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History of Research on the Thermal Regime of Oil and Gas Fields

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Abstract- The scientific interest in the evaluation of the thermal regime of various areas has come to the fore with a more complete understanding that all major processes inside the Earth are related to thermal events and that all physical properties of rocks, the basis for observed geophysical phenomena, are dependent. to a greater or lesser extent the temperature. This article analyzes the history of research on the thermal regime in romania and also presents the thermal regime of surface geological layers.

Keywords – thermal regime, geological layers, history research

I. INTRODUCTION

The scientific interest in the evaluation of the thermal regime of various areas has come to the fore with a more complete understanding that all major processes inside the Earth are related to thermal events and that all physical properties of rocks, the basis for observed geophysical phenomena, are dependent. to a greater or lesser extent the temperature.

The characterization of the thermal regime of the geological layers is followed by the analysis of the basic elements, namely:

- Geological layer temperature and geothermal gradient,
- Thermal conductivity and geothermal flux.

The quantitative study of geothermal phenomena began with temperature measurements performed in mining or car tunnels, ore wells and drilling.

Through these measurements, it was highlighted in addition to the increase in temperature with depth and the fact that this increase differs from one area to another.

Thus, the notions of geothermal stage and its inverse, the geothermal gradient were defined, notions that proved to be very useful in geothermal research carried out on a regional scale. For geothermal research on the scale of the globe, a complex size is used, namely that of geothermal flow.

The geothermal flow is represented by the product between the geothermal gradient and the thermal conductivity of the rocks, which constitute the geological formations.

It follows that in order to determine the geothermal flux it is necessary to know the geothermal gradient, resulting from temperature measurements at different depth levels and the thermal conductivity obtained, in general, by measurements in the laboratory.

As the observation data accumulated, there was a need to synthesize them on different structures and for different purposes.

II. HISTORY OF THERMAL RESEARCH IN ROMANIA

The first attempts to synthesize the temperature data of the geological perimeters were made within two diploma projects elaborated by Negoiță V. (1954) [1] and Moldoveanu N. (1965) [2] at the Geophysics Department of the Faculty of Technical Geology.

A more comprehensive synthesis of the thermal regime on the territory of the country was made by Negoiță V. in 1970 [1], regarding the distribution of temperatures, geothermal gradients and estimation of thermal flux.

Based on the maps with geoisotherms built, the distribution of the regional temperature field can be studied according to the geological and structural characteristics and the importance of knowing the temperature distribution in identifying areas with hydrocarbon potential can be highlighted.

The main features of the geothermal regime of the Pannonian Depression are highlighted in two works by Cristian M. and Paraschiv D. [3], for the NE of Romania(1971) and SE of Romania(1973).

Preliminary data on the distribution of the geothermal gradient in Muntenia and Oltenia were published by engineer Aurelian Neguț in 1982 [4].

Based on the studies performed, it is estimated that the two sectors of the Pannonian Depression have very close geothermal characteristics, but clearly different from the other major structural units of Romania.

High precision electric thermometers (+/- 0.03^{o}C) were built and used to study the temperature distribution in depth and calculate the heat flux.

Average geothermal gradients were calculated based on temperature measurements [5].

Paraschiv D. and Cristian M. (1976) [6], find an important variation in the distribution of the geothermal gradient, even within the same major geological unit and the fact that geothermal anomalies have an oblique direction (in the Moesic Platform and the Carpathian outpost) or even perpendicular (in the Depression Pannonian), compared to the main structural lines.

The authors conclusion is that the regional distribution of temperatures in sedimentary deposits depends on two factors:

-position of the metamorphosed foundation (thickness of sedimentary formations)

-existence of deep tectonic accidents.

Numerous practical procedures have been developed to determine the thermal conductivity of rocks in laboratory conditions, based on working methods in a stabilized or transient regime, so that the fields of variation of thermal conductivity for different rocks are now known [7].

Knowledge of the distribution of the thermal field as a whole (temperatures, geothermal gradients, heat flux), appears necessary both for understanding and substantiating modern geodynamic models and for the practical-economic purpose of highlighting, evaluating and capitalizing useful minerals [8,9,10].

