Pet.Sci.(2014)11:122-130
DOI 10.1007/s12182-014-0323-8

Operation optimization of plugged screen cleanup by rotary water jetting

Dong Changyin[1]*, Li Yanlong[1], Long Jiajia[1], Zhang Qinghua[1], Wang Dengqing[2] and Wu Jianping[2]

[1] College of Petroleum Engineering, China University of Petroleum, Qingdao, Shandong 266580, China
[2] Research Institute of Production Technology, Shengli Oilfield, SINOPEC, Dongying, Shandong 257000, China

Abstract: The rotary water jetting is one of the most important techniques for horizontal well cleanup. The jet flow is used to remove plugging particles from sand control screens to recover their permeability. Currently, the operation optimization of this technique depends mainly on experience due to absence of applicable evaluation and design models for removing plugging materials. This paper presents an experimental setup to simulate the cleanup process of plugged screens by rotary water jetting on the surface and to evaluate the performance of a jetting tool. Using real plugged screens pulled from damaged wells, a series of tests were performed, and the qualitative relationships between the cleanup efficiency and various operational parameters, such as the type of fluids used, flow rate, mode of tool movement, etc., were obtained. The test results indicated that the cleanup performance was much better when the rotary jetting tool moved and stopped periodically for a certain time than that when it reciprocated at a constant speed. To be exact, it was desirable for the rotary jetting tool to move for 1.5-2 m and stop for 2-4 min, which was called the “move-stop-move” mode. Good cleanup performance could be obtained at high flow rates, and the flow rate was recommended to be no lower than 550-600 L/min. The test results also indicated that complex mud acid was better than clean water in terms of cleanup performance. Good cleanup efficiency and high screen permeability recovery could be achieved for severely plugged screens. Rotary jetting is preferred for the cleanup of horizontal wells with severely plugged screens, and the screen permeability recovery ratio may reach 20% if optimized operation parameters were used.

Key words: Sand control screen, cleanup performance, rotary jetting, operation optimization, experimental simulation

1 Introduction

Sand production is one of the most intractable problems of unconsolidated sandstone reservoirs in gas and oil production. Mechanical screens and gravel packing are two major categories of sand control techniques used to deal with sand production problems in horizontal wells. For a well with sand control, the sand retention media are likely to be plugged due to silts, clays, and mechanical debris produced during the production process and carried by formation fluids (Asadi and Penny, 2000a; 2000b; Asadi and Conway, 2001; Dong et al, 2011; Fattahpour et al, 2012; McElfresh and Welch, 2008). The productivity of a horizontal well is thus affected due to the low permeability of plugged sand retention media. Plugging of sand control media has become one of major problems affecting the normal production of horizontal wells (Dong et al, 2011; Guan et al, 2002; Hu et al, 2004; Liu et al, 2010; Zhang et al, 2007).

Many studies were focused on the mechanism of downhole screen plugging and cleanup technologies, especially for horizontal wells with metallic screens for sand control. Sand control screens can sustain only a slight degree of plugging, without significantly influencing the well productivity (Ali and Dearing, 1996; Asadi and Conway, 2001). However, the low permeability due to screen plugging is really one of the main causes of well productivity decline (Dong et al, 2011). The main causes of screen plugging may be the invasion into sand retention media by drilling fluids while running the screen (Garcia-Orrego, 2005; Lau and Davis, 1997; Ladva et al, 1998), or by silts, clays, mechanical debris, scale and polymer derivatives produced during the production process (Guan et al, 2002; Hu et al, 2004; Dong et al, 2011). Larsen (2012) put forward a new model for reasonable screen slot width design to prevent the screen from plugging by formation sands only, but not clays, silts and other plugging media. Screen cleanup is the main treatment to remove the screen damage and a series of screen cleanup

*Corresponding author. email: dongcy@upc.edu.cn
Received April 12, 2013

techniques have been developed, which involve flushing and dissolving with acid (Browne et al, 1995; Lau and Davis, 1997; Ladva et al, 1998; Asadi and Penny, 2000a; 2000b) or biological enzymes (Zhang et al, 2013) and physical and chemical washing by jet flow (Asadi, 1999; Stanley et al, 2004; Mao et al, 2002; Huang et al, 2004; 2006; 2008; Li et al, 1998; 2002; 2005; Wang et al, 2001; Zhang and Pu, 2004; McCulloch et al, 2003).

High pressure rotary jetting is one of the effective methods for removing plugging materials and debris in screens in horizontal wells. The high pressure jet flow from the rotary nozzle can directly flush and clean the screens (Mao et al, 2002; Huang et al, 2004; 2006; 2008; Li et al, 1998; 2002; 2005; Wang et al, 2001; Zhang and Pu, 2004). The cleanup performance is directly related to fluid type, flow rate, tool moving velocity, etc. Currently, the optimization of cleanup operation parameters mainly depends on experience and little work has been done concerning cleanup performance prediction and evaluation. In this work, the cleanup performance was evaluated by using the designed experimental setup. The cleanup tests were conducted with the use of real plugged screens pulled from damaged wells. The effects of fluid type, flow rate and mode of tool movement on the cleanup performance were analyzed to obtain the optimal operation parameters and a new preliminary cleanup evaluation model was developed.

