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ROTARY – PERCUSSION DRILLING METHOD – HISTORICAL REVIEW AND CURRENT POSSIBILITIES OF APPLICATION***

1. HISTORICAL BACKGROUND

Some information about new drilling techniques are written in papers of Wiśniowski and Stryczek [11] and Wiśniowski et al. [12]. Rotary – percussion drilling has widely been recognized for its potential to drill faster, in comparison to conventional rotary drilling method, where traditional roller-cone and PDC bits had been used. This ability becomes more evident when the drilling takes place in hard formations like granits, sandstones, dolomites and limestones [3].

In this reason, at the beginning of 20^{th} century, this drilling method was commonly used in oilfield applications, as a simple way to drill heavy formations. In the mid 1930s, a large percentage of the oilfield hammer drilling was replaced with the introduction of improved rotary rigs. Technological development caused that it was more efficient and faster that standard percussion method and, for a long time, this percussion method was forgotten in Oil&Gas industry, became a niche technology and was perceived even as old-fashioned. However, percussion drilling was still used in mining, industry, and in drilling very shallow oil wells, especially using air or air/mist as a circulating medium, what decresed the rate of mud escapes, its cost and permeability destruction near the well.

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In the early 1960s a high frequency, low energy hammer made its way back into oil-fields applications. The air-operated percussion tool was placed directly above the rollercone drill bit. The hammering action added the advantage of percussion to conventional air rotary drilling, because of the frequency of approximately 1800 strokes per minute. Moreover, the roller-cone bit welds were strengthened and enhanced in order to withstand the hammering action. The frequency of strokes was conditioned by the model of the hammer and by the volume of air being circulated through the hammer. In practice, the roller-cone bits did not withstand the strokes of the hammer, especially in wells with higher deviation. This ability to avoid deviation problems could be reduced by decreasing rotary speed and lowering the weight on the bit, but it ultimately reduced efficiency and increased drilling costs.

1980s brought following evolution of rotary-percussion drilling, which took place in the north of United States, and in Arkoma Basin (Oklahoma). The difference between previous percussion BHAs was the addition of a ‘fixed head’ bit (drilling bit connected with percussion mechanism, Fig. 1). This construction substituted tricone bits, which had been used so far. Because of this solution, penetration rates and atotal footage performance in the targeted large surface hole applications were significantly increased.

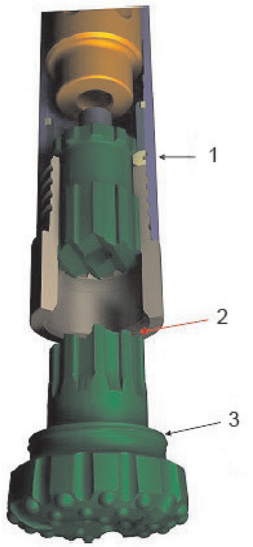

Fig. 1. The shank section on standard hammers tend to separate leaving the bit head in the wellbore [3]; 1 – split rings are the only means of attachment, 2 – shanking results in the loss of the bit head in the hole, 3 – conventional hammer bits have built in fishing thread to facilitate retrieval

At that time, field and design engineers recognized diamond enhanced tungsten carbide (TC) inserts could be added to a hammer bit to improve cutting structure wear resistance and increase penetration rates [11].

However, drilling bit and the spline section still could be separated during drilling operations. Insufficient durability of the drilling bits was still a big challenge for the engineers; during long runs of the drilling bit, because of the sectional construction of the hammer, it could be separated and could fall down in the hole. Retrieving of the separated element was time-consuming and costly process, so the industry was losing its convenience to this method.

In 1991, design engineers implemented a patented retaining device, which is still in use today. This system nearly eliminate the separation of the bit during drilling operation. Additional use of PCD inserts let percussion-drilling method to be more effective and more commonly used (Fig. 2). This system is in use until now.

