PETROVIETNAM JOURNAL
Volume 6/2019, p. 58 - 62
ISSN-0866-854X

Predicting water influx for gas production wells of Lan Do field using material balance method

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Summary

Lan Do gas field (Block 06-1 in Nam Con Son basin) started producing gas and condensate in October 2012. The cumulative production up to February 2018 was 6,854 billion cubic metres of gas and 0.09 million barrels of condensate which account for 62% and 41% of the reserve, respectively. At present, there is no water influx phenomenon in Lan Do production wells. However, it is necessary to forecast water influx period for reservoir production and management strategies. This paper analyses and forecasts this phenomenon for the production wells of Lan Do field and proposes optimal production strategy.

Key words: Lan Do field, water influx, water-gas ratio, gas-water contact.

1. Introduction

Lan Do field started producing gas and condensate in October 2012 with two production wells LD-1P and LD-2P. The production rate of Lan Do field in 2013 reached 925 million m^3 (0.033 trillion ft^3) of gas and 0.014 million barrels of condensate. In the 2014 - 2017 period, gas production rate reached over 1.2 billion m^3 per year (0.04 trillion ft^3) and condensate production rate was 0,17 million barrels per year. By the end of October 2018, the cumulative production of Lan Do field was 6,854 billion m^3 of gas and 0.09 million barrels of condensate [1].

The produced water of Lan Do is the amount of condensed water in the gas, so the chloride content of produced water is quite low, averaging 80 - 110ppm. When the chloride content in the produced water of the field increases and exceeds the permitted level (150ppm), that means gas-water contact (GWC) is gradually approaching the perforation interval of production wells. The current water-gas ratio (WGR) of Lan Do field is 0,45 barrel/million ft^3 (Figure 1).

In this paper, the authors analyse and calculate the current GWC, forecast the possibility of water influx to production wells based on the principle of material balance method and propose solutions to improve production in Lan Do field more effectively.

Date of receipt: 14/6/2018. Date of review and editing: 14/6 - 25/10/2018.
Date of approval: 3/6/2019.

2. Determination of reservoir drive mechanisms and prediction of water influx for gas production wells of Lan Do field

2.1. Determination of reservoir drive mechanisms

The reservoir pressure support of Lan Do field is very good. From 2012 to February 2018, the reservoir pressure reduced by 63psi, from 1,948psi to 1,885psi. With the declining trend of reservoir pressure (Figure 2), the cumulative gas production at the end of production will reach 0.39 trillion ft^3, while the reservoir pressure will decline to 1,858psi at 1,132m TVDss.

For gas condensate reservoirs, the reservoir drive mechanism can be determined by the relationship between reservoir pressure (or P/z ratio) and cumulative gas - condensate production (G_p) [4].

For gas reservoirs produced by natural drive mechanism without aquifer, the relationship between reservoir pressure and accumulated gas - condensate production is linear and can be expressed as:

$$\frac{P}{z} = -\frac{Pi}{ziG} G_p + \frac{Pi}{zi}$$

For the reservoir produced by water drive mechanism, the relationship between reservoir pressure and accumulated gas-condensate production is nonlinear because the reservoir pressure decreases during production is smaller than the reservoir pressure produced by the natural drive mechanism without aquifer (Figure 3).

From the results of the reservoir pressure measurements, the construction of P/z curve (Figure 4) shows that the wells of Lan Do field have the volume of aquifer which supports Lan Do is 250Bbbl.

2.2. Prediction of water influx

Production in Lan Do field is on-going with stable flows without water influx into the production wells. However, the reservoir has a large aquifer which can accumulate water influx. Therefore, analysis and forecast of the water influx are very important to improve the efficiency of operation and production.

The gas-water contact (GWC) during production and at the end of production is determined through the amount of water influx into the reservoir, based on the material balance equation [4].

$$G(B_g - B_{gi}) + GB_{gi}\left[\frac{C_w S_{wi} + C_f}{1 - S_{wi}}\right]\Delta\bar{p} + W_e = G_p B_g + B_w W_p \quad (1)$$

In which:

G: Gas and condensate initially in place;

B_g: Gas formation volume factor;

B_{gi}: Initial gas formation volume factor;

B_w: Water formation volume factor;

C_w: Water compressibility;

C_f: Rock compressibility;

S_{wi}: Initial water saturation;

W_e: Cumulative water influx;

W_p: Cumulative water production.

