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ORIGINAL PAPER - PRODUCTION ENGINEERING

Performance evaluation and application of modified urea–formaldehyde resin water shutoff agent

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Abstract Because of bad cement job quality, water is one big problem that causes reduction in oil production, higher water cut and lower eventual oil recovery. Usually the main way to solve this problem would be to use a cement nonselective water shutoff agent. But this agent has small plugging radius, big field test risk, poor resistance to acid/alkali and pollutes the formation seriously. Therefore, one effective shutoff agent which can lower pollution from the formation must be developed. Making use of a large number of experiments and hard work, the curing agent, thickening agent and solid filling material are chosen. In this way modified urea–formaldehyde resin water shutoff agent is developed. The formula is as follows: 0.1–0.35 % curing agent GH-1, 0.1–1 % thickening agent KYPQ and 10–20 % solid filling material CT-1. Its performance such as curing time, viscosity and plugging strength is also studied in laboratory. Its curing time is controllable from 12 to 1200 min and the viscosity is flexible from 30 to 10,000 mPa s. Injecting this new shutoff agent into sand packs whose permeability is 7 μm^2, the displacement pressure is up to 7 MPa. After maintaining at 70 °C in an oven for 8 h, the breakthrough pressure is more than 20 MPa and the plugging ratio is more than 99 %. This water shutoff agent is successfully used in 25 oil wells. Three typical wells are chosen as examples to plug channeling or bottom water. The result of pilot test shows that the cumulative quantity of oil is 14,711 tons and the water cut rises slowly.

Keywords Modified urea–formaldehyde resin · Water shutoff · Curing time · Thickening agent · Solid filling material · Plugging capacity · Pilot test

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Introduction

Excessive water production in oil fields is becoming a challenging and serious economic and environmental problem in more and more developed reservoirs (Seright 1997). An estimated average of 85 m^3 of water is produced for 15 m^3 of oil produced in China. An estimated average of 3 bbl of water is produced for each barrel of oil produced worldwide. It is estimated that the total cost to separate, treat and dispose of this water is about USD 50 billion per year. Water can flow into wellbore as a result of either near wellbore problems or reservoir-related problems (Seright 2000; Sydansk 1990; Sydansk et al. 2005). The mechanism that contributes to undesired water production needs be fully understood before appropriate measures can be taken. Undesirable water channeling, one of the primary reservoir conformance problems, is caused by reservoir heterogeneity that causes the existence of high-permeability streaks. These streaks include open fractures and fracture-like features, such as worm holes, caves and conduits (Bai 2007; Fengming et al. 2011). The high conductivity features in the reservoir occupy only a small fraction of the reservoir but will capture a significant portion of injected water (Yan et al. 2012). As a result, large amounts of oil remain unswept because large water drive will bypass oil-rich unswept areas.

Reservoir heterogeneity severely affects the flow of oil, gas and water in the reservoir and also influences the way we choose effective production strategies and oil enhanced recovery methods. Reservoir heterogeneity is the most important reason for both low oil recovery and excessive water production. After the reservoir was explored with high production rate for a long time there are high-permeability channels (Liu et al. 2015; Mercado et al. 2009).

Chemical water shut off technology is the most effective way to solve the problems which channels cause. Chemical water shut off agents can be divided into non selective water shutoff agents and selective water shutoff agents according to their action mechanism. Selective water shutoff agents are studied in the laboratory, but the actual application examples are less; non-selective water shutoff agents have been matured after a lot of study; many varieties have been developed including cement, calcium silicate, resin, gel and so on (Xin et al. 2010; Van Eijden et al. 2005). Among them the cement shutoff agent is the earliest used shutoff agent that has the advantages of low price, high strength, wide applicable temperature range and simple operational procedure. It is still the most widely used water shutoff agent. But it has the following disadvantages: its particles are too big to go easily into the medium and low permeability layer, and its plugging strength is not high; it is not acid-proof; it has poor liquidity, and high operational risk. The main advantage of resin shutoff agents is insolubility and infusibility after consolidation, acid-proof and alkali-proof, stable properties, and its high strength. It is an ideal material for water shutoff. But resin shutoff agents exist as a kind of solution before consolidation, because formation heterogeneity inevitably leads to non-linear flow which makes plugged oil layer non-full and ineffective. How we improve resin plugging ability is one important influence factor. By researching curing time control, system thickening agents and phase filling, the filling phase, modified urea–formaldehyde resin water shutoff agent, is developed and has good plugging performance.

