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SECONDARY RECOVERY OF NATURAL GAS

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ABSTRACT

During recent years, the increase in contract prices of natural gas and in its value to the oil operator, have provided the incentive to improve reservoir recovery of this material. Secondary recovery of natural gas will be limited to those parts of the world where its value is several times the value of some other high-pressure gas. High-pressure gases suitable for the recovery of natural gas include air, nitrogen, carbon dioxide, exhaust gases, and some low-value natural gases. The application of current miscible displacement techniques can result in the recovery of one-half of the natural gas normally remaining in a reservoir at abandonment.

INTRODUCTION

During the many years when natural gas was produced as a by-product of oil production, its value was largely ignored. In many cases large volumes of natural gas were flared with no effort being made to conserve this valuable material. Only a slight improvement was realized when many of the first sales contracts were written for ridiculously low prices. Until recently, large volumes of natural gas were sold for less than the cost of compression to the sales pressures. Such contracts completely ignored the intrinsic value of this high-quality fuel. This poor situation was made worse when these distress prices were recognized by a federal regulatory body as proper price levels for natural gas moving in interstate commerce.

The production of natural gas from a reservoir is inherently more efficient than the production of oil from a reservoir. In volumetric reservoirs, at moderate depths with high formation permeabilities, recoveries of 90 per cent of the gas originally in place are common.

In many other cases, high recoveries are not attained. In reservoirs with low permeabilities, the producing rates may fall below the economic limit while large portions of the original gas are still in the reservoir. The minimum economic gas production rate is raised by the production of liquids or by any other difficulties which tend to increase operating problems and expenses. In reservoirs with strong water drives and unequal water invasion, large amounts of gas may be lost in the residual gas saturation or by premature watering out of the producing wells. In such cases, the recovery of the gas originally in place may be as low as 50 per cent.

In the past, such high losses of natural gas were not as important because of the low sales prices. As with any other resource, the amount of gas which may be economically recovered is a function of its value. In recent years, with increasing gas prices for intrastate sales, and particularly for use in connection with secondary oil recovery operations, the secondary recovery of natural gas has become

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economically feasible.

The use of water to displace gas comes to mind at first. However, a brief examination of water's physical properties reveals a number of shortcomings. At reservoir pressures below 100 psig, at least 20 bbl of water are required to replace 1,000 scf of gas. At water-injection costs of one cent per bbl, this is equivalent to 20 cents per Mscf for the water alone.

In tight formations, the pressures required to displace gas with water at significant rates are prohibitive even if the permeability to water is equal to the permeability to gas, which will not be true in most cases. High residual gas saturation after water displacement is another serious deficiency of water as a secondary recovery agent for natural gas.

The next logical approach is to displace natural gas with some cheaper gas. Air, nitrogen, carbon dioxide, inert gases, engine exhaust gases, underground combustion vent gases, and low value natural gases may be suitable for this application. Because all of these gases are miscible with natural gas, high efficiency displacement can be obtained.

BACKGROUND AND THEORY

The use of air or some other low value gas to displace higher value natural gas is a logical extension of conventional cycling of a gas condensate reservoir. It may also be considered a reasonable extension of the use of inert gas to supplement solution gas for the production of oil.

The use of dry gas to displace wet gas in a gas-condensate reservoir is a well established production practice.[1] Field results indicate that a wet-gas recovery of 50 per cent at dry-gas breakthrough may be expected for a typical case. Similar recoveries may be expected when injecting another gas to displace natural gas.

The use of inert gas to increase oil recovery has been discussed in several articles.[2-4] The project in Elk Basin field, Park County, Wyo., is one of the oldest. In this field, inert gas in injected to supplement a small secondary gas cap. At Bayou Des Glaise field it has been used for the recovery of up-dip oil by injection into existing producing wells.

The microscopic efficiency of one gas displacing another gas within the pores of a reservoir rock will approach 100 per cent. With air or inert gas, either of which is slightly more viscous than natural gas, the area of a five-spot pattern swept out at breakthrough will be at least 70 per cent.[5] The vertical sweep efficiency will depend upon the permeability variation within the particular formation. If 70 per cent of the vertical section can be swept at breakthrough, the over-all efficiency will be 49 per cent of the gas in place at breakthrough.

Because of the high mobility of natural gas, most of the injection patterns will be more favorable than a simple five spot. In this aspect, the operations will be nearer gas-condensate cycling practice than waterflooding practice. For example, in the case of an elongated reservoir it may be swept from one end to the other.[1]

The differences in density between natural gases and air or inert gas are slight. In those cases where air is injected because of low well productivity, the effects of gravity will be slight. In high-permeability reservoirs, a lighter gas should be injected in the high portions of the reservoir or a dense gas in the lower portions of the reservoir to permit gravity to improve the efficiency of displacement.

