ZERO EMISSION STEAM GENERATION PROCESS

Inventors: Gary L. Bunio, Calgary (CA); Ian Donald Gates, Calgary (CA); Paul Sudlow, Calgary (CA); Roger E. Anderson, Gold River, CA (US); Murray E. Propp, Calgary (CA)

Assignees: Paxton Corporation, Calgary (CA); Paramount Resources Ltd., Calgary (CA); Clean Energy Systems, Inc., Rancho Cordova, CA (US)

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ABSTRACT

This invention provides a new process to generate steam directly from untreated water produced simultaneously with thermally recovered crude oil, and to inject the steam and combustion products into a hydrocarbon reservoir to recover hydrocarbons and to sequester a portion of the carbon dioxide produced during the creation of steam. The invention removes the ongoing additional water requirements for thermal oil recovery and the need for surface treatment of produced water for re-use, yielding improved process efficiencies, reduced environmental impact, and improved economic value.
CSS

1. INJECT STEAM
2. SOAK
3. PRODUCE BITUMEN & WATER

FIG. 7
Steam Flood

Injector Steam

Heat Losses to Overburden

Producer Oil and Water

Steam Zone

Hot Oil

Heat Transfer to Oil Zone

Cold Oil

FIG. 8
ZERO EMISSION STEAM GENERATION PROCESS

FIELD OF THE INVENTION

[0001] The current invention pertains to an area of generating of steam for the thermal recovery of oil and bitumen from subsurface hydrocarbon reservoirs. Specifically, to the area of using an oxygen fuel combustor as a steam generator.

BACKGROUND OF THE INVENTION

[0002] Thermal oil recovery projects, including but not limited to Steam Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), or Steam Flooding, or recovery processes that potentially start with steam injection (e.g. in situ combustion) utilize large amounts of water in the form of steam, to carry heat energy underground to mobilize the oil, heavy oil, or bitumen. This water, typically in a ratio of three or higher parts water to one part oil, is transported back to the surface with the oil. Previous processes have required extensive water treatment and handling to clean the water prior to it being re-used as boiler feed water. For example, water treatment can involve one or more of gravity segregation, water softening, filtration, de-salting, de-oiling, and chemical treatments.

[0003] Water treatment is an essential part of any process since the introduction of the “dirty” water into the boiler would hold back or even shut down the process due to scaling of the boiler, and other process disrupting events. The build-up of the impurities in the boiler requires cleaning up of the boiler, constructing a subsidiary boiler for the maintenance periods to clean the main boiler and so on. Dealing with the impurities result in increased capital, maintenance, operating cost, and environmental impact. Usually in a traditional thermal oil recovery system the water treatment process, accounts for up to 50% of the operating costs.

[0004] Therefore, there is a need to remove the reliance of the oil production process on water treatment and cleaning operations.

[0005] Further there is a need for a process to utilize poor quality or “dirty” water, or a water that has not undergone any softening and treatment, to create steam for thermal oil recovery.

[0006] Moreover, all thermal recovery projects have ongoing water requirements to make up water losses and water treating blow down. These losses can be up to 20% per operating day. There is a need to reduce or eliminate these additional water requirements.

[0007] Further there is an environmental requirement to reduce the release of combustion by-products such as nitrous oxide components and carbon oxide components into the atmosphere.

[0008] Traditionally heating/cooling processes take place in heat exchanger vessels and devices, which have one common deficiency: all those vessels and devices used in all industries maintain a separation between reactive substances and the targets of heating or cooling. For example, all industrial boilers either use fire tubes or single or multiple pass boiler tubes, segregating water (to be heated) from the heat source (combustion zone). Similarly, glycol or ardal coolers separate the cooling media from the process fluid. This separation reduces the efficiency of the heaters and coolers substantially.

[0009] There is an opportunity to gain more efficiency and process flexibility by combining the combustion process and the feed-water intimately within a single process vessel. Commingling the combustion gases with the feed-water, removes all heat transfer surfaces and leads to higher thermal efficiency than a typical drum boiler or once-through steam generator, since no heat is lost with the stack gases. The examples of such a vessel taught in U.S. Pat. Nos. 5,680,764 and 6,170,624 among others and is referred to as “oxy-fuel steam generator” in the current application.