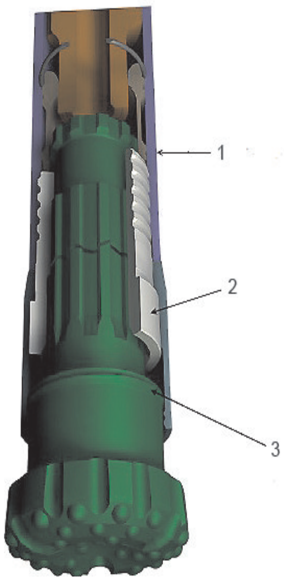

Fig. 2. Retaining system has essentially eliminated the shank separation problem common on hammer bit [3]; 1 – the primary retention mechanism is a retaining ring at the top of the bit, 2 – the retainer consists of a sleeve positioned between the shoulder of the driver sub and the hammer case, 3 – the secondary catch mechanism is a rope thread machined on the retainer and the bit

2. DRILLING MUD

At the beginning, rotary-percussion drilling method was connecting mainly with application of air mud. Thanks to the technological development foam mud and recently fully filtrated (clean) water were brought into use [8].

In Brazil, in the São Francisco basin, where tight gas plays occurs, instead of air, were applied mixture of nitrogen and air in order to eliminate or decrease risk of ignition. [3].

It is obvious that, amount of mud depends on diameter and dept of borehole. Maximum pressure of mud, when water is used, doesn't exceed usually 180 bar. As an example, air consumption was presented on the basic of the data shared by Drill co Tools company in the Table 1.

Table 1

Air consumption for Drillcotools's hammers [9]

HAMMER		PUMA 3		PUMA 4		PUMA 5		PUMA 6		PUMA 7		PUMA 8		PUMA 9	
Length		836 mm	32 7/8"	1002 mm	39 3/8"	1093 mm	43"	1098 mm	43 1/4"	1373 mm	54 1/8"	1305 mm	51 3/8"	1694 mm	66 3/4"
Outer diameter:		[mm]	[inches]	[mm]	[inches]	[mm]	[inches]	[mm]	[inches]	[mm]	[inches]	[mm]	[inches]	[mm]	[inches]
Hammer S		79	3 1/8	96	3 3/4	115	4 1/2	142	5 5/8	168	6 5/8	180	7 1/8	–	–
Hammer HD/HDW		82	3 1/8	–	–	128	4 5/8	147	5 3/4	173	6 7/8	185	7 1/4	215	8 1/2
Hammer HdWR		84	3 1/4	99	3 7/8	12	4 3/4	150	5 7/8	176	7	188	7 3/8	221	8 3/4
Airconsumption		[m^3/min]	SCFM	[m^3/min]	SCFM	[m^3/min]	SCFM	[m^3/min]	SCFM	[m^3/min]	SCFM	[m^3/min]	SCFM	[m^3/min]	SCFM
Bar	PSI														
150	10.3	4.4	155	5.1	180	8.8	310	8.2	290	13.9	490	13.5	475	19.5	690
200	13.8	6.5	230	7.4	260	12	425	12.7	450	19.8	700	19	670	27.8	980
250	17.2	8.8	310	9.8	345	15.4	542	17.3	610	25.8	910	25.9	915	36.3	1280
300	20.4	11.2	395	12.3	435	18.7	660	21.5	760	31.7	1120	34	1200	45.4	1600
350	23.8	13.7	485	15	530	22	775	25.3	835	37.7	1330	43.6	1540	54.8	1940

3. APPLICATION OF ROTARY-PERCUSSION DRILLING METHOD IN THE WORLD

The laboratory drill-of test for conventional method, as well as for two types of down-hole air percussion hammer conducted in 1984 Finger. Figure 3 shows the test results. In the test, Finger compared ROP of industrial hammers, conventional rotary method and oil field hammer (older type of industrial hammer) obtained in Sierra White Granite.

