Abstract: Methods are provided for mitigating thief zone losses during hydrocarbon recovery by thief zone pressure maintenance through downhole radio frequency radiation heating. A thief zone situated near a hydrocarbon reservoir poses a risk of losing valuable components from the reservoir to the thief zone. In addition to the risk of loss of diluent, heat, or steam to the thief zone, valuable hydrocarbons may also be lost to the thief zone. One way to mitigate these losses is by maintaining thief zone pressure. RF radiation may be used to heat a thief zone fluid to maintain pressure in the thief zone, decreasing the driving force for losses to the thief zone. In some cases, steam generated thusly may be used to enhance hydrocarbon thermal recovery. Advantages of methods herein include: lower costs, higher efficiencies, higher hydrocarbon recovery, less hydrocarbon contamination, increased hydrocarbon mobility, and fewer thief zone losses.
MITIGATING THIEF ZONE LOSSES BY THIEF ZONE PRESSURE MAINTENANCE THROUGH DOWNHOLE RADIO FREQUENCY RADIATION HEATING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a non-provisional application which claims benefit under 35 USC §119(e) to U.S. Provisional Application Ser. No. 61/714315 filed October 16, 2012, entitled "Mitigating Thief Zone Losses by Thief Zone Pressure Maintenance through Downhole Radio Frequency Radiation Heating," which is incorporated herein in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] None.

FIELD OF THE INVENTION

[0003] The present invention relates generally to methods and systems for mitigating thief zone losses during heavy oil recovery by thief zone pressure maintenance through downhole radio frequency radiation heating.

BACKGROUND

[0004] The production of hydrocarbons from low mobility reservoirs presents significant challenges. Low mobility reservoirs are characterized by high viscosity hydrocarbons, low permeability formations, and/or low driving forces. Any of these factors can considerably complicate hydrocarbon recovery. Extraction of high viscosity hydrocarbons is typically difficult due to the relative immobility of the high viscosity hydrocarbons. For example, some heavy crude oils, such as bitumen, are highly viscous and therefore immobile at the initial viscosity of the oil at reservoir temperature and pressure. Many countries in the world have large deposits of bitumen oil sands, including the United States, Russia, and various countries in the Middle East. The world's largest deposits, however, occur in Canada and Venezuela. Oil sands are a type of unconventional petroleum deposit. The sands contain naturally occurring mixtures of sand, clay, water, and a dense and extremely viscous form of petroleum technically referred to as "bitumen," but may also be called heavy oil or tar. Indeed, such heavy oils may be quite thick and have a consistency similar to that of peanut butter or heavy tars, making their extraction from reservoirs especially challenging. Due to its high viscosity, these heavy oils are hard to mobilize, and they generally must be made to flow to produce and transport them. Indeed, such heavy oils are typically so heavy and viscous that they will
not flow unless heated or diluted with lighter hydrocarbons. At room temperature, it is much like cold molasses.

[0005] As used herein, the term, "heavy oil" includes any heavy hydrocarbons having greater than 10 carbon atoms per molecule. Further, the term "heavy oil" includes heavy hydrocarbons having a viscosity in the range of from about 100 to about 100,000 centipoise at 100°F, and an API gravity from about 5 to about 22° API; or can be a bitumen having a viscosity less than about 100,000 centipoise, and an API gravity less than or equal to about 22° API.

[0006] Conventional approaches to recovering heavy oils often focus on methods for lowering the viscosity of the heavy oil or heavy oil mixture so that the heavy oil may be mobilized and produced from the reservoir. Examples of methods for lowering the heavy oil viscosity include introducing a diluent to the heavy oil or heating the heavy oil. Commonly used thermal recovery methods include a number of technologies, such as steam flooding, cyclic steam stimulation, and steam assisted gravity drainage (SAGD), which require the injection of hot fluids into the reservoir. A 100°F increase in the temperature of the heavy oil in a formation can lower its viscosity by two orders of magnitude. Accordingly, heating a formation containing heavy oils can dramatically improve the efficiency of heavy oil recovery.

