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Woodward

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[54] **METHOD FOR RECOVERING VISCOUS PETROLEUM**

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[51] **Int. Cl.²** **E21B 43/24**

[58] **Field of Search** 166/256, 272, 259, 245, 166/268

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[57] **ABSTRACT**

The efficiency of an oil recovery process, being applied to a subterranean, viscous petroleum containing formation such as a tar sand deposit involving the injection of a thermal recovery fluid such as steam, heated air or hot water into an injection well to mobilize and displace petroleum toward a production well is improved by drilling a series of secondary injection wells or pressurization wells around the production wells. Unheated air is injected into the secondary injection wells at a pressure from about 10% to about 90% and preferably around 50% of the pressure at which the thermal recovery fluid is being injected into the central injection wells. A pressure gradient is maintained around the production wells which confines the mobilized petroleum and the thermal recovery fluid to the intended pattern. A low temperature oxidation reaction also occurs as a consequence of the unheated air injection which pretreats petroleum in the formation between the air pressurization wells and the production wells so that the next phase of oil recovery is improved.

11 Claims, 2 Drawing Figures

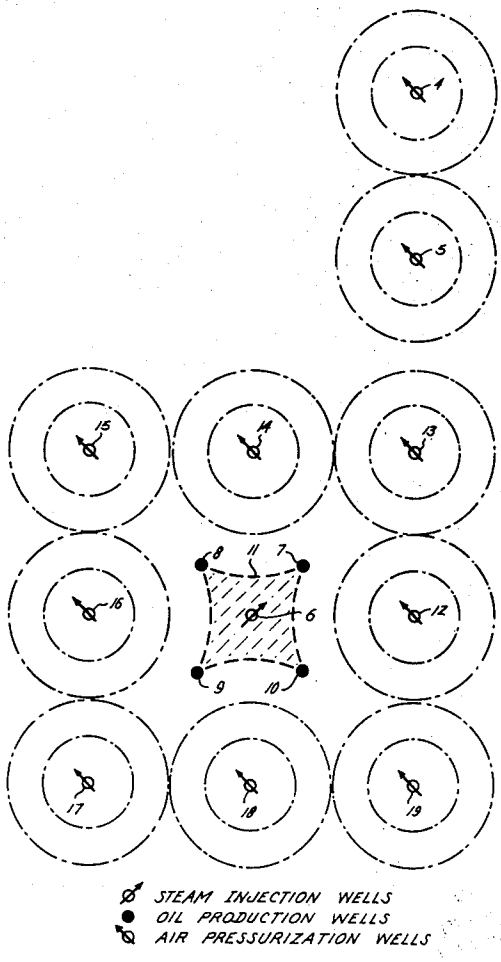
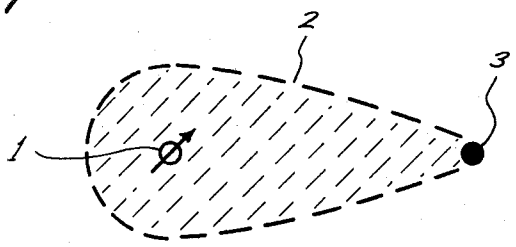