2 Experimental setup and procedure of cleanup of plugged screens

2.1 Experimental setup and materials

The rotary jet ejector is the key component of water jetting cleanup systems for plugged sand control horizontal wells. The ejector with four 3-mm-diameter holes is rotated by the high pressure jet while the tool moves with the string. The high pressure jet flow produced by the rotary ejector can directly flush the screens. By reciprocating the rotary ejector several times, the plugged screens can be reopened.

As shown in Figs. 1 and 2, the experimental setup was consisted of a horizontal wellbore simulator, a plugged screen, rotary jet assembly, a pumping unit, a storage tank, and a data acquisition and measuring system. In order to simulate field operation conditions, a pump truck was used to maintain the required high flow rate and pressure. The specifications of the experimental setup are listed in Table 1.

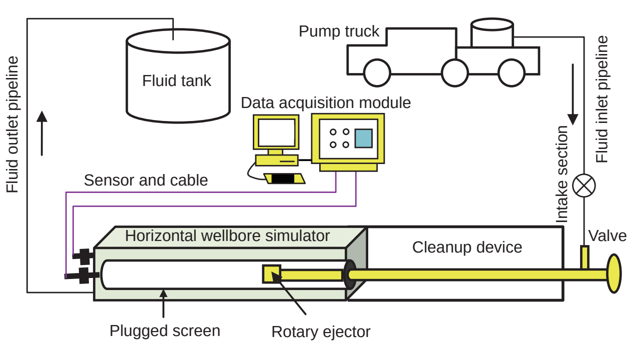


Fig. 1 Schematic of experimental setup for cleanup of plugged screens

Fig. 2 Photograph of the experimental setup

Table 1 Specifications of the experimental setup

Specifications		Value
Wellbore simulator	Length/width/height, mm	5200/400/400
	Number of drain holes	5
	Diameter of the drain hole, mm	30
Screen	Type	Metal cotton
	Length, m	4.8
	OD, mm	140
	ID, mm	108
	Hole size, mm	10
	Hole spacing, mm	30-35
Jetting tool	OD, mm	101
	Number of holes	4
	Diameter of the hole, mm	3
	Reciprocating length, m	4.2
Pumping parameters	Flow rate, m^3/min	0.25-0.75
	Pump pressure, MPa	18-30
	Pressure rating, MPa	40

The tests were conducted under ambient pressure and temperature, in which clean water and mud acid were used as flushing fluids. The mud acid was composed of 4%-6% HF, 10-15% HCl and chemical additive, the ratio of each component could be adjusted according to the well parameters, such as clay content and oil viscosity. The plugged screens used in tests were pulled from the damaged wells in the Gudao Oilfield. The screens were type of metal cotton screens, composed of inner base pipe, in-between sand retention media of metal cotton and outer protective cover pipe. Holes with a diameter of 10 mm and spacing of 30-35 mm were evenly distributed on the cover pipe, as shown in Fig. 3.

2.2 Test procedures

The test procedures for cleanup of plugged screens are as follows:

1) The plugged screen equipped with a rotary jetting tool was put into the horizontal well simulator.

2) The plugged screen was immersed in water for 20 min to simulate real downhole conditions.

3) The flushing fluid was pumped into the screen

Fig. 3 Plugged metal cotton screens used in the tests

through the jetting tool. The flow rate and jet pressure (i.e. the pressure inside the screen) with time were recorded continuously. According to the field data, the flow rate was kept at 400-600 L/min.

When the flow rate remained unchanged, low pressure inside the screen indicated high screen permeability. As the test continued, the screen pressure decreased, indicating high cleanup efficiency and thus low pressure loss through the screen. The permeability of the screen can be calculated from data of screen size, flow rate, and pressure drop across the screen:

$$k = \frac{Q\mu_l \cdot \ln(r_o / r_i)}{2\pi L(P_i - P_o)} \quad (1)$$

where k is the permeability of the screen after cleanup, m^2; Q is the flow rate, m^3/s; μ_l is the viscosity of the flushing fluid, Pa·s; r_o and r_i are the outside and inside radii of the screen, m; L is the cleanup length of the screen, m; P_i is the pressure inside the screen, Pa; P_o is the pressure outside the screen, i.e. atmospheric pressure of 101,325 Pa.

3 Test results and analysis

3.1 Tests arrangement and implementation

A total of ten screens were used to perform cleanup tests and some test data are summarized in Table 2. For the same screen, test locations A, B, C or D just indicated different locations where the rotary jetting tool was temporarily fixed manually at a high pump pressure. The distance between different locations is unfixed.

