2009 American WJTA Conference and Expo
August 18-20,2009 • Houston,Texas

Paper

AN EXPERIMENTAL STUDY ON HYDRAULIC PULSED CAVITATION JET DRILLING IN DEEP WELLS

Li Gensheng, Shi Huaizhong, Huang Zhongwei, Zhang Zhiyun
China University of Petroleum (Beijing)
Beijing 102249, China

Luo Faqian, Kang Yanjun
Drill Technology Office of Tarim Oilfield Company, PETROCHINA
Kuerle, Xinjiang 841000, China

Wu Zhonghua, Nie Yunfei
Drilling Technology Research Institute of Shengli Petroleum Administration Bureau, SINOPEC
Dongying, Shandong 257062, China.

ABSTRACT

Hydraulic pulsed cavitation jet drilling is a combined drilling technology that the hydraulic pulsed cavitation jet generator is installed on the bit. Based on modulating pulse jet and cavitating jet, a new drilling tool is designed which couples advantage of both pulse jet and cavitating jet. When drilling fluid flows through tool during drilling process, fluid is modulated to pulse and cavitate. Thus, pulse cavitating jet is formed at outlet of bit nozzle. Because of jet pulsation, cavitating erosion and local negative pressure effect, bottomhole rock. cleaning and breaking is enhanced and penetration speed improved. The paper have studied the mechanism of increasing the rock breaking and clearing, improving rate of penetration （ROP） in hydraulic pulsed cavitation jet drilling process. Field experiments in three deep wells demonstrate that hydraulic pulsed cavitation jet drilling can more effectively change bottom flow field and improve rate of penetration. At the same time, Hydraulic pulsed cavitation jet drilling is quite adaptive in deep and ultra-deep wells.

INTRODUCTION

With the exploration and development of oil and gas in deep formation, especially the continual growing amount of more than 6000m ultra-deep well in western district of China, the complex condition in drilling process increases. At the same time, with the increase of well depth, the penetration rate decreases greatly and the cost of drilling increases rapidly, which directly influences the speed and pace of exploration and development. (Shen Zhonghou, 2005. Sun Ning, 2006. Wang Haige, 2005.)The slow rate of penetration （ROP） becomes bottle neck which restricts the development of drilling technology in deep well and ultra-deep well. How to improve the ROP has been one of the most important topics in drilling field. (Liu Rushan, 2005. Wang Zhifang, 2005. Yege J.C, 1981. Zeng Yijin, 2005.)

The problems of energy transfer, conversion, distribution, utilization efficiency of conventional drilling is still not resolved, especially integrated utilization efficiency is quite low in deep and ultra-deep well. Researchers all around the world have been trying to explore and study new drilling methods. As researches and tests shown, the transfer efficiency of hydraulic energy is much more than that of mechanic energy, and improving ROP by hydraulic pulse and cavitating jet technology is an effective method. (Li Gensheng, 2003, 2005.)

The drilling hydraulics in deep wells has some particularities; hydraulic factor is one of the most important factors which influence ROP in deep wells. Based on modulating hydraulic pulse and cavitating jet, a new drilling tool is designed which couples advantages of both pulse jet and cavitating jet. According to oilfield experiments in three ultra-deep wells, satisfactory results are obtained. (Li Gensheng, 2008.)

1. STRUCTURE AND OPERATING PRINCIPLE OF HYDRAULIC PULSED CAVITATION JET GENERATOR

The hydraulic pulsed cavitation jet generator consists of basement, snapring, baffle, impeller bed, impeller shaft, impeller and bushing components, and cavitating oscillation cavity as shown in Fig.1.

A baffle is placed on the top, whose most important part is slope flow channel. It could change the flow direction and the speed of the drilling fluid and generate the tangential force that could make impeller revolve continuously at a high speed. The impeller assembly mainly consists of the basement, impeller, impeller shaft and bushing. The impeller is installed on the shaft, and sits on the impeller bed coupled with bushing. In the presence of impulse force to impeller blade from the drilling fluid, impeller rotates at a high speed, changes the flow aisle areas continuously, and generates the impulse.

