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Application of Information Technologies during Control of Exploitation of Underground Gas Storages

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SUMMARY

One of the important problems during the exploitation of underground gas storages (UGS) is the determination of behind the gas escape. This problem can be solved by geophysical methods. Diversity of factors, which influence on temperature distribution in the well, complicates the problem solving at control of UGS, thus it is necessary to use the information technologies (IT). Use IT allows to provide the reliable interpretation of data of well thermometry, in particular, building and analysis of model thermograms received on the base of developed mathematical models with taking into consideration the complex influence of factors relating to certain well conditions of UGS, which adequately describe heat processes that happen in the wellbore and surrounding rocks.

Examples of usage of information technologies during solving of problems of control of UGS exploitation are given. Mathematical modeling of heat processes in the wells of underground gas storages allows determination of the peculiarities of temperature distributions under unsteady conditions and allows provision of reliability of interpretation at determination of industrial damages, determination of working intervals, behind the casing flows etc.

Introduction

One of the important problems during the exploitation of underground gas storages (UGS) is the determination of behind the gas escape. This problem can be solved by geophysical methods. Thermometry is one of the most informative methods along with numerous methods. Diversity of factors, which influence on temperature distribution in the well, complicates the problem solving at control of UGS, thus it is necessary to use the information technologies (IT). Use IT allows to provide the reliable interpretation of data of well thermometry, in particular, building and analysis of model thermograms received on the base of developed mathematical models with taking into consideration the complex influence of factors relating to certain well conditions of UGS, which adequately describe heat processes that happen in the wellbore and surrounding rocks. It is necessary to use the modern package of software for areal analysis of temperature conditions and analysis of series of log curves on concrete the well.

Mathematical model

Mathematical statement of the problem of convective-conductive heat transfer in the system UGS production well – surrounding rocks during the process of effect (injection or production of gas), and also after stop of effect takes into consideration radial and vertical heat transfer, convective transfer in the well and reservoir, intervals of behind the casing fluid flow and reservoir flow of underground water, lithology, well construction. An equation of heat transfer in general view has the following view:

$$\rho c\frac{\partial T}{\partial t}+\frac{1}{r}\frac{\partial}{\partial r}\left(rm\rho_{\text{фл}}c_{\text{фл}}\upsilon_r T\right)+\frac{\partial}{\partial z}\left(m\rho_{\text{фл}}c_{\text{фл}}\upsilon_z T\right)=\frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right)+q^*(r,z,t)$$

Here: ρ, c are density and heat capacity of the rock with saturating fluids; ρ_i, c_i are densities and heat capacities of the correspondent fluid; *m* is porosity; λ is medium heat conduction; υ_z is velocity of fluid flow; *T* is temperature; q^* are heat sources; *r, z* are coordinates.

On the boundaries of the mediums it is satisfied the conditions of equality of temperature $T_i\,|_{r=R_i-0}=T_{i+1}|_{r=Ri+0}$ and heat sources $\lambda_i\left.\frac{\partial T_i}{\partial r}\right|_{r=R_i-0}=\lambda_{i+1}\left.\frac{\partial T_{i+1}}{\partial r}\right|_{r=R_i+0}$.

Initial temperature distribution in the system "well-reservoir" is geothermal one. It is set the flow rates of production and gas flow rate, flow rates of behind the casing flows and reservoir flow of underground waters.

It is set the following condition on the external boundaries:

$$\left.\frac{\partial T}{\partial r}\right|_{r=0}=\left.\frac{\partial T}{\partial r}\right|_{r=R_{mesh}}=0,\left.\frac{\partial T}{\partial z}\right|_{z=Z_{top}}=\left.\frac{\partial T}{\partial z}\right|_{z=Z_{bot}}=\Gamma,$$

where $0\le r\le R_{mesh}; Z_{roof}\le z\le Z_{bottom}$.

The problem was solved by finite-difference method.

Examples of problem solution

Some results of calculation of influence of different factors on the formation of thermal field in the UGS well and results on interpretation of field log data are given below on the figures.

It is given the typical lithologic section, geothermal temperature distribution (curve 1) and series of curves of temperature build-up for UGS on fig.1. Oversalt rock mass of UGS is presented by sequence of shale, sandstones, siltstones, shaly sandstones and gravel. The bottom part is presented by deposit of carbonates rocks. Productive rock mass of UGS is presented by carbonate rocks. Geotherm of the wells reflects the lithology of the section.

