Title: PROCESS FOR SIMULTANEOUS RECOVERY AND CRACKING/UPGRADING OF OIL FROM SOLIDS

Abstract:
The present invention relates to a process for the simultaneous recovery and cracking/upgrading of oil from solids such as tar sand and oil shale. With this process a number of the obstacles with the existing technology are solved, and the process upgrades the oil into a lighter product than the existing technology, remove sulphur in the order of 40% and heavy metals in the order of 90%.
ABSTRACT

The present invention relates to a process for the simultaneous recovery and cracking/upgrading of oil from solids such as tar sand and oil shale. With this process a number of the obstacles with the existing technology are solved, and the process upgrades the oil into a lighter product than the existing technology, remove sulphur in the order of 40% and heavy metals in the order of 90%.
PROCESS FOR SIMULTANEOUS RECOVERY AND CRACKING/UPGRADING OF OIL FROM SOLIDS

The present invention is related to a process for recovery of oil from tar sand (also called oil sands) and/or oil shale and upgrading the oil in the same process.

Tar sand is found in enormous quantities in a number of countries, the greatest resources are found in Canada and consist of heavy oil and sand in natural resources in different depths. These resources have been the subject of intensive research in an effort to develop technologies for recovery of the oil from the sand. Thus, a number of different technologies exist.

Alberta’s most important mineral resources are oil and natural gas, and they account for about 90 percent of Alberta’s income from mining. Alberta produces approximately two-thirds of Canada’s oil and more than three-quarters of its natural gas. Nearly half of Alberta’s oil is mined from vast oil sands, which are deposits of a heavy crude oil called bitumen. Alberta’s oil sands represent the largest known deposits of bitumen in the world. The oil sands occur in three major areas of the province: the Athabasca River Valley in the northeast, the Peace River area in the north, and the Cold Lake region in east central Alberta. Bitumen is more costly to mine than conventional crude oil, which flows naturally or is pumped from the ground. This is because the thick black oil must be separated from the surrounding sand and water to produce a crude oil that can be further refined.

During the 1950s and 1960s, oil deposits were discovered in other regions, such as the Peace River area and the Swan Hills, south of Lesser Slave Lake. By the late 1960s the last major oil deposits had been found.

The bitumen, which contrary to normal crude found in deep reservoir, does not have the same light fractions as these, have been evaporated off over thousands of years. The bitumen thus consists of heavy molecules with a density exceeding 1,000 kg/dm³ (less than 10 API) and a viscosity 1000 times higher than light crude. In addition the tar sand contains sulphur over 4% by weight and hundreds of ppm with heavy metals. The content of organic matter in tar-sand can range from 5% by weight up to 20% by weight, and thus extraction of oil from tar sand involves huge mass transport.
Because of the composition of the bitumen, it has to be upgraded before it can be refined in a refiner as light crude.

Because of the economical potential of these huge resources, a number of different processes exist for the recovery of oil from tar sand. Such technologies involve biological, solvent, thermal and processes where the oil is washed out of the sand by superheated water.

Because of the enormous amounts of sand (tailings) associated with tar sand extraction, the different processes face a number of environmental constrains.

Contrary to tar sand, oil shale is shale containing organic matter known as kerogens which can not be washed or dissolved as for the bitumen in tar sand. To recover oil from oil shale, it must be heated to a temperature of 500 – 600 C whereby the organic matter is cracked into liquid products. As for tar sand, oil shale contains a number of unwanted constituents, which cause environmental constrains. And as for technologies for recovering oil from tar sand, there exist a number of different technologies for recovering oil from oil shale.

The present invention is related to an energy self sustained process where a number of the obstacles with the existing technologies are solved, and which in addition to the oil recovery, upgrades the oil into a lighter product than any other existing technologies, remove sulphur in the order of 40% and heavy metals in the order of 90%. In addition the process disposes of tailings with limited environmental constraints as the inorganic matter (sand) is disposed of in dry condition.

