A Study on well killing fluid system for reservoir protection in Daqing Xushen gas field

Yuxue Sun, Feng Chen, Fulei Zhao

Northeast Petroleum University, Department of Petroleum Engineering, Daqing 163318, China

Abstract

The volcanic rocks in the Xujiaweizi fault depression area of Daqing oil field are the most important reservoirs, which are with low porosity and super-low permeability. The reservoirs contain rich natural gas resources. The decline of the actual production capacity caused by gas reservoir damage is often greater than the decline caused by oil reservoir damage; especially when compared to oil reservoirs, gas reservoirs with low porosity and low permeability are more vulnerable to water blocking, water sensitivity, stress sensitivity and other damages. A study has been carried out on the reservoir sensitivity of Yingcheng group in Xushen gas field. This study develops a new formula of formate well killing fluid system according to the deep volcanic rock reservoirs of Xushen gas field, determines the ratio of sodium formate and potassium formate when the density of well killing fluid reaching 1.30g/cm3 and 1.41g/cm3, and evaluates the reservoir protective ability of the formula. The experiment of plugging effect and flow-back-broken-down effect evaluation proves that the new formate well killing fluid can effectively protect the volcanic rock reservoirs in the Xushen gas field area.

Keywords

Xushen gas field, low permeable reservoir, reservoir protection, formate, adjustable density

1. Introduction

During down hole operation of gas well, it is necessary to inject well killing fluid with appropriate density into the well to balance the pressure of backpressure and stratum caused by the bottom of the well. If the well killing fluid is improperly selected, it will cause stratum blockage and lead to inconspicuous increase of natural gas production after well completion and well repair, and even cause severe damage to the gas layer [1-3]. In Xingcheng development zone of Xushen gas field, a section of volcanic rocks of Yingcheng group was mainly developed. The lab carried out sample analysis to 60 full diameter cores of Xushen block1, Xushen6-Xushen6-105 well area; the porosity was between 2.42%-13.7%, the average was 7.67%; the permeability was between 0.002×10^{-3}-$5.11 \times 10^{-3}\mu m^2$, the average was $0.147 \times 10^{-3}\mu m^2$; it was a medium porosity and super-low permeability reservoir. Therefore, a study has been carried out on reservoir protective technology of the volcanic rocks in Xushen gas field. This study developed a new formula of formate well killing fluid with various densities and minimized the damage to the gas layer so as to effectively protect the reservoirs.

2. The evaluation on the reservoir sensitivity of Xushen gas field

Reservoir sensitivity refers to a phenomenon of low permeability caused by the hydration swelling of clay minerals, particle migration or occurrence of sediment due to the incompatibility when the reservoir contacts with foreign fluids [4]. The reservoir sensitivity analysis is to study the damage degree of the reservoirs caused by various sensitivities so as to put forward preventive measures for the purpose of protecting oil-gas layers.

In general, the evaluation on the sensitivity of oil-gas layers included velocity sensitivity, water sensitivity, salinity sensitivity, alkali sensitivity, and acid sensitivity experiments. The specific experimental methods were basically implemented in line with *The Evaluation Methods of Reservoir Sensitivity Flow Experiment*（SY/T 5358-2002）. The lab evaluated the sensitivity index, sensitivity degree and the corresponding critical conditions of the five sensitivities at three different layers of

Yingcheng group in Xushen gas field (Xushen well 1-2, Xushen well 401, Xushen well601). The experimental results are shown as in Table 1:

Based on the aforesaid results, it could be analyzed that: the reservoir core sensitivities of deep volcanic rocks of Yingcheng group in Xujiaweizi area are: water (salinity) sensitivity (medium strong), velocity sensitivity (weak), alkali sensitivity (medium weak), acid sensitivity (none).

3. The development of formate well killing fluid system

3.1 Formate

In the formate system, sodium formate and potassium formate are often used [5]. Formate is a kind of organic carboxylate. The density scope of the well killing fluid can be adjusted to 1.0-2.3g/cm^3 by using sodium formate and potassium formate in a single way or compound way and changing the addition amount of formate. In aqueous solution, formate exists in the form of Na^+ (K^+, Cs^+) and $HCOO^-$ ions. Formate does not only have the effect of Na^+, K^+, but also have the unique effect mechanism of $HCOO^-$