[0010] Thermal oil projects use large amounts of energy, and emit carbon dioxide to the atmosphere as a by-product. Canadian Patent 2,576,896 by Kresnyak and Bunio, among others, illustrates the use of oxygen burning technology to create a gas emission steam consisting predominantly of carbon dioxide, which can then be sequestered or used for enhanced oil or gas recovery. Canadian Patent Application 2,619,557 by Turta et al., among others, illustrates methods of using carbon dioxide for enhancing oil and gas recovery. In all those cases the methods of capturing carbon dioxide for use in enhanced hydrocarbon recovery are complicated and capital intensive.

[0011] It is well known in the art of enhanced oil recovery that carbon dioxide can act as a solvent and swelling agent, increasing oil recovery in some situations when injected into the oil formation.

[0012] In thermal recovery however, free gas in a reservoir may lower the in-situ reservoir temperature, which in turn will reduce oil recovery. The right mixture of carbon dioxide and steam that enables at least the same level of recovery while sequestering the greenhouse gas is required.

[0013] Therefore, there is a need for a process for generating high quality steam, that is, steam with a majority of its mass in vapour form, from the produced water without treating this water beforehand. There is a need for a new method of capturing carbon dioxide for use in thermal hydrocarbon recovery and sequestration. Finally there is a need to reduce the reliance on the make up water for the thermal oil recovery processes.

[0014] Further and other objects of the invention will become apparent to one skilled in the art when considering the following summary of the invention and the more detailed description of the preferred embodiments illustrated herein.

SUMMARY OF THE INVENTION

[0015] There is provided a new thermal process for generation of a gaseous mixture of steam and carbon dioxide, by the provision of an oxy-fuel steam generator relying on untreated water, which obviates the requirement for water handling and treatment prior to steam generation.

[0016] Specifically, the process uses the apparatus, designed as a gas generator, as a new concept of the process vessel to use subterranean waters, which are co-produced with oil, directly for steam without softening or treating prior to boiling. Thermal recovery includes, but not limited to, Steam Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), Steam Flooding, or combined steam-additive processes where the additive can be one or more of non-condensable gas, solvent, or surfactant. In addition the process captures all combustion gases produced and injects steam and combustion gases underground simultaneously, removing the ongoing requirement for make up water in thermal oil recovery.
The alternative gas generator was developed initially to create a stream of superheated steam and carbon dioxide for use in electrical power generation, and is illustrated in U.S. Pat. Nos. 5,680,764 and 6,170,624 among others. This alternative gas generator is a new generation of the process vessel that intimately commingles process fluids with heat or cooling media. In all other process vessels, the heat source or sink is physically separated by a barrier such as a metal tube wall across which heat transfer occurs. For example, all conventional boilers use either fire tubes or boiler (water) tubes to maintain a separation of combustion gases and feed-water fluids. In the original embodiment, the gas generator used demineralized water, natural gas and oxygen to create a relatively pure steam carbon dioxide mixture to power an electric turbine. At the tail end of the process, the steam was condensed for re-use and the carbon dioxide sequestered underground. The Gas Generator which can be used as oxy-fuel steam generator is manufactured by "Clean Energy Systems".

This invention expands the previous Patent Application WO 2010/101647 by Anderson et al, which demonstrated an initial embodiment of the gas generator as a replacement of a traditional boiler in a Steam Assisted Gravity Drainage (SAGD) operation. In the original disclosure, 100% quality steam and carbon dioxide are produced, with trace impurities being removed by a salt separator prior to use in a SAGD process.

This invention enables the use of the oxygen-fuel steam generator to use untreated oil field produced water to produce 100% quality steam for use in thermal oil recovery. This is accomplished by changing generator operating conditions, creating less than 100% quality steam in the steam generator, and the addition of a steam separator to remove resulting brine. Unlike all other steam generation process, all of which require water softening above approximately 5000 ppm suspended solids in boiler feed-water, this invention requires no input water conditioning at any level of suspended solids in the water.

In this application the terms "dirty water", "brackish water" and "untreated water" refer to liquids with high content of impurities approximately 500 to 20,000 ppm or higher. While the impurities may constitute salts, oils residuals and other organic and non-organic contaminants. The source of the water can be the local ground water, underground water or the water extracted from the hydrocarbons recovery process. In the preferred embodiment, the dirty water is not treated prior to introduction into the steam generator.

This invention also expands uses to all thermal oil recovery applications and discases other substances for injection, which could further improve thermal oil recovery.

According to a preferred embodiment of the invention, there is provided a steam processing system having:

a) an oxy-fuel steam generator having an inlet for fluids, a reaction chamber and an outlet. This generator adds heat directly to inlet fluids by intimately combining the combustion fuels, oxygen and water feed in the reaction chamber in sufficient proportions, for a substantially complete combustion. This system provides a steam mixture with carbon dioxide and traces of impurities in the outlet.

b) a steam separator controlling the quality of the steam mixture.

