The Research and Application on Fracturing Technology of Online Preparation for Polymer Fracturing Fluid

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Abstract. In recent years, the measure of fracturing fluid blending was adopted prior to operation. The traditional form of fluid blending not only has the problem of long operation cycle and high strength of fluid blending and so on, but also has difficult disposal of flowback waste fluid and reservoir damage. For avoiding the disadvantages of traditional fluid blending, the online preparation for polymer fracturing fluid (OPPFF) is developed to replace the traditional melon gum system for preparing fracturing fluid continuously on-line. Laboratory e-valuation results show that the viscosity of OPPFF is above 60 mPa•s after 90min shearing at 120ºC and 170 s⁻¹, which could meet the requirements of conventional fracturing. Low molecular polymer emulsion, multifunction additive and ammonium persulfate are pumping into sand blender by metering pump, then mixed with water and propping agent to finish the fluid blending process with 50% sand ratio. It has strengths such as easy preparation, less waste of materials, low reservoir damage and no pollution, and obtains a high efficient and environment protected fracturing operation. The application results are desirable and it has prosperous future for dissemination.

1. Introduction

At present, most of the fracturing fluids used at home and abroad are water-based fracturing fluids, which can be roughly divided into three types: natural vegetable gum fracturing fluids, VES clean fracturing fluids, synthetic polymer fracturing fluids, of which guar gum and its modified fracturing fluids are the most frequently used. Water-based fracturing fluid has some shortcomings in fluid mixing and construction technology: 1. Generally, it is pre-mixed [2], and then constructed. The process is complicated and inefficient. The fracturing fluid needs a certain amount of surplus, which is easy to be wasted due to overdue deterioration, and it will also cause waste liquor treatment difficulties and pollution of the environment; 2. Vegetable gum fracturing fluid contains residue, for example. Formation and supporting fractures are harmful; and alkaline cross-linking environment will cause greater damage to alkaline-sensitive reservoirs, resulting in poor fracturing effect [3]; 3) VES surfactant clean fracturing fluid has poor temperature resistance and high cost [4-9].

Using hyperbranched molecular chemistry and structural fluid rheology theory, a fracturing fluid system with "reversible structure" is developed. The non-covalent bonds (electrostatic interaction, hydrogen bonding, hydrophobic association effect, etc.) between the molecules of the solution interact with each other, thus forming a reversible space network and increasing viscosity. Based on this theory, an on-line polymer fracturing fluid was optimized and evaluated by using the electrostatic
attraction between anionic polyacrylamide and cationic surfactant molecules to increase viscosity without chemical crosslinking. The system and fracturing technology have achieved good results in field application.

2. Experimental Study of OPPFF

2.1. Material and Equipment

(1) Polymer emulsion: pale yellow emulsion, with a density of 1.05 to 1.10g/cm³, an effective content greater than 30%, a swelling time of less than 60 seconds, and 2% viscosity greater than 150mPa / S. The main component is anionic modified polyacrylamide, with molecular weight between 6 million and 10 million, and the degree of hydrolysis is 25% to 40%. Production unit: Dongying noer Chemical Co., Ltd.

(2) TF281: fluorocarbon nonionic surfactant, yellowish to reddish brown liquid, with an effective content of more than 30%. Production unit: Shanghai Futian Chemical Technology Co., Ltd.

(3) 1231: Twelve alkane three methyl ammonium chloride, colourless or light yellow liquid, the effective content is more than 40%. Production unit: Shandong long chain Chemical Co., Ltd.

(4) 1631: Sixteen alkane three methyl ammonium chloride, colourless or light yellow liquid, the effective content is more than 40%. Production unit: Shandong long chain Chemical Co., Ltd.

(5) Industrial methanol.

(6) Ammonium persulfate is a white crystal with a content of more than 98%, produced by Hebei Ji Heng Group Co., Ltd.

(7) 30/50 mesh ceramsite, sodium bentonite, kerosene and so on.

