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Woods et al.

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[54] **THERMAL PROCESS FOR RECOVERING OIL**

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[52] **U.S. Cl.** ..... **166/303,** 166/305 R

[51] **Int. Cl.** **E21b 43/24**

[58] **Field of Search** ..... 166/303, 305 R, 308, 166/263

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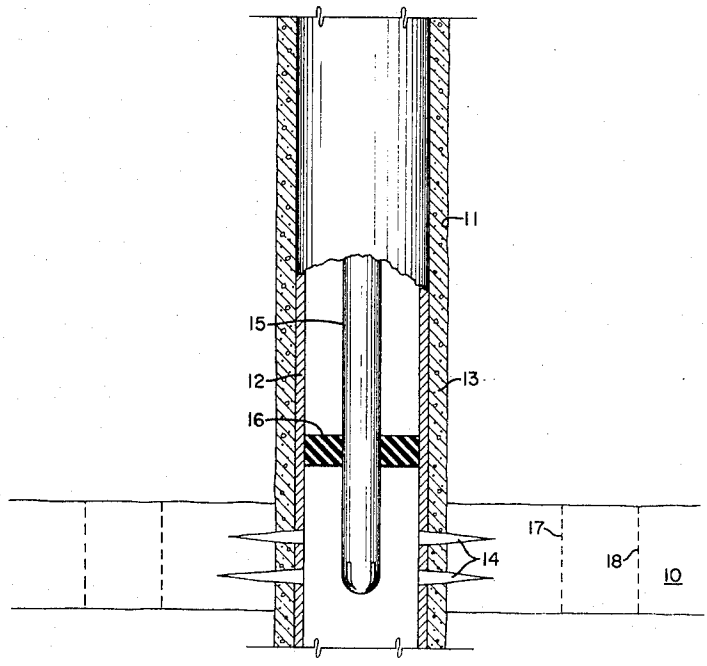
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[57] **ABSTRACT**

Disclosed herein is a thermal method for recovering oil from a subterranean formation in which a substantially cylindrical heated zone is created in the formation and in which heat can be introduced into the formation at a high rate. In the method a heated fluid (preferably steam) is injected down a well and into the formation at a pressure which is less than the formation breakdown pressure. Preferably, formation fluids are then withdrawn by means of the well. Subsequently, a heated fluid (again, preferably steam) is injected into the formation at a pressure greater than the formation breakdown pressure. Oil which has been heated by the injected fluids is recovered, preferably by means of the injection well, from the formation.