Fig. 1



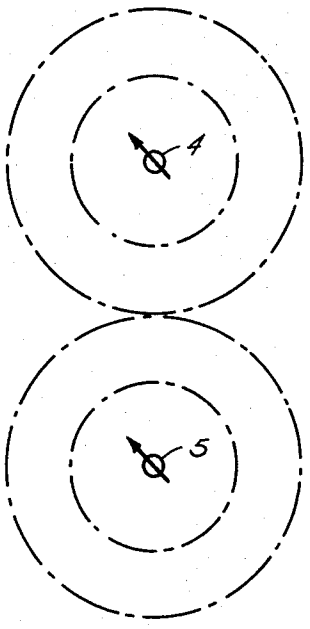
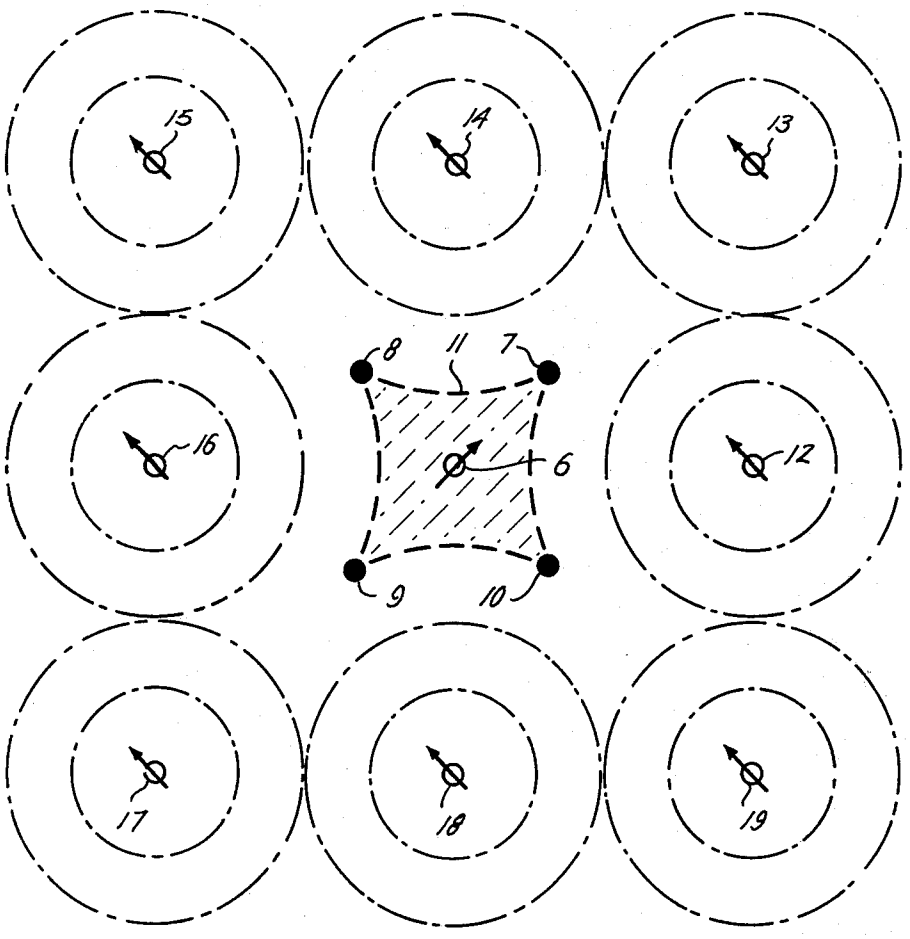


Fig. 2



STEAM INJECTION WELLS
OIL PRODUCTION WELLS
AIR PRESSURIZATION WELLS

METHOD FOR RECOVERING VISCOUS PETROLEUM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to commonly owned application Ser. No. 493,286, filed July 31, 1974.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention pertains to an oil recovery process and more particularly to a supplemental oil recovery process for use in recovering viscous petroleum from subterranean formations including tar sand deposits. Still more particularly, this invention pertains to a method for pretreating a section of the formation immediately surrounding a pattern being subjected to a supplemental oil recovery process in order to confine the recovery fluid in the pattern and also to pretreat the formation in preparation for the second phase of the oil recovery process.

2. Description of the Prior Art

When oil is discovered in subterranean reservoirs, certain conditions must be present in order to be able to recover the oil from the formation. It is necessary that the oil viscosity be sufficiently low that it is mobile, e.g. that it will flow if sufficient force is applied to it. Moreover, the formation must have adequate permeability or flow channels so that fluids may move from one point in the formation to another. Finally, some drive force must exist naturally or be supplied to the formation in order to move the formation petroleum to a production well where it may be pumped to the surface of the earth. When natural energy such as solution gas, gas cap or bottom water drive is present, oil may flow spontaneously without the application of any additional drive force and this phase of oil recovery is referred to as primary recovery. When the oil viscosity is sufficiently low and there exists satisfactory formation permeability but insufficient natural energy exists to cause it to flow to the surface of the earth, water drive or water injection may be utilized to drive or displace oil toward a production well. This is commonly referred to as secondary recovery.

There are many formations throughout the world which contain petroleum whose viscosity is so great that the petroleum will not move even if sufficient natural or artificial drive force is applied to it, even though the formation permeability is adequate. This petroleum is commonly referred to as viscous oil or heavy oil or low API gravity oil. For the purpose of this application, viscous petroleum or heavy oil is defined as petroleum whose API gravity is less than about 12° API. The most extreme example of viscous petroleum containing formations are the so called bitumen sand or tar sand deposit such as those located in the western United States and in Alberta, Canada. The bituminous petroleum contained in tar sand deposits is essentially immobile at formation temperature, and so substantial supplemental treatment must be applied to bituminous petroleum in order to render it sufficiently mobile that it will move to a production well so that it may be recovered to the surface of the earth.