3.2 Result analysis

3.2.1 Screen No. 1

Cleanup test 1 was conducted on screen No. 1 using clean water at a flow rate of 500 L/min and a pump pressure of 17 MPa. The changes of pressure and permeability with time are shown in Fig. 4. This test was conducted in two stages:

Stage 1 (0-35 s): The counteracting force on the screen end was very high due to the high jet pressure at this stage. The rotary jetting tool moved rapidly from front to back and it is difficult to keep it stationary manually. Therefore, the

Table 2 Test data of cleanup tests performed on 10 screens

Test No.	Screen No.	Flushing fluid	Testing stage/Location	Flow rate L/min	Pump pressure MPa	Time duration s
Test 1	1	Water	Stage 1	500	17.0	36
			Stage 2	500	17.0	29
Test 2	2	Water	Stage 1/Location A	400	10.0	700
			Stage 2/Location B	400	10.0	700
			Stage 3/Location C	550	18.0	480
			Stage 4/Location D	550	18.0	620
Test 3	3	Water	Stage 1/Location A	400	12.0	400
			Stage 2/Location A	500	17.0	270
			Stage 3/Location B	500	17.0	360
			Stage 4/Location C	500	17.0	130
			Stage 5/Location D	500	17.0	410
			Stage 6/Location E	500	17.0	270
Test 4	4	Water	Stage 1/Location A	550	17.0	560
			Stage 2/Location B	550	17.0	300
Test 5	5	Mud acid	Stage 1/Location A	400	12.0	100
			Stage 2/Location A	500	17.0	600
			Stage 3/Location B	500	17.0	800
			Stage 4/Location B	600	25.0	900
Test 6	6	Mud acid	Stage 1/Location A	350	11.5	350
			Stage 2/Location B	450	13.0	400
Test 7	7	Mud acid	Stage 1/Location A	500	15.0	320
			Stage 2/Location B	500	15.0	450
Test 8	8	Water	Stage 1/Location A	400	10.0	220
			Stage 2/Location B	400	10.0	250
Test 9	9	Water	Stage 1/Location A	600	22.0	450
Test 10	10	Water	Stage 1/Location A	550	19.0	290

pressure inside the screen showed an irregular change. The screen permeability was about 0.3 μm^2. The fast reciprocation of the rotary jetting tool resulted in a poor cleanup efficiency.

Stage 2 (35-67 s): At 35 s, the rotary jetting tool reached to the end of the screen and remained stationary. The pressure was raised to 0.75 MPa and then decreased as the cleanup process continued. The permeability was recovered to 3.5 μm^2 at 65 s. This proved that the stationary jetting has high cleanup efficiency even if the time duration was short. Fig. 5 shows the photograph of outlet flow at location B of screen No. 1 after 65 s of cleanup. Apparently, some of the screen holes were opened, but some still remained plugged.

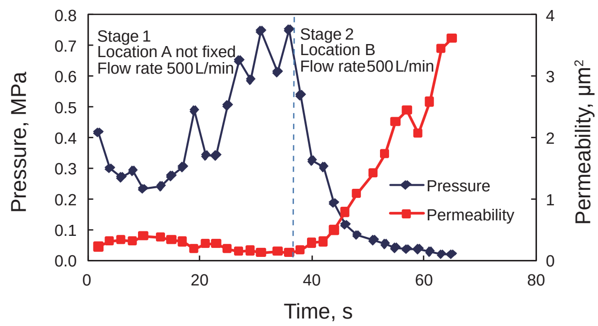


Fig. 4 Measured pressure and permeability varying with time for screen No. 1

Fig. 5 Photograph of outlet flow at location B of screen No. 1 after cleanup

3.2.2 Screens No. 2 and No. 8

A pressure of 10 MPa or 18 MPa was applied to screen No. 2. The rotary jetting tool was placed at four locations with variable flow rates. The pressure in the screen and permeability changes with time are plotted in Fig. 6. The test was divided into four stages:

Stage 1 at location A (0-700 s): It was hard to keep the rotary jetting tool stationary manually due to high counteracting force on the end of the screen, which led to an irregular change in screen pressure and permeability, and poor cleanup performance.

Stage 2 at location B (700-1,400 s): At a flow rate of 400 L/min, the pressure inside the screen fell slowly and hence the permeability was gradually restored, i.e. from 0.6 μm^2 to 0.9 μm^2 in 700 seconds.

Stage 3 at location C (1,500-1,850 s): The screen pressure increased sharply as the flow rate rose to 550 L/min, and then decreased gradually as the test continued. The permeability recovered rapidly from 0.9 μm^2 to 1.8 μm^2 in 350 s. This illustrated that the rate of permeability recovery at a flow rate of 400 L/min was much lower than that at 550 L/min.

Stage 4 at location D (2,000-2,500 s): At the new location D the flow rate was kept at 550 L/min, the screen pressure increased rapidly and then decreased fast as the test continued, indicating a rapid screen permeability recovery. It should be noted that with the jetting tool moving from location C to location D where the plugging material and debris had not been removed, a steeply increasing pressure was observed, indicating low permeability of the plugged location D. As a result, the permeability at the start of stage 4 was lower than the permeability at the end of stage 3.

