石油技術協会誌　第 71 巻　第 6 号（平成 18 年 11 月）
JOURNAL OF THE JAPANESE ASSOCIATION FOR PETROLEUM TECHNOLOGY
VOL. 71, NO. 6（Nov., 2006）

報　告

Gas-condensate well test results interpretation at Helang field*

Ooi Kiam Chai**, Takeshi Kano*** and Jotaro Tomoeda**

(Received August 30, 2006；accepted November 9, 2006)

Abstract：　Gas condensate reservoirs exhibit a complex behavior caused by the existence of two-fluid system, reservoir gas and liquid condensate, around the well when bottomhole pressure drops below the dew point. Numerous published literatures（Gringarten *et al.*[1), Marhaendrajana[2), Raghavan[3)）based on field data have demonstrated that when this happens, two different mobility regions can be observed in the pressure derivative response in well test data. These two mobility regions are（1）an outer region away from the well, with initial liquid condensate saturation and（2）a region near to the well, with increasing condensate saturation and corresponding lower gas mobility. Some laboratory/theoretical data（Boom *et al.*[4), Mott *et al.*[5)）even showed an additional third region：（3）a region in the immediate vicinity of the well with high capillary number corresponding to reduced condensate saturation and higher gas mobility.

In Helang gas condensate field, offshore Sarawak, East Malaysia, multiple wells were tested in year 2004 and again in year 2005. Modified isochronal tests（MIT）were conducted in each productive zone with bottomhole shut-in condition. This report investigates the identification of 2-region radial composite model from the analyses of Helang field 2004/2005 well test data. Furthermore, the existence of the high capillary number region（region 3）is also investigated from the well test data. With the availability of well test data from two time periods, this report also examines the possible growth of the liquid condensate drop-out region versus time.

Key words：　well test analysis, gas condensate reservoir, condensate build-up, condensate banking, mobility region

1.　Introduction

Helang gas condensate field was discovered in 1990 by the well Helang-1 and was delineated by three appraisal wells, Helang-2, -3 and -4. As shown in Fig. 1, Helang gas field is a part of the SK-10 block, about 70 km offshore of Miri, Sarawak, Malaysia, with a water depth of 90 m. The gas production from Helang field was commenced with ten wells in November 2003. The field is producing about 300 MMscfd of gas and 16 Mstbd of condensate currently. Out of the ten producers, eight wells were completed at Cycle VI lower reservoirs（B, C, D and E-lower sands）and two wells at Cycle VI middle reservoirs（P1 and P1a

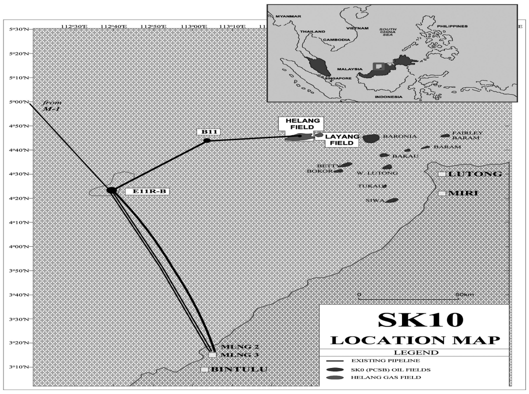

Fig. 1　Helang Field（SK-10 PSC）Location Map

---

[*] 平成 18 年 6 月 1 日，平成 18 年度石油技術協会春季講演会開発・生産部門シンポジウム「特色ある貯留層流体に関する技術」で講演　This paper was presented at the 2006 JAPT Development and Production Technology Symposium entitled “Technologies on unique reservoir fluid” held in Sendai, Miyagi, Japan, June 1, 2006.

[**] 日石マレーシア石油開発㈱　Nippon Oil Exploration (Malaysia), Ltd.

[***] 日石マレーシア石油開発㈱　Nippon Oil Exploration (Malaysia), Ltd.（現帝国石油㈱　Teikoku Oil Co., Ltd.）

sands). Table 1 shows the initial dew point and 2005 reservoir pressures as well as the in-place condensate gas ratio (CGR) for each Cycle VI lower reservoir. The structural cross section of Helang Cycle VI lower reservoirs is shown in Fig. 2. Fig. 3 shows the well completion with selectivity in the Cycle VI lower reservoirs. Fig. 3 also shows the location where the downhole shut-in tool (DHSIT) and gauges were set during the tests.

In 2004, as part of the initial well test campaign, pressure transient tests were conducted on 12 individual zones of the five production wells. The original plan was to conduct modified isochronal tests (MIT) or flow after flow (FAF) using DHSIT. However, only three out of the 12 tests were successfully conducted with DHSIT. The remaining tests were conducted with surface shut-in instead due to malfunction of the DHSIT. Due to the unsatisfactory results obtained with surface shut-in condition, pressure transient tests were conducted once again on nine individual zones of the same five wells in 2005. All multi-rate MIT were successfully completed with downhole shut-in condition in 2005. The data obtained using DHSIT provided for a better and more interpretable results compared to surface shut-in.

