SPE 113145

A Mathematical Model for Emulsion Mobilization and Its Effect on EOR During ASP Flooding

Zhengdong Lei, Shiyi Yuan, Jie Song, Jiangru Yuan, Research Inst. of Petroleum Exploration and Development, PetroChina, and Yu-Shu Wu, SPE, Lawrence Berkeley National Laboratory

This paper was prepared for presentation at the 2008 SPE/DOE Improved Oil Recovery Symposium held in Tulsa, Oklahoma, U.S.A., 19–23 April 2008.

Abstract

Large-scale pilot tests of alkali-surfactant-polymer (ASP) flooding in the China's Daqing Oilfield reveal that emulsification occurs during ASP flooding and displacement. The flow of emulsions in porous media exhibits high viscosity, well-behaved chemical stability, and apparent non-Newtonian flow features. The genesis and mobilization of emulsions in reservoirs are an important part of ASP flooding processes, and entrainment and capture of such emulsions in porous media are considered to be important for improving oil recovery by ASP flooding. However, there are few studies that attempt a quantitative description of emulsion mobilization in porous media. As a result, the physicochemical phenomena of emulsions are not included in the current numerical simulation of ASP flooding processes.

Based on our experimental studies and field tests, we conducted an in-depth analysis of displacement mechanisms, emulsification, and flow behavior of emulsions in porous media during ASP flooding processes. In this paper, we describe the development of a mathematical model to describe such physicochemical emulsion phenomena. This mathematical model incorporates the mechanisms governing the interaction between emulsion droplets and pore structures, including emulsion genesis criteria, correlation of emulsion viscosity and water content, and permeability reduction caused by droplet capture. The model is implemented into an existing chemical reservoir simulator for numerical modeling studies of ASP flooding that considers emulsification mechanisms. Simulation results show that oil emulsification during ASP flooding has a significant impact on, and could improve, *in situ* oil displacement efficiency. The proposed model can be used for understanding the effects of emulsions in ASP flooding, within both laboratory studies and field applications.

Introduction

The result of laboratory testing and large-scale pilot testing[1] of alkali-surfactant-polymer flooding shows that emulsification occurs with different intensities and characteristics. The flow of emulsions during ASP flooding processes exhibits high viscosity, high density and apparent non-Newtonian flow behavior. Laboratory tests show that oil emulsification of ASP flooding can improve interlayer and *in situ* interference, as well as oil recovery efficiency. Since emulsions play an important role in ASP processes, attempts have been made to simulate the process with increasingly complex compositional models. These models require a detailed understanding of the main effects involved during the ASP flooding process, and underscore the need for a mathematical model to describe emulsion mobilization during ASP flooding.

Significant research has been carried out on the formation, stability and de-emulsification of ASP crude oil emulsions. However, very little work has been reported on mathematical modeling of emulsion flow through porous media, especially during chemical flooding processes. Furthermore, most of those studies have only considered the case in which emulsion is diluted and the only phase present in the system. Alvarado and Marsden[2] introduced their bulk viscosity model, dependent on shear-rate, in which emulsion was considered to be a continuous, single-phase fluid. The so-called droplet retardation model was introduced by McAuliffe[3] and used by Devereux[4], who modified the Buckley-Leverett theory for two-phase flow by including a retardation factor in the pressure driving force of the dispersed oil phase. However, within this model, the permeability of the porous media returns to its initial value when emulsion is followed by waterflood. Soo and Radke[5-6]presented a filtration model describing the flow of stable, dilute emulsions in porous media. The formulas underpinning this filtration model are suited for droplet flow in a 100% brine-saturated porous medium, but do not consider the possibility of droplet generation from a residual oil phase present in the porous medium. By contrast, Islam and Farouq[7-8] presented a model in which they considered emulsion as an independent phase. They also introduced permeability reduction as a step function of emulsion throughput and incorporated permeability reduction as a function of initial permeability. Their model,

however, cannot capture transient permeability reduction, nor can it explain the relationship between pore throat size and emulsion droplet size. More recently, Islam and Farouq[8] presented a complete description of both stable emulsion flow and *in situ* generation of emulsions, based on three-phase aqueous-oil emulsions. Abou-Kassem and Farouq[9] proposed a correlation for a modified Darcy's law with non-Newtonian fluids.