Fig. 7 shows screen permeability varying with time for screen No. 2. In stage 1 at location A, as the jet flow continued, the screen permeability was gradually restored from 0.2 μm^2 to 1.6 μm^2, indicating good cleanup efficiency. In stage 2 at location B, a similar tendency was observed.

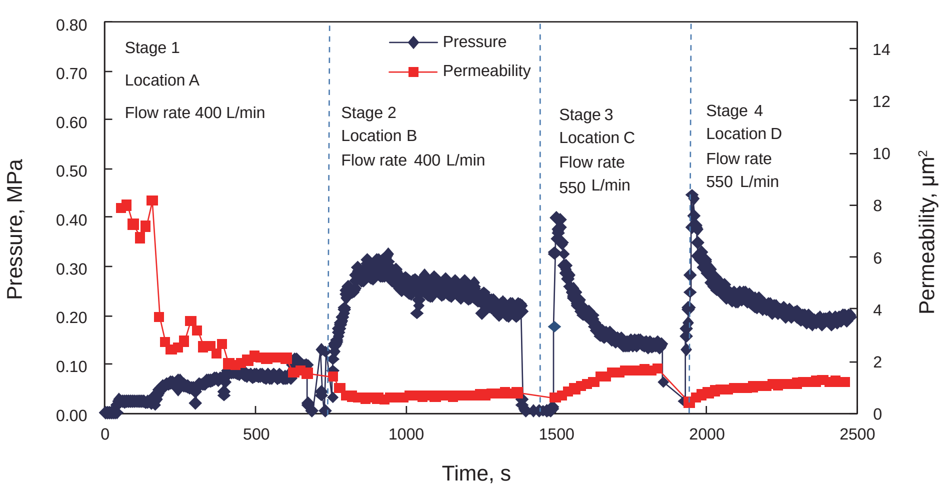


Fig. 6 Measured screen pressure and permeability varying with time for screen No. 2

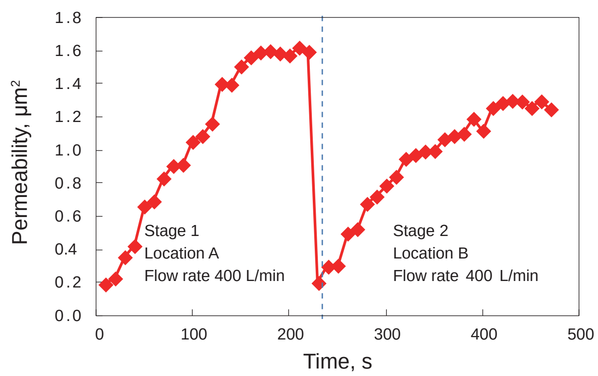


Fig. 7 Screen permeability varying with time for screen No. 8

Fig. 8 Photograph of outlet flow at location D of screen No. 2 after cleanup

Fig. 8 shows the photograph of outlet flow at location D of screen No. 2 after cleanup, in which a few holes were reopened. Due to different plugging severity, the screen pressure decreased rapidly once the holes with light plugging severity were cleaned up, and the other plugged holes were not reopened due to the reduction in pressure. Then the rotary jetting tool would be moved to the next location.

3.2.3 Screens No. 3 and No. 4

Clean water was used to remove the materials and debris plugging screens No. 3 and No. 4. The test results are shown in Figs. 9 and 10. At a flow rate of 400-500 L/min, the pressures in screens No. 3 and No. 4 were only 0.1-0.2 MPa, which indicated that these two screens were slightly plugged, and the pressure change could not represent the cleanup

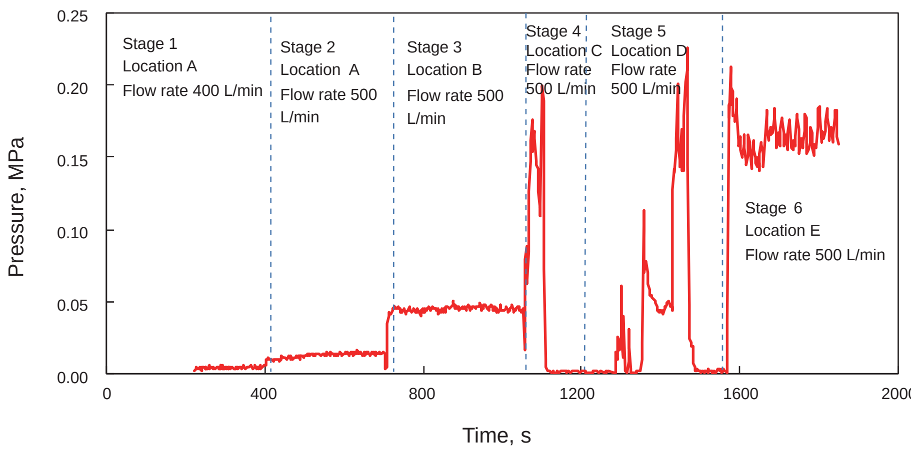


Fig. 9 Screen pressure varying with time for screen No. 3

process. Therefore, the rotary jetting was not effective for slightly plugged screens, and it is more applicable to severely plugged screens.

