Research Progress on rheological properties of polymer-bearing produced fluid

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Abstract

As the development of oil field enters in the mid and later period, polymer flooding technology, which is one of the three oil recovery methods, has been widely used in oil field after water flooding. Different from water flooding, the existence of the polymer in produced fluid is bound to affect its rheological properties.And its complex nature has a very important influence on the calculation of the gathering and transportation process, the starting pressure of the shutdown and restart process, and the screening of demulsifier. Therefore it is necessary to study the rheological properties of polymer-bearing produced fluid.

Keywords

Produced fluid, Polymer flooding, Rheological property.

1. Introduction

Polymer flooding technology is the main technical means to improve oil recovery. So far, China has become the main application country of polymer flooding technology. Daqing oil field began the polymer flooding technology test in 1989. In 1995, the first large-scale industrial production of polymer flooding was carried out in the Sa Bei oil field[1]. At present, the polymer used in oil displacement technology is mainly hydrophobic associating polymer and partially hydrolyzed polyacrylamide[2]. The addition of polymer increased the viscosity of water, and the mobility ratio of oil and water decreased significantly after the polymer is added to the formation, which enhanced the recovery of crude oil. Over the years, domestic and overseas scholars have done a lot of research on the rheology and stability of the produced fluid. However, most of the studies on emulsion properties are limited to the properties of waxy crude oil emulsions. There are few studies on the properties of polymer flooding produced fluid.

2. Rheological Property of Produced Fluid

In the early stage of oil field development, most of the produced fluid is emulsified water, that is, oil in water emulsion. With the development of oil field into the mid and later period, the emulsified crude oil produced by alkali flooding and surfactant flooding in the three oil recovery is mostly oil in water emulsion. Many domestic scholars have done a lot of research on the flow and rheological properties of oil in water emulsion.

Through the research on the relationship of high water content crude oil rheological properties and rheological properties of crude oil and water content and temperature, Dali Gong et al. provided a regression formula for calculating the rheological parameters of high water cut crude oil[3]. In the process of transporting water bearing crude oil, the energy consumed by the oil in water type of water in which the continuous phase is water is smaller than that of the oil in water type water bearing oil for the continuous phase. It is suggested that the high water cut crude oil transportation in Daqing should adopt the continuous phase of oil in water type.

Yuan Xu et al. studied on rheological properties of heavy oil emulsion in Bozhong oil field by using HAKKE RS600 rheometer[4]. It is found that the turning point of Bozhong heavy oil is 70%, and according to the rheological curve, it is found that the emulsion of the heavy oil in Bozhong accords with the characteristics of Newton fluid under the condition of small water content. But when the water content is greater than 50%, the fluid is in accordance with the characteristics of power-law fluid. At the same time, the greater the water content, the greater the influence of temperature on apparent viscosity, while the effect of pressure on the apparent viscosity of heavy oil emulsion is not significant.

Liwei Liu et al. studied on the rheological behavior of crude oil in Bohai Oilfield by using rotary viscometer[5]. The results show that the viscosity of emulsion decreases with the increase of shear rate, decreases with the increase of temperature, increases with the increase of water content, and increases with the increase of polymer concentration. When the water content is greater than 40%, the properties of the emulsion show the characteristics of non Newtonian fluid in the temperature range of 0~55℃. With the increase of temperature, when the water content is lower than 40%, the properties of emulsion show the characteristics of Newton fluid at the temperature range of 55~70 ℃.

By using RV2 type rheometer, Shixuan Li studied the boundary condition of Newtonian and non Newtonian characteristics of Xifeng crude oil emulsion[6]. The results show that when the water content of Xifeng crude oil emulsion is small, the fluid exhibits the characteristics of Newton fluid when the temperature is higher than 25 ℃. When the temperature is less than 25 ℃, the characteristics of non Newtonian fluid are presented. With the increase of water content, the temperature of reaching non Newtonian fluid increases.

