaces. The deposits arise e.g. from the fluids in the equipment, microbial growth and/or dirt.

[0006] Spiral heat exchangers may over time get fouled due to a slow deposition of material on the surfaces of the sheets. Such so called crystallized fouling leads to a decreased heat transfer and increased pressure drop, and results in an overall reduced performance of the spiral heat exchanger. Depending e.g. on the fluids used the spiral heat exchanger may be seriously fouled and difficult to clean, thus requiring strong detergents and/or powerful mechanical cleaning over a substantial time period in order to restore the performance of the heat exchanger. The cleaning of spiral heat exchangers may both be time consuming and costly. Also, the process to which the spiral heat exchanger is connected, may have to be shut down during said cleaning.

[0007] The sheets of spiral heat exchangers are made of metal. The base material, i.e. metals used, may have a high surface free energy that results in most liquids easily wetting the surface of the sheets.

[0008] Also, when spiral heat exchanger sheets are produced the forming operation thereof may increase the surface roughness which often is associated with faster build up of fouling deposits.

[0009] Other types of heat exchangers have been described wherein surfaces of the heat exchangers have been coated with a coating possessing anti-fouling properties.

[0010] WO2009034359 discloses provision of a coating to reduce bio-fouling of surfaces in aquatic environments wherein the coating is applied by use of Plasma Assisted Chemical Vapour Deposition (PACVD).

[0011] US20090123730 discloses a surface of a heat exchanger which is to be soldered by means of a flux, and said surface is in addition to the flux also provided with at least one more layer containing an additive. The additive is reacted in order to modify the surface during soldering.

[0012] WO2008119751 discloses production of a hydrophobic coating for condensers wherein the coating comprises sol-gel materials based on e.g. silicon oxide sol.

[0013] JP2000345355 relates to improving corrosion resistance and discloses a film consisting of 55-99 wt% SiO₂ and 45-1 wt% ZrO₂ which film is formed using sol-gel processing.


[0015] It would be desirable to find new ways to ensure less fouling of heat exchangers, especially spiral heat exchangers and their sheets in order to keep the spiral heat exchangers running for longer time periods. Also, a reduced shut down time for processes where spiral heat exchanger are involved would be desirable.

[0016] A problem encountered with presently known anti-fouling coatings is the poor wear resistance of the coatings in applications with abrasive heat exchanging media, e.g. sand or other particulate material which enters the spiral heat exchanger with the heat exchanging fluids. Furthermore, cracks in the coating may occur due to torque and tension forces acting on the spiral heat exchanger sheets in applications under high pressures.

SUMMARY OF THE INVENTION

[0017] It is an object of the invention to provide an improved spiral heat exchanger, which show a reduced fouling of the sheets. Another object is to obtain embodiments of a spiral heat exchanger which are wear resistant in abrasive environments and have high resistance against formation of cracks.

[0018] This object is achieved by a spiral heat exchanger comprising a spiral body formed by at least one spiral sheet wound to form the spiral body forming at least a first spiral-shaped flow channel for a first medium and a second spiral-shaped flow channel for a second medium. The spiral body is enclosed by a substantially cylindrical shell being provided with connecting elements communicating with the first flow channel and the second flow channel. The spiral heat exchanger is provided with a coating comprising silicon oxide, SiO₂, having an atomic ratio of O/Si=1, a content of carbon 10 atomic % and a coating layer thickness of about...
5-60 μm, which coating was prepared by sol-gel processing and applied to at least a part of the sheets.

[0019] The spiral heat exchanger is advantageous in that fouling of the sheets is reduced significantly. By applying a coating composition comprising sol-gel material with organosilicon compounds to the spiral heat exchanger sheets both the surface free energy and roughness is lowered, leading to reduction of fouling, and less and easy cleaning of spiral heat exchanger sheets. Moreover, the sol-gel coated spiral heat exchanger sheets of the invention exhibit an excellent wear resistance and have a flexibility that reduces the risk of cracks appearing in the coating.

[0020] Generally, not only a part of but one side or both sides of the respective sheets may comprise the coating.

[0021] According to a further aspect of the invention the sheets of the spiral heat exchanger have a thickness of 2-6 mm.

