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(54) **PROCESS FOR THE MICROWAVE  
TREATMENT OF OIL SANDS AND SHALE  
OILS**

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(57) **ABSTRACT**

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A method of extracting hydrocarbon fuel from oil sand or shale. The oil sand or shale is admixed with a sensitizer and subjected to exposure to microwave energy. This acts to remove the hydrocarbon fuel from the oil sand or shale and can also crack the hydrocarbon, lower sulfur content as well as water content.

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## PROCESS FOR THE MICROWAVE TREATMENT OF OIL SANDS AND SHALE OILS

### TECHNICAL FIELD

[0001] The present invention relates to the use of microwave energy or other high frequency energy forces for the treatment of oil sand and shale oil in order to separate the oils from their sand or shale sources. If needed, the present invention also contemplates the cracking and desulphurization of the heavy oil fractions so removed as well as the extraction of water from minerals employed in carrying out this present process.

### BACKGROUND OF THE INVENTION

[0002] Although it is well recognized that oil sands and shale oils represent a potentially large but untapped source of hydrocarbon fuel, use of such materials to produce heavy oil fractions has been limited due to the high cost of processing such raw materials. In doing so, oil sands and shale oil must be processed to separate the oil (bitumen) from its source rocks and sands which is then upgraded and refined to produce a commercial product. As such, it is now well recognized that in order to commercialize oil sands and shale oil, new technologies must be applied to (1) maximize yield, (2) produce products that require minimum upgrading, and (3) minimize the number of intermediate processing operations.

[0003] There have been some efforts devoted to recovering oil sand and shale oil but none of them have adequately addressed the above-noted three criteria necessary to produce commercially viable products. The efforts to date have focused upon thermal and solvent extraction methods. For example, U.S. Pat. No. 3,939,057 to Reed Jr. discloses a process for obtaining petroleum products from oil shale by retorting crushed oil shale in an indirectly heated rotary calciner. The shale residue, it is taught, is to be fed to a furnace where it is burned to produce heat for retorting and preheating of the shale. U.S. Pat. No. 4,401,551 to Mitchel discloses a method for extracting oil from shale which includes contacting previously recovered bitumen with bituminous sand and separating the resulting liquids from the resulting solids.

[0004] It is noted that all solvent extraction processes for oil sand and shale oils produce bitumen which requires further extensive treatment, including retorting, to produce marketable fuel. Retorting requires significant energy and the process can be maintained only by combusting a substantial part of the gases so formed.

[0005] In general, in carrying out any of the prior art known to date, a substantial portion of the shale oil must be combusted in order to create sufficient energy to carry out the processes. Further, thermal and solvent extraction methods involve high processing costs associated with the grinding of the shale, the high boiling range of the oil produced and the difficulty of separating solvent and product oil from the spent shale. As a result, operational and capital costs for these prior art processes are much too high to make hydrocarbon oil extracted from shale and oil sands competitive with natural crude oil.

[0006] The present invention is not the first teaching of the use of microwave energy in this area. For example, U.S. Pat.

No. 4,419,214 to Balint, et al., describes a method of separating bitumen and tars from shale oils and tar sands through the use of microwave treatment of feedstock under pressure and in the presence of chlorinated-fluorinated hydrocarbons, carbon tetrachloride and chloroform. U.S. Pat. No. 4,153,533 to Kirkbride, teaches a process for recovering oil from shale through the microwave irradiation of feedstock under high pressure and in the presence of hydrogen and water vapor. It is taught that the moisture content of the feedstock is to be kept below 3% while the process includes the drying of the feed shale oil particles. It is further noted that Canadian Patent No. 1,308,378 to Philippe teaches separating bituminous materials from tar sands through the use of gravity. The tar sands are treated by microwave irradiation in the presence of water. Separation of the bituminous fractions from the mineral fractions by gravity takes place at temperatures less than the boiling point of water.

