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An agency of Industry Canada

CA 2875034 A1 2016/06/17

(21) **2 875 034**

(12) **DEMANDE DE BREVET CANADIEN**
CANADIAN PATENT APPLICATION

(13) **A1**

(22) **Date de dépôt/Filing Date:** 2014/12/17

(41) **Mise à la disp. pub./Open to Public Insp.:** 2016/06/17

(51) **Cl.Int./Int.Cl.** *E21B 43/24* (2006.01)

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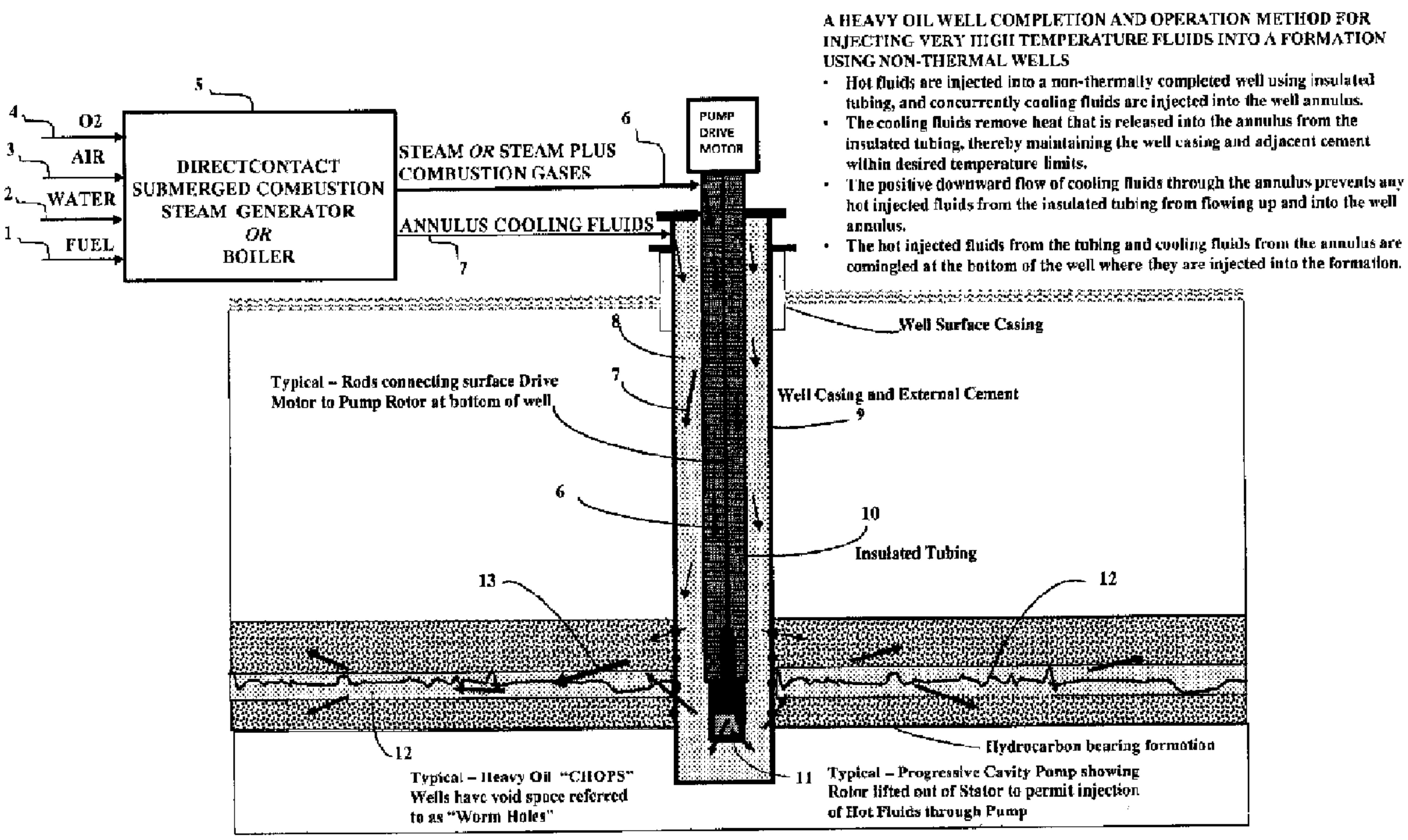
(54) **Titre : METHODE, SYSTEME ET APPAREIL POUR OUVRIR ET EXPLOITER DES PUITS DE PETROLE NON THERMIQUES SELON DES PROCEDES DE RECUPERATION HAUTE TEMPERATURE**