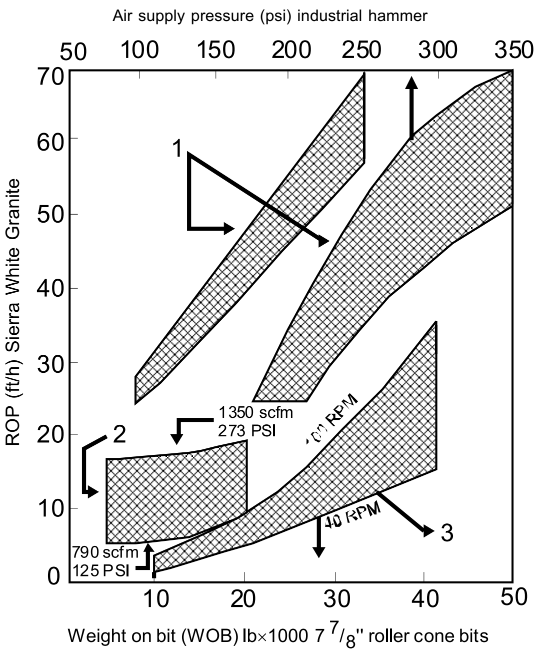

Fig. 3. Drill-of test for granite [2]. 1 – industrial hammers (15-25 RPM, 5000 lbswob, 8"–8 1/2" bits), 2 – oil field hammer, 3 – conventional rotary (air flow = 800 scfm)

Test results are clear, ROP in hard formations when rotary-percussion drilling method is applied, is significantly bigger. What is more, test showed that, for rotary-percussion drilling greater weight on bit is required to keep strict contact between bit and formation.

Rotary-percussion drilling method was applied inter alia in drillings on the area of São Francisco basin – called “GrupoBambui”. The São Francisco basin consist of a family of geologically old metamorphic rocks that include carbonates, sandstones, shale sandstones and conglomerates. The typical well profile consist on vertical holes with TD at 2000–4000 meters (depending on the region of the basin to be drilled). This is done in three different sizes: 17 1/2", 12 1/4" and the production section 8 1/2". Casing sizes are: 13 3/8", 9 5/8", 5 1/2".

The main problem to drill in describing basin were interbeddedshales, hard limestones and hig dip angles which frequently generate wellbore deviation in short drilled distances (up to 20^{o}). All of described problems generate extra costs, that is the reason to compare results of drilling when conventional and rotary-percussion drilling method are applied [3].

The suggested percussion BHA was run in 12 1/4" and 8 1/2" hole section in different wells. With the first diameter of the bit (hammer job-1), BHA drilled 393 m with ROP of 9.4 m/h. In hammer job-2, BHA drilled 474 m with ROP of 13.5 m/h. Drilling with 8 1/2" diameter, BHA drilled 850 m in the hammer job-1 (with ROP of 13.8 m/h) and 630 m in the hammer job-2, with ROP of 12.2 m/h [3]. Figure 4 shows the ROPs achieved in 16 wells made by conventional drilling, and two wells drilled with hammer BHA. Figure 5 shows the drilled intervals achieved in 16 wells made by conventional drilling, and two wells drilled with hammer BHA.

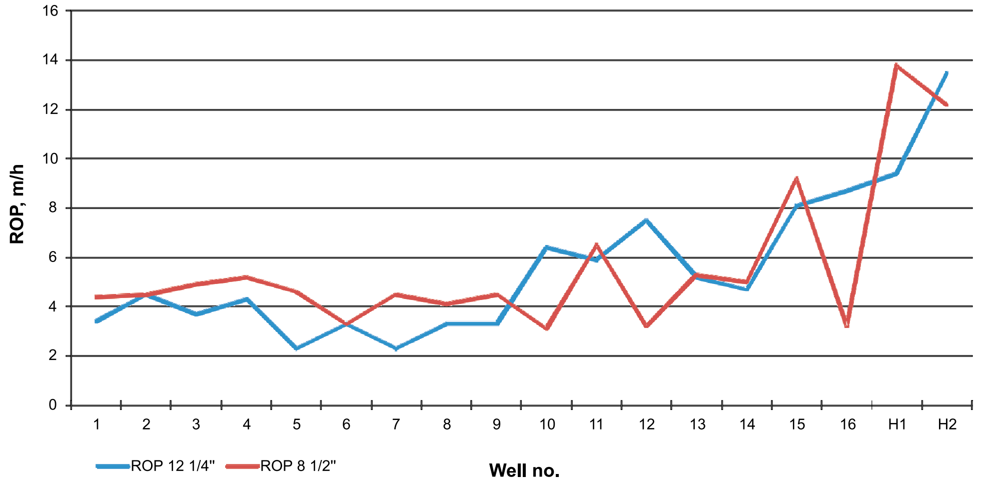

Fig. 4. São Francisco basin – Bambui lithology performance with conventional drilling vs air drilling with hammers (2011–2013) [3]