III.EARTH TEMPERATURE MEASURENMENT

For any geothermal investigation performed in probes, the parameter measured directly is the temperature which is determined using probe thermometers.

Temperature was the first physical parameter measured in wells in Romania.

Thus, in 1906, Prof. Dimitrie Bungețianur [1] made the first temperature measurements at great depths, in a 1000 m well dug at Filaret in a hydraulic system.

In the oil regions, temperature measurements were performed in 1911 by the geologist Ion Tănăsescu [1].

The data obtained from the Câmpina, Filipeștii de Pădure, Moinești and Lucăcești-Zemeș oil areas were used to calculate the geothermal stage.

Probe temperatures are usually measured with [4,5,11,12]:

-mercury thermometers - which give the temperature at a single point, usually at the bottom of the probe (maximum thermometers);

-thermometers with ohmic transducers- with metallic conductor (copper, platinum) or with semiconductor resistors (thermistors); these thermometers ensure the continuous recording of the temperature along the profile traversed by the probe.

In connection with temperature measurements performed in wells, two main issues need to be considered:

- disturbance of the thermal regime of the crossed geological formations,

and

-thermal regime of surface layers.

A. Disturbance of the thermal regime of the crossed geological formations

Digging a well and circulating the drilling fluid changes the thermal regime of the traversed formations, so that the temperature measurements, made in the wells, very rarely give the original temperatures of the formations.

The main role in this change belongs to the drilling fluid, whose temperature is different from that of the rocks, to which are added the variations produced in the heat released in the process of cutting the rocks by the screed.

The degree to which the thermal regime of the rocks changes depends, in a complex way, on:

a) the temperature difference between the drilling fluid and the crossed rocks;

b) the thermal properties of the rocks (conductivity, diffusivity) and the geological and hydrogeological particularities of the region;

c) the time elapsed from the opening of the formations to the performance of the measurements;

d) the drilling system and regime used.

The disturbance of the thermal regime of the rocks attenuates after stopping the drilling and the circulation of the fluids.

In order to measure the temperatures, which must be as close as possible to the original temperatures of the formations traversed, the stationary time required to restore the initial thermal state must be assessed.

This time is called thermal recovery time [13].

The analytical treatment of the temperature variation produced by the drilling process or other non-stationary probe processes, starting from the thermal conductivity equation, has been approached by many researchers, taking into account some initial conditions and the simplifying limit.

Among these conditions, we mention [4,5,6]:

a) the temperature disturbance produced by the drilling mud is caused by a constant heat source located along the axis of the well;

b) the intensity of the source is chosen so that the real temperature disturbance is reached at the end of the drilling;

c) the heat source is considered to be an infinitely long cylinder that is heated or cooled in an infinitely homogeneous environment in order to determine the thermal field of this cylinder;

d) the thermal properties of the drilling mud are the same as those of the surrounding rocks;

e) determination of the temperature field of an infinite rock massif with a cylindrical cavity of infinite length and given radius, on the wall of which the temperature is constant:

f) the drilling fluid moving downwards through the inside of the rods and upwards through the annular space acts as a counter-flow of heat exchanger, from which there is a conditional heat exchange to the surrounding rock.

And in these cases, the results are usually obtained in a complicated mathematical formulation, difficult to apply in practice on real cases.

Most authors conclude that, for a relative temperature measurement error of 10%, the probe rest time must exceed at least ten times the drilling time when the probe fluid is in circulation.

It is obvious that the shortest thermal recovery time will be at the foot of the probe because the time of fluid circulation at this depth in a probe is the shortest.

Therefore, the temperatures measured at the bottom of the well show the smallest deviation from the original rock temperature.

Although this deviation is a function of the depth of the well and therefore of the temperature, it is estimated that the recovery times at the base of a well for a deviation from the original rock temperature of 10% are of the order of one or two days.

It can be seen that the thermal recovery times at the bottom of the well are of the same order of magnitude as the time of extraction of the drilling rig and preparation of the well for geophysical operations which include temperature measurements.