[0022] According to another aspect of the invention the layer thickness of said coating on the spiral heat exchanger sheets is 5-30 μm, preferably 2-20 μm.

[0023] According to yet another aspect of the invention the coating comprising silicon oxide, SiO₂, has an atomic ratio of O/Si=1.5-3, preferably O/Si=2.2-5.

[0024] According to still another aspect of the invention the composition has a content of carbon ≥20-60 atomic %, preferably ≥30-40 atomic %.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Further objects, features and advantages of the invention will appear from the following detailed description of different embodiments of the invention with reference to the accompanying schematic drawings, in which

[0026] FIG. 1 is a perspective view of an open spiral heat exchanger according to the present invention;

[0027] FIG. 2 is a schematic cross sectional view of a spiral heat exchanger according to the present invention, and

[0028] FIG. 3 is a schematic cross section of a sheet for a spiral heat exchanger comprising an anti-fouling coating according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] A commonly known spiral heat exchanger includes at least one spiral sheet extending along a respective spiral-shaped path around a common centre axis and forming at least two spiral-shaped flow channels which flow channels are substantially parallel to each other. Each flow channel includes a radially outer orifice, which enables communication between the respective flow channel and a respective outlet/inlet conduit and which is located at a radially outer part of the respective flow channel with respect to the centre axis, and a radially inner orifice, which enables communication between the respective flow channel and a respective inlet/outlet chamber, so that each flow channel permits a heat exchange fluid to flow in a substantially tangential direction with respect to the centre axis. The centre axis extends through the inlet/outlet chambers at the radially inner orifice.

Distance members (not shown in FIG. 1), having a height corresponding to the width of the flow channels may be attached to the sheets or be formed on the surface of the sheets. The distance members or studs support the spiral body formed by at least one spiral sheets and the inner surface of the shell to resist the pressure of the working fluids of the spiral heat exchanger 1.

[0030] In FIG. 1 is shown a perspective view of a spiral heat exchanger 1 according to the present invention. The spiral heat exchanger 1 includes a spiral body 2, formed in a conventional way by winding two sheets 3 of metal around a retractable mandrel. The sheets 3 are provided with distance members or supports 4 (not shown in FIG. 1) attached to the sheets 3. The distance members or supports 4 serve to form the flow channels 5a, 5b between the sheets 3 and have a length corresponding to the width of the flow channels 5a, 5b. In FIG. 1 the spiral body 2 only has been schematically shown with a number of wounds, but it is obvious that it may include further wounds and that the wounds are formed from the centre of the spiral body 2 all the way out to the peripheral of the spiral body 2. The spiral body 2 is enclosed by a shell 6.

[0031] The shell 6 is formed as a cylinder having open ends, the open ends being provided with a flange. Lids or covers 7a, 7b are provided to close the shell 6 in each end. Connection elements 8a, 8b are attached to the outer surface of the shell 6. The lids or covers 7a, 7b are provided with connection elements 8a, 8b. The connection elements 8a-b and 9a-b are typically welded to the shell 6 and the covers 7a, 7b, and are all provided with a flange for connecting the spiral heat exchanger 1 to a piping arrangement of the system of which the spiral heat exchanger 1 is a part of. Other configurations of the connection elements are also possible.

[0032] The spiral heat exchanger 1 is further provided with gaskets, each gasket being arranged between the open ends of the shell, the spiral body 2 and the lids or cover 7a, 7b. The gaskets serves to seal off the different wounds of the flow channels 5a or 5b from each other to prevent that a medium in the flow channels to bypass wounds of flow channels 5a or 5b and lowering the thermal exchange. The gaskets, which can be formed as a spiral similar to the spiral of the spiral body 2, is then squeezed onto each wound of the spiral body 2. Alternatively the gaskets are squeezed between the spiral body 2 and the lids or covers 7a, 7b. The gaskets can also be configured in other ways as long as the sealing effect is achieved.

