An Overview: Practice, Experience and Achievement of Polymer Flooding In Daqing Oilfield

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Abstract. Daqing oilfield was put into production in 1960. Excellent achievement is acquired. It has maintain the production of 5000×10^4 tons / year for 27 years and 5500×10^4 tons / year for 13 years. Main technologies adopted in Daqing oilfield include early-stage water flooding for pressure maintenance, separate-zone water injection and separate-zone production, division of series of development-zone, well infilling, chemical flooding and conventional stimulation measures such as hydraulic fracturing and acidizing. Research on polymer flooding was started in 1960s. This technology was widely put into industrialized application since 1996. Current proportion of production rate from polymer flooding is over 25%. Technology of polymer flooding experienced laboratory experiment, pilot field test, industrialized field test and industrialized application, successively. In this paper, practice, experience and achievement of polymer flooding in Daqing oilfield were elaborated in view of class I reservoirs, class II reservoirs and class III reservoirs respectively. When it comes to class I reservoir, its effective thickness of single layer is more than 3 meters and effective permeability is greater than 0.3 . When it comes to class II reservoir, its effective thickness of single layer is between 1 meter and 3 meters and effective permeability is between 0.1 and 0.3. Daqing oilfield use HPAM as polymer usually. When it comes to class III reservoir, its effective thickness of single layer is less than 1 meter and effective permeability is lower than 0.1 . Each types of reservoir were produced by polymer flooding in different period. Class I reservoir was put into production for polymer flooding at first stage. Concentration of polymer solution is 2000mg/L and relative molecular weight of polymer is 2.5×10^7. Polymer dosage is 1100 PV.mg/L and injection rate is 0.12 PV/a. Injection-production well spacing is between 200 meters and 250meters. Class II reservoir was put into production with polymer flooding at second stage. Concentration of polymer solution is 1000mg/L and relative molecular weight of polymer is between 1.2×10^7 and 1.6×10^7. Polymer dosage is 640PV.mg/L and injection rate is 0.14 PV/a. Injection-production well spacing is between 150meters and 175meters. Class III reservoir was put into production with polymer flooding at third stage. Concentration of polymer solution is between 800mg/L to 1000mg/L and relative molecular weight of polymer is 5×106. Polymer dosage is 570PV.mg/L and injection rate is 0.25 PV/a. Injection-production well spacing is between 100meters and 125meters. Each types of reservoir adopt five-spot polymer flooding well pattern. Perfect achievement from polymer flooding is acquired. Compared with water flooding, water cut is declined by 20% to the maximum, and recovery efficiency is increased by 10% for polymer flooding of class I reservoir. Water cut is declined by 11% to the maximum, and recovery efficiency is increased by 7.8% for polymer flooding of class II reservoir. Water cut is declined by 6% to the maximum, and recovery efficiency is increased by 5% for polymer flooding of class III reservoir. Daqing oilfield has accumulate lots of experience for polymer flooding in aspects of oil displacement mechanism, design of reservoir engineering program, adjustment of scheme, evaluation and prediction of technique indexes and distribution of remaining oil.

Introduction

Daqing oilfield has entered high water cut development stage at present, polymer flooding has become general technology of EOR in Daqing oilfield [1]. This technology has been widely applied for class I reservoirs, an integrated theoretical system also been established [2]. For class II reservoirs and class III reservoirs. Daqing oilfield also carried out a series of laboratory experiment and pilot field test[3,4]. Through continuous summary test dynamic reflect characteristics, analyzes the existing problems in the process of polymer flooding, an integrated theoretical system also been established [5,6]. It is proved that each kind of reservoirs has acquired good effect, water cut rise rate was controlled, recovery ratio was improved. In this paper, we summarized the producer injector spacing and polymer flooding parameters in terms of class I reservoirs, class II reservoirs and class III reservoirs [7].

