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Unconventional Experimental Methods of Drilling Management with the Perspective of Their Use in Deep Drilling

Gabriel Wittenberger [1] ● Erika Škvareková[1]

[1]Technical University of Košice, Faculty of Mining , Ecology, Process Control and Geotechnologies, Letná 9, 04200 Košice, Slovakia, e-mail: gabriel.wittenberger@ tuke.sk

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Abstract : The development of technologies for deep drilling is closely related to improving the quality of drilling. Around 30% of new deep drilling techniques are used in the world today, while 70% still uses traditional methods. Advances in new deep drilling technologies are leading to the development of new types of drilling rigs for deep drilling (depending on the techniques used). The issue of drilling technique has a mechanical and physical influence on rock drilling. In recent years, several tests and analyzes of disintegration and drilling methods have been performed. The article focuses on the description of the working principle and the possibilities of using new methods of rock separation. New physical - thermal methods of drilling are pointed out here. The mentioned methods are still the subject of research and hope for future technologies in the field of deep drilling..

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1 Introduction

The beginning of the use of rotary drilling technology in the world was the beginning of successful innovations in oil drilling in the 20th century [1]. Several innovations have helped to increase the efficiency of oil production, while enabling the exploration of new oil and gas deposits. The efficiency of the drilling process depends on the choice of drilling technology and techniques. Currently, the problem with drilling technology is the limited time of the drilling itself, because quite a lot of time is absorbed by other operations such as stop of the drilling and drilling fluid circulation [2,3]. These are usually tedious and dangerous operations with the drilling rig. Due to the physical-thermal impact on the rock, new experimental technologies achieve better drilling results than conventional rotary drilling. The mentioned advantages of physical-thermal drilling methods, although still partially investigated, are promising for the near future [4,5].

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2 Material and methods

Due to the physical -thermal impact on the rock, new experimental technologies achieve better drilling results than conventional rotary drilling. The mentioned advantages of physical-thermal drilling methods, although still partially investigated, are promising for the near future.

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 1000 - 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. It can be efficiently used for disintegration of hard rock with sheet structure [4]. In this article we describe three experimental thermal methods of rock destruction, which can be used in the implementation of deep wells.

2.1 *Flame drilling*

Flame drilling works in conditions between thermal stress and melting/vaporization of rock. Fuel and oxygen are fed to the combustion chamber at the bottom of well through pipes inside the conventionally rotating drilling pipe (Figure 1). The flame which is about 2400°C hot flashes from the nozzles to the bottom of well at app. 1800 $m.s^{-1}$.

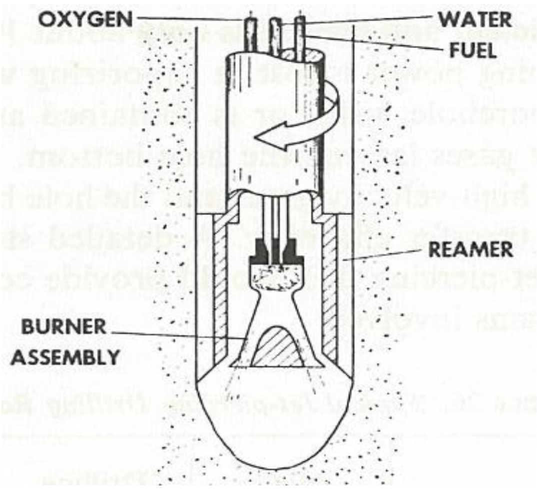

Figure 1 Flame drilling [1]

Water supplied through the third pipe is cooling down the combustion chamber, the nozzles and the burnt bore [6,7]. Operational characteristics of the drilling are listed in Table 1. The tool also includes a mechanical reamer for calibrating of the hole and removal of disintegrated rock [1]. Tests have shown that the maximum drilling progressive speed v_p was reached when more »rich« oil-oxygen mixture was used (0,33 - 0,36). The specific volumetric energy for this rock disintegration method is from 3000 to 1000 $MJ.m^{-3}$, which is from 2 to 7-times more than 1500 $MJ.m^{-3}$ required to heat-up the rock to 400 – 600°C [8].

