GAS RESERVOIR EVALUATION FOR UNDERBALANCED HORIZONTAL DRILLING

by

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A set of surface equipment for monitoring the parameters of fluid and pressure while drilling was developed, and mathematical models for gas reservoir seepage and wellbore two-phase flow were established. Based on drilling operation parameters, well structure and monitored parameters, the wellbore pressure and the gas reservoir permeability could be predicted theoretically for underbalanced horizontal drilling. Based on the monitored gas production along the well depth, the gas reservoir type could be identified.

Key words: *underbalanced drilling, horizontal well, surface monitoring, permeability evaluation, media type*

Introduction

During underbalanced horizontal drilling, because of the negative pressure at the bottom the reservoir gas flows into the well, which causes variations of several monitored parameters such as the wellbore fluid velocity, the standpipe pressure and the casing pressure, so the information of gas reservoir can be obtained timely by interpreting the monitored parameters [1, 2]. The objective of the present work is to study a methodology which can get the information of gas reservoir timely based on the interpretation of the monitored parameters during underbalanced horizontal drilling.

Monitoring equipment composition

The equipment which is used in parameter monitoring is composed of gas flow meter, standpipe pressure gauge, sensors for casing pressure and full hydrocarbon concentration, and bottom pressure gauge. Data obtained by the equipment are stored in the data acquisition module and transmitted wirelessly to the surface computer terminal. The monitoring equipment composition is shown in fig. 1.

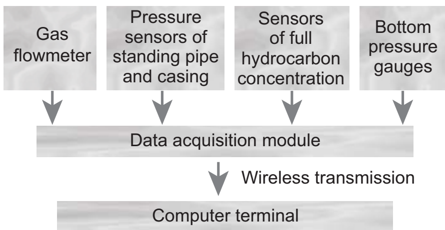

Figure 1. The monitoring equipment composition

Permeability evaluation

For analyzing the dynamic flow of reservoir gas, the whole reservoir can be divided into several small units which are assumed to be homogeneous, and permeability of each unit is

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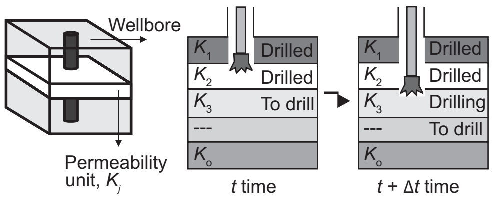

Figure 2. The process of underbalanced horizontal drilling

recorded successively as *K*1, *K*2… *Kn*. Then, during underbalanced horizontal drilling each unit is penetrated successively. The process of underbalanced horizontal drilling is presented in fig. 2. Supposing that there is no gas seepage among the units, and the outlet of each unit varies by time, the seepage formula of each unit can be derived based on the superposition principle and the Duhamel's theory [3]:

$$K = -\frac{1}{2\pi h\left[m_{\rm i} - m(r,t)\right]} \frac{p_{\rm sc}T_{\rm i}}{Z_{\rm sc}T_{\rm sc}\rho_{\rm gsc}} \sum_{j=1}^{n} \left\{ (q_j - q_{j-1}) Ei\left[-\frac{r^2}{4\eta(t - t_{j-1})} \right] \right\} \tag{1}$$

Permeability of each unit could be calculated by eq. (1) based on the monitored parameters and the wellbore pressure during underbalanced horizontal drilling, and the calculating method of wellbore pressure will be introduced below.

Wellbore pressure evaluation

The wellbore fluid flow is multiphase during underbalanced horizontal drilling, in order to calculate the wellbore pressure, the multiphase flow is simplified to gas-liquid two-phase flow necessarily.