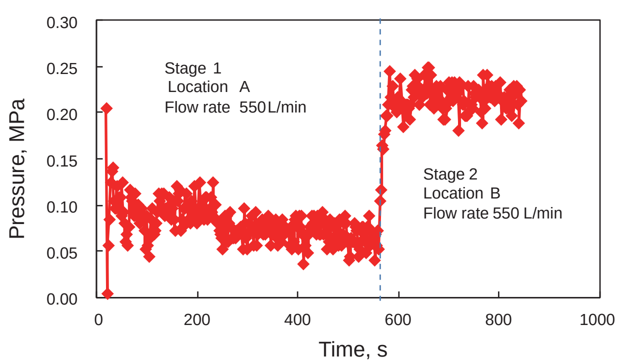


Fig. 10 Pressure inside screen No. 4 varying with time

3.2.4 Screen No. 5

Mud acid was used to flush screen No. 5 at a flow rate of 400-500 L/min. The rotary jetting tool was fixed at 4 locations for total 40 min. The screen after test is shown in Fig. 11. Fig. 12 shows the pictures of screen No. 5 before and after cleanup. As well as the fluid flush effect, which is the same as water, the mud acid can also dissolve clay, rust, and partial carbonate scales, and is more effective than water in removing materials and debris plugged in the screens. As a result, uniform flow and high permeability were achieved by the cleanup operation with mud acid.

4 Optimization of operational parameters

4.1 Tool movement mode

In conventional practice (test No. 1), the jetting tool was moved back and forth alternately (reciprocatingly) several

Fig. 11 Photograph of screen No. 5 flow after cleanup with mud acid

(a) Before cleanup

(b) After cleanup

Fig. 12 A comparison between screen No. 5 before and after cleanup

times at a constant speed to remove the plugging materials in the screens. The tests discussed here proved that satisfactory cleanup effectiveness could not be achieved when the rotary jetting tool was moving; but good cleanup could be achieved when the jetting tool stays stationary periodically. Therefore rather than moving at a constant speed, the "move-stop-move" mode is recommended, i.e. the rotary jetting tool remains stationary for some time and then moves ahead for a certain distance of 1.5-2 m and stops again.

4.2 Retention time

Fig. 13 shows the variations of pressure and permeability varying with retention time at location C and D in screen No. 2 during cleanup test. At the initial stage, the screen permeability increased abruptly and then changed gradually. This indicated that good cleanup performance was achieved at the initial stage, and then water jetting had little effect on removal of plugging materials. Therefore, if the mode of "move-stop-move" is used in field operation, staying stationary for 2-4 min at each location is recommended for the jetting tool.

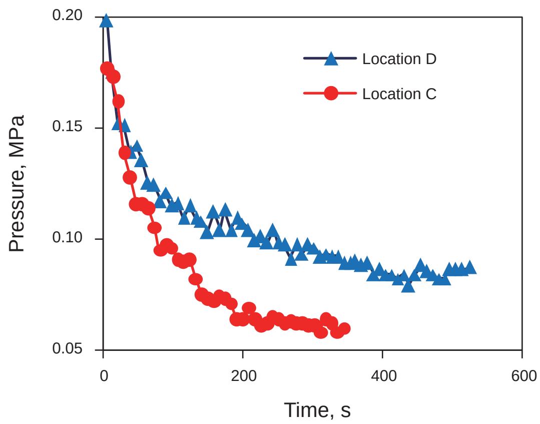
4.3 Flow rate

A comparison of flow rates in test No. 2 (screen No. 2) (Fig. 6) shows that at low flow rates the pressure decreased slowly and the permeability increased gradually; however, at high flow rates, the pressure decreased rapidly and the permeability recovered drastically. The permeability recovery rate was much lower at a flow rate of 400 L/min than that at 550 L/min, indicating better cleanup performance at higher flow rates. A water flow rate of 550-600 L/min is recommended for actual cleanup operations.

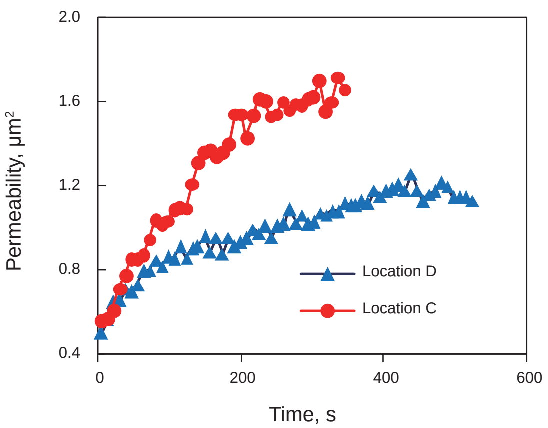
4.4 Cleanup fluid type and original plugging severity

A comparison between mud acid of HF-HCl type and clean water indicated that the mud acid was more effective in removing plugging materials due to its combined effects of erosion and dissolution. Therefore, the mud acid is recommended for field use. However, its damage to reservoir formations must be considered and some measures should be taken to minimize such damage and its extra costs.

