Is There A Compaction Drive in Bandra Formation of Heera Field, Mumbai Offshore

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Keywords

Overburden, pore pressure, rock compressibility, vertical strain, compaction drive

Summary

Bandra formation of Heera field has shown a meagre reservoir pressure drop of 121 psi even after the production of 32% initial gas in-place in a span of 10 years. This slower-than-usual pressure drop prompted us to review its reserves which resulted in an increase of 67% compared to its initial reserves. However even after this substantial increase, the unusual pressure decline is still inexplicable. In other words we still need to increase the reserves further, which does not seem to be a viable option now. In order to give a possible explanation for this strange pressure behavior, we brought forward the idea of compaction drive in addition to depletion drive acting in the reservoir. The possibility of a compaction drive acting along with depletion drive appeared to be very likely in this case considering the fact that the reservoir is shallow (700-750m) and globally there are evidences of strong compaction drive in shallow reservoirs.

When the pore pressure decreases during the production phase, the effective stresses increase. However the strain developed in the vertical direction is far more than the horizontal, and therefore the effective overburden increases. This increase in overburden leads to compaction of the rock and the extent of compaction will depend upon rock compressibility apart from its dependence on Poisson's ratio and other factors. The shallow reservoir rocks are more likely to get compacted compared to deeper reservoirs as they still have enough room for compaction due to unconsolidation. This effect leads to additional expulsion of oil or gas, in excess of what we get from natural depletion alone. In a sense it acts like a downhole pump. Thus it will result into slower pressure decline despite having a good recovery.

However, in order to have a conclusive proof of any compaction drive, we measured rock compressibility of some of the plugs in laboratory, subjecting them to different confining pressures and measuring the change in porosity. The rock compressibility or the pore volume compressibility (if the grain compressibility is neglected), if found in excess of the normal compressibility values of the sedimentary rocks, may be an indication of compaction drive acting in the reservoir.

The measured pore volume compressibility on these plugs is found to be in the range of 3×10^{-6} to 40×10^{-6} psi^{-1}, neglecting a few measurements which are either too high or too low. The typical compressibility values of sedimentary rocks range between 3×10^{-6} to 25×10^{-6} psi^{-1}. Hence the measured compressibility values, although largely in the range of normal compressibility values, show some departure towards the higher values. This may be indicative of a mild compaction drive. However, the possibility of any strong compaction drive is not established , which as per our industry experience, is believed to be a dominant derive only when the compressibility is in excess of 100×10^{-6} psi^{-1}.

Although compaction drives are not very common in carbonates and are mostly seen in clastics where unconsolidation is a major issue at shallow depth, there are still some cases globally where strong compaction drive is seen in carbonates. Ekofisk field in North Sea is an example where the reservoir is chalky and the drive is primarily compaction. Chalks have very high porosity and so the compaction becomes a dominant event with decrease in pore pressure. In our case we have micrites in the reservoir which also have high porosity (but not as high as

chalks) and may undergo compaction due to decrease in pore pressure, thus driving the fluid expulsion from the reservoir and sustaining the reservoir pressure.

Introduction

Bandra formation in Heera field of Mumbai Offshore basin is a shallow reservoir which is found to be gas bearing in the region close to the Northwest-Southeast major fault (Fig-1). Production from this reservoir stated in the year 2005 and a pressure measurement carried out in the year 2015 showed a reservoir pressure depletion of merely 121 psi against a production of 2.47 BCM which was almost 32% of initial recoverable. This slower-than-usual pressure decline prompted us to re-estimate the reserves which was subsequently increased to almost 67% of the initial reserves. However, even this increase could not match the history and demanded further increase in the reserves. In other words, the revised gas-in-place has still not reached the level where the material can be balanced with respect to observed pressure decline. Having affirmed that it was further not possible to improve the reservoir parameters, nor the reservoir thickness or its lateral extent, the problem prompted us to think in other possible directions.

One of the possible reasons for this slow pressure decline may be the presence of compaction drive in this shallow reservoir where the pore or rock compressibility may be large. The pore compressibility acts as an additional down-hole pump when the pore pressure decreases and the effective overburden increases during production phase of the reservoir. Due to this effect there will be additional expulsion of oil or gas, in excess of what we get from natural depletion drive alone. This will result into slower pressure decline despite having a good recovery.