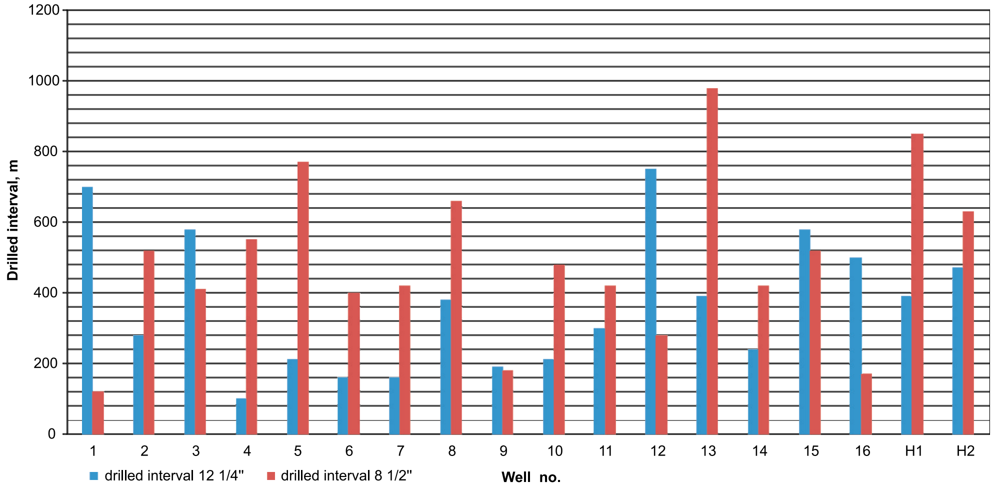

Fig. 5. São Francisco basin – Bambui lithology performance with conventional drilling vs air drilling with hammers (2011–2013) [3]

The Table 2 shows the the details of hammer job-1 and hammer job-2 with ROP and meters performance vs the average for rotary drilled wells.

Table 2

ROPs and meters performance in hammer job-1 and job-2 in comparison with the average for rotary drilled wells [3]

	12 1/4"				8 1/2"			
	AVG ROP	AVG METERS	GAIN IN ROP	GAIN IN METERS	AVG ROP	AVG METERS	GAIN IN ROP	GAIN IN METERS
Gr. Bambui	5	307	–	–	4.5	392	–	–
Hammer job-1	9.4	393	88%	28%	13.8	850	204%	117%
Hammer job-2	13.5	474	172%	54%	12.2	630	169%	61%

With the use of hammer in the BHA, the Brazilians achieved following advantages:

- possibility of drilling in approximately 30 days a well that previously took at least 50 days to TD,
- double to triple the ROP in this section versus conventional drilling,
- maintained verticality of the wells to below 5^o,
- simplicity of straight BHA to avoid gaining inclination and reduce directional tool cost to operator,
- introduction of hammers changes rock failure mechanism requiring much less WOB helping to control deviation.

Moreover, use of nitrogeon as a circulating medium decreased mud costs in Brazil (obviously, in comparison to rotary drilling). Lithologically, Sao Fransisco basin consists of following types of rocks: carbonates, sandstones, shale sandstones, conglomerates. All wells were drilled in this environment.

Consecutive area, where rotary-percussion drilling method were used, is Tarim Basin – placed in the north-western part of People's Republic of China. It's the fourth amongst the biggest oil basins in China. Drillings in this area are especially costly because of hard rock challenges. For this reason conventional drillings using the combination of roller-cone and PDC bits are carrying out with relatively low ROP, achieving 1.67 m/h on average. 2082 meters of sandstones, limestones and anhydrites were drilled with air-hammer during 454 hours that gives ROP of 4.74 m/h on average. Detailed data about drillings with air-hammer are shown in Table 3.

Comparison of rotary-percussion drilling method and conventional drilling in Tarim basin is shown in Table 4.

The achieved results was very interesting: ROP was 185% higher over the average offset run, 275% longer interval drilled over the average offset run and 187% longer interval over the average PDC run.

