

Treatment of hydrocarbon containing materials

The present invention relates to a method and apparatus for treating hydrocarbon containing materials using electromagnetic radiation. The invention particularly relates to continuous microwave treatment to separate hydrocarbons from a matrix of solid materials, although it is not limited in this regard.

Hydrocarbons are often mixed within a matrix of other solid materials such as sand, soil or rock, and it is frequently desirable to separate or remove the hydrocarbons from such a matrix. For example, a substantial fraction of the world's hydrocarbon reserves are to be found in oil sands and in order to extract the oil, it must first be separated from the sand with which it is mixed. A further example is oil contaminated drill cuttings, which are a mixture of rock fragments, oil and water, and which are produced in significant quantities during exploration for and production of hydrocarbons. Removing sufficient oil from such drill cuttings allows them to be disposed of in a more cost effective manner for instance by direct discharge into the sea. Whilst potentially the arrangements described herein could be used in the removal of oil from sands, the invention is directed primarily towards the removal of oil from drill cuttings.

It is known to use microwave energy to reduce oil levels in mixtures of oil and solid materials, and an example of such a method and apparatus is disclosed in WO2008/059240. This document describes an arrangement whereby a matrix of oil or hydrocarbon contaminated material is continuously treated by exposing it to microwave radiation, thereby causing rapid heating of the water content of the matrix leading to thermal desorption of the oil from the solid matrix. The oil carrying matrix is continuously fed through a microwave cavity on a trough conveyor belt. Microwave chokes are used to limit the levels of electromagnetic radiation escaping from the open input and output ends of the conveyor belt.

The present applicant has identified a number aspects of the arrangement disclosed in WO2008/059240 that could be improved. The conveyor belt and the microwave chokes are relatively large and comprise a significant fraction of the footprint of the apparatus described. A more compact system with a smaller footprint would be advantageous, particularly given the very limited space available on offshore platforms.

Due to the desirability of controlling the liquid, for example water, content in the matrix to be treated, it would be advantageous if some liquid was allowed to drain from it prior to exposure to microwaves.

5 The profile of the material on the conveyor belt is subject to variation, resulting in non-uniform interaction with the microwave radiation. It would be advantageous if the feed system provided a flow of material through the microwave cavity with a substantially uniform profile to allow the interaction to be more consistent and better optimised.

10 Arcing may take place within the microwave cavity. Such arcing is preferably avoided, since it may result in combustion of the hydrocarbon vapours, or other undesirable chemical reactions such as the formation of nitric oxides or ozone.

The conveyor belt system of the prior art must be fed material from bulk storage by a
15 further material handling system. Handling of the oil contaminated materials can be difficult. It would be desirable if the handling system that feeds the material through the microwave cavity was capable of feeding itself from bulk storage of the said material.

According to a first aspect of the present invention there is provided an apparatus for
20 separating a hydrocarbon content from a material matrix comprising the hydrocarbon content and a water content, the apparatus comprising: a material feeder arranged to feed material through a treatment chamber or applicator, the treatment chamber comprising a window which is substantially transparent to microwaves; a microwave
25 emitter arranged in use to expose feed material in the treatment chamber to microwaves via the window in order to cause heating, conveniently rapid heating, of at least part of the water content of the matrix to form steam, so as to remove at least part of the hydrocarbon content from the matrix; wherein the material feeder and treatment chamber are arranged so that in use, the treatment chamber is substantially filled with material matrix.

30 As described hereinbefore, rapid heating leads to thermal desorption of the oil from the solid matrix.

The material feeder may be arranged to allow at least some of the liquid content to drain from the material matrix before it passes through the treatment chamber.

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The material feeder may be oriented vertically, horizontally or inclined.

The material matrix may be pushed through the treatment chamber by the material matrix leaving the material feeder.

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The material feeder may comprise a screw conveyor. Conveniently, a twin screw conveyor is used. Such an arrangement is advantageous in that the interaction between the two screws of the conveyor serves, at least to some extent, to clean the conveyor and/or reduce clogging thereof.

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Alternatively, the material feeder could comprise, for example, a piston device, or a pump such as a peristaltic pump, positive displacement pump, or the like.

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The material feeder may be arranged to control a rate at which material is fed through the treatment chamber in response to, for example, a measurement of the reflected microwave power. Ideally, the feeder speed is dependent upon the cleanliness or oil content, or the dryness, of the material. By measuring moisture content, a value indicative of the oil content, and hence cleanliness, can be derived for used in controlling the feed rate.