(54) **Title: METHOD, SYSTEM AND APPARATUS FOR COMPLETING AND OPERATING NON-THERMAL OIL WELLS IN HIGH TEMPERATURE RECOVERY PROCESSES**



(57) **Abrégé/Abstract:**

A method is described for recompleting and operating non-thermally cased wells in high temperature cyclic thermal heavy oil or bitumen recovery processes. Non- thermally completed wells such as those employed in primary "cold heavy oil production with sand", commonly referred to as CHOPS wells, are recompleted with insulated tubing for conveying mixtures of high temperature combustion gases, steam and other heating fluids into a hydrocarbon bearing formation. Concurrently, in order to protect the well's non-thermal casing and cement from excessive temperatures, a continuous stream of cooling fluid is introduced into the annulus, absorbing heat energy emitted from the insulated tubing as it flows downward to the bottom of the well where it mixes with the tubing conveyed fluids and is introduced into the formation. The continuous positive downward flow of cooling fluids through the annulus also prevents hot tubing conveyed fluids at the bottom of the well from flowing up into the annulus. Introduction of a

(57) **Abrégé(suite)/Abstract(continued):**
continuous flow of cooling fluids into the annulus during a thermal injection cycle eliminates the need for a packer at the bottom of the well which would otherwise be required to isolate non-thermal casing from high temperature injection fluids. Since a packer is not required, the prior art requirement of recompleting the well for the subsequent production cycle by removing the insulated tubing and packer assembly and then reinstalling production tubing is eliminated.

ABSTRACT

A method is described for recompleting and operating non-thermally cased wells in high temperature cyclic thermal heavy oil or bitumen recovery processes. Non-thermally completed wells such as those employed in primary “cold heavy oil production with sand”, commonly referred to as CHOPS wells, are recompleted with insulated tubing for conveying mixtures of high temperature combustion gases, steam and other heating fluids into a hydrocarbon bearing formation. Concurrently, in order to protect the well’s non-thermal casing and cement from excessive temperatures, a continuous stream of cooling fluid is introduced into the annulus, absorbing heat energy emitted from the insulated tubing as it flows downward to the bottom of the well where it mixes with the tubing conveyed fluids and is introduced into the formation. The continuous positive downward flow of cooling fluids through the annulus also prevents hot tubing conveyed fluids at the bottom of the well from flowing up into the annulus. Introduction of a continuous flow of cooling fluids into the annulus during a thermal injection cycle eliminates the need for a packer at the bottom of the well which would otherwise be required to isolate non-thermal casing from high temperature injection fluids. Since a packer is not required, the prior art requirement of recompleting the well for the subsequent production cycle by removing the insulated tubing and packer assembly and then reinstalling production tubing is eliminated.

METHOD, SYSTEM AND APPARATUS FOR COMPLETING AND OPERATING NON-THERMAL OIL WELLS IN HIGH TEMPERATURE RECOVERY PROCESSES

FIELD OF THE INVENTION

The present invention relates to a method, system and apparatus for completing and operating a well for the production of viscous hydrocarbons from a heavy oil bearing formation. More particularly, it relates to completion of a non-thermally cased well for the purpose of injecting of a mixture of high temperature combustion gases and steam into the formation.

