Deep hole drilling modern disintegration technologies in process of HDR technology

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Through physical and chemical effect on rock, the new technologies are achieving good drilling results at higher progressive speeds and at shorter time than the conventional rotation drilling. The mentioned advantages of the physical-chemical drilling methods – though still partly under research – are promising for the near future.

Key words: *geothermal energy drilling, disintegration, rock, high temperature*

Introduction

Technological process necessary for the reaching of geothermal energy is basic problem, which must be solved for this purpose. Conventional geothermal technology entails the production of useful energy from natural sources of steam or, much more commonly, hot water. These hydrothermal resources are found in a number of locations around the world, but they are the exception rather than the rule. In most places, the earth grows hotter with increasing depth, but mobile water is absent. The vast majority of the world's accessible geothermal energy is found in rock that is hot but essentially dry -- the so-called hot dry rock (HDR) resource. [4]

Market conditions should naturally guarantee work discipline during technological procedures and rational utilization of equipment from both technical and economical points of view. Efficiency of drilling process therefore depends on selection of drilling techniques and technology. Current drilling technology limits the time for drilling itself as a lot of time is »consumed« by auxiliary operations. These are usually tiring and dangerous operations with drilling equipment. In addition, it is necessary not only to stop rotation of the drill string but also circulation of the mud.

Geothermal energy represents an important source of heat, whether in the system of the central supply with the level of performance in hundreds of local resources, or in the capacity of 40000 MWt. [6] The use of renewable energy sources, eliminating the environmental impact of energy. The use of alternative sources, in turn, made the process of diversification of energy sources and the structure of the production capacities. Both facts are essential for ensuring the needs of living and the general development of the company. [7]

Through physical and chemical effect on rock, the new technologies are achieving good drilling results at higher progressive speeds and at shorter time than the conventional rotation drilling. The mentioned advantages of the physical-chemical drilling methods – though still partly under research – are promising for the near future [1].

Basically, there are two ways of thermal attack on rock:

a, by heating it up to 400 - 600 °C and cooling it down, which would cause thermal stress and rock disintegration;

b, by heating it up to 1 000 - 2000 °C thus creating conditions for melting or vaporization of rock.

The latter method is more variable as it can be used for both thermal cracking and degradation of rock by distribution of the supplied energy across larger area in order to avoid melting. This method, however, has limited use only to low-diameter bores due to its high power requirements. [6]

High-frequency dielectric heating drilling

High-frequency dielectric heating drilling uses penetration energy of dielectric medium between two electrodes (fig. 1). Thanks to high-frequency current surges a molten highly conductive electrolyte is created between the electrodes [1], [3].

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Power of dielectric heating Pd is given by the relation:

$$P_d = k_1 \cdot \varepsilon \cdot \tan\psi \cdot U^2 \cdot f \qquad (\mathrm{W.cm^{-3}}) \qquad (3)$$

where k1- constants depending on type of selected electrode;
ε - dielectric constant;

$\psi = \frac{\pi}{2} - \phi$ - decrement angle (line);

U – voltage of electrode (V);
f – current frequency (Hz);
ϕ - phase angle between voltage and current vector (line).

Dielectric constant of most rocks is from within the range 5 - 15 (table 1).

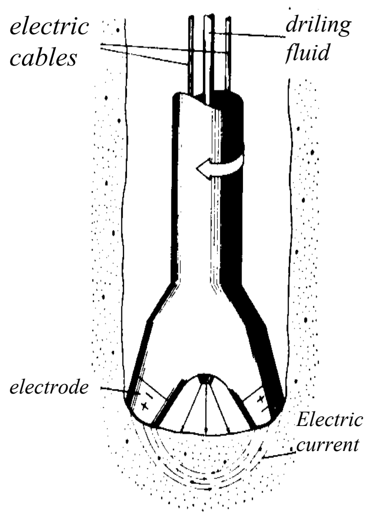

Fig. 1. High-frequency dielectric heating drilling.

Tab. 1. Dielectric constants of various materials.