2.2. Formulation optimization of OPPFF

2.2.1. Optimization of thickeners

As anionic polyacrylamide is characterized by good solubility, high viscosity, odourlessness and non-toxicity, it can be used as a thickening agent for fracturing fluid, and the molecular weight and hydrolysis of the polymer have a great influence on its performance. Low molecular weight, good water solubility, poor thickening ability; On the contrary, the water solubility is poor and the thickening energy is stronger. The higher the hydrolysis, the faster the anionic polyacrylamide is dissolved. It is preferred that anionic polyacrylamide with molecular weight of 6 million ~ 10 million and hydrolysis degree of 25% ~ 40% can not only achieve certain thickening effect, but also have better water swelling performance. In order to facilitate construction, anionic polyacrylamide emulsion produced by dongying noer chemical co., ltd. is selected as the thickening agent for fracturing fluid.

2.2.2. Optimization of crosslinking agent and clay stabilizer

According to the electrostatic adsorption theory, the cationic surfactant cetyl trimethylammonium chloride and dodecyl trimethylammonium chloride are optimized, which can not only make the anionic polyacrylamide molecules interconnect together, but also adsorb on the surface of sandstone rock, which has a better anti-swelling and stable effect on clay.

2.2.3. Optimization of drainage AIDS

The TF281 fluorocarbon non-ionic surfactant produced by Shanghai foton chemical technology co., LTD is preferred, which not only has low surface tension and good compatibility with cationic surfactant, but also has better dispersing and solubilization.

| Table 1: Surface (Interfacial) tension of fluorocarbon nonionic surfactant TF281 |
|---------------------------------|-----------------|-----------------|
| Concentration/ % | Surface tension /mN/m | Interfacial tension /mN/m |
|------------------|-----------------------------|-----------------------------|
| 0.1              | <21                         | <0.25                       |
| 0.01             | <23                         | <0.80                       |
In order to simplify the liquid mixing process and realize the on-line preparation of fracturing hydraulic fracturing process, a multi-effect additive was prepared according to the formula: 10% TF281 fluorocarbon non-ionic surfactant + 40% 1231 (content < 40%), 40% 1631 (content < 40%) and 10% industrial methanol. The multi effect additive has the functions of crosslinking, anti-swelling, drainage, washing oil, wetting and solubilizing.

2.3. Evaluation Experiment of OPPFF

2.3.1. Swelling property
400mL water was added into a 500 mL beaker and put into an electric mixer. Under the condition of stirring at a speed of 600rpm, 2.0 mL multi-effect additive and quantitative polymer emulsion were successively added. The viscosity of the gel at the time points of 20 s, 30 s, 1 min, 2 min, 3 min and 4 min was determined by a rotating viscometer.

| Formula | Liquid viscosity/mPa·s |
|---------|----------------------|
| 20 s    | 30 s  | 1 min | 2 min | 3 min | 4 min |
| 1       | 45    | 60    | 75    | 90    | 105   | 105   |
| 2       | 60    | 90    | 120   | 135   | 135   | 135   |
| 3       | 90    | 105   | 150   | 150   | 150   | 150   |

It can be seen from table 2 that the online fracturing liquid system is neutral with short swelling time and fast swelling. After 30 s of stirring, the viscosity is greater than 60 mPa·s, which can realize the online fracturing process.

2.3.2. Sand-carrying experiment
Under the condition of room temperature 15 ºC, according to the formula (1) polymer emulsion (1.0% + 0.5% multi-effect additives), formula (2) polymer emulsion (1.2% + 0.5% multi-effect additives), formula (3) polymer emulsion (1.5% + 0.5% multi-effect additives), formula (4) polymer emulsion (1.8% + 0.5% multi-effect additives) prepared well fracturing fluid, at the same time quickly evenly add 30/50 of the sand ratio is 35% ceramsite, stir well after incubation time, after 0.5 h, 1.0 h, 2.0 h observed phenomenon of carrier, The results show that the higher the concentration of polymer emulsion, the better the suspended properties. When the concentration of polymer emulsion is greater than or equal to 1.2%, it has a better sand carrying performance.

