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Research Article

Optimization Well-Type on the Conditions of Basal Groundwater

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Abstract: For optimization well-type on the conditions of basal groundwater, inasmuch as an analogy exists between electrical and fluid flow, the electrolytic analogy experiments have been conducted, which made a series of comparisons and evaluations between 9 types of complex well configurations and vertical well in terms of production. Taking into account the boundary condition of basal groundwater, we conducted 3×3×10 experiments in totally, including vertical well, horizontal well, radial well, snaky well, 3 types of fishbone well and 3 types of multilateral well. The experiment of every well mentioned above was conducted on the voltage values of 2V, 3V, 4V and conductibility values of 90μs/cm, 200μs/cm, 350μs/cm respectively. And then, specific settings were made for the stimulated well-types and reservoirs in order to make evaluations. The results indicate that production range in a diminishing sequence from horizontal well, 60°-fishbone well, 90°-fishbone well, 30°-fishbone well, 4-lateral Well, snaky well, radial well, 3-lateral Well, 2-lateral Well to vertical well. In the meantime, proposed the conception of radio of production and that even if changed the voltage value, the radio of production changed little for some specific well-types under the condition of the same resistivity. Utilizing the conclusion above, the production of complex well configurations's transformed from vertical wells can be calculated in specific conditions of the reservoir. The obtained experimental conclusions are useful for engineers and researchers to verify their analytical production model exactly and computer codes.

Keywords: Complex well configurations, electrolytic analogy, production evaluation, well-type optimizatio

INTRODUCTION

At present, sorts of well-types could be drilled successfully. Complex well configurations mean well-type which has multiple branches or arbitrary well track. It includes horizontal well, multilateral well, fishbone well, snaky well and others differing from vertical well. Flow into the complex well configurations geometries is mostly three-dimensional and requires analytical treatment of 3D diffusivity equation. It is not readily to calculate the production of every well-type by analytical methods. Analytical production solutions for these wells require use of advanced mathematical technique. In published relevant literature, complex functions, double or triple infinite series, even improper integrals were utilized in the model. Also, the analytical solutions for complex well configurations geometries require considerable computational effort and time.

Although physical law of which fluid flow in the differs from current law of which current flow in the fluid medium, the differential equations which describe steady state fluid flow in the porous medium can be considered identical to that describe current flow in the fluid medium by introducing several dimensionless variables. Single-phase fluid problems may be simulated by electrolytic analogy experiment based on hydroelectricity similarity principle. Experimental studies on electrolytic models are cost effective, fast and easier to control.

Electrolytic analogy experiments have been used to investigate many previous problems involving fluid flow in the porous medium. The earliest electrolytic analogy experiment was used to model flow into perforation.

McDowell and Muskat (1950) estimated the effects by the length, diameter and phase angle of borehole. In their conclusion, if the length of borehole was long enough, the production of perforated completion would be greater than that of barefoot completion. Howard and Watson (1950a, b) came to a similar conclusion.

Huskey and Crawford (1967) investigated the influence of symmetrically distributed multiple fractures on well flow capacity and effective permeability by carrying out experiments.

Aiyin *et al*. (1988) constructed electrolytic model to investigate drilling damage zone and perforation pollution.

Yildiz and Langlinais (1991) verified their 3-dimensional model for flow across gravel packs based

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on the experimental results from an electrolytic apparatus.

Abu-Elbashar *et al*. (1992) simulated the flowing in shale with low permeability by electrolytic analogy experiments.

Suprunowicz *et al*. (1998) investigated convergent flow to horizontal wells by carrying out electrolytic analogy experiments.

Turhan and Deniz (1998) used conducted electrical analog experiments to measure production of complex well configurations.

Guoqing *et al*. (2004), Yildiz (2005), Zhan-Qing *et al*. (2007), Guo and Huang (2009) and Fan *et al*. (2006) investigated respectively the seepage law of near-wellbore area including multilateral well, fishbone well and other complex well configurations s and optimized the branch patterns including length, angle, amount and interval, finally established production formulas of symmetrical branch well by carrying out electrolytic analogy experiment.

Mei *et al*. (2005), Haihong *et al*. (2006), Jinde *et al*. (2009), Fenxi *et al*. (2009), Wu *et al*. (2009), Chen *et al*. (2006) and Meng *et al*. (2007) investigated the production influencing factors of hydraulically-fractured horizontal wells and the optimization of fracture patterns.

Pang *et al*. (2006) investigated the production law of combination placing of vertical and horizontal wells.

