Evaluation of the Stranded Kavik Gas Field, North Slope of Alaska

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ABSTRACT

The Kavik gas field, located about 65 mi southeast of Prudhoe Bay in the Brooks Range foothills, Alaska, was discovered in 1969 on a thrust-faulted anticline representing the western, down-plunge extension of the Sadlerochit Mountains. Although one of the largest and best-defined foothills gas accumulations, for lack of a North Slope gas transportation system this field has not been developed and no public estimate of gas volume has previously been made.

Three wells delineate the Kavik field, but only two penetrate the gas column which is about 1,500 ft thick. On the basis of the gas pressure gradient from drillstem tests, the gas-water contact is estimated to be at 4,320 ft subsea (depth below sea level). At this depth, the field covers about 3,600 acres. The reservoir temperature and initial pressure are estimated at 122°F and 2,431 psi, respectively, at the datum of 3,500 ft subsea. Analyses indicate that the gas is dry, contains about 96 percent methane, and has a combined nitrogen and carbon dioxide content of 3 percent; the liquid-gas ratio ranges from 0.3 to 1.3 barrels per million cubic feet (MCF) of gas.

Kavik reservoirs, in decreasing order of importance, are the Ledge Sandstone Member of the Ivishak Formation, the Sag River Sandstone, and the Shublik Formation, all of Triassic age. Gas-in-place volume has been calculated at 165 billion standard cubic feet (BSCF). Assuming a 70-percent recovery factor, the Kavik field is estimated to have 115 BSCF of technically recoverable gas.

The median value of open-flow capacity of tested Kavik wells is 11.9 million standard cubic feet per day (SCF/D). Given an average production rate of 4–8 million SCF/D per well, the field could potentially be developed to produce at a rate of 20 million SCF/D, resulting in a field life of about 16 years.

INTRODUCTION

The Kavik gas field was discovered in 1969 at the height of exploratory drilling in the year following the discovery of the Prudhoe Bay oil field—the largest oil accumulation in North America. The Kavik gas field is about 65 miles southeast of Prudhoe Bay on an anticline in the foothills of the Brooks Range, in the same Triassic reservoirs that host oil at Prudhoe Bay. Like most hydrocarbon accumulations in the foothills, the Kavik accumulation is a nonassociated gas field. Whereas most foothills gas accumulations are poorly known because they are penetrated by just one well, and many of those were discovered before modern well logs were available, the Kavik gas field is unusual in that three wells delineate the field and all have a complete suite of relatively modern logs that have been released to the public. However, no estimate of the volume of gas in this accumulation has been released. Because of current interest in a North Slope gas transportation system and gas resources, we have assembled available data on the Kavik gas field and made an estimate of the volume of gas in this accumulation.

GEOLOGIC SETTING

Structure- The Kavik structure represents a closure on the west-plunge flank of the Sadlerochit Mountains anticlinorium, a major 45-mi-long structural feature in the frontal part of the northeastern Brooks Range. Structures in this part of the northeast Brooks Range formed in mid-Tertiary time in various episodes of deformation and uplift dated at 45–23 Ma by apatite fission track analysis (O'Sullivan and others, 1993). The trap at Kavik, illustrated by the cross section to the left, is formed by the thrust-faulted anticline, the top and lateral seals being provided by the Kingak Shale; the seal to the north is apparently provided by a combination of the bounding fault and Cretaceous Canning Formation mudstone in the footwall.

Reservoirs- Gas in the Kavik field occurs in four rock units: Sag River Sandstone, Shublik Formation, and two members of the Ivishak Formation (Fire Creek Siltstone and Ledge Sandstone) in the Sadlerochit Group. All reservoirs are Triassic in age (Detterman and others, 1975) and are regional North Slope rock units. They are also the main reservoir units in the Prudhoe Bay oil field (Jones and Speers, 1976), and they crop out nearby in the western Sadlerochit and Shublik Mountains, east of the Kavik field (Bader and Bird, 1986; Robinson and others, 1989). These rocks were deposited in nonmarine (Ledge) to shallow marine (Sag River and Fire Creek) to moderately deep marine (Shublik) environments. Together, they are part of the Ellesmerian tectono-stratigraphic sequence, a passive margin during Mississippian to Triassic when sediment source areas lay to the north and the open ocean to the south (in present-day coordinates). Overlying the reservoir rocks are Jurassic and Lower Cretaceous marine mudstones succeeded by Cretaceous and Tertiary foreland basin marine and nonmarine sediments shed from the rising Brooks Range to the south.