[0007] In addition to the above, it is noted that a number of patents describe the application of microwave energy for heating oil shale, tar sand and similar hydrocarbon sources. For example, microwave energy was used to retort feedstock in U.S. Pat. No. 2,543,028 to Hodge, in U.S. Pat. Nos. 3,449,213 and 3,560,347 to Knapp and in U.S. Pat. No. 3,503,865 to Stone. U.S. Pat. No. 4,408,999 to Nadkarni treats the oil shale and coal under microwave irradiation in an acidic slurry to assist the solution of the mineral components.

[0008] As noted previously, those methods as described above, have not been embraced commercially for they simply do not produce a product which is economically competitive with natural crude oil. Those processes which employ the use of microwave energy require the high consumption of electrical energy for implementation. Microwave energy is absorbed by water, a substance exhibiting extremely high dielectric losses. The same microwave energy is often times employed for the heating and evaporation of water, again, resulting in an economically uncompetitive process. Further energy losses arise from the heating of the rock and sand sources while only a small fraction of the microwave energy is applied to the oils themselves.

[0009] It is thus an object of the present invention is to provide a process for the efficient and economically competitive removal of hydrocarbon oils from oil sand and shale oil.

[0010] Yet a further object of the present invention to provide a method for the simultaneous separation of oils from shale, sands and other natural sources which contains such oils together with the catalytic conversion of oil fractions into marketable fuel by subjecting initial feedstock to microwave irradiation pursuant to the present process.

[0011] These and further objects will be more readily apparent in considering the following disclosure and appended claims.

### SUMMARY OF THE INVENTION

[0012] The present invention is directed to the use of microwave irradiation in order to extract hydrocarbon fuel from oil sand or shale. The method includes admixing the oil sand or shale with a sensitizer while subjecting the oil sand and sensitizer or shale and sensitizer to exposure to micro-

wave energy. As a preferred embodiment, the process is carried out in an oxygen starved atmosphere such as a hydrogen atmosphere or nitrogen atmosphere. In addition, in-situ hydrogen can be added to the shale or oil sand in order to reduce the sulphur content in the fuel derived from carrying out the present process.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is directed to the schematic representation of a device used for carrying out the present invention.

[0014] FIGS. 2-4 present graphical data related to the removal of water from sand oil as part of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

[0015] Turning to FIG. 1, apparatus **10** is depicted for carrying out the present invention as a one step continuous process. Specifically, feedstock in the form of sand oil or shale is introduced, schematically shown by arrow **1**, into a hopper which then carries the feedstock through dryer **3** having recirculated air or steam **18** passing therethrough. The dryer can also be driven by microwave energy, the benefits of which are discussed later in the present application. The heated feedstock is then applied to moving conveyor belt **7** supported by wheels **8** and driven by power drive wheel **9**.

[0016] Optionally, the feedstock introduced within apparatus **10** can be admixed with carbon shown schematically by arrow **4**, the purpose for which will be more thoroughly discussed hereinafter. As the feedstock moves along conveyor belt **7**, it is subjected to microwave energy through quartz wave guides **5** and **6**. Treatment of the feedstock is ideally conducted in a hydrogen atmosphere, the hydrogen being introduced within the device, schematically depicted by arrow **11**. The treated feedstock is then removed from conveyor belt **7** by blade **19** causing solid residue to be introduced within screw conveyer **14** while hydrogen and other gaseous products exit the system, schematically shown by arrows **16**. The liquid hydrocarbon product derived from the operation of device **10** can then be caused to fall upon chute **12** which, through gravity, accumulates within tank **17** and which is ultimately discharged, schematically shown by arrow **13**.

[0017] Oil sands, also known as tar sands, as well as shale containing shale oil which is useful as feedstock in carrying out the process of the present invention are found in deposits occurring in many countries of the world including the United States, Canada, Australia, Venezuela and Russia. The oil sand resources found in Northwestern Alberta, Canada are among the most significant sources of such raw materials. The main ingredients of this naturally occurring mineral matter are 6-20 wt % bitumen, 20-40 wt % crystalline silica, 40-60 wt % amorphous silica and water.