Found through research, comprehensive comparisons of complex well configurations s have not been drawn a nd that the optimal well-type of specific reservoir conditions has not been proposed as well. This study extended the application range of electrolytic analogy experiment and the calculations of the production of the multilateral well-types were made based on the experimental date for the first time.

Accordingly, the evaluations of the exploitation effect about 10 well-types were made under the conditions of basal groundwater. T he obtained experimental conclusions are useful for engineers and researchers to verify their analytical production model exactly and computer codes.

EXPERIMENTAL RPINCIPLES

The differential equation which describes steady state fluid flow in the porous medium can be considered identical to that describes current flow in the fluid medium, namely hydroelectricity similarity principle.

Single variable approach is adopted in the experiment. Table 1 illustrates the parameters of the simulated reservoir.

The relationship between production of practical well and formation pressure in the reservoir can be obtained by similarity coefficient conversion, according to the experimental data including potential drop, current resistivity and so on.

Table 2 illustrates the corresponding relationships between resistivity of solution and viscosity of crude oil, potential drop in the experiment and drawdown pressure in the reservoir.

Table 1: Parameters of modeling and reservoir

Parameters of model		Parameters of reservoir	
Length of tank in the module (cm)	80	Length of reservoir (m)	200
Width of tank in the module (cm)	80	Width of reservoir (m)	200
Height of level in the module (cm)	10	Thickness of reservoir (m)	25
Radius of simulated wellbore (cm)	0.05	Radius of wellbore (m)	0.125
		Permeability (μm^2)	0.2

Table 2: Parameters of modeling and reservoir

Resistivity of solution (μs/cm)	350	Viscosity of crude oil (mPa/s)	35
Voltage (V)	200	Drawdown pressure (MPa)	20
	90		9
	4		4
	3		3
	2		2

Table 3: Similarity coefficients

Geometrical similarity coefficient C_l	0.004	Non-dimensional
Pressure similarity coefficient C_p	1	V/MPa
Flow similarity coefficient C_ρ	0.006125	s/A/MPa/(V/cm^3)
Resistance similarity coefficient C_r	40816.3265	V/cm^3/(s/A/MPa)
Flux similarity coefficient C_q	0.0000245	A/s/cm^3

Based on the basic data, several coefficients can be calculated:

Geometrical similarity coefficient:

$$C_l = \frac{L_m}{L_o}/100 \tag{1}$$

Pressure similarity coefficient:

$$C_p = \frac{(\Delta U)_m}{(\Delta p)_o} \tag{2}$$

Flow similarity coefficient:

$$C_\rho = \frac{\rho\mu}{k}/10000000 \tag{3}$$

Resistance similarity coefficient:

$$C_r = \frac{1}{C_\rho}/C_l \tag{4}$$

Flux similarity coefficient:

$$C_q = C_p/C_r \tag{5}$$

If the value of current is given, then:

$$Q = I/C_q \tag{6}$$

Similarity criterion of the modeling is $C_q = C_p C_\rho C_l$.

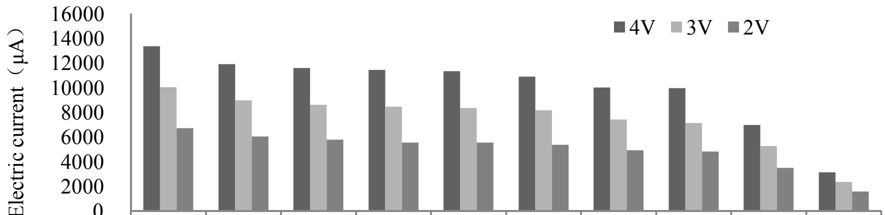
Table 3 illustrates similarity coefficients based on Eq. (1-5).

The practical production can be calculated by Eq. (6) based on the experimental data.

EXPERIMENTAL DESIGN

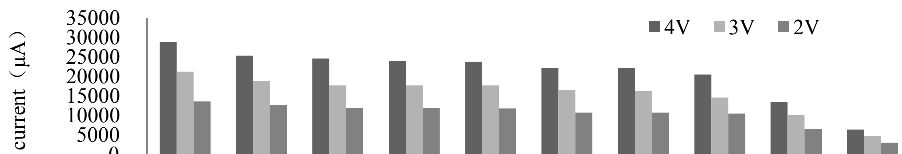
A schematic of the experimental setup is given in Fig. 1. Electrolytic analogy experimental apparatus is basically composed of simulation module of reservoir, low-voltage current module, positioning measurement system and data acquisition system (Fig. 1). In the simulation module of reservoir, organic glass tank simulated the area of reservoir, particular concentration