Table 1 Initial Dew Point, 2005 Reservoir Pressures and In-Place CGR for each Cycle VI Lower Reservoir

Dew Point Pressure:
- B sand : ~4100 psia
- C/D sand : ~4200 psia
- E lower sand : ~4300 psia

2005 Reservoir Pressure:
- B sand : ~3800 psia
- C/D sand : ~3650 psia
- E lower sand : ~3800 psia

In-Place Condensate Gas Ratio:
- B sand : 30-40 stb/mmscf
- C/D sand : 85-95 stb/mmscf
- E lower sand : 70-80 stb/mmscf

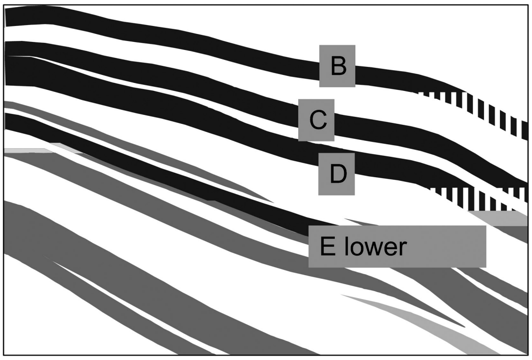

Fig. 2 Structural Cross-Section of Helang Cycle VI Lower Reservoirs

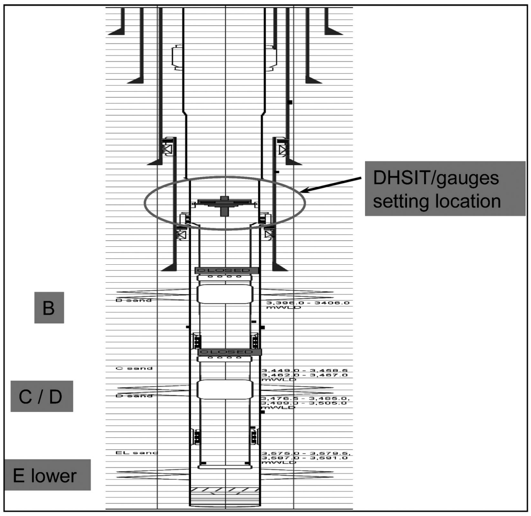

Fig. 3 Well Completion Diagram with Selectivity in the Cycle VI Lower Reservoirs. (Depicting Condition during E-lower Test with DHSIT/Gauges Setting Location)

2. Behavior of gas condensate well

It is well known that in gas condensate reservoirs when wells are produced below dew point pressure, retrograde condensation occurs resulting in a condensate banking effect around the well. Thus, a 2-region composite behavior exists (Fig. 4) (Gringarten[6)]) in the inner region close to the well with high condensate saturation (liquid drop-out), corresponding decrease in gas relative permeability. Away from the well, there is the outer region maintaining the initial condensate saturation. In actual well tests, this 2-region composite behavior can be observed as two mobility stabilizations in the pressure derivative response in well test, as demonstrated in Fig. 5 (Gringarten[6)]). Fig. 5 shows two successive gas condensate well tests in the same well, which are compared with a dry gas test. The gas condensate tests correspond to two different production time

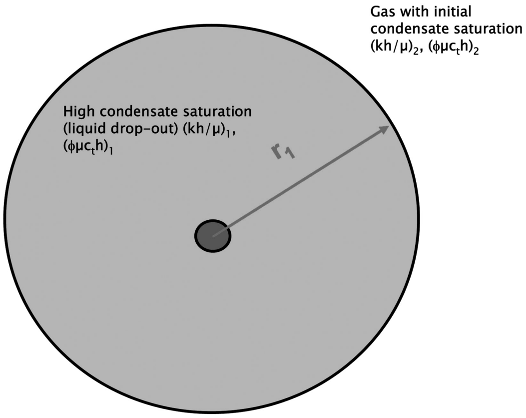

Fig. 4 Schematic of 2-Region Composite Model (Reference from Gringarten[6])

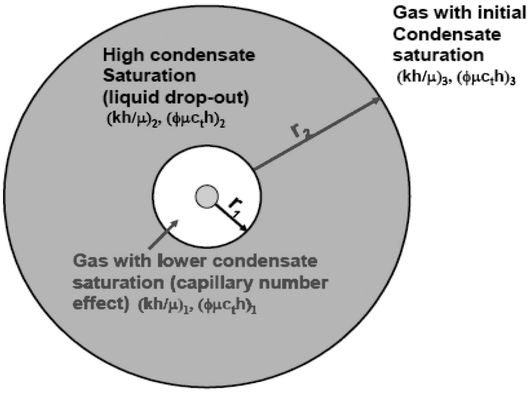

Fig. 6 Schematic of 3-Region Composite Model (Reference from Gringarten *et al.*,[1])

©2000 Society of Petroleum Engineers Ref. 1

periods：curve (a) is typical of DST tests when the wellbore pressure has just fallen below the dew point, whereas curve (b) is representative of production tests, when the wellbore pressure has been below the dew point for a long time.