[0018] Typically, bitumen has been separated from oil sands in extraction plants operating a hot water extraction process. Extract which is produced by hot water extraction contains approximately 60 wt % bitumen, 30 wt % water and 10 % by wt minerals. The bitumen extracted by this process is typified by a low specific gravity and high sulphur content in the 5-6 wt %. It is a complex mixture of high molecular

weight organic compounds containing a relatively high proportion of hydrocarbons having carbon numbers predominately greater than C<sub>25</sub> together with a high carbon-hydrogen ratio. Converting the extracted bitumen and producing a marketable product is quite complicated requiring further refining, thermal cracking, catalytic hydrocracking and distillation among other processes.

[0019] Shale oil, on the other hand, is sedimentary rock with a relatively high organic content having approximately 30-60 wt % volatile matter and fixed carbon. When shale oil is heated in the absence of air, approximately 20-50 gallons of a viscous heavy oil is derived per ton of typical shale. The organic matter, namely kerogen, is believed to exist between particles of inorganic minerals and some portion may be chemically bound with these minerals. It is believed that the typical composition of kerogen is 66-80 wt % carbon, 7.1-12.8 wt % hydrogen, 0.1-8.8 wt % sulphur, 0.1-3 wt % nitrogen and 0.75-27.4 wt % oxygen.

[0020] As previously noted, in practicing the present invention, the oil fraction contained within the oil sand or shale oil is separated from its mineral residue while undergoing catalytic cracking with simultaneous sulphur, nitrogen and oxygen removal in a one stage microwave-induced catalytic process. Microwave energy has not typically been used in processes such as those suggested herein-for organic chemicals, by and large, do not significantly absorb microwave energy. The present invention, however, recognizes the ability to carry out microwave induced catalysis by facilitating the transfer of electromagnetic energy to non-absorbing organic molecules through the use of sensitizers. Electromagnetic energy can be absorbed by sensitizers, which comprise solid materials with moderate electrical conductivity. This energy is then transferred to the organic molecules which exhibit low dielectric loss characteristics. The process includes the cracking of the hydrocarbon fraction of the feedstock which is a process in which higher molecular weight organic molecules are converted to lower molecular weight hydrocarbons and other monomers through carbon-carbon bond fission.

[0021] The process of hydrocarbon thermal cracking and depolymerization are endothermic and involve free-radical chain reactions. The energy required for such a process is supplied as heat or can be provided by electromagnetic irradiation. The present microwave activated cracking process has a different mechanism for the initiation stage of the free radical chain reactions as compared to thermal cracking. Specifically, in thermal cracking, the formation of primary free radicals initiating chain reactions is the rate-limiting mechanism. By contrast, the present invention is based upon the concept of microwave cracking in the presence of conducting sensitizers.

[0022] As is well known, the efficiency of microwave absorption depends upon the electronic structure of the materials subjected to the microwave energy. Electrical conductivity provides a major contribution to dielectric losses. It is known that the best absorbers of microwave energy have moderate electrical conductivity and can consist of activated or amorphous carbon, amorphous or highly dispersed metals, transition metaloxides as well as their salts. By contrast, non-polar organic molecules do not absorb microwaves.

[0023] The sensitizers contemplated for use herein are materials which strongly absorb microwave radiation and

subsequently transfer the energy required to initiate certain desired chemical reactions. Catalysts allow for the localization of temperature increases creating conditions for the generation of micro-discharges near the surfaces of the sensitizer when the process mixture is irradiated with microwaves. The micro discharges represent a highly non-equilibrium system of ionized molecules and electrons with a kinetic energy (temperature) of the electrons that is significantly higher than the average temperature of the system. Without being bound by any particular theory, it is believed that the electron energy is sufficient to break the chemical bonds in molecules forming free radicals. As a result, the hydrocarbon oil derived from the oil sands and shale is upgraded. At the same time the sulphur, nitrogen and oxygen atoms, as well as the in-situ solid hydrogen sources are activated in the microwave reactor. If sulphur is to be removed from the shale and oil sand, it is caused to react with hydrogen and oxygen as well as with sulphurizing additives to form inorganic salts such as sulfates, sulfites and sulfides. This process is described in applicant's co-pending U.S. application Ser. No. 10/116,257, the disclosure of which is incorporated by reference.