Further, the resulting steam mixture is used as an injectant in a thermal oil process.

According to another preferred aspect of the invention there is provided a steam processing system having:

an oxy-fuel steam generator with an inlet for fluids including combustion fuels, oxygen and water including a percentage of dirty returned process water having substantially over 4,000 p.p.m. suspended solids. Said generator adding heat directly to inlet fluids by intimately combining the combustion fuels, oxygen and water feed in a reaction chamber in sufficient proportions at the operating pressure substantially:

a) generally between 690 and 17,800 kPa,

b) for SAGD between 500 to 5000 kPa and preferably between 1000 and 3000 kPa.

c) for CSS at or above the fracture pressure of the reservoir.

for a substantially complete combustion. This system providing a steam mixture with carbon dioxide and traces of impurities in the outlet. The system also has a steam separator, constructed utilizing advanced inert metallurgy, and controlling the quality of the steam mixture; wherein the resulting steam mixture is used as an injectant in a thermal oil process.

According to another aspect of the invention, there is provided a method of using the steam processing system having the following steps:

a) Injecting fuel and oxygen together into a combustion chamber/flare unit;

b) Igniting the mixture/or keeping the mixture ignited;

c) Passing feed water through the combustion gases;

d) Adding additional water downstream of the flare until a desired carbon dioxide and steam mixture is attained;

e) Removing entrained impurities downstream, prior to the injection of a 100% quality steam and carbon dioxide mixture.

According to a preferred embodiment, the feed water includes untreated subterranean water, which is co-produced with oil production. The ability to use this untreated produced water will result in following advantages:

It will remove the ongoing requirement for additional water into a thermal oil recovery process such as, but not limited to, Steam Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), or Steam Flooding, or other recovery processes that start with steam injection e.g., in situ combustion. By capturing the water of combustion, once the production process is stable, no further water will be required.

It will increase the thermal efficiency of the process. By capturing heat lost to stack emissions and further piping losses, thermal efficiencies can increase by more than 10%.

It will reduce thermal oil recovery process capital and operating costs by up to 50%, through the complete removal of water treatment equipment.

According to yet another aspect of the invention there is provided a method for using a steam processing system wherein the mixture generated for injection consists largely of steam and carbon dioxide. This mixture being used as an injectant in a thermal oil process such as, but not limited to, Steam Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), Steam Flooding, or other recovery pro-
cesses that start with steam injection e.g. in situ combustion. This mixture being generated by:

- injecting fuel and oxygen together into a reaction chamber at a pressure between 690 and 17,800 kPa;
- igniting the mixture of the combustion gases/or maintaining the ignition
- passing produced water through the combustion gases;
- adding additional produced water downstream of the flame until a desired carbon dioxide, vapor steam and liquid water mixture are attained.
- removing any liquid salt water or brine downstream, prior to the injection of a substantially pure quality steam and carbon dioxide mixture.

Ultimately, the method provided above might result in a lower quality steam (<100% saturation) and carbon dioxide generated by the steam processing system.

Preferably, the fuel for the process is selected from: methane, oil, heavy oil, bitumen, emulsions, or mixtures thereof or similar fluid materials that undergo combustion with oxygen.

The method may further result in production of water condensed from injected steam and associated oil from the thermal recovery process through the injection well, a production well, an adjacent well, or combination of those.

According to yet another aspect of the invention the method may further utilize some liquid blow down water from the steam separator as process feed water, and dispose of the balance of liquid blow down water. Preferably, the method further comprises the removal of solids from liquid blow down prior to sequestration or re-use as feed water.

The method may optionally have variations such as:

- varying the fraction of carbon dioxide in the injectant stream through the use of other fuels and/or carbon dioxide recirculation.
- altering carbon dioxide in the injectant stream used to increase thermal oil recovery from a reservoir.
- adding light hydrocarbons or other substances to the mixture of steam and carbon dioxide downstream of the steam separator to act as a further solvent.

The steam processing system may further include a reservoir and surface facilities to capture the majority of produced carbon dioxide to re-inject the carbon dioxide back into the reservoir.

According to yet another aspect of the invention the steam processing systems utilized by the methods listed above may be located remotely at well sites, in contrast to the standard practice of building a central plant.

