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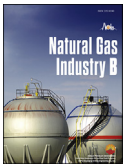


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Research article

# Recovery and treatment of fracturing flowback fluids in the Sulige Gasfield, Ordos Basin

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**Abstract**

Centralized and group well deployment and factory-like fracturing techniques are adopted for low-permeability tight sandstone reservoirs in the Sulige Gasfield, Ordos Basin, so as to realize its efficient and economic development. However, environmental protection is faced with grim situations because fluid delivery rises abruptly on site in a short time due to centralized fracturing of the well group. Based on the characteristics of gas testing after fracturing in this gas field, a fracturing flowback fluid recovery and treatment method suitable for the Sulige Gasfield has been developed with the landform features of this area taken into account. Firstly, a high-efficiency well-to-well fracturing flowback fluid recovery and reutilization technique was developed with multi-effect surfactant polymer recoverable fracturing fluid system as the core, and in virtue of this technique, the treatment efficiency of conventional guar gum fracturing fluid system is increased. Secondly, for recovering and treating the end fluids on the well sites, a fine fracturing flowback fluid recovery and treatment technique has been worked out with "coagulation and precipitation, filtration and disinfection, and sludge dewatering" as the main part. Owing to the application of this method, the on-site water resource utilization ratio has been increased and environmental protection pressure concerned with fracturing operation has been relieved. In 2014, field tests were performed in 62 wells of 10 well groups, with 32980 $m^3$ cumulative treated flowback fluid, 17160 $m^3$ reutilization volume and reutilization ratio over 70%. Obviously, remarkable social and economical benefits are thus realized.


*Keywords:* Ordos Basin; Sulige Gasfield; Environmental protection; Multiwell cluster; Flowback fluid; Well-to-well reutilization; Recoverable fracturing fluid; Water standard; Treatment process; End fluid treatment

With the deepening of exploration and development in the Sulige Gasfield, its production keeps rising. For green and economic development in the gasfield, factory-like fracturing conformable with the overall development conception has been popularized and applied. An analysis of fracturing fluid quantity in the gasfield shows that centralized factory-like fracturing can lead to drastic rise of discharge fluid of well groups in a short period. Taking a well group with 9 wells as an example, its cumulative fluid discharged in 28 days could reach 9000 $m^3$ (Fig. 1). Under this condition, fast recovery and treatment of flowback fluid is crucial in protecting the ecological environment of the operation area.

## 1. Recovery and treatment techniques for flowback fluid in the Sulige Gasfield

In 2014, in view of the features of fracturing gas test in the Sulige Gasfield, and its topographic characteristics, a recovery and treatment method suitable for fracturing flowback in the Sulige Gasfield were worked out [1–3] (Fig. 2). This method includes two parts, i.e. recovery and reuse of fracturing fluid

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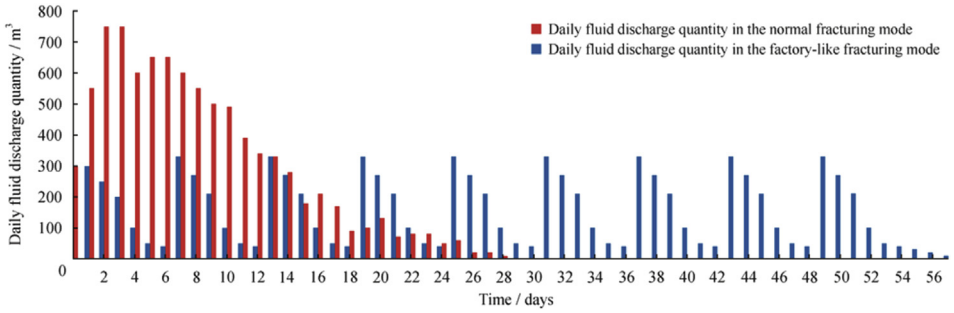


Fig. 1. Statistics on fracturing water quantity used in a 9-well group in different fracturing modes.

between wells and centralized treatment of end fluid. Recovery and reuse of fracturing fluid between wells includes the recovery and reuse of fracturing flowback inside a well group or between nearby well groups by using a new type of multi-functional polymer recovery system and its matching processing technique. Centralized end fluid treatment includes trucking the end fracturing fluid to centralized processing site to be processed and reinjected into waste water wells [4].