The continuity equations of gas and liquid are given, respectively, as:

$$\frac{\partial}{\partial t}(\rho_g \alpha_g) + \frac{\partial}{\partial z}(\rho_g \alpha_g v_g) = 0 \tag{2}$$

$$\frac{\partial}{\partial t}(\rho_l \alpha_l) + \frac{\partial}{\partial z}(\rho_l \alpha_l v_l) = 0 \tag{3}$$

The constraint equation of gas-liquid mixture is given as:

$$\alpha_g + \alpha_l = 1 \tag{4}$$

The kinematic equation of gas-liquid mixture is given as:

$$\frac{\partial}{\partial t}(\rho_g \alpha_g v_g + \rho_l \alpha_l v_l) + \frac{\partial}{\partial z}(p + \rho_g \alpha_g v_g^2 + \rho_l \alpha_l v_l^2) + $$

$$+ (\rho_g \alpha_g + \rho_l \alpha_l) g \cos\theta + \frac{f(\rho_g \alpha_g {v_g}^2 + \rho_l \alpha_l {v_l}^2)}{2D} = 0 \tag{5}$$

The state equation of the ideal gas is given as:

$$\rho_g = \frac{pM}{Z{\rm R}T} \tag{6}$$

Equations from (2) to (6) constitute the governing equations of gas-liquid two-phase flow in the wellbore [4], and the wellbore pressure can be calculated based on these equations by finite difference method.

Identification of reservoir types

The reservoir type can be distinguished by the gas production curve along the well depth. While drilling porous medium reservoir, because of its well homogeneity, the gas production should be gradually increased with the well depth, as shown in fig. 3(a). While drilling fractured-porous medium reservoir, due to the sudden increase of the reservoir permeability, the gas production steps up, as shown in fig. 3(b).

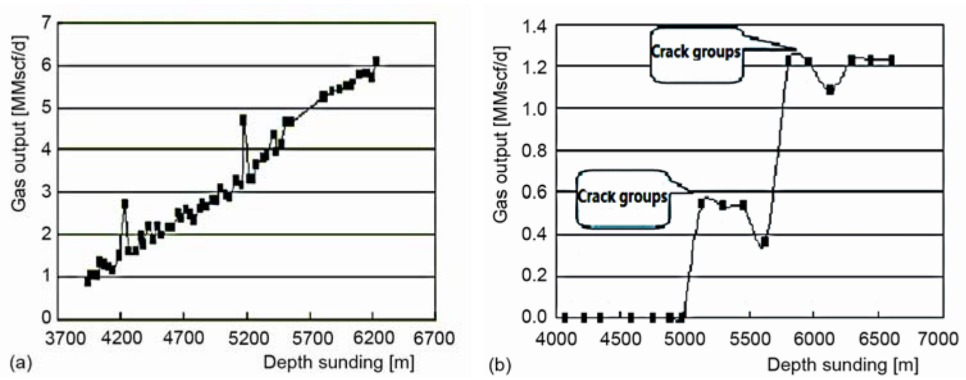

Figure 3. The gas production curve of different medium type reservoir along the well depth (a and b indicate the porous and fractured-porous reservoir, respectively)

Conclusions

- The developed surface monitoring equipment can monitor several parameters such as the injection and return parameters of fluid, the standpipe pressure and the casing pressure during underbalanced horizontal drilling, and by interpreting these parameters with the seepage equation and the wellbore flow governing equations, the gas reservoir permeability and the wellbore pressure can be calculated timely. Besides, the media type of gas reservoir can be identified by the gas production curve.
- Compared with previous testing techniques while underbalanced horizontal drilling, the technique integrates the reservoir parameters identification, the wellbore pressure and flow condition monitoring comprehensively and organically. The service cost is far less than similar testing technique services, and the technique has a good application prospect.

Nomenclature

D – equivalent diameter of the wellbore annulus, [m]
Ei – exponential integral function
f – friction coefficient
h – reservoir thickness, [m]
K – gas reservoir permeability, [m^2]
M – molar mass of gas, [$gmol^{-1}$]
m – pseudo-pressure, [Pas^{-1}]
p – pressure, [Pa]
q – gas production, [m^3s^{-1}]
r – distance to the wellbore, [m]
R – gas constant, [$Jmol^{-1}K^{-1}$]
T – temperature, [K]
t – time, [s]
v – velocity, [ms^{-1}]
Z – gas compressibility factor

Greek symbols

α – volume fraction
η – pressure transmitting coefficient, [m^2s^{-1}]
θ – hole deviation angle, [°]
ρ – density, [gm^{-3}]

Subscripts

g – gas
i – original reservoir
j – natural number, from 1 to n
l – liquid
sc – standard condition

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