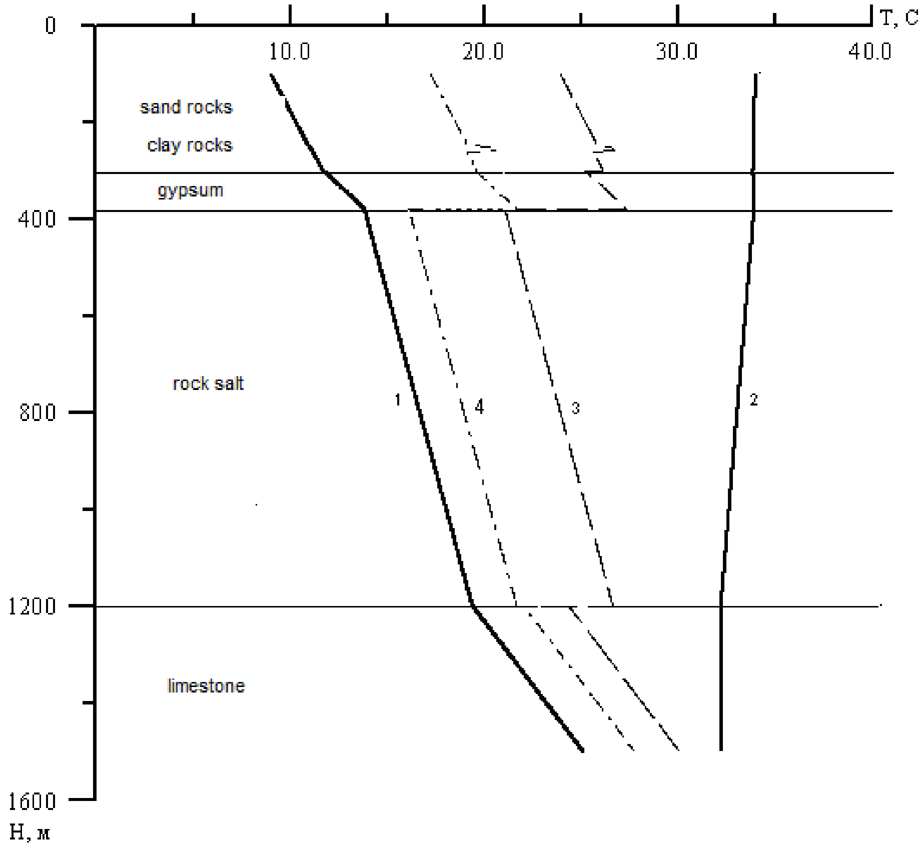


Figure 1. Curves of temperature build-up along the wellbore after stop of fluid injection (injection – 100 days): 1 is geotherm, 2 is injection temperature, 3 - after 1 hour, 4 - after 5 hours. Initial temperature drop is 25 C. It is cement stone behind the conductor.

Lithology influence

Character of temperature distribution after stop of thermal disturbance, caused by gas injection, is given on fig.1. Here, it is shown the temperature in the moment of stop of thermal disturbance (curve 2) and curves of temperature build-up along the wellbore for the times of 1 and 5 hours after stop of disturbance (curves 3,4). Time of thermal disturbance is equaled to 100 days.

It is used the lithologic differences in the calculations: 980-1000 m (rock salt); 1000- 1009 m (dolomite); 1009- 1017 m (shale rocks); 1017- 1036 m (anhydrite); 1036- 1040 m (shale rocks). It is seen from fig.1 that the correlation of temperature anomalies connected with lithology is observed. Influence of thermophysical properties connected with difference of lithology along the depth in the process of temperature build-up along the wellbore leads to non-monotonous change of temperature along the depth, which is especially typical for rocks with clay bands. This circumstance is necessary to take into consideration during the interpretation of thermometry data in the UGS wells.

Estimation of thermal effect of neighbor production well of UGS

Continuous injection and production of gas from UGS wells leads to disturbance of temperature condition around this well and neighbor wells. Although the periodic injection and production of gas from the UGS wells (half of the year – production with temperature increasing and half of the year – injection with temperature decreasing in the wellbore) leads to decreasing of amplitude of temperature oscillations, though it is observed the thermal disturbances caused by gas injection in the neighbor wells. The next example in well illustrates this principle (fig.2A).

On the curve of thermometry in the interval of 450-770 m it was observed the positive temperature anomaly (up to 1.3^{0}C) according to log data. Maximum of thermal anomaly is on the depth of 650 m. According to log data it is marked that form and interval of thermal anomaly didn't change, but during the whole period of research it is gradually changed the amplitude of thermal anomaly from 1.3 to 2.7 ^{0}C.

In order to explain the reason of this anomaly we can propose the presence of behind the casing flow of fluid from the formation, which is situated below the false bottom. But due to the fluid throttling in behind the casing space and creation of anomaly of 1.3 ^{0}C it is necessary the depression of 6.5 MPa.