Fig. 1: Scheme of experimental apparatus



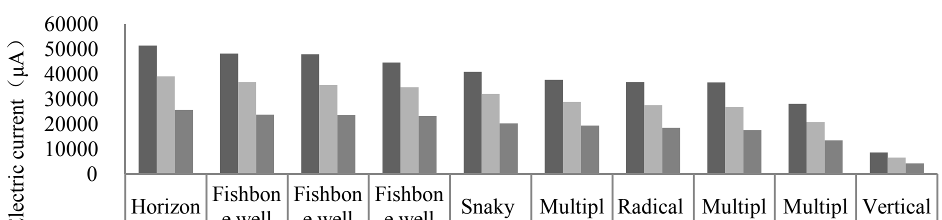
	Horizontal well	Fishbone well (60°)	Fishbone well (30°)	Fishbone well (90°)	Snaky well	Multiple well-4	Radical well	Multiple well-2	Multiple well-3	Vertical well
4V	13384	11927	11623	11448	11358	10914	10024	9965	6987	3150
3V	10064	8996	8615	8457	8372	8193	7429	7145	5278	2362
2V	6729	6063	5780	5571	5563	5369	4925	4819	3502	1597

(a) The resistivity value is 90μs/cm



	Horizontal well	Fishbone well (60°)	Fishbone well (30°)	Fishbone well (90°)	Snaky well	Multiple well-4	Radical well	Multiple well-2	Multiple well-3	Vertical well
4V	28711	25231	24551	23853	23745	22084	22063	20410	13448	6359
3V	21212	18715	17698	17649	17633	16507	16271	14550	10146	4724
2V	13578	12560	11854	11834	11742	10750	10695	10450	6443	3038

(b) The resistivity value is 200μs/cm

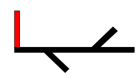
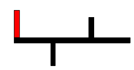
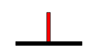
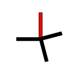
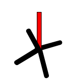
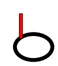


	Horizontal well	Fishbone well (60°)	Fishbone well (30°)	Fishbone well (90°)	Snaky well	Multiple well-4	Radical well	Multiple well-2	Multiple well-3	Vertical well
4V	51400	48160	47940	44670	40860	37651	36801	36641	28141	8531
3V	39060	36812	35675	34687	32107	28791	27579	26820	20746	6480
2V	25601	23722	23538	23178	20216	19385	18471	17561	13521	4206

(c) The resistivity value is 350μs/cm

Fig. 2: Current comparisons on the condition of basal groundwater

Table 4: Description of simulated well-type

Well-type	Description	Graphic representation (black stands for completion section)
Vertical well	The length of completion section is 8 cm by barefoot well completion.	
Horizontal well	The horizontal section is completed by barefoot completion , and the length of drilling is 40 cm.	
Snaky well	The snaky section is completed by barefoot completion , and the length of drilling is 40 cm.	
30°-fishbone well	Both of the horizontal section (30 cm) and branches (5 cm) are completed by barefoot completion and the total length of drilling is 40 cm. The branches locate on the trisection points of horizontal section. The angle between chief wellbore and branch is 30 °.	
60°-fishbone well	Both of the horizontal section (30cm) and branches (5 cm) are completed by barefoot completion and the total length of drilling is 40cm. The branches locate on the trisection points of horizontal section. The angle between chief wellbore and branch is 60°.	
90°-fishbone well	Both of the horizontal section (30 cm) and branches (5 cm) are completed by barefoot completion and the total length of drilling is 40 cm. The branches locate on the trisection points of horizontal section. The angle between chief wellbore and branch is 90°.	
2-lateral well	Both of the two simulated branches (10 cm) are completed by barefoot well completion and the angle between them is 180°.	
3-lateral well	All of the three simulated branches (10 cm) are completed by barefoot well completion and the angle between every two of them is 120°.	
4-lateral well	All of the four simulated branches (10 cm) are completed by barefoot well completion and the angle between every two of them is 90°.	
Radical well	The real displacement is 40 cm completed by barefoot well completion.	

NaCl solution was used to simulate the porous medium, copper plate electrodes were used to simulate supply boundary and copper wire was for simulating the wellbore. The size of the organic glass tank is 800 mm×800 mm×200 mm. In the low-voltage current module, the potential drop was kept below 36 V for the reasons of safety. And then, the reduced potential drop was conveyed to well model or supply boundary with the frequency of 600 Hz which avoided polarization.