[0024] As noted previously, sensitizers used in the present process are materials which strongly absorb microwave energy and are suitable to play the role of "energy converter." Suitable sensitizers are disclosed in U.S. Pat. No. 6,184,427, the disclosure of which is incorporated by reference herein, and which include activated carbon and metal oxides such as NiO, CuO, Fe<sub>3</sub>O<sub>4</sub>, MnO<sub>2</sub>, Co<sub>2</sub>O<sub>3</sub> and WO<sub>3</sub>.

[0025] The catalysts used in the present process are also disclosed in U.S. Pat. No. 6,184,427 and can be a metal powder such as a para-ferromagnetic material, iron, copper or nickel. The concentration range is preferably approximately 0.5 to 10 w % based upon the weight of the fuel oil being processed.

[0026] If the hydrocarbon fuel derived from the sand oil or shale is desulphurized, certain desulphurizing additives can be employed. They may consist of granulated limestone and other forms of CaCO<sub>3</sub>, calcite (CaO), magnesite (MgO), dolomite (MgO—CaO), sodium hydroxide (NaOH), potassium hydroxide (KOH) and sodium bicarbonate (NaHCO<sub>3</sub>). The preferred concentration range of the sulphurizing additives is preferably approximately 0.5 to 25 w % based upon the weight of the fuel oil being processed.

[0027] In referring to FIG. 1, it is taught that the present process is to be conducted preferably within a hydrogen atmosphere. It is possible, as an alternative, to employ an in-situ solid source of hydrogen to provide hydrogen atoms for hydrocracking and desulphurization without direct use of hydrogen gas. This solid source of hydrogen may be derived from various hydrides, such as sodium borohydride (NaBH<sub>4</sub>), titanium hydride (TiH<sub>2</sub>), potassium hydride (KH), copper hydride (CuH), zinc hydride (ZnH), sodium hydride (NaH), chromium hydride (CrH), and nickel hydride (NiH<sub>0.5</sub>). The concentration range for this component is preferably approximately 0.5-20 w % based upon the weight of the fuel oil being processed.

[0028] Without being bound by any particular theory, it is believed that electromagnetic energy in the present microwave activated cracking process is transferred to the feed stock using sensitizers. The electromagnetic energy can be absorbed by the sensitizers which, again, comprise solid

materials with moderate electrical conductivity. The conduction electrons in the sensitizers are accelerated in the oscillating electric field and dissipate the kinetic energy as heat. When the thickness of the conducting material is small and comparable to the penetration depth of the electromagnetic irradiation, the surface becomes hot. Under these conditions, the electrons can be emitted from the material and accelerated in the electrical field causing micro-discharges. Conditions are thus created for the generation of such micro-discharges near the surface of the sensitizers when the process material is irradiated with microwaves. The micro-discharges represent the highly non-equilibrium system of ionized molecules and electrons where the kinetic energy (temperature) of the electrons is significantly higher than the average temperature of the system. The electron energy is sufficient to break the chemical bounds into molecules forming free radicals. As a result, free-radical chain reactions are initiated at a lower temperature as compared to thermal cracking, which precedes through an activation barrier and thus requires higher temperatures for the reactions to develop at reasonable rates. At the same time, atoms of the chemical components of the reactive mixture are activated by microwave irradiation and desired chemical reactions, such as desulphurization, can be facilitated.

[0029] Although the present microwave activated cracking process of the liquid hydrocarbons extracted from the shale or sand oil usually requires the presence of a catalyst-sensitizer, the process does not necessarily proceed through stages of chemisorption of the reagents on the catalytic surface together with the formation of intermediate compounds with the catalyst.