Thus, the performance of any gas for natural-gas displacement will depend upon its viscosity, density, and, to a lesser extent, upon its diffusion coefficient. Its viscosity will control the displacement efficiency. Its density at reservoir conditions will determine the effects of gravity segregation. The diffusion coefficient will have a minor effect upon the microscopic displacement efficiency. Laboratory studies have shown that higher diffusion coefficients will reduce mixing and therefore will improve displacement efficiencies.

The economic performance of any gas will depend upon its cost, corrosion characteristics, and how serious a contaminant it is. In most cases the basic displacement efficiencies of the available gases will be close enough that most selections will be determined by these economic considerations.

GASES FOR INJECTION

Air

In many cases, air will be the best material for injection. It is the only gas that will be available at all locations. The primary cost in injecting air will be the cost of compressing it to the necessary pressures. Although there are a number of problems associated with compressing air, because of the recent interest in underground combustion, the technology involved is well developed. Most major oil companies are familiar with the equipment and techniques required to safely inject large volumes of high-pressure air.

There are a number of problems which must be faced when injecting air. [1] It forms explosion mixtures with most hydrocarbons including natural gas and some lubricating oils. [2] It is a very corrosive agent at high temperatures and in the presence of water vapor. [3] Many of its corrosion products are capable of plugging injection wells. [4] It reacts with some formation waters.

There are compensating advantages for the problems associated with injecting air. In low-pressure reservoirs where the unchanged air is produced with the gas, there is no loss in burning quality of the gas. Although its heat content will be reduced, it will produce the same combustion temperature when mixed with the proper amount of air. In deeper, high-temperature reservoirs where there are residual hydrocarbons present in the formation, the oxygen may be completely consumed in the reservoir. At room temperature, a fifty-fifty mixture of air and natural gas will be flammable only above 800 psig.[6] In most cases, it will become uneconomic to produce such gas before it becomes dangerous.

The density of air will be greater than the density of most natural gases, although a standard cubic foot of air will occupy more reservoir volume than a standard cubic foot of natural gas under most reservoir conditions. The viscosity of air will be greater than that of natural gas under most conditions. The diffusion coefficient of air will be similar to that of natural gas.

In most cases, air will be the cheapest gas available. A typical cost for compressed air at pressures less than 1,000 psia would be 6 cents per Mscf. Of course, such costs will depend upon fuel costs, volumes, discharge pressures, type of compressors, and other variable factors.

Nitrogen

Nitrogen may offer economic advantages where it is available as a by-product under pressure. For instance, most liquid oxygen plants produce nitrogen at temperatures slightly below atmospheric. When such gas is available near the point of use, nitrogen offers advantages in terms of eliminating the explosion hazard and reducing the corrosion associated with air. The density, viscosity, and diffusion coefficient of nitrogen will be similar to those of air.

Carbon Dioxide

Carbon dioxide is available at many field locations where it is removed from natural gas. Particularly where it is available under pressure, it may be cheaper to inject than air. Where a gas plant is already removing carbon dioxide, small additional amounts of carbon dioxide in the gas from the displacement process could be removed at a minimum expense. It is the only gas considered in this paper that may be removed by such simple processing. The density of carbon dioxide will be even greater than air and in most cases a greater standard volume of carbon dioxide than air will be required to displace a given volume of natural gas. The atmospheric viscosity of carbon dioxide is intermediate between the viscosities of air and natural gas. The diffusion coefficient of carbon dioxide will be less than that of air. The corrosion problems associated with it will be greater than those with nitrogen and less than those with air.

Inert Gases

In most cases, inert gases must be produced by carefully controlled combustion in boilers or heaters. The reservoir performance of inert gases will be similar to air or nitrogen. In most cases, some processing is necessary to eliminate corrosive gases from the combustion products. In all cases, the combustion products must be cooled and at least part of the water removed. Such additional processing will result in increased costs when compared with air.

Engine Exhaust Gases

Engine exhaust gases are another source of inert gases. They are similar to other inert gases in most respects. They have the advantage of being more generally available and the disadvantage of being more difficult to control with respect to chemical composition.

Underground Combustion Vent Gases

Underground combustion vent gases are merely another form of combustion products. They have the advantage of being available under pressure in some cases. If the injection well is operating at 670 psia for instance, and vent gases are available at 100 psia, vent gases could be compressed for approximately 50 per cent less than exhaust gases. In most other aspects such gases are similar to engine exhaust gases.

Natural Gases

In many parts of the country, high pressure natural gases other than hydrocarbons are encountered. In the Rocky Mountain region, carbon dioxide and nitrogen are frequently the major constituents of such gases. If these gases will not burn, they usually are not developed.

Under optimum conditions such gases could be produced for less than 1 cent per Mscf. Certainly where such gases are present in deeper formations and the upper formations are producing hydrocarbon natural gas, such non-hydrocarbon natural gases are the most practical injection material. The physical properties of such gases will vary widely, depending upon their compositions. Some of these gases are almost pure nitrogen or carbon dioxide, while others contain large amounts of methane.