One of the most popular methods for recovering viscous petroleum such as bituminous petroleum from subterranean formations such as tar sand deposits which are too deep to permit strip mining thereof, is

steam flooding. Steam is injected into one well and travels to a remotely located well from which it is recovered to the surface of the earth. The principal effect of steam injection is the increase in petroleum temperature which reduces the viscosity of the petroleum. Although the viscosity of bituminous petroleum in a tar sand deposit is in the range of millions of centipoise at normal formation temperatures, the viscosity-temperature relationship is exceedingly sharp, and the viscosity of the bituminous petroleum is reduced to only a few centipoise at around 300°F.

Numerous problems prevent effective utilization of steam injection in tar sand deposits. Because of the fact that steam is principally in the vapor phase when it is injected into the formation, the steam does not displace petroleum in a piston-like fashion, and much loss of the injected steam to the surrounding formation beyond the confines of the pattern being utilized in the supplemental oil recovery process occurs, with the attendant loss of thermal efficiency. Moreover, because of the extremely high viscosity of bituminous petroleum, the viscosity reduction resulting from petroleum being contacted with steam is frequently not sufficient to mobilize the highly viscous petroleum, and some form of pretreatment must be utilized.

Even though the petroleum viscosity is reduced as a consequence of being heated with steam, bituminous petroleum is quite prone to form high viscosity water-in-oil emulsions, which are viscous and difficult to displace through the formation.

In view of the foregoing discussion, it is apparent that there is a substantial unfulfilled need for a method of conducting a steam flooding operation in viscous petroleum containing formation so as to minimize the loss of injected steam to the surrounding formation beyond the confines of the pattern of the wells being utilized in the supplemental oil recovery process, and further to pretreat the formation so as to improve the efficiency of the steam flooding operation and to minimize the formation of water-in-oil emulsions.

SUMMARY OF THE INVENTION

Briefly, my invention comprises a process for recovering viscous petroleum from the subterranean formation wherein at least one injection well is drilled in the formation and a plurality of production wells are arranged symetrically around the production well, and a thermal recovery fluid such as steam, heated air, a mixture of steam and air or hot water is injected into the injection well to heat the formation within the pattern defined by the production wells so as to mobilize the viscous petroleum contained in the formation within the pattern. A plurality of air pressurization wells are drilled around the production wells in a generally symetrical fashion, and air is injected into the air pressurization wells at a pressure from about 10% to about 90% of the pressure at which the thermal recovery fluid is being introduced into the injection well. As a consequence of the air pressurization step, a pressure gradient is formed around the pattern which serves to confine the thermal recovery fluid, thereby improving the capture efficiency of and thermal efficiency of the thermal recovery operation. Air injection also pre-exposes the subterranean formation to air at a low temperature, thereby pretreating the formation so as to render it more responsive to oil recovery by thermal means such as steam, in situ combustion, or low temperature oxida-

tion recovery. After the main thermal recovery fluid has broken through at the production wells in the pattern, the production wells are converted to thermal recovery fluid injection wells and the air pressurization wells are converted to new production wells, and the thermal recovery operation is extended outward to the area previously pretreated by air pressurization.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates in plan view a four well pattern for practicing my invention comprising one thermal recovery fluid injection well, one production well, and two air pressurization wells.

FIG. 2 depicts in plan view a field being exploited by means of a thermal drive in which a central thermal recovery fluid injection well is surrounded by four production wells, and located around the four production wells are eight air pressurization wells for use in practicing the process of my invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Briefly, my invention involves the drilling of one or more wells in an area of the formation remote from a group of injection and production wells being used to recover oil by a thermal recovery means such as steam flooding, in situ combustion, air-steam controlled combustion, or hot water flooding. The additional wells are drilled outside of the area in which recovery is expected to be effected during the course of the first phase of the supplemental oil recovery operation.

