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Analysis of reliability distributed temperature sensor measurements

H.Kh. Malikov[1*], A.A. Suleymanov[1], N.F. Mammadli[1]

[1]Scientific Research Institute "Geotechnological Problems of Oil, Gas and Chemistry", Ministry of Science and Education of Azerbaijan, Dilara Aliyeva Street 227, AZ1010 Baku, Azerbaijan

Abstract

The article analyzes some of the features of the practical application of the Distributed Temperature Sensor (DTS) technology.
Discrepancy in measured depth of borehole and length of DTS fiber is due the difference in tension of fiber at deviated parts of the hole. That needs to be taken into consideration for reliability of temperature measurements. It is recommended to calibrate the fiber length with Gamma Ray log data before analysis of the data.
The small changes in temperature are important for diagnostic purpose.
Oscillations in DTS raw data create an additional noise in temperature measurements and make them less reliable. Numerical analysis of the distribution of DTS data by using Entropy and Gini Coefficient allows to understand the nature of the oscillations.
It is recommended to calibrate the DTS data with the response of permanent bottom hole temperature gauge. The data can be also filtered by applying the averaging method.

Key words: well, monitoring, temperature profile, DTS, reliability, noise, distribution.
*Corresponding author Tel. 0506447759
Email address: h.malikov@gpogc.az **(**H. Malikov)

1. Introduction

The thermometry is one of the methods of well logging, which allows us to solve a number of important tasks of diagnosing the state of the reservoir and the well (Brown et al., 2009; Tabatabaei et al., 2011):

- Defining of production features of reservoir;
- Control and monitoring of technical condition of the well;
- Control over the work of oil lifting equipment.

A significant drawback in the use of conventional temperature logging system for the analysis of formation-borehole is that, its conduct makes an interference with the normal operation of the well, with certain technical and technological difficulties, material and financial costs and etc. In addition, when the device is used for well logging, only one temperature curve can be obtained from one operation.

In recent years, the cost of downhole logging has increased significantly due to the increase in the number of horizontal wells, for lowering logging tools in which you need to use CT and traction systems to wireline. In certain cases, for example in certain subsea wells, use of downhole devices for

logging of wells is generally impossible. Therefore, it becomes necessary for the introduction of alternative technologies, provided financial and technical feasibility.
System DTS (distributed temperature measurements) allows to remove many of the disadvantages of traditional methods of thermometry and can produce a considerable amount of thermograms during the operating cycle of the well. Such an approach allows detection of changes in the well more quickly than in the downhole logging, and, unlike the production logging, DTS does not require intervention in normal operation of the well.
At the same time the presence of a large amount of measurement data, DTS stimulate research for monitoring wells of [1-6] evaluating the effectiveness of new technologies [7-14], and others.
It should be noted that the solution of many practical problems requires non-standard approach, as the change in temperature is influenced by such factors as the heterogeneity of filtration characteristics of the formation in the wellbore, thermodynamic and thermal properties of rocks, oil, gas, and water, gas factor, saturation pressure, bottom hole pressure, reservoir temperature and pressure, and others [6,14].
The article analyzes some of the features of the practical application of the DTS technology.

2. Methodological part

2.1. Distributed Temperature Sensor Data Analysis. Error in matching of measured depth of wells and DTS. After installing the DTS, the difference between the measured depth DTS and the borehole (the difference between the length of optic fiber and the length of the borehole) should be determined.
It is necessary to determine the temperature at a certain point of the borehole, as DTS initial measurements indicate the temperature along the length of the optic fiber.
But in the case of directional and horizontal wells this difference is ambiguous for different intervals of the wellbore due to unequal tension on optic fiber along the wellbore. In deviated and horizontal wellbore sections difference is greater than the vertical sections, this should be considered when analyzing the changes in the wellbore temperature. To correct this technical error DTS data must be compared with the results of logging.
As an example, DTS data in Well 1 is considered.
Thus, according to logging, basis (bottom) of the formation A corresponds to the MD 4556 m. Based on analysis of the dynamics of the temperature while well is shut-in, we can assume that this value corresponds to the MD DTS 4559m (Figure 1). This follows from the fact that in the depths of 4556-4558m MD DTS - observed temperature drop while well is shut-in, which is the characteristic for the inflow of low gas-oil ratio (probably lower intervals of the overlying layer A), and at a depth of 4560m and below - the temperature increase is characteristic of the large gas factors (probably the upper ranges of the underlying formation B). At the same time, at a depth of 4559m character temperature dynamics in the well shut-in is virtually unchanged.