[0030] As noted previously, tar sand and shale oil includes minerals such as amorphous and crystalline silica together with oil fractions. Amorphous silica provides a developed surface for free radical reactions. In addition, shale oil and oil sand feedstock can potentially initiate and maintain micro-discharges under microwave irradiation. Such energy, delivered directly to the surface of the silica, is required for the anticipated cracking reactions as well as activation of heteroatoms such as sulphur, nitrogen and oxygen. However, as further noted previously, a small amount of external sensitizer, such as activated carbon as well as the sensitizers recited above and which are further disclosed in U.S. Pat. No. 6,184,427, is generally deemed required to initiate the necessary free radical chain reactions. Again, without being bound by any particular theory, it is proposed that the silica, having both amorphous and crystalline structures, cannot convert sufficient amounts of energy, taken alone, to generate the necessary micro-discharges. Thus, a small amount of external sensitizer such as 0.1 w % of activated carbon, on the surface of the oil sand or shale oil initiates the process under suitable microwave irradiation.

[0031] In carrying out the process as schematically shown in FIG. 1 has been determined that it is not necessary to mix external sensitizer with the feedstock after initiation of the present process. For example, carbon, formed during the proposed chain reactions, can act as an activating sensitizer. Such internally created carbon provides for the generation and maintenance of conditions creating free radical chain reactions and for such chain reactions to break the carbon-carbon bonds found within the hydrocarbons, and to activate sulphur, nitrogen and oxygen atoms in the organic mol-

ecules. Sulphur and nitrogen react with hydrogen and/or other additives to form inorganic compounds. A more thorough description of this process can be found in applicant's co-pending U.S. application Ser. No. 10/116,257, the disclosure of which is incorporated by reference. Such newly formed carbon is able to generate suitable micro-discharges while the amorphous silica catalyzes the above-described cracking reactions as well as the desulphurization, nitrogen and oxygen removal reactions. As a consequence, separation of the oil fraction from the surrounding minerals while cracking and catalytically converting compounds within the reactor takes place simultaneously. This thus allows for a one step continuous process for production of a marketable product, such as low sulphur fuel oil from natural feedstock, such as shale oil and oil sands.

### EXAMPLES

#### Example I

[0032] In order to demonstrate the process of the present invention, samples of oil sand were treated under the microwave irradiation. Feedstock for the testing (Examples I-IV) was supplied by Syncrude Canada Ltd. It was a typical mining product derived from deposits in Northwestern Alberta with 11-12 wt % oil fraction.

[0033] 0.7 kg of oil sand was treated under microwave irradiation (1 kW, 2450 MHz) with the addition of 1 wt % of activated carbon in a nitrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0034] 7.8 wt % of liquid fuel, with API gravity—19@60 F., viscosity—11 Cst@40° C., density—0.94 g/cm<sup>3</sup>, calorific value—18,793 BTU/lb, flash point—40° C., pour point—35° C., sulphur content—3.1 wt %, nitrogen content—0.3 wt %.

[0035] 3.2 wt % of gas fuel: methane—85 vol %, ethane—9 vol %, propane—3 vol %, butane—3 vol %.

[0036] 89 wt % of solid residue.

#### Example II

[0037] 1 kg of oil sand was treated under microwave irradiation (1 kW, 2450 MHz) with the addition of 0.1 wt % of activated carbon in a nitrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0038] 8.0 wt % of liquid fuel, with API Gravity—22@60° F. viscosity—8Cst@40° C., density—0.92 g/cm<sup>3</sup>, calorific value—19,027 BTU/lb, flash point—40° C., pour point—35° C., sulphur content—3.0 wt % nitrogen content—0.3 wt %.

[0039] 3.6 wt % of gas fuel: methane—85 vol %, ethane—9 vol %, propane—3 vol %, butane—3 vol %.

[0040] 88.4 wt % of solid residue.

