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Review Article

Physical Basics of Infrared Logging, Well Device, Obtained Practical Results and Expected Application

Seyidov Vagif Mirqamza Oglu*

Professor, Azerbaijan Institute of Oil and Chemistry, Doctor in Technical Sciences, Azerbaijan

***Corresponding Author:** Seyidov Vagif Mirqamza Oglu, Professor, Azerbaijan Institute of Oil and Chemistry, Doctor in Technical Sciences, Azerbaijan.

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Abstract

Known methods of GEIW (Geophysical explorations in wells) such as electrical logging, radioactive logging, acoustic logging and thermometer are applied in determining the saturation of formations in the drilling and development wells, oil and gas and gas and water contacts, tracking the temperature change along the well axis. However, there are a number of shortcomings in these methods: electrical logging (EL) becomes difficult after lowering production casing into well; the change in salinity degree of formation waters negatively affects the results of radioactive logging (RL); sensitivity rate of well thermometer does not allow to record negligible changes occurring in rock voids etc. And for this reason, there is a big need for development of interpretation of physical basics and information of new well geophysical exploration methods in order to conduct explorations in the wells.

The main essence of proposed logging is based on physical features of infrared rays, i.e. when heating the "black object" it releases infrared rays that reflect the individual features of radiated object. Oil, water, gas and their mixture located in formation (rock voids) as well as rock skeleton have the feature of heated object, and it is possible to get the picture of environment of log of hole by converting infrared rays radiated from them into the light. And for this reason, the proposed method may be applied in the study of log of hole. This method allows to get accurate information on petrophysical peculiarity of rock in the wells with/without casing.

The proposed logging method has been registered as invention and has been patented.

Keywords: Well; Logging; Infrared; Temperature; Spectre

Introduction

Analysis of the implementation of thermometry works in the well. The study of the temperature change along the log of hole has been performed by D.V. Golubyatnikov at the beginning of the twentieth century. Then V.N. Dakhnov, D.I. Dyakonov and others developed theoretical basics, interpretation methods as well as the project of well devices released with series [2].

While the temperature measurement that is based on the study of geothermal area in the drilling and active development wells varies for its method and technique, the development of both of these two directions does not differ sharply from each other. The analysis of this area is reviewed in development wells since the temperature area changes in a wide range in the development wells.

Temperature distributing process can be divided into three fields in operating and permanent fluid producing oil-wells (from bottom to top).

1. Dry fluid area with inactive bottom,
2. Alloy field arising before filter interval,
3. Conductive heat exchange field with environment of fluid flow acting toward to top.

Temperature is arisen basing on the geometric distribution of the heat of surrounding rocks at the unmoveable fluid area in the well bottom (Figure 1).

The practice and theoretical data show that, after release of production casing, heating conductivity bases on the geometric distribution in layers non-operated for a long time [2].

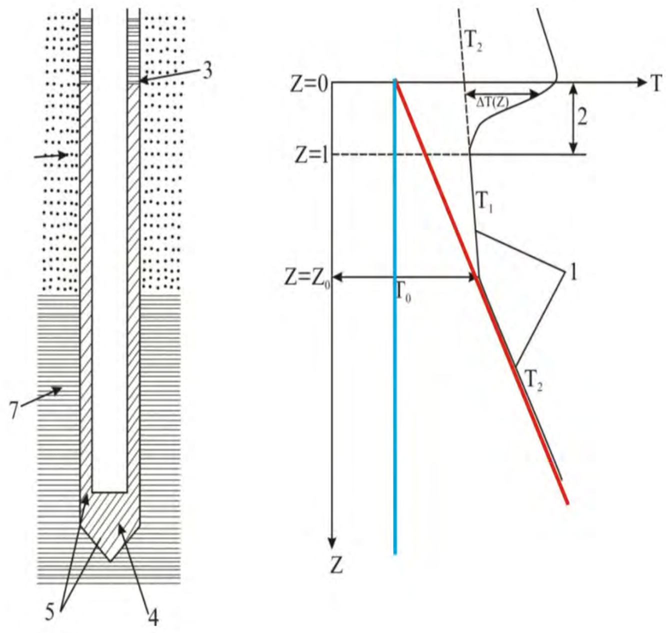

Figure 1: Measured thermogramm at the section of active well. 1 - geometric distribution of the well; 2 - modified field of temperature according to the fluid heating at the perforation part of layer; 3 - heel of perforation interval; 4, 5- cement cup and cement ring; 6, 7 - productive and clay layers; T1 and T2 - geometric gradient value according to the productive and clay layers; gradient temperature is shown by red lines but gradient temperature compensation by blue lines.