The self-resonating cavity placed at the bottom of tool to amplify the pulsating signal of drilling fluid and generate the fluid resonance. When the drilling fluid flows through cross-section outside the self-resonating cavity into the resonance nozzle, pulsation of pressure appears. The fluctuation of pressure is reflected into the resonance cavity and then feedback pressure oscillation is amplified. when the frequency of the pulsation of pressure equals with the frequency of resonance cavity, the feed back pressure oscillation is amplified, thus fluid acoustic resonance is generated in the resonance cavity, the intense pulsating turbulent circuit in the outlet of the flow, stroke the bottom of the well by pulsating pressure, improve the flow field of bottom of the well.

The hydraulic pulsed cavitation jet generator is placed on the top of the bit, which couples the advantages of both pulse jet and cavitating jet. When drilling fluid flows through tool during drilling process, fluid is modulated to pulse and cavitation. Thus, pulse cavitating jet is formed at outlet of bit nozzle. It generates three kinds of effects:

- Hydraulic pulse—To improve flow field at the bottom, and enhance the well purification and cuttings cleaning efficiency at the bottom of well, reduce pressure holds and regrinding;
- Cavitating erosion—To Assist the rock-broken, and enhance the rock-broken efficiency;
- Instantaneous negative pressure—To produce instantaneous negative pressure pulse at the bottom, and local instantaneous underbalance.

Pulse jet is formed around the jet nozzle. First, there will have a low-pressure area formed around the bit because of the pressure pulse generated by the hydraulic pulse generator, which could reduce the chip hold down effect caused by annulus fluid column pressure. This mechanism is similar to the underbalanced drilling and it can improve drilling speed greatly. (Huang Changwu, 2007. Long Zhihui, 2006. Zhou Weiyuan, 1993.)Meanwhile, the low-pressure area is limited to the local area around the bit while the whole annulus is still overbalanced, so it is a better method of stabilizing the wellbore than the underbalanced drilling. Second, when the pressure pulse is generated, the pressure will drop, so the vacuole will be formed around the bottom. At the same flow rate, the impulse pressure of cavitating jet is about 8.6~124.0 times than the dead pressure of continuous water jet; these could greatly enhance the bottom hole rock cleaning and breaking under low pressure water jet. (Yang Yongyin, 2002.)

The drilling tool combined with hydraulic pulse and cavitating jet, which is stimulated by hydraulic pulse and coupled with self-resonating jet from the nozzle, can greatly enhance the fluid pulse at the bottom. The negative pulse is instrumental to overcome the high peripheral pressure and promote to generate cavitating, which helps to enhance rock-broken efficiency, erase or alleviate the chip hold down effect, improve the purification at the bottom, avoid the repeating rock-broking and enhance the drilling speed.

2. HYDRAULIC PERFORMANCE TESTS OF HYDRAULIC PULSED CAVITATION JET GENERATOR

According to the charts of conventional drilling and hydraulic pulsed cavitation jet drilling origined from the above groud test, we can ascertain the regulation of impulse pressure, pulse frequency and pressure loss when the hydraulic pulsed cavitation jet generator is under different delivery rate.The test circuit is shown as Fig.2, the result was shown in Fig.3, and the analysis of the test result shown:

(1) When the flow rate is fixed between 27.5~32.0L/s, hydraulic pulse and cavitating jet drilling

tool generates obvious pressure pulse（1.5~2.2MPa）and the amplitude multiplies with the flow rate increasing.
(2) The pulse frequency of hydraulic pulse and cavitating jet drilling tool was slow multiply with the flow rate. At the rate of 32.0L/s, the pulse frequency was about 10Hz.
(3) When the test flow rate is fixed between 27.5~32.0L/s, the pressure loss of hydraulic pulse and cavitating jet drilling tool is between 0.56 ~0.60MPa.