Here, we report on our recently conducted in-depth analysis of displacement mechanisms, emulsification, and emulsion flow behavior in porous media during ASP flooding processes. In particular, we present a mathematical model to describe the main effect of ASP emulsions, which improves the ASP compositional simulator's ability to incorporate emulsification mechanisms. This work thus provides a methodology for effective numerical simulation of emulsion flow and transport.

Formation and Flow Behavior of ASP Emulsions

The work described in this paper has been undertaken to improve mechanistic understanding of emulsion formation and flow behavior in porous media during the ASP process. The low interfacial tension and mechanical shear between the oil and water phases in the medium are the main factors causing emulsion formation. Because of the high chemical concentration of alkali and polymer and low interfacial tension with the injection of ASP, ASP emulsions form easily and alter the mobility of water flooding residual oil by changing the capillary force, driving force, and adhesive force. Residual oil is removed by emulsifying, so kick-off of emulsions is the key factor in ASP enhanced recovery efficiency. Flow behavior, including migration and enrichment of ASP emulsions, depends on emulsion types and characteristics. Entrainment is the main mechanism for oil-phase migration and enrichment of oil-in-water (O/W) emulsions, whereas coalescence is the main mechanism for oil-phase migration and enrichment of several common configurations from outside to inside, water-oil (W/O), oil-water-oil (O/W/O), or water-oil-water (W/O/W) emulsions. The enrichment of the oil phase forms an oil wall, which, with the increasing enriched oil phase, gradually expands, finally producing oil in the form of emulsions. Once the oil wall is formed, with the rise in water cut, the emulsion transforms into O/W, because the oil-water ratio cannot maintain a W/O type emulsion.

Emulsification can be helpful to enhanced oil recovery, specifically in emulsification kick-off, entrainment, and profile control. Emulsification removes water from the pore space—water that competes for flow paths with oil—and emulsions also improve mobility control and conformance by plugging the more permeable zones of the formation. On the other hand, emulsification may not be helpful to enhanced oil recovery if it is caused mainly by high injection pressure, because then it reduces oil-phase mobility and causes a decline in the liquid production index, owing to the high viscosity of emulsion. To quantitatively evaluate how emulsification affects oil recovery, **we propose** a mathematical model for describing emulsification degrees and residual oil during *in situ* emulsification and entrainment of ASP emulsions. This mathematical model includes a mobility model, to describe profile control, and a viscosity model, to describe the harmful factors of emulsions.

Mathematical Model

We first construct an ASP combined flooding mathematical model that fully takes into consideration emulsification mechanisms. The mechanisms incorporated include emulsion formation criteria, type, emulsification degree, viscosity modification, and permeability modification. The phenomenological parameters used for describing ASP emulsion have a definite physical meaning, so that they are more practical and useful to simulation and modeling studies of practice reservoir application.

Basic model assumptions: We assume that (1) the reservoir is isothermal; (2) local equilibrium exists; (3) the generalized Darcy law is applicable to multiphase flow; (4) the generalized Fick Law is applicable to multicomponent dispersion; and (4) more general chemical reactions within one phase are ignored. Owing to the low concentration of surfactant (generally Cs<1%) in ASP flooding, two phases (W,O) are taken into consideration (in most cases). The number of components (nc), components and pseudo-components, is considered, including: w (water), o (oil), s (surfactant), p (polymer), Na^+, Ca^{2+}, Mg^{2+}, OH-, CO_3^{2-}, SiO_3^{2-} (SiO_4^{4-}), CO_2, HA, crosslinking agent, and rock solids, etc.