In order to analyze the relationship of cleanup performance and plugging severity, the screens of No. 1,



(a) Screen pressure versus time



(b) Screen permeability versus time

Fig. 13 Cleanup performance of water jetting at different locations vs. time for screen No. 2

No. 2, No. 3 and No. 4 with different plugging severity were used to perform the cleanup tests. The tests show that the permeability recovery values of more severely plugged screens No. 1 and No. 2 were higher than those of slightly plugged screens No. 3 and No. 4. Therefore, cleanup operations are not recommended for slightly plugged screens.

4.5 Confining pressure

The materials and apparatus used in the tests were similar to the real situation of clean out of actual plugged horizontal wells, the only difference lay in the downhole confining pressure. In real wells, the screen and the rotary jetting tool are surrounded by formation fluid with a high bottomhole pressure. However, in the surface experiments, the confining pressure inside the screen was very low and the pressure outside the screen was just the atmospheric pressure, which was much less than the real bottomhole pressure. The confining pressure would obviously influence the cleanup efficiency of the rotary jetting. Low confining pressure would be helpful for the physical flushing of jet flow and lead to good cleanup efficiency. So, in actual well clean up, it will be more difficult to achieve the same cleanup efficiency as was achieved in the surface experiments.

5 Empirical prediction model

5.1 Return permeability model

The permeability of sand retention media can be restored partially in cleanup operations conducted on sand control wells. The ratio of the return permeability after cleanup test to the original screen permeability before plugging can be expressed:

$$k_r = \frac{k_s}{k_{s0}} \tag{2}$$

where k_{s0} is the original screen permeability before plugging; k_s is the return permeability of the screen after cleanup; k_r is the ratio of the return permeability after cleanup test to the initial screen permeability before plugging.

The return permeability of the screen after cleanup k_s is related to the permeability of the plugged screen before cleanup test, expressed as k_{sd}. To describe their relationship, a coefficient, named permeability recovery coefficient X_s, is put forward, which is defined as the recovery ratio of partially damaged permeability due to plugging recovered by cleanup measures.

$$X_S = \frac{k_s - k_{sd}}{k_{s0} - k_{sd}} \tag{3}$$

So, k_s can be expressed as:

$$k_s = k_{sd} + \left(k_{s0} - k_{sd}\right) X_S \tag{4}$$

where k_{sd} is the permeability of the plugged screen before cleanup test; X_S is the permeability recovery coefficient, which refers to the recovery coefficient of plugged permeability recovered by cleanup measures.

The ratio of the return permeability after the cleanup test to the initial screen permeability before plugging, k_r, can be expressed as:

$$k_r = \frac{k_{sd}}{k_{s0}} + \left(1 - \frac{k_{sd}}{k_{s0}}\right) X_S \tag{5}$$

This coefficient affecting cleanup efficiency involves the original plugged permeability, flow rate, cleanup time, and fluid type used. To establish a prediction model, it is necessary to carry out experiments to reveal both qualitative and quantitative relations among permeability recovery coefficient X_S and various operational parameters.

5.2 Empirical model of permeability recovery coefficient X_S

On the basis of experimental data of ten joints of screens at 26 plugging locations, an empirical model is developed to predict the permeability recovery coefficient X_S, the fitted equation considered all affecting factors and can be expressed as in follows :

$$X_S = \left[0.2 - B_Q \exp\left(-\frac{Q_a}{100} A_Q\right)\right]\left[0.2 - B_T \cdot \exp\left(-A_T T_a\right)\right] X_{fa} \tag{6}$$

where A_Q, B_Q, A_T, and B_T are empirical coefficients obtained regression of experimental data, A_Q =0.65, B_Q =0.2, A_T=0.65 and B_T =0.22, respectively; Q_a is the flow rate, L/min; T_a is time, min; X_{fa} is the coefficient related to the flushing fluid. X_{fa} is 0.5 for water, 1.0 for mud acid.

Fig. 14(a) shows a comparison of X_S measured at different flow rates and calculated with the empirical model when the screen is flushed with the mud acid. Fig.14(b) shows a comparison of X_S measured at different cleanup times and calculated with the empirical model when the screen is flushed with water. The calculated results are agreed with experimental values.