[0007] While these diluent and thermal recovery methods are often effective at recovering heavy oils, these methods may fail to be economical under certain conditions. For instance, some hydrocarbon reservoirs may be in thermal or fluid communication with a thief zone. Thief zones are gas or water pools to which steam, diluent, heat, or hydrocarbons may escape. In the example of SAGD-assisted hydrocarbon recovery, a well pair is used to develop a steam chamber in the hydrocarbon reservoir that interacts with and acts to produce the heavy oil around the steam chamber. If the SAGD steam chamber happens to establish thermal or fluid communication with a neighboring thief zone in the vicinity thereof, steam, hydrocarbons, or heat will be lost to the thief zone or conversely, the thief zone gas/liquids could invade the SAGD steam chamber. The amount of steam lost to a neighboring thief zone can render thermal recovery processes uneconomical.

[0008] Where diluent-assisted recovery methods are employed, thief zones can similarly rob the producing zone of valuable diluent or otherwise contaminate the diluent as the case may be. Because solvent is typically quite expensive, the process economics of using diluents are highly sensitive to solvent losses. Thus, as is the case for thermal recovery processes,
neighboring thief zones can also render diluent-assisted recovery methods uneconomical as well.

[0009] Conventional methods for mitigating losses to thief zones rely on the injection of non-condensable gases into the thief zone. In these conventional methods, the non-condensable gas is injected into the thief zone with the hope of maintaining or increasing the pressure in the thief zone to minimize or eliminate losses to the thief zone. These conventional methods however remain fairly new and accordingly, operators have not accumulated much experience with these methods. Thus, the predictability of these conventional methods remain fairly unpredictable. Another disadvantage of these conventional methods is the risk of contaminating the hydrocarbon reservoir with the injected non-condensable gases.

[0010] Still another disadvantage of conventional methods is the contamination that results to the thief zone itself. In some cases, the thief zone may be another hydrocarbon-bearing reservoir (in some cases owned by a different operator). Injecting non-condensable gases into another's hydrocarbon-bearing reservoir will result in contamination of the thief zone hydrocarbons. Where these hydrocarbons are owned by another operator, liability for the devaluation of those thief zone hydrocarbons will be borne by the contaminator of the thief zone. Accordingly, avoiding thief zone contamination in such instances is highly economically desirable to avoid incurring such liability to other operators.

[0011] Accordingly, enhanced methods for mitigating or reducing thief zone interactions are needed that address one or more disadvantages of the prior art, especially as relating to thermal and diluent-assisted hydrocarbon recovery techniques.

**SUMMARY**

[0012] The present invention relates generally to methods and systems for mitigating thief zone losses during heavy oil recovery by thief zone pressure maintenance through downhole radio frequency radiation heating.

[0013] One example of a method for mitigating thief zone losses during heavy oil recovery by thief zone pressure maintenance through downhole radio frequency radiation heating comprises the steps of: introducing a steam assisted gravity drainage (SAGD) well pair into a subterranean formation, wherein the SAGD well pair comprises a producing well and a steam injection well, wherein subterranean formation comprises a hydrocarbon reservoir wherein the hydrocarbon reservoir comprises hydrocarbons; introducing steam into the steam injection well to establish a steam chamber in the hydrocarbon reservoir; introducing an antenna into the subterranean formation, wherein the antenna is operable
connected to an energy source, wherein the subterranean formation comprises a thief zone, wherein the thief zone is in thermal communication, fluid communication, or both with the steam chamber, wherein the thief zone comprises water; inducing radio frequency radiation in the antenna by way of the energy source; allowing the radio frequency radiation to propagate into the thief zone to heat at least a portion of the water therein to form steam to increase the pressure in the thief zone from a first thief zone pressure to a second thief zone pressure, wherein the second thief zone pressure mitigates or eliminates hydrocarbon or heat losses to the thief zone that would otherwise occur if the thief zone had remained at the first thief zone pressure; and producing the hydrocarbons from the hydrocarbon reservoir through the producing well.