Table 1 The summary of sensitivity experimental results

Well No.	Sensitivity Parameters	Velocity Sensitivity	Water Sensitivity	Salinity Sensitivity	Acid Sensitivity	Alkali Sensitivity
Xushen 1-2 3 282m	Sensitivity index	29.44%	54.36%	63.08%	-	39.03%
	Sensitivity degree	Weak	Medium strong	Medium strong	None	Medium weak
	Critical parameter	25.00 mL/min		6 000 mg/L		
Xushen 401 3 692m	Sensitivity parameter	22.35%	63.79%	49.23%	-	13.31%
	Sensitivity index	Weak	Medium strong	Medium	None	Weak
	Sensitivity degree	20.00 mL/min		8 000 mg/L		
Xushen 601 3 096m	Sensitivity parameter	31.42%	69.11%	65.95%	1.95%	31.42%
	Sensitivity index	Medium weak	Medium strong	Medium strong	Weak	Medium weak
	Sensitivity degree	20.00 mL/min		8 000 mg/L		

The action mechanism of formate is as follows:

1. $HCOO^-$ hydrolyzed from formate in the water solution is a kind of water structure formers. It can greatly improve the transition temperature of polymer and has good compatibility with the polymer that is often used in the oil field. A large amount of $HCOO^-$ in the formate water solution has reductive groups, which can remove the dissolved oxygen in the well killing fluid so that the treatment agent dissolved in the water is not easy to have thermal oxidative degradation reaction so as to effectively protect various treatment agents used in the well killing fluid system and make sure it can play a stabilizing role under high temperature. 2. Formate brine has high mineralization degree. With small surface tension, it can effectively reduce the damages of water sensitivity and water blockage to the low permeable reservoir. 3. With low activity, the inhibitory property of formate filtrate can be realized in the super low permeable reservoir through activity balance principle so that stratum slurry effect can be well controlled so as to achieve the protection of the reservoirs.

3.2 Tackifier

Add tackifier with a certain concentration to the system. Low filtration loss membrane will be formed after the dissolution of tackifier, which can improve the viscosity of well killing fluid, reduce the filtration loss amount of well killing fluid and decrease the damage of well killing fluid filtration to the stratum so as to protect the reservoirs. The common tackifiers mainly are biopolymer, hydrolyzed polyacrylamide and so on [7]. By selecting among several trackifier in this experiment, we finally chose sodium carboxymethyl cellulose HV-CMC as tackifier and determined the addition amount of HV-CMC as 1.0%-1.2% through experiment.

3.3 Filtrate loss reducer

The low filtration loss property of solid-free well killing fluid can not only avoid the loss and damage of the well killing fluid in the stratum, but also avoid the damage of the filtration to the stratum. It is crucial to effectively control the system filtration loss index. Therefore, we should add treatment agent that can resist temperature and resist salt, and play a significant role in the solid-free environment. There are many kinds of filtrate loss reducer, such as resin, Lignite, polymer, starch, hydrolyzed polypropylene salt [8]. PAC-142 selected in the experiment is taken as filtrate loss reducer, with 1.0% HV-CMC fixed addition amount. Through the experiment, the appropriate addition amount of PAC-142 is 0.8-1.0% under comprehensive consideration.

3.4 Anti water blocking agent for reducing the surface tension

According to curved interface differential pressure formula at the time of the occurrence of water blocking damage, the only effective way to eliminate it is to try to reduce the oil/water interface tension in the reservoirs. With regard to the gas reservoirs, it is mainly to reduce the surface tension of aqueous phase.

We can learn from the selective preference experiment of anti water blocking agent that the addition of a certain amount of surface active agent OCL-ZZP can significantly reduce the surface tension of well killing fluid filtration so that the occurrence of water blocking damage can be prevented effectively. Therefore, we added anti water blocking agent OCL-ZZP with various concentrations to the formate well killing fluid system and chose the best addiction concentration. See Table 2 for the situation that the surface tension of well killing fluid filtration and the interface tension of oil/water vary along with the changes of the amount of OCL-ZZP added.

Table 2 The effects of the concentration of anti water blocking agent on the surface tension of well killing fluid system and the interface tension of oil/water

OCL-ZZP concentration/%	0	0.1	0.2	0.3	0.4	0.5
surface tension/(mN m^{-1})	47.82	28.23	24.65	24.52	24.50	24.39
interface tension/(mN m^{-1})	1.61	0.11	0.07	0.05	0.05	0.05

From Table 2 we can obviously see that when 0.1% OCL-ZZP is added, the surface tension of well killing fluid system and the interface tension of oil/water are obviously decreased. When OCL-ZZP concentration is increased from 0.1% to 0.2%, the surface tension decreases greatly; with the continuous increase of the OCL-ZZP concentration, the surface tension of the filtration and the interface tension of oil/water decrease inconspicuously. Therefore, in consideration of the prevention of water blocking damage, the preparation costs and the consumption of the solid phase surfactant, it is appropriate to add 0.3%-0.5% OCL-ZZP to the well killing fluid.