Closely correlated with the accuracy of temperature measurements made with mercury thermometers (depending on the type of thermometers used) it can be seen that the temperature measurements at the bottom of the well made during the drilling process are close to the temperatures measured in stabilized mode within a deviation of about 10% and give a correct picture of the geothermal conditions in a certain research area.

This observation has both methodological implications suggesting that it is desirable to use any interruption of drilling interruptions to perform temperature measurements on the sole and economic implications, not requiring a very long probe retention time to achieve thermal equilibrium, especially in deep wells and in difficult technical conditions.

Obviously the temperature measurements performed in wells with stabilized regime provide the most correct values of the temperature of the formations crossed by the probe.

Due to the current interest in the formation temperature of hydrocarbons and the fact that virtually no deep wells can be kept at rest for long periods of time to achieve thermal equilibrium, various methods have been developed to correct temperatures measured at the bottom of the well due to their disturbing effects. of drilling mud.

The method proposed by Evans and Coleman [14], approximates the effect of circulating drilling mud with a constant heat line in an infinitely homogeneous environment.

The solution obtained for this case, at a depth given in a well, is:

$$t(\tau_2) = C \log(1+ \tau_{1/} \tau_2) +t(\infty) \qquad (1)$$

in which:

- τ_1 - the cooling time of the formation through the fluid circulation (h);
- τ_2 - the time elapsed from the moment the cooling stopped until the temperature measurement was performed (h);
- $t(\tau_2)$ - temperature measured at time τ_2 (ºC);
- $t(\infty)$ - the actual temperature of the formation (ºC);
- C – constant.

If several values $t(\tau_2)$, τ_1 and τ_2 are known, the equation (1.1) can be represented on a semilogarithmic graph $t(\tau_2) = f(1 + \tau_1/\tau_2)$ (figure 1).

From this graph we can obtain the real temperatures of the formation, which is given by the intersection of the line drawn through the observation points with the ordinate, so at a ratio $(1 + \tau_1/\tau_2)$ equal to unity, a value that corresponds to a very long rest time τ_2. Because temperature measurements are made at a given depth within about 10 meters above the wellbore, the total cooling time τ_1 is the sum of the time required to dig the last 10 m of the well and the time in which the drilling fluid is maintained in circulation (for homogenization) after drilling has stopped.

The method proposed by Dowdle and Cobb (1975) [15] for determining the static temperature of the formation is based on the analysis of the phenomenon of pressure recovery in a well after its closure, compared to restoring the temperature at the bottom of the well after stopping the flow.

The equation that describes the pressure correction at each point and at any time in the drainage area of a well is:

$$p_s=p_i-D \log((\tau+\Delta\tau)/\Delta\tau) \qquad (2)$$

where:

- p_s - pressure on the sole with the probe closed (atm.);
- p_i - initial pressure of the formation (atm.);
- D - constant;
- τ - well production time (h);
- $\Delta\tau$ - the time elapsed since the probe closed (h).

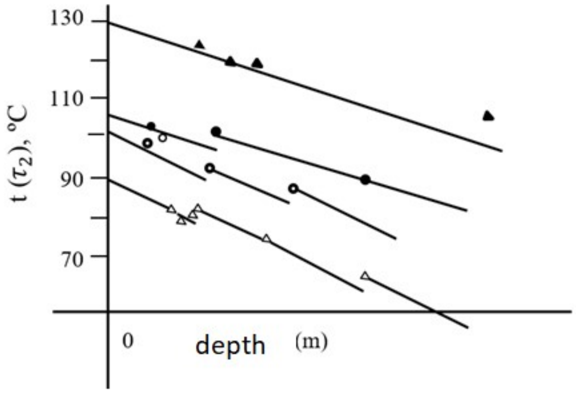

Figure 1. Determination of the actual formation temperature in Romanian four wells [5]

The graph $ps = f [\log ((\tau + \Delta\tau)/\Delta\tau)]$, known as the Horner graph, is the line whose extrapolation to the value of the time ratio equal to unity will give the initial pressure of the tank, p_i.

In solving equation (2) it is assumed that before closing the probe, the pressure gradient on the surface of the probe is constant and has values other than zero and after closing, the pressure gradient is zero.