The process is a rapid "dry-wet" fluidised process where the sand is mixed into a fluidised reactor fuelled with part of the organic components in the tar sand. The combustion gases strip off the oil from the sand, together they act as a pneumatic carrier transporting sand and its associated gases to a cyclone reactor where the sand is
separated from the gas stream, which then is routed to a condenser system. A portion of the condensed oil can be routed back into the stream via an atomisation nozzle for a second cracking whereby the process recovers and upgrades the oil in one operation without the need for upgrading units.

To optimise collisions between the particles in order to obtain maximum shear forces between the solids the stream of sand, combustion gasses and hydrocarbon gasses are accelerated and retarded in a riser of varying diameter.

The collisions between the particles give rise to a mild hydrogenation of the oil by sonoluminiscence of microscopic steam bubbles trapped between the colliding solid particles. When steam bubbles are trapped between uneveness in the tumbling particles, the steam is subject to an adiabatic compression whereby the temperature and pressure in the bubbles is raised several thousand times above overall temperature and pressure in the process. This causes water to enter into a supercritical state where water is cracked into hydrogen and hydroxyl radicals. Hydrogen, which is absorbed by the heavy oil chains, reduces their bonding whereby the impact forces from the tumbling grains can crack the molecules and the “explosion” of the microscopic steam bubbles takes place. The majority of the hydrogen is then released and react back with the hydroxyl radicals into water, but a part of the hydrogen causes a mild hydrogenation of the product.

It is highly desirable to achieve good sand/oil mixing as early and as quickly as possible. The method described to achieve this requires the above-mentioned acceleration and retardation of the stream. Traditionally, steam is the medium used to maintain solid bed fluidity and movement in the riser. Steam, however, has a deleterious effect on the very hot solids that is met in residue cracking processes. Under these conditions steam causes hydrothermal deactivation of the catalyst in for example FCC-crackers.

This is overcome by the present invention by using the off gasses from the fluidised bed reactor regenerator (CO/CO2 and hydrocarbon gasses) as the carrier of the solids, which will act as a catalyst in cracking of the oil.
To have the process verified, a 2.5x2.5x3 m test rig was built and located at SINTEF ENERGY RESEARCH AS in Trondheim, Norway with a maximum power of 125 kW.

The lay-out of the rig is shown in the following drawing.

The following picture shows the rig during testing.

The energy requirement to process one kg of oil sand is given by:

\[
Q = x_s \cdot c_s \cdot dt + x_o (c_s \cdot dt + r_o) + x_w \cdot H
\]
Where:
\( x_s = \) weight part sand (including metals and sulphur), example 80%
\( x_o = \) weight part oil, example 15%
\( x_w = \) weight part water, example 5%
\( c_s = \) specific heat of sand \( \text{kJ/kgK} = 1 \text{kJ/kgK} \)
\( c_o = \) specific heat of oil at operating temperature \( \text{kJ/kgK} = \text{approx} 2.25 \text{kJ/kgK} \)
\( z_o = \) heat of evaporation \( \text{kJ/kg} = \text{approx} 225 \text{kJ/kg} \)
\( \Delta t = \) temperature difference between operating temperature and feed temperature of sand \( K \)
\( H = \) enthalpy of water at operating temperature \( \text{kJ/h} = 3500 \text{kJ} \)
Operating temperature 360 \( ^\circ \text{C} = 633 \text{K} \)
Feed temperature 90 \( ^\circ \text{C} = 363 \text{K} \)
\( \Delta t = 270 \text{K} \)

\( Q = 516 \text{kJ/kg} \) and which gives a capacity of the test rig of 872 kg/hr sand containing 130 kg oil which gives a capacity of approx. 20 bbl/day.

The tests were carried out with tar sand from the Athabasca River Valley deposits with the properties listed above where the following results were obtained:

Density of oil recovered from the fluidiser: 21 API.
Density of oil recovered in the riser: 29.3 API.
Density of oil drained from the oil condenser: 25.15 API.