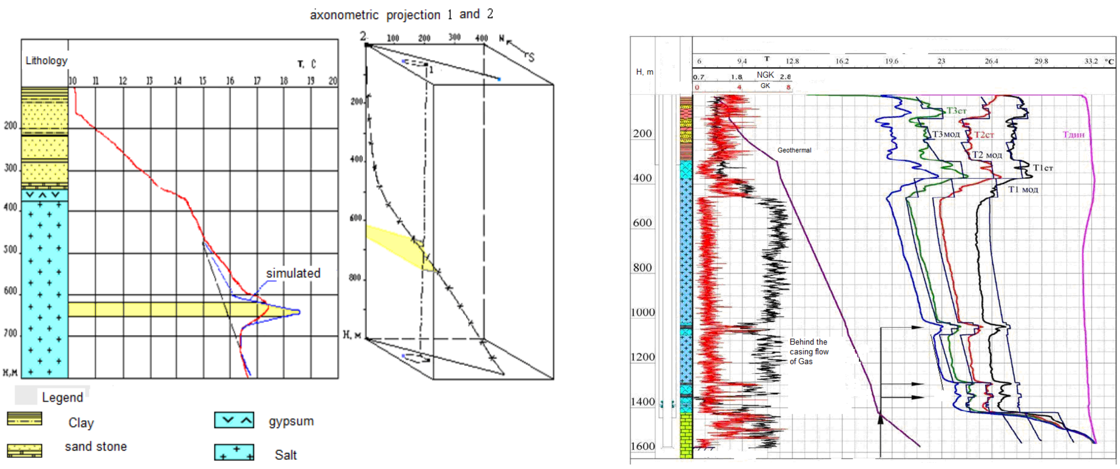
In 1998 the value of thermal anomaly is equaled to 2.7 ^{0}C, and correspondingly, the value of depression should be equaled to 13.5 MPa, but it doesn't correspond to hydrologic conditions of UGS. Analysis of trajectory of well 2 shows that in the interval of 620-660 m the wellbores of well 2 and 1 are situated on the distance of 10-12 m from each other. The well 1 is in the exploitation for 20 years. During these years the wellbore generated the thermal disturbance on surrounding rocks, which could be registered by well 2. In order to examine it the mathematical modeling of thermal influence of production well 1 on well 2 was made. In sulphate-halogen deposits the thermal disturbance with amplitude of 0.1 ^{0}C distributed on 77 m during 20 years.

Thus, the results of mathematical modeling showed that during 20 years of exploitation of well 1 the thermal disturbance reached the bore of well 2, and as the result it was generated the observed temperature anomaly. I.e. the thermal anomaly is caused by thermal influence of well 1 and not by behind the casing flow.

Influence of behind the casing flows of the gas on temperature build-up

The development of heat-mass transfer of gas flow on the way of its movement behind the casing is the physical base of determination of behind the casing flows of gas. The heat transfer with the surroundings influences greatly on the process of generation of temperature distribution, which limits the value of gas flow rate, at which it is observed the temperature anomalies. According to estimations of different researches this values oscillate in the range from 600 up to 6000 m^3/day of gas [4].

The results of thermometry of UGS well and its comparison with calculation data of thermograms along the wellbore are given on fig.3.



A)　　　　　　Б)

Figure 2.
A) Results of mathematical modeling of heat influence of well 1 on well 2
B) Comparison of calculated thermograms with field data of well 3.

Field-geophysical researches were started from the regime of continuous gas injection – curve Tdyn (Fig.2B) and continued after stop through 1, 5, 16 and 107 hours (curves T1st, T2st, T3st and T4st). Calculation curves T_{1mod}, T_{2mod}, T_{3mod} are given correspondingly for 1, 5 and 16 hours from the moment of well stop. It is seen from the figure that in the interval of 1130-1400 m against the background of conditional geotherm it is observed the increased values of temperature on the curves T1st – T4st in comparison to similar ones in the interval of 400-1130 m. The indicated intervals are presented by salt stone excluding two interlayers of 1147-1200 and 1303-1321 m, where the rock are presented by sequence of shale-carbonates and limestones, dolomites. Character of temperature build-up in the well for salt stone should by equal on any depth. Slowing-down of this process in the interval of 1200-1400 m, according to author's opinion, is connected with presence of behind the casing flow of the gas in upper direction from the storage to reservoirs, which are situated on the depths of 1147-1200 and 1303-1321 m.

Conclusions

Mathematical modeling of thermal processes in the wells of underground gas storages allows finding out the peculiarities of temperature distribution under unsteady conditions. Creation of album of curves of temperature build-up for different conditions of exploitation wells of UGS allows increasing the level of interpretation, which is directed on determination of anthropogenic disturbances; determination of working intervals, behind the casing flows etc. Thermometry is one of the effective methods of monitoring of underground gas storages exploitation.

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