2.3.3. Gel breaking experiment
According to SY/T 5107-2005 Water-based Fracturing Fluid Performance Evaluation Method, the prepared on-line fracturing fluid is poured into a 150 mL conical bottle when the temperature is less than 90 ºC, sealed and placed in an electrothermal constant temperature water bath to break the gel; when the temperature is above 90 ºC, the prepared on-line fracturing fluid is poured into the stainless steel barrel of the high temperature and high pressure filter. After sealing, it is placed in the heating sleeve of the high temperature and high pressure filter. A capillary viscometer was used to determine the viscosity of the gel at different time points. The amount of gel breaker needed for fracturing fluid breaking at different temperatures and at different time points was optimized. The results are shown in Tab. 3.

| Formulaa | Temperature /ºC | Ammonium persulfate concentration/% |
|----------|-----------------|-----------------------------------|
|          | Temperature /ºC | 0.5h  | 1h   | 2h   | 4h   | 6h   | 8h   | 16h  | 24h  |
| 1        | 60              | 0.1   | 0.08 | 0.06 | 0.03 | 0.02 | 0.015| 0.01 | /    |
| 2        | 70              | 0.08  | 0.05 | 0.02 | 0.01 | 0.005| 0.003| 0.002| /    |
2.3.4. Determination of surface tension, residue and swelling resistance of the gel breaking solution

2.3.4.1. Determination of surface (boundary) surface tension of gel breaking solution
According to the formula (1.4% polymer emulsion 0.05% + 0.5% + multi-effect additive ammonium persulfate) prepared well fracturing fluid, in the 80 ºC gel breaking 2 h, remove the cooling to room temperature, use JYW - 200 type automatic determination of interfacial tensiometer gel breaking liquid surface tension and interfacial tension, measurement data are shown in table 5.

2.3.4.2. Determination of residue
Take the gel breaking liquid 1.3.4.1 100 ml in centrifuge tube (centrifugal tube has been dried at 105 ºC and weighing), centrifugal after 30 min under 3000 RPM, remove the supernatant fluid, residue in 105 ºC oven drying to constant weight, calculate residue content.

The on-line fracturing fluid after breaking the gel and centrifuging the broken gel presents white transparent water, no residue, and there is a small amount of foam floating on the surface, which is the foam produced by the active agent composition.

2.3.4.3. Determination of swelling resistance
According to SY/T 5791-5791 "water injection with clay stabilizer performance evaluation methods", respectively in three 10 mL scale centrifuge tube in 0.50 g of sodium bentonite powder (accurate to 0.01 g), then add water, kerosene, and respectively 1.2.4.1 steps of gel breaking liquid 10 ml, sufficient oscillation mixed with sodium bentonite powder shake, place 2 h at room temperature, loading TDL - 40 hepatitis b - C bench centrifuge, the centrifugal 15 min under speed 1500 RPM, read the volume of sodium bentonite, calculation of expansion rate, as shown in table 4.

According to the test, the gel breaking solution has low viscosity, surface tension and interfacial tension, and no residue.

| Name        | Viscosity /mPa·s | Surface tension /mN/m | Interfacial tension /mN/m | Residue content /mg/L | Anti-swelling rate /% |
|-------------|------------------|-----------------------|---------------------------|-----------------------|-----------------------|
| Gel breaker | 2.16             | 21.6                  | 0.25                      | /                     | 80.6                  |

Tab.4 Results of gel breaking tests on online polymer fracturing fluid
2.3.5. Rheological experiment

For online detection of polymer fracturing fluid resistance to shear rheological property of heat-resistant, using HAAKE · MARS III rheometer in temperature 60 °C ~ 120 °C, is above 60 mPa·s after 90min shearing at 120°C and 170 s⁻¹, can fully meet the requirements of fracturing operation, rheology curve is shown in figure 1.