$T(Z) = T_0+\Gamma(Z-Z_0)$ (1)

Here, T(Z) - temperature of inactive fluid area at the well bottom in Z depth; T_0 - well temperature in Z_0 depth; $\Gamma=q/\lambda$ - is a geometric gradient (q - flow of heating field – so that oil deposit has a flat structure and this value can be considered constant, λ - heat transfer constant of rocks).

Well devices with maximum $0.01^oC/m$ sensitivity are usually used upon investigation of active wells. In this case, heating convection fault isn't observed at the result of measurement. Temperature anomaly arising due to the natural heat convection is approximately changed between $0.001 - 0.01^oC$.

Lets view the temperature distribution upon one or two phase fluid entrance to the well from the layer, at the fluid mixture before the filter interval in active well. In this condition, temperature distribution is determined due to three factors.

1. Temperature distribution from the influence of the natural heat fields of the earth,
2. Temperature distribution creating on the base of Joul Tohmsin efficiency at the layer during the fluid action,
3. Temperature distribution creating from the callometric influence during fluid mixture entering into the well from filter intervalls in wells.

At the result of drossel action of the fluid in well interval, value depression obtained during its heating (at the result of pressure difference) is determined by the following formula according to the operative fluid features causing a drossel.

$\Delta T=\varepsilon\Delta P$ (2)

Here, *ε*- is a Joul-Thomson constant, has several values for oil, water and gas ($0.04-0.06^0C$/atm. - for oil, $0.02-0.03^0C$/atm. $_{\text{for water}}$, 2 - 4K/MPa - for gas).

The temperature distribution in fluid entering into the well, that's the temperature in well – layer borders is calculated by the following formula.

$T_{lay}=T_g+\Delta T=T_g+\varepsilon(P_{lay}-P_{w.b})$ (3)

Here, T_{lay}- is a fluid temperature entering into the well; T_g- is a geometric temperature (this temperature is defined for z depth till the processing of deposit by practice); P_{lay}- is a pressure in front of investigating layer; $P_{(w.b)}$- is a pressure in the well bottom. Let's note that, T_{lay} causes a callometric effected barrier for measurment in well.

The feature of the measured termogram in fluid placed out of the fluid interval flowing into the well bases especially on the heating exchange of the rocks around the well shaft of the fluid. The rocks are able to keep temperature in 10 - 20m distance from well shaft that doens't practically differ from the natural geometric temperature. If the well operates by permanent debit for a long time (5 - 10 days), temperature distribution is stabilized at the well shaft and this temperature is expressed by the following differential formula.

$$T_{w.b}= \frac{cQT_{w.b}(Z)}{K2\pi r} + T_g \quad (4)$$

Here, *K*- is a heating exchange constant of the fluid with surrounding rocks; - is a well radius; - fluid volume temperature capacity; *Q* - is a flow debit.

The below mentioned matters are studied using of the above mentioned features of thermometry processes in the well: flow investigation; discovering of fluid providing interval; determination of damage place in the pipe; definition of water entrance interval into the well; estimation of depression arisen in layer; evaluation of layer pressure; definition of water interval entered upward into the well; definition of the rise height of pipeback cement ring etc. So, it is clear that, temperature field is exchanged at the result of artificial and natural proccesses either in drilling or exploitation wells.

Materials and Methods

The essence of the infrared logging

The essence of the offered logging is based on physical characteristics of the infrared rays [1]. So that, it irradiates infrared rays by itself upon heating of the "black body" and it reflects individual features of the irradiating body. Infrared rays are the rays spcifying the heated body temperature, that's why it belongs to the heating-temperature section of physics.

Types and sources of infrared rays: 1) natural: the sun, the earth, the planet etc.; 2) artificial: any bodies whose temperature is higher than the temperature of environment etc.

The features of infrared rays: passes thorugh some untransparent meduim; has a chemical influence; heats it winnowing by substance; invisible; has an interference and difraction feature; are noted by its heating method.

The energy of inrared rays irradiated by several bodies is stated in figure 2. As it is seen, infrared rays irradiated by the black body have necessarily the greatest energy (at the same time length).

