The Future of Energy Is Geothermal

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# Abstract

The static formation temperature (SFT) is required to determine the thermophysical properties and production parameters in geothermal and oil reservoirs. However, the SFT is not easy to be obtained by both experimental and physical methods. In this paper, a mathematical approach to predicting SFT based on a new model describing the relationship between bottom hole temperature (BHT) and shut-in time was proposed. The unknown coefficients of the model were derived from least squares fit by Particle Swarm Optimization (PSO) algorithm. Besides, the ability to predict SFT based on a small number of BHT data (such as first 3, 4, or 5 ones of a data set) was evaluated. The accuracy of the proposed method to predict SFT was testified with a deviation percentage less than$\pm 4\%$ and high values of regression coefficient $R^{2}$ ($>0.98)$. The proposed method could be used as a practical tool to predict SFT in both geothermal and oil wells.

# 1. Introduction

Drilling deep borehole is needed for the exploitation of geothermal energy (Saito et al., 1998). The borehole drilling is a complicated process in which a constant thermal anomaly (added to a circulating drilling mud) affects the static formation temperature (SFT) around the borehole (Fomin et al., 2013). Determining SFT at any depth needs a certain length of time, in which the bottom-hole temperature (BHT) and shut-in time measurements are conducted (Santoyo et al., 2000). Measuring BHT can be costly due to the usage of sophisticated log equipment and the necessity to stop the wellbore drilling (Wisian et al., 1998).

PSO has some advantages in solving optimization problems: (1) few parameters to be tuned by user; (2) high accuracy; (3) less affected by initial solutions comparing with other algorithms; (4) fast convergence; (5) easy codes due to the simple underlying concepts; (6) no requirement for preconditions such as continuity or differentiability of objective functions (Jordehi, 2015).

# 2. METHODOLOGY

In this section, a function correlating BHT and shut-in time was derived to fit the BHT data and estimate SFT. The coefficients of this function can be obtained from least squares fit method using Particle Swarm Optimization (PSO) algorithm. Besides, other methods were also introduced and used to compare with the new one. Statistical tests were applied to evaluate the validity of those predicting methods.

## 2.1 Method Development

### 2.1.1 Function derivation

Horner method for obtaining the static formation temperature has been widely used in oil and gas industry (Dowdle and Cobb, 1975). This analytical method is based on assumption that the thermal effect of drilling is a constant linear heat source. The approximation solution is given by:

$BHT\left(t\right)=T\_{HM}+(b\_{HM})∙log⁡\left\{{\left(t\_{C}+t\right)}/{t}\right\}$ (1)

Where *THM* is static formation temperature,$ log⁡\left\{{\left(t\_{C}+t\right)}/{t}\right\}$ is known as the Dimensionless Horner Time (DHT), *tc* and *t* are the circulation time before shut-in and the time elapsed since the circulation stops, respectively.

One can see that the problem that Equation (1) has is solved in Equation (2). When the maximum and minimum of BHT are both decided, the shape of the BHT-time curve only depends on the values of c. The curve of the BHT-time function is illustrated in Figure 1. The equation can characterize the BHT-time function in a big scope, as shown in Figure 1.

Figure 1: Relationship between BHT and shut-in time where a=100, b=-50, and c varies from 1E-9 to 1.

### 2.2.2 Solutions to the three parameters in the new function

## 2.3 Data sources

Eight thermal recovery data sets were collected from the published literature for the accuracy and application tests:

1. Four synthetic data sets were selected from literature;
2. Four data sets logged in some boreholes from long logging work including geothermal and petroleum field data.

Those data sets were summarized in the Table 2.

It should be pointed out that Data 1 to Data 6 all have reported SFT values, which can be very useful to evaluate the proposed method and conduct the comparisons between different methods.

Table 2: Summary of the BHT data sets used in this paper.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Data | Type | n | tc (hr) | Sources | Data name in this paper |
| SHBE | Synthetic data | 8 | 5 | Shen and Beck (1986) | Data 1 |
| CLAH | Synthetic data | 15 | 5 | Cao et al. (1988) | Data 2 |
| CJON | Synthetic data | 12 | 0.2 | Cooper and Jones (1959) | Data 3 |
| KJ-21 | Geothermal field data | 6 | 2.5 | Steingrimsson and Gudmundsson (1989) | Data 4 |
| SG | Geothermal field data | 12 | 3 | Schoeppel and Gilarranz (1966) | Data 5 |
| MOU | Synthetic data | 3 | 10 | Mou (2013) | Data 6 |
| DA-XIN | Geothermal field data | 40 | 5 | Da-Xin (1986) | Data 7 |
| UASM | Petroleum field data | 14 | 10 | Kutasov (1999) | Data 8 |

# 3. Conclusions

(1) A modified method was proposed to estimate SFT from the BHT data and shut-in time.

(2) The estimation accuracy and fitting ability of the proposed method was verified using 8 BHT data sets, including synthetic data, geothermal, and petroleum field data.

(3) Comparison among different methods was also conducted. The proposed method can estimate SFT accurately and stably, even from a small number of BHT data.

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