The present invention relates to an oil recovery process with composition-adjustable multi-component thermal fluid, the process comprises: adding oxygen produced by air together with fuel and water into a reactor, in which the oxygen and the fuel combust to produce flue gas and heat, the heat heats water to generate hot water/steam, and then the flue gas and the hot water/steam are mixed to form multi-component thermal fluid, wherein the purity of oxygen added into the reactor is controlled so as to produce the multi-component thermal fluid with various mass ratios of flue gas to hot water/steam; then the obtained multi-component thermal fluid with various mass ratios of flue gas to hot water/steam are injected into various types of oil reservoirs for oil recovery. The oil recovery process of the present invention is applicable for various types of crude oil reservoirs.
OIL RECOVERY PROCESS WITH COMPOSITION-ADJUSTABLE MULTI-COMPONENT THERMAL FLUID (MCTF)

TECHNICAL FIELD

[0001] The present invention relates to an oil recovery process with multi-component thermal fluid, and especially to an oil recovery process with composition-adjustable multi-component thermal fluid.

BACKGROUND OF THE RELATED ART

[0002] The heavy oil resources are widely distributed all over the world, and their reserves are enormous. The OOP of heavy oil only in Canada reach 400 billion cubic meters, which is twice the crude oil reserves in the Middle East. However, the heavy oil has a high content of colloidal asphaltene, high viscosity and poor mobility, and thus is difficult to recover. Steam thermal recovery is a method which is verified to effectively improve recovery efficiency of heavy oil. This method is carried out through the following steps: producing high-temperature (above 300°C) steam by a steam boiler on the ground; injecting the steam into the stratum by tubing; and then the injected steam condenses and releases heat in the stratum so as to heat the rock and fluids in the stratum. The viscosity of the crude oil is reduced and the mobility thereof increases after warming up, so that the crude oil is easy to output.

[0003] The steam boiler used in the oilfield generally uses heavy oil (or crude oil) as fuel, and the flue gas produced by combustion are emitted directly. Such a boiler has the following three problems: firstly, the combustion of the fuel produces considerable carbon dioxide, the direct emission of which will result in greenhouse effect; secondly, the direct combustion of the crude oil without deep processed will produce considerable acidic gases (SOx and NOx), which causes serious environmental contamination; finally, parts of the thermal energy are taken away by exhausted gases, which causes a low availability of the thermal energy. At present, the thermal efficiency of the steam-injection boiler for oilfield is only 80%–87%. If a thermal recovery well needs injection of 3000 t steam, 180 t crude oil is required to be combusted, which results in 560 t carbon dioxide, 1.8 t sulfur dioxide (the sulfur contained in the crude oil is 1% by mass), and 0.47 t NOx to be produced. The direct emission of these gases will cause environmental problem, and the recycling in return greatly increases the cost for oil recovery.

[0004] Researches show that, the addition of noncondensable gases such as carbon dioxide and nitrogen into the steam will form multi-component thermal fluid, which can improve the thermal recovery yield. This is because, the carbon dioxide entered the oil layer is easy to be dissolved in the crude oil, which plays the role of significantly reducing the viscosity of heavy oil; the carbonic acid formed by dissolving of the carbon dioxide in water plays the role of removing plug in the stratum, whereas the nitrogen is difficult to compress, therefore the nitrogen entered the oil layer plays the role of expanding the spread range of the multi-component thermal fluid, increasing energy and maintaining pressure for stratum, and improving the water recovery rate during thermal recovery.

[0005] The latest researches show that, the injection of the multi-component thermal fluid formed by mixing the flue gas produced by direct combustion of the fuel and air with water steam into the oil reservoir can solve the three problems faced by the traditional steam boiler. The new process cannot only reduce the emission of harmful gases and increase the thermal energy availability, but also effectively utilize the flue gas so as to improve the thermal recovery yield of the heavy oil.

[0006] However, the flue gas produced by the direct combustion of the fuel and air has a fixed composition, that is, the mass ratio of the main ingredients, carbon dioxide and nitrogen of the flue gas is fixed, which cannot be changed at will. Therefore, the multi-component thermal fluid formed by mixing the flue gas and water steam have a fixed composition, that is, a fixed mass ratio of carbon dioxide, nitrogen and water steam. Therefore, the existing oil recovery process with multi-component thermal fluid is unable, due to the relatively fixed composition of the multi-component thermal fluid, to adjust the composition with regard to various types of oil reservoirs, and thus is unable to obtain the multi-component thermal fluid with the optimal composition to be possessed for achieving the optimal thermal recovery effect of various types of oil reservoirs, therefore, the existing oil recovery processes of multi-component thermal fluid have limited application range and efficiency.