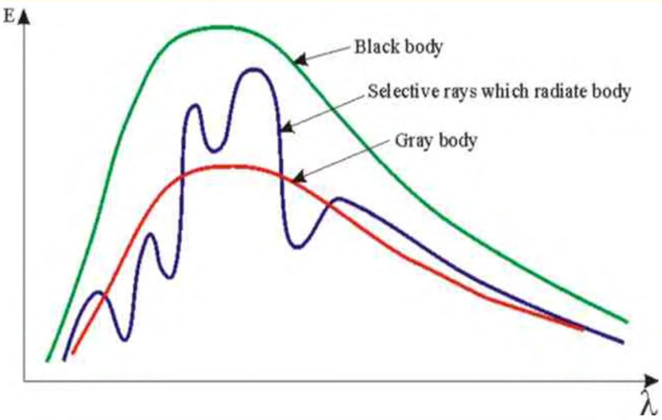

Figure 2: Energy of infrared rays irradiated by several bodies.

The physical essence of infrared ray is as follows: electromagnit irradiation having 2 mm lenght of wave, as well as radiowaves having a range more than 8* 10^{-7} m and the light ray with visible range is called infrared rays (Figure 3).

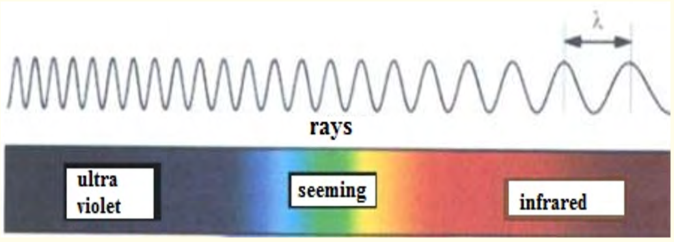

Figure 3: Whole range of infrared rays consist of three organizers: small wave area - 0.74-2.5 mkm; middle wave area - 2.5-50 mkm; long wave area - 50-2000 mkm.

The source of infrared irradiation can be oven, water heatings, electric lamp etc. Such rays are specified by the following quantities [3].

a) Density of energetic lightning spectre of the object (its iraradiation at the unique interval of $1m^2$ environment) [3].

$$R_{V.T} = \frac{dW^{irr}_{V,V+dV}}{dV} \quad (5)$$

Here, V and $V+dV$ interval frequency of irradiation; $\frac{dW^{irr}_{V,V+dV}}{dV}$ - is the electromagnet irradiation energy turned on at the frequency interval from V and $V+dV$ environment having $1m^2$ per a second (power of irradiation);

b) But the energetic lightening is used by the following formula [3]:

$$R_T = \int_0^\infty R_{V,T} dV \quad (6)$$

c) Lightening energy of the black environment is used by the following formula [3]:

$$R_e = \int_0^\infty R_{\lambda.T}\, d\lambda \quad (7)$$

Here, $R_{\lambda.T}$ - is the density of energetic lightening spectre.

It is possible to get a picture of irradiating body in dark by turning infrared radiation into the visible light by special devices.

Measurement of infrared rays

Infrared radiation can be measured by the following devices [3]:

- Optic Pyrometre - is the measurement method of the high temperature and notes the pectral density of energetic lightening of the heated environment or independence of energetic lightening on the integral temperature;
- Pyrometre - the device registers the spectre of the intensity of heating radiation in optic range by measuring of the heated environment temperature (Figure 4).

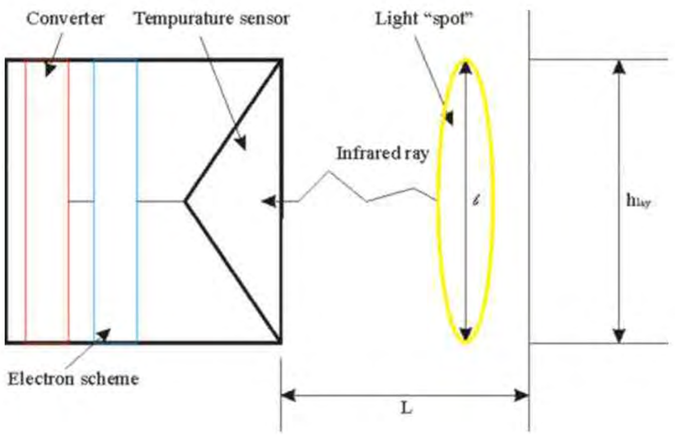

Figure 4: Structure and operation principle of pyrometre: 1-length of the light spot arisen by infrared rays radiated by the body; L-distance between the heating and body radiating infrared rays; hlay- layer (body) thickness.