7 Claims, 4 Drawing Figures



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SHEET 1 OF 2

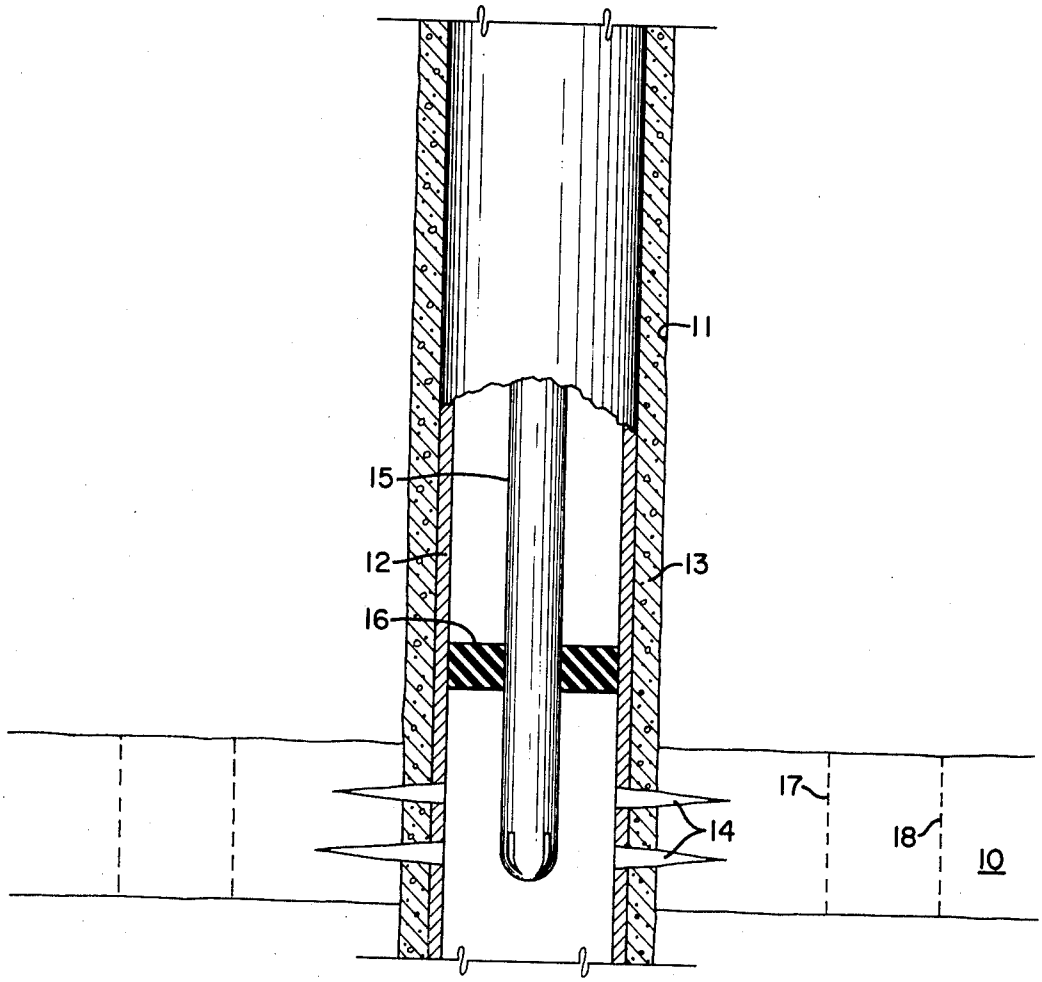


FIG. 1

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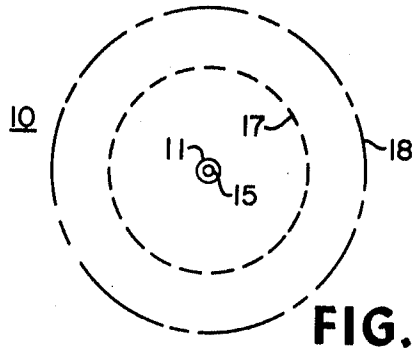