Material	Dielectric constant ε	Material	Dielectric constant ε
Vacuum	1	**Marble**	8
Lava	4 - 5	**Lime stone**	8 - 12
Glass	4 - 6	**Gneiss**	8 - 15
Quarts	7	**Whinstone**	12
Mica	6 - 8	**Hematite**	25
Granite	7 - 9	**Greenstone**	19 - 40

Specific volumetric energy of disintegration w is from within 30 - 1570 MJ.m^{-3}. It depends on frequency, rock and size of disintegration products [1]. Dielectric heating reduces strength of rocks in uniaxial pressure by 50 to 75 % (Tab. 2) – according to A.V.Vazarin.

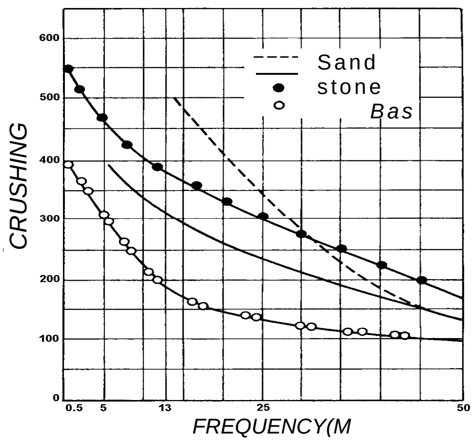

Chart 1. Effect of the frequency used for dielectric rock disintegration [1].

Tab. 2. Rock disintegration by use of dielectric heating: 60 - 80 s; 50 Hz; 6 kV.

Rock	Simple compression strength σ_p [MPa]	
	Prior to application	After application
Sand stone	95	32 - 52
Basalt	160	47 - 95
Granite	180	44 - 62
Hornstone	280	68 - 110

The time required to disintegrate rock by dielectric heating is rapidly reduced with increased frequency (Chart 1).

Rock disintegration through electrical current drilling

Electrical current drilling/rock disintegration principle is based on the idea to create a thermal stresses which would degradate the rock and thus making conventional drilling easier (fig. 2).

Most rocks are semi-conductive. Only metallic minerals/ores have higher conductivity (by several orders), depending on content of metallic elements. Hence, this disintegration method is used mainly for this type of rocks.

During drilling is electrical current with the frequency 60 Hz generated and transferred to the rock through a sharp bit. The bit rotates with low rpm and the air which circulates through the well is removing the rock fragments while attacking the rock with high temperature. This creates thermal stresses which crush the rock [1], [3]. Research results are presented in the tab. 3.

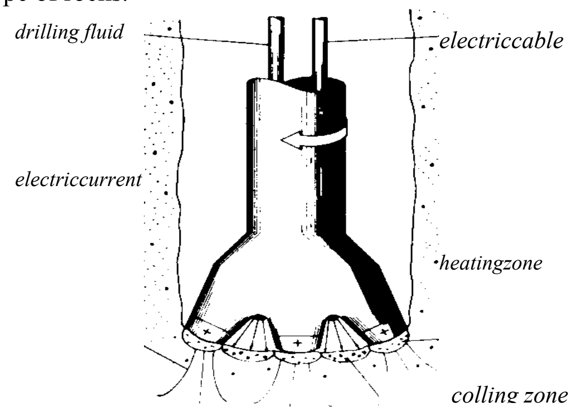

Fig. 2. Electrical current drilling [3].

Electrical power attacking the rock is expressed by the relation:

$$P = k \cdot \frac{U^2}{R} \quad [\mathrm{W}] \qquad (1)$$

where k – constant specifying type of electrode (cm),
U – voltage on electrode (V),
R – rock resistance (Ω).

Total progressive speed depends on type of drilled rock.

Power P transferred to elementary volume of the rock under the bit can be expressed by the equation:

$$P = i^2 \cdot R \quad (W) \qquad (2)$$

where – current intensity (A).

Tab. 3. Electrical current drilling operational characteristics[1],[3].