B. Thermal regime of surface layers

In the thermal regime of the surface layers, the main role is played by solar radiation.

The influence of terrestrial heat flux on Earth's surface temperatures is very small, less than 0.02 ºC.

The amount of heat obtained from the Sun at each point on the surface depends on the geographical coordinates, the position of the Earth in orbit, the intensity of solar radiation and its degree of absorption into the atmosphere.

The distribution of solar heat on the Earth's surface also depends on the local relief, the degree of coverage, the relationship between land and water, atmospheric and marine currents and other factors [16].

Temperature conditions at a given point of observation are usually characterized by average daily, monthly, and annual temperatures.

In the surface layers there is a periodic variation of the daily and annual temperature related to the corresponding changes in the intensity of the flow of solar heat to the Earth's surface.

Taking into account the periodic oscillations of the surface temperature in close connection with the thermal diffusivity of the rocks, their amplitude decreases with depth according to an exponential law and the penetration is higher the longer the period of oscillations.

The layer at which the amplitude of the daily and annual temperature oscillations becomes smaller than the observation error, ie it is practically equal to zero, is called the constant daily and annual temperature layer.

The layer of constant daily temperature has a thickness of 1 - 2 m.

The depth of the lower limit depends on the magnitude of the amplitude of the daily temperature variations and the thermal properties of the soil at the point of observation.

The layer with a constant annual temperature at its base is called a neutral layer.

The depth of the lower limit depends on the amplitude of the annual temperature variations, the thermal properties of the rocks, the spatial position of the layers, the geomorphological and hydrogeological factors.

The thickness of the neutral layer varies between 10 - 40 m.

If the surface temperature variations are sinusoidal in nature, for a thermal diffusivity $a = 0.01$ cm^2/s, their amplitude decreases with depth in a ratio equal to $e^{(-\pi)} = 1/23$, at a depth $H = \sqrt{a\pi T}$, where T is the period in seconds.

For T = 1 day, a depth of 52 cm is obtained and for a year a depth of about 10 m.

The depth of the lower limit of the neutral layer (H_n) can be determined from the value of the depth of the layer of constant daily temperature (H_z) by the relation [16]:

$$H_n = 19 \cdot H_z \tag{3}$$

For most geothermal problems the diurnal and annual temperature variations are neglected and the temperature at the Earth's surface is taken as the average annual temperature which is accepted as the temperature (t_n) at the base of the neutral layer.

The average annual surface temperature of the Earth usually exceeds the average annual air temperature, a value given by climatological atlases based on the values measured in meteorological observation points.

Due to the measurement of the air temperature in the meteorological points and the dependence of the average annual air temperature on the degree of coverage, humidity and inclination of the surface, to obtain the average annual soil temperature it is recommended to add 1ºC to the average annual air temperature in observation

$$t_n\ sol = t_{n\ aer} + 1^\circ\ C \tag{4}$$

This is also in line with the accuracy with which climate maps can be made with average annual temperature values.

For geothermal research in wells, the average annual temperature in the soil is of interest, a value that is attributed to the lower limit of the neutral layer.

IV. GEOTHERMAL GRADIENT

The geothermal gradient represents the variation of temperature with depth [4,5,6]. The thermal regime of the deep layers of the earth's crust is determined by the heat inside the Earth. Below the neutral layer there is an increase in temperature with depth in the direction of heat flow.

The temperature variation with depth represents the geothermal gradient defined by the relation:

$$G_t=(t_2-t_1)/(H_2-H_1) \qquad (5)$$

In principle, two temperature measurements (t_1 and t_2) performed at different depths (H_1 and H_2) are required to calculate the geothermal gradient.

V. EXPERIMENT AND RESULT

To observe the thermal gradients of a geological structure in Romania (Salt Lake Oil Structures), we calculated the equations of temperature variation with depth by measuring three temperatures (Table 1).

The equations of temperature variation with depth are given in Table 2 (Figure 2).

