Application of NPI Decline to Gas-injection Transient Analysis

TANG Ligen[1,2], , WANG Jieming[1,2], BAI Fengjuan[3]

1. PetroChina Research Institute of Petroleum Exploration & Development-Langfang, Langfang 065007, China;
2. CNPC Key Laboratory of Oil and Gas Underground Storage, Langfang 065007, China;
3. China Kunlun Constracting & Engeering Corporation, Beijing 100037, China

Abstract: According to no theory nor software for gas-injection transient analysis published yet, the equation for gas injection seepage was solved to obtain NPI decline curves for gas-injection on the basis of modified material balance time. Production data were handled by use of calculator programs in Matlab to acquire drainaged parameters for gas-injection through typicalcurves fitting, which has the feature to forecast gas-injection performance in the future using the results of gas-injection analysis eventually. Calculation of C21well production data using the method above shows that the drainage parameters for gas-injection close to that from Well Testing, and the forecasted production performance is in line with the real injection data, which prove the method above valid in analyzing gas-injection effectively. The result above provides a new tool for gas-injection transient analysis.

Keywords: UGS; gas-injection; transient analysis; NPI decline; modified theory for gas withdraw

The peak shaving capability of underground gas storage in gas field mostly depends on numerous inject-produce wells [1-3]. So it is very important to predict the performance of single well injection-production accurately. The analysis method of single well production gas performance mainly referring to the theory of gas reservoir development represented by NPI transient production analysis based on the principle of the transient testing and daily production data [4-6] to solving drainage parameters by fitting production typicalcurve and then to forecast the future production. As an important analysis tool for gas reservoir development, this production transient

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作者简介：唐立根（1982-），男，2010 年毕业于中国科学院研究生院，主要从事储气库设计与动态分析；

E-mail：tangligen@petrochina.com.cn

method has been developed into commercial softwares such as FAST. RTA and Topaze [7-8] etc.However those softwares have no feature to analyze the injection gas data. The reason mainly embodies no mathematical model has been published up to now yet. In view of the problem above, new NPI model for gas injection was established to calculate drainage parameters during gas injection by typicalcurve matching and form a tools for gas injection forecasting eventually.

1 Seepage equation for gas injection

Single well drainage area can be simplified into closed formation as a result of the existence of fluid boundary among gas injection wells. Now the problem is converted into solving circular closed formation with a well injecting (-Q) and the comprehensive seepage shows as equation (1):

$$\begin{cases} \frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial p_m}{\partial r}) = \frac{\phi\mu c_t}{K}\frac{\partial p_m}{\partial t} \\ p_m(r,t) = p_{mi} \\ r\frac{\partial p_m}{\partial r}\Big|_{r=r_w} = \frac{Q\mu}{2\pi Kh}r \\ \frac{\partial p_m}{\partial r}\Big|_{r=r_e} = 0 \end{cases} \qquad (1)$$

Solve the above equation (1) by dimensionless treatment and using laplase transform, and obtain the result as equation (2) shows:

$$\begin{cases} \frac{d^2\overline{p}_D}{dr_D{}^2} + \frac{1}{r_D}\frac{d\overline{p}_D}{dr_D} = s\overline{p}_D \\ \frac{d\overline{p}_D}{dr_D}\Big|_{r_D=1} = -\frac{1}{s} \\ \frac{d\overline{p}_D}{dr_D}\Big|_{r_D=r_{eD}} = 0 \end{cases} \qquad (2)$$

The general solution of equation (2) is a linear combination of Bessel fuction I_0 and K_0:

$$\overline{p}_D = A_0 I_0(r_D\sqrt{s}) + B_0 K_0(r_D\sqrt{s}) \qquad (3)$$

Put in the definite conditions and obtain the expression of A0 and B0, then get the expression of pressure for gas injection as equation (4) bellow. Pressure for gas injection shows the same expression as that for gas withdrawing with different parameters meaning.