Basic equation system: The basic equations are as follows: Mass conservation for each component (n_c)

$$div[\bar{F}_i + \bar{D}_i] + \frac{\partial A_i}{\partial t} = B_i \qquad i = 1,...,n_c \tag{1}$$

where the convection term is:

$$\bar{F}_i = \sum_j y_{ij} \rho_j \bar{V}_j \tag{2}$$

$$\bar{V}_j = -\frac{\bar{\bar{K}} \cdot K_{rj}}{\mu_j} (grad\, \bar{P}_j - \rho_j \cdot \bar{g}) \tag{3}$$

the dispersion term is:

$$\bar{D}_i = -\phi \sum_j S_j \rho_j \bar{D}_{ij}\, grad\, \bar{Y}_{ij} \tag{4}$$

the accumulation term is:

$$A_j = [\alpha_i \phi Z_i \sum_j \rho_j S_j + q_i] \tag{5}$$

and the source/sink term is:

$$B_i = Q_i + R_i \tag{6}$$

According to the definitions,

$$\sum_j S_i = 1 \tag{7}$$

$$\sum_j Z_i = 1 \tag{8}$$

$$\sum_j Y_{ij} = 1 \qquad j = 1,...,n_p \tag{9}$$

The relationships among Z_i, Y_{ij} and S_j ($n_p n_c$-1) are

$$Y_{ij} = Y_{ij}(Z_k) \quad i = 1,...,n_c - 1;\ j = 1,...,n_p;\ k = 1,...,n_c \tag{10}$$

$$S_j = S_j(Z_k) \quad j = 1,...,n_p - 1;\ k = 1,...,n_c \tag{11}$$

The capillary pressure curves (n_p-1) are:

$$P_{ck} = P_{ck}(S_k, \sigma_k) \qquad k = 1,...,n_p - 1 \tag{12}$$

The basic unknown variables in the above system are $n_p(n_p+2)+n_c$, which are equal to the equation number, so that the equation system can in principle be solved. However, the equation system is nonlinear, complicated, and fully coupled, with many variables and parameters. For numerical solution techniques to solve the system, we need **complementary** and constitutive functional relationships for describing phenomenological parameters and their correlations

Description of emulsification parameters and factors: The model considers other phenomenological parameters, such as alkali concentration conversion, alkali loss (or OH^-consumption), adsorption of injected surfactant, polymer adsorption, ion exchange, interfacial tension, residual saturation, relative permeability, capillary pressure, residual resistance factor (RRF), polymer-inaccessible porous volume, and *in situ* methodology [10-11]. We focus on important emulsification parameters and factors of an ASP system, including kick-off and entrainment, viscosity, and the permeability decline indexes of the displacing phase.

The formation and reverse phase condition of ASP emulsions: For *in situ* generation of emulsions with increasing shear, the microscopic analysis based on the Weber number (We) for extensional flow by Chin and Han[12] was re-interpreted by Cuthiell[13] as an effective porous media capillary number(Nc), since both the average shear rate in the pore and the average throat size can be expressed in terms of the hydraulic radius $R = (8K/\phi)^{1/2}$ and an average aspect ratio $\bar{\alpha}$ That is:

$$W_e = \frac{\mu a \gamma}{\sigma} = \frac{\mu R_t}{\sigma}\frac{v}{R_p} = \bar{\alpha}\frac{\mu v}{\sigma} = \bar{\alpha} N_c \tag{13}$$

The dimensionless capillary number is a useful predictor of emulsification induced by shear. The threshold value of N_c at which emulsification becomes significant is typically between 10^{-4} and 10^{-3}.

Based on ASP flooding characteristics, the reverse phase of emulsions can be attributed to the change of oil-water volume ratio:

$$S_{pr} = \frac{S_w - S_{wr}}{1 - S_{wr} - S_{or}} \tag{14}$$

The critical value of oil-water volume ratio is between 30% and 50%, as established through a number of experiments[14].When S_{pr} is larger than the critical value, the emulsions type is oil-in-water emulsion, rather than water-in-oil emulsion. With the injection of an ASP chemical system, the mechanism of formation and the reverse phase of ASP emulsions are too complicated to be described by mathematics, so the formation and reverse phase conditions should be best measured by experiments.