There may also exist a third region in the immediate vicinity of the well (Fig. 6) (Gringarten *et al.*[1]) when low interfacial tension and/or high velocity of gas induce a decrease of the condensate saturation causing an increase of the gas relative permeability, also known as capillary number effect or gas stripping effect. This 3-region composite behavior can be observed as three mobility stabilizations in the pressure derivative response in well test. Fig. 7 (Gringarten *et al.*[1]) illustrates the associated pressure derivative behavior. Curve (a) in Fig. 7 corresponds to a 2-region composite behavior and exhibits two stabilizations with the lowest stabilization representing

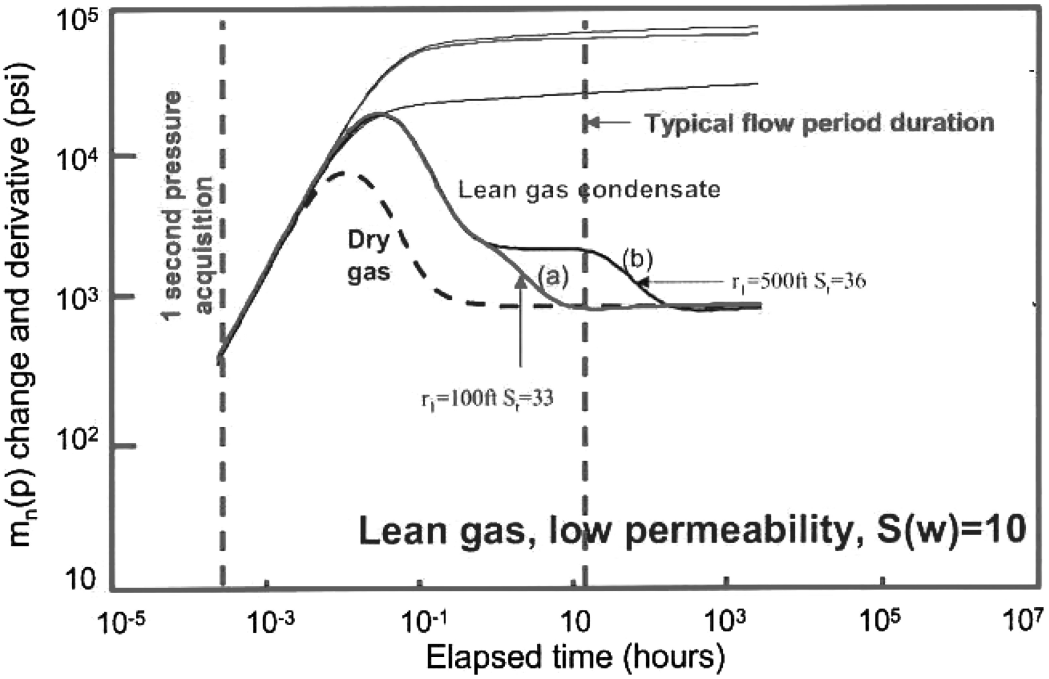

Fig. 5 Theoretical Gas Condensate Well Test Data (Reference from Gringarten[6])