3. Result and discussion

3.1. Noise in DTS output. DTS technology uses sophisticated electronic equipment that causes noise, which are reflected in the values of the output signal, and thus at the represented values of the temperature.

This phenomenon is observed in the analysis of DTS measurements at a particular point in the Well 2 at its flowing and shut-in periods (Figures 2 and 3).
As can be seen from the data, even while the well is shut-in temperature which is defined by DTS technology is oscillating.
This feature of DTS technology is most clearly evident when result of DTS measurements is compared with the measurements of Permanent Bottom Hole Temperature Gauge (PBHTG) at a depth of installation of temperature sensor (Figure 4).

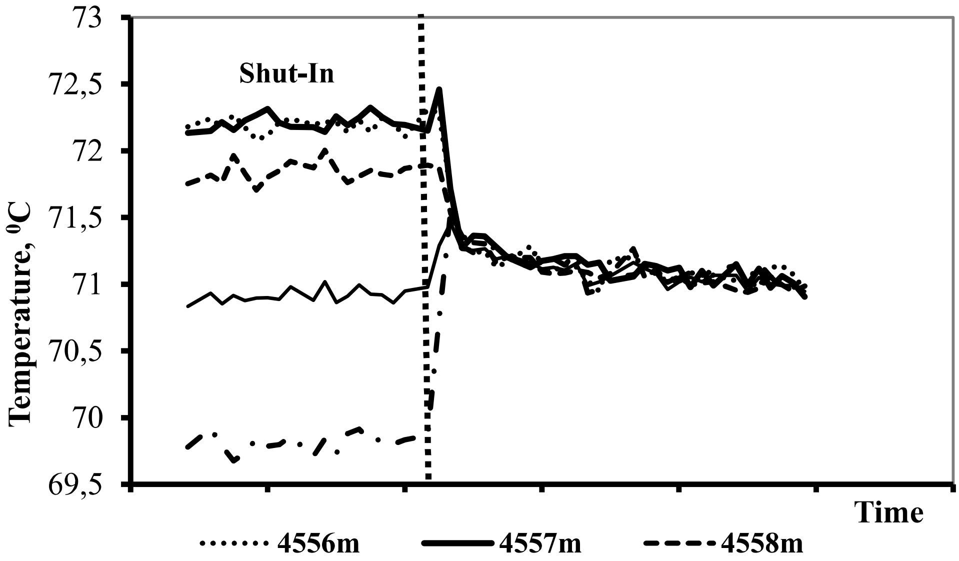

Figure 1. Temperature change curves for different depths. Well 1.