Ultimately, the method may be conducted in the way when a partial combustion is taking place to produce a synthesis gas that is delivered to a thermal oil well for injection in a thermal oil recovery process.

BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1 is a schematic flow diagram according to the preferred embodiment of the invention.
- FIG. 2A displays a pressure-temperature-solubility-viscosity map for mixtures of carbon dioxide and bitumen and FIG. 2B is an example of the viscosity of mixtures of hexane and bitumen.
- FIG. 3 is an example of a material flow diagram in the preferred embodiment of the invention.
- FIG. 4 is a schematic illustration of a conventional thermal oil recovery process.

- FIGS. 5 and 6 are side and front schematic views of Steam Assisted Gravity Drainage thermal recovery process.
- FIG. 7 is a schematic view of the Cyclic Steam Stimulation thermal recovery process.
- FIG. 8 is a schematic view of Steam Flood thermal recovery process.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Several deficiencies in current thermal oil recovery schemes known in the art are addressed in the current invention:

First, thermal recovery schemes use vast amounts of water. While modern schemes meet up to 95% of their water requirements through the re-use of produced water, some make-up water is still usually required. According to the current invention, the water is created as a byproduct of combustion, when fuel, e.g. natural gas, and oxygen are combined. This water is captured and added to the steam available for injection. This means that once the system is operating at the steady state, make-up water is no longer required. In most cases, it is expected that the process will require that a small amount of blow down water is disposed of in deep subsurface formations.

Second, thermal recovery schemes are noted to produce carbon dioxide emissions, a greenhouse gas. In this embodiment, all the carbon dioxide produced during steam generation is injected down hole. Once down hole, the majority of the carbon dioxide is retained there through dissolution in the connate water present in the reservoir. Some fraction of the carbon dioxide will also dissolve in non-produced oil in the reservoir. Potentially, some other fraction of the carbon dioxide can be chemically converted to solid form through mineralization reactions. In addition, the majority of carbon dioxide entrained in produced fluids will be captured in the surface plant, flowed through the steam generator with associated fuel gas, and injected once again. When a well is finally depleted of a resource, a significant mass of carbon dioxide will be permanently left behind, that is, sequestered, in the reservoir.

Third, the capital expenditure and equipment required to re-use produced water (produced with oil from the reservoir) in conventional thermal oil recovery schemes are immense, approaching one-half of the total capital and operating expenditure required. Because this embodiment removes the requirement for water treatment, capital costs are significantly reduced, and the environmental footprint is diminished. With the new technology, given the elimination of water treatment and handling equipment and operation, capital and operating costs will be reduced by up to 50% from that of a traditional facility system.

Fourth, the carbon dioxide that is simultaneously injected with the steam may have solvent properties when used in specific reservoirs, and specific fractions. By tuning the carbon dioxide mass fraction the impact on oil recovery can be maximized, from no incremental impact to up to 25% additional recovery.

In the first embodiment of this new process, shown in FIG. 1, the oxy-fuel steam generator directly mixes fuel such as natural gas, oxygen and feed water to generate a steam, liquid water and carbon dioxide mixture. The fuel and the Oxygen are mixed and burned in the reaction chamber which also known as a combustion chamber of the flaming unit. The feed water is added directly to this reaction chamber
into the mixture of the combustion gases while part of the impurities in the water takes part in the burning process while generating steam mixture.

[0072] The water in the inlet of the generator containing anywhere from 500 to 20,000 ppm dissolved solids. This is a substantial improvement, since the current industrial boilers have an upper limit to dissolved solids of up to 5,000 ppm. The steam generator output quality will be altered from 100% to under 60%, depending on the suspended solids present in the input water. Steam generator metallurgy will be altered to ensure corrosion will not occur in the brief contact within the steam generator. In the preferred embodiment, the carbon dioxide fraction in the steam is between 7% and 15% by mass. Carbon dioxide acts both as an agent to reduce the viscosity of oil and as a swelling agent. While oil swells, it comes out of tight pores, and since it is more mobile (viscosity is lower), it flows more readily to the production well. FIG. 1 further illustrates the use of the generated steam in several thermal oil processes. Those processes illustrated in further details in FIGS. 4 to 7. In FIG. 1 there are illustrated injection wells, receiving the steam and the production wells, from which oil and water are extracted. Consequently, after the separation of the oil from the produced water, in the oil treatment unit, the produced water is fed directly into the steam processing system without any additional treatment.