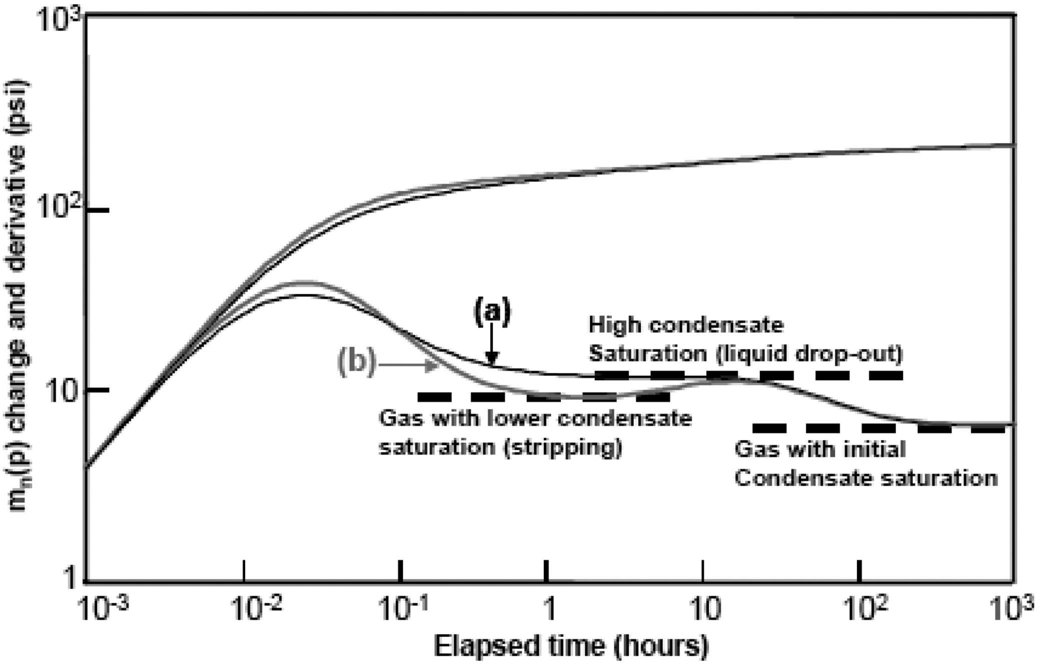

Fig. 7 Schematic of Pressure and Derivative Composite Behavior：(a) 2-region composite; (b) 3-region composite (Reference from Gringarten *et al.*,[1])

the reservoir effective mobility and the highest one relating to condensate bank mobility. Curve (b) shows a 3-region composite behavior where it exhibits an additional stabilization between the other two reflecting the capillary number effect or gas stripping effect with enhanced relative gas mobility around the wellbore.

3. Analysis of pressure build-up test from Helang field

In this section we discuss our analysis and interpretation of selected pressure buildup cases taken from Helang gas field. In some examples, both 2004 and 2005 well test data were compared and interpreted. In most cases, only 2005 data was available. The 2004 well test data were not interpretable mainly due to dominating wellbore storage effect with surface shut-in. All interpretations were on build-up data because drawdown data were affected by flow rate fluctuations and noise from condensate unloading in the wellbore. Fig. 8 shows a typical MIT at Helang wells. The three different flow rate (drawdown, DD) periods were 6 hours each. The first two shut-in periods (build-up, BU) were 6 hours each and the final extended shut-in period was 27 hours.

The following well test cases are presented：

- Well HL-7 E-lower reservoir
- Well HL-6 C/D reservoirs
- Well HL-4 C/D reservoirs
- Well HL-7 C/D reservoirs

3.1 Well HL-7 E-lower reservoir

HL-7 E-lower tests were successfully conducted with DHSIT in both 2004 and 2005 campaigns. Three flow rate MIT with extended final BU period were performed. A superposition plot of all the interpretable flow periods (build-ups) from both 2004 initial well test and 2005 well test are plotted as log-log graph in Fig. 9 and Fig. 10 respectively. The log-log graph in Fig. 11 compares all the flow periods (build-ups) in both tests. Two regions of stabilization are clearly observed in all build-ups which are indicative of condensate banking in the near vicinity of the well.

A 2-region composite model is used to represent the condensate bank formed around the wellbore by condensate drop-out. The most consistent match of the model with the 2005 well test data yields a condensate

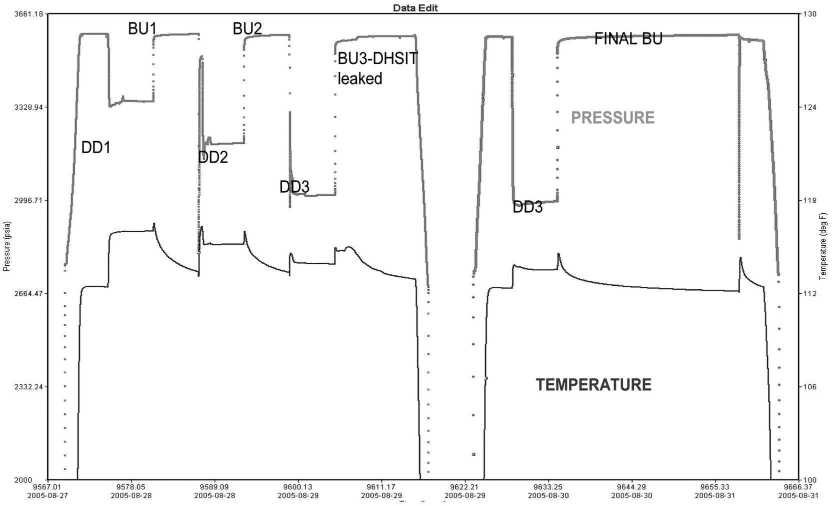

Fig. 8 Typical Multi-Rate Modified Isochronal Test at Helang Wells

bank external radius of 55 ft, a permeability of 27 md near the wellbore and 37md in the outer region. The 2004 initial well test data also yields consistent good match with a condensate bank external radius of 55 ft, a permeability of 27 md near the wellbore and 37 md in the outer region. The result shows no indication of significant condensate bank radius increase from the time of 2004 initial well test to 2005 well test. In addition, no boundary effect was observed in both 2004 and 2005 well tests.

