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4D Case History in North Kuwait

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دراسة حالة بشمال الكويت باستعمال التحليلات السيزمية ذات الأربعة أبعاد

تيم بيرين

حقول النفط كاملة التكوين وخاصة بعض الشاسع منها على اليابسة في منطقة الشرق الأوسط قد تحتوي على مئات من آبار النفط تم حفرها على مسافات بينية متساوية الأبعاد.

وقد تكون هناك معلومات بتروفيزيائية وجيولوجية مفصلة ومعروفة عن كل موقع، ولكن هذه البيانات تكون صحيحة لمسافات قصيرة تتجاوز نصف قطر حفرة البئر بقليل، مما يتسبب في تفسيرات مشكوك بينها للمسافات الهائلة بين مواقع الآبار.

يعزز الحصول على المعلومات السيزمية ذات الثلاثة أبعاد وما لازمه من تفسير للمكمن ثقة مهندسي المكامن عند تفسيرهم نموذج بنية وطبقية المكمن بشكل كبير. وعند التخطيط لإدارة المكمن يميل في أغلب الأحيان مهندسوا المكمن إلى النمذجة العشوائية للإنتاج ومعدلات تدفق الحقن. إلا أن نماذجهم تتضمن العديد من المتغيرات والتي بعض منها غير معروف بدرجة عالية من الثقة، ونتيجة لذلك لا يوجد حل فريد لهذه المشكلة وتبقى الشكوك موجودة.

إن المعلومات السيزمية، لكونها تقييم محدد لنتاج مجموعة من الصفات المميزة، تعطي لقطة سريعة للمكمن في وقت معلوم من تاريخ المكمن. ويمكن إشتقاق التغير في البيانات السيزمية عند المكمن بادخال لقطة سريعة ثانية وثالثة وطرح مجموعة من البيانات الأخرى. وتمثل هذه التغيرات السيزمية التغير المطلق في خواص المكمن إلا أنها أقل وضوحاً من معلومات قاعدة بيانات البئر.

وبالإمكان عند هذه النقطة مقارنة نتائج نمذجة المكمن ببيانات الإختلافات السيزمية المقاسة وتحديث نموذج المكمن عن الحاجة. وبعد إعادة متكررة للنمذجة المتقدمة والتحسين بمضاهاة التجاوب السيزمي المقاس عن قرب يمكن توضيح نموذج مقبول للمكمن. ومن هنا تكمن إمكانية لتخطيط مواقع آبار أخرى وبدرجة عالية من الثقة بناء على تنبؤات تدفق الموائع وليس على أساس المسافات البينية المتساوية.

INTRODUCTION

Mature oilfields, especially some of the large onshore oilfields in the Middle East, may have hundreds of oil wells drilled, often on a regular grid. There may be detailed petrophysical and geological information known for each location. But this information is only valid over a short radius from the well bore. Therefore, uncertainty exists over the considerable distances between the well locations.

Acquisition of high resolution, 3D seismic data, and the subsequent interpretation of the reservoir, improves the confidence of the reservoir engineer's structural and stratigraphic model of the reservoir

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enormously. Co-krigging of seismic attributes and well data can further improve the well model.

Reservoir engineers often turn to Stochastic modeling of production and injection flow rates to plan the management of the reservoir. However, their models include a large number of variables, some of which are not known with absolute confidence, and as a result there is not a unique solution to the problem and uncertainty exists.

Seismic data, a deterministic evaluation of the product of a combination of attributes, provides a snapshot of the reservoir at a defined time in the reservoir's history. By introducing a second or third snapshot, and subtracting one data set from another, the changes in the seismic data at the reservoir are derived. These seismic changes represent absolute changes in the reservoir characteristics, albeit with lower resolution than well based data.

At this point it is possible to compare the results of reservoir modeling with measured seismic difference data set, updating the reservoir model as necessary. After numerous iterations of forward modeling and refinement, a close match to the measured seismic response will indicate a reliable reservoir model. Clearly there is then potential to plan further well locations with confidence on the basis of fluid flow rather predictions rather than on a simple geometric grid basis.

GEOLOGICAL SETTINGS

The Albian Mauddid Carbonate reservoir in the Sabiriyah Oilfield of North Kuwait, is situated on broad north-south trending anticline on the Kuwait Arch.