#### Example III

[0041] 1 kg of oil sand was treated under microwave irradiation (3 kW, 915 MHz) with the addition of 0.1 wt %

of activated carbon in a hydrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0042] 8.4 wt% of liquid fuel, with API Gravity—32@60° F. viscosity—2.4 Cst@40° C., pour point—35° C., sulphur content—0.1 wt %, nitrogen content—0.04 wt %.

[0043] 3.6 wt % of gas fuel: methane—85 vol %, ethane—9 vol %, propane—3 vol %, butane—3 vol %.

[0044] 88 wt % of solid residue.

#### Example IV

[0045] 1 kg of oil sand was treated under microwave irradiation (3 kW, 915 MHz) with the addition of 0.1 wt % of activated carbon, 3 wt % of calcium carbonate and 2 wt % of sodium hydroxide in hydrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0046] 8.8 wt % of liquid fuel, with API Gravity—33@60° F. viscosity—2.4 Cst@40° C., density—0.85 g/cm<sup>3</sup>, calorific value—19,800 BTU/lb, flash point—40° C., pour point—35° C., sulphur content—<0.01 wt %, nitrogen content—0.02 wt %.

[0047] 3.2 wt % of gas fuel: methane—85 vol %, ethane—9 vol %, propane—3 vol %, butane—3 vol %.

[0048] 88 wt % of solid residue.

#### Example V

[0049] Feedstock for the testing (Examples V-VI) was supplied by Southern Pacific Petroleum, Australia. 1 kg of shale oil was treated under microwave irradiation (1 kW, 2450 MHz) with the addition of 0.1 wt % of activated carbon in a hydrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0050] 12.2 wt % of liquid fuel, with API Gravity—32, viscosity—2.9 Cst@40° C., density—0.88 g/cm<sup>3</sup>, calorific value—19,515 BTU/lb, flash point—59° C., pour point—25° C., sulphur content—0.06 wt %, nitrogen content—0.04 wt %.

[0051] 2.1 wt % of gas fuel: methane—86 vol %, ethane—8 vol %, propane—4 vol %, butane—2 vol %.

[0052] 85.7 wt % of solid residue.

#### Example VI

[0053] 1 kg of shale oil was treated under microwave irradiation (3 kW, 915 MHz) with the addition of 0.1 wt % of activated carbon, 3 wt % of calcium carbonate and 2 wt % of sodium hydroxide in a hydrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0054] 12 wt % of liquid fuel, with API Gravity—32, viscosity—2.9 Cst@40° C., density—0.86 g/cm<sup>3</sup>, calorific value—19,515 CTU/lb, flash point—59° C., pour point—25° C., sulphur content—0.06 wt %, nitrogen content—0.04 wt %.

[0055] 2.1 wt % of gas fuel: methane—86 vol %, ethane—8 vol %, propane—4 vol %, butane—2 vol %.

[0056] 85.7 wt % of solid residue.

#### Example VI

[0057] 1 kg of shale oil was treated under microwave irradiation (3 kW, 915 MHz) with the addition of 0.1 wt % of activated carbon, 3 wt % of calcium carbonate and 2 wt % of sodium hydroxide in a hydrogen atmosphere at ambient pressure. Residence time was 20 minutes. The product consisted of:

[0058] 12 wt % of liquid fuel, with API Gravity—32, viscosity—2.9 Cst@40° C., density—0.86 g/cm<sup>3</sup>, calorific value—19,515 BTU/lb, flash point—59° C., pour point—25° C., sulphur content—<0.01 wt %, nitrogen content—0.02 wt %.

[0059] 2.2 wt % of gas fuel: methane—86 vol %, ethane—0 vol %, propane—3 vol %, butane 2 vol %.

[0060] 85.8 wt % of solid residue.

[0061] As a preferred embodiment, it is also contemplated that microwave energy be employed in order to reduce the water content of commercially available oil sand. Surprisingly, it is determined that typical oil sand contains high water content, generally approximately 24% by weight. In determining the appropriate approach to take in removing water from oil sand prior to or at the point of introducing the mineral into the continuous process schematically shown in FIG. 1, two methods of drying were considered, that is, heating of the feedstock in a furnace at up to 250° C. and irradiating the feedstock with microwave energy. The dynamics of water removal were thus studied with the goal of estimating the optimum protocol for drying oil sand feedstock to provide dry feedstock for further microwave cracking.