3.5 Clay stabilizer

According to the features of the reservoirs in Xushen gas field and the characteristics of the commonly used clay stabilizer, we selectd small cationic polymer NW-1 as clay stabilizer and respectively took NW-1 with concentrations of 0.2%, 0.3%, 0.4%, 0.5%, 1.0% to carry out the evaluation experiment of anti-swelling rate. The result is shown as in Fig. 1.

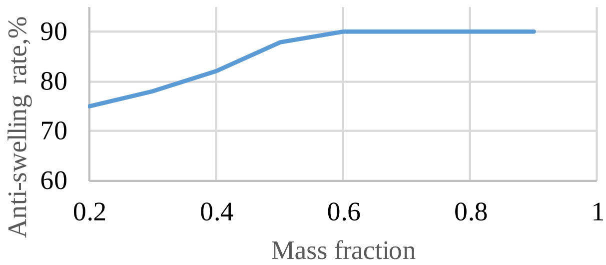

Table 1 The anti-swelling rate of NW-1 under different concentrations

From Fig.1, we can see that the anti-swelling effect is the best when NW-1 concentration is 0.5%; with the continuous increase of NW-1, the anti-swelling rate is basically unchanged. Therefore, we chose the addition amount of NW-1 is 0.5%-1.0%.

3.6 Oil-gas layer protective agent BST-Ⅲ

Oil-gas layer non-intrusive protective agent BST-Ⅲ is comprised of bio polymer, cationic colloid and other raw materials. The product also includes soluble, partially soluble and insoluble polymer materials. This kind of product is developed through accurate calculation and proportioning.

With regard to reservoir protection, the most effective way is to prevent or reduce the entering of foreign objects (solid, liquid phase) into the reservoirs. BST-Ⅲ can transfer various well killing liquid system into non-permeable and non-intrusive well killing liquid and greatly improve the comprehensive performance of well killing liquid system. BST-Ⅲ is a kind of well killing fluid prepared by treatment agent, and the addition of it can form an effective shielding layer. This shielding layer can restrict the filtration permeability in the system and restrict the damage of solid phase to the stratum so as to effectively control the dynamic filtration loss amount of porous medium and achieve the purpose of keeping reservoirs from damages. Because BST-Ⅲ contains fibrous material, it has broader plugging capacity to seal the cracks and gaps well.

3.7 The selection of corrosion inhibitor

Formate well killing fluid, especially high-density well killing fluid will cause corrosion to the down hole string. Therefore, the addition of corrosion inhibitor in the formula can effectively reduce the corrosion rate of well killing fluid so as to protect the sleeves effectively.

We carried out selective preference experiment on 5 corrosion inhibitor: $HEDPNA_2$ (hydroxy ethyl two phosphoric acid salt), OCL-SHS, $ATMPNA_5$ (amino sanya methyl phosphoric acid salt), EDTMPS (ethylenediamine four methylene phosphoric acid salt), AA/MA (copolymer of maleic anhydride and acrylic acid). The experimental method was in line with oil and natural gas industrial standard SY-T 5273-2000 *The Evaluation Method on the Performance of Corrosion Inhibitor for Produced Water of Oil Field*. The pipes used in the experiment are ordinary on-site N80 pipes. Base fluid adopts on-site formate well killing fluid system with temperature of 40℃, pressure of 30 MPa and 7d immersion. We selected OCL-SHS as the corrosion inhibitor of well killing fluid system and determined that the corrosion inhibition rate of the well killing fluid exceeded 82% when the best addition amount of corrosion inhibitor OCL-SHS was 1.2%-1.5%.

3.8 The determination of formate well killing fluid system formulas with two different densities

New $1^{\#}$ well killing fluid system (with density of 1.30g/cm^3): water 400mL+175g sodium formate+(1.0%-1.2%) HV-CMC+(0.8%-1.0%) PAC142+(1.0%-2.0%) BST-Ⅲ+(0.5%-1.0%) small cation NW-1+(0.3%-0.5%) anti water blocking agent OCL-ZZP+(1.2%-1.5%) corrosion inhibitor OCL-SHS.