[0073] One consequence of having direct combustion of fuel with water for steam generation is that the other main product of combustion is carbon dioxide. To separate steam from the carbon dioxide is technically difficult (while preserving steam quality) and expensive. Thus, the carbon dioxide is injected with the steam and has impact on the process as a solvent in the oil. (Which lowers oil viscosity and causes oil swelling). The diagram displays the viscosity of oil-carbon mixtures versus pressure and temperature. The temperature of the oil is set by the temperature of the steam and the carbon dioxide solubility and consequent viscosity of the oil is set by both the temperature and partial pressure of the carbon dioxide in the vapore chamber in the recovery process. Thus, an additional benefit of the steam is the capability to inject steam plus carbon dioxide (a solvent and oil swelling agent) into the reservoir. FIG. 2A displays this. Further addition of heavier solvents into the steam-carbon dioxide mixture can be made. This addition lowers the oil phase viscosity even lower than that with steam-alone and steam-carbon dioxide injection thus yielding even higher oil rates.

[0074] The fraction of carbon dioxide can be varied to achieve the optimum economic recovery from the reservoir by changing the volume percent of carbon dioxide in the injectant stream through the use of other fuels and/or carbon dioxide recirculation. FIG. 2A displays a pressure-temperature-solubility-viscosity map for mixtures of carbon dioxide and bitumen. While “x” denotes the mole fraction of the carbon dioxide dissolved in the oil phase. The solubility presented is the solubility of carbon dioxide in the bitumen at a given temperature and partial pressure of carbon dioxide in the injectant stream. The isoviscosity lines reveal that the viscosity of the carbon dioxide and bitumen versus temperature and pressure can be altered by varying the solubility, in other words the temperature and partial pressure, of the carbon dioxide in the injectant stream. The partial pressure of the carbon dioxide in the injectant stream is set by the total injection pressure and the volume percent of carbon dioxide in the injectant stream. Also, the temperature of the injectant stream is set by the partial pressure of the steam in the stream.

Thus, there is a competition between the steam temperature (higher temperature means lower oil viscosity) and carbon dioxide partial pressure (higher carbon dioxide content means more dissolved in oil which means lower oil viscosity). For bitumen production processes such as SAGD, the production rate is mainly proportional to the oil mobility (ratio of oil effective permeability and oil viscosity) thus the optimum reduction of the oil viscosity can be realized by using varying amounts of carbon dioxide in the injectant stream. Other solvents beyond carbon dioxide can be added to the injectant stream to further reduce the oil viscosity. For example, propane, butane, pentane, hexane, natural gas condensates, diluent, naphtha and combinations can be added to the injectant stream to reduce the oil viscosity below that achieved by dissolving carbon dioxide in the oil phase. By example, FIG. 2B displays viscosity of a mixture of hexane and bitumen versus volume percent of hexane. Solvents such as propane, butane, pentane, hexane, natural gas condensates, diluent, naphtha and combinations can be expensive thus adding carbon dioxide to the injectant will reduce the overall cost of the solvent package (solvent plus carbon dioxide) added to the injected steam.

[0075] FIG. 3 shows an example of the mass balance of the system of the steam processing unit comprising the oxy-fuel steam generation of FIG. 1.

[0076] Downstream of the steam generator, a high-pressure steam separator removes the liquid water fraction from the 100% to 60% steam & carbon dioxide mixture (blow-down water). The metallic composition of the steam separator is critical to the success of the new process. Previous steam separators used with conventional or direct-fired boilers limited the brine composition because of corrosion and erosion issues. In this embodiment the separator is constructed of an extremely inert metal, such as Hastelloy Inconel, which allow the liquid water to be saturated with extremely corrosive salts, metals and combustion products. This water may be re-injected directly for steam generation, unlike traditional boilers where this blow down water must be disposed of and make-up water must be added. In this embodiment only water superficial to steam requirements is disposed of through injection. In all cases the water is re-injected deep underground along with all corrosive and combustion products, some of which in traditional thermal oil recovery processes is released to the atmosphere.

[0077] From the high-pressure separator, the steam carbon dioxide mixture flows to one or more injection wells to deliver it to the underground reservoir. The mixture of steam and carbon dioxide may be delivered at any pressure between 690 to 17,800 kPa (100 and 2,000 psi) and at any steam quality between 65 and 100%, dependent only on retaining enough liquid water to suspend the solids entrained in the produced water input. Recommend range of conditions of operation between 500 kPa and 12,000 kPa while the preferred range for SAGD is 500 to 5000 kPa and most preferred is between 1000 and 3000 kPa. Preferred operational range for CSS is at or above the fracture pressure of the reservoir. With regards to steam quality—the preferred value is 100% (but in practice it is >90% for SAGD and ~65% for CSS).