BACKGROUND OF THE INVENTION

Heavy oil is produced throughout the world using non-thermally completed wells to recover cold viscous hydrocarbons from formations. Primary cold recovery methods often result in production of less than 10% of the original oil in place due to reservoir pressure depletion and loss of a drive mechanism, and due the extremely high viscosity of the oil which restricts flow through the formation. In North America alone, 10's of 1000's of heavy oil wells have been drilled and following a number of years of primary production have been shut-in or suspended awaiting development and implementation of an economic secondary recovery mechanism. Many of these wells have been completed and operated using a recovery process of "Cold Heavy Oil Production with Sand" commonly referred to as CHOPS. The production of sand along with cold heavy oil in CHOPS wells results in the production of voids and pathways commonly referred to as "worm holes" and massively enhanced permeability because of the remolding and plastic deformation that takes place. These worm holes and areas of enhanced permeability serve are conduits for the introduction of fluids into the formation including steam, solvents and non-condensable gasses at pressures below fracture or virgin pressure of the formation.

In one cyclic secondary recovery technique, steam is first injected into a thermally completed well, after which heavy oil is produced from the same well following a short period of time during which the formation is allowed to soak, commonly referred to as "cyclic steam stimulation" or CSS. In another cyclic secondary recovery technique, a non-condensable gas such as methane, flue gas or nitrogen is compressed, heated and saturated with water prior to injection into a CHOPS well. The non-condensable gas serves to pressure the formation thereby providing a drive mechanism for production of the heavy oil. The latent heat of condensation released as the water of saturation changes from the vapor phase to the liquid phase provides energy to heat the formation. Following pressuring and heating of the formation, the well is recompleted to convert it from an injection well to a producing well and placed on production.

In the prior art, for these CSS secondary recovery techniques a well is preferentially equipped with insulated tubing plus an isolation packer for the purpose of injecting the hot fluids into a formation. The isolation packer is installed between the tubing and annulus at the bottom of the well for the purpose of preventing hot fluids introduced into the well via the insulated tubing from entering the CHOPS well annulus where the fluids could otherwise heat the non-thermal casing and cement above their maximum design operating temperature. Following completion of the injection cycle and before the well can be placed on production, the insulated tubing and associated packer isolating the annulus must first be removed so that gas which is separated from the heavy oil at the bottom of the well can be produced up the annulus. Following removal of the isolation packer, conventional or insulated production tubing is reinstalled in the well, a bottom-hole pump is installed in the well and oil flowing into the well from the formation is pumped to the surface via the production tubing.

Petroleum industry operating experience has confirmed that injection of non-condensable gas or solvent can be an effective method of reestablishing a drive mechanism in pressure depleted heavy oil reservoirs, and that injection of steam is an effective method of heating a formation to reduce heavy oil viscosity and thereby increase the flow rate of fluids from the formation. Canadian Patent Application 2,747,766 describes a pressurized Submerged Combustion Vaporizer (hereafter referred to as a SCV) for the purpose of producing a reservoir heating and pressurizing fluid consisting of both steam and water saturated combustion gases for use in recovery of viscous hydrocarbons and bitumen. Prior field operating experience confirms that injecting these hot fluids into an existing heavy oil reservoir is an effective hybrid secondary recovery mechanism. An efficient and cost effective method of implementing secondary recovery is to utilize existing shut-in and suspended CHOPS wells and related field and site infrastructure for this purpose.

Many CHOPS wells are not completed with production casing and cement that is capable of withstanding the high temperature that would occur in the well annulus during injection of thermal fluids. Accordingly, a new method, system and apparatus is required whereby non-thermal CHOPS or other wells can be recompleted and operated so that the temperature of the casing and cement is maintained within maximum operation temperature limits during continuous injection of very hot fluids at temperatures up to 350 C. Furthermore, it is advantageous to develop a CHOPS well completion method and operating system and apparatus that does not require the installation of an isolation packer to prevent hot fluids introduced into a well via the insulated tubing from entering the CHOPS well annulus. Elimination of the packer provides the added benefit and advantage of substantially reduced well recompletion work for cyclic secondary recovery processes due to the fact that the insulated tubing installed for the injection phase can also be used for the subsequent production phase.

Relatively new advances in design and manufacture of high efficiency vacuum insulated tubing have made it possible to continuously inject fluids at temperatures up to 140 C in non-thermally completed heavy oil wells, at the same time maintaining the temperature of the well casing and cement within maximum temperature limits. In this case, the heavy oil well is equipped with a bottom-hole packer between the tubing and annulus to isolate and prevent the hot injected fluids from entering the annulus and overheating the non-thermal casing and cement.