New $2^{\#}$ well killing fluid system (with density of 1.41g/cm^3): water 400mL+346g sodium formate+233g potassium formate +(1.0%-1.2%) HV-CMC+ (0.8%-1.0%) PAC142+(1.0%-2.0%)

BST- Ⅲ +（0.5%-1.0%）small cation NW-1+（0.3%-0.5%）anti water blocking agent OCL-ZZP+（1.2%-1.5%）corrosion inhibitor OCL-SHS.

4. The evaluation on the performance of formate well killing fluid system

4.1 The evaluation on the plugging effect

We carried out pollution evaluation test to the cores with different permeability by adopting natural cores in the Xushen area and using two newly developed well killing fluid systems. The conditions of pollution experiment are: differential pressure 3.5 MPa, temperature 80℃, shear rate $100s^{-1}$, pollution time 60min. See Table 3 for the result.

Table 3 The experimental result of new well killing fluid plugging effect evaluation

System	Core No.	Well No.	Well depth/m	Permeability before plugging/ ($10^{-3}\mu m^2$)	Permeability after plugging/ ($10^{-3}\mu m^2$)	Permeability Plugging rate /%
New1# system	XS-62	Xushen 401	1758.21	1.31	1.24	92.32
	XS-65	Xushen1—1	1924.72	2.60	2.44	93.91
	XS-70	Xushen6—2	1655.48	2.78	2.58	92.74
New1# system	XS-45	Xushen1—2	3724.50	1.584	0.093	94.15
	XS-48	Xushen 401	4141.66	4.569	0.291	93.64
	XS-50	Xushen 601	3471.03	3.625	0.297	91.88

We can see that with regard to the cores with different permeability, the plugging rates of two newly developed formate well killing fluid are more than 90% so as to avoid the further intrusion of well killing fluid filtration and solid phase into the inside of the oil-gas layers.

4.2 The evaluation on flow-back-broken-down effect

On the core flow testing apparatus, we made use of core pollution clamper to measure the kerosene forward permeability of the rock samples. We connected the core pollution clamper to the high-temperature and high-pressure dynamic comprehensive testing instrument for drilling fluid and used new formate well killing fluid to plug the rock samples reversely. We took down the core pollution clamper, connected it to the core flow testing apparatus and used kerosene forward displacement（flow back）to measure the forward kerosene permeability in differential pressure. And then we calculated the permeability recovery rate under different conditions. See Table 4.

Table 4 The experimental result of anti broken-down

Core No.	Permeability before plugging/ (10-3μm2)	Permeability after plugging/ (10-3μm2)	Flow back pressure (MPa)/Permeability recovery value(%)				
			1.0	2.0	3.0	4.0	5.0
FY-14	6.47	2.44	32.46	47.06	70.19	80.94	84.21
FY-15	4.93	1.14	34.18	49.01	68.94	81.23	83.96
FY-20	3.82	1.27	33.81	48.99	71.32	82.01	85.64
XS-54	1.095	0.110	31.25	48.44	73.68	80.63	83.65
XS-56	2.134	0.189	35.67	52.12	67.91	81.56	85.31
XS-58	2.986	0.231	33.29	49.33	72.39	82.36	85.13

We can learn from Table 4 that as the increase of the flow back pressure, the core permeability recovery rate increases, and when the flow back pressure is increased to 5.0 MPa, core permeability recovery values of the rock samples are more than 83%, which reflects the success of the flow back an removes plugging layers.

5. Conclusion

(1) We can learn from reservoir sensitivity evaluation result that: deep Xushen gas field reservoir, located in the north of Songliao Basin in Daqing oil field, has main damage of water sensitivity (salinity sensitivity), damage of velocity sensitivity, weak damage of alkali sensitivity, basically no damage of acid sensitivity.

(2) We determined new formate well killing fluid:

formate +(1.0%-1.2%) HV-CMC+(0.8%-1.0%) PAC142+(1.0%-2.0%) BST- Ⅲ + (0.5%-1.0%) small cation NW-1+(0.3%-0.5%) anti water blocking agent OCL-ZZP+ (1.2%-1.5%) corrosion inhibitor OCL-SHS.

(3) The well killing fluid used on site cannot realize the plugging to the cores. With regard to the cores with different crack widths, the permeable rate and plugging rate of two newly developed formate well killing fluid are more than 90% so as to avoid the further intrusion of well killing fluid filtration into the inside of the oil-gas layer.

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