FIG. 2

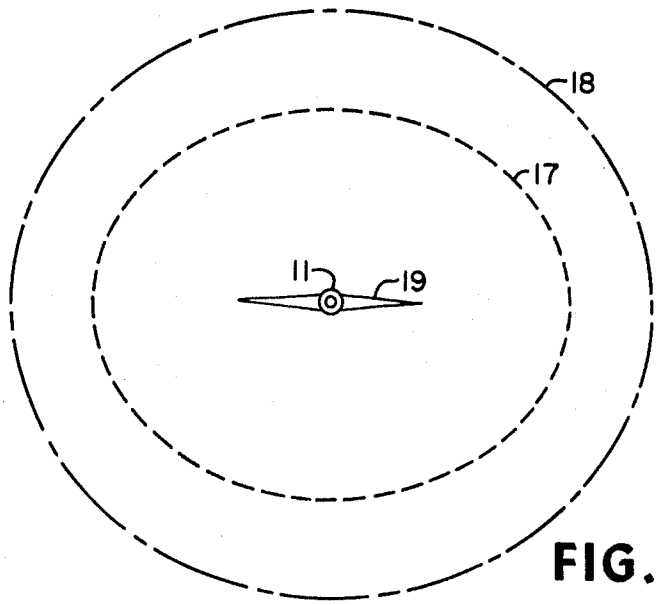


FIG. 3

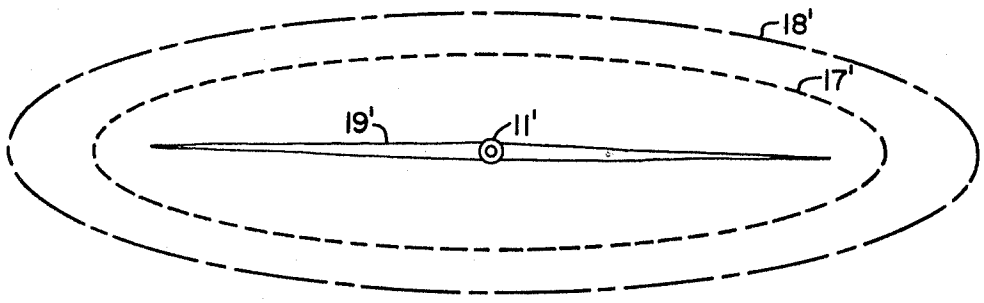


FIG. 4

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THERMAL PROCESS FOR RECOVERING OIL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the recovery of petroleum from a subterranean formation utilizing a well or wells for the injection of heated fluids and for the withdrawal of petroleum.

2. Description of the Prior Art

Among the more promising methods that have been suggested or tried for the recovery of oil from viscous oil reservoirs are those which introduce thermal energy into the reservoirs. The viscosity of the oil in these reservoirs is generally so high that the oil cannot be recovered at economical rates using conventional techniques. However, the viscosity of these oils can generally be radically reduced by heating. Consequently, when thermal energy is introduced into these reservoirs and the oil is heated, the viscosity will generally be reduced to a point that the oil can flow at efficient and economical rates.

The thermal energy may be in a variety of forms. Hot water, in situ combustion, and steam are examples of forms of thermal energy which have been used to recover oil from these viscous oil reservoirs. Each of these thermal energy agents can be useful under certain conditions. However, steam is generally the most efficient and economical and is clearly the most widely employed thermal energy agent.

A number of suggestions have been advanced for improving the efficiency of "steaming operations" for oil recovery. Considerable effort has been directed to one facet of this problem—increasing the fluid conductivity of such reservoirs. For example, it has been suggested that the formation may be fractured wth steam to increase its permeability and to place heat quckly into tht formation at a substantial distance from the wellbore. Similarly, it has been suggested that, in an unconsolidated formation, steam be injected at a pressure which is greater than the overburden pressure to create a fluidized zone within the formation. Also, it has been suggested that a plugging agent be included in a fracturing fluid to create an extensive fracture within the formation prior to steam injection. Each of these methods has the underlying purpose of increasing the permeability of the formation to the injected heated fluid and of permitting the steam to travel a substantial distance from the wellbore in a relatively short period of time.

These techniques can be effective in accomplishing their purpose of creating a highly conductive flow path within the formation for injected steam and of heating the formation at a substantial distance from the well. These fracture systems are plane-like heat sources and can be beneficial to certain oil recovery processes. For example, where steam is continuously injected through one well into a fracture in the formation to drive oil before it to an offset producing well, the heat from the fracture covers a wide portion of the formation. Nevertheless, such planar heat sources can be undesirable in other steaming operations.

In steam stimulation processes, it is preferable to retain the heat near the injection well. In this process, commonly referred to as the "huff-and-puff" process, steam is injected into the formation through a well and subsequently heated oil is withdrawn from the formation by means of the same well. Since the same well is used for both injection and production, it is desirable to have a substantially cylindrical heated zone around the well. Such a cylindrical heated zone is most efficient in transferring thermal energy to the oil in the formation. A fracture formed in accordance with the teaching of the prior art at the location of the injection-production well will not assist in forming a cylindrical heated zone; the heated zone around such a fracture would resemble an ellipse with a high degree of eccentricity. The thermal energy which passes through the fracture heats oil in the more remote areas of the reservoir. This heated oil which is remote from the well has a tendency to cool to the point where it will no longer flow before it can be produced. As a consequence, the efficiency of the process declines.