[0014] One example of a method for mitigating thief zone losses by thief zone pressure maintenance through downhole radio frequency radiation heating comprises the steps of: introducing an antenna into a subterranean formation, wherein the antenna is operable connected to an energy source, wherein the subterranean formation comprises a hydrocarbon reservoir and a thief zone, wherein the thief zone is in thermal communication, fluid communication, or both with the hydrocarbon reservoir, wherein the hydrocarbon reservoir comprises hydrocarbons, and wherein the thief zone comprises a thief zone fluid susceptible to heating from radio frequency radiation; inducing radio frequency radiation in the antenna by way of the energy source; allowing the radio frequency radiation to propagate into the thief zone to heat at least a portion of the thief zone fluid therein to vaporize the thief zone fluid to form a thief zone gas to increase the pressure in the thief zone from a first thief zone pressure to a second thief zone pressure, wherein the second thief zone pressure mitigates fluid or heat interaction between the thief zone and the hydrocarbon reservoir that would otherwise occur if the thief zone had remained at the first thief zone pressure; and producing the hydrocarbons from the hydrocarbon reservoir.

[0015] The features and advantages of the present invention will be apparent to those skilled in the art. While numerous changes may be made by those skilled in the art, such changes are within the spirit of the invention.
BRIEF DESCRIPTION OF THE DRAWINGS

[0016] A more complete understanding of the present disclosure and advantages thereof may be acquired by referring to the following description taken in conjunction with the accompanying figures, wherein:

[0017] Figure 1 illustrates an example of a system using a radio frequency radiation to mitigate thief zone losses in accordance with one embodiment of the present invention.

[0018] While the present invention is susceptible to various modifications and alternative forms, specific exemplary embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0019] The present invention relates generally to methods and systems for mitigating thief zone losses during heavy oil recovery by thief zone pressure maintenance through downhole radio frequency radiation heating.

[0020] In certain embodiments, methods and systems are provided for mitigating losses to thief zones using radio frequency radiation. In one embodiment, a thief zone may be situated in a hydrocarbon reservoir or in proximity to the hydrocarbon reservoir in a way that poses a risk of losing valuable components from the hydrocarbon reservoir to the thief zone during hydrocarbon recovery efforts. Thief zones include any zone that allows loss of valuable components from the hydrocarbon recovery process including produced oil, diluent, solvent, treatments, heat, water, steam, pressure, and the like. Thief zones include areas of the reservoir that cannot be produced or that reduce productivity of the reservoir including lean zones, bottom water and the like. Examples of hydrocarbon recovery processes that may be employed are diluent-assisted recovery processes or thermal recovery processes such as the SAGD process. Not only does the presence of the thief zone pose a risk of loss of either diluent, heat, or steam to the thief zone, but valuable hydrocarbons can be lost to the thief zone as well.

[0021] One way to mitigate or eliminate these losses to the thief zone is by maintaining or increasing the thief zone pressure to alter the driving forces that motivate losses to the thief zone. Radio frequency radiation may be used to heat a fluid in the thief zone, such as water
for example. By vaporizing the water to steam, pressure is maintained in the thief zone decreasing the driving force for losses to the thief zone. In some cases, the steam generated in the thief zone may be used to further enhance thermal recovery of the hydrocarbons.

Advantages of the enhanced methods and systems described herein include one or more of the following advantages: lower cost, higher efficiencies, higher recovery of reservoir hydrocarbons, less hydrocarbon contamination, and fewer losses to the thief zone (e.g. heat, steam, hydrocarbons, or diluent). Additionally, the methods herein may also have the positive effect of introducing heat to the heavy oils to reduce their viscosity and increase their mobility, making them easier to recover. Other features, embodiments, and advantages will be apparent from the disclosure herein.