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The microwave power output of the microwave emitter may be arranged to be controlled in response to a measurement of the reflected microwave power.

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The window may be arranged to cover an aperture in the treatment chamber with a first area of the window, the window extending beyond the extent of the aperture, and for the window to be repositioned during operation of the apparatus to present a second area to the aperture.

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The window may comprise a flexible film or belt.

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The treatment chamber may be of substantially circular cross section. However, where the material feeder comprises a twin screw conveyor, the treatment chamber may match the profile of the conveyor and so have generally planar sides, and part cylindrical ends. The window, in such an arrangement, may be formed on the side and so be of generally planar form, easing manufacture.

The treatment chamber is may be substantially disposed within a microwave cavity arranged to direct microwave radiation from the microwave emitter to the treatment chamber.

The treatment chamber may be substantially concentric with the microwave cavity.

The microwave cavity may comprise a moveable microwave reflector operable to adjust the modes of the microwave cavity.

The material matrix leaving the treatment chamber may be deposited within an output container which substantially confines microwave radiation escaping from the treatment chamber. A discharge feeder, for example in the form of a screw or rotary valve, may be used to extract and control the level of materials within the output container.

According to a second aspect of the present invention there is provided a method for separating a hydrocarbon content from a material matrix comprising the hydrocarbon content and a water content, comprising the steps of: continuously feeding the material matrix through a treatment chamber; exposing the material matrix within the treatment chamber to microwave radiation arranged to cause rapid heating of at least some of the water content to form steam, wherein the rapid steam formation results in thermal desorption of at least some of the hydrocarbon content from the matrix; wherein the treatment chamber is substantially filled with the material matrix to be treated.

The method for separating a hydrocarbon content from a material matrix comprising the hydrocarbon content and a water content may use an apparatus as described hereinbefore.

The present invention will now be described, by way of example, with reference to the following drawings in which:

Figure 1 is a schematic diagram of an embodiment of the invention wherein the material is fed vertically through a treatment chamber of a first type.

Figure 2 is a schematic diagram of an alternative arrangement wherein a cylindrical treatment chamber is disposed within a substantially cylindrical microwave cavity.

Figure 3 is a schematic diagram of an embodiment of the invention wherein the window of the treatment chamber comprises a film.

5 Figure 4 is a schematic diagram of an embodiment of the invention wherein the window is larger than the aperture of the treatment chamber.

Figure 5 is a schematic diagram of an embodiment of the invention wherein the material feeder is oriented horizontally.

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Figure 6 is a schematic diagram of an embodiment of the invention wherein the material feeder is inclined at an oblique angle.

15 The apparatus shown in Figure 1 takes a material matrix 1 comprising hydrocarbons and water and for example rock fragments or sand, and separates at least some of the hydrocarbons from the material matrix 1 to leave a treated material matrix 2. The apparatus comprises an input container 3, a material feeder 5, a treatment chamber or applicator 8, microwave emitter 6 and output container 4. The treatment chamber 8 comprises a window 13 which is substantially transparent to microwave radiation. The
20 microwave emitter 6 is provided with a waveguide 7. The input container 3 and output container 4 are provided with doors 12 and 11 respectively. A fluid inlet 9 and a fluid outlet 10 are provided within the output container 4 and/or treatment chamber 8.

25 In use, material matrix 1, which may comprise rock chippings, hydrocarbons, sludge, filter cake, sand, etc, is introduced to the input container 3 via the door 12. The door 12 may be closed when material is not being introduced to the chamber. The material feeder 5 is a vertical screw conveyor which takes material matrix 1 from the input container 3 and feeds it through the treatment chamber 8. Conveniently, the screw conveyor is a twin screw arrangement, the interaction between the screws or augers of
30 which serves, at least in part, to clean the conveyor and to reduce the risk of clogging thereof. The screw conveyor 5 ends before the treatment chamber 8, and the material within the treatment chamber 8 is pushed through the chamber by the material leaving the screw conveyor 5. Within the treatment chamber 8 the material matrix 1 is exposed to microwave radiation, which causes rapid and preferential heating of the water in the
35 material matrix 1, producing steam. This in turn causes thermal desorption of the

hydrocarbon component, leaving substantially hydrocarbon free treated material matrix
2. The general principles of hydrocarbon removal by continuous microwave treatment are described in more detail in WO2008/059240.