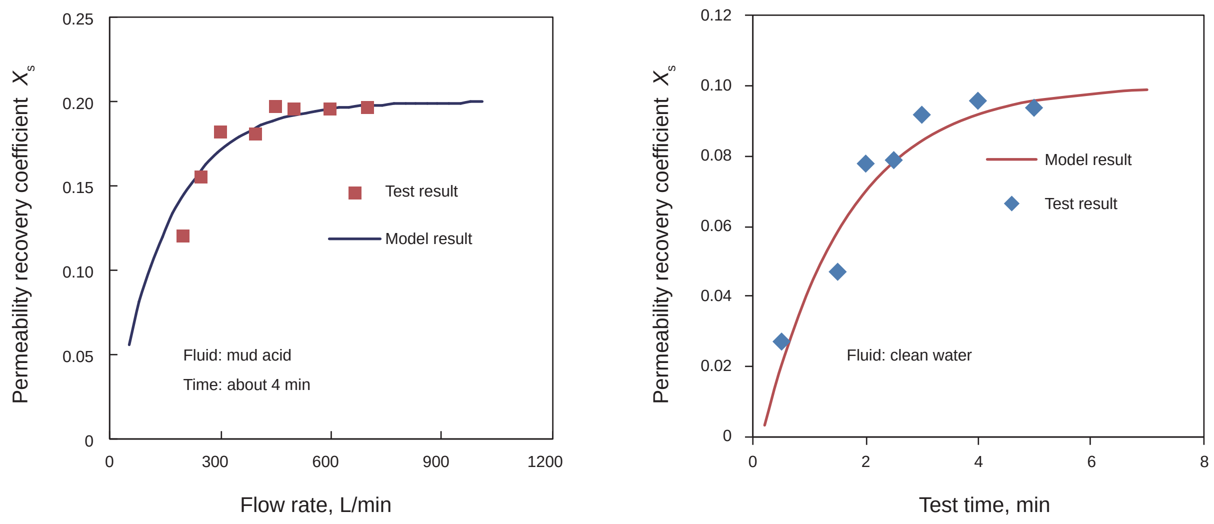
Fig. 14 shows that the permeability recovery coefficient was about 20% when the mud acid was used and about 10% when clean water was used.

6 Conclusions

1) The rotary jetting tool had poor cleanup performance when it was moving, but it performed well while it was stationary for a short time. The experimental results suggested that the “move-stop-move” mode should replace the reciprocating constant speed mode. Moving for 1.5-2 m each time would achieve good performance.

2) The test results indicated that with the recommended mode of tool movement the screen permeability was restored fast in the early period, then decreased gradually and remained nearly as a constant in the later test period. Therefore, long retention time of the rotary jetting at one location is not recommended and 2-4 min of jetting at each location was recommended.

3) High flow rate would lead to good cleanup performance. The recommended value was no less than 550-600 L/min. The mud acid outperformed clean water. The



(a) X_S varying with flow rate (b) X_S varying with time

Fig. 14 A comparison of calculated and measured values of X_S varying with flow rate and time

screen permeability recovery reached over 20% if the optimal parameters were used.

4) The plugging severity of screen pipes directly affects the cleanup efficiency. The efficiency for the slightly plugged screen was much less than that for the severely plugged screen. The badly plugged horizontal wells would be selected for actual cleanup operations if the rotary jetting technique was used.

5) The empirical prediction model was developed on the basis of qualitative and quantitative relations among cleanup efficiency, flow rate, time, etc., obtained from the tests, which provided practical assistance for effect prediction and parameter optimization in cleanup operations.

6) The tests were just performed on metal cotton screens of a particular structure. Technically, the resultant analysis and conclusions are reasonable only for metal cotton screens. However, in consideration of the similar sand retention mechanisms, the experimental results and the prediction model may provide useful information for other types of screens.

References

Ali S A and Dearing H L. Sand control screens exhibit degrees of plugging. Petroleum Engineer International. 1996. 69(7): 36-41

Asadi M and Conway M W. Mudcake/screen cleanup investigation in openhole gravel-packed completions. SPE Annual Technical Conference and Exhibition, 30 September-3 October, 2001, New Orleans, Louisiana, USA (paper SPE 71670)

Asadi M and Penny G S. Large-scale comparative study of prepacked screen cleanup using acid and enzyme breaker. IADC/SPE Asia Pacific Drilling Technology, 11-13 September, 2000a, Kuala Lumpur, Malaysia (paper SPE 62792)

Asadi M and Penny G S. Sand control screen plugging and cleanup. SPE Asia Pacific Oil and Gas Conference and Exhibition, 16-18 October, 2000b, Brisbane, Australia (paper SPE 64413)

Asadi M. Screen performance and cleanup characterization in horizontal well drill-in-fluids using a large-scale radial flow-cell. SPE Annual Technical Conference and Exhibition, 3-6 October, 1999, Houston, Texas, USA, (paper SPE 56777)

Browne S V, Ryan D F, Chambers B D, et al. Simple approach to the cleanup of horizontal wells with prepacked screen completions. Journal of Petroleum Technology. 1995. 47(9): 794-800

Dong C Y, Jia B X and Liu C M. Experimental study on sand control mechanism of sand retention media. Journal of China University of Petroleum. 2011. 35(5): 82-88 (in Chinese)

Fattahpour V, Moosavi M and Mehranpour M. An experimental investigation on the effect of grain size on sand production. Petroleum Science. 2012. 9(3): 343-353