### *1.1. Recoverable fracturing fluid system*

Guar gum fracturing fluid was used mostly in the early fracturing of Sulige Gasfield. The recovery of this fracturing fluid system faces challenges, such as easy decay and poor salt resistance of plant gum, low recovery efficiency, and complex processing flow. To lower the processing difficulty and enhance recovery efficiency, a fracturing fluid system with the new type of multi-functional surfactant as main additive has been developed, the core idea of which is that 2–3 kinds of active groups is introduced to the molecular chain of the big molecule polymer fracturing fluid system, and reversible molecular aggregates will be formed due to the intermolecular force produced by multiple kinds of big molecular chains.

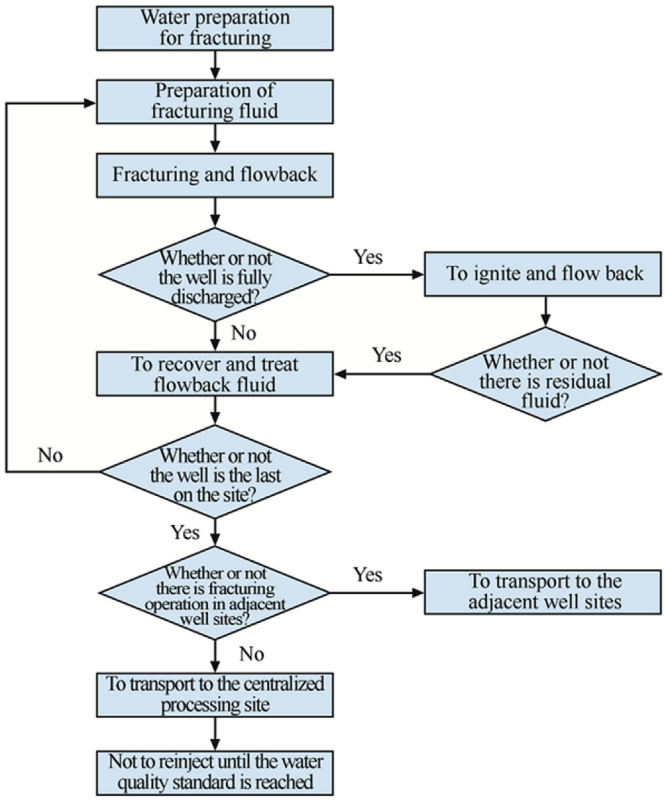


Fig. 2. Schematic of fracturing flowback fluid processing flow.

With the advantages of polymer and surfactant fracturing fluid integrated, the time, temperature, pH value of reaction, concentration of initiator and monomer, and content of surface active monomer were optimized to synthesize the new multi-functional surface active polymer recoverable fracturing fluid system [5,6] (Fig. 3).

Its molecular structure is characterized by: ① long carbon chain with better resistance-reducing performance; ② unsaturated organic carboxylic acid in the main chain to lower cost; ③ introduction of non-ionic surface active groups to enhance flowback performance and realize non-crosslinking sand carrying and reutilization; and ④ more hydrophilic groups to enhance water solubility.

The decomposing products of the fracturing system are small in molecular size, and can decompose quickly and completely in normal oxidizing condition, avoiding damage caused by big molecular retention, the average core damage rate of its flown fluid is 11.48% (Table 1), the core damage rate after multiple recovery keeps below 15% (Fig. 4).

The fracturing fluid prepared with recovered fluid has similar rheological properties to fracturing fluid prepared with fresh water, and the performance of the recovered fluid is stable (Fig. 5).