5 The fluid inlet 9 may be provided in the walls of the treatment chamber 8 and/or the output container 3 to allow inert gas to be swept through or over the material matrix after or while it is exposed to radiation. The inert sweep gas will entrain the steam and thermally desorbed hydrocarbons from the material matrix and may be removed via the fluid outlet 10. The sweep gas may subsequently be directed to a condenser (not
10 shown) where the hydrocarbons and/or water may be recovered from the sweep gas. The sweep gas may comprise steam or nitrogen.

The microwave emitter 6 is connected to a waveguide 7 which is arranged to direct microwave radiation from the emitter 6 to the treatment chamber 8. The treatment
15 chamber 8 comprises a window 13 made from a material which is substantially transparent to the microwave radiation from the emitter 6 to allow the microwave radiation to enter the treatment chamber 8. The microwave emitter 6, waveguide 7, output chamber 4 and treatment chamber 8 are arranged to provide an electric field with appropriate uniformity within the treatment chamber 8. One approach for achieving
20 this is described in more detail in WO2008/059240, and the output container 4 and treatment chamber 8 of the present invention may be arranged to provide an analogous configuration wherein the microwave cavity is provided by the output container 4 and the treatment chamber 8 confines the material matrix 1 in a position corresponding to that of the material on the conveyor of WO2008/059240. The walls of
25 the treatment chamber 8 may substantially comprise microwave transparent windows 13, or chamber walls which are not microwave transparent may be provided with an aperture which is covered by a microwave transparent window 13.

Where a twin screw conveyor is used, it will be appreciated that the shape thereof may
30 include part cylindrical end walls and generally planar side walls. Conveniently the chamber 8 is similar shaped, and the window 13 is conveniently formed in or on one of the side walls, and thus can also be of generally planar form. The window is conveniently of a suitable ceramic glass material.

The treatment chamber 8 conveniently includes a dead-zone or section which extends into the output container and is after the point at which treatment takes place. In use, the section, like the remainder of the treatment chamber, is full of material and so serves to contain the applied electrical field. Its length is chosen to achieve a sufficient level of containment whilst being sufficiently short that reabsorption of oil into the treated material is avoided or limited to an acceptable level.

In use the microwaves may be confined within the closed output container 4 which may comprise materials which are not microwave transparent such as metal, thereby preventing unwanted emissions of microwave radiation from the apparatus. The door 11 of the output container 4 may be opened to discharge treated material 2, and the door 11 may be provided with a safety interlock to cut power to the microwave emitter 6 in the event that the door 11 is open. Microwave radiation entering the screw conveyor 5 will be rapidly attenuated by the material matrix 1, but the input container 3 may similarly comprise a material which is non-transparent to microwaves and the door 12 may be kept closed in use. The use of microwave chokes is thereby rendered unnecessary, considerably reducing the size and footprint of the apparatus over prior art systems.

The arrangement of the chamber 8 and screw conveyor 5 is such that the treatment chamber 8 is substantially full of material matrix 1 during operation of the apparatus. This results in a consistent profile of material and allows the characteristics of the apparatus to be optimised to provide appropriate levels of microwave heating throughout the material as it passes through the treatment chamber 8. This is in contrast to prior art systems employing an open treatment area through which material was conveyed using a belt system, and where control over the distribution of material on the belt was a significant challenge.

The use of a screw conveyor 5 to move material through the treatment chamber 8 means that a single material feeding system can be used to take up material from the input container 3 and feed it through the apparatus to the output container 4. The need for a separate material handling system to introduce material from a container to a conveyor as required in prior art systems is thereby avoided.

The vertical orientation of the screw conveyor 5 allows unbound water to drain from the material matrix 1 before it is introduced to the treatment chamber 8, controlling the water content of the material matrix 1. Such control over water content is known to be advantageous, since an excess of water content has a negative impact on the efficiency of the process. The vertical orientation has further advantages in reducing the footprint of the equipment. Equipment with a small footprint is highly advantageous in offshore applications, where platform area is typically in short supply.