Table -1 Temperature measurenment (ºC) function by depht driling wells

Name of wells driling	**Temperature measurenment 1000 m**	**Temperature measurenment 2000 m**	**Temperature measurenment 3000 m**
C.A.ROSETTI	**31ºC**	**56 ºC**	**81 ºC**
LACU ROȘU	**31 ºC**	**53 ºC**	**76**
URZICENI	**28 ºC**	**40 ºC**	**54 ºC**

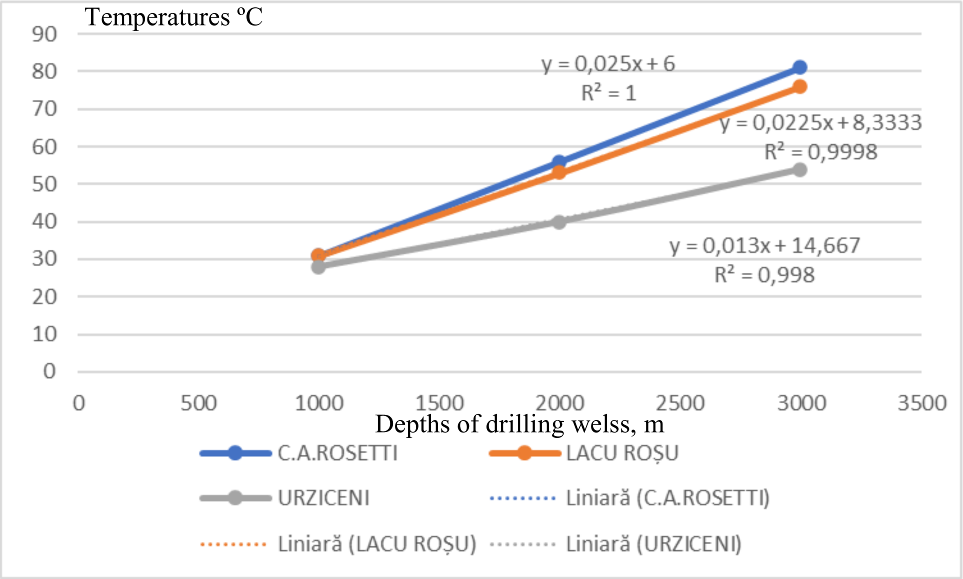

Figure 2. Equation of temperature function by depht wells (Lake Salt Oil Structures)

Table -2 Equation of variation of temperatures (ºC) function by depht driling wells and geothermal gradient (Salt Lake Oil Structures)

Name of wells driling	**equation y is temperatures (ºC) and x is depht of drilling wells (m)**	**R^2**	**Geothermal gradient (ºC/10 m)**
C.A.ROSETTI	**y = 0,025x + 6**	**1,000**	**2,50**
LACU ROȘU	**y = 0,0225x + 8,3333**	**1,000**	**8,80**
URZICENI	**y = 0,013x + 14,667**	**0,998**	**5,45**

VI.CONCLUSION

Following the analysis performed on the drillings in Romania it was observed that the temperature increases proportionally with the depth.

The gradient of the temperature field is very varied, starting from the increase by 1ºC, every 10 m depth, up to 11ºC in the case of areas with rocks with high thermal conductivity.

The temperature gradient depends on the following factors:

a. Thermal conductivity of rocks,
b. The presence of volcanic masses in the area considered,
c. Presence of salt masses,
d. The fluid content of the rock.

The known limits of variation of the temperature gradient are between:

- 5.2 m for one grade (Osseg coal mine in Bohemia),
- 125 m for one grade (South African diamond mine).

In the calculation and tracing of the regression lines, in the hypothesis of a linear variation of the temperature, with the depth, obvious changes of the slope were noticed.

The changes of slope, respectively of gradients, found are part of two “models:

a) The transition from a high gradient in the upper parts of the wells of the structures to a lower gradient in the lower parts.

Such a "model" is considered normal, given the variation in the thermal conductivity of the rocks with the depth of the deposit. At higher thermal conductivities recorded at consolidated deep rocks, lower geothermal gradients are obtained.

b) The transition from a small geothermal gradient in the upper parts of the wells or structures to a higher geothermal gradient in the lower parts.

This "model" can be more difficult to relate to the local geological environment and primarily to changing the thermal conductivity of rocks.

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