Remaining coke in spent sand 1.25 W%.
Reduction of sulphur in the oil: 45%
Reduction of heavy metals: 87%
Energy consumption in % of recovered oil: 9.3 = approx. 12.5 kg oil/hr = approx. USD 3.93 per bbl. (Oil price USD 50 per bbl)

The following pictures show oil sand, recovered oil and clean sand from the test.
The process is described further in the simplified flow diagram in Fig. 1.

A) shows the vertical fluidised reactor which have a fluidising mesh B) positioned a distance from the bottom of the vessel. The space between the bottom and the fluidised mesh B) is a plenum C) which receives the combustion gasses from a combustor D) which can be fuelled either by gas and/or recovered oil. The combustion gasses will heat and fluidise the solids (sand) E) entrained in the reactor A). The pressure from the combustion gasses built up in the reactor, will cause the solids and the entrained gasses which consists of combustion gasses, steam and hydrocarbon gasses, to be pneumatically transported through a riser JJ) into a reactor cyclone G) which is so designed that, contrary to ordinary cyclones, the solids are spinning several hundred times in the cylindrical part of cyclone before falling down the conical part H) and back into the fluidiser. At the bottom of the conical part of the cyclone, superheated steam is injected into the cyclone by the pipe I) to strip off hydrocarbons between the falling solids in the cyclone which falls into the reactor A) via a dip-leg.

Oil sand is injected into the reactor A) by a feed system Cc) and Dd). The same amount of sand injected into the reactor A) has to be drained from the reactor. This is done through the pipe arrangement K) where the sand is transported to a fluidising combustor L) where remaining coke is burned off by injection of air through M). The exhaust gasses from L) are passed through a gas cleaning and heat recovery system N) before it is vented to air.

The “clean” solids from L) are routed to a solid/liquid heat exchanger O) which is heating cooling water from the heat exchanger Z) delivered from the water supply pump P). The hot water is further transported to a boiler Q) located in the combustor L). The boiler is producing steam where a part of this is routed to a super-heater R) located in the plenum C) of the reactor A). The superheated steam is routed to the injection nozzle S) for steam atomisation of oil, the dip-leg J) on the reactor cyclone H) and the dip-leg T) on the separation cyclone U). The cooled “clean” sand can be disposed of from the heat exchanger O) to a land fill as the sand will be dry and free from any volatile hydrocarbons.

Excess steam not being superheated is routed through pipe V) for preheating of feed, process purposes or for generating electricity through a steam turbine system.
From the reactor cyclone G) and the separation cyclone U) the gaseous stream is routed to a condenser W) set to about 95C whereby the main part of the oil gas is condensed into liquid oil. The gas is condensed by the mean of the recovered oil as the oil collected at the bottom of the condenser is pumped by the pump X) through a heat exchanger Z) and cooled by water delivered by the pump P). From the heat exchanger Z), the cooled oil is routed to the top of the condenser and condenses the incoming oil gasses. As the level of the oil rises in the condenser, the product is drained off through the pipe BB). The non-condensable gasses and steam are routed to a second condenser CC) which is cooled by water injected from the pump P). Condensed water is drained off from the condenser through the pipe DD) and is collected in a settling tank EE). In the settling tank EE), light oil brought over from the oil condenser CC) will be decanted off through the pipe FF) to the product line from the oil condenser W) and routed to a receiver via pipe AA). Water is drained off through the pipe GG) to drain.

Non-condensable in the condenser CC) is exhausted through the pipe HH) either to air or to a gas cleaning system depending on the local emission requirements.

A portion of the product is returned to the riser JJ) through the pipe NN) by a high pressure pump LL) to the atomisation nozzle S) attached to the riser JJ).

The atomisation nozzle S) receives the steam for the atomisation of the oil from the super heater R).

Excess formed combustion gasses in the reactor which are not needed for the transport of the sand in the riser JJ), can be vented from the reactor via the pipe OO) into a gas cleaning and heat recovery system not shown.