Table 1. Flame cutting operational characteristics [1]

Bore diameter D_V (mm)	160-320
Drilling progressive speed vp ($m.hour^{-1}$)	3-12
Oxygen consumption m_{KYS} (l; $kg.cm^{-2}$)	28000; 10,5
Oil consumption m_{OL} ($kg.cm^{-2}$)	7
Oil/water ration ($kg.kg^{-1}$)	0,355
Water consumption m_{VOD} ($kg.cm^{-2}$)	4,2
Flame temperature t_{pl} (°C)	2400
Flame speed v_{pl} ($m.s^{-1}$)	1800
Power P (kW)	373-746

A considerable portion of the energy is consumed for heating-up of walls, thermal and kinetic the energy of gases escaping from the well. The only smaller portion of the energy is transferred to the good face, especially due to short contact time of high-speed gases and the rock. Flame cutting uses a relatively cheap energy source. It can be used where fast rock heating is required [9,10].

2.2 *Ultrasonic and infrasonic drilling*

The sound for ultrasonic tools is generated by electric current with the frequency 20-30 kHz running through a coil, which generates synchronous oscillation of its magnetostrictive core with the amplitude of several micrometers (Figure 2). The amplitude is amplified (10-100 times) in cone-shaped pipe of the length chosen so as not to produce standing waves. Length of the pipe plus the drilling tool is an exact multiple of half-wave of the given frequency. Energy is supplied to the wider end and released from the narrow one, thus increasing wave amplitude [8,11].

There are two mechanisms for rock disintegration using the described tool:

(1) The sound creates cavitations in the liquid, energy transfer principle makes the micro bubbles proceed towards the rock and disintegrate it by implosion. The disadvantage, however, lies in the fact that the cavitations disappear at the pressure above 0,5 - 0,7 MPa so it’s not usable for deeper wells.

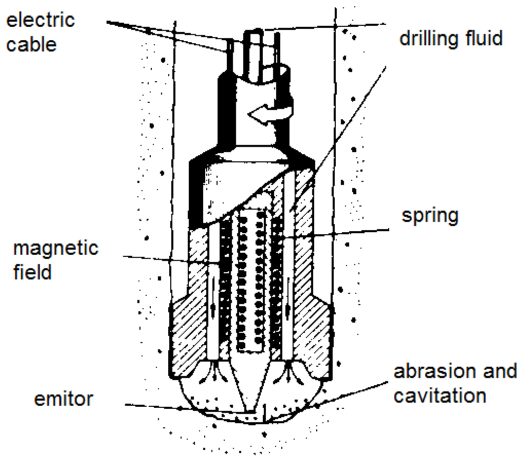

Figure 2 Ultrasonic drilling [1]

(2) The principle applied here is an abrasive disintegration. Hard abrasive materials are put below the tool, making a suspension. Turbulence accelerates the particles, which are breaking and removing the rock.

In water environment, the emitter generates cavitations advancing to the rock where they collapse generating strong impulsive pressure microscopically crushing the rock. Research of AV SNŠ shows major influence of abrasion, while cavitations are considered less important. Drilling progressive speed depends on type of used abrasive material (which can be seen in Table 2). The ultrasonic drilling progressive speed increases with increasing grain size of the abrasive material and increasing vibration amplitude, as the maximum speed and moment of impact are equal to this amplitude.

Table 2 Abrasive material type effect on ultrasonic drilling speed [1]

Type of abrasive	Drilling progressive sped v_p ($cm.min^{-1}$)	
	Soda glass	Wolfram carbide
Boron carbide	2,0	0,082
Diamond	1,8	0,082
Silicone carbide	1,6	0,051
Aluminium	1,3	0,004
Sand	0,9	0,004

Progressive speed of such ultrasonic tools is 0,06 - 1,2 $m.h^{-1}$ (0,1-2 $cm.min^{-1}$); water proved to be the most suitable environment for transfer of waves [6,9]. As the sound frequency is related to the bore diameter (the higher the diameter the lower the frequency) ultrasound can be used for drilling of wells to the max diameter ϕ 6,5 cm. Exceeding this value, the sound would reach audible range and could cause troubles to operators [12]. The specific energy w is from within the range 10^4 - 10^5 $MJ.m^{-3}$, depending on type of rock. These are generating an amplitude up to 5 cm at frequencies under 16 Hz; this amplitude creates large impact forces targeted usually directly at conventional disintegration tools. This way the large impact forces are used optimally. Total power is only from 2 to 4 kW [1]. Due to low drilling progressive speed and low power, practical use is impossible, unless someone would come up with the method how to increase total efficiency of this technology.