Polymer Flooding Parameters of Class I Reservoirs

Concentration of Polymer Solution. Through laboratory experiment, taking north-two-east eastern block as an example, four sets of schemes were designed to study concentration of polymer solution. Research results show that the greater the concentration of polymer solution, the higher the recovery efficiency. When concentration of polymer solution increase from 1000mg/L to 1500mg/L, recovery efficiency increase by 2.8%; When concentration of polymer solution increase from 1500mg/L to 2000mg/L, recovery efficiency is increased by 4.6%; When concentration of polymer solution increase from 2000mg/L to 2500mg/L, recovery efficiency increase by 0.8%, rise amplitude is indistinct. Therefore, for class II reservoirs, taking north-two-east eastern block as an example, concentration of polymer solution is 2000 mg/L [8].

Relative Molecular Weight of Polymer. Through same methods, taking north-two-east eastern block as an example, four sets of schemes were designed to study relative molecular weight of polymer.

Research results show that the greater the relative molecular weight of polymer, the higher the recovery efficiency. When relative molecular weight of polymer increase from 1.4×10^7 to 1.9×10^7, recovery efficiency increase by 1.5%; When relative molecular weight of polymer increase from 1.9×10^7 to 2.5×10^7, recovery efficiency increase by 3.6%; When relative molecular weight of polymer increase from 2.5×10^7 to 3.5×10^7, recovery efficiency increase by 0.5%,rise amplitude is indistinct. Therefore, for class II reservoirs, taking north-two-east eastern block as an example, relative molecular weight of polymer is 2.5×10^7[9].

Injection Rate of Polymer Solution. By using method of numerical simulation, four sets of computational schemes were designed to research injection rate of polymer solution.

Concentration of polymer solution is guaranteed as 2000mg/L, Relative molecular weight of polymer is 2.5×107, polymer dosage is 700PV.mg/L, injection rate of polymer solution is designed as 0.10PV/a、0.12PV/a、0.14PV/a、0.16PV/a respectively[10].

Relationship between polymer flooding incremental oil and injection rate is shown in Fig.1. The greater the injection rate, the higher the degree of reserve recovery. But range ability is not obvious. With the increase of injection rate, elastic viscosity of polymer solution increased, shear viscosity of polymer solution decreased. However, the degree of increase is greater than the degree of decrease. So valid viscosity of polymer solution raised.

With the increase of injection rate, polymer flooding incremental oil increased gradually, rise amplitude is indistinct.

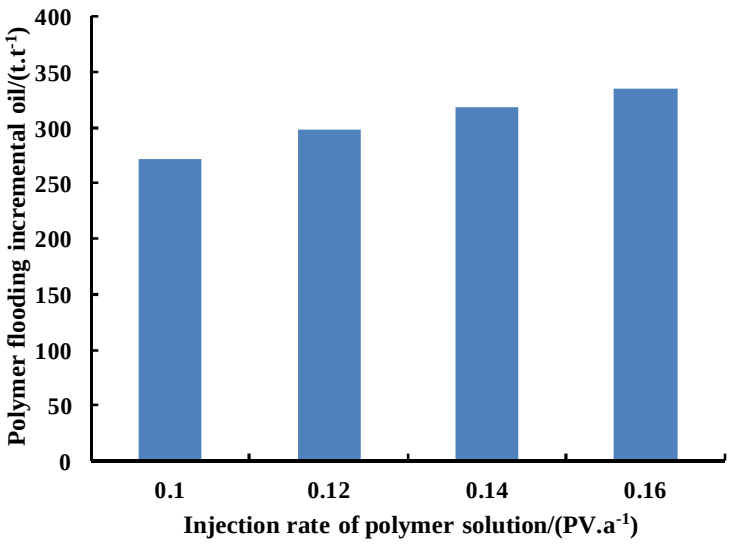

Fig.1 Relationship between polymer flooding incremental oil and injection rate

When injection rate is 0.16PV/a, maximum pressure of well head is 13.61MPa, this pressure is greater than breakdown pressure of reservoir, which is 13.5MPa. When injection rate is 0.12PV/a, maximum pressure of well head is 11.16MPa, this pressure is lower than breakdown pressure of reservoir.