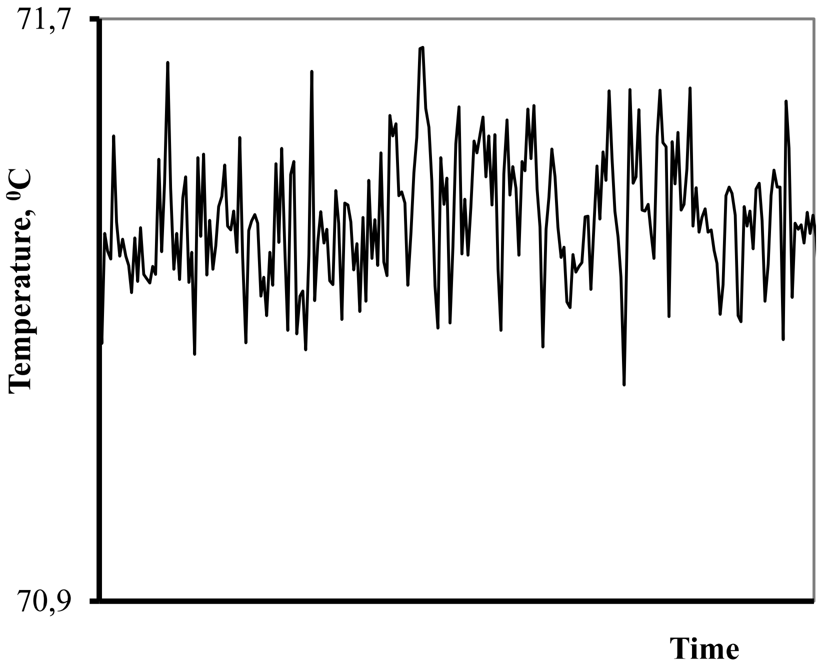

Figure 2. Measurements of DTS (flowing period). Well 2.

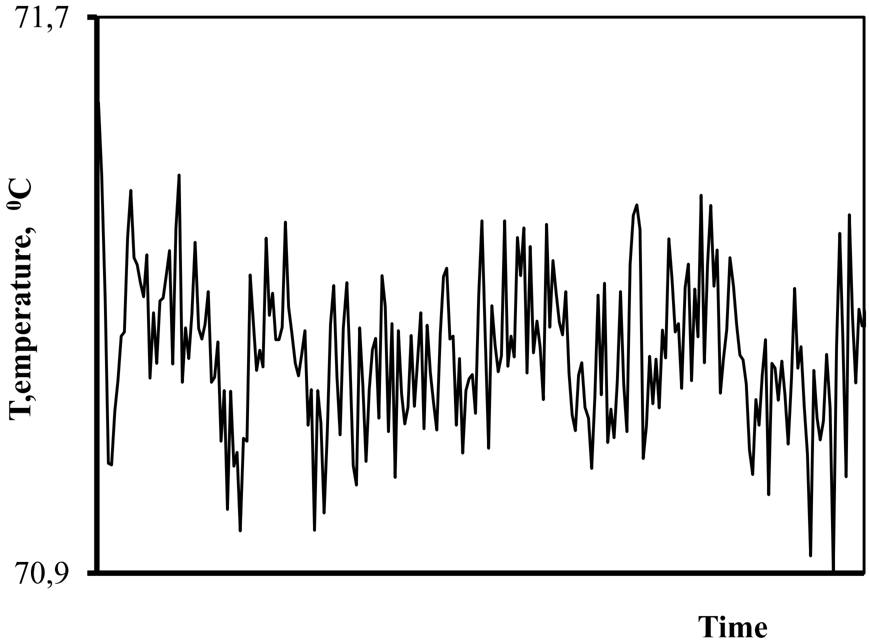

Figure 3. Measurements of DTS (shut-in period). Well 2.

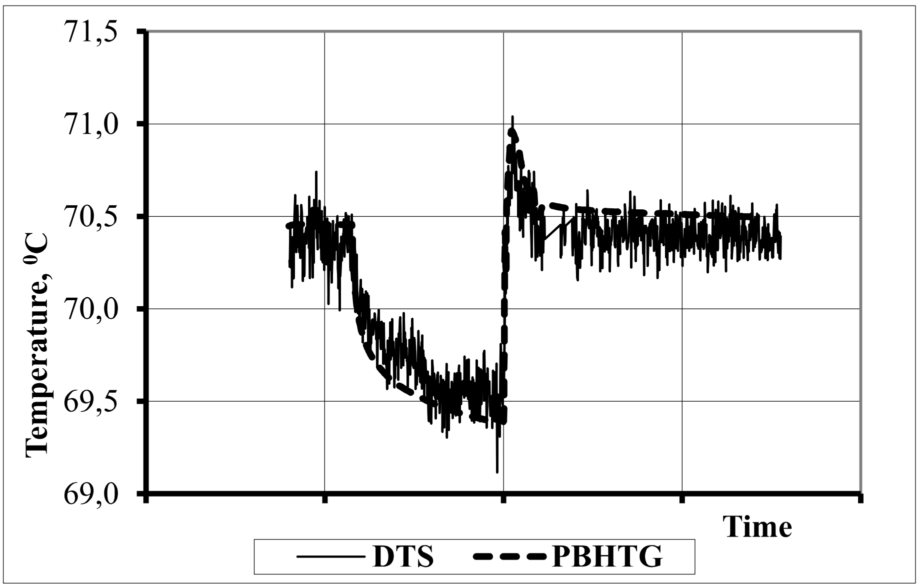

Figure 4. Comparison of DTS and Permanent Bottom Hole Temperature Gauge measurements. Well 2.