Table 3

Hammer Motor Run Data [4]

WELL NO.	WELL 1	WELL 2	WELL 3	WELL 4
WELL TYPE	VERTICAL	VERTICAL	VERTICAL	VERTICAL
DEPTH IN	5651.8	5790.37	4912	5530
DEPTH OUT	5901.29	6414.77	5489	6162
DRILLED [m]	249.49	624.4	577	632
HOURS	54.25	152.8	93	153.1
ROP [m/h]	4.6	4.09	6.18	4.1

Table 4

Results achieved by rotary-percussion drillin method vs achieved by rotary drilling [4]

DRIVE TYPE	BIT CLASS	TOTAL RUNS	AVG. DEPTH IN	AVG. DEPTH OUT	AVG, INTERVAL DRILLED [m]	AVG. HOURS	AVG. ROP [m/h]
HAMMER MOTOR	PDC	4	5471	5992	521	113.5	4.74
CONVENTIONAL MOTOR	PDC&RC	46	5992	6131	139	82.4	1.67
	PDC ONLY	28	5987	6168	181	108.2	1.66
	RC ONLY	18	6000	6073	73	42.2	1.7

Since Fall 1983, a mining hammer was successfully tested in Canadian a Jumping Pound field well. To 1989, 117 percussion hammer bits had been used on 48 wells. Initial results were encouraging and led to an testing-and-development program.

Instantaneous ROP with the mining hammer in 8-5/8" well exceeded 80 m/h maximally, and value 57 m/h existed commonly. These rates resulted in 440 m/day. Average ROP on wells drilled with the fully modified industrial-hammer system was 170 m/day drilling to the depth of 2300 m. Planned depth was reached in 12 days, while drilling analogous well to the same depth was lasting 54 days before (35 m/day). To compare, rotary drilling with air as a circulating medium took 95 m/day. The chart in Figure 6 shows the time needed to reach given depths using various types of drilling methods.

On American Berea basin 37 drilling wells were drilled with DTH hammer. The purpose of this venture was decreasing of well costs. Because of this solution, horizontal well costs drilled in strongly abrasive sandstones of Berea decreased by 1/3 in comparison to standard rotary method. Moreover, less runs were required. Drilled analogous horizontal section it was found that the costs of this action decreased by 50%. This cost reduction was not only connected with faster ROP, but also with using nitrogen as a circulating medium – what overcame the risk of ignition [7]. Generally, the cost of making drilling wells were decreased by 30%, what is shown in the chart on the Figure 7.

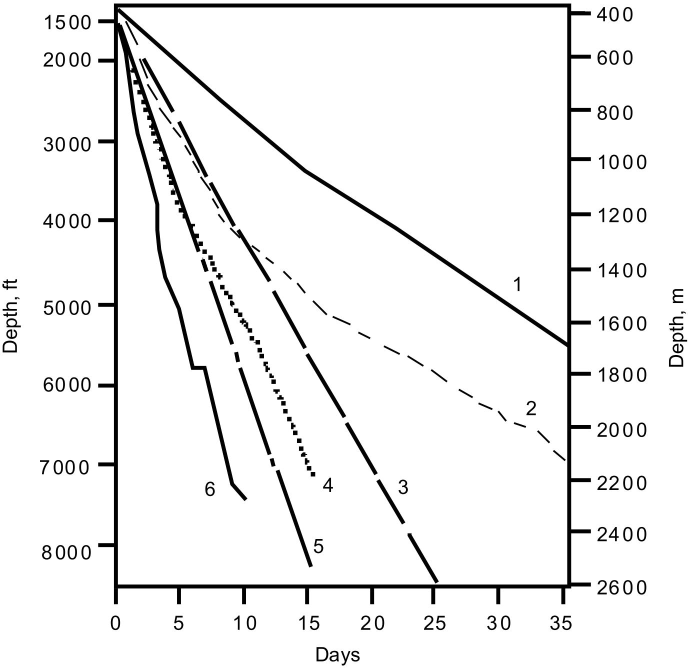

Fig. 6. Drilling time curve [4]. 1 – average results with conventional mud, 2 – best result with conventional mud, 3 – average result of rotary drilling with air mud, 4 – best result of rotary drilling with air mud, 5 – average result of rotary-percussion drilling, 6 – best result of rotary-percussion drilling

