Environmental impact correction for resistivity logging in CBM horizontal well

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Abstract: The resistivity logging in CBM horizontal well is under the influence of factors such as borehole, mud invasion and anisotropy. The environmental impact correction can improve the interpretation accuracy of CBM the horizontal well. This paper introduced in detail the correction methods of borehole, mud invasion and anisotropy, and the environmental impact of the resistivity logging in CBM horizontal well are automatically corrected using computer correction program. The results show that the method is easy to operate and feasible, and is highly operable. The corrected resistivity in horizontal well can approximately represent the real resistivity of the coal reservoir, which is able to improve the evaluation accuracy of the coal reservoir resistivity logging.

1. Introduction
With the advancement of CBM exploration and development in China, the number of CBM wells has increased significantly[1]. Compared to conventional oil and gas logging, the coal seam is shallower buried, with low mechanical strength, brittle and fragile, and developed fracture. Thus, it is easy to collapse in the process of drilling, especially the influence of expanding diameter. The micropores and fractures of coal reservoirs are relatively developed, and the influence mechanism of the characteristics and combination of micropores and fractures on mud invasion is quite different from that of conventional oil and gas reservoirs[2-3]. Due to the different sedimentary environment and diagenetic evolution of coal reservoir and conventional oil and gas reservoir (sandstone, carbonate rock, etc.), the arrangement direction of microparticles in the formation is different in the process of sedimentation and diagenesis, especially the particularity of coal metamorphism degree and coal rock composition, so its anisotropy is also different. Therefore, it is urgent to carry out the correction of the influence of environment on resistivity logging[4].

2. Correction method of environmental impact for resistivity logging in CBM horizontal well

2.1. Borehole correction method
In the presence of a well, the current from the main electrode is affected by the well diversion and flowing through the well, which makes the measured resistivity value lower[5]. Figure 1 is a
correction chart for resistivity borehole influence. In Figure 1, the ratio of apparent resistivity ($R_{LLD}$ is the deep laterolog resistivity, and $R_{LLS}$ is the shallow laterolog resistivity) to mud resistivity ($R_m$) is used as abscissa ($R_{LLD}/R_m$ or $R_{LLS}/R_m$); correction factor ($R_{LLD}/R_{LLD}^c$ or $R_{LLS}/R_{LLS}^c$) is used as ordinate; well diameter ($d$) is used as chart module. Using the chart, the resistivity of original formation can be obtained by multiplying the apparent resistivity of the formation with infinite thickness and no invasion by the correction coefficient.

Figure 1. Correction chart of borehole effect for resistivity logging

2.2. Mud invasion correction method
Resistivity logging is widely used in the determination of undisturbed formation resistivity because of its strong transverse detection depth and vertical formation resolution. Because the mud column pressure is greater than the formation pressure, it is inevitable for formation to have mud filtrate invasion, resulting in the formation resistivity logging response characteristics under different invasion conditions[6-7]. Therefore, it is necessary to carry out the corresponding resistivity of mud filtrate intrusion correction. As shown in Figure 2, the ratio of deep and shallow laterolog resistivity ($R_{LLD}/R_{LLS}$) is used as abscissa; $R_{LLD}/R_{XO}$ is used as ordinate; the vertical dotted line number is the diameter of the invasion zone ($d_i$), m; the vertical solid line number is the ratio of original formation true resistivity and flush zone resistivity ($R_t/R_{LLD}$); the horizontal dotted line number is the ratio of original formation true resistivity and resistivity of formation flushing zone ($R_t/R_{XO}$). Before using this chart, it is necessary to conduct borehole correction for the apparent resistivity. According to the position of the corrected resistivity in the chart, the borehole correction resistivity can be obtained, as well as the invasion zone diameter and other parameters.
2.3. Correction method of formation anisotropy

In highly deviated wells and horizontal wells, the measured values of most instruments are affected by the well inclination or formation inclination, and the measured curves appear "abnormal" and "deformation"[8]. In a vertical well, if the formation is horizontal, the instrument measures the horizontal resistivity. However, when the instrument is drilling a horizontal well in the same formation, the measurement current will flow through the horizontal plane and vertical plane of the formation. Lead to the apparent resistivity measurement $R_a$ is a combination of horizontal resistivity $R_h$ and vertical resistivity $R_v$. Assuming that the formation has anisotropy in the horizontal well, the resistivity in the direction of the vertical layer interface is $R_v$; the resistivity in the direction of the parallel layer interface is $R_h$; and the radial direction (the direction parallel to the formation) is macroscopically isotropic can be deduced formation apparent resistivity $R_a$.

\[
R_a = R_h/\sqrt{\cos^2\theta + \sin^2\theta/\lambda}
\]

Where, $\lambda$ is the anisotropy coefficient of formation resistivity, $K = (R_v / R_h)^{0.5}$; and $H$ is relative inclination, that is, the relative angle between hole axis and ground level normal line can be obtained from deviation angle and formation dip. It can be seen that the formation apparent resistivity is mainly related to the coefficient of formation electrical anisotropy and relative inclination, and the number is between $R_h~(R_v / R_h)^{0.5}$.

3. Application case analysis

The above correction chart and model are programmed and linked to the logging interpretation platform to realize the inversion correction of the environmental impact of CBM horizontal wells in the work area. Figure 3 shows the inversion and correction results of environmental impact of resistivity logging in well X1 in the target area. It can be seen from the figure that the effects of expanding diameter, anisotropy and invasion are very large. Compared with the measured resistivity, the correction result of the effect of expanding diameter is higher. In addition, compared with the measured deep and shallow resistivity curves, there is no obvious separation between the curves, indicating that the impact of ground invasion is small. Formation anisotropy has great influence, which makes the measured resistivity logging value increase. On the whole, because the influence of anisotropy is greater than that of expanding and invasion, the resistivity after correction of expanding,
anisotropy and invasion influences is reduced. It is proved that the corrected resistivity of horizontal wells approximately represents the real resistivity of coal reservoirs.

![Figure 3. Environmental impact correction results of resistivity logging in well X1](image)

4. Conclusions
(1) The resistivity logging in CBM horizontal well is less affected by borehole enlargement and mud invasion, and most affected by formation anisotropy.

   (2) Practice shows that the corrected resistivity in CBM horizontal well can approximately represent the real resistivity and can truly reflect the lithologic characteristics of the coal reservoir, which improving the evaluation accuracy and reliability of the coal reservoir resistivity logging.

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