Wang Weimin et al. studied on the rheological properties of the water bearing super heavy oil in Liaohe Oilfield[7]. The results show that the viscosity is affected greatly by the temperature before the phase inversion point, and is less affected by temperature after the phase inversion point. Meanwhile, it is verified that the Richardson equation can be used to describe the relationship between temperature and viscosity in the straight line of the viscosity temperature curve.

Liping Guo et al. conducted research on the yield characteristics of W/O waxy crude oil emulsion by VT550[8]. The results show that the yield stress of W/O waxy crude oil increases slightly with the increase of water content. When the water content is higher, the yield stress increases relatively greatly with the increase of water content. The relationship between volumetric water content and yield stress is fitted.

Jinjun Zhang et al. studied on the thixotropy of waxy crude oil emulsion by using RS150H rheometer produced by HAKKE company[9]. The results show that the thixotropy of waxy crude oil emulsion is similar to that of dehydrated crude oil. Based on the improvement of Houska model, a mathematical model was proposed to calculate the shear stress attenuation of waxy crude oil emulsion, and the shear stress attenuation data of Daqing waxy crude oil emulsion at constant shear rate were fitted.

Chuanxian Li et al. studied the effect of emulsification conditions on the viscosity of heavy oil emulsion by using the German Haake-RS75 controlled stress rheometer[10]. The results show that with the increase of emulsifier concentration (0.5%~5%), the droplet diameter decreases and the emulsion viscosity decreases first and then increases. When the emulsifier concentration is less than 4%, the emulsion is a simple Newton fluid. Increasing the concentration of emulsifier to 5% leads to the conversion of emulsion into non Newtonian fluid. With the increase of emulsification temperature (40~70 ℃), the viscosity of the emulsion and the diameter of the droplets are reduced, while the emulsion is always Newton fluid.

2.1 Page Numbers.

Generally speaking, the main factors that affect the rheological properties of polymer solution include shear rate, salinity, temperature, concentration, relative molecular mass, relative molecular mass distribution, pH value, hydrostatic pressure and so on. The results show that the polymer solution has obvious non Newtonian properties, which shows the characteristics of pseudoplastic fluid. The apparent viscosity decreases with the increase of shear rate[11]. Since 1960s, many domestic and overseas scholars have studied the rheological properties of polymer solution systematically and deeply from the perspective of structural rheology. Some rheological models are presented as well. At present, there are two kinds of models to study the rheological properties of polymer solution: empirical model and semi empirical model.

The Flory-Huggins equation was proposed by Huggins[12]. He believes that if the concentration of polymer increases, the apparent viscosity of the solution subsequently increases. However, this equation is only applicable to the three - component system composed of polymer - double solvent and to the case where the solution concentration is infinitely small. The application of this method is limited.

Meter found that the rheological properties of polymer solution is complex, can not be expressed in a simple mode[13]. Therefore, in order to better describe the rheological behavior of polymer solution in a large shear rate range, a four parameter model was proposed

In 1965, Cross proposed a more complex four parameter model[14]. After fitting, the model can be applied to a large range of shear rate, and can describe the rheological properties of polymer solution with different concentration. In view of the complexity of the model, it is mainly used in numerical simulation.

Caihong Li has done a lot of experiments to study the rheological properties of polymer solution system[15]. The data were fitted with the existing rheological model, and the parameters in the model were described quantitatively. The results show that the Meter model and Cross model can describe the rheological properties of polymer solutions with different concentrations in a wide range of shear rates. At a certain temperature and shear rate, the Flory-Huggins equation can be used to describe the rheological properties.

Experimental study of Fujun Li shows that: the rheological behavior of the polymer solution exhibits a power-law model in the actual situation[16]. The specific performance is that with the increase of the concentration of polymer solution, the consistency coefficient increases and the power law index decreases. That is, thickening characteristics become more and more obvious and the degree of deviation from Newton fluid is also more and more significant.

Tang JinXing used simulated water to prepare polymer solution[17]. The preparation of polymer solutions refers to the API standard operation. Before use, the polymer solution was filtered by 3 m membrane under the pressure difference of 0.02Mpa. The results show that the Cross model and the Powe-Law model can fit the data well. And rheological parameter calculation formula under the influence of polymer concentration and temperatureare presented.