3. Research and Application of Online Polymer Fracturing

3.1. Research of Online Polymer Fracturing

During construction, the water of the tanker is pumped into the mixing tank of the mixer truck through the suction pump of the mixer truck. At the same time, a gear pump or plunger pump (displacement of 0 ~ 200L/min) is used to mix the polymer emulsion A agent into the mixing tank of the sand mixing truck, and a multi-purpose additive B agent is mixed into the sand mixing truck by using a plug pump or a vacuum pump (displacement of 0 ~ 100L/min). In the sand mixing tank, ammonium persulfate is added to the sand mixing tank of the sand mixing truck by dry powder adder or manually. The proppant is added by the winch of the sand mixing truck to the sand mixing tank of the sand mixing truck. After mixing, the proppant is evenly supplied to the fracturing truck by the discharge pump of the sand mixing truck and injected into the formation through the fracturing wellhead.

3.2. Field Application

The fracturing fluid system was used in two wells in the Fourth Oil Production Plant of Huabei Oilfield from January to February, 2017. Example 1: Q44-23 oil well, fracturing interval 1921.6-1933.4 m, formation temperature 63 ℃. According to the formula (1.2% low molecular polymer emulsion +0.5% multi effect additive +0.02 ~ 0.05% ammonium persulfate, adding ammonium persulfate in the front fluid by 0.02%, adding ammonium persulfate in 0.03% to 0.1% wedge in the carrier liquid, the low molecular polymer emulsion, the multi effect additive and the ammonium persulfate through the metering pump are directly driven into the mixer. The mixture of water and proppant in the mixing truck is injected into the stratum through the main truck. The fracturing fluid is 215 m³ and sand added 25 m³. Pre production of 0.36 t/d, water 0.15 m³/d, pressure after oil production 11.5 t/d, water 1.68 m³/d, the construction curve is shown in figure 2. Example 2: A321 well production well, fracturing section: the first layer 2824.0-2838.2 m, 10.6 m/4 thickness, formation temperature 105; the second layer 2789.8-2814.2 m, 12.4 m/2 thickness, formation temperature 104; the third layer 2331.0-2365.0 m, 11.8 m/4 thickness, formation temperature 89. The first and second layers are formulated according to the formula (1.6% low molecular polymer emulsion +0.5% multi effect additive +0.001 ~ 0.1% ammonium persulfate, 0.001% in the front fluid by adding ammonium persulfate, and adding ammonium persulfate in 0.005% to 0.1% wedges in the
sand carrying liquid), and then the low molecular polymer emulsion, the multi effect additive and ammonium persulfate are directly mixed into the mixture through the metering pump. The sand truck is mixed with water and proppant in the mixer, and then injected into the stratum by the main truck. The third layer is formulated as a formula (1.2% low molecular polymer emulsion +0.5% multi effect additive +0.005 ~ 0.1% ammonium persulfate, 0.005% added ammonium persulfate in the front fluid, and added ammonium persulfate in 0.01% to 0.1% wedges in the carrier liquid), and the low molecular polymer emulsion, the multi effect additive and the ammonium persulfate are directly driven into the mixer through the metering pump. It is mixed with water and proppant in the mixer, and then injected into the stratum by the main truck. The amount of fracturing fluid added in this well is 847 m³ and three layers of sand are 30+22+28=80 m³. Before the production is low, production is stopped; after pressing, the oil production is 13.19 t/d and the water is 3.51 m³/d.

![Fig.2 Fracturing treatment curves for well Q44-23](image)

4. Conclusions
(1) On-line fracturing fluid has good sand-carrying property and strong shear resistance. Under the condition of 60 ~120 ~170s⁻¹, the viscosity of continuous shearing for 90 minutes is > 60 mPa•s.
(2) The pH value of the online fracturing fluid system is neutral, no residue, and little damage to the formation.
(3) On-line fracturing fluids can be allocated according to the site operation conditions, and used with no residual fluid, so as to reduce environmental pollution.
(4) Oil increment is remarkable in field application, realizing the purpose of simple operation, saving environment, protecting reservoir and increasing production and efficiency.

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