Experiment

Modified formula of urea–formaldehyde resin water shutoff agent

To improve the plugging ability of urea formaldehyde resin shutoff agents such as curing time, viscosity, wall building property, curing agent, thickening agent and solid filling material agents were chosen by a lot of experiments in lab.

Curing agent chosen

Hydrochloric acid, ammonium chloride and GH-1 (mainly composed of ammonium salt and phenol) were chosen as curing agents. Three different curing agents, the concentration of which was 0.5 %, were put into pure urea formaldehyde resin respectively. The solution was stirred briskly to dissolve fully in constant temperature bath the temperature of which was 65 °C. Then parameters such as consolidation time and solid strength were measured. The results were as follows in Table 1.

From these results it is found that there is a significant difference between consolidation times and there is little difference between solid strength. Curing reaction occurs very fast after adding hydrochloric acid or ammonium chloride and it is difficult to control the reaction. After adding curing agent GH-1, it can effectively prolong curing time.

Thickening agent chosen

Carboxymethyl cellulose ether, polyacrylamide and polymer KYPQ were chosen as three kinds of thickening agent. After adding different thickening agents the results of urea formaldehyde resin viscosity were shown in Table 2.

From Table 2, thickening ability of carboxymethyl cellulose ether and polyacrylamide is relatively low because of the impact of high ion concentration. After adding KYPQ polymer, the concentration of which was 0.5 %, liquid viscosity increases more than 20 times.

Table 1 Results of curing agent chosen

Curing agent	Consolidation time/min	Solid strength/MPa
Hydrochloric acid	2	16
Ammonium chloride	30	15
GH-1	>360	12

Table 2 Results of thickening agent chosen

Thickening agent	Concentration/%	Viscosity/mPa s
No	0	30
Carboxymethyl cellulose ether	0.5	35
Carboxymethyl cellulose ether	1	38
Polyacrylamide	0.5	40
Polyacrylamide	1	42
Polymer KYPQ	0.5	610
Polymer KYPQ	1	3230

Table 3 Results of solid filling material chosen

Solid filling material	Concentration/%	Settling time	Wall building property	Consolidation condition
Sepiolite	10	120	Good	Bad
Bentonite	10	20	bad	Bad
Fly ash	10	16	Bad	Bad
Drilling plugging agent	10	98	Bad	Good
CT-1	10	80	Good	Good

Table 4 Effect of curing agent concentration

Concentration	Curing time/min					
	50 °C	60 °C	70 °C	75 °C	80 °C	95 °C
0	–	–	–	–	–	–
0.1	–	–	–	–	1140	780
0.15	–	960	680	540	370	255
0.2	660	375	200	150	120	141
0.35	95	60	30	22	15	12

The symbol of "–" shows that curing time is more than 20 h

Solid filling material chosen

The solid filling material which is added into urea formaldehyde resin must have good suspension ability and strong wall building properties.

First, KYPQ polymer the concentration of which was 0.2 % was added into pure urea formaldehyde resin. When the viscosity was up to 180 mPa s, curing agent GH-1 whose concentration was 0.2 % is added and the solution was stirred evenly. Sepiolite, bentonite, fly ash, drilling plugging agent, CT-1 (a kind of organic silicon powder) were chosen as solid filling material. Then parameters such as settling time, wall building property and consolidation condition were studied after adding these five solid filling materials. The results were as follows in Table 3.

The experimental results show that the addition of CT-1 can not affect urea formaldehyde resin consolidation. It has good suspension; good wall building properties and is an ideal solid filling material (Table 4).

Performance evaluation

Effect of curing agent concentration

0.2 % Polymer KYPQ is added into synthetic urea formaldehyde resin. Then different concentrations of curing agent are also added. On the condition of constant temperature oven, whose temperature is from 50 to 95 °C, the effect of curing agent concentration on curing time is as follows. When the curing agent concentration is from 0 to 0.35 %, curing time is also changeable from 12 min to 20 h. The curing time has strong controllability, and this water shutoff agent can be used according to plugging depth and operational time.

Effect of thickening agent concentration on viscosity

Different concentrations polymer KYPQ are added into synthetic urea formaldehyde resin. Then 0.2 % curing agent GH-1 is added, the solution is stirred evenly and its viscosity is measured. The results are shown in Fig. 1.