[0078] After sufficient residence time in the reservoir to allow for heat transfer, the condensed steam—water—is produced by production well. The injection well may also act as a production well alternatively an adjacent well or wells may be used for oil production. The water and oil are then
separated in conventional oil field separation equipment, and the “dirty” produced water is fed untreated to the inlet of the oxy-fuel steam generator.

[0079] The oxy-fuel combustor which may be used as an oxy-fuel steam generator is produced, for example, by Clean Energy Systems. The oxygen for the process can be provided by any means known in the art such as cryogenic methods, pressure swing from the air techniques or any other air treatment devices.

[0080] The additional benefits of the new system are as follows: The new oxy-fuel combustor is small and modular and can be easily moved around the field whereas old ones were very large and are never or rarely moved. Further, given nature of steam generation in new generator (direct contact of combustion front and water), heat transfer is much more efficient. In the prior art, combustion heats pipe which heats water to steam within. In the new one, there are no pipes, therefore no pipe heat losses occurs reducing heat transmission inefficiencies. The steam quality from new generator can be high or close to 100%, since impurities are driven convexly through system. In old generator, the steam was often generated at lower quality to prevent build-up of solids in the pipes. Since there are no pipes in the new design, the build-up of solids is not an issue.

[0081] In a second embodiment, the process uses the steam generator and separator combinations directly at the remote well site (at satellite locations in the oil field) instead of conventional practice where they are located at a central plant. Fuel (e.g. natural gas), oxygen, and produced water are piped to the remote satellites where the steam generators can be sited. In this embodiment, the location is no longer tied to an extensive and expensive water treatment apparatus. The suggested capacity for the remote oxy-fuel steam generator is about 20 MW. However, the sizes and capacities of those generators may vary according to the requirements of the industry.

[0082] In a third embodiment of the invention, the oxy-fuel steam generator can use partially enriched air, with up to 10% remaining nitrogen content, instead of pure oxygen. The use of lower purity oxygen as the oxidizer may increase nitrogen oxides (NOx) in combustion gases, but since all combustion products are injected underground, there are no ill environmental effects.

[0083] FIG. 4 shows a conventional thermal oil process, with the water treatment block and water disposal and make-up streams highlighted. These water treatment process blocks have been required for all previous technologies because all previous thermal oil processes use either current industrial boilers, which have an upper limit to dissolved solids of up to 5,000 ppm with much lower thresholds for water hardness and silica, or have referenced operating conditions for direct fired boilers which require “dirty water” to still be below thresholds which require softening. Those process blocks are all eliminated in the proposed embodiment.

[0084] In a typical thermal oil recovery process, the water treatment and handling capital and operating expenses can approach 50% of the total capital and operating costs. The equipment required to achieve the required water quality can constitute up to one-half of the surface facility of a thermal oil project. This invention thus has the result of drastically lowering capital and operating costs as well as a footprint of the facility.

[0085] A fourth embodiment of the invention, allows for the use of heavier fuels, such as distillate or heavy fuel oil, to create a larger fraction of carbon dioxide, as high as 35%. In this embodiment, the carbon dioxide mass fraction is tuned to the reservoir and oil parameters to maximize recovery.

[0086] A fifth embodiment of the invention allows for the addition of lighter hydrocarbons or other compounds to the steam carbon dioxide stream downstream of the steam separator, to act as additional solvents for use in hydrocarbon recovery.

[0087] A sixth embodiment of the invention allows for partial oxidation of the fuel which, together with pyrolysis and aquathermolysis, can produce a synthesis gas (consists of water, hydrogen, carbon dioxide, and carbon monoxide) which can be injected into the oil formation to enable oil recovery and partial upgrading if the injected gas is at sufficiently temperatures to enable in situ gasification of the oil (typically above about 300° C.).

[0088] Another benefit of injection of the water with trace amounts of oil and impurities into the oxy-fuel steam generator, is the use of those impurities as a fuel during the burning process. In this case, the impurities are incinerated and provide additional heat energy for steam generation. Up to 80% of the oil in the water may be consumed during this process.

[0089] The steam generated from the oxy-fuel steam generator can be used in various thermal oil recovery projects such as those illustrated in FIGS. 5, 6, 7, and 8. However, this process can be also used in other industries requiring the use of steam. Those industries may include oil and gas industries, chemical manufacturing industries, food industries, pharmaceutical industries and other. The process can be tailored to the requirement of the gas, allowed rate of impurities in the steam and the quality of the water.