Reference will now be made in detail to embodiments of the invention, one or more examples of which are illustrated in the accompanying drawings. Each example is provided by way of explanation of the invention, not as a limitation of the invention. It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used on another embodiment to yield a still further embodiment. Thus, it is intended that the present invention cover such modifications and variations that come within the scope of the invention.

Figure 1 illustrates an example of a system using a radio frequency radiation to mitigate thief zone losses in accordance with one embodiment of the present invention. In this example, hydrocarbon recovery process 120 intersects subterranean formation 105 for producing hydrocarbons from hydrocarbon reservoir 107. Here, for illustrative purposes hydrocarbon recovery process 120 is depicted as a thermal recovery process, in this case, a SAGD well pair comprising production well 121 and steam injection well 122. Other thermal recovery processes that may be used with the methods described herein include, but are not limited to, a cyclic steam stimulation, a vapor extraction, a J-well SAGD, in situ combustion, a high pressure air injection, an expanding solvent-SAGD, a cross-SAGD process, or a combination thereof.

Where a SAGD thermal recovery process is employed, steam is typically introduced by way of upper steam injection well 122 to mobilize heavy oil in hydrocarbon reservoir for production through production wellbore 121. Over time, the circulation of steam and condensing fluids establishes steam chamber 124 about hydrocarbon recovery process 120 in hydrocarbon reservoir 107.
As might be expected, expanding steam chamber 124 may come into heat or fluid communication with first thief zone 111. Thief zone 111 poses a risk of losses from hydrocarbon reservoir 107 to thief zone 111. For example, heat may propagate through conduction and/or convection from hydrocarbon reservoir 107 to thief zone 111. Thief zone 111 comprises a thief zone fluid, in this case, water, which can act as a significant heat sink into which sizable heat losses may transfer. In addition to heat losses, hydrocarbons and/or steam may also be lost to thief zone 111. Where hydrocarbon recovery process 120 is a diluent-assisted recovery process, thief zone 111 can rob the hydrocarbon reservoir of valuable diluent or solvent as well.

Energy generator 162 is operably connected to antenna 164 for generating radio frequency radiation directed to thief zone 111. The thief zone fluid, in this case water, is heated through interaction with the radio frequency radiation and is vaporized to a thief zone gas, in this case steam. The steam thus produced maintains or increases the pressure in thief zone 111 so as to reduce any driving force that might motivate fluids to escape to thief zone 111. Additionally, heating thief zone 111 reduces any thermal driving force that would otherwise motivate heat transfer from hydrocarbon reservoir 107 to thief zone 111. In this way, losses to thief zone 111 are thus mitigated.

Likewise, thief zone 112 poses a similar risk of losses to hydrocarbon reservoir 107. Unlike thief zone 111, which is situated in the overburden, thief zone 112 is situated in hydrocarbon reservoir 107 itself. In this example, thief zone 112 is a depleted steam chamber remaining from an earlier SAGD thermal recovery process in hydrocarbon reservoir 107.

Antenna 164 may be situated in any configuration suitable for directing radio frequency radiation to thief zones 111 or 112. In certain embodiments, antenna 164 will follow all or a portion of injection well 160. Antenna 164 may be oriented along a horizontal length, a vertical length, or both in relation to one or more thief zones. In Figure 1, antenna 164 follows an initially vertically orientation and then, multiple horizontal branches or orientations along thief zone 111 and thief zone 112. In certain embodiments, antenna 164 may be situated above hydrocarbon reservoir 107 in the overburden in or adjacent to thief zone 111.

In certain embodiments, the frequency of the generated radio frequency radiation is from about 30 kHz to about 300 GHz. Indeed, any suitable frequency for interacting with the fluids contained in the thief zone may be used with the instant invention.
[0031] It is recognized that although the methods described herein are with reference to water as the thief zone fluid, the thief zone fluid may be any fluid capable of interacting with and susceptible to heating by the generated radio frequency radiation.