3.2 Well HL-6 C/D reservoirs

HL-6 C/D tests were conducted in 2004 and 2005. However, due to malfunction of DHSIT during 2004 test, only 2005 well test data was interpretable. A 2-region composite model is then used to represent the condensate bank created around the wellbore by condensate drop-out. The most consistent match of the model with the data yields a condensate bank external radius of 50-70 ft, a permeability of 33-43 md near the well and 63 md in the outer region.

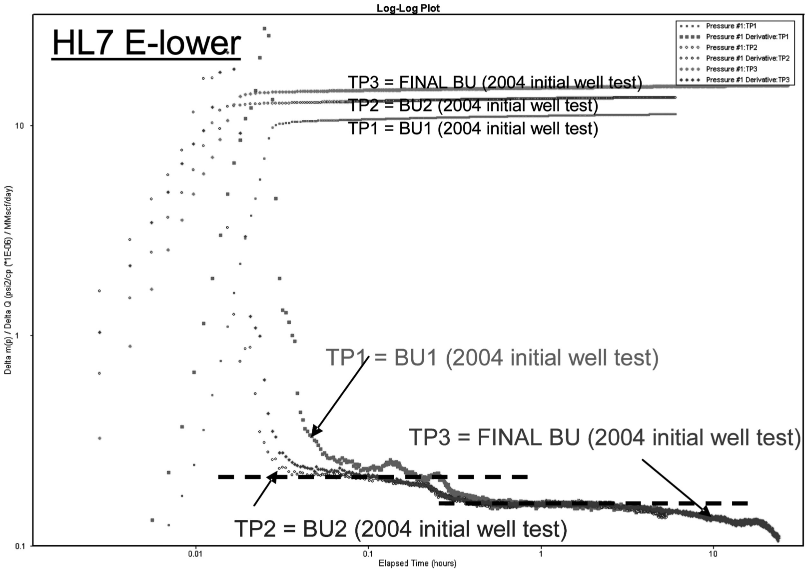

Fig. 9 Log-Log Plot for All Build-Ups Periods of HL-7 E-Lower Sand Test during 2004 Well Test

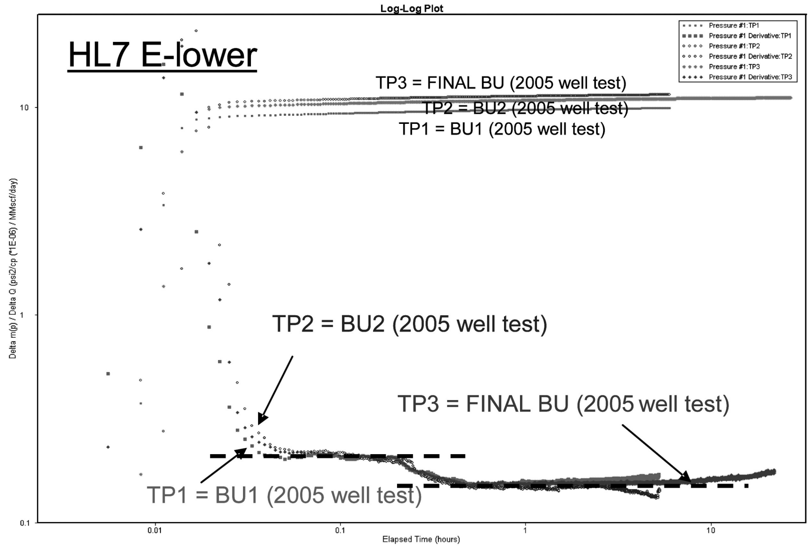

Fig. 10 Log-Log Plot for All Build-Ups Periods of HL-7 E-Lower Sand Test during 2005 Well Test

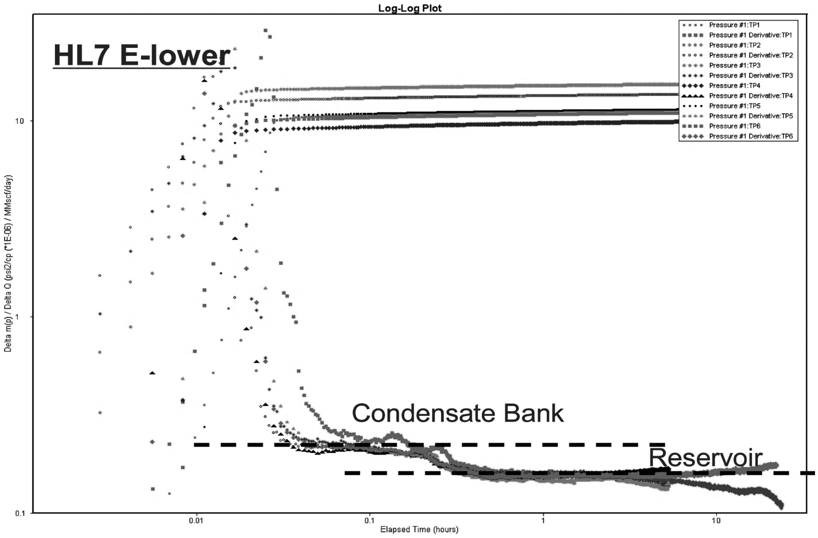

Fig. 11 Log-Log Plot for All Build-Ups Periods of HL-7 E-Lower Sand Test during 2004 & 2005 Well Test