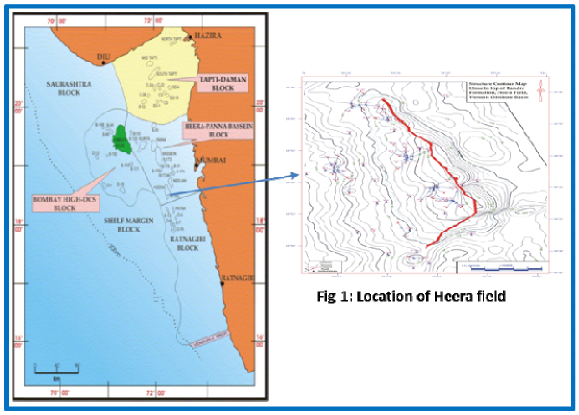

Fig 1: Location of Heera field

Experience in Bachaquero field of Venezuela or Ekofisk field in North Sea, which also have shallow reservoirs on compaction drive, shows that any rock compressibility in excess of about 100×10^{-6} / psi may result into a compaction drive. This prompted us to make an attempt to measure the rock compressibility on the cores available in a couple of wells in Bandra formation to examine if the rock compressibility is really high. The high rock compressibility will not only prove our hypothesis of compaction drive giving extra pressure support to the reservoir but will also help us assess the risk of reservoir compaction arising out of such drive and its ultimate fallout in terms of surface subsidence.

Theory

A reservoir is subjected to an overburden pressure caused by the weight of overlying formations. The overburden pressure is mainly dependent on the depth of the reservoir and a typical overburden gradient is approximately 1 psi per foot.

Assuming that the reservoir is sufficiently consolidated, the overburden pressure is not transmitted to the fluids in the pore space and a typical pore pressure gradient is approximately 0.5 psi per foot. The pressure difference between overburden and internal pore pressure is referred to as effective overburden pressure. During the production phase of any reservoir the internal pore pressure decreases and therefore the effective overburden increases. This increase causes the following two effects:

- The bulk volume of the reservoir rock reduces
- Sand grains within the pore spaces expand

These two volume changes tend to reduce the pore space or the porosity of the rock. The reduction in pore space due to increase in effective overburden will depend on the compressibility of the formation. Geertsma (1957) pointed out that three different types of compressibility must be distinguished in rocks. These are as follows:

1. Rock Matrix Compressibility (Cr)**:** Fractional change in volume of the solid rock material (grains) with a unit change in pressure. The rock compressibility coefficient is given by

$$Cr = - 1/Vr\ (\partial Vr/\partial p)_T$$

Where Cr = rock- matrix compressibility, psi^-1

Vr = volume of solids

The subscript T indicates that the derivative is taken at constant temperature.

2. Rock-Bulk Compressibility (CB)**:** It is defined as the fractional change in volume of the bulk volume of the rock with a unit change in pressure. The rock-bulk compressibility is defined mathematically as:

$$CB= -1/VB(\partial VB/\partial p)_T$$

Where CB= rock-bulk compressibility coefficient, psi^-1

VB= bulk volume

3. Pore Compressibility (Cp)**:** The pore compressibility coefficient is defined as the fractional change in pore volume of the rock with a unit change in pressure and given by the following relationship:

$$Cp = -1/Vp\ (\partial Vp/\partial p)_T$$

Where p= pore pressure, psi

Cp= pore compressibility coefficient, psi^-1

Vp= pore volume

Considering the fact that pore volume and porosity are same for a single saturating fluid, the above equation can be expressed in terms of porosity, as follows:

$$Cp = -1/\phi\ (\partial\phi /\partial p)_T$$

For most petroleum reservoirs, the rock and bulk compressibility are considered small in comparison with the pore compressibility Cp. The formation Compressibility Cf is the term commonly used to describe the total compressibility of the formation and is set equal to Cp, i.e.,

$$Cf=Cp= -1/\phi\ (\partial\phi /\partial p)_T$$

Typical values for the formation compressibility range from 3×10^{-6} to 25×10^{-6}/psi.

The above equation can be written as,

$$Cf= -1/\phi\ (\Delta\phi /\Delta p)$$

Where $\Delta\phi$ and Δp are change in porosity and change in pore pressure respectively.

Method

In reservoirs, overburden pressure is constant and the pressure of fluid in pores changes, resulting in pore volume change. In the laboratory, we change the confining pressure on the core plug (overburden) while holding the pore pressure constant. The net compaction pressure on the matrix is the difference between the overburden and pore pressure. This allows us to obtain useful results in the laboratory.

14 nos. of core plugs of 1" diameter were extracted from conventional cores of two wells. These plugs were subjected to different confining pressures to estimate compressibility. Initially three plugs were subjected to confining pressures of 500, 1000 and 1500 psi but later the rest of the plugs were subjected to confining pressures of 500, 1500 and 2500 psi to approximately match with the formation overburden, which is around 2500 psi. The change in porosity with change in pressure is exhibited in Fig-2 while the estimation of compressibility for all these 14 plugs is summarized in Table-1.