[0007] Therefore, there is a need for an oil recovery process with composition-adjustable multi-component thermal fluid so as to adapt to the exploitation of various types of crude oil reservoirs and obtain an excellent thermal recovery effect and recovery efficiency.

CONTENT OF THE INVENTION

[0008] The purpose of the present invention is to provide an oil recovery process with composition-adjustable multi-component thermal fluid.

[0009] During the study, the inventor of the present application found that the carbon dioxide can easily dissolve in the crude oil reservoir to play the role of reducing viscosity, so as to improve the recovery efficiency of the oil reservoir; whereas, the nitrogen has a poor dissolving capacity in the crude oil and the stratum. The nitrogen is present in the stratum in the form of free gas, which will reduce the average temperature of the oil reservoir, weaken the effect of viscosity reduction, and thus affect the thermal recovery effect. However, on the other hand, the nitrogen can increase the stratum energy, expand the heating range, and play a positive role in improving the thermal recovery effect of crude oil. Therefore, as to exploiting a crude oil with high viscosity, viscosity reduction is the most important; as to exploiting a crude oil with low viscosity and an obvious oil reservoir deficit, the supplement of stratum energy is more important. Therefore, when exploiting various types of oil reservoirs, in addition to adjusting the temperature, the composition of the multi-component thermal fluid should also be adjusted, so as to obtain the best thermal recovery effect.

[0010] The oil recovery process with composition-adjustable multi-component thermal fluid of the present invention, comprises: adding oxygen produced by air together with the fuel and water into a reactor, in which the oxygen and the fuel combust to produce the flue gas and heat, the heat heats the water to generate hot water/steam, and the flue gas and the hot water/steam are mixed to form the multi-component thermal fluid, wherein the purity of oxygen added into the reactor is controlled so as to produce the multi-component thermal fluid with various mass ratios of flue gas to hot water/steam; then the obtained multi-component thermal fluid with various
mass ratios of flue gas to hot water/steam are injected into various types of oil reservoirs for oil recovery.

[0011] In one embodiment of the present invention, the purity of oxygen added into the reactor is controlled according to the viscosity of the various types of oil reservoirs, the higher the viscosity of the oil reservoirs, the relatively higher the purity of oxygen added into the reactor, and the lower the viscosity of the oil reservoirs, the relatively lower the purity of oxygen added into the reactor.

[0012] In one embodiment of the present invention, as for the oil reservoirs with a viscosity of greater than 10,000 mPa·s, the purity of oxygen added into the reactor is controlled to be 50%-90%; as for the oil reservoirs with a viscosity of 150-10,000 mPa·s, the purity of oxygen added into the reactor is controlled to be 30%-50%; as for the oil reservoirs with a viscosity of 50-150 mPa·s, the purity of oxygen added into the reactor is controlled to be 21%-30%.

[0013] In one embodiment of the present invention, when the purity of oxygen added into the reactor is 50%-90%, multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.20-0.37 is obtained; when the purity of oxygen added into the reactor is 30%-50%, multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.36-0.61 is obtained; and when the purity of oxygen added into the reactor is 21%-30%, multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.31-0.62 is obtained.

[0014] In one embodiment of the present invention, the purity of oxygen added into the reactor is controlled to be 50%-90% so as to obtain multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.20-0.37, the multi-component thermal fluid at a temperature of 250°C-350°C is injected into an oil reservoir with a viscosity of greater than 10,000 mPa·s to carry out oil recovery in a manner of multi-component thermal fluid assisted gravity drainage thermal recovery.

[0015] In one embodiment of the present invention, the purity of oxygen added into the reactor is controlled to be 30%-50% so as to obtain multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.36-0.61, the multi-component thermal fluid at a temperature of 250°C-350°C is injected into an oil reservoir with a viscosity of 150-10,000 mPa·s to carry out oil recovery in a manner of cyclic multi-component thermal fluid stimulation thermal recovery.

[0016] In one embodiment of the present invention, the purity of oxygen added into the reactor is controlled to be 21%-30% so as to obtain multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.31-0.62, the multi-component thermal fluid at a temperature of 150°C-250°C is injected into an oil reservoir with a viscosity of 50-150 mPa·s to carry out oil recovery in a manner of multi-component thermal fluid flooding thermal recovery.

[0017] As used herein, the term “hot water/steam” refers to hot water and/or water steam, including the condition where the hot water and the water steam coexist.

[0018] As used herein, the term “fuel” comprises fuels commonly used in the art, which include, but are not limited to, diesel oil, natural gas, and the like.