2005 well test identified clearly two different mobility regions (derivative stabilizations), again exhibiting condensate drop-out behavior near the well in the inner region (Fig. 12). However, interestingly the pressure response shows that the final BU has a lower derivative level in the inner region compared to BU1 and BU2. All three BUs eventually stabilized to the same level in the late time region (LTR). This lower stabilization does suggest a higher relative mobility in the condensate bank region for final BU. One possible explanation is that a higher flow rate period (DD3) preceded the final BU may have lowered the condensate saturation, thus effecting the relative mobility in the near wellbore region. However, no unique explanation can be concluded from the well test alone as the effects of layered reservoirs, vertical heterogeneity and C/D sands commingling (different pressure) have not being fully considered.

A boundary effect is observed at late time region in all build-up periods (Fig. 12). It is analyzed as

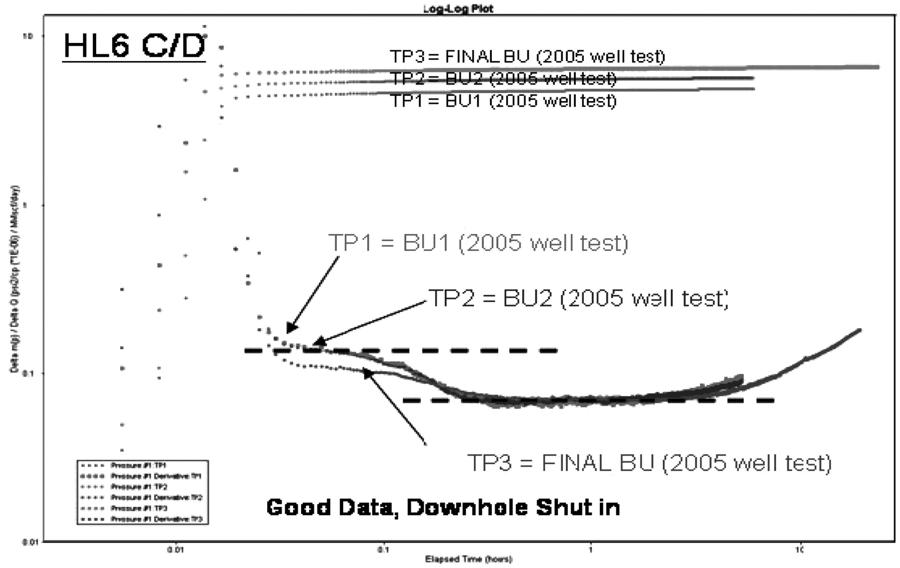

Fig. 12 Log-Log Plot for All Build-Ups Periods of HL-6 C/D Sands Test during 2005 Well Test

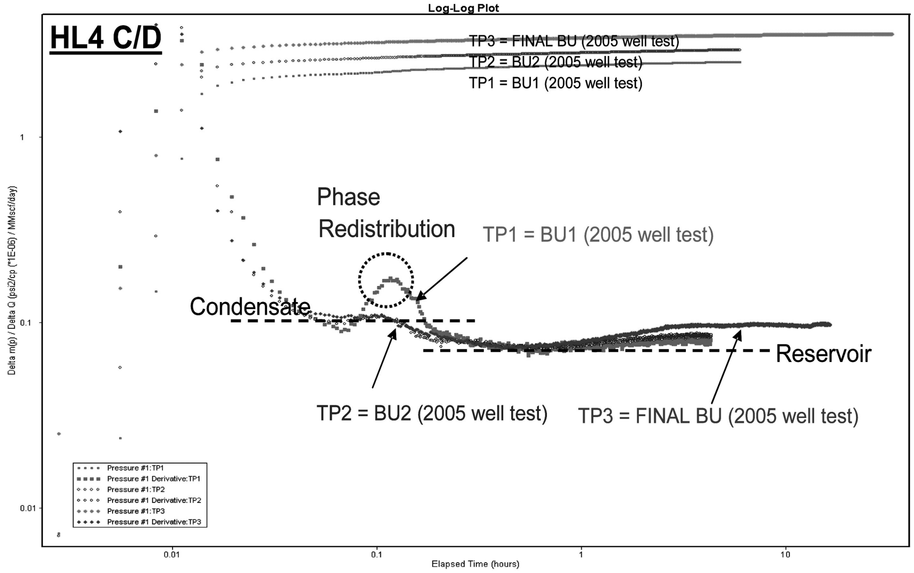

Fig. 13 Log-Log Plot for All Build-Ups Periods of HL-4 C/D Sands Test during 2005 Well Test

parallel boundaries as this model provides the best consistent match for all build-up periods. The matching of the data yields no flow parallel boundaries with distance of 320 ft and 500 ft away from the well to the individual boundary. The parallel boundary is possibly indicative of a channel /sandbody with no flow boundaries in either side.