This same type of high efficiency vacuum insulated tubing has also been used in high temperature thermal recovery processes in which high pressure steam is injected into formations for the recovery of heavy oil and bitumen. In these cases, the injection and production wells are equipped with thermal grade casing and cement which are capable of handling the high temperatures. Use of insulated versus conventional production tubing in these thermally completed wells provides the benefit of reduced heat loss from the tubing to the overburden during injection of the steam and increased overall efficiency of the thermal recovery process.

Some thermal project operators have further reduced heat loss to the overburden by placing a static blanket of nitrogen or other non-condensable gas in the annular space between the casing and insulated tubing. A further benefit of utilizing insulated tubing and blanket gas in thermally completed wells is that it reduces the thermal stresses in casing strings and therefore reduces potential for casing failure.

Deficiencies of the Prior Art

None of the prior art literature discloses a method, system and apparatus to pressurize and heat a formation containing heavy oil or bitumen by recompleting an existing CHOPS or other non-thermal heavy oil well with insulated tubing but without the above referenced isolation packer, thereby permitting the concurrent continuous injection of both tubing conveyed heating fluids and annulus conveyed cooling fluids into the formation.

None of the prior art discloses a method, system and apparatus for injecting a mixture of high pressure steam and combustion gas fluids into a formation via an insulated tubing string installed in a well, at the same time continuously injecting a cooling fluid into the well annulus between the insulated tubing and casing for the purpose of maintaining casing and cement temperatures within maximum temperature limits, which cooling fluid is subsequently mixed at the bottom of the well with the products injected via the tubing, following which the entire mixture is introduced into the formation.

None of the prior art discloses a method of producing a well annulus cooling fluid having the same composition as a SCV or other direct contact steam generator's outlet product, the cooling fluid being produced by extracting and cooling a small side-stream of the outlet product and injecting it into a well annulus.

None of the prior art discloses a method for preventing hot fluids injected into the bottom of a well via an insulated tubing from entering and flowing backwards and up into the well annulus by injecting a continuous stream of cooling water, non-condensable gas, solvents, hydrocarbons, CO_2, nitrogen and flue gas or any combination or mixture thereof into the annulus at the top of the well, thereby providing both cooling of the annulus, casing and adjacent cement plus directing and ensuring the flow of all injected fluids is downwards and into the formation.

SUMMARY OF THE INVENTION

The present invention provides an oil recovery method, system and apparatus which are uniquely applicable to recovery of viscous hydrocarbons from a formation. It is an advantage of the present invention that it overcomes prior art deficiencies, providing a means of injecting high temperature fluids into a formation using wells that are not completed with production casing and cement capable of withstanding the high temperatures, without the risk of casing and cement failure due to the high temperature of the injected fluids. A further advantage of the present invention is that it also provides a means of reducing temperatures and therefore stresses imposed on well casing and cement in thermally completed wells as it does for non-thermally completed wells.

In accordance with the present invention, a length of insulated tubing is installed in a well and landed adjacent to the hydrocarbon containing formation for the purpose of injecting hot fluids such as steam and hot gases into the formation. In the prior art, in cases where heavy oil wells are completed without the benefit of thermal casing and cement, a packer is installed between the tubing and casing immediately above the formation to isolate and prevent the hot injected fluids from entering the annulus and heating the non-thermal casing. In accordance with the design of the present invention, a packer is not installed between the tubing and casing and instead a continuous stream of pressurized cooling fluids is introduced into the well annulus between the insulated tubing and casing. Injection of these cooling fluids provide a positive downward flow from the top of the well, through the annulus, and into the bottom of the well where it mixes with the high temperature fluids injected via the insulated tubing after which the entire mixture is injected into the formation. The aforementioned cooling fluids serve the purpose and advantage of maintaining casing and cement temperatures within maximum design operating temperature limits plus prevent the hot fluids injected into the bottom of a well via the insulated tubing from entering and flowing backwards and up into the well annulus.