Kick-off and entrainment of ASP emulsions: Emulsification kick-off and entrainment removes water from the pore-space, which competes for flow paths with the oil. The relationship between emulsification degree and residual oil saturation is as follows:

$$\Phi_e = \frac{S_d - S_{dr}}{1 - S_{sr} - S_{dr}}\left(\frac{N_s}{a_1 + a_2 N_s}\right) \tag{15}$$

where S_d is saturation of the dispersed phase; S_{dr} is residual saturation of the dispersed phase; S_{sr} is saturation of the external phase; N_s is the capillary number, and a_1 and a_2 are empirical parameters.

Viscosity of ASP emulsions: Because ASP emulsions exhibit non-Newtonian flow behavior, the viscosity of emulsions

is not constant and depends on the value of shear rate. The methods for predicting non-Newtonian emulsions flow in porous media may be classified into three categories: (1) the viscosity-volume fraction of the dispersed phase (emulsion quality) model, (2) the viscosity shear-rate model, and (3) the viscosity-emulsion-quality shear-rate model. It has been shown that the emulsion-viscosity prediction model, including not only the volume fraction of the dispersed phase but also shear rate, can be more accurate. Based on P&R (Pal and Rhodes, 1989[15]), the viscosity-emulsion quality-shear rate model and experimental data, an improved viscosity model, including the porous medium shear role and the relationship between water cut and emulsion quality, can be developed. Taking into account the non-Newtonian behavior of high-concentration emulsions, Pal and Rhodes[15-16] developed an empirical and theoretical model, based on Brinkman, to predict the viscosity of Newtonian and non-Newtonian emulsions:

$$\eta_r = (1 - K_0 K_f(\gamma)\Phi)^{-2.5} \tag{16}$$

where K_0 is the hydration factor, which may vary from one emulsion system to another system, depending upon the nature of emulsifier; and $K_f(\gamma)$ represents the flocculation, used for non-Newtonian emulsions only. This model accounts for the flocculation of dispersed droplets and hydration effects.

Water cut generally declines with ASP injection, and the volume fraction of the dispersed phase should be the function of water cut. Based on large sets of experimental data, we derive a functional relation between water cut and emulsion quality in a forms:

$$\Phi = \frac{(2 + 5\Phi_0 - 2f_w)}{5f_w} \tag{17}$$

for dilute emulsions (water cut larger than emulsion transition type criteria), and

$$\Phi = \frac{3}{2h}(1 + f_w) + \frac{\Phi_0}{2}(1 - f_w) \tag{18}$$

for dense emulsions (i.e., a water cut smaller than the emulsion transition-type criteria). In Equations (17) and (18), Φ_0 is the volume fraction of the dispersed phase; Φ is the initial volume fraction of the dispersed phase; and f_w is the water cut of the ASP system.

The equation expressing the relationship between a porous medium and shear rate is as follows

$$\gamma = \frac{10^4 v}{\sqrt{8C' K\phi}} \tag{19}$$

In Equations (19), v is flow velocity, $v = \phi v_f$; v_f is average pore velocity; K is permeability; ϕ is porosity, and C' is the coefficient related with tortuosity.

An improved viscosity model of ASP emulsions is thus established:

$$\eta_r = (1 - K_0 K_f(\frac{10^4 v}{\sqrt{8C' K\phi}})(\frac{(2 + 5\Phi_0 - 2f_w)}{5f_w})) \tag{20}$$

where γ is shear rate; v is flow velocity; f_w is water cut; and η_r is viscosity of emulsions.

Permeability decline index of driving phase: The permeability reduction of the porous medium is caused by flow restriction, in turn caused by captured emulsion droplets. Two major droplet-capture mechanisms of deep-bed filtration theory, straining and interception, are considered. In each, the droplets reduce the effective pore diameter and therefore divert flow toward other pores, leading to reduction in permeability. If the droplet size of emulsion is very close to pore size, then droplets can be captured primarily by straining. In contrast, droplets can **also** be captured by interception. The captured droplets block the pores, resulting in reduced permeability. Re-entrainment of captured liquid droplets can also occur when the local pressure gradient is increased sufficiently to overcome the capillary forces, especially at the low interfacial tensions typical of ASP flooding. In addition, it is evident that the generation of oil drops from residual oil plays an important role in permeability reduction. According to the model of diluted emulsion flow, based on deep-bed filtration theory in a porous medium[5-6], we construct a modified filtration model to include re-entrainment and residual oil effects, then incorporate them into the numerical simulator to account for the droplet capture mechanism.

