Parameters of the models

Attached table 1 Air permeability of different layers of the heterogeneous models

Model	layer	Φ (%)	K_g (10^{-3} μm^2)
RI	K1	23.73	586.6
	K2		
	K3		
RII	K1	24.56	590.3
	K2		
	K3		
RIII	K1	24.22	581.2
	K2		
	K3		
WI	K1	24.87	805.5
	K2	23.71	507.0
	K3	22.11	287.5
WII	K1	24.82	789.8
	K2	24.47	510.3
	K3	23.04	277.7
WIII	K1	23.88	818.0
	K2	23.09	525.1
	K3	22.39	295.2

Added photos

Attached fig.1 Planform of an heterogeneity core model

The uncertainty calculation

Enhanced oil recovery can be calculated from the following formula:

$$\Delta R_e = \Delta V_{po} / V_{so} \tag{1}$$

It's worth noting that:

$$\Delta V_{po} = \sum_{i=1}^{n} v_{oi} \tag{2}$$

Besides, ΔRe has a function relationship with the injection volume (V_i) of ASP slug according to the empirical formula:

$$\Delta Re = 11.81 \ln(V_i/PV + 0.24) + 19.43 \tag{3}$$

And the temperature has an impact on the viscosity of Daqing oil, which possesses the following law when the temperature is between 43 and 50℃.

$$\mu = e^{1.0362-0.0086294T} \tag{4}$$

The relation of oil viscosity and the enhance oil recovery is as follows:

$$\Delta Re = -0.0011\mu^2 - 0.2769\mu + 36.644 \tag{5}$$

Merge the formula (4) and (5), the relation of ΔR_e and temperature is obtained:

$$\Delta Re = -0.0011 \times e^{2.0724-0.0172588T} - 0.2769 \times e^{1.0362-0.0086294T} + 36.644 \tag{6}$$

The formula (1), (3) and (6) are independent respectively, the uncertainty of ΔRe can be calculated by the uncertainty propagation formula:

$$u(\Delta Re) = \sqrt[2]{\left(\frac{\partial f}{\partial \Delta V_{p0}}\right)^2 u(\Delta V_{po}) + \left(\frac{\partial f}{\partial V_{s0}}\right)^2 u(V_{so}) + \left(\frac{\partial f}{\partial V_i}\right)^2 u(V_i) + \left(\frac{\partial f}{\partial PV}\right)^2 u(PV) + \left(\frac{\partial f}{\partial T}\right)^2 u(T)} \tag{7}$$

The standard uncertainty of the parameters was as shown in the Attached table 2.

Attached table 2 Standard uncertainty of the parameters

parameter		Uncertainty				
		Type-A (statistics)	Type-B1 (measurement)	Type-B2 (instrument)		Combined
				relative	standard	standard
PV	Intralayer	89.46 cm^3	--	1.5%	34.64 cm^3	95.93 cm^3
	Interlayer	68.02 cm^3	--	1.5%	34.49 cm^3	76.26 cm^3
V_i	Intralayer	--	--	1.5%	10.39 cm^3	10.39 cm^3
	Interlayer	--	--	1.5%	10.35 cm^3	10.35 cm^3
V_{so}	Intralayer	72.15 mL	3.128 mL	--	0.288 mL	72.22 mL
	Interlayer	49.70 mL	3.128 mL	--	0.288 mL	49.80 mL
	v_{oi}	--	0.125 mL	--	0.0115mL	0.126mL
	T	--	--	--	1.0 ℃	1.0 ℃

Note:The relative uncertainty caused by the flux pump was 1.5% in flow, by the thermotank was 1℃ in temperature. The uncertainty caused by the measurement when reading measuring cylinder was calculated based on basic theory of maximum error.

The uncertainty of $\varDelta V_{po}$ can be calculated by the uncertainty propagation formula:

$$u(\varDelta V_{po})=\sqrt[2]{\sum_{i=1}^{n}(v_{oi})^2}$$

n=160 in intralayer heterogeneous models, and $u(\varDelta V_{po})$=1.59mL; n=120 in interlayer heterogeneous models, and $u(\varDelta V_{po})$=1.38mL.

By calculation, the uncertainty of $\varDelta R_e$=0.2901% in intralayer heterogeneity models and 0.2309% in interlayer heterogeneity models. The $\varDelta R_e$ with uncertainty was as shown in Attached table 3.

Attached table 3 $\varDelta R_e$ with uncertainty in core flooding experiments.