In the preferred embodiment to the present invention, when used in conjunction with a SCV as described in Canadian Patent Application 2,747,766, a small side-stream of the SCV steam-combustion gas product is cooled and introduced into the well annulus for the purpose of removing heat from the annulus and preventing hot injected fluids from entering the annulus at the bottom of the well. Depending on the enhanced oil recovery process employed, other cooling fluids can be used to maintain the well annulus within temperature limits plus provide a positive downward flow to prevent hot injected fluids from flowing backwards and up into the annulus, including water, solvents, hydrocarbons, CO_2, nitrogen and other non-condensable gases.

This invention in its broadest application relates to a method, system and apparatus for thermal recovery of viscous heavy oil and bitumen from subsurface deposits throughout the world using non-thermally completed wells. More specifically, throughout Western Canada's heavy oil belt thousands of partially depleted non-thermal CHOPS heavy oil wells are either suspended or near the end of their primary production life, and many of these wells can be recompleted and operated for thermal enhanced oil recovery by employing the present invention.

BRIEF DESCRIPTION OF THE DRAWING

These and other features and advantages of the present invention will become apparent from the following detailed description of the accompanying drawing.

FIG. 1 is a simplified pictorial representation showing a SCV or other system for production of formation heating fluids and annulus cooling fluids, in conjunction with a method and apparatus for injecting high temperature fluids into a formation using a non-thermal well. Included is a cross section elevation view of a typical non-thermally completed CHOPS well. In this drawing the CHOPS well is shown as recompleted with vacuum insulated tubing and configured for the purpose of injecting steam and combustion gases into a subsurface formation during an injection cycle and for production of oil during a subsequent production cycle.

Fuel **1** is combusted in the presence of air **3** or oxygen **4** in a SCV **5**. The products of combustion are mixed with water **2** in a direct contact steam generation process, producing a thermal fluid product **6** for heating a formation. Where the product is produced by a direct contact SCV steam generator **5**, the heating fluid stream **6** consists of both steam and combustion gases. The SCV **5** is advantageous for this purpose since it produces steam to heat the formation plus non-condensable gases for pressurizing the formation. The SCV system produces an annulus cooling fluid **7** having the same composition as the SCV outlet product stream **6** by incorporating an internal process whereby a small side stream of product is extracted and cooled prior to introduction into the well annulus **8.** This is an ideal embodiment: variations are possible depending on the enhanced oil recovery process selected. Alternatively, the formation heating fluids **6** consist of steam produced in a conventional boiler, hot water, hot hydrocarbons, hot flue gases, hot gases and solvents, or any combination of these and other thermal fluids. The annulus cooling fluids **7** can consist of any fluids that are suitable for the purposes of removing heat from the annulus **8**, preventing flow of hot injected fluids from entering the annulus at the bottom of the well, and for injection into the formation **12** for enhanced oil recovery purposes.

A further advantage of using a SCV to produce formation heating fluids **6** in larger projects is that it can be configured and operated so that the combustion gas product is mostly CO2. This can be achieved by incorporating a low pressure oxygen separation PSA process and feeding the SCV burner with oxygen **4** instead of air **3**. The CO2 can be injected along with the steam to enhance an oil recovery process, or be recovered for other EOR or sequestration purposes.

A typical CHOPS well consists of a bore hole that is drilled into and through a heavy oil containing formation, after which it is equipped with a steel casing **9** that is cemented in place and perforated to allow oil into the well bore. The well is then completed with a string of conventional tubing, downhole pump and surface pump drive system. To recomplete the CHOPS well for thermal operation, the conventional tubing and pump is removed, and a string of insulated tubing **10**, preferentially vacuum insulated tubing known as VIT, is installed inside the well casing **9**. A progressive cavity pump **11** also known as a PCP is either mounted on the end of the insulated tubing **10** before it is installed in the well, or alternatively a through-tubing PCP and rods are installed after the tubing is in place. To commence heating of the formation in wells where a PCP is installed, the rotor is lifted out of pump stator to permit injection of hot fluids through the pump **11** and into the formation. Primary CHOPS production from wells results in heavy oil reservoir formations containing void spaces or areas of enhanced permeability referred to as “wormholes” **12** which serve as conduits for the introduction of heating and pressurizing fluids into the formation. To heat and pressure the formation, heating fluids **6** and annulus cooling fluids **7** are injected into the bottom of the well **9** where they mix to form a combined fluid **13** which flows into the formation through wormholes **12**.