The mass conservation equation for the flowing droplets in one dimension can be written as:

$$\phi\frac{\partial C_o}{\partial t} + u\frac{\partial C_o}{\partial x} = \frac{u}{\Phi}(S_o - S_{or}) - u\lambda C_o \tag{21}$$

where C_o is the number of oil drops per unit pore volume λ is the filtration coefficient, cm^{-1}; ϕ is porosity; and Φ is the

volume fraction of the dispersed phase.

The rate of droplet capture with re-entrainment can be written as[17-18]:

$$\frac{\partial \sigma}{\partial t} = \lambda_I (1 - \frac{\alpha\sigma}{\phi}) u\Phi - \lambda_{II} u (\frac{\alpha\sigma}{\phi}) \tag{22}$$

The reduction in porosity from trapped droplets can be written as

$$\phi = \phi_0 - (C_{oin} C_o^t \Phi) \tag{23}$$

Based on a modified Carman-Kozeny equation[19], the relational expression of permeability-porosity is as follows:

$$\sqrt{\frac{K}{\phi}} = FZI \cdot (\frac{\phi}{1-\phi}) \tag{24}$$

with

$$\log(\frac{K}{\phi}) = \log(FZI)^2 + 2\log(\frac{\phi}{1-\phi}) \tag{25}$$

and

$$FZI = \frac{1}{\sqrt{F_s \tau \sum_p}} \tag{26}$$

where σ is the oil droplet retention concentration; λ_I is the primary filtration coefficient (cm^{-1}), λ_{II} is the re-entrainment filtration coefficient (cm^{-1}), C_{oin} is initial droplet concentration, C_o^t is trapped droplet concentration, *FZI* is the flow zone indicator, F_s , is the geometry factor, τ is tortuosity, and $\sum_p$ is the Gross surface of solid porous matrix. Combining Equations (24), (25, and (26) with the basic equation of deep-bed filtration theory, the analytical solution of permeability affected by trapped droplets is as follows:

$$K / K_i = 1 - \frac{FZI \cdot D_d}{L} (\frac{D_d}{D_p})^2 (2 - \frac{(\lambda_I - \lambda_{II}) D_d}{D_p})^2 Log(K_i) \tag{27}$$

where D_d is droplet diameter; D_p is grain diameter; and K_i is initial permeability. The model also implies that permeability reduction increases with a decreasing flow rate and an increasing drop-size to pore-size ratio. The more detailed derivation is shown in Lei and Song[20].

Numerical Solution: The above equation system is solved numerically by an implicit pressure and explicit overall composition method.

Results and Discussion

Under different chemical concentration conditions, the relationship curves between water cut and the emulsion viscosity are measured at China's Daqing Oilfield[21]. The concentration conditions are broken into two different categories: System 1(0.3% ORS-41+1.2% NaOH+1200mg/L, Alcoflood1275A) and System 2 (0.05% ORS41+0.1% NaOH+100mg/L, Alcoflood1275A). The reverse-phase point of System 1 is 50%; the reverse phase point of System 2 is 30%. As shown in Figure 1, the simulation results using the viscosity model discussed in this paper gives the best match to the measured data.

To study the profile control role of ASP emulsion, we designed a typical reservoir profile model with nine different permeability variation coefficients in a positive-rhythm geological model, as shown in Figure 2. It is classified into three layers in the vertical direction, each with a thickness of 5 m. First, water is injected until water saturation reaches 90%. At this moment, we injected a 0.3 PV chemical compound (with 1.2% of alkali, 0.3% of surfactant, and 1,500 mg/L of polymer) and continued to inject water until the water saturation rose to 98%. As shown in Figure 3, the simulation result shows that the sweep efficiency is enhanced more significantly by ASP flooding with emulsification rather than with water flooding, indicating that ASP emulsions have good mobility control.