### *1.2. Recovery and reuse of interwell fracturing flowback fluid*

#### *1.2.1. Processing technique*

Because of the reversible molecular aggregate structure of the recoverable fracturing fluid system, the processing flow of recovered flowback can be simplified into filtering away big suspending particles like proppants and cuttings and supplementing thickener according to on-site test, which results in the increase of flowback fluid processing speed and the reduction of processing procedures and costs (Fig. 6).

Flowback in gas wells can be divided into three stages, i.e. flowback of liquid without natural gas, flowback of liquid with

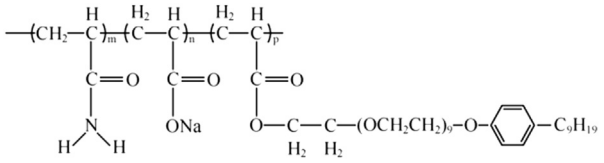

Fig. 3. Molecular structural formula of the new recoverable fracturing fluid.

little gas, and flowback of gas with a little liquid. For continuous and highly efficient operation and safe and efficient recovery of flowback fluid, only the flowback fluid in the first two stages is recovered at present. In the stage of flowback of gas with a little liquid, fluid will be discharged and tested after the gas is ignited in the grit chamber.

### 1.2.2. Processing standard

According to the characteristics of the fracturing flowback fluid, and for purpose of enhancing the recovery and reuse efficiency of flowback fluid, a processed water quality standard with total suspended particle content as the main control index for new recoverable fracturing flowback fluid system has been set up [7–9], by which the performance of fracturing fluid will not be affected and formation damage will not increased (Table 2). Compared with the processing of conventional guar gum fracturing flowback fluid, the water processing standard for this system is broader with better operability and adaptability.

The recovery and reutilization of the new recoverable fracturing flowback fluid featuring simple treatment process, high efficiency, small occupation area, and high operability etc, will replace conventional guar gum fracturing fluid gradually to enhance the overall reutilization rate of fracturing flowback fluid, with the reutilization rate in factory-like fracturing reaching over 70% (Fig. 7).

## 1.3. Centralized processing of end fluid

### 1.3.1. Processing standard

Fracturing flowback fluid is complex in composition, and compared with fresh water, it has higher indexes. According to the waste water reinjection standard in oil industry and flowback fluid test results, a processing method with total suspended particle content and bacterium content as main control indexes was worked out (Table 3).

Table 1
Evaluation results of core damage rate by the fracturing fluid system.

| Experiment no. | Air permeability/mD | Permeability/mD | | Damage rate/% |
|---|---|---|---|---|
| | | Before damage | After damage | |
| 1 | 0.479 | 0.00772 | 0.00685 | 11.27 |
| 2 | 0.461 | 0.00588 | 0.00523 | 11.05 |
| 3 | 0.503 | 0.00950 | 0.00835 | 12.11 |
| Average | | | | 11.48 |

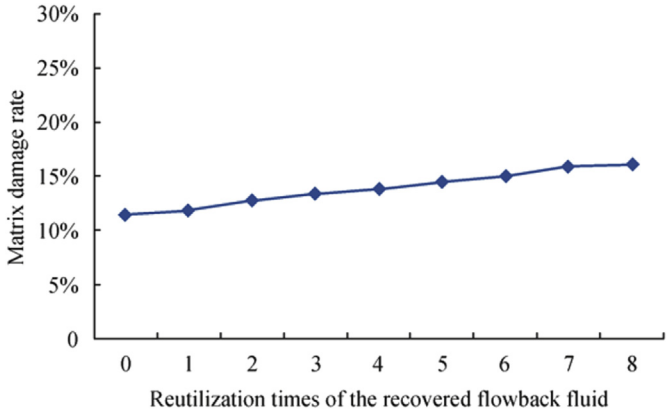


Fig. 4. Evaluation results of core damage rate after repeated reutilization of the recovered fracturing fluid.

### 1.3.2. Treatment process

According to the water characteristics of fracturing flowback fluid and requirements of field reutilization, a fracturing flowback fluid treatment unit was developed, with the main treatment process of "coagulation and precipitation, sludge dewatering, and filtration and disinfection" [10,11] (Fig. 8). For waste water with viscosity and acid–base property below requirement, matching pre-treatment process, pre-oxidation + adjusting pH value, can be adopted [12].