3.3 Well HL-4 C/D reservoirs

2005 well test showed clearly the two different mobility regions derivative stabilizations (Fig. 13). A 2-region composite model is used to represent the condensate bank created around the wellbore by condensate drop-out. The most consistent match of the model with the 2005 well test data yields a condensate bank external radius of 60 ft, a permeability of 42 md near the wellbore and 52 md in the outer region.

BU1 from 2005 well test shows a clear 'humping' behavior (shown inside the dotted circle in Fig. 13) in the pressure derivative between the early time region (ETR) and middle time region (MTR). This distinct 'humping' behavior is most likely a response of a wellbore phase redistribution effect. Phase redistribution occurs when different phases flow in different directions in the wellbore. This wellbore phase redistribution effect was more pronounced in BU1 because a lower rate flow period (DD1) preceded the BU1, where more condensate will travel toward the bottom of the well. This example shows that the availability of multiple rate BUs data allowed us to distinguish the wellbore effect more confidently. The effect could have being easily misinterpreted for reservoir behavior if only one rate BU data was available.

3.4 Well HL-7 C/D reservoirs

A superposition plot of all the interpretable flow periods (build-ups) is plotted as log-log graph in Fig. 14. The log-log graph in Fig. 14 exhibits a three mobility regions (derivative stabilizations) response common to all build-up periods. A 3-region composite model is used to better represent the additional stabilization in the immediate vicinity of the well that the 2-region composite model is unable to match. The most consistent match of the model yields an inner radius of region 2 and region 3 of 43 ft and 80 ft respectively, a permeability of 75 md in region 1 (the immediate vicinity of the well), 38 md in region 2 (the inner region) and 93 md in region 3 (the outer region).

The three mobility regions or stabilizations in the derivative suggest the existence of capillary number effect region (enhanced gas relative permeability region) in the immediate vicinity of the well. However, this region of supposedly increased gas mobility is difficult to identify with confidence because phase redistribution may also exhibit the same behavior response.

There is an indication of a boundary effect in the late time region of the final build-up. It is analyzed as single fault boundary 600 ft away from the well. It is an indication of non-sealing fault with constant pressure. This is consistent with known minor fault nearby, which was also predicted by seismic interpretation.

4. Summary and Conclusion

In all well test data presented in this report, a 2-region composite behavior can be identified and appears as two different mobility regions on the pressure derivative. Comparison of 2004 well test data with 2005 well test data showed minor or no significant changes in behavior response exhibited from conditions near the well or the reservoir. Radius

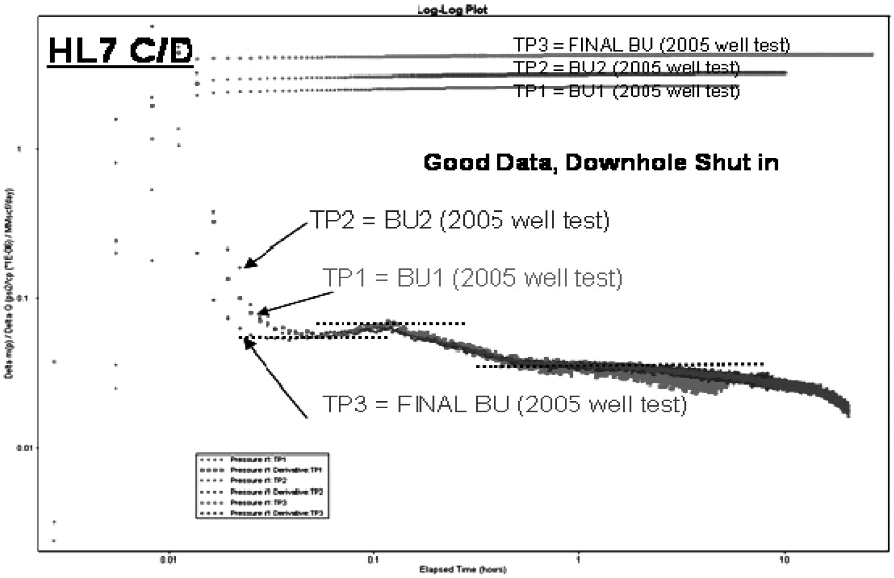

Fig. 14 Log-Log Plot for All Build-Ups Periods of HL-7 C/D Sands Test during 2005 Well Test

of the condensate banking was interpreted to be approximately 40-70 ft from the well in all tests. For the one test (HL-7 E-lower) that we have good data from both tests, no evidence of significant condensate bank radius growth was identified from the time of 2004 well test to 2005 well test. In addition, there is minor or no reduction in gas mobility from 2004 well test to 2005 well test.