In its simplest embodiment, as little as one injection well and one production well may be involved in a supplemental recovery operation, and one or more additional wells may be drilled outside of the anticipated swept area between the injection well and production well for the purpose of injecting unheated air into the formation to create the desired pressure gradients. As can be seen from FIG. **1**, the wells will be located on the opposite side of the production well from the injection well, so as to form an encircling pressure gradient when unheated air is injected into the additional air pressurization wells. After the thermal recovery fluid injected into well **1**, which may be air or steam or a mixture of air and steam or hot water, it sweeps the formation to form the expected tear shaped swept area **2** and ultimately the injected fluid breaks through into production well **3**. Once the thermal recovery fluid has broken through at the production well, that phase of the production operation is concluded and generally little or no additional oil will be recovered by continuing injection of thermal recovery fluid into well **1**. If additional air pressurization wells **4** and **5** are drilled and unheated air is injected into wells **4** and **5** during the period when thermal recovery fluid is traversing through the formation from injection well **1** to production well **3**, the formation between air pressurization wells **4** and **5** and production well **3** will have been pretreated as a consequence of unheated air injection into wells **4** and **5**. Several benefits result from this pretreatment process. The pressure gradients created around wells **4** and **5** confine the recovery fluid so as to avoid its loss into the formation, and similarly avoid the movement of mobilized petroleum from the formation away from the vicinity of production well **3**. Thus the pressure gradients assist in improving the thermal efficiency and capture efficiency of the supplemental oil recovery operation. In addition, a gas saturation is established in that portion of the formation between wells **3**, **4**, and **5**, which will improve the receptivity of the oil formation to the subsequent injection of thermal recovery fluid in the next phase of the recovery program. Additionally, it has been discovered that bituminous petroleum such as is found in tar sand deposits is beneficiated by a prior contact with unheated air for a prolonged period of time. Numerous benefits result from such prior contact, including increased oil recovery efficiency and a reduction in the pressure gradient between wells necessary to drive the fluid toward the production well. Additionally, it has been observed that the pretreatment wih unheated air causes an additional improvement in the response of bituminous petroleum such as tar sands to steam flooding where the principle mechanism for transporting viscous petroleum through the porous formation involves the formation of a low viscosity oil-in-water emulsion. In application of a steam drive to a tar sand deposit which has not been pretreated with untreated air, both oil-in-water emulsions and water-in-oil emulsions are formed. Water-in-oil emulsions have relatively high viscosities and require additional treatment in order to break the emulsions, whereas oil-in-water emulsions are very low in viscosity and are very readily resolved into their separate phases by contacting the emulsion with a mineral acid. Pretreating the bituminous petroleum with unheated air causes a preference for oil-in-water emulsions which explains the reduction in pressure required to drive the bituminous petroleum toward the production well.

While the above described process contemplates the simplest method of applying the process of my invention, ordinarily supplemental oil recovery of the type wherein a thermal recovery fluid such as steam or hot water or heated air for in situ combustion is injected into the formation involves the use of a pattern in order to achieve greater sweep efficiency. The most common type of pattern is so called inverted five spot, such as is shown in FIG. **2**. In a simple five spot pattern, an injection well **6** is located in the center of the square grid and four production wells **7**, **8**, **9** and **10** are located on the corners of the square. Thus steam is injected into the central injection well and moves outwardly toward the four production wells, sweeping nearly all of the area within the square whose corners are defined by production wells **7**, **8**, **9** and **10**. The shape of the swept area in a conventional inverted five spot pattern is approximately as is shown in FIG. **2** by dotted line **11**. It can be seen that the swept area cusps outward as the injected fluid approaches the production well, with the result that not quite all of the square pattern is swept by the fluid. Nonetheless, relatively high sweep efficiency is realized. Frequently, the five spot pattern is part of an even larger pattern in which there are many contiguous five spot patterns. The performance of a field may be analyzed by examining only the single five spot element, however, and so only one five spot element is shown in FIG. **2**.

An application of the process of my invention to a supplemental oil recovery process employing a five spot pattern is shown in FIG. **2**. The air pressurization wells **11**, **12**, **13**, **14**, **15**, **16**, **17** and **18** are drilled around production wells **7**, **8**, **9** and **10**. Although the spacing between the inner grid and the outer grid can

vary, it is convenient to make the spacing somewhat equal for reasons that will be explained later.