[0090] While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system are possible and are within the scope of the invention. For example, the relative dimensions of various parts, the materials from which the various parts are made an operating parameter can be varied, so long as the system and methods retain the advantages discussed herein. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

[0091] As many changes therefore may be made to the preferred embodiment of the invention without departing from the scope thereof. It is considered that all matter contained herein be considered illustrative of the invention and not in a limiting sense.

1. A steam processing system comprising:
   a) an oxy-fuel steam generator having an inlet for fluids, said generator adding heat directly to inlet fluids by intimately combining the combustion fuels, oxygen and water feed in a reaction chamber in sufficient proportions, for a substantially complete combustion; this system providing a steam mixture with carbon dioxide and traces of impurities in the outlet; and
   b) a steam separator, utilizing advanced inert metallurgy, controlling the quality of the steam mixture; wherein the resulting steam mixture is used as an injectant in a thermal oil process.

2. A method of using the steam processing system of claim 1, said method comprising:
a) Injecting fuel and oxygen together into a reaction chamber. 
b) Igniting the mixture. 
c) Passing feed water through the combustion gases. 
d) Adding additional water downstream of the flame until a desired carbon dioxide and steam mixture is attained. 
e) Removing entrained impurities downstream, prior to the injection of a 100% quality steam and carbon dioxide mixture.

3. The method of claim 2, wherein the feed water comprises untreated subterranean water which may contain unlimited suspended solids (greater than 5,000 ppm) hardness and any other components, that is co-produced with oil production.

4. The method of claim 2, wherein the mixture generated for injection consists largely of steam and carbon dioxide for use as an injectant in a thermal oil process such as, but not limited to, Steam Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), Steam Flooding, or other thermal recovery processes that start with steam injection e.g. in situ combustion; 
the mixture being generated by: 
 a) injecting fuel and oxygen together into a reaction chamber at a pressures between 690 and 17,800 kPa;  
b) igniting the mixture;  
c) passing produced water through the combustion gases;  
d) adding additional produced water downstream of the flame until a desired carbon dioxide, vapour steam and liquid water mixture is attained;  
e) removing any liquid salt water or brine downstream, prior to the injection of a substantially pure quality steam and carbon dioxide mixture.

5. The method of claim 2 wherein lower quality steam (<100% saturation) and carbon dioxide is generated by steam processing system.

6. The method of claim 2 wherein the fuel is selected from: methane, oil, heavy oil, bitumen, emulsions, or mixtures thereof or similar fluid materials that undergo combustion with oxygen.

7. The method of claim 2 further comprising production of water condensed from injected steam and associated oil from the thermal recovery process through the injection well, an adjacent well, or both.

8. The method of claim 2 further comprising the use of some liquid blowdown water from a steam separator as process feed water, and disposing of the balance of liquid blowdown water.

9. The method of claim 8 further comprising the removal of solids from liquid blowdown prior to sequestration or re-use as feed water. 

10. The method of claim 2 further comprising varying the fraction of carbon dioxide from 1 to 50 volume percent of the injectant stream through the use of other fuels and/or carbon dioxide recirculation.

11. The method of claim 10, further comprising altering carbon dioxide in the injectant stream used to increase thermal oil recovery from a reservoir where the carbon dioxide is ramped up from 1 to 50 volume percent as the recovery process evolves or ramped down from 50 to 1 volume percent as the recovery process evolves.

12. The method of claim 2, further comprising operating the reservoir and surface facilities to capture the majority of produced carbon dioxide to re-inject the carbon dioxide back into the reservoir.

13. The method of claim 2, further comprising locating steam processing systems remotely at well sites, as opposed to the standard practice of building a central plant.

14. The method of claim 2, further comprising adding light hydrocarbons or other substances to the mixture of steam and carbon dioxide downstream of the steam separator to act as a further solvent.

15. The method of claim 14 where the preferred solvent is propane, butane, pentane, hexane, natural gas condensates, diluent, naphtha and combinations.

16. The method of claim 2, wherein partial combustion is taking place to produce a synthesis gas that is delivered to a thermal oil well for injection in a thermal oil recovery process. This is accomplished through the partial oxidation of the fuel which, together with pyrolysis and aquathermolysis, can produce a synthesis gas (consists of water, hydrogen, carbon dioxide, and carbon monoxide) which can be injected into the oil formation to enable oil recovery and partial upgrading if the injected gas is at sufficient temperatures to enable in situ gasification of the oil (typically above about 300° C.).