After sufficient combined fluid **13** has been injected to achieve the desired pressure and temperature in the oil reservoir formation, in a typical cyclic injection-production well operation known as “huff-and-puff” the well is placed on production. At the end of the injection cycle, followed by a suitable length of temperature “soak” time, the direction of flow in the formation and well is reversed. Initially and without the need for artificial lift, gas, oil and water may flow up the insulated tubing **10** simply by opening the tubing production valve installed on a conventional wellhead and allowing produced fluids to flow to a production tank. Once the initial flow has declined, the pump **11** is activated for the purpose of lifting liquids out of the well. For the above well completion method, the PCP rotor which was lifted out of the pump stator for the injection cycle is now inserted back into the pump stator and the pump placed in operation. Concurrently, non-condensable gas that is produced along with the oil and water is separated from the liquids at the bottom of the well and produced up the annulus **8**.

Optionally, if the near well bore fluid stabilized temperature exceeds the temperature limit of the well's non-thermal casing and cement **9**, before the pump **11** is placed in operation a selected amount of cooling fluid such as water, liquid carbon dioxide or nitrogen is introduced into the well to lower the near well bore fluid temperature.

Another application of the present invention is for enhanced oil recovery from formations where heavy oil exists without the benefit of wormholes. In this application, injected fluids **6** and **7** can are used in a conventional flood enhanced recovery process whereby hot injected fluids are used to pressurize and heat the formation, initiating a flood drive mechanism whereby heavy oil is pushed towards surrounding wells where it is produced.

A further application of the present invention is use in establishment of a CHOPS production mechanism in suspended heavy oil wells that do not have wormholes due to having been previously produced in a manner that prevented sand from being produced along with the oil. In this application, fluids **6** and **7** are injected to re-pressure the partially depleted formation up to its original pressure. The formation is then allowed to cool enough to achieve desired heavy oil viscosity, and then the well is placed on production by maintaining the low well bore pressure necessary to initiate CHOPS production. The production of sand along with the viscous oil results in the creation of worm holes **12** in the formation which following a period of CHOPS production can be used for introduction of heating and pressurizing fluids for further enhanced oil recovery.

CLAIMS

What is claimed is:

1. A method for enhancing the recovery of viscous hydrocarbons from subsurface formations containing heavy oil deposits or bitumen deposits, comprising:

   (a) employing known methods of producing high pressure steam, hot combustion gases and other hot fluids for the purpose of heating and pressuring a subsurface hydrocarbon bearing formation;
   (b) equipping and operating a non-thermally cased heavy oil well for use in a thermal oil recovery process, without the requirement for installing a bottom hole packer between the well tubing and the annulus which prior to the present invention has been required to prevent hot tubing injected fluids from flowing up and into the annulus.
   (c) employing an existing well bore or establishing at least one vertical or horizontal bore hole complete with casing extending from the surface of the earth to at least the bottom of the subsurface formation, the well and casing being completed with perforations or other means of connection between the well bore and the formation;

initial flow has declined, the pump **11** is activated for the purpose of lifting liquids out of the well. For the above well completion method, the PCP rotor which was lifted out of the pump stator for the injection cycle is now inserted back into the pump stator and the pump placed in operation. Concurrently, non-condensable gas that is produced along with the oil and water is separated from the liquids at the bottom of the well and produced up the annulus **8**.