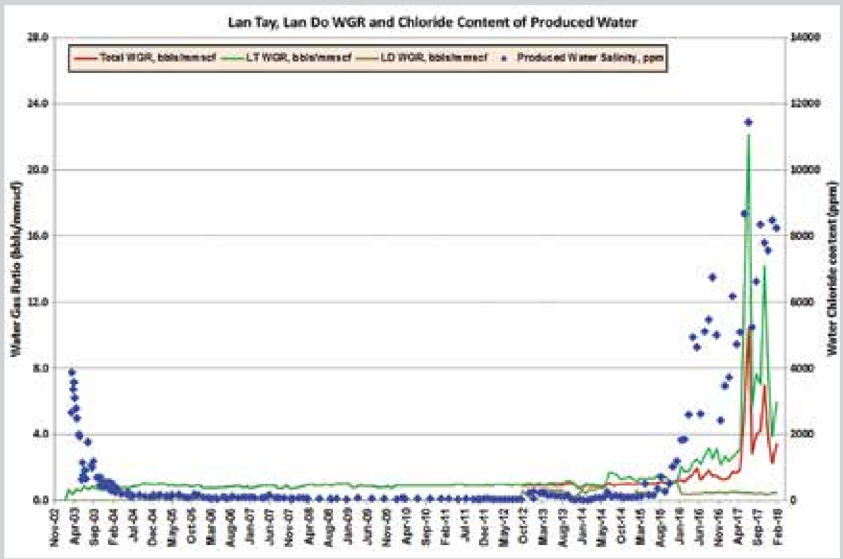

Figure 1. Lan Tay, Lan Do water-gas ratio and chloride content of produced water [2].

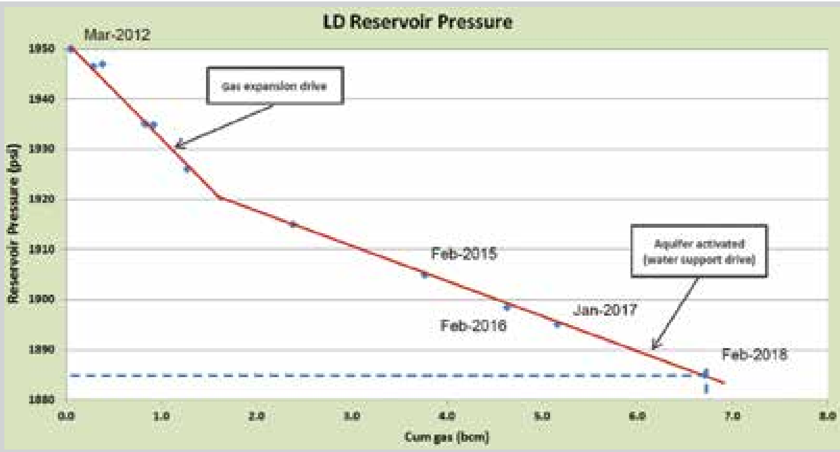

Figure 2. Reservoir pressure and cumulative gas production [3].

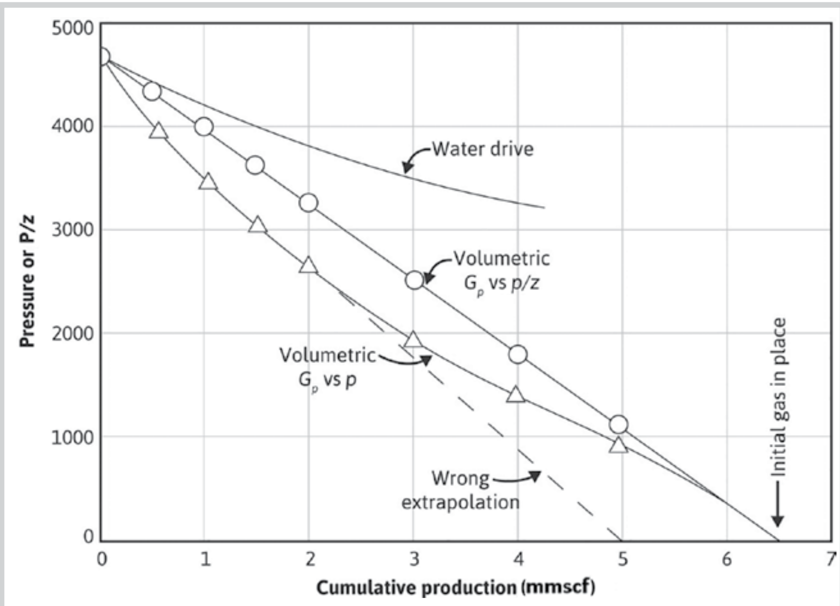

Figure 3. Relationship between P/z and G_p for gas field in case of production reservoir with the aquifer and volumetric reservoir [4].