In prior art systems, arcing may occur within the microwave cavity as a result of electric field interactions with the distribution of material matrix within the treatment area, leading to the potential for combustion of the hydrocarbon vapours that are formed during operation of the apparatus. Substantially filling the treatment chamber 8 with material matrix 1, and minimising air spaces in the chamber 8, limits the potential for electrical arcs to occur, since microwave absorbing material 1 will prevent arcs in the chamber 8, and a properly designed waveguide 7, output container 4 and chamber 8 will not be subject to arcing. It may be desired to provide a nitrogen purging arrangement to further reduce the risk of arcing.

It is known from the prior art that monitoring the reflected microwave power can provide an indication of the appropriate feed rate or microwave power radiated from the emitter 6. Where the microwave power output substantially exceeds the power required to remove the water in the inflowing material 1, the material matrix 1 will become less microwave absorbent, resulting in an increase in reflected power. The feed rate of the material 1 or the output microwave power from the emitter 6 may therefore be adjusted in response to the measured reflected power. For instance, the feed rate may be increased when a predetermined threshold reflected power is measured, or the microwave power output may be reduced. In addition, an automatic control system may be provided in which the feed rate or microwave power or both are adjusted while the reflected power is monitored to characterise the optimum feed rate and/or microwave power for a given material matrix 1.

A moveable microwave reflector (not shown) may be provided within the waveguide 6 or the output container 4 and its position used to tune the microwave cavity, for example to compensate for variations in effective dielectric properties of the material matrix 1, or to provide a mode stirrer to continuously vary the distribution of the electric

field within the chamber 8 thereby providing substantially uniform average heating therein. However, a non-uniform heat distribution may be acceptable in some applications.

5 A cooling arrangement may be provided to extract heat from the treated materials.

Figure 2 shows an alternative arrangement in which the treatment chamber 8 comprises a microwave transparent tube 13 which is arranged within a microwave cavity 18. The tube provides a continuous window 13 through which the material 1
10 within the chamber 8 may be exposed to microwave radiation. The microwave cavity 18 is substantially cylindrical and may comprise a single mode microwave cavity. This arrangement of chamber 8 and cavity 18 may be advantageous since it may provide a substantially axisymmetric or radially symmetric electric field leading to relatively uniform heating of the material matrix. The microwave cavity 18 may be fed microwave
15 radiation from the microwave emitter 6 via a waveguide 7, and the modes of the microwave cavity 18 may be adjusted or stirred by varying the position of a microwave reflector 16 arranged within the cavity.

During use hydrocarbons, or other components of the material matrix which are not
20 microwave transparent, may be deposited on the window 13 of the treatment chamber 8. Such deposits may interfere with the functioning of the equipment by preventing microwaves passing through the window 13 properly. Where the deposits are microwave absorbing, they may lead to heating of the window 13 resulting in damage. It is therefore advantageous for the window 13 of the treatment chamber 8 to be kept
25 clean and free from such deposits.

Figure 3 shows an arrangement whereby the window 13 is formed from a film or belt of flexible microwave transparent material which may be continuously fed from a reel 14, and stored on a further reel 14. Such a film may be used only for a single pass and
30 subsequently discarded, thereby ensuring that the window 13 is kept clean. Alternatively the film may be used for multiple passes. The film may be cleaned by fixed wipers 15, or by a further cleaning means (not shown). Although as illustrated the film moves vertically, an arrangement in which the film moves horizontally or in other orientations is also envisaged.

Figure 4 shows an arrangement whereby the window 13 comprises a rigid material which is larger than is required to cover the aperture in the treatment chamber 8, so that the window may be moved between a first position in which a first area of the window covers the aperture of the treatment chamber 8 and a second area is exposed for cleaning, and a second position in which a second area of the window covers the aperture of the treatment chamber 8 and a first area is exposed for cleaning. Fixed wipers 15 may be provided which clean the window 13 when it is moved between positions. The window may be periodically or continually moved in order to keep it clean, and such movements may take place while the apparatus is in operation. Although as illustrated the window moves vertically, an arrangement in which the window moves horizontally or in other orientations is also envisaged.

Where the window 13 is of substantially circular cross section, as for example in the embodiment of Figure 2, the window may be continuously or periodically rotated past a fixed wiper (not shown) arranged within the treatment chamber 8 so that the internal surface of the window 13 is kept clean.