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   (c) employing an existing well bore or establishing at least one vertical or horizontal bore hole complete with casing extending from the surface of the earth to at least the bottom of the subsurface formation, the well and casing being completed with perforations or other means of connection between the well bore and the formation;

(d) equipping the well or cased bore hole with insulated tubing for the purpose of injecting heating and pressuring fluids into the formation;
(e) equipping the well with means of injecting a cooling fluid into the annulus between the insulated tubing and the casing such that the cooling fluid flows down through the annulus to the bottom of the well where it is mixed with tubing injected heating and pressuring fluids and introduced into the formation;
(f) equipping the well with a bottom hole pump, typically a PCP, that is capable of withstanding high fluid injection temperatures;
(g) equipping the well with a PCP that is designed such that the rotor can be lifted out of the stator to permit injection of fluids through the pump and into the formation;
(h) continuously injecting heating and pressurizing fluids downwards through the insulated tubing and PCP, and into the formation for the purposes of reducing the viscosity of the normally immobile oil or bitumen and increasing the pressure of the formation;
(i) simultaneously continuously injecting cooling fluids downwards through the annulus to maintain the well casing and cement within its temperature limits by removing heat released from the insulated tubing, the downward flow of fluids also serving to prevent hot tubing injected fluids from flowing up into the annulus;
(j) comingling fluids injected through the tubing and annulus at the bottom of the well followed by injection into the formation

2. The method as set forth in Claim 1, characterized in that the annulus cooling fluid is comprised of a small side-stream of cool condensed SCV steam and combustion gases.

3. The method set forth in Claim 1, characterized in that the annulus cooling fluid is comprised of any one or combination of fluids that are suitable for the purposes of removing heat from the annulus, for preventing flow of hot injected fluids from entering the annulus at the bottom of the well, and for injection into the formation for enhanced oil recovery purposes.

4. The method set forth in Claim 1, characterized in that with the downward flow of cooling fluids through the annulus and into the bottom of the well, a packer is not required for the purpose of isolating the well annulus and casing from high temperatures during injection of hot fluids through the tubing; the forgoing providing a substantial cost benefit in that the insulated tubing and packer do not need to be removed and tubing reinstalled prior to commencement of a subsequent production cycle as is the case under the prior art.

5. The method set forth in Claim 1, characterized in that cooling fluids can alternatively be injected into the annulus of a thermally completed well that is not equipped with insulated tubing, the cooling fluids subsequently recovering heat that is emitted from the uninsulated tubing and which would otherwise be lost into the earth behind the casing, thereby further reducing the potential for casing failure due to high temperatures and transporting addition heat downwards and into the formation for improved recovery energy efficiency.