Above mentioned inter quantities relations are given below:

$$\frac{L}{l} = \frac{10}{1};\ l = h_{lay};\ L = 10h_{lay} \qquad (8)$$

Comparison of the distance (L) between heater and body radiating infrared rays and the length of the light "spot" (l) is received its comparison to one. The length of the light "spot" arisen by the body equals approximately to its length. It means, it is possible to note the infrared rays only on the distance equals to ten equivalent of the body thickness.

Both (optic pyrometr and pyrometre) register device can be considered acceptable upon logging in well. The first can be used in simple infrared logging, but the second one in spectral infrared one. Certainly, the probe used in both cases must be fitted to the well condition. So, pressure and temperature proof probes are to be produced.

The development of the method (infrared logging) that is able to measure even a little change in temperature field along the well axis will allow to study the change of different geological features of the layers.

Rocks forming layer, oil-water-gas and their mixture presented in the porosities of the rocks are also body featured and it is possible to study the pertophysics features of the environment at the well cross by turning the infrared rays radiaeting from them into the visible light. That's why offered methods can be applied upon investigation of the well section.

Structure of the well device

The features and operation principles of the device that will be used on registration of infrared rays are as mentioned below.

The well devices having the below mentioned structure is offered to be used in infrared logging (Figure 5):

a) Device (pyrometer) registering infrared rays (1);
b) Converter the infrared ray flow into the current (2);
c) Amplifier that strengthens obtained current and transfers to the ground devices (3);
d) Operational unit (4);
e) Supply source (5);
f) Registerer (6).

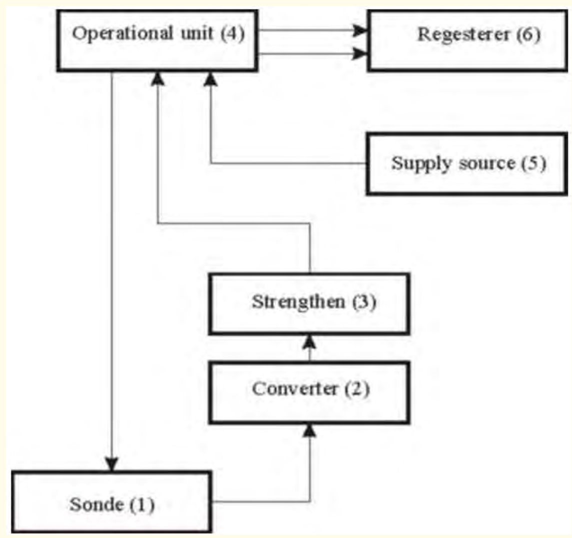

Figure 5: Scheme of well device.

Operational unit: The compensation calibrator of gradient temperature is placed here (the primary temperature is prefered). The primary temperature and gradient temperature change on depth (belonging to the area) is transferred to the compensation device and the device compensates the temperature along the cut. If there is no anomaly (due to a quantity enough to satiate or for any other reason), compensation is as a straight line as in figure 1.

The principe of the well device is supplied by continuous current to the probe (pyrometer) from the ground device to logging cable (let's note that, three branches logging cable is used). While the device acts along the well axis (let's mention that, the well device is to be pressed to the well wall by ressor in order to minimize the influence of clay and well diameter - figure 6, the infrared rays irradiating at the result of temperature change in rocks cause to the potential difference in the sensible element of the probe and as a result the obtained potential difference turns to the current by converter.

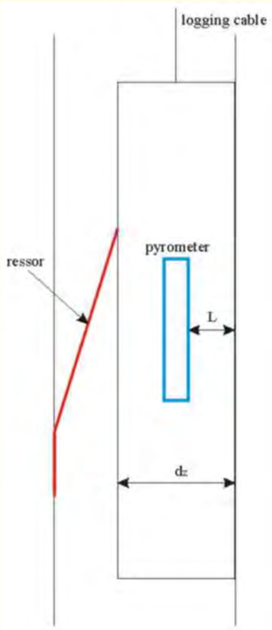

Figure 6: EStructure of the well device.

It is strengthened by amplifier transformer in current and transfers to the ground device by another cable vessel. It regulates the stregthened impulses entering into the ground device and passes it to the registerer. The following feature is kept in well device:

$$L = \frac{d_{sonde}}{2} = cons\,tan\,t$$

Practical results obtained from the application of the offered method are stated as graphic in figure 7. These practical results are realized in "stand well". As it is shown by the picture, temperature rate were compensated before clay layers.