SUMMARY OF THE INVENTION

In the practice of this invention, the heated zone around an injection well has a desirable configuration, i.e., approximately cylindrical, and the zone has a high conductivity to injected fluids. These desirable results are accomplished by first heating the formation by injecting a heated fluid, such as steam, at a pressure which is less than the formation breakdown pressure. This first injection step creates a heated zone which is substantially cylindrical. Preferably, fluids are then withdrawn from the formation by means of the well to reduce the oil saturation within the heated region. Subsequently, a heated fluid, which also may be steam, is injected into the formation at a pressure exceeding the formation breakdown pressure. This second injection step generally creates a fracture or pressure-parting of the formation which is highly conductive to injected fluids. In addition, due to the higher pressure of the second injection step a relatively high fluid injection rate is achieved. However, due to the first injection step, the fracture is less extensive than it would be in the absence of the first injection step. As a consequence, the heated region around the injection well is larger but remains approximately cylindrical. Thus, in the practice of this invention, two desirable results are achieved. The heated fluid can be injected at a high rate, and the heated region around the injection well retains an approximately cylindrical configuration.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic elevation view in partial section of a well intersecting an oil-bearing formation.

FIG. 2 is a schematic plan view of the oil-bearing formation penetrated by the well and illustrating the heated regions around the well following the initial injection of steam into the formation.

FIG. 3 is a schematic plan view of the oil-bearing formation penetrated by the well and illustrating the heated regions around the well following the subsequent injection of steam.

FIG. 4 is a schematic plan view of an oil-bearing formation penetrated by a well and showing the heated regions around the well where the formation is fractured in accordance with the teachings of the prior art.

DESCRIPTION OF THE INVENTION

The practice of this invention can perhaps be most easily understood by reference to the drawings. Referring to FIG. 1, an oil-bearing formation shown generally at 10 is penetrated by a well or borehole 11 which

has been drilled from the surface of the earth (not shown). A string of large diameter pipe or casing **12** is placed in the hole and bonded to the walls of the well by the cement sheath **13** in a conventional manner. The casing **12**, the cement sheath **13**, and the formation **10** are then perforated to provide paths **14** for fluid communication between the interior of the casing and the formation. A string of small diameter pipe or tubing **15** is suspended within the casing **12** for the injection of fluids into, and for the withdrawal of fluids from, the formation. The exterior of the tubing is fitted with a packer assembly **16** which engages the interior of the casing to bar fluid communication within the casing-tubing annulus at that location. It should be understood that this is a conventional well completion which may be used in the practice of this invention. However, the invention is not limited to this specific apparatus. Any well completion apparatus which is capable of being used in the following described process will be satisfactory.

With a completion assembly such as that illustrated in FIG. **1**, a heated fluid is injected down the tubing and into the oil-bearing formation. As will be discussed in more detail later, a number of fluids may be used in the practice of this invention. However, saturated steam generally will be preferred and the most convenient to use. The invention will therefore be discussed in terms of saturated steam.

The initial volume of saturated steam is injected at a pressure which is less than the fracturing pressure for the formation. As a consequence of this initial steam injection, steam will exist out to some radial point **17** from the well. Hot water from condensed steam and heated formation water will extend for a further distance into the reservoir to a radial point **18.**

The configurations of the heated zones within the formation following the injection of the initial volume of saturated steam can perhaps be more clearly seen in FIG. **2.** As shown in FIG. **2**, the portion of the formation which has been heated to steam temperature is substantially circular in cross-section and cylindrical in volume. The portion of the formation containing the hot water from condensed and heated connate water **18** will form an annular ring around the steam heated zone **17.** It will be understood, of course, that the configurations of the heated zones shown in FIG. **2** and in subsequent FIGURES are illustrative of the process only. These precise geometric shapes would not be realized in most instances due to the presence of permeability streaks, faults or other reservoir heterogeneities that would more or less distort the heated zones from the configurations illustrated. However, the benefits of this method will still be realized even though such reservoir heterogeneities are present. Where the method of this invention is used, heat can be introduced into the reservoir at a relatively high rate and the heated regions around the well will be more nearly cylindrical than they otherwise would have been.

After the injection of the initial volume of steam, it will generally be preferred to shut the well in and to permit the formation to "heat-soak." During this heat-soaking period, thermal energy is transferred from the heated regions **17** and **18** to the rock matrix and to the formation fluids, including oil. This heating of the oil reduces its viscosity and makes it more susceptible to flow.

Preferably, the well is then opened to production, and formation fluids including the heated oil are withdrawn by means of the tubing **15.** This intermediate production step will reduce the oil saturation within the heated regions, thus, increasing the conductivity of these regions to subsequently injected steam.