From what has been discussed above, considering degree of reserve recovery, polymer flooding incremental oil, breakdown pressure of reservoir and other technical indexes, injection rate of class I reservoir is 0.12 PV/a[11].

Polymer Dosage. By using method of numerical simulation, four sets of computational schemes were designed to research injection rate of polymer solution.

Concentration of polymer solution is guarantee as 2000mg/L, Relative molecular weight of polymer is 2.5×10^7, injection rate of polymer solution is 0.12PV/a, polymer dosage is designed as 900 PV.mg/L、1100 PV.mg/L、1300 PV.mg/L、1500 PV.mg/L.[12]

Relationship between rise scope of recovery efficiency and polymer dosage is shown in Fig.2. With the increase of polymer dosage, recovery efficiency and the rise scope of recovery efficiency all increased. Because the greater the polymer dosage and the longer the coverage time, the better the effect of the remaining oil tapping, but the rise scope decreased gradually.

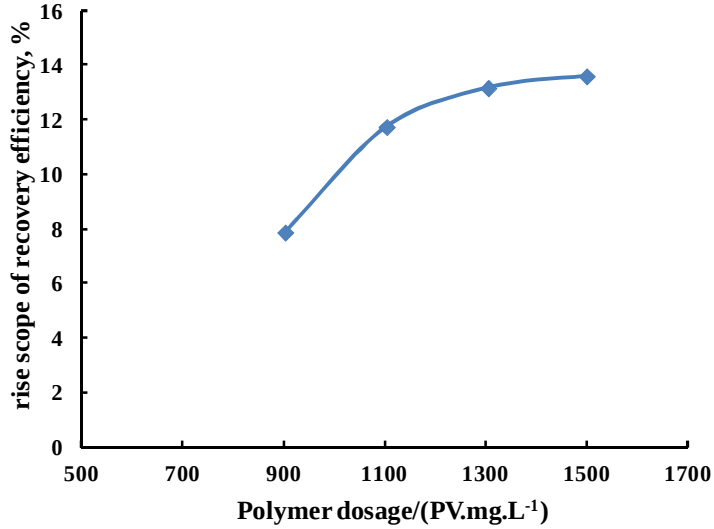

Fig.2 Relationship between rise scope of recovery efficiency and polymer dosage

Relationship between polymer flooding incremental oil and polymer dosage is shown in Fig.3. With the increase of injection rate, polymer flooding incremental oil decreased gradually.

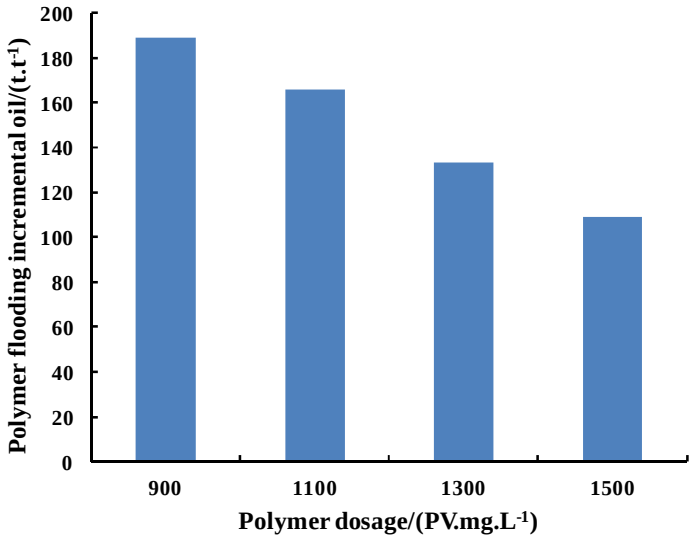

Fig.3 Relationship between polymer flooding incremental oil and polymer dosage

From what has been discussed above, considering rise scope of recovery efficiency, polymer flooding incremental oil and other technical indexes, polymer dosage of class I reservoir is 1100 PV.mg/L[13].

Polymer Flooding Parameters of Class II Reservoirs

In order to study polymer flooding parameters of class II reservoirs, we take sanan oilfield as an example[14].