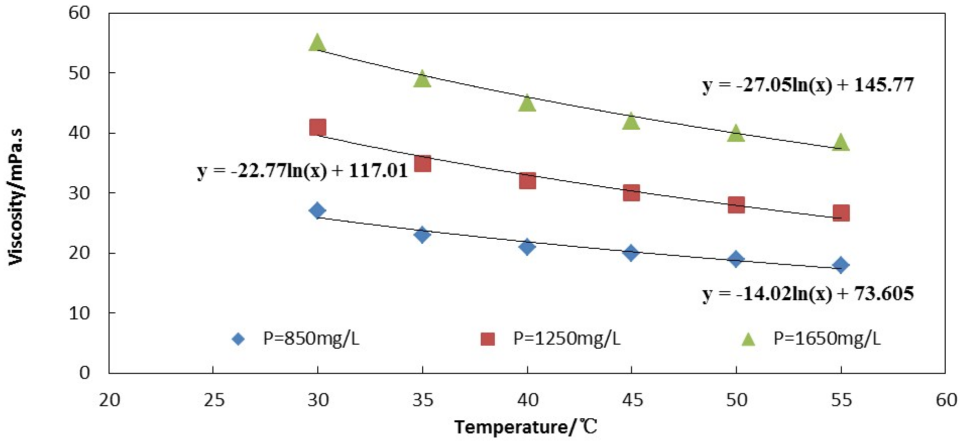
model	$\varDelta R_e$/%	Standard $u(\varDelta R_e)$ /%	$\varDelta R_e$ with uncertainty /%
RI	28.25	0.2901	28.25±0.29
RII	26.01	0.2901	26.01±0.29
RIII	30.76	0.2901	30.76±0.29
WI	23.17	0.2309	23.17±0.23
WII	22.87	0.2309	22.87±0.23
WIII	25.24	0.2309	25.24±0.23

Nomenclature

$\varDelta R_e$	Enhanced oil recovery (incremental recovery by ASP flooding in this paper)	%
$\varDelta V_{po}$	Total produced oil volume by ASP flooding	mL
V_{so}	Saturated oil volume	mL
v_{oi}	Produced oil volume in sample i	mL
V_i	Injection volume of ASP slug	mL

PV	Pore volume	cm^3
μ	viscosity	mPa.s
T	temperature	℃
u	uncertainty	

During the measurement of viscosity, the factors affecting the test result containing temperature and the error caused by the viscometer. Thus, the relatively uncertainty of viscosity caused by the viscometer is 2.0%. The uncertainty of temperature caused by the thermostatic waterbath is 0.1℃. The relation of ASP viscosity and temperature under different concentration was shown in Attached fig.2.



Attached fig.2 Viscosity of ASP solution as a function of temperature

The Combined relative standard uncertainty of viscosity can be calculated basing on the uncertainty propagation formula.

Attached table 4 Relative uncertainty of viscosity

Polymer concentration/$mg.L^{-1}$	Relative $u(\mu)$ /%
850	2.0012
1250	2.0032
1650	2.0045

Total slug size of injection fluid (S_{si}) can be calculated by the following formula:

$$S_{si}=\Delta V_l/PV_m \tag{8}$$

PV_m refers to the monolayer pore volume. And the monolayer produced liquid volume (ΔV_l) during the injection of ASP and polymer slug:

$$\Delta V_l=\sum_{i=1}^{n} v_{oi} \tag{9}$$

The uncertainty of ΔV_l can be calculated by the uncertainty propagation formula:

$$u(\varDelta V_l)=\sqrt[2]{\sum_{i=1}^{n}(v_{oi})^2}$$

n=64 during the injection process of ASP and polymer slug in interlayer heterogeneous models, and $u(\varDelta V_l)$=1.01mL.

In the same way with the calculation of $u(\varDelta R_e)$, $u(Ssi)$ can be obtained by the following formula:

$$u(Ssi)=\sqrt{\left(\frac{\partial f}{\partial \Delta V_l}\right)^2 u(\Delta V_l)+\left(\frac{\partial f}{\partial PV_m}\right)^2 u(PV_m)} \tag{10}$$

By calculation, the uncertainty of Ssi =0.0290PV in 800md layer, 0.0137PV in 500md layer and 0.0079PV in 300md layer.

The monolayer oil recovery by primary waterflooding (R_{ew}) can be calculated from the following formula:

$$R_{ew}=\varDelta V_{ow}/V_{so} \tag{11}$$

The uncertainty of oil recovery by primary waterflooding $u(R_{ew})$:

$$u(R_{ew})=\sqrt{u_A{}^2(R_{ew})+u_B{}^2(R_{ew})} \tag{12}$$

And:

$$u_B(R_{ew})=R_{ew}\sqrt{\frac{u^2(\Delta V_{ow})}{\Delta V_{ow}{}^2}+\frac{u^2(V_{so})}{V_{so}{}^2}} \tag{13}$$

The monolayer uncertainty of $\varDelta R_e$ can be obtained by the similar procedure with the method mentioned above, and the process won't be repeated here.

$$R_e= R_{ew}+\varDelta R_e \tag{14}$$

As a result, the uncertainty of total recovery $u(R_e)$:

$$u(R_e)=(u^2(R_{ew})+u^2(\varDelta R_e))^{1/2} \tag{15}$$

The calculated results were as follows:

Attached table 5 Monolayer uncertainty of oil recovery by primary waterflooding and enhance oil recovery

Layer	$u(R_{ew})$ /%	Injection pattern	$u(\varDelta R_e)$ /%	$u(R_e)$/%
800	2.1283	Constant	0.2724	2.1457
		Ascending	0.2746	2.1459
		Descending	0.2602	2.1442
500	1.5550	Constant	0.3202	1.5876
		Ascending	0.3185	1.5873
		Descending	0.3310	1.5898
300	1.3718	Constant	0.1270	1.3777
		Ascending	0.1196	1.3770
		Descending	0.1559	1.3806
summation	1.4150	--	0.2309	1.4337