To study the emulsification effect of ASP systems, we designed two-layer geological models with four injection wells and one production well in the center, as shown in Figure 4. The injection-recovery balance is maintained such that the oil production rate is at 80 m^3 and the injection rate of each well is at 20 m^3. Accumulative oil production and water cut are compared among four different emulsion categories: Φ = 0.01,Φ = 0.015,Φ = 0.02 and Φ = 0.2. Our calculations show that accumulative oil production is not affected when Φ is smaller than 0.1, but the accumulative oil production increases when Φ is larger than 0.15. The same behavior is observed with respect to water cut. Our calculations also show that water cut is essentially the same when Φ is smaller than 0.1, but water cut obviously declines when Φ is smaller than 0.15. The declining rate is, respectively, at 16.9% and 19.9%, as shown in Figures 5 and 6. Figure 7 shows a comparison of computational results

for the effect of emulsification on APS systems, indicating that emulsification improves oil recovery and (to some extent) reduces water cut.

Conclusions

1. Emulsification in ASP processes improves oil recovery through kick off, entrainment and profile control. The mathematical model proposed for relationship between emulsification degree and residual oil is able to describe the in-situ emulsification and entrainment of ASP emulsions.
2. An ASP combined flooding mathematical model is presented for incorporating emulsification mechanisms, including kick off and entrainment, viscosity, and permeability-decline coefficients of emulsion.
3. The simulation results of the ASP model considering emulsification shows that emulsification is helpful in enhanced oil recovery. In addition, the validity of the proposed model is under an ongoing, in-depth study of ASP emulsification mechanisms in reservoirs.

Acknowledgments

The work was supported by the "Research Program (973) of Leading Tasks and Frontiers in Energy Science" under the title: "Fundamental Study on Enhanced Oil Recovery by Chemical Flooding and Microbial Flooding" of Task No.2005CB221300. The author would also like to thank G. Zhang and D. Hawkes at the Lawrence Berkeley National Laboratory for reviewing this manuscript.

Nomenclature

C	concentration
E	cation strength
G	gravity acceleration constant
K	absolute permeability
HA	acid component
Q	mass rate in unit porous volume
q	adsorption in unit porous volume
R	reaction rate
S	fluid saturation
V	Darcy velocity
Y_{ij}	mass fraction of component i in phase j
Z_i	overall mass fraction of component i
A	accessible porous volume fraction
Σ	interfacial tension
μ	viscosity
ρ	density
ϕ	porosity

Subscript

i	component
j	phase
w	aqueous phase
o	oleic phase
p	polymer
s	surfactant

References

[1] Wang, D. and Cheng J., "Summary of ASP Pilots in Daqing Oil Field", SPE-57288, 1-14, 1999.
[2] Alvarado, D. A. and Marseden, S. S., "Flow of Oil-in-water emulsions through tubes and porous media". Soc. Pet. Eng. J Vol.19, pp.369-377, 1979.
[3] McAuliffe, C. D., "Oil-in-water emulsions and their flow properties in porous media", Journal of petroleum technology, pp.727-733, 1973.
[4] Devereux, O. R., "Emulsion flow in porous solids II. Experiments with a Crude Oil-in-Water Emulsion in Porous Sandstone". Chem. Eng. J., pp.129-136, 1974.
[5] Soo, H. and C. J. Radke, "A filtration model for the flow of dilute, stable emulsion in porous media", Chemical Engineer Science, Vo1.41, No.2, pp.263-281, 1986.
[6] Soo, H. and C. J. Radke, "Velocity effects in emulsion flow through porous media", Journal of Colloid and Interface Science, Vo1.102, No. 2, pp.462-476, 1984.
[7] Islam, M. R. and Farouq, A. S. M., "An experimental and numerical study of blockage of a mobile water zone by emulsion" paper no.133, proc. UNITAR/UNDP 4th conf. on heavy-crude and Tar sands, 1988.