Concentration of Polymer Solution. If polymer dosage is same, but concentration of polymer solution is different, the final displacement characteristics are different. In order to study the relationship between displacement characteristics and concentration of polymer solution, in the condition of injection rate is 0.14PV/a and polymer dosage is 640 PV.mg/L, concentration of polymer solution is designed as 400mg/L to 1400mg/L. With the increase of concentration of polymer solution, decrease of water cut ahead of schedule, decrease scope of water cut become apparent. If concentration of polymer solution is 1400mg/L, compared with the concentration of 800mg/L, recovery efficiency increase by 0.47%, polymer flooding incremental oil is 4.4 ton, when water cut reached 98%, water is saved by 0.21PV. Therefore, in terms of technical effect, in the process of oil displacement, we should adopt high concentrations of slug. However, with the increase of concentration of polymer solution, the viscosity of polymer solution increased. It is also more difficult to inject polymer solution. Compared with class I reservoir, class II reservoir heterogeneity become obvious. Therefore, concentration of polymer solution of class II reservoir should different from that of class I reservoir. Design of concentration of polymer solution should depend on actual injection capacity of each well group, and performance index of selected polymer solution. Concentration of polymer solution is closely related to proportion of channel sand. The greater the proportion of channel sand, the bigger the selective space of concentration of polymer solution.

Therefore, considering reservoir heterogeneity, proportion of channel sand, polymer flooding control degree, pressure remaining space of polymer flooding and other factors, concentration of polymer solution of class II reservoir is 1000mg/L[14].

Relative Molecular Weight of Polymer. In view of geologic characteristic of class II reservoir, when study relative molecular weight of polymer, firstly, relative molecular weight of polymer should as high as possible. So recovery efficiency can be enhanced and polymer dosage can be decreased.

Secondly, the matching relationship between weight of polymer and different permeability of reservoir should be considered, the better polymer flooding effect can be obtained.

Through the research results of matching relationship, also, in the process of optimize relative molecular weight of polymer by using polymer flooding control degree, many experience are accumulated. A series of laboratory experiment also carried out to optimize relative molecular weight of polymer. Therefore, relative molecular weight of polymer of experimental area (class II reservoirs) is designed as 1.2×10^7 to 1.6×10^7[14,15].

Injection Rate of Polymer Solution. In the process of optimize reasonable injection rate of polymer solution, two aspects should be considered. In one hand, limit of injection capacity of reservoir should be considered. In the other hand, we should guarantee selected injection rate of polymer solution can maintained normal production, develop period can be shortened and overall economic benefits of block can be improved. In the process of polymer solution injection for class II polymer solution, injection pressure is too high. It is difficult to inject polymer solution. Therefore, in the process of optimized injection rate of polymer solution of class II reservoir, the main considered factors are reasonable rise scope of pressure and polymer flooding control degree.

Finally, injection rate of polymer solution of class II reservoir is 0.14PV/a[16].

Polymer Dosage. Through theoretical research and practical development, the result show that with the increase of polymer dosage, the decrease scope of water cut increased and the rise scope of recovery efficiency increased. However, because of the increase of polymer dosage, the utilization ratio of polymer solution declined. Therefore, we should consider both technology and economy, so the rise scope of recovery efficiency and polymer flooding incremental oil are great.

Therefore, polymer dosage of class II reservoir is 640 PV.mg/L[17].

Producer Injector Spacing. Channel sand of class II reservoir become narrow. The development area of poor permeability and fringe are lager. Therefore, if the producer injector spacing of class II reservoir keep for 250 meters, polymer flooding control degree is low. Relationship between polymer flooding control degree and producer injector spacing is shown in Table 1. Producer injector spacing of western of north one-two rows and the west of the second north block are 250 meters, polymer flooding control degree is lower than 70% of returning class II reservoir. When producer injector spacing is declined to 175 meters, polymer flooding control degree is increased by 8% to 10%, polymer flooding control degree is more than 70%. When producer injector spacing is declined to 150 meters, polymer flooding control degree is increased by 8% to 10%, polymer flooding control degree is more than 80%. When producer injector spacing is declined to 125 meters, rise scope of polymer flooding control degree is lower than 4%. Therefore, the advisable producer injector spacing is 150 meters to 175 meters[14].