3. APPLICATIONS OF HYDRAULIC PULSED CAVITATION JET DRILLING IN ULTRA-DEEP WELLS

Hydraulic pulsed cavitation jet drilling technology has been applied in ultra-deep wells about 6500m in Zhonggu block of Tarim Oilfield and Yuanba district in the northeast of Sichuan basin. The drilling interval of well with bit size 311.2mm(12 1/4″) in Yuanba block is lower Jurassic system ziliujing formation, which contains tight gray fine sandstone and mudstone formation, having poor drillability and low penetration rate.
The drilling interval of well with bit size 311.2mm (12 1/4″) in Zhonggu block drilled through the Carboniferous, Devonian, Silurian system and Ordovician Sangtamu formation. Which is mainly consisted of limestone, shale, sandstone and drillability level 5 ~ 7, medium~hard formation, and low penetration rate.

3.1 Test Wells Introduction

The borehole with bit size 311.2mm(12 1/4″) in well Zhonggu-162 was drilled to 4125m, and the casing was run down to 4124m then cemented. Afterwards it drilled deeper through cement plug by using drill bit HJ517G with bit size of 215.9mm(8 1/2″), and pulled out of hole at 4184m, then installed hydraulic pulsed cavitation jet generator to start the drilling experiment until bit size 215.9mm(8 1/2″) finish drilling. During the test, the tool was applied with screwdrill in parts of well sections.

The borehole with bit size 311.2mm(12 1/4″) in well Zhonggu-171 was drilled to 4142m, and the casing was run down to 4140m then cemented. Afterwards it drilled deeper through cement plug by using drill bit HJ517G with bit size of 215.9mm(8 1/2″), and pulled out of hole at 4193m, then installed hydraulic pulsed cavitation jet generator to start the field experiment. When drilled to 5567 m, pulled the pipe out of hole to change bit and check out hydraulic pulsed cavitation jet generator, the impeller didn't have erosion or damage on the whole after continuously working for 485 hours, But considering downhole safety, a new hydraulic pulsed cavitation jet generator was used. The tests were not completed until the third interval finished drilling.

3.2 Adaptability of Hydraulic Pulsed Cavitation Jet Generator to Drill Bit

In order to verify the adaptability of hydraulic pulsed cavitation jet generator to drill bit, tests were processed by using two different types bits of M1355SG and FS2563BGZ, which were produced by different manufacturers and designed with different nozzles.

It consumed two FS2563BGZ bits and one M1355SG bit in test well Zhonggu-162. And three bits of M1355SG in test well Zhonggu-171. Meanwhile seven bits were consumed for each neighboring wells, that depends on bit type selection, but it also demonstrated that there is no particular requirements for drill bit when using hydraulic pulsed cavitation jet genentor. At the same time, it can prolong the service lives of the bits.

3.3 Bottom Hole Assembly

The bottom hole assembly（BHA） was assembled as follows when using hydraulic pulsed cavitation jet generator in test well Zhonggu-162 and Zhonggu-171, as shown in Table 1.

Φ8 1/2"Bit+Φ7" hydraulic pulsed cavitation jet generator +Φ6 1/4"DC*2 +Φ8 1/2"LF*1 +Φ6 1/4"DC*1+Φ8 1/2"LF*1+Φ6 1/4"LDC*17+Φ5"WDP+Φ5"*DP
There is no change of BHA during the tests except fixing hydraulic pulsed cavitation jet generator on the bit. The hydraulic pulsed cavitation jet generator doesn't have special requirements for the bit so it has good adaptabilities.

3.4 Test Parameters

Hydraulic pulsed cavitation jet drilling test parameters are shown in Table 2. As can be seen from Table 2, no special drilling parameters are requested by hydraulic pulsed cavitation jet drilling. The drilling parameters of Zhonggu-162 and Zhonggu-171 well were not deliberately adjusted in the test section. Pump pressure, displacement, weight on bit（WOB） and speed are basically the same as that of compared wells, only drilling fluid density used in the test wells slightly smaller than the adjacent wells which were fixed by the drilling team and not the special requirements of the experiments.