[0032] The methods contemplated herein may further comprise the step of determining an optimal frequency or range of frequencies of the generated radio frequency radiation for heating the reservoir hydrocarbons. In this way, an optimal radiation frequency may be determined that maximizes energy transfer to the hydrocarbons for a given energy input.

[0033] Although the examples depict one injection well and one production well, it is understood that the methods described herein could be applied to any number of injection and/or production wells, including typical circular drive patterns such as the five-spot, seven-spot, and nine-spot patterns. In certain embodiments, it may be desired to a single well for both injection (e.g. air injection and introduction of radio frequency radiation) and hydrocarbon production. Further, it is recognized that the term "mixture" as used herein also refers to non-homogeneous mixtures.

[0034] Although these examples depict any thief zone, they are applicable to a lean zone or bottom water. Lean zones are thin zones with high water saturation within the targeted hydrocarbon formation that can act as thief zone during production. Bottom water is a highly water saturated zone below the targeted hydrocarbon zone. Pressure, steam, heat, produced oil or combinations thereof may be lost to a lean zone or bottom water. Loss may be prevented in a lean zone or bottom water by inserting an antenna in the lean zone or bottom water to heat the water, when the water is sufficiently heated it will increase pressure and/or generate steam. In one example a lean zone is identified during production of heavy oil from a SAGD well, an antenna is placed within the lean zone, the water is heated above boiling point to release steam until the pressure in the lean zone is raised sufficiently to prevent loss of steam, heat, or produced oil into the lean zone. In another embodiment, an antenna is placed below a SAGD reservoir in a bottom zone, during production if the pressure is reduced, the bottom water is heated using the antenna. Once the water is sufficiently heated the pressure in the bottom water will increase and prevent loss of heat, steam or produced oil into the bottom water.

[0035] It is recognized that any of the elements and features of each of the devices described herein are capable of use with any of the other devices described herein without limitation. Furthermore, it is recognized that the steps of the methods herein may be performed in any order except unless explicitly stated otherwise or inherently required otherwise by the particular method.
[0036] Therefore, the present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered or modified and all such variations and equivalents are considered within the scope and spirit of the present invention. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee.
What is claimed is:

1. A method for mitigating thief zone losses by thief zone pressure maintenance through downhole radio frequency radiation heating comprising the steps of:
   introducing an antenna into a subterranean formation, wherein the antenna is operable connected to an energy source, wherein the subterranean formation comprises a hydrocarbon reservoir and a thief zone, wherein the thief zone is in thermal communication, fluid communication, or both with the hydrocarbon reservoir, wherein the hydrocarbon reservoir comprises hydrocarbons, and wherein the thief zone comprises or contains a thief zone fluid (thief zone liquid) susceptible to heating from radio frequency radiation;
   inducing radio frequency radiation in the antenna by way of the energy source;
   allowing the radio frequency radiation to propagate into the thief zone to heat at least a portion of the thief zone fluid therein to vaporize the thief zone fluid to form a thief zone gas to increase the pressure in the thief zone from a first thief zone pressure to a second thief zone pressure, wherein the second thief zone pressure mitigates fluid or heat interaction between the thief zone and the hydrocarbon reservoir that would otherwise occur if the thief zone had remained at the first thief zone pressure; and
   producing the hydrocarbons from the hydrocarbon reservoir.

2. The method of claim 1 wherein the step of producing the hydrocarbons comprises the step of recovering the hydrocarbons by way of a thermal recovery process.

3. The method of claim 2 wherein the thermal recovery process is a steam assisted gravity drainage (SAGD) process, a cyclic steam stimulation, a vapor extraction, a J-well SAGD, in situ combustion, a high pressure air injection, an expanding solvent-SAGD, a cross-SAGD process, or a combination thereof.

4. The method of claim 2 wherein the thief zone fluid comprises water and wherein the thief zone gas comprises steam.

5. The method of claim 4 further comprising the step of:
   determining an optimum excitation frequency of the radio frequency radiation by determining which frequency of the radio frequency radiation optimizes the thermal recovery process based on a depth of radio frequency penetration, a heat absorption of the
radio frequency radiation, and an overall heat input by the radio frequency radiation at a given frequency;

wherein the step of inducing radio frequency radiation in the antenna generates radio frequency radiation at the optimal excitation frequency.