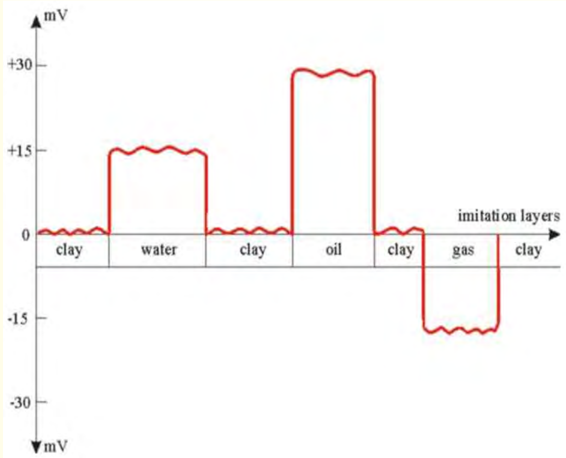

Figure 7: Diagram sample.

Exceptional layers	Indications (mV)	Cross rates (mV)
Clay	0 (gradient is compensated per a temperature)	-
Oil saturated collector	+ 15	+5 ÷ + 30
Gas saturated collector	- 20	-5 ÷ - 30
Oil-water saturated collector	+ 7	+5 ÷ + 15
Oil-gas saturated collector	+ 2	-7 ÷ + 6

Table 1

("-" sign in table describes the diminishing of temperature in compared with the clay layer, it doesn't mean the negative temperature against the layer by anyway).

Let's note that, the logging was registered as patent (invention) [1].

Basis of the spectral infrared logging

As the infrared rays irradiated by each of the bodies are different so their spectres are also different (Figure 8). Layers (bodies) are of different content and saturated, that's why their typical feature can be described as multinominal.

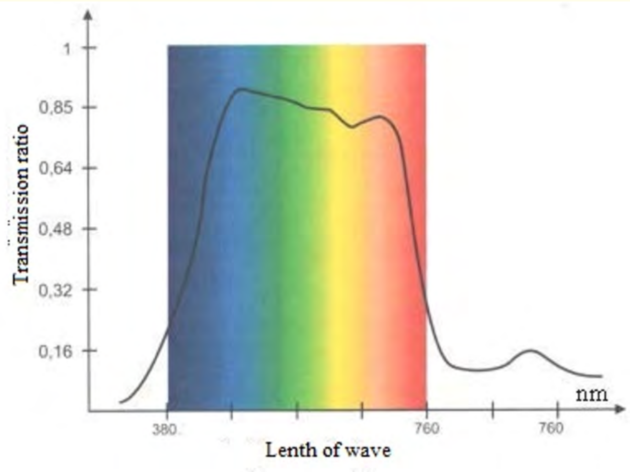

Figure 8: Infrared logging spectrum..

Environment spectrum studying by spectrum infrared logging can de defined by the following formula:

$$A\bar{C} = \bar{I} + E$$

$\bar{I} = (I_w, I_{oil}, I_{gas}, \ldots, I_n)$-number of impulses noted by the well device against water, oil and gas saturated layers (the number of impulses is proportional to the infrared rays' energy falling on the registerer):

- I_n - Other components of the rock (minerals, fractions etc.);
- $\boldsymbol{A}$ - Matrix is determined during the calibration of pyrometer;
- $\bar{C}$ - Numerical number of infrared rays arisen by environment (body), water, oil and gas;
- $\boldsymbol{E}$ - Accidental fault.

C mentioned in above formula is solved basing on the theorem Qaussa-Marcola.

$$\bar{C} = (A^{/}A)^{-1}A^{/}(\bar{I} - \bar{I_0})$$

Here $\bar{I}_0=(I_1,I_2,I_3,...,I_n)$ - pyrometer channel indicator; $\bar{I}$ - unique matrix; $A^{/}$ - is matrix fitting to each component.

Result

The below mentioned geological - geophysical tasks can be solved by considering the characters of infrared rays.

1. Collector selection;
2. Determination of gas-oil, oil-water contacts and cross zones;
3. Estimation of saturation by quality;
4. Approximate determination of lithological content;
5. Definition of the quality of pipe back cement;
6. Determination of interval and place of pipe back fluid action;
7. Appointment of the operative thickness of layer etc.

Conclusion

During the geophysical survey of the well, it is not possible to apply the methods used in all wells. Thus, the accuracy of the results is low. For this reason, the method developed by us allows increasing the accuracy of the results obtained during the well cut.

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