3.5 Tests Results Analysis

The results are shown in Table 3 and Tigure 4 according to field tests in ultra-deep wells. The average ROP is 3.88m/h in well Zhonggu-162 and 3.09m/h in well Zhonggu-171, the average ROP of the two well is 3.45m/h. The ROP increased by 84.73% in Zhonggu-162 and 47.1% in Zhonggu-171 compared to neighboring well Zhonggu-16 and Zhonggu-17, the total average ROP raised by 61.9% in the two wells.

The pure drilling time is 44.5h and average ROP is 0.949m/h by using hydraulic pulsed cavitation jet generator in drilling test interval 4100~4142m of well Yuanba-12, finally the test consumed two tri-cone bits and the total drilling footage is 42m. Compared with the drilling interval 4083~4100m by using conventional drilling, the average ROP increased by 32.4% with the same drilling parameters.

The drilling time consumed in Zhonggu-162 and Zhonggu-171 well is obviously less than that of adjacent wells which can be seen in the Fig.4.

Test wells used hydraulic pulsed cavitation jet drilling technology which ROP improve significantly compared to neighboring wells. In addition, there have some other factors that can affect the ROP: 1.The bit size was 12 1/4" in Carboniferous section of the comparison well. 2. The drilling fluid density of test well was a little less than the comparison wells.3.There has part of borehole of Zhonggu-162 was matched with screwdrill.

4.CONCLUSION

(1).The ROP can be improved by using hydraulic pulsed cavitation jet generator which also can decrease rock strength and get fractured rock removed timely from the bottom of well, and reduce the repeat cutting and chip hold down effect.
(2).The tests in deep and ultra-deep wells have approved that hydraulic pulsed cavitation jet drilling can enhance the drilling efficiency and ROP. Compared with the neighboring well, the ROP was improved by 61.88% at Zhonggu-162 and about 32.4% at Yuanba-171.
(3)The performance of hydro pulse and cavitating jet drilling tool is steady, the quantity is reliable and its life can meet the desire time of bit and screwdrill. Hydraulic pulsed cavitation jet drilling is quite adaptive in deep and ultra-deep wells.
(4)There only have used 3 drill bits in the two test wells of Zhonggu oilfield, but in two comparing wells have used 7 drill bits, it is shown that hydraulic pulse and cavitating jet drilling can increase the life of drill bit.

ACKNOWLEDGMENTS

The authors express their appreciations to the Key Projects of Ministry of Education of China （No.306003） and the Ph. D. Programs Foundation of Ministry of Education of China (No. 20070425006) for the financial supports of this work..

REFERENCES

Huang, Changwu. “The future development of drilling technology.” *Petroleum Exploration and Development*. 34. 6 (2007): 723.

Li, Gensheng, Shen Zhonghou, and Zhou Changshan. “Advances in Investigation and Application of Self-resonating Cavitating Water Jet.”*Engineering science*. 7.1 (2005): 27～32.

Li, Gensheng, Shen Zhonghou, and Zhang Zhaoping. “Development and Field Tests of Self-Resonating Cavitating Water Jet Nozzle for Oilwell Drilling.” *Petroleum drilling techniques*. 31. 5 (2003): 11～12.

Li, Gensheng, Shi Huaizhong, and Huang Zhongwei. “Mechanisms and tests for hydraulic pulsed cavitating jet assisted drilling.” *Petroleum Exploration and Development*. 35. 2 (2008): 256～60.

Liu, Rushan, Zhu Dewu. “Main Technical Difficulties Encountered While Drilling Deep Wells and Countermeasures.” *Petroleum drilling techniques*. 33. 5 (2005): 6～10.

Long, Zhihui, Wang Zhiming, and Fan Jun. “A dynamic modeling of underbalanced drilling multiphase-flow and numerical calculation.” *Petroleum Exploration and Development*. 33. 6 (2006): 749～53.

Shen, Zhonghou. “Development trend of the modern drilling technology.” *Petroleum Exploration and Development* 32. 1 (2005): 89～91.

Sun, Ning, Su Yinao, and Li Gensheng. *Drilling Engineering Technical Progress*. Beijing: Petroleum Industry Press, 2006.