Bore diameter D_v, [mm]	25 - 51
Voltage U, [V]	600 - 1 000
Current I, [A]	2 - 10
Current frequency f_p, [Hz]	60
Power P, [kW]	1,2 - 11
Power coefficient k_v, [dim. free]	0,93 - 1,06
Circumferential speed a, [rpm]	90
Bit axial pressure F, [A]	110 - 120
Air consumption m_{VZD}, [l.min^{-1}]	57
Progressive speed of drilling v_p, [cm.min^{-1}]	8 - 64

Application of this procedure in mining industry is proven by experience from the USA. In one iron-ore deposit they registered increase of driving speed from 0,025 to 0,6 m.hour^{-1} ; in other ore-deposit it was the increase from 0,2 to 0,9 m.hour^{-1} (they used an autotransformer with the power 100 kWA resp. 60 kWA).

In addition to this, many tests were made during which the rock was preheated by electrical current to 816 °C (with simultaneous use of a cutting-type bit). With this temperature, the rock lost practically all its strength [3].

This method can be used for drilling of rock with very good conductivity (e.g. quartz) even though the specific volumetric energy w is the same as for conventional rotation drilling.

Inductive drilling

The last drilling method using thermal stresses is inductive drilling. Very hard rocks with high magnetic susceptibility, such as taconite (very hard rock which are found in the USA, containing quarts and iron) can be disintegrated by inductive heating generated by high-frequency magnetic field. The tool consists of induction coil with the axis perpendicular to the face of well and of the reamer that calibrates the well (Fig. 3) [1, 3]. Electrical current is supplied to the coil by cable led in the middle of the drill string. At the same time, drilling fluid is fed through the special pipe inside the string.

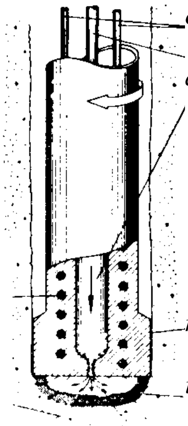

Fig. 3. Inductive drilling.

Heat in rock is generated thanks to remagnetizing (hysteretic) losses. Hysteretic loss Ph varies app. according to the equation:

$$P_h \cdot \alpha \cdot B^2 \cdot f = \varepsilon^2 \cdot H^2 \cdot f \quad (4)$$

while vortex current loss Pe follows the equation:

$$P_e \cdot \alpha \cdot B^2 \cdot \frac{f}{R^2} = \varepsilon^2 \cdot H^2 \cdot \frac{f^2}{R} \quad (5)$$

$$\overline{B} = \mu_0 \cdot \mu_r \cdot \overline{H}$$

where B – magnetic induction;,
H – magnetic field force [A.m^{-1}],
ε – magnetic permeability [H.m^{-1}],
R – resistance [Ω],
f – current frequency [Hz].

These two losses occur simultaneously.

Minerals with low susceptibility are heated thanks to thermal conductivity. Rock is then disintegrated by different thermal expansivity of minerals.

The relation between magnetic permeability ε and magnetic susceptibility is as following:

$$\varepsilon = 1 + 4 \cdot \pi \cdot k \Rightarrow k = \frac{\varepsilon - 1}{4\pi} \quad (6)$$

Where k is magnetic susceptibility. For diamond materials, k 〈 0 and for paramagnetic materials k 〉 0. Table 4 shows that magnetic susceptibility is different for every rock and can be applied to volume unit (1 cm^3) or reference unit (g).

Tab. 4. Rock magnetic susceptibility k[1].

Rock	**Magnetic susceptibility k** [$.10^{-6}$ cm^3]
Clay	0 - 60
Granite	0 - 4 500
Hematite	20 - 490
Lime stone	0 - 25
Magnetite	64 - 135 000

Thermal gradients in the silica iron block heated by induction coil of the diameter 9 cm can be seen from the chart 2. The surface temperature of the block close to the middle of the coil was 240 °C. The temperature approximately 5cm under the surface was ca. 50 °C. The temperature directly under the coil reached 110 °C, while in the depth 5 cm it went down to 55 °C. Thermal gradient was measured along one of generated cracks [1], [3].

Problem of inductive tools is low energy transfer efficiency (10 - 15 %) and also the fact that electromagnetic waves can be successfully used only for disintegration of rocks with high magnetic susceptibility.