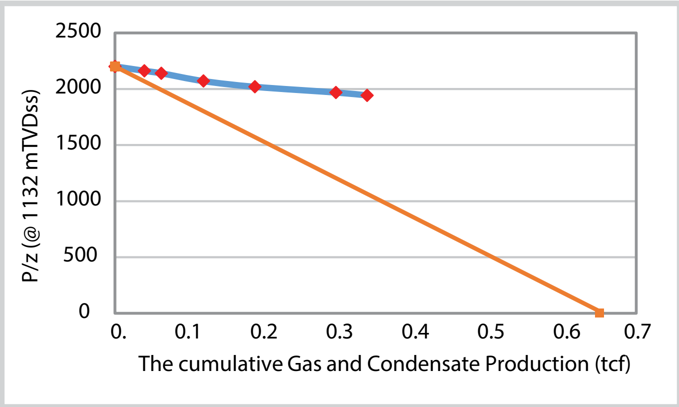

Figure 4. *Relationship between P/z ratio and cumulative gas condensate production.*

Table 1. *Characteristics of fluid and reservoir*

Gas initially in place (trillion ft³)	0.65
Condensate initially in place (million barrels)	0.33
B_g (cuft/SCF)	0.008548733
B_{gi} (cuft/SCF)	0.007874
C_w (psi^{-1})	3.46×10^{-6}
S_{wi}	0.05
C_f (psi^{-1})	6.30×10^{-6}
Rock porosity Φ, (%)	37.5
Initial bulk rock volume - BRV (million m³)	1,518
B_w, rb/stb	1.01537
Water-gas ratio - WGR (barrel/million ft³)	0.45
Residual gas saturation	0.283
Compression factor z	0.87
Reservoir pressure at 1,132m TVDss (psi)	1,885
Reservoir temperature (°F)	157
Initial reservoir pressure at 1,132m TVDss (psi)	1,948
Initial compression factor Z_i	0.88
Pressure gradient (psi/ft)	0.04

2.2.1. Determination of gas-water contact

By February 2018, the cumulative production of Lan Do reached 0.2420 trillion ft³ of gas (equivalent to 62% of the reserve) and 0.09 million barrels of condensate (equivalent to 41% of the reserve). Cumulative water production is 30.7 thousand barrels. The magnitude of the reservoir pressure which decreases with the cumulative production of Lan Do field is shown in Figure 2 and the reservoir pressure in February 2018 was about 1,885psi at 1,132m TVDss. The parameters showing the properties of fluid and reservoir are presented in Table 1 [5].

Condensate production and water production are converted via the below equation [4]:

- For condensate production:

$$GE = V = \frac{nR'T_{sc}}{p_{sc}} = \frac{350.5\gamma_0(10.73)(520)}{M_{wo}(14.7)} = 133{,}000\frac{\gamma_0}{M_{wo}} \quad (2)$$

in which:

$$M_{wo} = \frac{5954}{\rho_0 API - 8.811} = \frac{42.43\gamma_0}{1.008 - \gamma_0} \quad (3)$$

- For water production:

$$GE_w = \frac{nR'T_{sc}}{p_{sc}} = \frac{350.5 \times 1.00 \times 10.73 \times 520}{18 \times 14.7} \quad (4)$$

$$= 7{,}390\ SCF/surface\,barrel$$

- The converted condensate production via equation (2) và (3) is 0.074 billion ft³;

- The converted water production via equation (4) is 0.227 billion ft³

Thus, the total gas production included converted water and condensate, G_p = 0.2423 trillion ft³.

Water influx into the reservoir (W_e), which is determined by material balance equation (1), is 290.3 million barrels (46.2 million m³).

So, the remaining bulk rock volume: BRV = initial BRV - $[W_e/\Phi \times (1-S_{wi}-S_{gr})]$ = 470 million m³.

Thus, by the end of February 2018, the gas water contact, which is determined by Figure 5, is 1,153m TVDss.