Water quality test before and after the treatment (Table 4) shows that the liquid after this treatment can meet the water quality requirements for reinjection in the Sulige Gasfield.

The fracturing flowback fluid treatment unit has the following main modules [13–15]: ① coagulation and precipitation, which involves pumping the flowback fluid with sand preliminarily settling removed to the treatment tank, adding coagulant and ion precipitant in the tank to make the suspended solids and $Ca^{2+}$ and $Mg^{2+}$ ions coagulate and precipitate, realizing the preliminary separation of solids and liquid; ② filtering, which involves filtering the supernate after coagulation and precipitation with 2-stage filtering bag filter to remove the remaining solid particles as far as possible; ③ disinfection, which involves disinfecting the liquid after filtering with ultraviolet wave to get rid of bacteria and microorganisms in the treated liquid; and ④ centrifugal dewatering, which involves concentrating the coagulant sludge from coagulation by using centrifugal dewatering principle to enhance the reutilization rate of flowback fluid, and sending the solid waste to the solid waste storage tank.

## 1.4. Economic benefit

Currently, the price of conventional guar gum fracturing fluid is about RMB ¥378.9/$m^3$. By recovering and reusing fracturing flowback fluid, using the low cost new polymer recoverable fracturing fluid system, the fracturing fluid cost can be lowered substantially. It is estimated that about RMB ¥300000 per well can be saved on average in cluster well groups (Fig. 9).

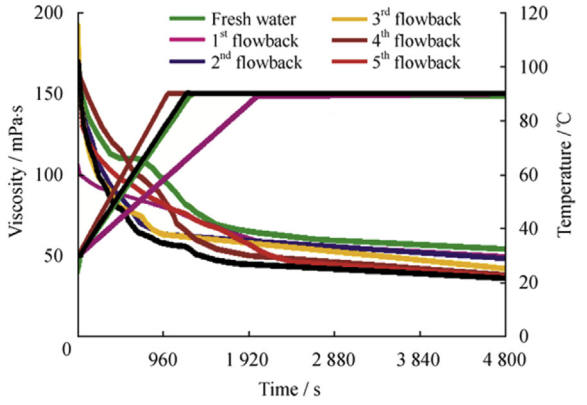


Fig. 5. Rheological curves of repeated utilization of the recovered flowback fluid.

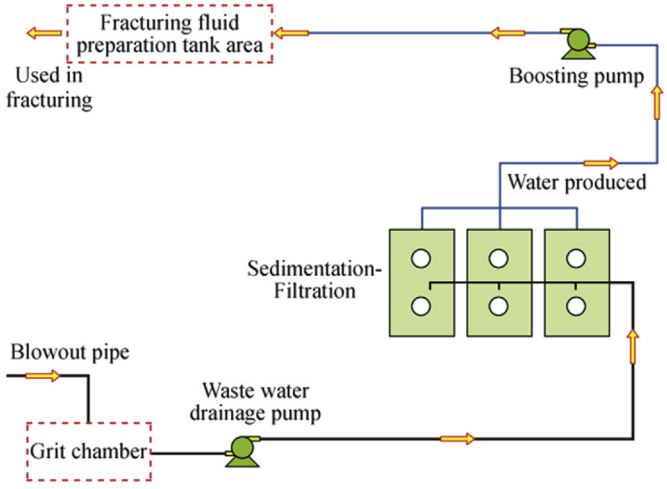


Fig. 6. Recovery and processing flow of the recoverable fracturing fluid system.

## 2. Case study

Located in the Ordos Basin, the Sulige Gasfield is a typical tight gas reservoir, with low porosity, low permeability, low pressure and low abundance, so most gas wells there need to be fractured to get industrial gas flow. To deal with the conflict between waste fracturing fluid and the fragile ecology, pilot test of fracturing flowback fluid recovery and treatment was carried out in 62 wells of 10 well groups, in which 17160 $m^3$ fracturing fluid in total was recovered and reused (Fig. 7), and 15820 $m^3$ of end fluid was treated.