[0033] FIG. 2 shows a schematic cross section of the spiral heat exchanger 1 of FIG. 1 having a spiral body 2, connections 8a, 8b provided on the covers 7a, 7b of the spiral heat exchanger 1 and connected to the flow channels 5a, 5b, respectively, at the centre of the spiral body 2, and connections 9a, 9b provided on the outer of the shell 6 of the spiral heat exchanger 1 and connected to the flow channels 5a, 5b, respectively. The coating used according to the present invention may be referred to as a non-stick coating and makes it easy to clean the sheets 1a of a fouled spiral heat exchanger 2. The coated sheets 3 according to the present invention show a better heat transfer over time compared to conventional spiral heat exchanger sheets since the latter ones gets fouled much quicker and thus decrease the heat transfer performance to a larger extent. The coating of the sheets also results in a much more even surface thus resulting in better flow characteristics. Also the pressure drop is reduced over time for a spiral heat exchanger according to the present invention in comparison with conventional spiral heat exchangers, since the buildup of impurities, microorganisms and other substances is not as pronounced.

[0034] The coated spiral heat exchanger 1 according to the present invention may easily be cleaned just using high pressure washing with water. With a sheet 3 according to the present invention there is no need for extensive time consuming mechanical cleaning or cleaning using strong acids, bases or detergents.
According to the present invention the sheets 3 of a spiral heat exchanger 1 is coated with a composition comprising organosilicon compounds using a sol-gel process. The organosilicon compounds are starting materials used in the sol-gel process and are preferably siliconalkoxy compounds. In the sol-gel process a sol is converted into a gel to produce nano-materials. Through hydrolysis and condensation reactions a three-dimensional network of interlayered molecules is produced in a liquid. Thermal processing stages serve to process the gel further into nano-materials or nanostructures resulting in a final coating. The coating comprising said nano-materials or nanostructures mainly comprise silicon oxide, SiO₂, having an atomic ratio of O/Si>1, preferably an atomic ratio of Si/Si=1.5-3, and most preferably O/Si=2-2.5. A preferred silicon oxide is silica, SiO₂. The silicon oxide forms a three-dimensional network having excellent adhesion to the sheets.

The coating of the present invention further has a content of carbon such as found in hydrocarbon chains. The hydrocarbons may or may not have functional groups such as found in hydrocarbon chains of aromatic groups, e.g. C—O, C—O—C, C—N, N—C—O, N—C—O, etc. Preferably the carbon content is ≤10 atomic %, preferably ≤20-60 atomic %, and most preferably ≤30-40 atomic %. The hydrocarbons impart flexibility and resilience to the coating. The hydrocarbon chains are hydrophobic and oleophobic which results in the non-stick properties of the coating.

In FIG. 3 is shown a schematic drawing of a sheet 3 for a spiral heat exchanger provided with a silicon oxide sol gel coating 10. Between the sheet 3 itself and the silicon oxide coating 10 is an interface 11 between the coating 10 and a metal oxide film of the sheet 3. The coating bulk that follows said interface is the siloxane network 12 with organic linker chains and voids that impart flexibility to the coating 10. The outermost layer of the coating 10 is a functional surface 13, i.e. hydrophobic/oleophobic surface for fouling reduction.

By the combination of a durable and yet flexible coating, a sheet 3 for a spiral heat exchanger 1 is achieved which has excellent non-stick properties and also is wear and crack resistant. The flexibility of the coating is especially important in order to avoid cracking of the coating when the sheets move in relation to each other.

In one embodiment of the present invention at least one sol comprising organosilicon compound is applied to the surface to be coated. The surface may be wetted/coated with the sol in any suitable way. It is preferable for the surface coating to be applied by spraying, dipping or flooding. At least a part of one side of the spiral heat exchanger sheet is to be coated. Alternatively, all surfaces of at least one side of a sheet which during use in a spiral heat exchanger would be in contact with a fluid are coated. Also, at least one side of a spiral heat exchanger sheet may be entirely coated. Alternatively, both sides of the sheet may be coated. If both sides are coated, they may be partly or fully coated, in any combination. Naturally, more surfaces than the surfaces intended to be in contact with fluid may be coated. Preferably, all surfaces in contact with a fluid giving rise to fouling are coated.

In another embodiment the method comprises a pretreatment of at least the surfaces on the heat exchanger sheets to be coated with at least one sol. This pretreatment is also preferably carried out by means of dipping, flooding or spraying. The pretreatment is used to clean the surfaces to be coated in order to obtain increased adhesion of the latter coating to the heat exchanger sheet. Examples of such pretreatments are treatment with acetone and/or alkaline solutions, e.g. caustic solution.