2.2.2. Calculation of gas-water contact at the end of production when the expected cumulative gas production G_p = 0.39 trillion ft³

According to Lan Do prediction, the cumulative gas and condensate production are 0.39 trillion ft³ and 0.22 million barrels respectively at the end of production and the average reservoir pressure at that time is expected to reach 1,858psi at 1,132m TVDss.

- Gas reserves: 0.39 trillion ft³

- Cumulative water production: 43.8 thousand barrels

- Condensate reserves: 0.22 million barrels

- Converted condensate reserves: 0.18 billion ft³

- Converted water production: 0.32 billion ft³

Thus, the total gas production including the converted water and condensate reserves is G_p = 0.391 trillion ft³.

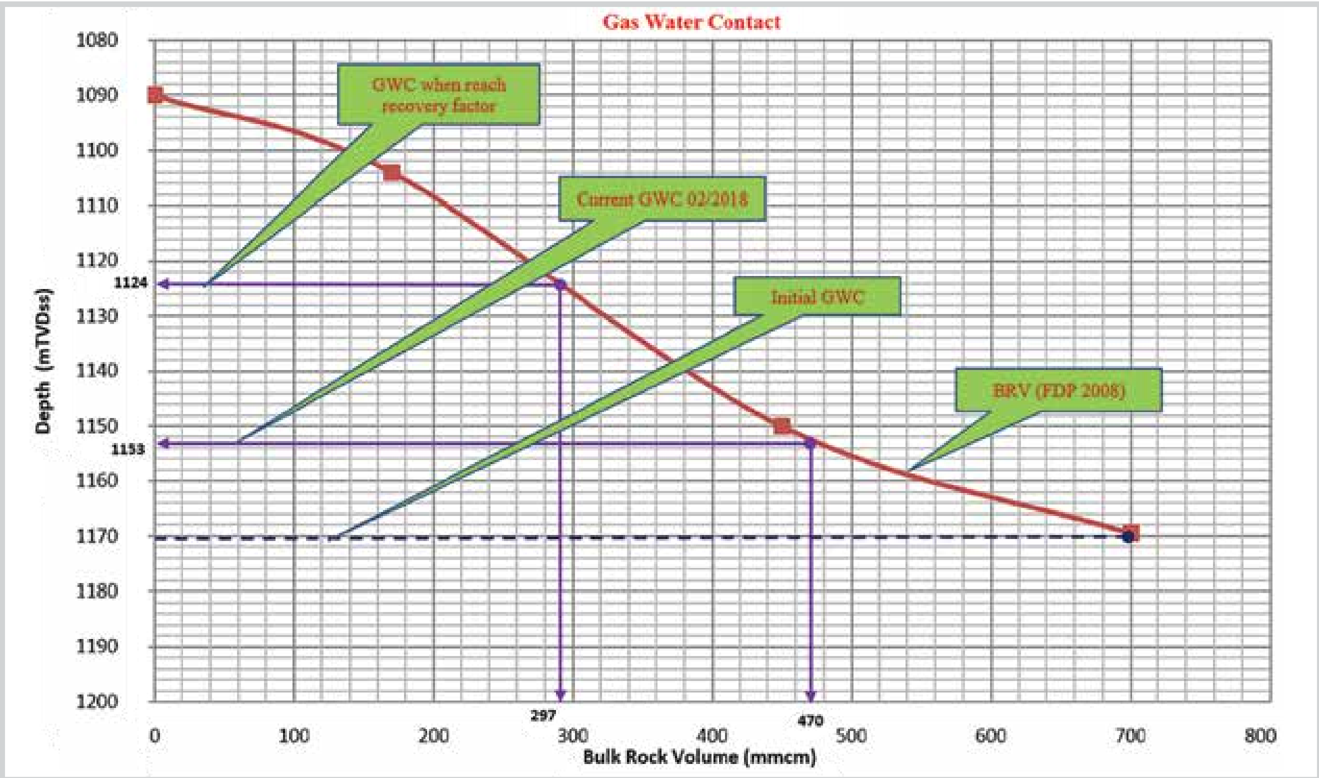

Figure 5. *Determination of gas water contact via BRV [5].*

Table 2. *The results of calculating the amount of water influx based on accumulated gas and condensate production*

Cumulative gas and condensate production (billion ft³)	Water influx into reservoir (million barrels)
32.7	0.57
44.6	12.6
84.7	61.7
134.4	132.6
228.2	271.03
242.3	290.3
390	508.9

