The present invention relates to an improved process for the recovery of liquid bitumen from underground deposits, and to apparatus suitable therefore. More particularly it relates to the use of hot combustion gases in the recovery of liquid bitumen from underground deposits therefrom, and to apparatus used therefor.

The term "bitumen" as used above and hereinafter throughout the specification and claims is intended to mean any number of inflammable mineral substances consisting mainly of hydrocarbon and including the oil petroleum and even the volatile naphthas.

Bitumen has been previously recovered from subterranean deposits by heating and introducing the said deposits so that they could be recovered by pumping. This has customarily been done by introducing heated bitumen and water into the deposits so as to make the removal of the oil by pumping easier. The fluid of the liquid bitumen, so as to permit rapid and complete recovery by pumping, is improved by removing the viscosity and the surface and/or interface tensions of the liquid bitumen. The water introduced into the deposit applies pressure to the liquid bitumen in the deposit. The decrease of the yield of a deposit always occurs at the bitumen-contact zone. Therefore, it is desirable in a bitumen field to set up a treatment zone in the vicinity of the bitumen-water contact zone where so-called test drillings are effected and test bores drilled through which the contents of the deposit are removed by bringing the bitumen to the surface in the form of a heated liquid, through a closed, heat-insulated pipe system. The liquid bitumen is heated after removal from the ground and additives mixed with it, and then returned under pressure into the deposit through the so-called treatment bores. These test-bores and treatment bores are so arranged with respect to each other that a direction of flow is set up perpendicular to the continuously progressing direction of the field, resulting from the water introduced into the deposit under pressure.

According to the present invention it has been found that by adding combustion gases to the deposit content, (bitumen and water) brought to the surface by test bores and by returning the deposit content as a heat transfer medium through the treatment bores the removal of the deposit from the ground is materially accelerated. It has been found that the addition of hot combustion gases is particularly effective. It is well known that gases have previously been added to petroleum deposits for the purpose of increasing the pressures in the deposits and to facilitate the removal of additional petroleum. The method of introduction of the gas depends upon the particular structure in which the petroleum is found; when the gas is introduced into the upper part of the structure it serves to increase the pressure, but when injected deep into the structure it functions in a manner known as "gas drive." An essential factor in the addition of the gas besides the purpose of increasing the pressure is in dissolving a portion of the gas in the oil inside the deposit so that viscosity is decreased and the forces affecting the adherence of the oil to the oil-bearing rocks are influenced by decreasing both the surface and interfacial-tensions.

When used as a pressure gas, products such as natural gas, air, flue gases etc., have previously been used. The natural gas from the deposit itself is not always available in sufficient amounts, and the greater part thereof is methane which is not very soluble in the oil. Air has the disadvantage that the higher petroleum hydrocarbons become oxidized, which results in an increase in insolubility, thus resulting in an increase in viscosity and increases the viscosity difference toward the deposit water. Even in the case of flue gas the oxygen fraction is still undesirably high because the combustion in modern heating installations is carried out with 10-30% excess of air. The high nitrogen content is also a disadvantage since nitrogen is dissolved only to a small extent, its solubility in oil or water being only about $\frac{1}{2}$ as that of carbon dioxide. Gases which cannot be dissolved in the oil can be distributed in the latter in the form of tiny gas bubbles, which are liberated from the oil in the same general manner as when gases are subjected to an increase in yield resistance. This increase in the yield resistance through gas discharge is known as the Jamin effect.

In the present invention a combustion gas is employed whose $CO_2$ components are enriched, thus giving a good solubility in bitumen and accordingly not only the viscosity of the bitumen is decreased, but also the surface and interface tensions thereof are advantageously changed. For such further enrichment with solubility-

increasing compounds, the combination of the combustion gas production with an enrichment with paraffinic $C_1-C_7$ hydrocarbon vapors is suggested, by which means a loaded combustion gas is obtained which contains largely carbon dioxide, water vapor and paraffinic $C_1-C_7$ light hydrocarbons as solution enhancing components, and at the same time the nitrogen and oxygen, which have an unfavorable effect, are materially reduced in amount. Depending upon the kind and state of the deposit into which it is to be introduced, the composition of the loaded combustion gas and/or its application may be varied so that the gas with high $CO_2$ content has steam and light hydrocarbons added to it, or only steam alone. It can also be advantageous to feed the hydrocarbon into the deposit as liquids and then to introduce the combustion gas.