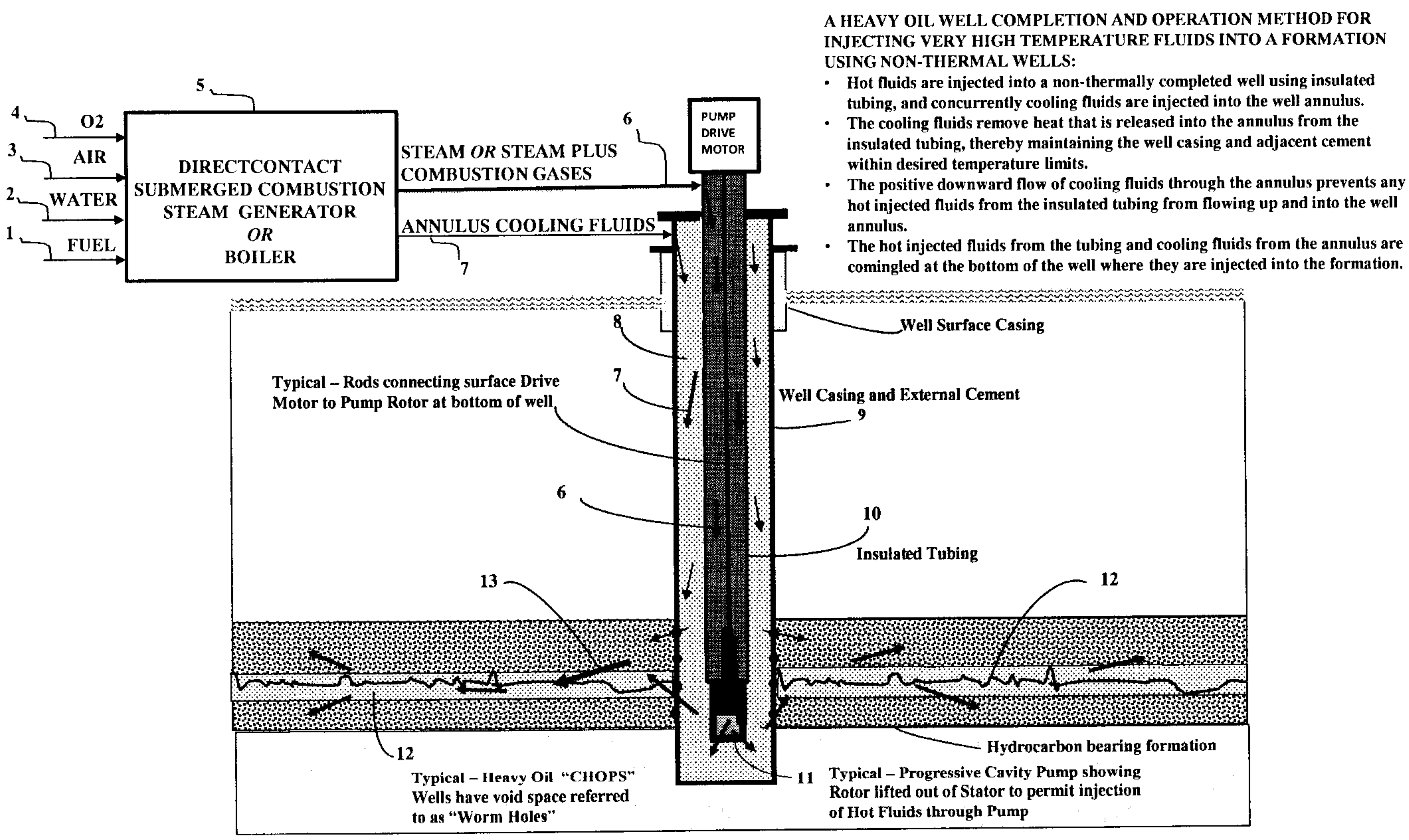
A HEAVY OIL WELL COMPLETION AND OPERATION METHOD FOR INJECTING VERY HIGH TEMPERATURE FLUIDS INTO A FORMATION USING NON-THERMAL WELLS:
• Hot fluids are injected into a non-thermally completed well using insulated tubing, and concurrently cooling fluids are injected into the well annulus.
• The cooling fluids remove heat that is released into the annulus from the insulated tubing, thereby maintaining the well casing and adjacent cement within desired temperature limits.
• The positive downward flow of cooling fluids through the annulus prevents any hot injected fluids from the insulated tubing from flowing up and into the well annulus.
• The hot injected fluids from the tubing and cooling fluids from the annulus are comingled at the bottom of the well where they are injected into the formation.
5
4
O2
3
AIR
2
WATER
1
FUEL
DIRECTCONTACT SUBMERGED COMBUSTION STEAM GENERATOR OR BOILER
STEAM OR STEAM PLUS COMBUSTION GASES
6
ANNULUS COOLING FLUIDS
7
PUMP DRIVE MOTOR
Well Surface Casing
8
7
Typical – Rods connecting surface Drive Motor to Pump Rotor at bottom of well
Well Casing and External Cement
9
6
10
Insulated Tubing
13
12
12
Hydrocarbon bearing formation
Typical – Heavy Oil "CHOPS" Wells have void space referred to as "Worm Holes"
11
Typical – Progressive Cavity Pump showing Rotor lifted out of Stator to permit injection of Hot Fluids through Pump

FIG. 1

A HEAVY OIL WELL COMPLETION AND OPERATION METHOD FOR INJECTING VERY HIGH TEMPERATURE FLUIDS INTO A FORMATION USING NON-THERMAL WELLS

- Hot fluids are injected into a non-thermally completed well using insulated tubing, and concurrently cooling fluids are injected into the well annulus.
- The cooling fluids remove heat that is released into the annulus from the insulated tubing, thereby maintaining the well casing and adjacent cement within desired temperature limits.
- The positive downward flow of cooling fluids through the annulus prevents any hot injected fluids from the insulated tubing from flowing up and into the well annulus.
- The hot injected fluids from the tubing and cooling fluids from the annulus are comingled at the bottom of the well where they are injected into the formation.