TYPICAL FIELD APPLICATIONS

Low-Pressure Dry Gas

The simplest application would involve a dry gas field where the wells are approaching their economic limit. For purposes of illustration, let us assume ideal flow behavior, 50 psia flowing bottom-hole pressure, and 100 psia reservoir pressure. If one-fourth of the wells are converted to air-injection wells such as could be done for the nine spot injection pattern, the reservoir pressure would need to be increased to 112 psia to maintain the same over-all production rate. The required pressure at the injection well would be 207 psia. This is assuming that lower temperatures and lower water saturations near the injection well will compensate for the higher viscosity of the air.

This situation would require the injection of a volume of air equal to approximately 20 per cent of the volume of the remaining gas to develop the required pressure gradients. Somewhat higher injection pressures would be required if increased production rates were desired.

Air could be injected at any time and the natural gas produced as needed. In some cases, this would permit the compressors to be used for air injection during a portion of the year and for gas sales during the balance of the year.

The situation would be somewhat more favorable if poor producing wells or edge wells which had watered out, could be used for air-injection wells. If air costs 6 cents per Mscf, the displaced natural gas will cost at least 9 cents per Mscf. In most cases this will limit the application of this process to regions with relatively high natural gas prices.

High-Pressure Natural Gas

The availability of non-commercial natural gases would not modify the basic process. However, if such gas were available for 1 cent per Mscf it would reduce the cost of the displaced natural gas to approximately 2 cents per Mscf.

Recovery of Gas Over Oil

Some of the most favorable economic applications will be in those areas where the natural gas is needed for lease fuel. On leases where there is a shortage of natural gas, additional natural gas is worth what an equivalent amount of the replacement fuel is costing. Typically, such gas will be worth at least 25 cents per Mscf. If the gas is produced on the same lease, no compression or sales line will be required in most cases. Air contamination up to 50 per cent could be tolerated under these conditions.

Recently, bottom-hole heaters, steam injection, and underground-combustion process have required increasing amounts of lease fuel. For underground-combustion operations, compressed air or exhaust gases are already available. This process would permit the production of gas-cap gas without allowing oil to invade the gas zone. In many cases it will be desirable to inject the air into the gas cap and produce the desired natural gas from the producing oil wells. This would provide the benefits of gas drive for oil recovery and accelerated recovery of the natural gas.

Strong Water-Drive Reservoirs

Another field application would be in a highly permeable reservoir with a strong water drive. Down-structure wells which already have watered out will be available in most cases. A dense gas will be desirable to take advantage of gravity segregation. In such cases, the displacing gas could be injected below the water level to sweep part of the residual gas out of the water zone and to settle between the gas in the reservoir and the encroaching water to reduce the rate of water encroachment and to provide a less valuable residual gas phase as the water invades the gas zone.

FACTORS DETERMINING APPLICATION

1. What is the value of the natural gas? On leases where fuel is being purchased, check to be sure a value as high as the cost of an alternate fuel to provide the same amount of heat is used.
2. What gases are available in the area? High-volume, high-pressure natural gases are the most desirable. Air is available in any case.
3. What compression facilities are available? Of course, the economics will usually be most favorable when compressors can be converted for this use. Large-capacity compressors will usually provide compressed gases at lower cost.
4. What flow lines and wells are available for air injection? Some consideration

should be given to segregation of contaminated gases.

5. If the gas is being sold, what are the contract limitations on contamination? Is nitrogen or oxygen specifically prohibited or must the gas merely meet certain minimum Btu specifications?

6. Are there favorable effects on oil production that can be expected from increasing the pressure in the gas zone?

7. Would increasing reservoir pressures reduce problems with water or liquid hydrocarbon production? In some cases, increasing the pressure will facilitate the production of such liquids and in other cases it will prevent such liquids from entering the well in the first place.

8. How much natural gas is being trapped by water as residual hydrocarbon saturation?

9. What are the possible secondary uses of the contaminated gases? Any lease fuel use such as heaters, steam generators, engine fuel or compressor fuel is attractive.

10. What is the nature of the reservoir? Can reasonable recoveries of the natural gas in place be expected at breakthrough? Fracture systems, high permeability zones, or large fracture treatments on producing wells could cause early breakthrough.

CONCLUSIONS

1. The secondary recovery of natural gas by gas injection is economically feasible under some conditions.

2. In most cases, the application of this process will be limited to those regions where the price of the natural gas approaches that of equivalent fuels on a heat-content basis.

3. Secondary recovery of natural gas offers an application for high-volume natural gases that are not suitable for use as fuels.

4. The technology required to accomplish this objective is well developed.

5. Under typical conditions, the recovery of at least one-half of the gas normally remaining in the reservoir at abandonment is attainable.

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