Xing Zhang et al. studied the rheological behavior of polymer solution by using DVIII rotary viscometer and carried on the mathematical regression to the experimental data[18]. It is found that the polymer solution has the characteristics of shear dilution, which is consistent with the rheological model of power law fluid.

Huifen Xia et al. applied dynamic shear test and steady shear flow experiment to studied the partial factors affecting the viscoelasticity of polymer solution in 2002[19]. The experimental results show that the polymer solution is not only viscous but also elastic. At low frequency, the viscosity is dominant, while in the middle and high frequency, the elasticity is dominant.

3. The Effect of Polymer on the Rheological Property of Fluid Flow

At present, there are few researches on the rheological behavior of polymer solution. The main conclusions are as follows.

Dongfeng Lu, Xiaze Zhang et al. studied the rheological properties of polymer solution and rheological characteristics of oil well produced fluid by experiment[20]. The instrument is RS-150 stress rheometer. The instrument used is RS-150 stress rheometer. It is found that the injected polymer solution is non Newtonian fluid, which exhibits the flow characteristics of pseudoplastic fluid. In addition to oil and water in the oil well fluid, there are polymers. The polymer solution in produced liquid exists in the oil phase in the presence of dispersed phase, that is water in oil emulsion.

Lixin Wei et al did Rheological property test on Sa Bei oilfield high polymer bearing produced liquid by using AR2000EX type rheometer produced by TA company[21]. The experimental results show that the rheological behavior is affected by temperature, water content and polymer concentration. Around 35℃ is the critical temperature of critical temperature of flow structure transition. With the increase of water content and the decrease of polymer concentration, the low temperature flow performance of the system is improved.

Hui Chen et al. studied the rheological behavior of polymer solution with oil[22]. In the experiment, the water used in the preparation of polymeric solutions was the on-site water quality, and the equipment used was Physica MCR301 rotary rheometer. It is found that no matter whether the crude oil exists in the polymer solution, it shows obvious non Newtonian fluid characteristics, which is consistent with the rheological model of the power-law fluid.

The effect of polymer and surfactant on apparent viscosity of produced fluid was studied by Yuxia Chang using W/O emulsion prepared in laboratory[23]. The experimental results show that the stability of W/O emulsion is closely related to the critical shear strength. When the stirring speed is 1600r $\cdot$min^{-1} and the time is 10min, the emulsion system is close to the field produced liquid. Both polymer and surfactant can increase the apparent viscosity of W/O emulsion, thus enhancing the stability of emulsion. When the concentration of polymer was 400mg $\cdot$L^{-1}, the viscosity of emulsion reached maximum, while the viscosity of emulsion increase with the increase of surfactant concentration.

Wei Liu test for stability of polymer containing W/O emulsions in different concentration conditions by using Turbiscan Lab stabilimeter[24]. The results show that with the increase of polymer concentration, the worse the water clarity, the smaller the thickness of the water. At the same time, the influence of polymer concentration on the stability of W/O emulsion was explained from the microscopic point of view. The results show that the interfacial tension of oil and water can be increased with the addition of polymer, and the interfacial tension increases with the increase of polymer concentration, which leads to the increase of the stability of W/O emulsion.

4. Conclusion

The rheological properties of polymer produced fluid are affected by temperature, water content and polymer concentration. The regularity is that the low temperature flow performance of the produced fluid system is improved with the increase of temperature, water content and the decrease of polymer concentration, which is consistent with the rheological properties of conventional produced fluid. However, the interfacial tension of the produced liquid is increased after the addition of polymer, which leads to the increase of the stability of the polymer produced fluid. Especially at lower temperature, the addition of polymer will have a certain impact on the separation of oil and water. The addition of colloid and other components can greatly enhance the strength of the original interfacial film and increase the difficulty of demulsification. The existing processing and conveying equipment for the recovery of the produced liquid should be especially should be particularly good control of temperature, water content and other indicators, so as to avoid the occurrence of a condensate pipe due to shut down and restart.

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