Hot combustion gases are added above the ground to the heat transfer medium, the bitumen or deposit water removed close to the bitumen-water-contact zone. The individual components of the hot combustion gases, such as carbon dioxide, water vapor, nitrogen, hydrocarbon gas and/or vapor form a completely homogeneous mixture. The component ratios are adjusted to the pressure and temperature of the heat transfer medium so that all of the components become completely dissolved therein. The water vapor contained in the gas as a combustion product releases its sensible and its latent heat of combustion to the heat transfer medium, dissolves, when in the liquid state, the carbon dioxide from the combustion gas and distributes in fine aqueous droplet form the dissolved carbon dioxide with the heat transfer medium in the bitumen deposit head of the moving bitumen-water-contact zone and facilitates, due to the influence of the carbon dioxide in changing the interface- and surface-tensions, the release of the bitumen layer from the carrier medium, i.e. from the grains of sand of the deposit.

It is preferred to subdivide the loaded combustion gas mechanically into small gas bubbles, i.e. about 0.15 mm. in diameter, at the point where it is mixed with the heat transfer medium. After the condensation of the water
rounded by liquefied hydrocarbons which also carry dissolved carbon dioxide. The water droplets, therefore, are surrounded by a protective film of carbon dioxide which penetrating deep into the deposit produce in the latter over a wide area changes in the surface-and interfacial-tensions on both the bitumen and the water.

The combustion gases can, if preferred, be introduced into the deposit through drilled holes without having been previously mixed with the heat transfer medium.

An embodiment of the apparatus suitable for the generation of a combustion gas for use in the present invention is shown in the figures.

In the figures:
[FIGURE 1] is a cross-section of the apparatus for producing modified and activated gases of combustion;
[FIGURE 2] is a plan view of the distributor disk located in the apparatus of [FIGURE 1]; and
[FIGURE 3] is a plan view of the rotating disk located in the apparatus of [FIGURE 1].

In FIGURE 1, attached hereto and a part of the present disclosure, is shown a typical form of apparatus for the generation of a loaded combustion gas mixed with the heat transfer medium suitable for use in the present invention. In this apparatus simultaneous mixing is effected with additional components with which the combustion gas will form a homogeneous mixture in the form of very small bubbles by distribution with heat transfer medium. The apparatus consists of a combustion chamber 8 to which gaseous or liquid hydrocarbons are supplied through line 1 at pressures ranging from 10–20 atmospheres gauge. An oxygen carrier containing 80–95% oxygen is introduced through line 2. Combustion takes place in the burner 3. The combustion products formed in the burner contain a higher thermal energy than is either necessary or desirable for the next step of the process, i.e., the evaporation of the light hydrocarbons and the mixing thereof with the combustion gas. The combustion chamber 5 is accordingly surrounded by a steam generator 4 in which part of the thermal energy is transferred into high-pressure steam of 55–75 atmospheres gauge (36–76 absolute atmospheres) pressure at a temperature of 475–525°C. The amount of the thermal energy that must be utilized in this manner depends upon the amount and composition of the light hydrocarbons to be evaporated. Water is supplied to the boiler through pipe 20 and the steam formed is removed through conduit 19.

Paraffinic light hydrocarbons having 1 to 7 carbon atoms are introduced through conduit 7, containing liquid distributors 6, into the combustion chamber 5 where they are evaporated and homogeneously mixed with the gas, which at this point has a temperature which makes it possible to evaporate the C₄₇–C₇ hydrocarbons at the existing pressure with no substantial degree of cracking. Should additional cooling be required in the evaporation zone, part of the heat transfer medium to be treated can be supplied through a pipe (not shown in the drawing) from the conduit 15.

By mixing with light hydrocarbons a loaded combustion gas is obtained having the composition shown in the table below. Depending upon the operating pressure and temperature, the kind of deposit being treated, and the weight ratio of the loaded combustion gas to be supplied on the basis of these data, per unit of heat transfer medium, the composition of the combustion gas may vary between the tolerance limits set forth below:

<table>
<thead>
<tr>
<th>Water vapor</th>
<th>Carbon Dioxide</th>
<th>Hydrocarbons C₁₇-C₇ (vapor or gas)</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent by volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper limit, percent by volume</td>
<td>38.68</td>
<td>23.77</td>
<td>28.43</td>
</tr>
<tr>
<td>Lower limit, percent by volume</td>
<td>37.16</td>
<td>21.05</td>
<td>20.48</td>
</tr>
</tbody>
</table>

It has been found that under such operating conditions the amount of nitrogen present is completely dissolved in the heat transfer medium.