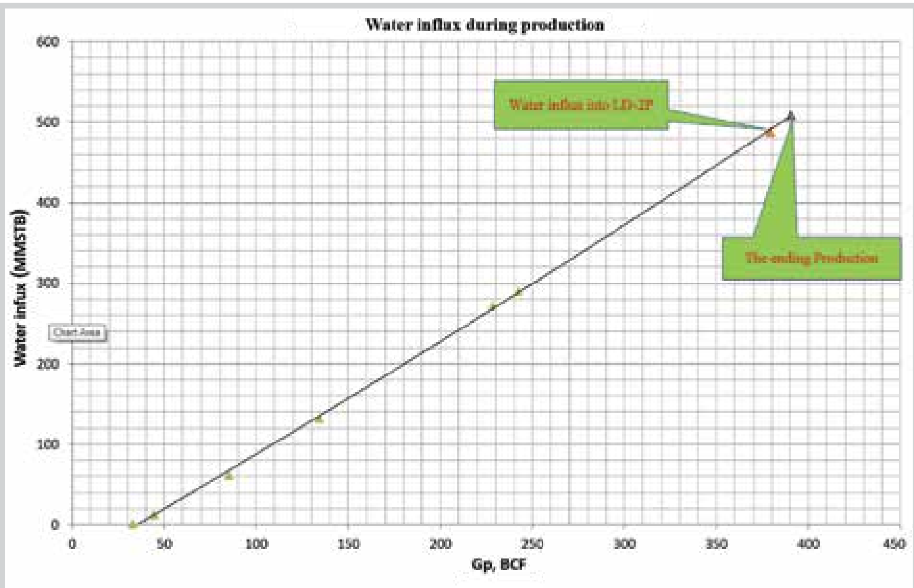

Figure 6. *Prediction of water influx during production.*

Water influx into the reservoir (W_e), which is determined by material balance equation (1), is 508 million barrels (81 million m^3)

The remaining bulk rock volume: BRV = initial BRV - $[W_e/\Phi \times (1-S_{wi}-S_{gr})]$ = 297 million m^3.

Therefore, the gas-water contact at the end of production is 1,124m TVDss (Figure 5)

The amount of water influx into the reservoir during production is calculated by the material balance equation and it has a close relationship with the cumulative gas and condensate production. The results of forecasting the water influx into the reservoirs via the cumulative gas and condensate production are shown in Table 2 and Figure 6.

With the bottom hole depths (TD) of wells LD-1P and

Table 3. *Lan Do GWC estimation*

Depth (m TVDss)	Bottom hole depth (m TVDss)		Water-gas contact (m TVDss)		
	LT-1P	LT-2P	Initial	February 2018	At G_p = 0.39 trillion ft^3
1,080					
1,090					
1,100	1,101				
1,110					
1,120					1,124
1,130		1,138			
1,140					
1,150				1,153	
1,160					
1,170			1,170		
1,180					

Table 4. *Prediction of water influx into the Lan Do wells*

Well	Depth (m TVDss)	BRV at well depth (million m^3)	Water influx volume at the time of flooding		Cumulative production (trillion ft^3)	Time of starting to flood
			million m^3	million barrels		
1P	1,101	140	132	832	0.62	N/A
2P	1,138	370	78	490	0.38	August 2020

LD-2P are 1,101m TVDss and 1,138m TVDss respectively and GWC in February 2018 is 1,153m TVDss, the water will be present in well 2P before the end of production (Table 3).

Prediction for water influx is calculated with the assumption that the average annual production of Lan Do is 1,642 billion m^3 of gas and 0.02 million barrels of condensate to the end of field life. At the end of production, when cumulative production G_p = 0.39 trillion ft^3, well LD-2P will be flooded with water. The results of predicting time and cumulative production at the time wells start to flood are presented in Table 4.

3. Conclusion

The prediction of water influx for Lan Do field is calculated based on the reservoir and fluid parameters, the reservoir pressure prediction and calculations based on the material balance method with the average annual production of 1,642 billion m^3 of gas and 0.02 million barrels of condensate. From the results, the gas-water contact will move upwards and the earliest flooded well is LD-2P (in August 2020). Therefore, it is necessary to consider adjusting the production with reasonable rate of LD-2P to slow the water produced time and prolong the time of production of Lan Do field.

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