In the pattern as shown in FIG. **2**, when steam injection is initiated into steam injection well **6**, air pressurization may similarly be initiated in wells **11–18**. Injection may be initiated simultaneously into all the wells, or it is sometimes satisfactory to inject into only part of the wells initially, after which unheated air injection is switched to the other wells. For example, injection may initially be into wells **11, 13, 15** and **17** for a period of time, after which injection is switched to wells **12, 14,** 16 and **18.**

The pressure at which air is injection into the air pressurization wells surrounding the production wells may be maintained between about 10% and about 90% of the pressure at which the thermal recovery fluid is injected into injection well **6.** I have found that in an especially preferred embodiment, the pressure in the air pressurization wells is maintained at approximately 50% of the pressure at which steam is being injected into the steam injection wells. Since production wells **7, 8, 9** and **10** are at a pressure much lower than central injection well **6** and also lower than air pressurization wells **11–18,** there will be a positive pressure gradient not only between central injection well **6** and production wells **7, 8, 9** and **10,** but there will also be a similarly positive pressure gradient between air pressurization wells **11–18** and production wells **7–10.** Thus there will be some flow of air from air pressurization wells into the production wells.

In one embodiment of the process of my invention, the pressure at which unheated air is injected into air pressurization wells **11–18** is maintained at the lowest level which will give a slight indication of gas being produced at production wells **7–10,** indicating that a slow movement of unheated air through the formation is being accomplished. This can be facilitated by adding a small amount of a readily detectable material to the injected air to function as a tracer.

While the above described method of applying the process of my invention has generally referred to the use of steam injection, it is to be understood that it is not so limited. The same procedure may be used in an in situ combustion operation, in which heated air is injected into central injection well **6** to initiate a combustion reaction within the formation, which propagates through the formation toward production wells **7–10.** Unheated air is similarly injected into wells **11–18,** which will not result in the same combustion reaction as occurs within the central pattern, since the oil temperature is never raised to a point at which the combustion reaction is initiated. Once the in situ combustion reaction has been initiated by heating the air being injected into well **6** or by direct application of heat to the oil formation while injecting unheated air, the supplemental heating step may be terminated and the injection of unheated air into well **6** is sufficient to maintain the in situ combustion reaction which propagates through the formation toward production wells **7, 8, 9** and **10.** Thus after the initial ignition step, unheated air is being injected into well **6** and also unheated air is being injected at a lower pressure into air pressurization wells **11–18;** however, a totally different kind of reaction is occurring as a consequence of injection of unheated air into well **6** from that which is occurring as a consequence of injection of unheated air into wells **11–18.**

The above described process may similarly be used in the application of a modified combustion process known as a controlled combustion reaction, in which the temperature of the combustion front propagating outwardly from injection well **6** is regulated by the injection of water or steam simultaneously or intermittently with the injection of air into the formation after the combustion reaction has been initiated. This type of process appears to be more suitable for use in recovering viscous asphaltic petroleum from tar sand deposits than either steam flooding or in situ combustion alone. Thus the application of the process of my invention to a formation being exploited by means of controlled combustion would entail in one example, the simultaneous injection of steam and air into well **6** while unheated air is being injected at a reduced pressure into wells **11–18** to maintain the desired pressure gradients around production wells **7–10.**

The process of my invention may also be used with other patterns, such as a seven-well delta pattern, a hexagonal pattern, or other arrangements of a plurality of production wells around one or more central injection wells.

While air is the especially preferred fluid for injection into pressurization wells **11–18,** certain benefits of the process of my invention may be realized by injecting gases other than air into pressurization wells **11–18.** For example, carbon dioxide, natural gas, other gaseous hydrocarbons such as ethane, propane, or butane, as well as inert gases such as nitrogen may be injected into wells **11–18** at a pressure below the pressure at which the thermal fluid is being injected into central injection well **6,** in order to create the gas saturated zone and to establish the confining pressure gradients around the production wells. The use of gases other than air or oxygen containing gases will not achieve the low temperature oxidation pretreatment of the bituminous petroleum as is achieved when air is injected into the outer wells. Accordingly, the especially preferred embodiment employs the injection of unheated air or an oxygen containing gas into pressurization wells **11–18.**

By the term "unheated air" it is meant that the air is not deliberately heated prior to injection. Some heating occurs in the compression of air, however. As used herein, unheated air means air having a temperature below about 400°F and preferably below about 200°F.

FIELD EXAMPLE

In order to demonstrate the operability of the process of my invention, and further to supplement the disclosure contained above, the following description of a field experiment is presented.