In another embodiment the method comprises thermal processing stages, e.g. a drying operation may be carried out after a pretreatment and a drying and/or curing operation is often necessary after the actual coating of the sheet with said sol. The coating is preferably subjected to heat using conventional heating apparatus, such as e.g. ovens.

The composition comprising SiO₂ is applied to a sheet 3 to be used in a spiral heat exchanger. The application of the composition is made by means of sol-gel processing. The resulting film of said composition on the sheet is preferably between 1 and 30 μm thick. The thickness of the coated film is important for the use in a spiral heat exchanger. A film thickness below 1 μm is considered being not enough wear resistant since the sheets in a spiral heat exchanger in use are able to move slightly in relation to each other. This slight movement causes wear on the film and with time the coating will become worn down. Also the thickness of the film has an upper limit since the application of substances on the heat transfer sheets influences the heat transfer and thus the performance of the spiral heat exchanger. The upper limit for the applied film is preferably 30 μm. Thus, the film thickness of the silicon oxide sol containing composition is 1-30 μm, preferably 1.5-25 μm, preferably 2-20 μm, preferably 2-15 μm, preferably 2-10 μm and preferably 3-10 μm.

The base material for the sheets may be chosen from several metals and metal alloys. Preferably, the base material is chosen from titanium, nickel, copper, any alloys of the before mentioned, stainless steel and/or carbon steel. However, titanium, any alloys of the before mentioned or stainless steel is preferred.

EXAMPLES

In the search for prolonged operational time of offshore equipment, tests were conducted on low surface energy glass ceramic coatings.

Two low surface energy glass ceramic coatings, Coat 1 and Coat 2, were tested and the results are presented below. Coat 1 is a silan terminated polymer in butyl acetate and Coat 2 is a polyisloxan-urethane resin in solvent naphtha/butyacetate.

Phase A

The analysis shows properties of the coatings concerning substrate wetting and adhesion, contact angle, coating thickness and stability against 1.2% HNO₃ in H₂O, 1% NaOH in H₂O and crude oil. The results are summarized below in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Coat 1</th>
<th>Coat 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate wetting</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Substrate adhesion</td>
<td>AISI 0/0</td>
<td>AISI 0/0</td>
</tr>
<tr>
<td>Contact angle measurements</td>
<td>H₂O: 102-103°</td>
<td>H₂O: 102-103°</td>
</tr>
<tr>
<td>Coating thickness</td>
<td>4-10 μm</td>
<td>2-4 μm</td>
</tr>
</tbody>
</table>
Both coatings showed excellent wetting when spray coated onto either stainless steel or titanium substrates. Adhesion was determined by cross-cut/tape test according to DIN EN ISO 2409. Rating is from 0 (excellent) to 5 (terrible). Our 1 is acceptable while 2 to 5 is not. First digit indicates rating after cross cut (1 mm grid) and the second digit gives rating after tape has been applied and taken off again.

To obtain the best adhesion for Coat 1 and Coat 2 the substrates required pre-treatment. The substrate is submerged in an alkaline cleaning detergent for 30 minutes. Afterwards the substrate is washed with water and demineralized water and is dried before Coat 1 is applied within half an hour to achieve the optimal adhesion. Tests have shown that the adhesion is reduced if cleaning of the substrate is only carried out with acetone. Pre-treatment is also necessary for stainless steel substrates coated with Coat 2. This coating displayed unaffected adhesion whether an alkaline detergent or acetone was used as pre-treatment. If the pre-treatment step is neglected or not made correctly it will affect coating adhesion.

Both coatings showed good stability under acidic condition. The coatings were stable for 1 ½ hour at 75°C and more than 24 hours at room temperature.

Under alkaline conditions Coat 1 showed a better result than Coat 2. Coat 1 could withstand the alkaline conditions for 3 hours at 85°C and Coat 2 for 2 hours at 85°C. Both coatings showed no decomposition or reduction in oleophobic properties after being submerged in crude oil at room temperature for 6 months.