17. A steam processing system comprising:
an oxy-fuel steam generator having an inlet for fluids including combustion fuels, oxygen and water including a percentage of dirty returned process water having substantially over 4,000 ppm suspended solids, said generator adding heat directly to inlet fluids by intimately combining the combustion fuels, oxygen and water feed in a reaction chamber in sufficient proportions at a pressure substantially 
a) generally between 690 and 17,800 kPa,  
b) for SAGD between 500 to 5000 kPa and preferably between 1000 and 3000 kPa.  
c) for CSS at or above the fracture pressure of the reservoir  
for a substantially complete combustion; this system providing a steam mixture with carbon dioxide and traces of impurities in the outlet; and  
a steam separator, constructed utilizing advanced inert metallurgy, and controlling the quality of the steam mixture; wherein the resulting steam mixture is used as an injectant in a thermal oil process.

18. A method of using the steam processing system of claim 17, said method comprising: 
a) Injecting fuel and oxygen together into a reaction chamber.  
b) Igniting the mixture.  
c) Passing feed water through the combustion gases;  
d) Adding additional water downstream of the flame until a desired carbon dioxide and steam mixture is attained;  
e) Removing entrained impurities downstream, prior to the injection of a substantially pure quality steam and carbon dioxide mixture.

19. The method of claim 18, wherein the feed water comprises untreated subterranean water which may contain unlimited suspended solids (greater than 5,000 ppm) hardness and any other components, that is co-produced with oil production.

20. The method of claim 19, wherein the mixture generated for injection consists largely of steam and carbon dioxide for
use as an injectant in a thermal oil process such as, but not limited to, Steam Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), Steam Flooding, or other thermal recovery processes that starts with steam injection such as in situ combustion;

the mixture being generated by:

a) injecting fuel and oxygen together into a reaction chamber and igniting the mixture;

b) passing produced water through the combustion gases;

c) adding additional produced water downstream of the flame until a desired carbon dioxide, vapour steam and liquid water mixture is attained;

d) removing any liquid salt water or brine downstream, prior to the injection of a substantially pure quality steam and carbon dioxide mixture.

21. The method of claim 18 wherein lower quality steam (<100% saturation) and carbon dioxide is generated by said steam processing system.

22. The method of claim 18 wherein the fuel is selected from: methane, oil, heavy oil, bitumen, emulsions, or mixtures thereof or similar fluid materials that undergo combustion with oxygen.

23. The method of claim 18 further comprising production of water condensed from injected steam and associated oil from the thermal recovery process through the injection well, an adjacent well, or both.

24. The method of claim 18 further comprising the use of some liquid blowdown water from the steam separator as process feed water, and disposing of any balance of liquid blowdown water.

25. The method of claim 24 further comprising the removal of solids from liquid blowdown prior to sequestration or re-use as feed water.

26. The method of claim 18, further comprising varying the fraction of carbon dioxide from 1 to 50 volume percent of the injectant stream through the use of other fuels and/or carbon dioxide recirculation.

27. The method of claim 26, further comprising altering carbon dioxide in the injectant stream used to increase thermal oil recovery from a reservoir where the carbon dioxide is ramped up from 1 to 50 volume percent as the recovery process evolves or ramped down from 50 to 1 volume percent as the recovery process evolves.

28. The method of claim 18, further comprising operating reservoir and surface facilities to capture the majority of produced carbon dioxide to re-inject the carbon dioxide back into the reservoir.

29. The method of claim 18, further comprising a modular transportable steam processing system and locating said system remotely at well sites, as opposed to the standard practice of building a central plant.

30. The method of claim 18, further comprising adding light hydrocarbons or other substances to the mixture of steam and carbon dioxide downstream of the steam separator to act as a further solvent.

31. The method of claim 30 where the preferred solvent is selected from propane, butane, pentane, hexane, natural gas condensates, diluents, naphtha and combinations thereof.

32. The method of claim 18, wherein partial combustion is taking place to produce a synthesis gas that is delivered to a thermal oil well for injection in a thermal oil recovery process accomplished through the partial oxidation of the fuel which, together with pyrolysis and aquathermolysis, can produce a synthesis gas consisting of mixtures of water, hydrogen, carbon dioxide, and carbon monoxide injected into the oil formation to enable oil recovery and partial upgrading if the injected gas is at sufficient temperatures to enable in situ gasification of the oil (typically above about 300 °C.).

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