[0019] As used herein, the term “flue gas” refers to gaseous combustion product generated by the combustion of air/oxygen, which mainly comprises carbon dioxide, nitrogen, and the like.

[0020] In the oil recovery process of the present invention, the oxygen produced by air can be prepared by any oxygen production methods commonly used in the art, for example, various purities of oxygen can be produced by supplying the pressurized air to an oxygen production device, e.g., a pressure swing adsorption device.

[0021] In the oil recovery process of the present invention, the reactor to be used may be a multi-component thermal fluid generator, for example, a type II multi-component thermal fluid generator from Jiangsu Dajiugang petroleum Technology Co., Ltd., may be used.

[0022] In the oil recovery process of the present invention, the ratio of the fuel to oxygen added into the reactor depends on the property of the fuel (e.g., diesel oil or natural gas) and the purity of the oxygen, and the specific ratio can be determined by an operator according to the actual condition. In addition, the ratio of the fuel to water can be selected by an operator according to the specific oil reservoir condition (mainly the temperature of the multi-component thermal fluid).

[0023] In one embodiment of the present invention, the obtained composition-adjustable multi-component thermal fluid can be injected into the crude oil reservoir in a manner that is commonly used in the art, for example, in a manner of tubing injection.

[0024] The injection temperature of the multi-component thermal fluid can be determined according to the oil reservoir condition of the crude oil, and the temperature generally is 120-350°C. The injection rate of the multi-component thermal fluid is generally determined according to the device capacity, injection pressure and fracture pressure of the oil reservoir. Generally, under the precondition that the injection pressure is maintained to be no more than the fracture pressure, the injection rate is increased as much as possible to shorten the working cycle, for example, the injection rate of the multi-component thermal fluid generally is 150 m³/d-350 m³/d.

[0025] With regard to various types of crude oil reservoirs, the process of the present invention can adjust the content of carbon dioxide in the flue gas by use of the produced oxygen with various purities, so as to adjust the ratio of flue gas (nitrogen, carbon dioxide, etc.) to hot water/steam.

[0026] When carrying out oil recovery for an oil reservoir with a viscosity of more than 10,000 mPa·s in a manner of multi-component thermal fluid assisted gravity drainage thermal recovery, the viscosity of the crude oil and the steam chamber to be formed are crucial. The increase of the carbon dioxide proportion in the multi-component thermal fluid and the increase of the temperature of the multi-component thermal fluid can effectively reduce the viscosity of the heavy oil. Although the increase of the nitrogen proportion can expand the volume of the steam chamber, the temperature of the steam chamber is reduced in the meantime. Therefore, the mass ratio of the flue gas to the hot water/steam in the multi-component thermal fluid should be within 0.20-0.37, which can be achieved by controlling the purity of the oxygen added into the reactor to be 50%-90%.

[0027] When carrying out oil recovery for an oil reservoir with a viscosity of 150-10,000 mPa·s in a manner of cyclic multi-component thermal fluid stimulation, as the stimulation cycle increases, the stratum pressure gradually reduces, and thus the stimulation effect becomes poor. For the purpose of supplementing the stratum energy, it is required to increase the nitrogen proportion in the multi-component thermal fluid and thus to increase the stratum pressure. However, in order
that the nitrogen does not affect the average temperature of the stratum, the nitrogen proportion should not be too large as well. Therefore, the mass ratio of the flue gas to the hot water/steam in the multi-component thermal fluid should be within 0.36-0.61, which can be achieved by controlling the purity of the oxygen added into the reactor to be 30%-50%.

[0028] When carrying out oil recovery for an oil reservoir with a viscosity of 50-150 mPa.s in a manner of multi-component thermal fluid flooding thermal recovery, it is required to try to increase the nitrogen proportion in the multi-component thermal fluid and increase the displacement conformance factor, but the temperature of the multi-component thermal fluid should not be too high (if the temperature of the multi-component thermal fluid is too high, the heat is absorbed by water after entering the oil reservoir, and thus the heating capacity is limited). Therefore, the mass ratio of the flue gas to the hot water/steam in the multi-component thermal fluid should be within 0.31-0.62, which can be achieved by controlling the purity of the oxygen added into the reactor to be 21%-30%.