Garcia-Orrego G S. Laboratory evaluation of filtercake cleanup techniques and metallic screens plugging mechanisms in horizontal wells. Proceedings of the 52nd Annual Southwestern Petroleum Short Course, 20-21 April, 2005

Guan D, Yang Z, Zhang Y, et al. Diagnosis of oil well plugging and chemical remedial treatment tests in two oilfields in Bohai Bay. Journal of Southwest Petroleum Institute. 2002. 24(2): 35-37 (in Chinese)

Hu C Z, Pei B L, LI X F, et al. Laboratory research on plugging mechanisms in gravel packed wells. Journal of the University of Petroleum. 2004. 28(3): 40-42 (in Chinese)

Huang Z W, Li G S, Liu Q G, et al. Mechanisms and applications of removing plugging with oscillating jets and acid. Petroleum Exploration and Development. 2006. 33(5): 618-621 (in Chinese)

Huang Z W, LI G S, Luo H B, et al. Mechanisms and field test of rotating jets for plug-removing in horizontal screens. Oil Drilling & Production Technology. 2008. 30(3): 93-96 (in Chinese)

Huang Z W, Ma J J, Li G S, et al. Unplugging slotted tubing with a high pressure rotary water jet. Oil Drilling & Production Technology. 2004. 26(6): 65-67 (in Chinese)

Ladva H K J, Parlar M, Price-Smith C, et al. Mechanisms of sand control screen plugging from drill-in fluids and its cleanup using acid, oxidizers and enzyme breakers. SPE Formation Damage Control Conference, 18-19 February, 1998, Lafayette, Louisiana (paper SPE 39439)

Larsen O S, Fjellstad V, Mathisen A M, et al. New sand retention test setup exhibits no plugging tendencies with various screen types using non-uniform test sand. SPE International Symposium and Exhibition on Formation Damage Control, 15-17 February, 2012, Lafayette, Louisiana, USA (paper SPE 151346)

Lau H C and Davis C L. Laboratory studies of plugging and clean-up of production screens in horizontal wellbores. SPE Annual Technical Conference and Exhibition, 5-8 October, 1997, San Antonio, Texas, U S A (paper SPE 38638)

Li G S, Huang Z W and Zhang D B. Plug-removing technique of using high pressure water jets combined with acidization. Acta Petrolei Sinica. 2005. 26(1): 96-100 (in Chinese)

Li G S, Huang Z W, Zhang D B, et al. Study of treatment of near wellbore formation processed with high pressure rotating water jets. Petroleum Science and Technology. 2002. 20(9-10): 961-972

Li G S, Ma J J, Shen X M, et al. A study on mechanisms and effects of plug removal near wellbore with high pressure water jet. Acta Petrolei Sinica. 1998. 19(1): 96-99 (in Chinese)

Liu D, Li L, Zhou C S, et al. Plugging mechanism and unplugging sand control area in a polymer injection well. Journal of China University of Petroleum (Edition of Natural Science). 2010. 34(2): 78-81 (in Chinese)

Mao J, Chi S, Huang L M, et al. Application of technology of HHJ for plug-removing operation in Jilin Oilfield. Well Testing. 2002. 11(3): 35-37 (in Chinese)

McCulloch D J, Mann J, Macmillan P, et al. Damage removal in screened horizontal wells. SPE/ICoTA Coiled Tubing Conference and Exhibition, 8-9 April 2003, Houston, Texas USA (paper SPE 81732)

McElfresh P and Welch J. Protecting sand control screens against solids plugging suring installation. SPE International Symposium and Exhibition on Formation Damage Control, 13-15 February, 2008, Lafayette, Louisiana, USA (paper SPE 112314)

Stanley F O, Serrano F and Knopp S. Rotating jet technology improves stimulation fluid placement to effectively treat horizontal and gravel packed wells: lab model tests and global results are reviewed. The SPE Annual Technical Conference and Exhibition, 26-29 September, 2004, Houston, Texas, U S A (paper SPE 90174)

Wang Z Q, Nan Q Y, Wang H J, et al. Plug removal technology and application of combining pressure rotary fluidics and chemicals. Journal of Southwest Petroleum Institute. 2001. 23(1): 37-42 (in Chinese)

Zhang R J and Pu C S. Vibration-mud acidization treatment unplugging experiment. Petroleum Exploration and Development. 2004. 31(5): 114-116 (in Chinese)

Zhang X S, Sun F J, Feng G Z, et al. Research into influencing factors of polymer flooding and its field testing in Bohai Heavy Oilfields. China Offshore Oil and Gas. 2007. 19(1): 30-32 (in Chinese)

Zhang Y G, Wang H W, Liu G Y, et al. Applying biological enzyme to remove plugging in screen pipe completed horizontal wells in a volcanic gas reservoir. 6th International Petroleum Technology Conference, 26-28 March, 2013, Beijing, China (paper SPE 17152)

(Edited by Sun Yanhua)