Table 1 Relationship between polymer flooding control degree and producer injector spacing

Blocks	Producer injector spacing (m)	Polymer flooding control degree(%)			
		One-way	Two-way	Multi-way	Total
Western Part of B1 and B2	250	29.4	24.5	7.5	61.4
	175	16.5	17.7	37.1	71.3
	125	13.8	22.8	50.5	87.1
Eastern Part of B1 and B2	250	30.2	26.0	12.3	68.5
	175	8.0	28.2	39.7	75.9
	125	14.0	24.8	50.3	89.1
Western north II region	250	25.5	25.5	17.5	68.5
	175	18.8	25.3	35.1	79.2
	125	13.9	23.3	52.8	90.0
Western north II region	250	28.6	27.5	13.3	69.4
	175	10.5	27.2	42.5	80.2
	125	9.4	21.3	61.7	92.4

Currently, in Daqing oilfield, producer injector spacing of class III is between 100 meters and 125 meters[14,18].

Polymer flooding parameters of class III reservoirs

In order to study polymer flooding parameters of class III reservoirs, we take Eastern of Southern Fourth Block as an example [13].

Concentration of Polymer Solution. The results of numerical simulation show that when mobility ratio is greater than 1 and polymer dosage is same in different schemes, oil displacement effect have little relationship with concentration of polymer solution. With the increase of concentration of polymer solution, decrease of water cut ahead of schedule, decrease scope of water cut become apparent. Development period declined. In the other hand, with the increase of concentration of polymer solution, viscosity of polymer solution is also increased. Which can lead to the increase of injection pressure, it is different to inject polymer solution. Therefore, in the process of optimize concentration of polymer solution of class III reservoir, viscosity of polymer solution and injection pressure should be considered.

There is relationship between viscosity of polymer solution and quality of injection water. In order to obtained good effect, viscosity of well head is 12mPa.s to 17mPa.s, in the condition of meet the need of this viscosity, concentration of polymer solution of class III reservoir is 800 mg/L to 1000mg/L[13,18].

Relative Molecular Weight of Polymer. In terms of Eastern of Southern Fourth Block, its permeability is low. Thickness of layer is great. It has many layers and the change of permeability is great. Therefore, in the process of optimize relative molecular weight of polymer, we should guarantee large amount of polymer solution injected into thin and lower penetrability layers. If relative molecular weight of polymer is 5×10^6, the layers number of meet the standard of polymer flooding is 6 in pu II. Polymer flooding control degree is greater than 50%, proportion of valid thickness is more than 70%[18,19,20].

Therefore, relative molecular weight of polymer of class III reservoir is 5×10^6 [13,18,19,20].

Injection Rate of Polymer Solution. The research results show that with the increase of injection rate of polymer solution, recovery efficiency slightly declined. In practice, there is close relationship between injection rate and injection pressure. Therefore, in the process of optimize injection rate of polymer solution, injection pressure of injection well should not more than collapse pressure of reservoir. Collapse pressure of this block is 11.0 MPa to 11.5 MPa. In the process of polymer flooding, injection pressure should leave certain spacing. Combined the injection capacity of experimental area, injection rate of polymer solution of class III reservoir is 0.25 PV/a[19,20,21].

Polymer Dosage. In terms of Eastern of Southern Fourth Block, in the condition of its injection rate of polymer solution is 0.2PV/a and concentration of polymer solution is 800mg/L. We make a research on the main indexes of oil displacement effect in different polymer dosage. Finally, polymer dosage of class III reservoir is 570mg/L.PV.[21,22,23]

Tab.2 The impaction on oil displacement effect with different polymer dosage

Polymer dosage (mg/L.PV)	Recovery efficiency(%)	Rise value of recovery efficiency(%)	Polymer flooding incremental oil (t/t)
570	9.75	7.09	70.6
640	10.4	7.74	68.7
670	10.6	7.94	67.2

Producer injector spacing. Polymer flooding control degree has critical influence on polymer flooding effect. When producer injector spacing declined from 250 meters to 175 meters, polymer flooding control degree is increased by 8% to 10%. When producer injector spacing declined from 175 meters to 125 meters, polymer flooding control degree is increased by 8% to 10% again. Therefore, the

way of decline producer injector spacing is useful for the increase of polymer flooding control degree[24,25,26,27].