Well group Su-9, a typical big cluster well group had 1 vertical well and 8 directional wells. The well group was fractured in factory-like mode, namely, direct water supply

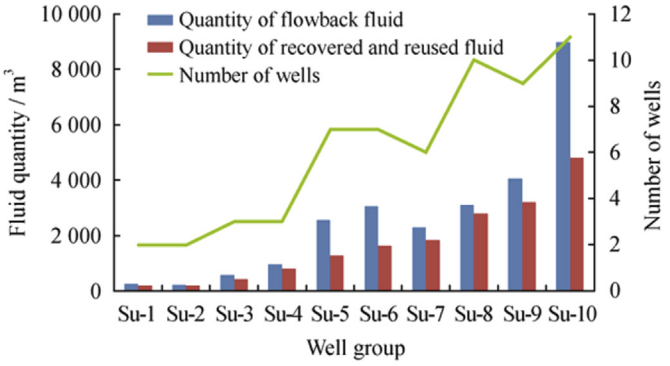


Fig. 7. Statistics on flowback fluid recovery and reutilization in Sulige Gasfield test wells.

from water well and centralized water supply from man-made lake in the well site and "six one-trips" streamline fracturing mode. Meanwhile, to enhance the water preparation efficiency of the well group and reduce the environmental stress of the well site, the fracturing flowback fluid recovery and reutilization process with the new multi-functional surface active polymer fracturing fluid system as core was adopted. All the 9 wells in the well group were fractured with mixed water fracturing process, in which the flowback fluid was sent to the grit chamber to filter away big particles such as proppant and cuttings, and prepared into non-crosslinking liquid (slick water and linear gel) to serve as low viscosity pad for the next well. With 3200 $m^3$ flowback fluid in total recovered (Fig. 10), the reutilization rate of flowback fluid of Well group Su-9 reached 78% (in Well Su-9C4, the last well fractured in this group, the flowback fluid was not reused). After fracturing, all the 9 wells were flown back successfully in one time, with an average open flow capacity of $13.38 \times 10^4$ $m^3$/d. All the flowback fluid was recovered and reinjected after fracturing, saving RMB2.4 million yuan in total.

## 3. Conclusions

1) The recovery and treatment of flowback fluid in the Sulige Gasfield, enhancing the water utilization rate, reducing discharged waste water, relieving environmental protection stress, and resolving the environmental protection issue in factory-like operation, makes up an indispensible link in the green "factory-like" fracturing.
2) The flowback fluid recovery and reutilization technique between wells centering on the new multi-functional surface active polymer recoverable fracturing fluid system can increase the reutilization rate of fracturing fluid

Table 2
Water quality standard for the processed flowback fluid.

| Fracturing fluid system | pH value | Content/(mg·$L^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Suspended matter | Bacteria | $Ca^{2+} + Mg^{2+}$ | $SO_4^{2-}$ | $HCO_3^- + CO_3^{2-}$ | Iron ion |
| New recoverable fracturing fluid system | 6.0–7.5 | <200 | $<10^5$ | $<10^4$ | / | / | <200 |
| Conventional guar gum fracturing fluid system | 6.0–7.5 | <200 | <100 | <150 | <1000 | <1500 | <150 |

Table 3
Requirements for reinjection water quality in the Sulige Gasfield

| Fracturing fluid system | pH value | Content/(mg·L$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $Ca^{2+}$ +$Mg^{2+}$ | $Cl^-$ | Iron ion | $SO_4^{2-}$ | $HCO_3^- + CO_3^{2-}$ | Bacteria | Suspended matter |
| Water quality test results of fracturing flowback fluid | 5.0–8.0 | 250–500 | 6000–9000 | 30–70 | 200–500 | 500–800 | 106 | 400–600 |
| Quality requirements on reinjection water | 6.0–9.0 | <150 | / | / | / | / | <100 | <10 |