The Mauddud Formation is a slope facies carbonate, which is preceded by fluvial sediments of the Burgan Formation, and overlain by basinal mudrocks of the Wara Formation. The Mauddud has a lower series of layered elastic and carbonate facies, and an upper series of carbonate facies, which progress, from compacted clay bearing layers at the base to cleaner carbonates at the top.

The Mauddud reservoir is approximately 90 m thick in the Sabiriyah Field. It is at 2100 m depth, has average porosity of 21% and average permeability of 31 millidarcies. There is, however, a high permeability layer 3-6 m thick which is thought to account for over 40% of fluid of injected water.

THE KOC WATERFLOOD EXPERIMENT

KOC were planning a water flood experiment in the Sabiriyah Field of North Kuwait in preparation for future wide scale injection programs. It consisted of an inverted 5-spot pattern, one water injection well surrounded by 4 production wells, making a square with sides approximately 600 m long.

4 D CONCEPT

Geco-Prakla made a series of presentations to KOC in 1996 and 1997 to demonstrate the concept of 4D seismic. Fluid movement caused changes in seismic attributes, which can be measured by carefully planned repeated 3D surveys, which are then subtracted from each other to reveal the lateral extent and magnitude of change.

Seismic data is a measure of the reflection coefficient between different layers of rock deep in the earth. It is directly related to acoustic impedance, and, therefore, to a selection of rock and fluid parameters, including the velocity, bulk moduli, density, porosity, water saturation, Poisson's ratio, temperature and pressure. Depending upon the situation several or all of these factors may be important.

FEASIBILITY OF 4D SUCCESS

It was decided that the Gassman Equations relating to the rock physical parameters were the most suitable for the reservoir conditions present in North Kuwait. Feasibility studies using these equations predicted potential time lapse results for several locations in Kuwait. Clastic reservoirs were expected to have up to 10% change in p-wave acoustic impedance, whereas carbonate reservoirs such as Sabiriyah were expected to have changes in acoustic impedance of up to 5%, and this assumes maximum potential replacement of oil with water.

With such a small potential change in acoustic impedance in carbonate reservoirs, the level of non-repeatable noise in the data set becomes significant. It was anticipated that this is likely to be up to 2% even in high-resolution good signal to noise data.

To verify the results of the feasibility studies, it was agreed to perform a small baseline 3D survey and a follow up survey. An area with high oil production was desirable as this would lead to early

results. The site of the KOC Water flood experiment was selected as a suitable area.

THE 4D EXPERIMENT

The layout of the 3D seismic surveys consisted of a static template of 8 parallel receiver lines 200 m apart with 60 traces at 50 m. Orthogonal and symmetrical to the receiver lines were 8 source lines 200 m apart with 60 source points at 50 m. An unweighted inline geophone array was used for the receivers, and a relatively heavy source effort was used to combat surface noise from roads and installations etc.

The Vaseline 3D survey was acquired in May 1997 prior to the start of water injection. By November 1997 when the repeat survey was recorded there had been 3 months of injection at a rate of about 10,000 bbls/day. The 3D data sets were processed by Geco-Prakla in Germany, under the direction of Roland Marschall.

The refraction static and velocity field were derived for the first data set and applied to both data sets. Whilst the same processing route was applied to both data sets there are going to be small differences due to determinist processes such as deconvolution, where different levels of noise will result in a different operator.

The final product from each data set was a 3D migrated cube, which had L1-norm deconvolution, followed by BORN-inversion for the high frequency part of acoustic impedance (AI). These acoustic impedance cubes were different to produce the final acoustic impedance difference cube.

Transit time changes through the reservoir due to velocity changes after water replacement result in spikes in the acoustic impedance difference cube, which are removed by median filtering.

The result at this stage is a map showing the change in acoustic impedance due to replacement of oil by water in the Mauddud Formation. This map can be calibrated as a saturation map, or fluid flow map.

RESULTS

The experiment proved that time lapse seismic could detect changes in reflection coefficient to map saturation changes within the reservoir.

The heterogeneity of the reservoir was shown by the saturation maps, and agreed closely with KOC own independently derived water cut maps.

Saturation maps derived from the 4D results can be used to plan future well locations, rather than simple geometric placement, resulting in higher efficiency and savings from reduced number of wells.

CREDITS

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