$$\overline{p}_D = \frac{K_1(r_{eD}\sqrt{\beta s})I_0(r_D\sqrt{\beta s}) + I_1(r_{eD}\sqrt{\beta s})K_0(r_D\sqrt{\beta s})}{s\sqrt{s}(K_1(\sqrt{\beta s})I_1(r_{eD}\sqrt{\beta s}) - I_1(\sqrt{\beta s})K_1(r_{eD}\sqrt{\beta s}))} \quad (4)$$

Dimensionless pressure p_D shows as (5):

$$p_D = \frac{2\pi Kh(p_{wf} - p_i)}{q\mu B} \quad (5)$$

Dimensionless time t_{DA} shows as (6):

$$t_{DA} = \frac{Kt}{\pi\phi\mu c_t r_e^2} \quad (6)$$

$$\beta = \frac{1}{\pi(r_e^2 - 1)} \quad (7)$$

Dimensionless radius r_D and r_{eD} shows as (8) and (9):

$$r_D = \frac{r}{r_w} \quad (8)$$

$$r_{eD} = \frac{r_e}{r_w} \quad (9)$$

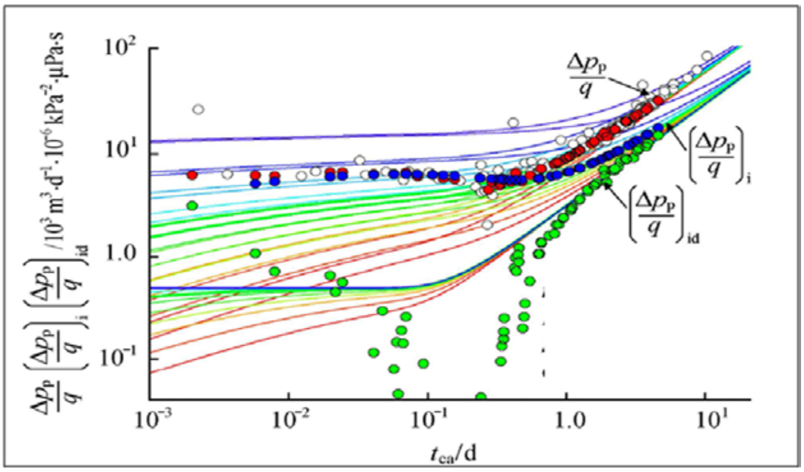
2 Typical curve for gas injection

2.1 Theoretical curve

Use Stefest [9-10] method to numerical inversion of equation (4) to get real space P_{Dd} nd tca/d, then draw the curve of P_{Dd} nd tca/d as shown in figure 1,which shows the same chart form as gas withdraw just with different meanings of P_{Dd} nd tca/d.

2.2 Actual curve

①Calculation of material balance time. A simplified method for calculation of material balance time was provided, firstly take viscosity and compressibility with the bottomhole flowing pressure correspondingly, then use numerical integration method, and calculate the material balance time enventually by equation (10):



Fugure 1 NPI curve of P_{Dd} nd tca/d for gas injection

$$t_{ca} = \frac{(\mu c_t)_i}{q} \int_0^t \frac{q}{\mu c_t} dt \qquad (10)$$

②Calculation of normalized pressure. Caculutate normalized pressure according to Lee and Holditch's pseudo pressure expression and eqution (12):

$$p_p = (\frac{\mu Z}{p})_i \int_0^p \frac{p}{\mu Z} dp \qquad (11)$$

$$\frac{\Delta p_p}{q} = \frac{p_{p_{wf}} - p_{p_i}}{q} \qquad (12)$$

③ Drawing curve with material balance time and normalized pressure obtained from the results of ②and① above.

3 Drainage parameters solving

Calculate material balance time and normalized pressure for each production point correspondingly. And then draw double logarithmic scatter diagram between $\Delta p_p / q - t_{ca}$ as shown in Figue 1 to solve parameters by theoretical curve and scatter diagram matching.