Phase C

Coating of Spiral Heat Exchanger Sheets

Table 1 - continued

<table>
<thead>
<tr>
<th>Stability</th>
<th>Coat 1</th>
<th>Coat 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2% HNO₃ in H₂O:</td>
<td>1.2% HNO₃ in H₂O:</td>
<td></td>
</tr>
<tr>
<td>1 ½ h at 75°C</td>
<td>1 ½ h at 75°C</td>
<td></td>
</tr>
<tr>
<td>1% NaOH in H₂O:</td>
<td>1% NaOH in H₂O:</td>
<td></td>
</tr>
<tr>
<td>3 h at 85°C</td>
<td>2 h at 85°C</td>
<td></td>
</tr>
<tr>
<td>Crude oil: 6 months at RT</td>
<td>Crude oil: 6 months at RT</td>
<td></td>
</tr>
</tbody>
</table>

Three different silicon oxide-coated Ti substrates were analyzed before and after use by means of XPS (X-ray Photoelectron Spectroscopy), also known as ESCA (Electron Spectroscopy for Chemical Analysis). The XPS method provides quantitative chemical information—the chemical composition expressed in atomic % for the outermost 2-10 nm of surfaces.

The measuring principle is that a sample, placed in high vacuum, is irradiated with well-defined x-ray energy resulting in the emission of photoelectrons. Only those from the outermost surface layers reach the detector. By analyzing the kinetic energy of these photoelectrons, their binding energy can be calculated, thus giving their origin in relation to the element and the electron shell.

XPS provides quantitative data on both the elemental composition and different chemical states of an element (different functional groups, chemical bonding, oxidation state, etc.). All elements except hydrogen and helium are detected and the surface chemical composition obtained is expressed in atomic %.

XPS spectra were recorded using a Kratos AXIS UltraDLD x-ray photoelectron spectrometer. The samples were analyzed using a monochromatic Al x-ray source. The analysis area was below 1 mm².

In the analysis wide spectra were run to detect elements present in the surface layer. The relative surface compositions were obtained from quantification of detail spectra run for each element.

The following three samples were XPS analyzed:
1. Siliconoxide (new) on Ti-plate—coating on both sides.
2. Siliconoxide (used) on Ti-plate—coating on one side
3. Siliconoxide on DIN 1.4401 stainless steel plate, coating on both sides.

The analysis was performed in one position per sample, except for sample 1, where two positions were analyzed. The results are summarized in Table 2 showing the relative surface composition in atomic % and atomic ratio O/Si.

Table 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>O/Si</th>
<th>C</th>
<th>O</th>
<th>Si</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 new (pt 1)</td>
<td>2.25</td>
<td>61.1</td>
<td>23.5</td>
<td>10.5</td>
<td>4.2</td>
</tr>
<tr>
<td>2 new (pt 2)</td>
<td>2.30</td>
<td>61.0</td>
<td>23.9</td>
<td>10.4</td>
<td>4.1</td>
</tr>
<tr>
<td>2 used</td>
<td>2.29</td>
<td>68.0</td>
<td>19.5</td>
<td>8.6</td>
<td>3.1</td>
</tr>
<tr>
<td>3</td>
<td>1.46</td>
<td>41.9</td>
<td>34.3</td>
<td>23.4</td>
<td>(0.2)*</td>
</tr>
</tbody>
</table>

*weak peak in detail spectra, signal close to noise level

As seen in Table 2 mainly C, O and Si were detected on the outermost surfaces, i.e. 41.9-68.0 atomic % C, 19.5-34.3 atomic % O and 8.6-23.4 atomic % Si.

Note that in the atomic ratios O/Si, the total amount of oxygen is used. This means that also oxygen in functional groups with carbon is included. Otherwise for silica, from theory is expected a ratio O/Si of 2.0 for the bulk pure silica SiO₂.

Inspection During Operation

After four months of operation an off-shore pre-inspection by thermo-imaging was performed.
The inspection showed an elevated temperature at the coated sheets. The non-coated sheets showed a lower operating temperature. The difference in temperature is presumed due to reduced fouling, hence a higher crude oil flow in the coated region which produces an elevated temperature.

The term fouling is used to describe the deposits formed on the sheets during operation. The fouling are residues and deposits formed by the crude oil and consists of a waxy, organic part and a mineral/inorganic part.