Wang, Haige, Zheng Xinquan. “Status Quo And Faced Challenges Of Deep Well Drilling

Technuqyes Of Petrochina. ” *Oil Drilling & Production Technology* 27. 2 (2005): 4～8.
Wang, Zhifeng. “Discussion on Theory & Methodology of Suction-Pulse Drilling Technique.”*Oil Drilling & Production Technology*. 27. 6 (2005): 13～15.
Yang, Yongyin, Shen Zhouhou, and Wang Ruihe. “Analysis of the Mechanisms of Improving ROP Using Low Pressure Pulse Jetting Techniques in Under-Balanced Drilling.” *Petroleum drilling techniques*. 30. 5 (2002): 15～16.
Yege, J.C, N.G.W Chuck, Trans. *The basis of rock mechanics*. By Chinese Academy of Engineering Mechanics Institute. Beijing: Science Press, 1981.
Zeng, Yijin, Liu Jianli. “Technical Status and Developmental Trend of Drilling Techniques in Deep and Ultra-Deep Wells.” *Petroleum drilling techniques*. 33. 5 (2005): 1～5.
Zhou, Weiyuan. *High Rock Mechanics*. Beijing: China WaterPower Press, 1993.

TABLES

Table 1 The parameters of test bits and nozzles

Bit type	Bit Size (mm)	Nozzle Size (mm)	Nozzle Number
PDC (M1355SG)	215.9	14.3	5
PDC (FS2563BGZ)	215.9	14.3	7
Three-cone Bit(HJT537GK)	311.2	17×18×18	3

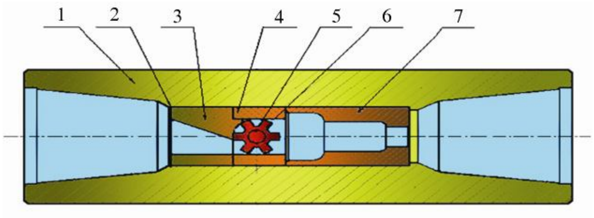
Table 2. The comparison of drilling parameters

	Well Names	Bit size	Pump Pressure (MPa)	Displacement (L/s)	Bit Weight (kN)	Rotation Speed (r/min)	Mud Density (g/cm^3)
Test Well	Zhonggu162	PDC(M1355SG, FS2563BGZ)	18-21	27-30	40-80	40-80	1.16-1.22
	Zhonggu171	PDC(M1355SG)	17-20	27-33	30-120	80	1.14-1.26
Comparison Well	Zhonggu16	PDC(M1655SS)	15-20	28-38	60-150	65-90	1.24-1.25
	Zhonggu17	PDC(M1655SS)	18-21	32-40	80-100	65-115	1.24-1.26
Test well	Yuanba12	Cone bit (HJT537GK)	19	42	240	40	1.55
Comparison Well	Yuanba12	Cone bit (HJT537GK)	19	42	240	40	1.50

Table 3 The comparison of the test results

Well NO.		Drilling Interval (m)	Pure Drilling Time(h)	ROP(m/h)	Average Drilling Speed (m/h)	ROP Increment(%)
Tests Interval	Zhonggu-162	4184-6114	497.3	3.88	3.45	61.9
	Zhonggu-171	4193-6036	596.3	3.09		
Compared Interval	Zhonggu-16	4120-6055	1057.7	1.83	2.13	
	Zhonggu-17	4250-6175	753.3	2.56		
Tests Interval	Yuanba-12	4100～4142	44.5	0.94	0.94	32.4
Compared Interval	Yuanba-12	4083～4100	23.9	0.71	0.71	

GRAPHICS



1——Basement; 2——Snapring; 3——baffle; 4——Impeller bed;
5——Impeller shaft; 6——impeller and bushing components; 7——Cavitating oscillation cavity