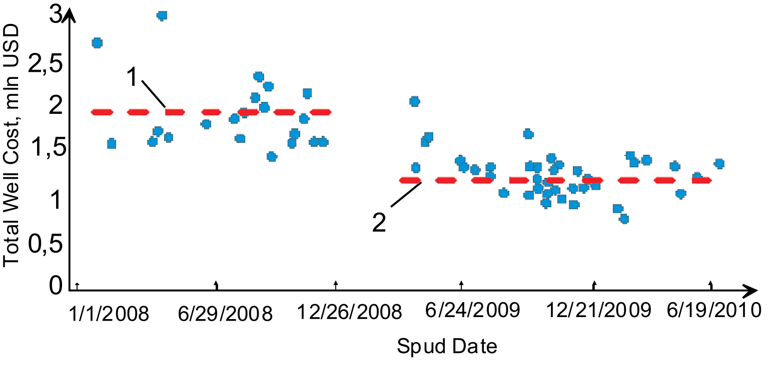

Fig. 7. Total Cost of Berea Wells (2008–2010). 1 – average well cost in 2008 (rotary drilling), 2 – average well cost in 2008–2009 (rotary-percussion drilling) [7]

This success led to testing DTH hammers in other American basins. Three geological formations in West Virginia and Kentucky had been chosen and a total of four trial wells were drilled. The first drilled formation to be tested was Ravencliff sandstone. The Ravencliff sandstones is a highly abrasive and well cemented formation with an unconfined compressive strength of 275,6 MPa. The Ravencliff had not been drilled horizontally but estimates made from drilling vertically through the Ravencliff using conventional assemblies showed ROP of 2–6 ft/hr with estimated bit runs of only 45 meters could be expected. Using BHA with DTH hammer ROP was increased to 12–18 m/h and expected bit runs heightened to even 150 m.

Subsequent formation where rotary-percussion technology was tested is Big Lime. This is a Mississipian carbonate located above the Berea. Previous horizontal drillings were drilled with roller cones with ROP of 7–12 m/h. Using DTH hammer, the ROPs were increased (7–12 m/h). Later PDC bits yielded ROP of 18–30 m/h. Consequently, in this carbonates formation the PDC bits are determined to be a better match.

The PDM-Percussion assembly was also trialed in the Lower Huron Siltstone, which has an unconfined compressive strength of above 96,5 MPa. Conventional assemblies using roller cone bits have previously drilled a horizontal section with ROP of 15–24 m/h. In the application with DTH hammer, the section was drilled with ROP of 18–27 m/h. A tiny difference between ROPs caused, that in this formation changing the BHA for this with DTH hammer was not economically effective.

4. POSSIBILITIES OF APPLICATION ROTARY-PERCUSSION DRILLING METHOD IN POLAND

Rotary-percussion method has been never applied in Oil&Gas industry in Poland. Nevertheless it is applied on a smaller scale in borehole heat exchangers, geoengineering or well. The main problem of this type of drills is no possibility of drilling in loose formations. The constant supply of groundwater and autogenous backfilling of the well, make the process of drilling less effective and increase total cost.

Therefore, first of all, should be drilled caprock of loose rocks with the application of rotary drilling method, then run casing tube, and finally rotary-percussion drilling method should be applied in hard formations. This is the reason, why rotary-percussion drilling method should be applied in the regions, where hard formations are situated below small cover of loose rocks.

In Polish slate basin, the biggest potential to apply described technology has Lublin basin, due to low thickness of loose formations (average 30 meters – mainly from Quaternary period, and writing chalk from Cretaceous period [10]. Baltic and Podlasie basin have considerably bigger thickness of adverse loose formations, what makes applications of rotary-percussion drilling method less profitable than in Lublin basin.

Thanks to the constant development and global dissemination of the above-mentioned technology, it is highly possible that in the nearest future it may become more popular and may be used during drilling operations in Poland.

5. CONCLUSIONS

From drills in the USA or Canada, to Brazil and China rotary-percussion drilling method showed better ROB than conventional method. This is more evident when the drilling takes place in hard, abrasive formations like granites, sandstones, dolomites and limestones. In most cases ROP was even three times bigger (China, Tarim), and in general speed of drilling was increased twice. Should not be forgotten disadvantages of described method, difficulties with drilling in loose formations, special drilling rig which can transmit the vibrations and appropriate mud (air, foam or clear water) are required. Application rotary-percussion drilling method to decrease the cost of drilling is reasonable only when geological conditions on drilling area are appropriate.

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