A one-half acre five spot pattern was drilled in the Athabasca tar sand deposit consisting of a central injection well and four surrounding production wells essentially as shown in FIG. **2.** Similarly, eight air pressurization wells drilled around the small pilot, with the expectation that these wells would later be used in an expanded pilot, and so were completed so that they may serve as air pressurization wells initially and as production wells in the later stages of the operation. Well spacing was chosen so that wells **12, 14, 16** and **18** defined a five acre pattern and wells **11, 13, 15** and **17** defined a 10 acre pattern. A mixture of steam and air was injected into the central injection well **6,** the ratio of steam to air being approximately 0.4 barrels of steam

(as water) per thousand standard cubic feet of air. The injection rate was increased from a fairly low initial level to the maximum rate at which air and steam could be injected into the central injection well, and was maintained in the later stages of the operation at a fairly constant level of about 500,000 standard cubic feet of air per day. While steam and air were being injected into central injection well **6** for the purpose of causing a controlled combustion reaction to propagate through the formation toward the four outer production wells **7, 8, 9** and **10,** air was injected into the outer ring of air pressurization wells. Air was injected sequentially into the eight outer air pressurization wells rather than simultaneously in this particular pilot because of equipment limitations. Nevertheless, during the course of the operation, unheated air was injected into each of the outer wells for the purpose of pretreating the formation between these outer pressurization wells and the middle ring of production wells. After the controlled combustion front reached the four production wells, these wells were converted to steam-air injection wells and a mixture of steam and air was injected into these four original production wells simultaneous with the continued injection of steam and air into the original central injection well. Outer wells **12, 14,** 16 and **18** which are originally used as air pressurization wells were converted to oil production wells, and oil recovery was obtained from these outer wells. It was noted that the produced fluid was predominantly in the form of a low viscosity oil-in-water emulsion, and a relatively low pressure gradient was maintained between the central injection wells and the outer production wells in the second stage of the operation.

While my invention has been describes in terms of a number of specific illustrative examples, it is not so limited since many variations thereover will be immediately apparent to those persons skilled in the related art without departing from the true spirit and scope of my invention. Similarly, while several mechanisms have been described for the purpose of explaining the benefits resulting from the application of the process of my invention, it is not necessarily represented hereby that these are the only or even the principal mechanisms responsible for such benefits, and I do not wish to be bound by any particular explanation of the mechanisms involved. It is my desire and intention that my invention be limited and restricted only by those limitations and restrictions that appear in the claims appended immediately hereinafter below.

I claim:

1. In a method of recovering petroleum from a subterranean petroleum containing formation penetrated by at least one injection well and by at least one production well, of the type wherein thermal recovery fluid is introduced into the injection well and petroleum is recovered from the remotely located production well, wherein the improvement for increasing the capture efficiency of the oil recovery operation and for pretreating a portion of the formation for the next phase of the oil recovery method comprises:

a. completing at least one gas pressurization well in the formation on the opposite side of the production well from the thermal recovery fluid injection well,

b. introducing a gaseous material into the pressurization well at a pressure less than the pressure at which the thermal recovery fluid is introduced into the injection well for the purpose of pretreating the formation petroleum and creating a pressure gradient around the additional well which serves to confine the injected fluid in mobilized petroleum, and

c. recovering petroleum from the production well.

2. A method as recited in claim **1** wherein the fluid injection into the pressurization well is air.

3. A method as recited in claim **1** wherein the temperature of the gaseous material is below 400°F.

4. A method as recited in claim **1** wherein the temperature of the gaseous material is below 200°F.

5. A method as recited in claim **1** wherein the pressure at which the gaseous material is injected into the pressurization well is from about 10% to about 90% of the pressure at which the thermal recovery fluid is injected into the injection well.

6. A method as recited in claim **1** wherein the thermal recovery fluid is steam.

7. A method as recited in claim **1** wherein the thermal recovery fluid is heated air.

8. A method as recited in claim **1** wherein the thermal recovery fluid is a mixture of air and steam.

9. A method as recited in claim **1** wherein a plurality of production wells are drilled around at least one centrally located injection well, and a plurality of pressurization wells are drilled around the pattern defined by the production wells.

10. A method as recited in claim **9** wherein the pressurization wells are later converted to production wells after the oil mobilizing fluid has broken through into the production wells.

11. A method of recovering bitumen from a tar sand deposit comprising

a. penetrating the tar sand deposit with at least one injection well;

b. penetrating the tar sand deposit with a plurality of production wells equally spaced around the injection well;

c. penetrating the formation with a plurality of air pressurization wells located at a greater distance from the injection wells than the production wells;

d. introducing a thermal recovery fluid into the injection well;

e. recovering petroleum from the production wells; and

f. injecting air into the outer pressurization wells at a pressure between about 10% and about 90% of the pressure at which the thermal recovery fluid is injected into the central injection well and at a temperature below 400°F.

* * * * *