Burial History- Burial of the Kavik reservoir rocks to depths of about 15,000 ft is suggested by basin reconstructions and a vitrinite reflectance value of about 1.3 percent R (Bird and others, 1999), which was attained prior to the onset of the structural deformation that created the structural trap. Timing of deformation was between 45 and 23 Ma, as inferred from the apatite fission-track record of uplift-related cooling. Basin reconstruction also indicates the possibility that a stratigraphic trap formed in the Kavik area prior to structural deformation. This trap may have formed by northward truncation of the reservoirs by the Lower Cretaceous unconformity and sealing by overlying mudstones, a trapping style demonstrated in several oil fields in the Prudhoe Bay area. However, lateral seals for a stratigraphic trap at Kavik have not been identified.

Origin of Gas- The origin of the gas in the Kavik field has not been determined. Possible source rocks include the coal-bearing Kekiktuk Conglomerate, the oil-prone Shublik Formation, the lower Kingak Shale, and the Hue Shale, as well as the moderately organic-carbon rich Canning Formation. Scattered oil shows and fluid inclusion observations suggest the possibility of a preexisting oil accumulation. Thermal maturity (vitrinite reflectance of 1.3 percent R) at the reservoir level indicates that the oil was likely thermally cracked to gas.

PETROPHYSICAL PARAMETERS

Although three wells delineate the gas field, only Kavik 1 and Kavik 3 penetrate the gas column whereas the third one (Kavik 2) encountered only water. Therefore, reservoir and petrophysical parameters have been determined with the well data from Kavik 1 and Kavik 3.

Log Evaluation- Using the well logs for Kavik 1 and Kavik 3, porosity and water saturation have been computed for intervals judged to be gas-charged and potentially gas productive. The Ledge Sandstone is the main gas reservoir. Porosity is less than 8 percent, permeability is less than 0.1 millidarcy (md), mercury entry pressures are 175 psi and higher (see graph below). Gas-charged sandstones having permeability less than 0.1 md are commonly referred to as tight-gas sandstones. Core measurements are not available for the Sag River Sandstone, but porosity appears to be somewhat lower than in the Ledge Sandstone. Gas flows and pressures measured in drill-stem tests (DSTs) suggest that gas flow is controlled by fractures, not by matrix permeability.

Porosity- Porosity was calculated from the density logs using a grain density of 2.67 g/cc for the Ledge Sandstone, which was determined from core measurements. A grain density of 2.70 g/cc was assumed for the Shublik Formation. A few core measurements are compatible with the density log estimates. Average values of porosity range from 3 to 8 percent in the three formations.

Permeability and Capillary Pressure- Conventional core analyses are available for only 6 samples from the Kavik 2 well and 6 samples from the Kavik 3 well, all from the Ledge Sandstone. Permeability values are 0.01 md or less in nine samples, 0.02 md in two samples, and 0.04 md in one sample. Mercury injection–capillary pressure tests from the Ledge Sandstone show a wide range of entry pressures ranging from 200 to 2,000 psi in the 12 samples shown in the graph below and from 175 to 1,050 psi in another 6 samples (not shown). No descriptions of the samples are available; however, inspection of well logs suggests that samples are from sandstone intervals. Porosities in both sets of samples are less than 7 percent.

Net Pay- Well logs for Kavik 1 well were used to determine the productivity of 274 ft of gas-charged sandstone in the main zone of the Ledge Sandstone and 36 ft in an upper zone, for a total of 310 ft. A main zone and an upper zone in the Ledge Sandstone were also found in Kavik 2 and Kavik 3 wells. A potentially productive interval was found in the Fire Creek Siltstone in Kavik 3; however, in Kavik 1 this interval does not appear to be potentially productive. Productive intervals were selected at the top of Shublik Formation in Kavik 1 and Kavik 3. The Shublik Formation is a shaly carbonate and is generally regarded as a source rock. The gas-producing DST in Kavik 3 was conducted through perforations in both the Sag River and the Shublik, so the Shublik Formation is possibly productive. The Sag River Sandstone is difficult to analyze because the suspected presence of glauconite makes the grain density estimate uncertain, so the estimates of net pay and porosity are less certain than estimates for the Ledge Sandstone.

Water Saturation- Water saturation values were computed using a “clean” Archie relationship. The average water saturation of the Ledge Sandstone, in both Kavik 1 and Kavik 3 is about 52 percent. The average water saturation of the Sag River Sandstone, determined only in Kavik 1 is 65 percent. The resulting estimate of gas saturation is shown graphically as red lines in the Kavik 1 and Kavik 3 well logs below.

Reservoir Pressures and Gas-Water Contact- Five DSTs were obtained from gas-charged Sag River and Ledge sandstones in Kavik 1 and Kavik 3. The pressure gradient through the five gas-producing DSTs is 0.074 psi/ft, equivalent to a gas density of 0.17 g/cc. This gradient intersects the hydrostatic gradient at a pressure of 2,491.7 psi and a depth of 4,320 ft subsea, which establishes the depth of the gas-water contact (the depth is uncertain to within 50 ft because Kavik 1 and 3 tests were combined on one depth plot and because the exact hydrostatic gradient is not known). At the reference depth of 3,500 ft subsea, the pressure is calculated to be 2,431 psi.