Fig.1 Hydraulic pulsed cavitation jet generator configuration

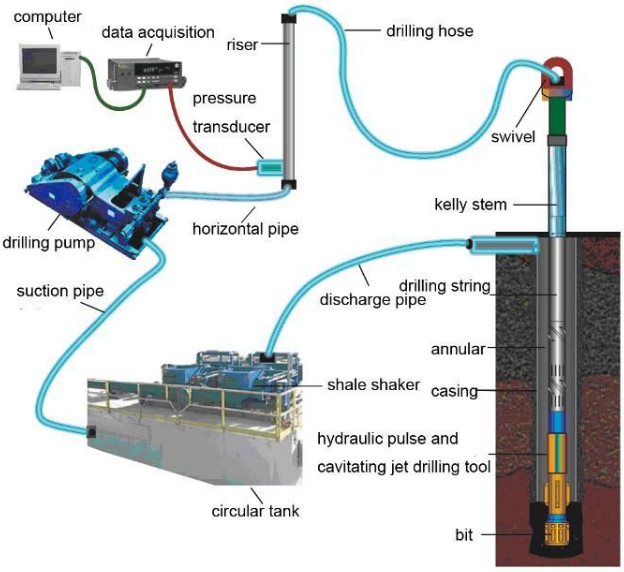


Fig.2 Diagram of connection of the equipments in field test

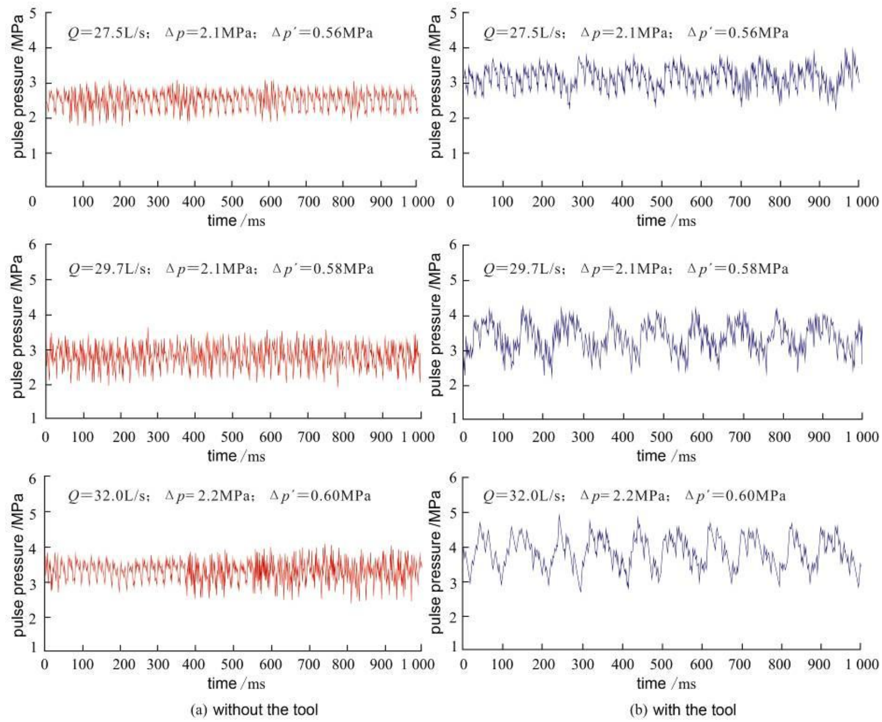


Fig.3 The plots of the results of the tool in field test

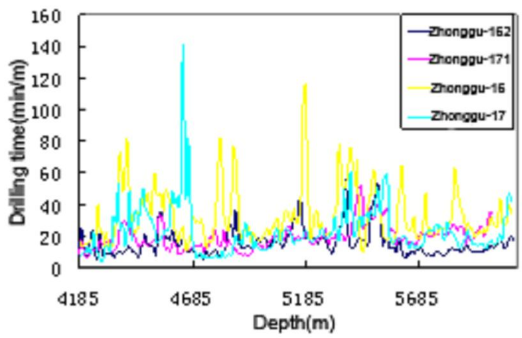


Fig.4 The comparison diagram of ROP between test well and adjacent well