[0062] In order to prepare water removal tests using microwave energy as compared to conventional heating techniques, oil sand samples again supplied by Syncrude were employed. An experimental lab reactor was established being characterized by providing microwave irradiation at a power of 1.32 kW. For different samples, the microwave power level was adjustable to 20%, 50% and 80% of the recited maximum. In each instance, a weighed portion of oil sand (about 200 g) was applied to a Pyrex beaker which was then placed within the reactor and microwave energy applied thereto. All tests which were performed were conducted under argon flow. The feedstock contained within the beaker was irradiated for a period of 15 to 20 minutes. To determine weight loss dynamics, the microwave irradiation was interrupted periodically at which point the hot beaker was removed and weighed. The test was terminated when the weight change became minimal and/or oil vapors were detected in significant amounts. Conventional drying was established similarly whereby a like sample of oil sand was heated in a resistance furnace at a temperature of 200-250° C. and, again, was periodically removed from the furnace and weighed. The duration of drying, however, was greater than that undergone in the microwave oven because of the observed lower weight loss rate in the electric resistance furnace.

[0063] As can be seen from curve 1 of FIG. 2, moisture removal (weight loss) occurs during the first five minutes of the microwave irradiation process. Weight loss of the sample then becomes fairly constant and increases again after 7½ to 10 minutes. This observation clearly indicates that oil evaporation begins at this time. After microwave irradiation, the water content of the oil sand sample was approximately 2.6 to 2.7 w %.

[0064] Certain observations can be made by reviewing FIG. 2 and the experimental data which results in the creation of the subject graph. Although water removal occurs at less than maximum microwave power, curves 2-4 of FIG. 2 indicate that total water removal amounts are lower than when maximum microwave power is employed. Further, oil evaporation begins (shown by the arrows on the graph) before all water is removed. At low microwave power (curve 4), no oil evaporation was detected even after a 20 minute exposure to microwave irradiation. It is believed that at maximum microwave power (curve 1 at FIG. 2), moisture is evaporated virtually instantly, without any significant heating of the oil sand. Complete water removal takes place within about 5 minutes under the test conditions provided herein. Further exposure leaves to heating of the oil sand itself which in turn results in evaporation of light oil fractions. If the power levels are too low (curves 2 and 3 of FIG. 2), power is not sufficient to result in rapid water vaporization. This is not an ideal situation for the sand oil particles as well as the oil retained therein are heated enough to cause some oil evaporation even before complete moisture removal has been effectuated.

[0065] As a comparison, FIG. 3 was developed to display sand oil weight loss as a function of time employing a conventional drying process at two different temperatures (curves 1, 2). Curve 3 reflects microwave drying and is provided within FIG. 3 as a simple comparison of the two recited methods of drying. In other words, curve 3 of FIG. 3 is identical to curve 1 of FIG. 2.

[0066] As FIG. 3 demonstrates, conventional drying at 200° C. provides for complete water removal (2.6-2.8%) over a period of about 30 minutes whereupon oil evaporation begins. At 250° C. (curve 2) oil evaporation begins after about 7 minutes although only approximately 1% of the retained water is removed by this time. If further water is removed, it evaporates from the sample with oil fractions. It is hypothesized that in order to remove retained water by conventional drying techniques, virtually all of the sand oil must be heated before water could be evaporated completely. At 200° C., this occurs, as noted above, in about 30 minutes. Because of this slow rate of evaporation, overheating and consequent vaporization does not take place. However, at higher temperatures, overheating leads to simultaneous vaporization of water and light oil fractions.