Next, a relatively large volume of saturated steam is injected through the tubing **15** and into the formation **10** at a pressure in excess of that required to fracture or pressure-part the formation. In most instances, this high pressure will, in fact, create a fracture **19** as shown in FIG. **3.** However, due to the initial steam injection step, the resultant fracture will be less extensive than it otherwise would have been. The initially injected steam will reduce the viscosity of the formation oil within the heated region and will increase the water saturation in the immediate vicinity of the well. As a consequence, when the steam is injected at a high pressure as a fracturing fluid it will have a tendency to rapidly bleed or leak into the heated region and less steam is available to pressure-part or fracture the formation. This bleeding or leak-off will be even more pronounced where oil has been withdrawn from the formation prior to the injection of the high pressure steam. This intermediate production step will have the tendency of further reducing the oil saturation within the heated regions **17** and **18** and consequently increasing the water saturation within these regions. Naturally, the high water saturation within the heated regions **17** and **18** will further promote bleed-off of the high pressure steam.

The results of these steps can be seen diagramatically in FIG. **3.** The portion of the reservoir that has been heated to steam temperature **17** has been greatly expanded due to the injection of the large volume, high pressure step. However, the heated regions have maintained a substantially cylindrical configuration due to the relatively small fracture which was formed.

The advantages of this invention over the prior art methods can perhaps be more clearly understood by comparison to FIGS. **2** and **4.** FIG. **2** (in addition to illustrating the heated regions in the reservoir following the initial steam injection step) would be representative of the heated regions existing within a formation in those prior art methods where the steam injection pressure was maintained below the point where the formation would fracture or pressure-part. Although the heated regions shown in FIG. **2** have a substantially cylindrical configuration, they are much less extensive than the heated regions formed in accordance with the teaching of this invention as illustrated in FIG. **3.** FIG. **4** is illustrative of the heated regions within a formation created in those prior art methods where high pressure steam is injected into the formation without the preceding low pressure steam injection step. In this instance, the fracture **19'** extends for a considerable distance into the formation. However, the heated regions **17'** and **18'** do not have the more desirable cylindrical configuration; these heated regions more nearly resemble an ellipse with a high degree of eccentricity. The oil which exists near the tips of the extended fracture **19'** is initially heated to the point that it is capable of flow, but due to its distance from the well, it has a tendency to cool to the point where it will no longer flow before it can be produced.

As was previously stated, the heated fluid which is preferred for use in the initial and subsequent injection sequences is saturated steam. Steam generation units

which will produce saturated steam at the pressure, temperature and quantity required for the practice of this invention are readily and commercially available. The steam produced by such units generally has a quality of from about 60 to 90 per cent.

The heated fluid may also be hot water or superheated steam. However, these fluids are generally not preferred. Hot water is less efficient than steam in transferring thermal energy to the oil since steam can release its latent heat of vaporization as well as its sensible heat. Superheated steam requires the use of expensive surface equipment such as a water knockout column downstream from the steam generator or expensive multi-pass steam generation equipment.

Although the heated fluid in the initial and subsequent injection sequences are preferably the same, i.e., saturated steam, these fluids may differ. For example, the initially injected fluid may be steam and the second injected fluid may be hot water or vice versa. As a further example, the initial fluid may be hot water and the subsequent fluid superheated steam.

With reference to the initial steam injection, it was previously stated that steam would be injected at a low pressure and low volume. The pressure employed should be less than the formation breakdown or fracture pressure; the pressure necessary to fracture or pressure-part a formation will be discussed in greater detail hereinafter. At this point, it is only necessary to note that during the initial injection step, the pressure of the steam should be below this level.