The addition of KYPQ polymer which is completely dissolved in the liquid can increase the viscosity of urea formaldehyde resin. With the dispersion of thickening agent, viscosity rapidly increases. With higher concentration, viscosity is higher and it has the rising trend. When the concentration is high enough viscosity can reach above 10,000 mPa s. According to the technical requirements, viscosity can be controlled from 30 to 10,000 mPa s. High viscosity makes comprehensive performance of the system improve greatly, and greatly enhances suspension, injection and consolidation stability (Figs. 2, 3, 4).

Evaluation of core plugging capability

The components of urea formaldehyde resin water shutoff agent system are as follows: pure urea formaldehyde resin + 0.2 % polymer KYPQ + 0.2 % curing agent GH-1 + 20 % solid filling material CT-1 (15 μm).

Urea formaldehyde resin water shutoff system is flooded into sand pipe. Then the sand pipe is put into an oven whose temperature is 70 °C. Third, parameters such as breakthrough pressure and permeability are measured. The results are shown in Table 5.

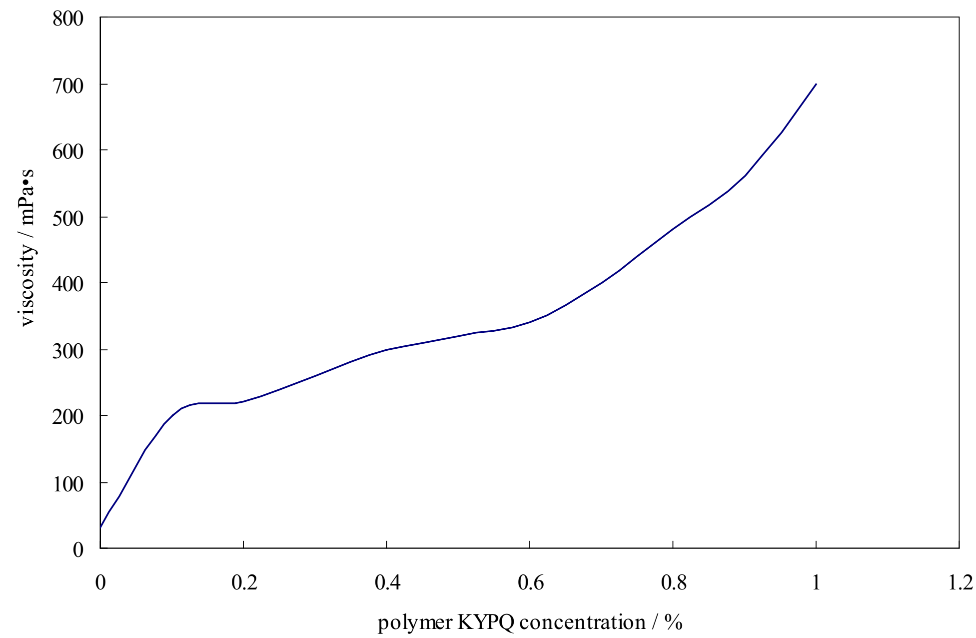

Fig. 1 Effect of thickening agent concentration on viscosity

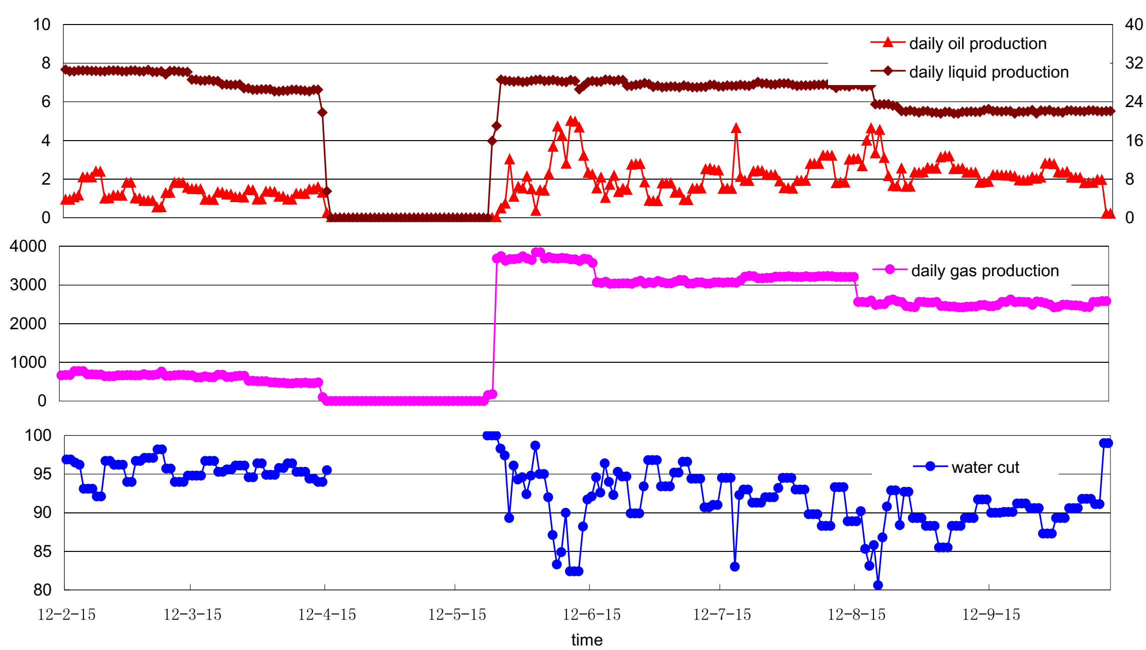

Fig. 2 Oil and gas production curve of well X205

The plugging ratio of this water shutoff agent system is up to 99.89 % and its breakthrough pressure is over 20 MPa. It has strong plugging capability.

Field application

The modified urea formaldehyde resin water shutoff agent system has been used on 25 wells in Jidong Oilfield during the last 2 years.

Case study of well X205

Well X205 which is located in the high point of the structure of NP1-3 area is one important pilot test well. The new water shut off agent system is used to plug final bottom water.

Before injecting modified UF resin, the water cut of this well is almost 98 %. To reduce the water cut and increase oil production, 40 m^3 modified urea formaldehyde resin is