Polymer Flooding Effect of Daqing Oilfield

Compared with water flooding, after polymer flooding, water content of class I reservoir reduces about 20%, and the recovery efficiency increases about 10% [28,29,30].

Class II reservoir of upward movement of test site in the middle block of southern third region, when injection pore volume multiple is 0.023 PV, composite water cut of the whole region would be the biggest about 94.3%. When injection pore volume multiple is 0.035PV, the whole region would begin to become effective. When injection pore volume multiple is 0.276 PV, composite water of the whole region would be the lowest about 76.6%, water cut declined by 17.7%. When injection pore volume multiple is 0.64 PV, finishing injecting polymer solution turns into subsequent water-flooding in the whole region. When composite water cut of the whole region is 98% and composite injection pore volume multiple is 1.016 PV, at the moment, the stage of polymer flooding of recovery percent of reserves is 17%, the whole region of ultimately recovery efficiency is 49.6%, expected then ultimately cumulative oil production is about 8.7193×10^4t. Compared with water drive, class II reservoir of polymer flooding of water cut declines by 11%, while recovery efficiency increases by 7.8%.[31,32,33]

Class III reservoir of polymer flooding of test site in Daqing oilfield put into production in the second half of 2004, and then the group of single well began to try to water flooding in eastern north II region and the center west in December 2004. Injects relative molecular of polymer that is 300×10^4 in eastern north II region, now, mass concentration of polymer is 800mg/L, viscosity of liquid is 7.0mPa.s at wellhead, and pressure injection keeps in 12.7MPa; compared with finishing water drive, injection pressure rises by 3.5MPa, while the value of upside potential is 1.1MPa to bursting pressure[34,35]. Injects relative molecular of polymer that is 500×10^4 in the center west, now, mass concentration of polymer is 800mg/L, viscosity of liquid is 10.0mPa.s at wellhead, and pressure injection is 11.0MPa, while the value of upside potential is 1.5 MPa to bursting pressure[36]. Now, water content of Class III reservoir reduces by 6%, recovery efficiency increase by more 5% on the basis of condition of polymer injection[37].

Conclusions

(1) Class I reservoir was put into production for polymer flooding at first stage. Concentration of polymer solution is 2000mg/L and relative molecular weight of polymer is 2.5×10^7. Polymer dosage is 1100 PV.mg/L and injection rate is 0.12 PV/a. Injection-production well spacing is between 200 meters and 250meters.

(2) Class II reservoir was put into production with polymer flooding at second stage. Concentration of polymer solution is 1000mg/L and relative molecular weight of polymer is between 1.2×10^7 to 1.6×10^7. Polymer dosage is 640PV.mg/L and injection rate is 0.14 PV/a. Injection-production well spacing is between 150meters and 175meters.

(3) Class III reservoir was put into production with polymer flooding at third stage. Concentration of polymer solution is between 800mg/L to 1000mg/L and relative molecular weight of polymer is 5×106. Polymer dosage is 570PV.mg/L and injection rate is 0.25 PV/a. Injection-production well spacing is between 100meters and 125meters.

(4) Perfect achievement from polymer flooding is acquired. Compared with water flooding, water cut is declined by 20% to the maximum, and recovery efficiency is increased by 10% for polymer flooding of class I reservoir. Water cut is declined by 11% to the maximum, and recovery efficiency is increased by 7.8% for polymer flooding of class II reservoir. Water cut is declined by 6% to the maximum, and recovery efficiency is increased by 5% for polymer flooding of class III reservoir.

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