The visual inspection revealed that the sheets with the coating designated Coat 1 was covered with the least amount of fouling on the crude oil facing sheet side. Also, the other coating system designated Coat 2 had a reduced amount of fouling on the crude oil facing sheet side compared to the bare titanium surface but to a lesser extent then Coat 1.

By subtracting the average weight of a clean sheet from the weight recorded for the individual fouled sheets the average amount of fouling per surface type was calculated (table 3). Note, the weight of the coating was not compensated for and so the real fouling reduction is slightly higher. If the coating is estimated to be pure SiO2 (density 2.6 g/cm³) then the amount of coating per sheet is about 20 g.

Some loss of coating was observed in the contact points but overall the coated surface that had been in contact with the crude oil was in a good condition.

On the sea water facing side both coatings had deteriorated and could be peeled quite easily.

**TABLE 3**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Average fouling (g)</th>
<th>STDEV</th>
<th>Fouling reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>585</td>
<td>125</td>
<td>—</td>
</tr>
<tr>
<td>Coat 1</td>
<td>203</td>
<td>48</td>
<td>65</td>
</tr>
<tr>
<td>Coat 2</td>
<td>427</td>
<td>144</td>
<td>27</td>
</tr>
</tbody>
</table>

For both coating systems the fouling of the sheets were more easily removed compared to the fouling adhering to the bare titanium surface, see Table 4. The difference in cleaning requirements was tested by manually wiping of the sheets with a tissue and by high pressure water cleaning. Just wiping the sheets with a tissue showed that the fouling was very easily removed from the coated sheets, contrary to the uncoated sheets. By using water jet all fouling except for one or two small patches could be removed from the Coat 1 coated surface. On the Coat 2 coated surface some more fouling was present after water jet cleaning. This fouling had the appearance of slightly burnt oil.

**TABLE 4**

<table>
<thead>
<tr>
<th></th>
<th>Coat 1</th>
<th>Coat 2</th>
<th>Non-coated</th>
</tr>
</thead>
<tbody>
<tr>
<td>View</td>
<td>very little fouling removed</td>
<td>reduced fouling</td>
<td>fouling significant and widespread</td>
</tr>
<tr>
<td>Wipe with tissue</td>
<td>very easy to remove fouling</td>
<td>very easy to remove fouling</td>
<td>fouling was not removed</td>
</tr>
<tr>
<td>High pressure water washing</td>
<td>sheets appeared as new</td>
<td>most of the fouling was removed</td>
<td>even after attempts of manual removal of fouling, still a considerable layer remains</td>
</tr>
</tbody>
</table>

1. A spiral heat exchanger comprising a spiral body formed by at least one spiral sheet wound to form the spiral body forming at least a first spiral-shaped flow channel for a first medium and a second spiral-shaped flow channel for a second medium, wherein the spiral body is enclosed by a substantially cylindrical shell being provided with connecting elements communicating with the first flow channel and the second flow channel wherein

   the spiral heat exchanger is provided with a coating comprising silicon oxide, SiOₓ, having an atomic ratio of O/Si=1, a content of carbon ≥10 atomic % and a coating layer thickness of about 5-60 µm, which coating was prepared by sol-gel processing and applied to at least a part of the sheets.

2. A spiral heat exchanger according to claim 1, wherein the sheets have a thickness of 2-6 mm.

3. A spiral heat exchanger according to claim 1, wherein the layer thickness of said coating on the sheets is 5-30 µm.

4. A spiral heat exchanger according to claim 1, wherein the coating comprising silicon oxide, SiOₓ, has an atomic ratio of O/Si=1.5-3.

5. A spiral heat exchanger according to claim 1, wherein the composition has a content of carbon ≥20-60 atomic %.

6. A spiral heat exchanger according to claim 1, wherein the layer thickness of said coating on the sheets is 2-20 µm.

7. A spiral heat exchanger according to claim 1, wherein the coating comprising silicon oxide, SiOₓ, has an atomic ratio of O/Si=2-2.5.

8. A spiral heat exchanger according to claim 1, wherein the composition has a content of carbon ≥30-40 atomic %.

* * * * *