[8] Islam, M. R. and Farouq A. S. M., “Numerical simulation of emulsion flow through porous media” The Journal of Canadian Petroleum Technology, pp.59-63, 1994.
[9] Abou-Kassem, J. H. and Farouq, A, S. M., “Modeling of emulsion flow in porous media ” The Journal of Canadian Petroleum Technology, pp.30-38, 1995.
[10] Yuan, S. and Van Quy N, “Chemical flooding Simulation (Part A: theory, Part B: application)”, Acta Petrolei Sinica, (1) 1988; and (3) 1989.
[11] Yuan, S., Yang, P., Dai, Z., and Shen, K., “Numerical Simulation of Alkali/Surfactant/Polymer Flooding”, SPE-29904, presented at the SPE International Meeting on Petroleum Engineering, Beijing, PR China, 1995.
[12] Chin, H. B. and Han, C. D. “Studies on Droplet Deformation and Breakup: Droplet Breakup in Extensional Flow”[J]. Rheology, 24(2), pp.1-37, 1980.
[13] Cuthiell, D. and Green, K., “The in situ formation of heavy oil emulsions”, SPE-30319, pp.675-683, 1995.
[14] Kang W., “The Study on effect Mechanism chemicals during ASP flooding in Daqing oilfield”, published by Petroleum Industry Press, Beijing, China, pp.96-120, 2001.
[15] Pal, R. and Rhodes, E.. “Viscosity/Concentration relationships for emulsions”, Journal of Rheology, 33(7), pp.1021-1045, 19891.
[16] Pal. R., “Effect of droplet size on the rheology of emulsions”, AIChE J, 42(11), 3 181-3 198. 1996,
[17] Khambharatana, F., S. T. and Farouq., A. S. M., “Numerical simulation and experimental verification of oil recovery by macroemulsion Floods”, 48th Annual Technical Meeting of the petroleum society in Calgary, Alberta, Anada, pp.1-12, 1997
[18] Khambharatana, F., S. T. and Farouq, A. S. M., “Macroemulsion Rheology and Drop Capture Mechanism during Flow in Porous Media,” SPE-48910, pp.223-229, 1998.
[19] Amaefule J.O., Altunbay M., Tiab, D., Kersey, D.G., and Keelan, D.K.: "Enhanced Reservoir Description: Using Core and Log Data to Identify Hydraulic (Flow) units and predict permeability in uncored Intervals/Wells", paper SPE-26436, presented at the 68th Annual SPE conference and exhibition, Houston, Texas, October 3 - 6, 1993.
[20] Lei, Z. and Song, J., “Numerical simulation of emulsion flow and effect on enhanced oil recovery in ASP flooding process”. The 19th World Petroleum Congress Program, 2008.
[21] Li, H., “The latest development and pilot test of ASP flooding”, published by Sicencep Press, Beijing, China, pp.367-368, 2007.

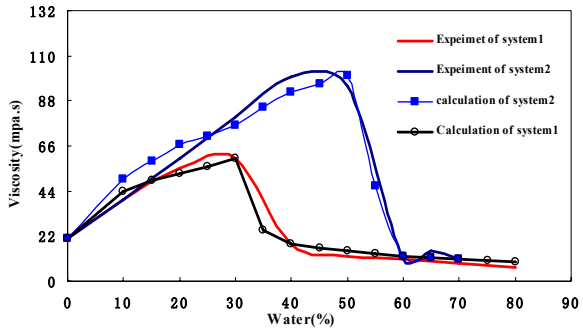

Fig. 1. Comparison of Experimental and Simulated viscosity value of ASP emulsions

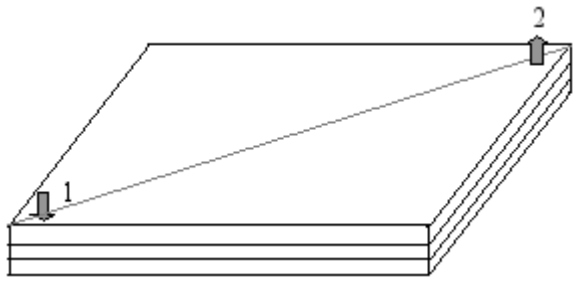

Fig. 2. Schematic chart of three-dimensional model(1-injector; 2-producer)