When the reactor is heated to operational temperature by the combustor D), the gas or oil supply for the combustion can gradually be turned off whereby the injected air will cause an internal combustion of the formed hydrocarbon gasses in the reactor A) whereby the process will be self sustained by energy extracted from the tar sand itself.
Alternatively the combustor can be fuelled with a part of the recovered oil delivered by the pump LL.

To obtain the abovementioned acceleration and retardation of the stream in the riser, this can be obtained by giving the riser varying diameters. One preferred embodiment is to form a part of the riser as a Laval nozzle where the atomisation nozzle(s) is(are) located either in the narrowest part of the ejector or where the ejector starts to expand.

The entire process is a high intensive thermal process with a high energy density because of the velocity of the gas and sand stream. Because of the velocities in the process, the intensive heat exchange between sand and oil and the low partial pressure of the hydrocarbon gasses caused by the combustion gasses and steam, the process can operate at a temperature in the range of 300 – 500 C. Apart from reduced thermal stress and energy consumption, this low temperature reduces polymerisation of the cracked product.

Fig. 2 shows an illustration of a 10,000 bbl/day plant.
Patent claims:

1. A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale, characterized in that oil containing solids are injected into a fluidised bed reactor where the hydrocarbons are evaporated off and where the heat for the evaporation is delivered by internal combustion of a part of the hydrocarbons in the solids or by an external combustor, and that the combustion gasses together with the evaporated hydrocarbons act as a pneumatic carrier of the solids and reduce the partial pressure of the hydrocarbon gasses and where the stream is routed to a cyclone reactor and further to a solids removal separator and further to a condensing system for the condensable gasses.

2. A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale, in accordance to claim 1, characterized in that a portion of the product from the condenser system is routed back to the stream in a riser via a atomisation nozzle whereby the stream of solids acts as a cracking medium by shear forces, heat exchange and sono-luminiscence.

3. A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale, in accordance to claim 1 and 2, characterized in that the riser have different diameters so as to obtain acceleration, retardation and optimised collisions between the solid particles in the stream.

4. A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale, in accordance to claim 1, characterized that the temperature in the regenerator is controlled by the injected wet oil sand into the regenerator.

5. A process for simultaneous recovery and cracking/upgrading of oil from solids such as tar sand and oil shale in accordance to claim 1, characterized in that the oil stripped sand is routed to a fluidised combustor where remaining coke on the sand is burned off
by injection of air into the combustor and where the released heat is used for production of steam, and where the exhaust gas from the combustor is alternatively routed to the plenum of the stripping reactor to participate with heat and fluidising gas for stripping of the oil trapped on the sand.

6.
A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale in accordance with claim 1, characterized in that a portion of the stripped sand is mixed with oil sand for heat recovery and homogenising of the sand improving the feed to the reactor.

7.
A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale in accordance with claim 1, characterized in that the fluidized bed reactor has two diameters, where the lower part of the regenerator has a smaller diameter than the upper part in order to reduce the gas velocities in the upper part of the regenerator.

8.
A process for simultaneous recovery and cracking/upgrading of oil from solids, such as tar sand and oil shale in accordance with claim 1, characterized in that stripped sand in the regenerator is continuously discharged from the regenerator via a pipe which outside of the regenerator has a “water” trap which may be U formed and where steam or gas is injected into the pipe opposite the “water trap” for pneumatic transport of sand falling into the trap.

9.
A process for simultaneous recovery and cracking/upgrading of oil from solids such as tar sand and oil shale in accordance with claim 1, characterized in that a battery of regenerators are arranged around a joint charging system and a joint sand receiving collector and heat recovery fluidiser (L) and where the off gasses from the regenerator share a joint sand separation system and a joint condenser set up and where cooled condensed oil acts as a condensing medium in the oil condenser by direct contact between the hot oil gasses and the cooled condensed oil.
Application number: numéro de demande: 2546940

Figures: 1 and 2

Pages: ______________________________

DRAWINGS-IP

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