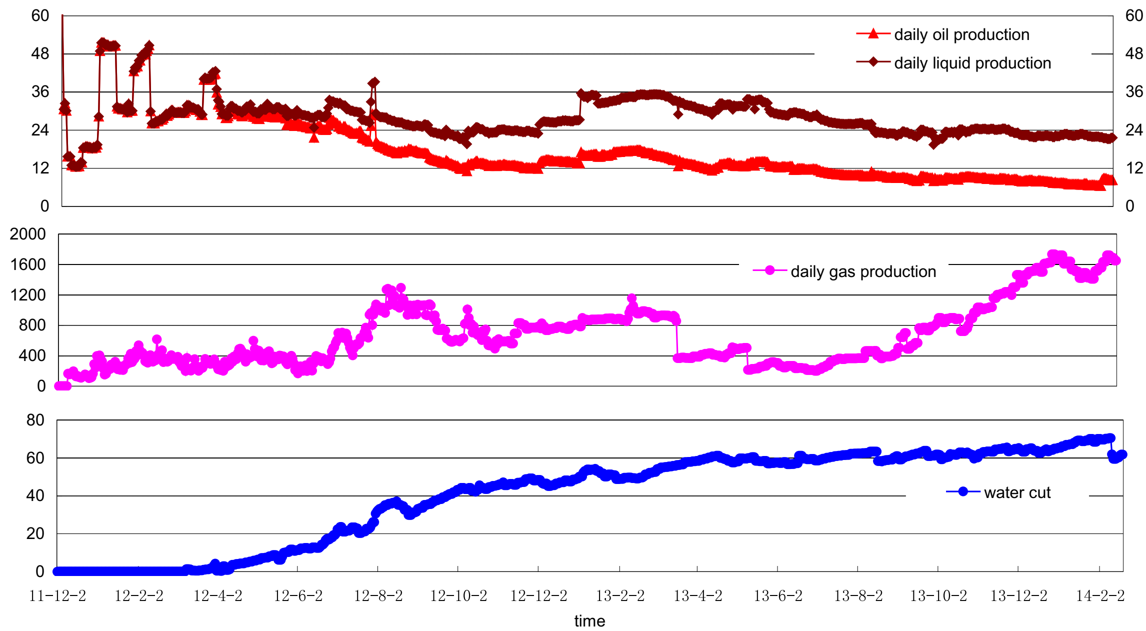

Fig. 3 Oil production curve of well X3214

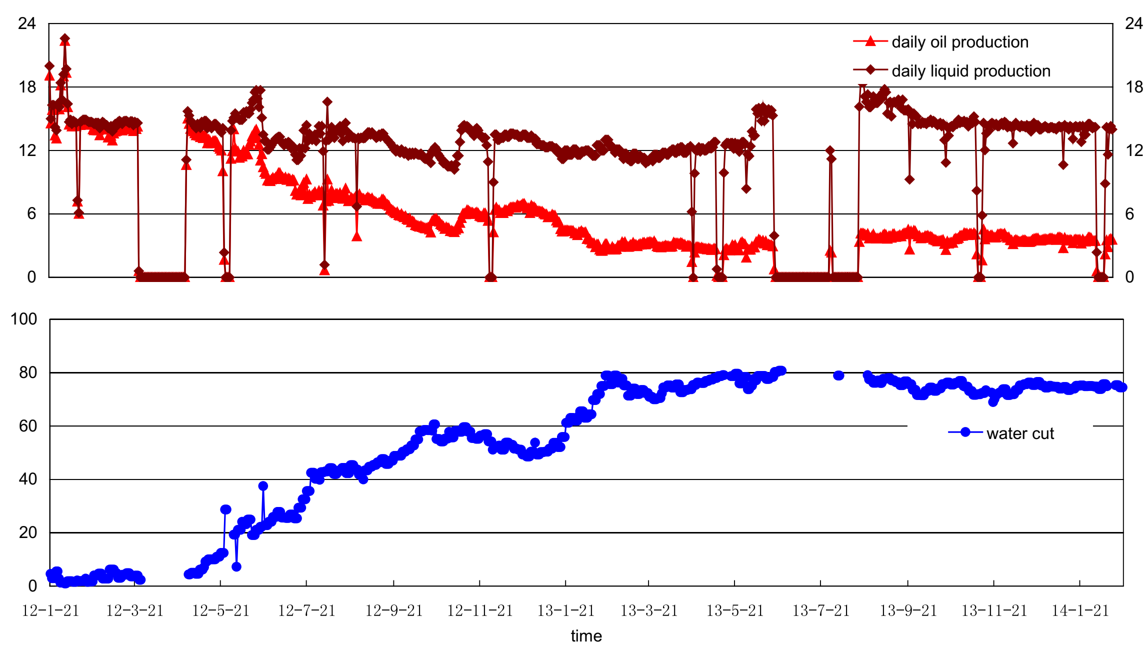

Fig. 4 Oil production curve of well T16

Table 5 Evaluation of core plugging capability

Permeability/μm^2		Plugging ratio/ %	Displacement pressure/MPa	Breakthrough pressure/MPa
Before injection	After injection			
7	0.0077	99.89	7	21

injected on May, 2012. The effect of increasing oil and gas production is obvious. Daily oil production increases 4 tons, daily gas production increases 3293 m^3 and its water cut decreases 12 %. The cumulative quantity of oil is 443 tons.

Case study of well X3214

Well X3214 which is located in the high point of the structure of NP 3–2 area is another important pilot test well. It is used to plug initial bottom water.

After injection of 24 m^3 modified urea formaldehyde resin, the water-free oil production period is 98 days. The cumulative quantity of oil production is 10,182 tons and the water cut rises slowly. At the same time there is no means to solve bottom water coning problem in well NP32-X3210. The water-free oil production period of well NP32-X3210 is 68 days. The cumulative quantity of oil production is 7179 tons and the water cut rises quickly. By comparison it is effective to use modified urea formaldehyde resin for solving bottom water coning problem.

Case study of well T16

Well T16 is located in high point of the structure of T70X1 area. For solving the problem of channeling, modified urea formaldehyde resin is used to plug initial channeling.

15 m^3 modified urea formaldehyde resin is injected. It is effective to solve the problem of channeling. The well is exploited for 8 months at a low water cut period. The cumulative quantity of oil production is 4086 tons till now. The water cut rises slowly and is stable at 75 %.

Conclusions

Curing time of modified urea formaldehyde resin water shut off agent is controllable from 12 to 1200 min and the viscosity is flexible from 30 to 10,000 mPa s.

Injecting this new shutoff agent into sand pipes whose permeability is 7 μm^2, the displacement pressure is up to 7 MPa. After maintaining a constant temperature oven whose temperature is 70 °C for 8 h; the breakthrough pressure is more than 20 MPa and the plugging ratio is more than 99 %.

Comprehensive performance of modified urea formaldehyde resin water shut off agent is improved greatly, and its suspension, injection and consolidation stability is greatly enhanced. It not only has the advantage of cement but also has high strength and good resistance to acid/alkali.

This water shutoff agent which is successfully used in 25 oil wells can be used to plug channeling or bottom water. The cumulative quantity of oil is 14,711 tons and the water cut rises slowly.

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