Reservoir Temperature- Six uncorrected bottom-hole temperature (BHT) points fall on a gradient of 1.65°F/100 ft. However, one BHT measurement from Kavik 1, which is within the gas reservoir, indicates a gradient of 1.85°F/100 ft. In our analysis we used a gradient of 1.85°F/100 ft and surface temperature of 32°F.

Gas Flow Rates- Four DSTs in Kavik 1 and Kavik 3 produced gas to surface (GTS) values at rates high enough to conduct flow tests with varying choke sizes. The horizontal lines in the flow-rate graphs represent the condition of zero pressure at the wellbore, corresponding to a completely open choke (Lee, 1982). Values of flow rate extrapolated to the horizontal lines give the absolute open flow rate. Field analysis of DST 1 in Kavik 3 well reported an absolute open flow of 170 million standard cubic feet per day (SCF/D); however, re-analysis of the flows and pressures through four choke sizes shows this value to be erroneous. Measurements did not align to give an unambiguous estimate of absolute open flow. The remaining measurements are considered valid and indicate a range of 11.9–61.9 million SCF/D. Four tests at depths greater than 4,000 ft subsea had no flow to surface, but all had indications of gas, such as an initial blow and gas-cut mud.

RESERVOIR ENGINEERING

Our volumetric estimation of the Kavik gas field first calculated the gross rock volume of the structure down to the gas-water contact and then applied a net-to-gross ratio giving reservoir rock volume. Application of porosity and water saturation to reservoir rock volume gave us hydrocarbon pore volume. Finally, the gas compressibility factor provided in-place (reservoir) gas volume and the formation volume factor (FVF) converted subsurface volumes to surface volume in standard cubic feet (SCF).

Gross Rock Volume Estimate- The gross rock volume was determined by using the subsurface contour map and the volumetric method described by Craft and Hawkins (1959). The area enclosed by each contour line was planimetered from the top of the structure down to the gas-water contact (GWC) at 4,320 ft subsea. Once the area enclosed within each successive contour line and the contour interval (250 ft) are known, the gross volume of rock may be calculated on the basis of the volume of the frustum of a pyramid. On the basis of the pyramidal equation, gross rock volumes for the Sadlerochit Group were calculated and a plot was constructed showing the gross volume as a function of depth from the crest of the structure. To estimate the volume of individual reservoirs within the Kavik field, the following assumptions were made:

(a) All the formations (reservoirs) conform to the contoured structure of the Sadlerochit Group.
(b) Structural mid-point of the reservoirs between the Kavik 1 and the Kavik 3 wells is the dividing line for a change of petrophysical properties; above the mid-point, formation properties are represented by that in Kavik 1 and below the mid-point by those in Kavik 3.
(c) Lower limit for the reserve estimation is 4,320 ft subsea, the gas-water contact.

Calculated gross volumes for each reservoir are presented in the volumetric determination table (below).

Compressibility Factor (z) and Formation Volume Factor (FVF)- The z factor is required to calculate the FVF, which converts the subsurface gas volume in cubic feet to surface volume in SCF. We obtained z by using the gas composition to determine pseudo-critical pressure and pseudo-critical temperature and then using a look-up chart by Standing and Katz (1942). The Kavik gas compressibility factor (z) was calculated to be 0.84 at reservoir conditions (temperature of 122°F and pressure of 2,431 psi). On the basis of this value of z, the formation volume factor for the Kavik gas field was calculated to be 176.84 SCF/cu ft.

Gas-in-place/Reserve Estimate- Once all the reservoir parameters were determined, the gas-in-place (GIP) for each individual reservoir was calculated. The volumetric determination table (below) represents the reservoir rock volumes along with all reservoir parameters and the estimate of the gas-in-place for each reservoir in the Kavik gas field at reservoir conditions (cu ft) as well as at surface conditions (SCF).

The four reservoirs within the Kavik gas field—Sag River, Shublik, Fire Creek, and Ledge—contain 6, 18, 6, and 134 billion SCF of gas, respectively, for a total of about 165 billion SCF. As can be seen from these values, Ledge is the major reservoir, contributing 82 percent to the Kavik's total GIP. On the basis of an assumed 70 percent recovery factor, the Kavik gas field has about 115 billion SCF of potential gas reserves.

A possible development scenario would be the drilling of five production wells to produce about 20 million SCF/D from the field over a period of 16–20 years, provided production could be tied to the Prudhoe Bay facilities. Also, because the Kavik reservoirs have low permeability, the drilling of horizontal wells could potentially improve production and enhance the economic viability of the field.

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