The loaded combustion gas is compressed by the compressor 8 to a pressure of 40–75 atmospheres gauge into the mixing space 9. The heat transfer medium is fed into space 9 through conduit 15. The gas is dissolved therein and the heat transfer effected. In order to bring both phases into intimate contact with each other, the stream of heat transfer medium is subdivided at the point of introduction into the mixing space by the action of the perforated disk 14. The combustion gas being introduced through the distributor disk 16, in which a number of holes 18 are arranged in lines and circles (as shown in the drawings), and ahead of which a winged cross 11 rotates and which is driven by the motor 13 through shaft 12. In this manner at one revolution e.g. 600 holes are covered at one time, causing the gas to be distributed in the heat transfer medium in the form of small bubbles. During this operation the heat transfer medium is heated to a temperature of 50–125°C. higher than that at which it enters the chamber. If required, additional heating can be effected by adding to the mixture high pressure steam delivered through the boiler 4 through the conduit 17. The heat transfer medium thus mixed with the loaded combustion gas and heated to a higher temperature is then passed through conduit 16 into treatment bore through which it passes into the deposit to be recovered.

The following specific example will illustrate the operation of the new process and apparatus disclosed in the drawings which are the subject of the present invention and furnish numerical values concerning the production, composition and use of combustion gases. It is understood, however, that the invention is not limited to the specific values shown in this example, which are for purposes of illustration only, and that variations known to one skilled in the art can be made within the limitations set forth herein and claimed in the appended claims.

**EXAMPLE**

Combustion gas was produced by burning in the burner 3 of the steam boiler 5 of the drawing 700 m³ per hour of natural gas with an upper heating value of (H₂) of 1150 Kcal. per normal cubic meter with 1740 m³ per hour of enriched oxygen carrier (90% oxygen, 10% nitrogen) at 15 atmospheres gauge, thus obtaining 7.8 x 10⁶ Kcal. heat per hour. Of this heat 10% was lost when being transformed, but 4.88 x 10⁶ Kcal. per hour were transferred into steam at 65 atmospheres gauge and 525°C. Superheat. If the feed water enters the boiler from 20 at a temperature of 65°C, the steam may then be used to generate about 2150 kwh of electricity per hour. The remaining amounts of heat (3.28 x 10⁶ Kcal./h.) were employed to heat 42.0 tons of liquid bitumen per hour to 95°C. (including heat losses) arriving from 15. The heating of the liquid bitumen occurs by solution of the loaded combustion gas, which is low in nitrogen and oxygen, in liquid bitumen under a pressure of 65 atmospheres gauge. Because the combustion gases have been saturated with 950 kilograms of light hydrocarbons, delivered through 7, the combustion gas transports per hour (in kilograms) 1510 carbon dioxide, 1300 water, 5
In the process of claim 4 wherein said modified gas of combustion is produced in a combustion chamber surrounded by a steam generator and having a mixing chamber adjacent to and connected to said combustion chamber for mixing said modified gas of combustion, said stratum contents, and said steam produced by said steam generator, and said heat transfer medium is forced into the stratum by means at the top of said drill holes for forcing said heat transfer medium.

The process of claim 3, wherein said loaded modified gas of combustion has an average composition of approximately 37.16 to 79.62% by volume of water vapor, 21.02 to 34.15% by volume of CO₂, 20.43 to 35.74% by volume of C₁₋₄ hydrocarbons and 2.31 to 6.01% by volume of N₂ whereby said composition is present only in liquid form after being forced into said deposits.

A process for the recovery of liquid bitumen from subterranean bituminous deposits by treating said deposits through drill holes with fluid media comprising burning hydrocarbons with an oxygen carrier containing 80 to 95% O₂ thereby producing a hot modified gas of combustion, loading said hot modified gas of combustion with paraffinic C₁₋₄ hydrocarbons, delivering stratum contents through certain said drill holes, mixing the loaded modified gas of combustion with portions of said stratum contents under increased pressure whereby the temperature of the fluid that is to be returned to said deposits is increased 50 to 125°C. thereby forming a heat transfer medium and introducing through other of said drill holes said heat transfer medium under pressure and at a temperature whereby the heated section of said deposits contains only liquid contents.

The process of claim 8 wherein steam is introduced into the mixture of modified gas of combustion and stratum contents in such amounts that the temperature of said stratum contents is raised 50 to 125°C.

The process of claim 8, wherein said loaded modified gas of combustion has an average composition of approximately 37.16 to 79.62% by volume of water vapor, 21.02 to 34.15% by volume of CO₂, 20.43 to 35.74% by volume of C₁₋₄ hydrocarbons and 2.31 to 6.01% by volume of N₂ whereby said composition is present only in liquid form after being forced into said deposits.

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