①Caculate the dimensionless radius of well drainage r_{eD} by picking up one fitting point according to the results of fitting diagram.

②Caculate the permeability of injection well drainage area K by picking up the theoretical fitting point（t_{caDA}，P_D)$_M$ and actural fitting point（t_{ca}，$\Delta p_p / q - t_{ca}$）$_M$.

$$K = \frac{(p_D)_M}{(\Delta P_p / q)_M} \frac{\mu B}{2\pi h} \quad (13)$$

③Caculate the injection well drainage radius r_e by the results of steps ② above.

$$r_e = \sqrt{\frac{K}{\pi \phi \mu c_t} (\frac{t_{ca}}{t_{caDA}})_M} \quad (14)$$

④Caculate the injection well drainage effective radius r_{wa} by the results of steps ② and steps ③ above.

$$r_{wa} = \frac{r_e}{r_{eD}} \quad (15)$$

⑤Caculate the injection well skin s by the results of steps ③ and steps ④ above.

$$s = \ln(\frac{r_w}{r_{wa}}) \quad (16)$$

⑥Put above parameters obtained from steps ①②③④⑤ into the in seepage equation in order to realize the dynamic performance forecasting of gas injection.

4 Example

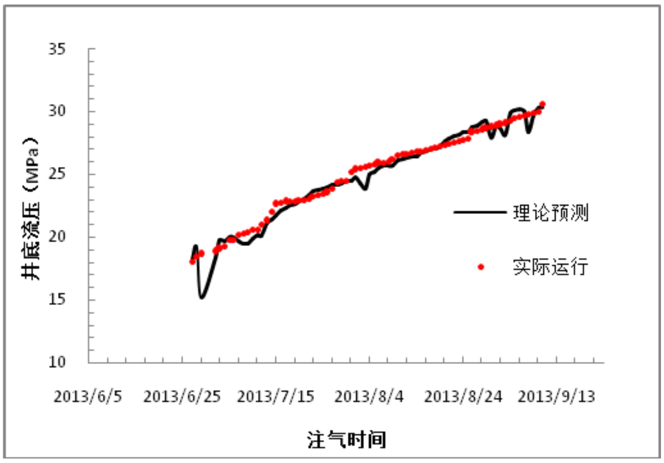
Take C21 well of some UGS in China’s circum-Bohai-Sea area for example, the net pay is 6.8m, porocity is 0.189, irreducible water saturation is 0.65, radius of well is 0.107m, formation temperature is 358 K and relative density of gas is 0.66. The well head pressure of C21 well increased from 17 MPa to 26 MPa after continuous gas injection for 74 days. Sovle the drainage parameters throug typecure fitting method mentioned above, and acquire the result shown as Table 1.

Table 1 Drainage parameters obtained frome NPI and Well-test

Methods	Permeability (mD)	Drainage Radius (m)
NPI	19.8	327
Well-test	21.2	341

It shows that the value of drainage parameters obtained from NPI method above close to that from well test, such as the two permeabilitys are 19.8 mD and 21.2 mD, and the drainage area radiuses are 327 mD and 341 mD, which increases confidence in the injection NPI method.

Put the drainage parameters into seepage equation and get the prediction model for gas injection. Forcast the flowing downhole pressure based on the injection rates, then compare with actual operation of bottomhole pressure correspondingly, therefor get the history matching results hown in Figure 2 Eventually. Comparison results show that the theoretical predictions close to the actual operation result within the scope of permissible error 5%.



Fugure 2 History matching of well head pressure by NPI method

5 Conclusion

(1) Obtain the expression of pressure for gas injection in NPI formation by modification of material balance time and pseudo-pressure.

(2) Get the NPI typicalcurve for gas injection by fitting theoretical cure and actual curve with the same expression as that of gas withdrawing but not the different meaning of parameters.

(3) Case study shows that the drainage parameters of injection well obtained by picking up the theoretical fitting point and actural fitting point close to that from well test, which increase confidence in NPI method for gas injection.

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