2.3 *High-frequency dielectric heating drilling*

High-frequency dielectric heating drilling uses penetration energy of dielectric medium between two electrodes (Figure 3). Thanks to high-frequency current surges a molten highly conductive electrolyte is created between the electrodes [7].

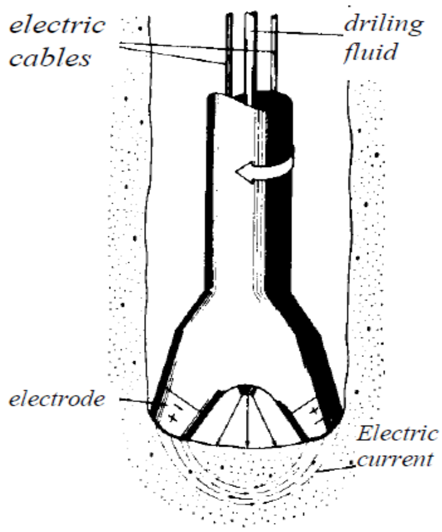

Figure 3 High-frequency dielectric heating drilling [9]

Power of dielectric heating P_d is given by the relation:

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

where k_1 - 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 3).

Table 3 Dielectric constants of various materials [1]

Material	Dielectric constant ε	Material	Dielectric constant ε
Vacuum	1	Marble	8
Lava	4 - 5	Limestone	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 [7]. Dielectric heating reduces strength of rocks in uniaxial pressure by 50 to 75 % (Table 4) – according to A.V.Vazarin.

Table 4 Rock disintegration by use of dielectric heating: 60 - 80s; 50 Hz; 6 kV [1]

Rock	Simple compression strength σp(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 (Figure 5).

3 Discussion and Summary

Some of the drilling methods mentioned in this article are still under development. The development of new drilling techniques, that meets the requirements for fast and efficient drilling, at the lowest possible costs and in the shortest possible time is supported worldwide [13,14].

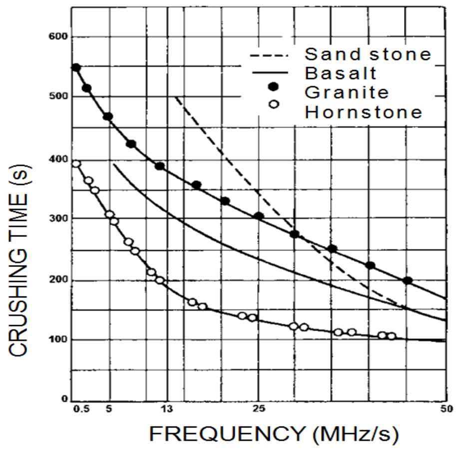

Figure 5 Effect of the frequency used for dielectric rock disintegration

The examples given in the article, point to the possibility of increasing the economical and safety issues in the field of deep drilling. This problem is closely related to geological exploration and involves a wide range of research, technical and economic activities [15-17]. The main task of the geological survey is to determine the geological composition of the surveyed area, to search for mineral deposits, to search for new sources of groundwater and thermal water, to determine the geological conditions of the subsoil, to examine conditions for possible construction of underground gas tanks / reservoirs and underground radioactive waste repositories [18,19], clarification of geological factors influencing the environment and solutions to technical and commercial problems [20,21].

4 Conclusions

From the paper follows that heat generates thermal compression stress which creates cracks and crushes the rock. The stress is created by high differential temperature in the rock. There are the basic factors contributing to generation of the differential temperature: high temperature gradient in the rock, heat stress difference between different rocks, phase of changes in minerals, water removal by crystallization, liquid heating and disturbance of mineral structure by chemical bond. When crystal undergoes phase change, high thermal stress is induced to surrounding minerals. Quartz crystals limit thermal stress of the crystal. Hence, generation of too high stresses is limited.

The authors conducted a study of the possibility of using some physical-thermal methods of deep drilling, which are currently used experimentally. These methods are based on physical-thermal principles, e.g.:

• flame cutting principle used where rapid heating of the rock is required,

• ultrasonic and infrasonic drilling - This way the large impact forces are used optimally - large impact forces are used here, disturbance by dielectric heating of rocks

• high frequency dielectric drilling - uses the energy of dielectric medium penetration between two electrodes.

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