As shown by comparative analysis of DTS measurements while shut-in the Well 2, at different depths there is almost the same distribution pattern of oscillations (Figure 5), which is close to the normal distribution law [9].

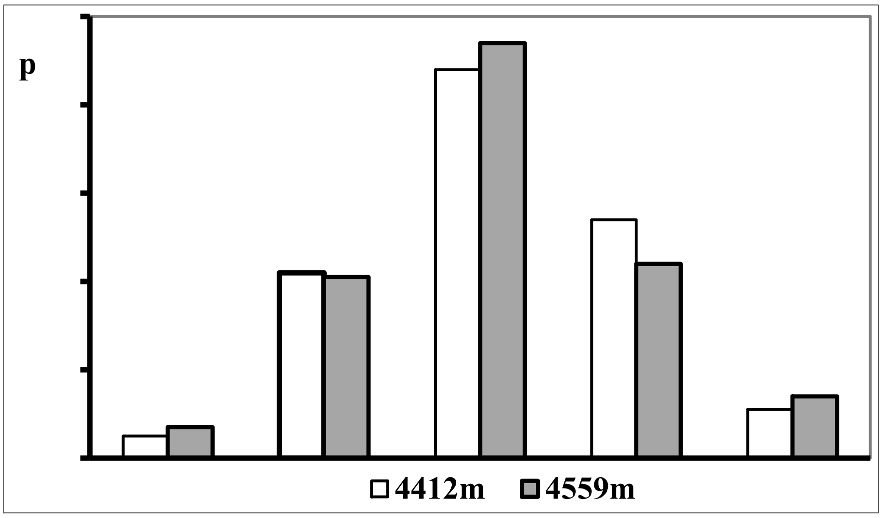

Figure 5. DTS measurements distribution in the Well 2.

For the numerical analysis of the nature of distribution of oscillations entropy and the Gini coefficient are used [10], [11].
The value of informational entropy is defined by Shannon equation [10]

$$S = -\sum_{i=1}^{k} p_i \log_2(p_i) \quad (1)$$

where, p – probability; k - the number of classes (bins).
For the analyzed data, the values of entropy are quite similar (1.87 and 1.89, respectively).
The Gini coefficient (Gini) evaluates (represents) the degree of non-uniformity of distribution of the data [11].

The algorithm for calculation of the Gini coefficient includes the construction of the Lorenz curve. For this purpose, the dependence of the cumulative values is constructed versus the number of values in percentages (Figure 6).

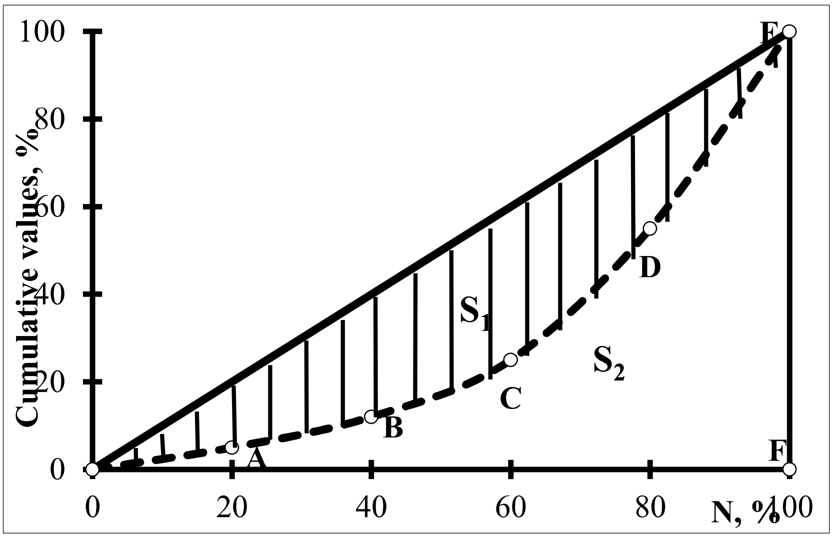

Figure 6. Determination of the Gini coefficient.