HL7 C/D reservoirs test showed an indication of 3-region stabilization, suggesting the existence of capillary number effect in the immediate vicinity of the well. However, this region of supposedly increased gas mobility is difficult to identify with confidence. Uncertainty remains because phase redistribution may exhibit the same behavior around the same ETR to MTR periods.

Wellbore phase redistribution can affect the pressure response of well test data and therefore the analysis of the data. Thus, recognizing the existence of wellbore phase redistribution is important in accurately interpreting the pressure behavior. HL4 C/D reservoir test showed that the availability of multiple rate BUs data allowed us to distinguish the wellbore effect more confidently. The effect could have being easily misinterpreted for reservoir behavior if only one rate BU data was available.

SI Metric conversion factors

bbl × 1.589 874	E − 01 = m^3
ft × 3.048*	E − 01 = m
ft^3 × 2.831685	E − 02 = m^3
md × 9.86923	E − 16 = m^2
psi × 6.894757	E + 03 = Pa
cp × 1.0*	E − 03 = Pa . sec

* Conversion factors are exact.

References

1) Gringarten A.C., Al-Lamki A., Daungkaew S., Mott R and Whittle T.M., 2000：Well test analysis in gas condensate reservoirs, SPE 62920 paper presented at the *SPE Annual Conference & Exhibition, Dallas, Texas 1-4 October 2000.*

2) Marhaendrajana, T., Kaczorowski, N.J. and Blasingame, T.A., 1999：Analysis and Interpretation of Well Test Performance at Arun Field, Indonesia, *SPE 56487 paper presented at the 1999 SPE annual Conference and Exhibition, Texas 3-6 October 1999.*

3) Raghavan, R., Chu, W.C. and Jones, J.R., 1995：Practical Consideration in the Analysis of Gas Condensate Well Tests, *SPE 30576 paper presented at the SPE annual Technical Conference & Exhibition, Dallas, Texas 22-25 October 1995.*

4) Boom, W., Wit, K., Schulte, A.M., Oedai, S., Zeelenberg, J.P.W., and Mass, J.G.., 1995：Experimental Evidence for Improved Condensate Mobility at Near-Wellbore Flow Condition, *SPE 30766 paper presented at the 70th SPE annual Technical Conference and Exhibition, Dallas, Texas 22-25 October 1995.*

5) Mott, R., Cable, A. and Spearing, M., 1999：A New Method of Measuring Relative Permeability for calculating Gas-Condensate Well Deliverability, SPE 56484 paper presented at *SPE Annual Technical Conference and Exhibition, Dallas, Texas 3-6 Oct 1999.*

6) Gringarten A.C., 2003：Interpretation of Well Tests in Gas Condensate Reservoirs, JNOC seminar course material presented in Japan, 20-21 January 2003.

要　旨

ヘランフィールドにおけるガス - コンデンセート井のテスト解析

ウイ キアム チャイ・狩野猛志・友枝城太郎

ガスコンデンセート貯留層は，ガスとコンデンセートの二相系であるため，露点圧力以下になった場合，坑井近傍で複雑な挙動を示す。坑井テストの圧力解析で易動度の異なる２つの領域が観察されることが，多数の文献(Gringarten *et al.*1), Marhaendrajana2), Raghavan3)）においてフィールドデータより示されている。これら２つの易動度領域とは，(1) 坑井から外側で初期のコンデンセート飽和率である領域，(2) 坑井に近くコンデンセート飽和率が増加しガスの易動度が小さい領域を指す。いくつかの実験および理論データ（Boom *et al.*4) , Mott *et al.*5)）では，さらに３つめの領域，(3) 坑井のすぐ近傍で高いキャピラリーナンバーでコンデンセートが減少しガスの易動度がより大きい領域が追加される。

東マレーシア，サラワク州沖のヘランガスコンデンセートフィールドでは，2004 年と 2005 年に複数の坑井

でテストを行い，ダウンホールシャットインツールを用いて，各生産層準で改良アイソクロ－ナルテストが実施された。本報告では同テスト解析結果から２領域ラジアルコンポジットモデルでの解析を行い，さらに第３の領域の存在についても調査した。また，同一坑井においてタイミングの異なる２つのテスト結果を用いて，コンデンセート飽和率の高い領域が広がっていく可能性についても検討した。