[0029] The oil recovery process with composition-adjustable multi-component thermal fluid of the present invention, not only possesses the advantages of zero exhaust emission, high thermal efficiency and improved steam thermal recovery effect possessed by the conventional oil recovery process with multi-component thermal fluid, but more importantly, the oil recovery process of the present invention can continuously adjust the content of carbon dioxide in the flue gas by simply and continuously adjusting the purity of the oxygen, for example, reducing the content of carbon dioxide in the multi-component thermal fluid by increasing the concentration of the oxygen. Therefore, the oil recovery process of the present invention can optimize the composition of the multi-component thermal fluid according to the features of the crude oil reservoir and oil recovery methods, and thus provide multi-component thermal fluid with an optimal composition for various types of crude oil thermal recovery, so as to obtain the maximal income with the minimal investment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] FIG. 1 is a schematic flow diagram of an oil recovery process with composition-adjustable multi-component thermal fluid according to one embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0031] The present application will be further described in detail hereinafter with reference to the drawing, so that a person skilled in the art is able to carry out the present application. It should be understood that, other embodiments may be applied, and suitable changes may be made without departing from the spirit or scope of the present application. In order to avoid the details which are unnecessary for a person skilled in the art to carry out the present application, the description may omit certain information that is known by a person skilled in the art. Therefore, the following detailed description should not be construed in the sense of limitation, and the scope of the present application is merely defined by the appended claims.

EXAMPLE 1

[0032] The viscosity of the heavy oil reservoir is 19,000 mPa.s, which belongs to extra-heavy oil reservoir. The burial depth of this oil reservoir is 1100 m, with a permeability of 1000 mD and oil layer thickness of 70 m. After depressurizing recovery, the pressure of the oil reservoir is 4.5 MPa. With regard to the oil reservoir with such viscosity, the multi-component thermal fluid assisted gravity drainage thermal recovery is carried out by use of a double-horizontal well. The temperature of the multi-component thermal fluid is set to be 270°C, and the length of the horizontal segment is 200 m.

[0033] With reference to FIG. 1, the air is compressed to 1.0 MPa by use of an air compressor 1 (Ingersoll Rand V160-12 type air compressor), and then the compressed air passes through a pressure swing adsorption (PSA) oxygen generating device 2 (pressure swing adsorption (PSA) oxygen generating device A004, manufactured by Wuxi Zhongxin air separation device co., Ltd) so as to obtain oxygen with a pressure of 0.2-0.3 MPa and a purity of 85%. The oxygen with a purity of 85% is compressed by a supercharger 3 (German BAUER K52.14 type supercharger) to 21 MPa and then injected into a multi-component thermal fluid generator 4 (type II multi-component thermal fluid generator from Jiaxing Dajiang petroleum technology Co., Ltd), and meanwhile, water and diesel oil with a mass ratio of 25.2 (the mass ratio herein refers to 25:2.1, and the same hereinafter) is injected into the multi-component thermal fluid generator 4, and the mass ratio of oxygen to diesel oil to be injected is allowed to be 14.6. The oxygen and diesel oil are mixed and combusted to produce flue gas in the multi-component thermal fluid generator 4, and meanwhile, the heat produced by combustion heats the injected water into water steam. Upon the blend of the flue gas and the water steam, multi-component thermal fluid where the mass ratio of the flue gas to the water steam is 0.21 is obtained. Subsequently, the multi-component thermal fluid is injected into an oil reservoir through an injection well, and finally are output from a producing well. Upon the calculation of numerical modeling software CMG, the final recovery efficiency of the oil reservoir reaches 56.7%.

EXAMPLE 2

[0034] The viscosity of the heavy oil reservoir is 2,200 mPa.s, the burial depth of the oil reservoir is 1,000 m, the permeability of the oil layer is 4500 mD, the thickness of the oil layer is 10 m, and the pressure of the middle of the oil reservoir is 10 MPa. With regard to the oil reservoir with such viscosity, the cyclic multi-component thermal fluid stimulation thermal recovery is carried out by use of a horizontal well. The length of the horizontal segment is 300 m. The temperature of the multi-component thermal fluid is set to be 310°C, and thus the mass ratio of water to diesel oil added into the multi-component thermal fluid generator 4 is 14.3, and the mass ratio of oxygen to diesel oil to be injected is allowed to be 14.6. The purity of the oxygen added into the multi-component thermal fluid generator 4 is controlled to be 40%, so as to obtain multi-component thermal fluid where the mass ratio of the flue gas to the water steam is 0.45. Subsequently, the multi-component thermal fluid is injected into an oil reservoir through an injection well to carry out oil recovery. Upon the calculation of numerical modeling software CMG, the final recovery efficiency of the oil reservoir reaches 25.2%.