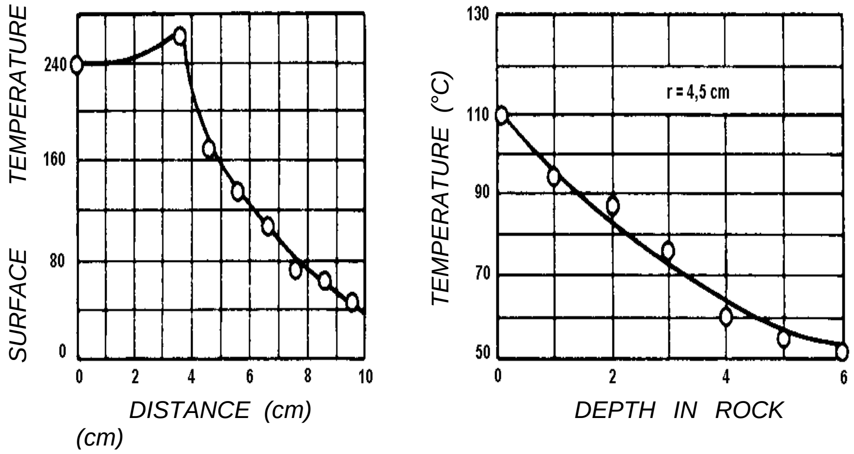

Chart 2 Thermal gradient generated in silica iron by inductive heating [3].

HDR technology and deep hole drilling

Drilling method performed mechanically especially progressive method of disintegrations, currently the most commonly drilling method used in practice; in principle it is based on final transfer of mechanical energy (from rotating table, rotation water swivel, submersible motors, etc.) to the drill bit.

This drilling technique has wide range of practical application (oil wells, gas wells, hydro and geothermal water wells, engineering and exploratory boring, and in opencast mines). Differences are only in the drill design which can be stable, mobile or portable.

Difficulty of drilling process is further increased by high geometrical gradient in the Eastern-Slovakia shell and Vienna shell. These are areas with concentrated geological-surveying activities. Basic character of the geological structure is formed by fault subsidence tectonics and folded deformations. Most deposits is in the form of double plunging anticlines, which are also disturbed by many faults.

It is therefore no doubt that in Slovak conditions, some of the above-described drilling technique (with the new physical-technological rock disintegration methods) would be a very advantageous, even if used only partially for drilling of problematic zones. [5]

In the last time there is geothermal heat frequently used for tourist attractions and thermal baths, which are having also medical treatment effects and are very popular worldwide. These sources are available shortly underground and are sign of better conditions in the deeper distances.

During the stage of governmental investigation of potential fields of fossil fuels there were executed more than 120 exploration drills over Slovakia in different regions and different deepness. The results are cumulated in several studies and professional reports and today are the best library for evaluating also the Slovakian Geothermal potential and availability of geothermal sources.

Conclusion

Drilling methods showed in this article are still subject to research. This documents an ongoing effort to develop new drilling techniques, meeting requirements for fast and efficient drilling to utilise HDR technology, at the lowest possible cost and in the shortest possible time.

The given examples are showing how time and money can be saved with increased drilling speed and overall safety. The effectiveness of the drilling process depends on many factors which directly affect the quantity characterizing drilling. This term, expressing the interaction machine - rock is dependent on a set of input variables are factors geological, technical and technological. Other influences are mainly the sum noncontrollable factors, such as voltage rock pillar, humidity, temperature and chemistry of rocks.

From the above it is clear that optimal management of the drilling process is subject to objective criteria defining drilling - specific volumic energy and measuring equipment installed on the drilling rig. [8]

Geological research and surveying includes a wide range of researching, technical and economical activities. The main task of geological surveying is determination of geological composition of the surveyed area, searching for deposits of minerals, finding new sources of underground mineral and thermal water, determining geological conditions of foundation beds, examining and redeveloping slide areas, examining conditions for potential construction of underground gas tanks/reservoirs, clarifying geological factors influencing the environment and solving technical and commercial issues.

The result of the geological investigation is essential for today's and future exploitation of minerals, solving of water management problems, protection and utilization of underground, healing and table mineral waters, rational/efficient piling, soil quality classification, prospective use of geothermal energy and further clarification of economical factors influencing human health and the environment. This wide spectrum of geological work requires use of new drilling technologies/techniques and equipment [1].

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