Figure 5 shows an alternative embodiment of the invention in which the screw conveyor 5 is oriented horizontally. Figure 6 shows a further alternative embodiment in which the screw conveyor is inclined at an oblique angle. Such arrangements may be advantageous in adapting the apparatus to the requirements of a particular installation, or in ensuring the proper feeding of material, and may permit the installation of a valve between the container 3 and the treatment chamber 8 to control free flowing liquid levels.

Whilst the use of screw conveyors, and in particular twin screw arrangements, is outlined hereinbefore, it will be appreciated that other forms of material feeder could be used. For example, peristaltic pumps, or piston based pumping arrangements could be used to move the material within the device.

Whilst several specific embodiments are described herein, it will be appreciated that a number of modifications may be made without departing from the scope of the invention.

CLAIMS:

1. An apparatus for separating a hydrocarbon content from a material matrix comprising the hydrocarbon content and a water content, the apparatus comprising:
5 a material feeder arranged to feed material through a treatment chamber, the treatment chamber comprising a window which is at least partially transparent to microwaves;
a microwave emitter arranged in use to expose feed material in the treatment chamber to microwaves via the window in order to cause heating of at least part of the water content of the matrix to form steam, so as to remove at least part of the hydrocarbon
10 content from the matrix;
wherein the material feeder and treatment chamber are arranged so that in use, the treatment chamber is filled with material matrix.
2. The apparatus of claim 1, wherein the material feeder stops short of, and does
15 not extend into, the treatment chamber.
3. The apparatus of claim 1 or claim 2 wherein the material feeder is arranged to allow at least some of the water content to drain from the material matrix before it passes through the treatment chamber.
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4. The apparatus of any of claims 1 to 3, wherein the material feeder is vertical.
5. The apparatus of any of claims 1 to 3, wherein the material feeder is inclined.
- 25 6. The apparatus of any of claims 1 to 3, wherein the material feeder is horizontal.
7. The apparatus of any preceding claim wherein the material matrix is pushed through the treatment chamber by the material matrix leaving the material feeder.
- 30 8. The apparatus of any preceding claim wherein the material feeder comprises at least one of a screw conveyor, a peristaltic pump, a positive displacement pump and a piston feed mechanism.
- 35 9. The apparatus of Claim 8, wherein the material feeder comprises a twin screw conveyor.

10. The apparatus of any preceding claim wherein the material feeder is arranged to control a rate at which material is fed through the treatment chamber in response to a signal indicative of the cleanliness or dryness of the material.

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11. The apparatus of any preceding claim wherein the microwave power output of the microwave emitter is arranged to be controlled in response to a measurement of the reflected microwave power.

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12. The apparatus of any preceding claim wherein: a window is arranged to cover an aperture in the treatment chamber with a first area of the window, the window extends beyond the extent of the aperture, and the window is arranged to be repositioned during operation of the apparatus to present a second area to the aperture.

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13. The apparatus of claim 12 wherein the window comprises a flexible film or belt.

14. The apparatus of any preceding claim wherein the treatment chamber is of substantially circular cross section.

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15. The apparatus of any preceding claim wherein the treatment chamber is substantially disposed within a microwave cavity arranged to direct microwave radiation from the microwave emitter to the treatment chamber.

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16. The apparatus of claim 15 wherein the treatment chamber is substantially concentric with the microwave cavity.

17. The apparatus of claim 15 or 16 wherein the microwave cavity comprises a moveable microwave reflector operable to adjust the modes of the microwave cavity.

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18. The apparatus of any preceding claim wherein material matrix leaving the treatment chamber is deposited within an output container which substantially confines microwave radiation escaping from the treatment chamber.

19. The apparatus of any of the preceding claims, further comprising a discharge mechanism extracting and controlling the level of materials within the output container.

5 20. The apparatus of any of the preceding claims, further comprising a valve located between the container and the treatment chamber to control free flowing liquid levels.

10 21. A method for separating a hydrocarbon content from a material matrix comprising the hydrocarbon content and a water content, comprising the steps of: continuously feeding the material matrix through a treatment chamber; exposing the material matrix within the treatment chamber to microwave radiation arranged to cause rapid heating of at least some of the water content to form steam, wherein the rapid steam formation results in thermal desorption of at least some of the hydrocarbon content from the matrix;
15 wherein the treatment chamber is substantially filled with the material matrix to be treated.

20 22. A method for separating a hydrocarbon content from a material matrix comprising the hydrocarbon content and a water content using an apparatus according to any of claims 1 to 20.