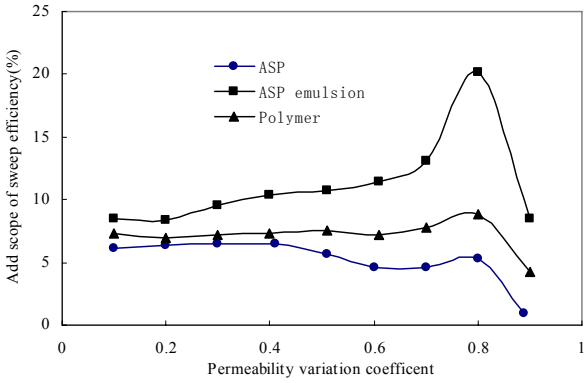

Fig. 3. The add scope of sweep efficiency larger than water flooding

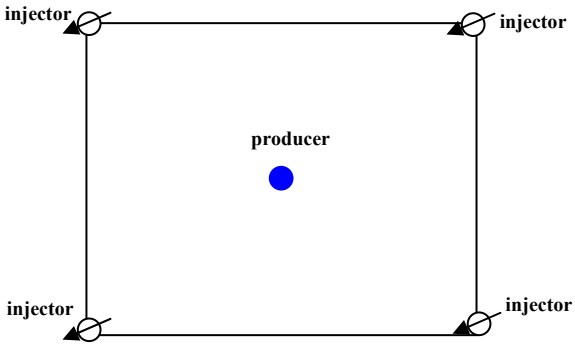

Fig. 4. The simplified geological model of simulation

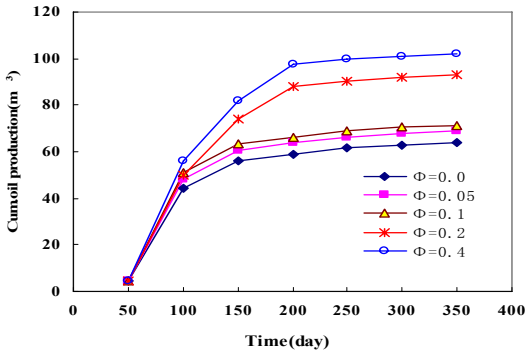

Fig. 5. Accumulation oil production change with time(varying dispersed phase content)

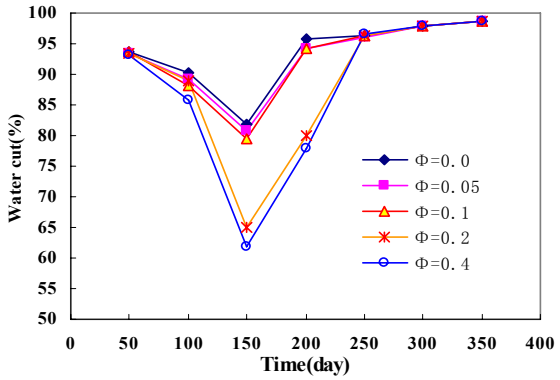

Fig. 6. Water cut change with time(varying dispersed phase content)

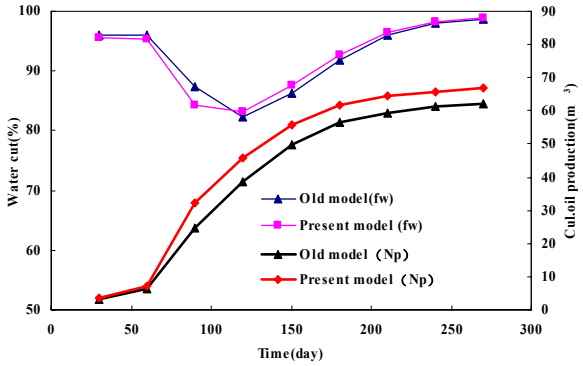

Fig. 7. Comparison of emulsification effect of APS system