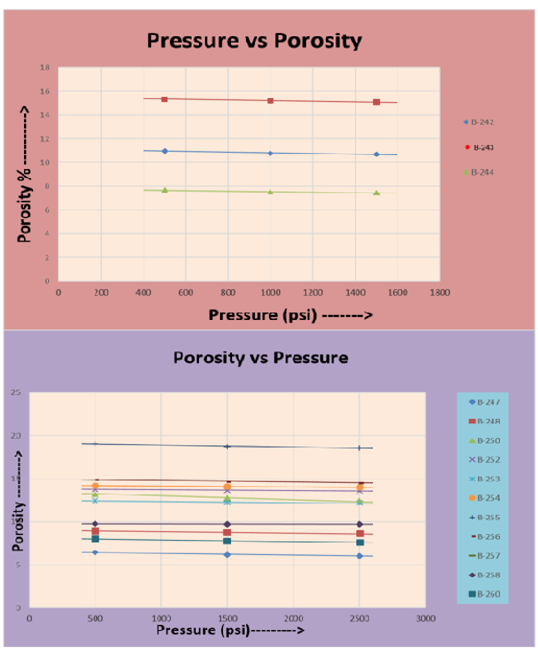

Fig-2: Pressure-porosity plot for 14 plugs

Results

Referring to Table-1, it can be seen that the measured pore volume compressibility on these 14 plugs is in the range of 3 × 10^{-6} to 40 × 10^{-6} psi^{-1}, neglecting a couple of measurements which are either too high or too low. Traditionally the compressibility values of sedimentary rocks lie in the range between 3 × 10^{-6} to 25 × 10^{-6} psi^{-1}. Hence the measured compressibility values, although largely in the range of normal compressibility values, show some departure towards the higher ranges. This may be indicative of a mild compaction drive. However, the possibility of any strong compaction drive appears unlikely, which as per our industry experience, is a dominant derive only when the compressibility is in excess of 100 ×10^{-6} psi^{-1}.

Table-1

Sr. No	Plug No.	Confining pressure (psi)	Ø (%) Porosity	Bulk Modulus	Compressibility
1	242	500	10.98		
		1000	10.80	59048.38711	16.9353E-06
		1500	10.70	56419.52055	17.7244E-06
2	240	500	15.30		
		1000	15.20	53975.35211	18.527E-06
		1500	15.10	6107 .71315	16.3742E-06
3	244	500	7.70		
		1000	7.53	2433 .81318	40.1094E-06
		1500	7.46	35063.92594	28.5 93E-06
4	247	500	6.46		
		1500	6.20	23670.32967	42.247E-06
		2500	6.10	3152 .95122	31.7202E-06
5	248	500	8.94		
		1500	8.77	51965. 1628	19.2437E-06
		2500	8.65	6164 .37931	16.2229E-06
6	250	500	13.24		
		1500	12.73	2533 .23571	39.4926E-06
		2500	12.40	30869.46307	32.3945E-06
7	252	500	13.80		
		1500	13.64	90763. 5789	11.0 77E-06
		2500	13.60	133294.636	7.50217E-06
8	253	500	12.44		
		1500	12.30	78703.53165	12.7061E-06
		2500	12.20	103195.0207	9.69032E-06
9	254	500	14.30		
		1500	14.10	103839.4161	9.63025E-06
		2500	14.03	148187.5	6.74821E-06
10	255	500	19.11		
		1500	18.73	50819. 4394	19.6776E-06
		2500	18.58	72516. 2903	13.79E-06
11	256	500	14.94		
		1500	14.70	57019.80097	17.538E-06
		2500	14.53	7359 . 33	13.5886E-06
12	257	500	8.30		
		1500	7.76	15453.51597	64.7 44E-06
		2500	7.57	2264 .20055	44.1673E-06
13	258	500	9.78		
		1500	9.75	326133.3333	3.06623E-06
		2500	9.76	698067.1429	1.43091E-06
14	260	500	8.02		
		1500	7.78	33148.76033	30.167E-06
		2500	7.63	40413.09324	24.7445E-06

Compaction drive in Bandra formation

Referring to Table-1 again, it can be seen that the measured porosity values of the plugs are on lower side compared to porosities seen on the logs in the reservoir section. This may also be one of the reasons of low compressibility values measured on the rock. If the cores are cut in the proper reservoir sections having good porosity, perhaps the rock compressibility values will be still higher.

Conclusions

The formation compressibility lies in the range of 3 $\times 10^{-6}$ to 40 $\times 10^{-6}$ psi^{-1} which is leaning towards the higher values. This may be indicative of a mild compaction drive acting in the reservoir along with the normal depletion drive. However, the possibility of any strong compaction drive appears unlikely as the same is supposed to be dominant when the formation compressibility is in excess of 100 $\times 10^{-6}$ psi^{-1}. The common belief that carbonates cannot have any compaction drive appears to be unbecoming, more so in cases where chalks or micrites are present in the reservoir.

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