EXAMPLE 3

[0035] The viscosity of the crude oil reservoir is 80 mPa.s, the burial depth of the oil reservoir is 950 m, the permeability
of the oil layer is 4200 m, the thickness of the oil layer is 8 m, and the pressure of the middle of the oil reservoir is 9 MPa. With regard to the oil reservoir with such viscosity, the multi-component thermal fluid flooding thermal recovery is carried out by use of a horizontal well. The temperature of the multi-component thermal fluid is set to be 150 °C, and thus the mass ratio of water to diesel oil added into the multi-component thermal fluid generator 4 is 74.1, and the mass ratio of oxygen to diesel oil to be injected is allowed to be 14.6. The purity of the oxygen added into the multi-component thermal fluid generator 4 is controlled to be 25%, so as to obtain multi-component thermal fluid where the mass ratio of the flue gas to the hot water/steam is 0.52. Subsequently, the multi-component thermal fluid is injected into an oil reservoir through an injection well to carry out oil recovery. Upon the calculation of numerical modeling software CMG, the final recovery efficiency of the oil reservoir reaches 38.3%.

[0036] As can be seen from the above examples, the improved oil recovery process with composition-adjustable multi-component thermal fluid of the present invention gains an enhanced thermal recovery effect and a higher recovery efficiency when applied to oil reservoirs from an extra-heavy oil reservoir with a recovery viscosity of more than 10,000 mPa·s to a conventional oil reservoir with a viscosity of about 50 mPa·s, which greatly broadens the application range of oil reservoirs compared with the prior oil recovery process with fixed-composition multi-component thermal fluid, and gains enormous economic and social benefits.

[0037] In conclusion, the above examples are merely preferred examples of the present application, and are not intended to limit the protection scope of the present application; therefore, any amendments, equivalent substitutions and improvements made within the spirit and principle of the present application shall fall within the protection scope of the present application.

What is claimed is:

1. An oil recovery process with composition-adjustable multi-component thermal fluid, comprising: adding oxygen produced by air together with fuel and water into a reactor, in which the oxygen and the fuel combusting to produce flue gas and heat, the heat heating water to generate hot water/steam, and then the flue gas and the hot water/steam being mixed to form multi-component thermal fluid, wherein the purity of oxygen added into the reactor is controlled so as to produce the multi-component thermal fluid with various mass ratios of flue gas to hot water/steam; then the obtained multi-component thermal fluid with various mass ratios of flue gas to hot water/steam are injected into various types of oil reservoirs for oil recovery.

2. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 1, wherein the purity of oxygen added into the reactor is controlled according to the viscosity of the various types of oil reservoirs, the higher the viscosity of the oil reservoirs, the relatively higher the purity of oxygen added into the reactor, and the lower the viscosity of the oil reservoirs, the relatively lower the purity of oxygen added into the reactor.

3. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 2, as for the oil reservoirs with a viscosity of greater than 10,000 mPa·s, the purity of oxygen added into the reactor is controlled to be 50%-90%; as for the oil reservoirs with a viscosity of 150-10,000 mPa·s, the purity of oxygen added into the reactor is controlled to be 30%-50%; as for the oil reservoirs with a viscosity of 50-150 mPa·s, the purity of oxygen added into the reactor is controlled to be 21%-30%.

4. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 3, wherein, when the purity of oxygen added into the reactor is 50%-90%, multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.20-0.37 is obtained; when the purity of oxygen added into the reactor is 30%-50%, multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.36-0.61 is obtained; and when the purity of oxygen added into the reactor is 21%-30%, multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.31-0.62 is obtained.

5. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 1, wherein the purity of oxygen added into the reactor is controlled to be 50%-90% so as to obtain multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.20-0.37, the multi-component thermal fluid at a temperature of 250 °C - 350 °C is injected into an oil reservoir with a viscosity of greater than 10,000 mPa·s to carry out oil recovery in a manner of multi-component thermal fluid assisted gravity drainage thermal recovery.

6. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 1, wherein the purity of oxygen added into the reactor is controlled to be 30%-50% so as to obtain multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.36-0.61, the multi-component thermal fluid at a temperature of 250 °C - 350 °C is injected into an oil reservoir with a viscosity of 150-10,000 mPa·s to carry out oil recovery in a manner of cyclic multi-component thermal fluid stimulation thermal recovery.

7. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 1, wherein the purity of oxygen added into the reactor is controlled to be 21%-30% so as to obtain multi-component thermal fluid where the mass ratio of flue gas to hot water/steam is 0.31-0.62, the multi-component thermal fluid at a temperature of 150 °C - 250 °C is injected into an oil reservoir with a viscosity of 50-150 mPa·s to carry out oil recovery in a manner of multi-component thermal fluid flooding thermal recovery.

8. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 1, wherein the injecting temperature of the multi-component thermal fluid is 120 °C - 350 °C.

9. The oil recovery process with composition-adjustable multi-component thermal fluid of claim 1, wherein the injecting rate of the multi-component thermal fluid is 150 m³/d-350 m³/d.