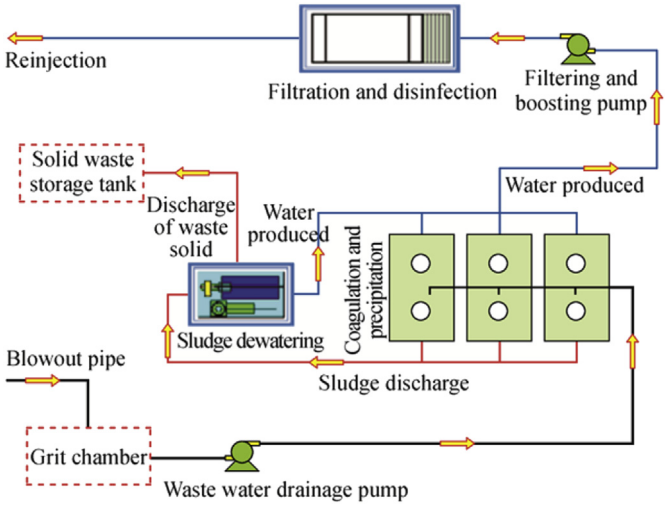


Fig. 8. Centralized treatment process of the end fluid.

Table 4
Water quality indexes of flowback fluid before and after treatment.

| Treatment stage | pH value | Content/(mg·L$^{-1}$) | | | |
|---|---|---|---|---|---|
| | | Suspended solid | $Ca^{2+}$ | $Mg^{2+}$ | Bacteria |
| Before treatment | 6.3 | 406 | 165 | 105.0 | 106 |
| After treatment | 7.3 | 10 | 89 | 37.5 | <100 |

substantially, with recovery and reutilization rate of up to 70% and great economic benefit.

3) Through coagulation and precipitation, filtering and disinfection, and sludge dewatering etc, the end fluid can reach the requirement for reinjection water quality in the Sulige Gasfield, ultimately realizing “zero” pollution in the fracturing site.

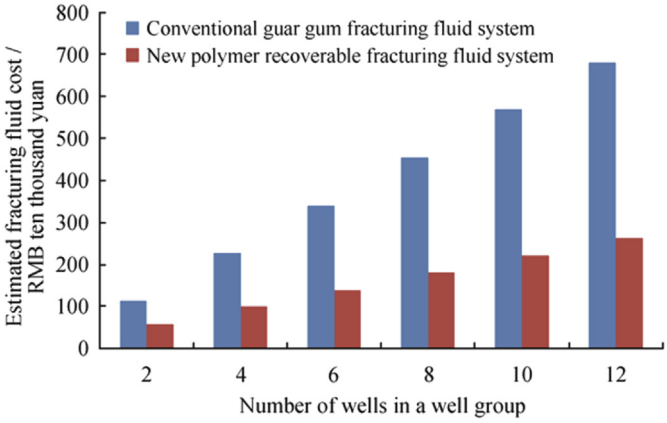


Fig. 9. Estimated saved cost of fracturing fluid in well groups.

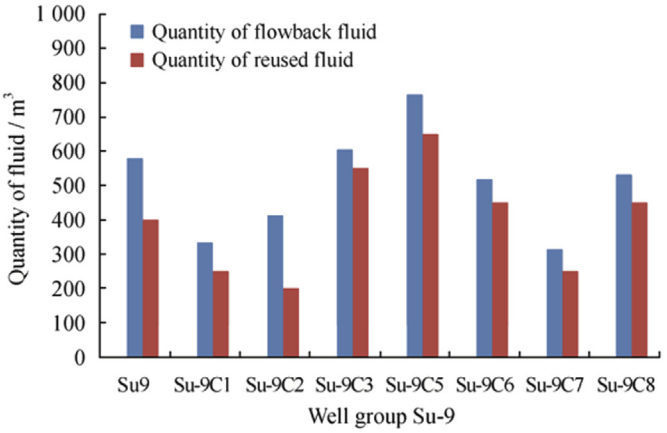


Fig. 10. Statistics on the recovered and reused flowback fluid quantity of the well group Su-9.

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