If the distribution of existed data represents absolute equality (all values are the same), then 20% of the numbers should correspond to 20% of the cumulative values, 40% - 40% and so on (the segment OE). In reality, the actual production distribution (curve OABCDE - Lorenz curve) deviates from the OE line, the more deviation means the greater the inequality in the distribution of data.
To determine the Gini coefficient (G), area between the OE segment and Lorenz curve OABCDE (S_1) should be divided by area of triangle OFE (S_2):

$$G = \frac{S_1}{S_2} \quad (2)$$

Obviously, the greater the deviation of the Lorenz curve (OABCDE) from the line OE, the area S1 will be greater, and therefore the Gini coefficient will be greater, closer to 1.
Figure 7 shows the Lorenz curves for the distribution of DTS fluctuations in Well 2 at the depths of 4412m and 4559m (Gini coefficient of 0.193 and 0.187 respectively).

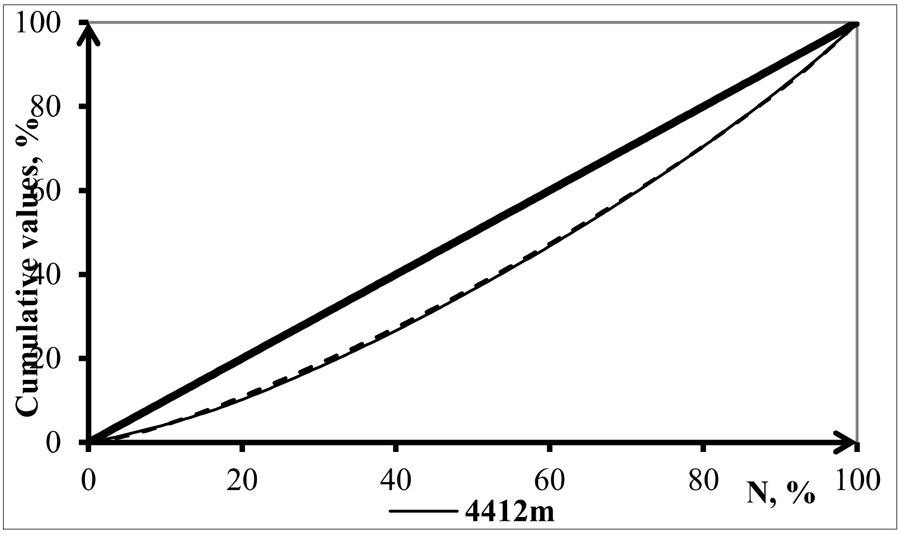

Figure 7. The Lorenz curves. Well 2.

Thus, the analysis of the values of entropy and the Gini coefficient showed identical distribution of oscillations of DTS measurements at different depths while well is shut-in. The results confirm the assumption that these fluctuations do not reflect the oil production processes and indicate the nature of these noise oscillations associated with temperature measurement features in DTS technology.
This allows us to apply a data filtering method such as the averaging to reduce the noise impact on the temperatures [9]. Application of this method requires the determination of the minimum interval between measurements and the minimum number of measurements to obtain a reliable average.
To do this, a comparative analysis of the measurements of Permanent Bottom Hole Temperature Gauge with DTS data at depth of installation of downhole temperature sensor can be made.

4. Conclusions

Discrepancy in measured depth of borehole and length of DTS fiber is due the difference in tension of fiber at deviated parts of the hole. That needs to be taken into consideration for reliability of

temperature measurements. It is recommended to calibrate the fiber length with Gamma Ray log data before analysis of the data.
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Conflict of interest
The authors declare that they have no conflict of interest in relation to this research.

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Analysis of methods for removing petroleum paraffins