[0067] An attempt was made to estimate energy consumption for moisture removal from oil sand samples. It was observed that the energy required for microwave drying would be at least four times less than that required by convention drying at 200° C. The measured data in support of this conclusion is as follows:

[0068] MW drying:

[0069] Applied power: P=1.32 kW;

[0070] Time of complete water removal: T=7 min, or 0.117 h;

[0071] Weight of oil sand sample: M=0.2 kg

[0072] Energy consumption:

$$E = \frac{P \cdot T}{M} = \frac{1.32 \cdot 0.117}{0.2} = 0.772 \frac{\text{kWh}}{\text{kg}}$$

[0073] Conventional drying at 200° C.:

[0074] Applied power: P=1.32 kW;

[0075] Time of complete water removal: T=30 min., or 0.5 h;

[0076] Weight of oil sand sample: M=0.2 kg

[0077] Energy consumption:

$$E = \frac{P \cdot T}{M} = \frac{1.32 \cdot 0.5}{0.2} = 3.3 \frac{\text{kWh}}{\text{kg}}$$

[0078] Finally, reference is made to FIG. 4 showing the results of the use of a microwave energy-induced drying process for two different oil sand samples. Curve 1 is directed to a sample such as that used previously in generating the data shown in FIGS. 2 and 3. Curve 2, however, was of a different consistency having inclusions of about 1 to 3 cm which were assumed to be clay. Regarding this latter sample, it is noted that the weight loss (moisture content) is higher than for the sample generating the data of curve 1. However, it is noted that the time required for complete moisture removal for the two samples (5 to 7 minutes) is approximately the same. Also, oil evaporation began at about the same time (7.5 minutes) from beginning of the drying process. As such, it was concluded that moisture removal is not particularly dependent upon the physical or chemical nature of the sand oil.

1. A method of extracting hydrocarbon fuel from oil sand or shale comprising admixing said oil sand or shale with a sensitizer and subjecting said oil sand and sensitizer or shale and sensitizer to exposure to microwave energy.

2. The method of claim 1 wherein said microwave energy exposure is of sufficient duration and power to extract said hydrocarbon fuel from said oil sand or shale and to convert said hydrocarbon fuel to liquid and gaseous sources of energy.

3. The method of claim 1 wherein said oil sand or shale is exposed to microwave energy in an oxygen starved environment.

4. The method of claim 3 wherein said oil sand or shale is exposed to microwave energy in a hydrogen-rich environment.

5. The method of claim 3 wherein said oil sand or shale is exposed to microwave energy in a nitrogen-rich environment.

6. The method of claim 1 wherein said oil sand or shale contains an in-situ source of hydrogen during microwave irradiation.

7. The method of claim 1 wherein said sensitizers comprise a member selected from the group consisting of amorphous carbon, amorphous-dispersed metals, transition metal oxides and salts.

8. The method of claim 1 wherein said sensitizers comprise a member selected from the group consisting of NiO, CuO, Fe<sub>3</sub>O<sub>4</sub>, MnO<sub>2</sub>, Co<sub>2</sub>O<sub>3</sub> and WO<sub>3</sub>.

9. The method of claim 1 wherein a desulphurizing additive is added to said oil sand or shale during exposure to microwave irradiation.

10. The method of claim 9 wherein said desulphurizing additive comprises a member selected from the group consisting of granulated limestone, CaCO<sub>3</sub>, CaO, MgO, MgO—CaO, NaOH, KOH and NaHCO<sub>3</sub>.

11. The method of claim 6 wherein said in-situ source of hydrogen comprises NaBH<sub>4</sub>, TiH<sub>2</sub>, KH, CuH, ZnH, NaH, CzH and NiH<sub>0.5</sub>.

12. The method of claim 1 wherein said oil sand or shale further contains a catalyst.

13. The method of claim 12 wherein said catalyst comprises a member selected from the group consisting of a para ferromagnetic material, iron, copper and nickel.

14. The method of claim 9 wherein said desulphurizing additive is contained in an amount between approximately 0.5 to 25 w % based upon the weight of the fuel oil being processed.

15. The method of claim 1 wherein said oil sand or shale is exposed to microwave irradiation to reduce water within said oil sand or shale.

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