6. The method of claim 1 for mitigating thief zone losses during heavy oil recovery, further comprising the steps of:

prior to introducing said antenna into the subterranean formation, introducing a steam assisted gravity drainage (SAGD) well pair into the subterranean formation, wherein the SAGD well pair comprises a producing well and a steam injection well; introducing steam into the steam injection well to establish a steam chamber in the hydrocarbon reservoir;

wherein the thief zone is in thermal communication, fluid communication, or both with the steam chamber;

wherein the thief zone fluid comprises water;

wherein the second thief zone pressure mitigates or eliminates hydrocarbon or heat losses to the thief zone that would otherwise occur if the thief zone had remained at the first thief zone pressure; and

wherein the hydrocarbons are produced through the producing well.

7. The method of claim 6 wherein the step of inducing radio frequency radiation in the antenna generates radio frequency radiation at a frequency from about 30 kHz to about 300 GHz.

8. The method of claim 6 wherein the hydrocarbons are bitumen.

9. The method of claim 6 wherein the thief zone is situated in an overburden of the hydrocarbon reservoir.

10. The method of claim 6 wherein the thief zone is situated in the hydrocarbon reservoir.

11. The method of claim 6 wherein the thief zone is a depleted steam chamber in the hydrocarbon reservoir.
12. The method of claim 6 wherein the antenna is situated above the hydrocarbon reservoir and wherein the antenna intersects the thief zone.

13. A method for mitigating thief zone losses during heavy oil recovery by thief zone pressure maintenance through downhole radio frequency radiation heating comprising the steps of:

   introducing a steam assisted gravity drainage (SAGD) well pair into a subterranean formation, wherein the SAGD well pair comprises a producing well and a steam injection well, wherein subterranean formation comprises a hydrocarbon reservoir wherein the hydrocarbon reservoir comprises hydrocarbons;

   introducing steam into the steam injection well to establish a steam chamber in the hydrocarbon reservoir;

   introducing an antenna into the subterranean formation, wherein the antenna is operable connected to an energy source, wherein the subterranean formation comprises a thief zone, wherein the thief zone is in thermal communication, fluid communication, or both with the steam chamber, wherein the thief zone comprises water;

   inducing radio frequency radiation in the antenna by way of the energy source;

   allowing the radio frequency radiation to propagate into the thief zone to heat at least a portion of the water therein to form steam to increase the pressure in the thief zone from a first thief zone pressure to a second thief zone pressure, wherein the second thief zone pressure mitigates or eliminates hydrocarbon or heat losses to the thief zone that would otherwise occur if the thief zone had remained at the first thief zone pressure; and

   producing the hydrocarbons from the hydrocarbon reservoir through the producing well.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US20 3/065068

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E21 B 43/24 (2014.01)
USPC - 166/248

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8): B01J 19/12; B23P 19/00; E21B 1/02, 36/00, 36/04, 43/00, 43/12, 43/16, 43/24, 43/30 (2014.01)
USPC - 166/57, 60, 247, 248, 272.1, 272.3, 272.6, 302, 303

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - C10G 15/08, 2300/1033, 2300/4037; E21B 36/04, 43/24, 43/305, 43/2401, 43/2406, 43/2408; H05B 2214/03 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patent, Google

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim</th>
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<tr>
<td>A</td>
<td>US 5,829,519 A (UTHE) 03 November 1998 (03.11.1998) entire document</td>
<td>1-13</td>
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<tr>
<td>A</td>
<td>US 5,120,935 A (NENNIGER) 09 June 1992 (09.06.1992) entire document</td>
<td>1-13</td>
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Further documents are listed in the continuation of Box C.

Date of the actual completion of the international search
21 February 2014

Date of mailing of the international search report
0 MAR 2014

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