The quantity of steam employed during the initial steam injection step preferably should be sufficient to heat the formation to steam temperature for a distance from about 25 to about 100 wellbore radii from the well. One purpose of this initial steam injection step is to heat the oil in the formation and, thus, reduce its viscosity and to enable it to flow. The flow rate of the oil in a radial system is dependent upon the pressure differential existing between the formation and the well. Furthermore, most of the pressure drop in a flowing radial system will occur very near the wellbore due to the logarithmic variation of pressure differential with drainage radius. For example, it has been calculated that approximately 40 per cent of the pressure drop occurs within 25 wellbore radii from the well; approximately 60 per cent of the pressure drop occurs within 100 wellbore radii. Muskat, *Physical Principles of Oil Production*, 1949, McGraw-Hill Book Co. Inc., New York, N.Y. Methods for determining the quantity of steam which must be injected to heat the formation and oil to steam temperatures to these distances are well known to those skilled in the art. See, for example, Farouq, Ali, *Marx and Langenheim's Model of Steam Injection*, Producer's Monthly, Nov. 1966, pp. 2–8.

As was previously stated, the subsequently injected steam is injected at a high pressure and in a large volume. The injection pressure should be at least as great as the formation breakdown or fracture pressure. A formation is normally fractured by injecting fluid down the well casing or tubing at rates higher than the rock matrix will accept. This rapid injection produces a build-up in wellbore pressure until a pressure large enough to overcome compressive stresses within the formation and the tensile stress of the rock matrix is reached. At this pressure, formation failure occurs and a fracture or pressure-part is generated within the formation. The pressure at which a formation will fracture is dependent upon a number of variables including the tensile strength of the rock, the rate at which the fracturing fluid will bleed into the formation, the extent to which the oil contributes to the competence of the formation and the like. For a given formation at a given location, the effect of these variables and the pressure necessary to breakdown or fracture the formation is generally well known. In some instances where a field experience is not extensive it may be necessary to estimate the formation breakdown pressure by taking these variables into consideration by methods which are well known to those skilled in the art. It is even possible to roughly estimate the formation breakdown pressure by calculating the overburden pressure existing at the formation. It is generally considered that a pressure equal to from about 0.6 to about 1.0 times the overburden pressure will create a fracture.

Due to the high steam bleed-off created by the preheating of the formation no fracture may, in fact, be formed during this subsequent steam injection step. There may be a pressure-parting of the formation or a fluidized zone which forms a channel of high fluid conductivity. However, in extreme circumstances, even such a fluidized zone may not be created due to the extreme bleed-off of steam during the high pressure injection. Under these circumstances, the heated region around the wellbore will be even more nearly cylindrical than that which would be formed in the presence of a fracture. This, of course, would be desirable since the heated oil would have the shortest possible flow path to the well.

The quantity of steam employed in this high pressure, large volume step will generally be from about five to about 20 times greater on a weight basis than that injected during the initial steam injection step. This volume will, of course, be dependent on reservoir conditions and existing facilities.

Following the injection of the high pressure, high volume steam the formation will again be shut in and permitted to heat-soak. Following this heat-soaking, the well will be returned to production. When the production from the well declines the formation can, of course, be restimulated by subsequent injection of additional quantities of steam.

The principle of the invention and the best mode in which it is contemplated to apply that principle have been described. It is to be understood that the foregoing is illustrative only and that other means and techniques can be employed without departing from the true scope of the invention as defined in the following claims.

What is claimed is:

1. A method of recovering oil from a subterranean formation which comprises injecting a heated fluid into the formation by means of a well at a pressure less than the breakdown pressure, then withdrawing oil from the formation by means of the well, subsequently injecting a heated fluid into the formation by means of the well at a pressure greater than the formation breakdown pressure, and recovering oil from the formation by means of the well.

2. A method as defined in claim **1** wherein the first injected heated fluid is steam.

3. A method as defined in claim **2** wherein the steam is injected in sufficient quantity to heat the formation to steam temperature at a distance of at least 25 wellbore radii from the well.

4. A method as defined by claim 3 wherein the steam is injected in a quantity to heat the formation to steam temperature at a distance of no more than 100 wellbore radii from the well.

5. A method as defined by claim 1 wherein the second injected heated fluid is steam.

6. A method as defined by claim 5 wherein the quantity of the steam is from about five to about 20 times as great on a weight basis as the quantity of the first injected heated fluid.

7. A method as defined in claim 1 further comprising injecting further quantities of heated fluid into the formation subsequent to recovering oil from the formation and producing further quantities of oil from the formation.

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