The organic glass tank was filled with NaCl solution of known salinity and conductivity. The boundary condition of basal groundwater or the boundary condition of edge water was simulated by connecting the positive pole of power supply with copper plates located on the edge or bottom. Well model made by copper wire was connected with negative pole of power supply. The well model was placed in the center of the tank.

To examine the effect of hysteresis and polarization, experiments were repeated with different salinities and potential drops. The resistivity of the solution was measured by a commercial resistivity-meter.

The height of the liquid level was 10 cm and the diameter of the well model was 1 mm.

Table 4 illustrates the description of 10 different simulated well-types.

The experimental consequences are showed in Fig. 2. Practical production of simulated well-type is not given, because the similar work has been done previously.

Figure 2 illustrates the current comparisons on the condition of basal groundwater with the resistivity values of 90, 200, 350 μs/cm, respectively. According to the Fig. 2, the sequence of exploitation effects for different well-types ranging from good to poor is: horizontal well, 60°-fishbone well, 90°-fishbone well, 30°-fishbone well, 4-lateral Well, snaky well, radial well, 3-lateral Well, 2-lateral Well , vertical well. The exploitation effect of horizontal well is best on the condition of homogeneous basal groundwater. There is an optimal angle between horizontal section and branch for fishbone well, rather than that the bigger angle is, the better exploitation effect is.

To investigate the effect of increasing production due to complex well configurations s, the conception of radio of production is proposed, which indicates the production radio of complex well configurations s and vertical well (Table 5).

Table 5: Current and radio of production on the conditions of basal groundwater

	2V		3V		4V	
Well-type	Current	Radio of production	Current	Radio of production	Current	Radio of production
(a) The resistivity value is 90μs/cm						
Horizontal well	13384	4.248889	10064	4.260796	6729	4.213525
Fishbone well-60	11927	3.786349	8996	3.808637	6063	3.796493
Fishbone well-90	11623	3.689841	8615	3.647333	5780	3.619286
Fishbone well-30	11448	3.634286	8457	3.58044	5571	3.488416
Multilateral well-4	11358	3.605714	8372	3.544454	5563	3.483406
Snaky well	10914	3.464762	8193	3.468671	5369	3.361929
Radical well	10024	3.182222	7429	3.145216	4925	3.083907
Multilateral well-3	9965	3.163492	7145	3.024979	4819	3.017533
Multilateral well -2	6987	2.218095	5278	2.234547	3502	2.192862
Vertical well	3150	1	2362	1	1597	1
(b) The resistivity value is 200μs/cm						
Horizontal well	28711	4.515018	21212	4.490262	13578	4.469388
Fishbone well-60	25231	3.967762	18715	3.961685	12560	4.134299
Fishbone well-90	24551	3.860827	17698	3.746401	11854	3.901909
Fishbone well-30	23853	3.751061	17649	3.736029	11834	3.895326
Multilateral well-4	23745	3.734078	17633	3.732642	11742	3.865043
Snaky well	22084	3.472873	16507	3.494285	10750	3.538512
Radical well	22063	3.469571	16271	3.444327	10695	3.520408
Multilateral well-3	20410	3.209624	14550	3.080017	10450	3.439763
Multilateral well -2	13448	2.114798	10146	2.147756	6443	2.120803
Vertical well	6359	1	4724	1	3038	1
(c) The resistivity value is 300μs/cm						
Horizontal well	51400	6.025085	39060	6.027778	25601	6.086781
Fishbone well-60	48160	5.645294	36812	5.680864	23722	5.640038
Fishbone well-90	47940	5.619505	35675	5.505401	23538	5.596291
Fishbone well-30	44670	5.236197	34687	5.352932	23178	5.510699
Multilateral well-4	40860	4.789591	32107	4.954784	20216	4.806467
Snaky well	37651	4.413433	28791	4.443056	19385	4.608892
Radical well	36801	4.313797	27579	4.256019	18471	4.391583
Multilateral well-3	36641	4.295042	26820	4.138889	17561	4.175226
Multilateral well-2	28141	3.298675	20746	3.201543	13521	3.214693
Vertical well	8531	1	6480	1	4206	1

According to Table 5, a conclusion can be drawn that the radio of production changes little by changing the voltage value with the same resistivity. Utilizing the conclusion, the production of the well transformed from vertical well can be calculated under the conditions of specific reservoir.

CONCLUSION

- **An electrolytic analogy experiment was conducted:** Evaluations and optimizations of complex well configurations were made by electrolytic analogy experiment.
- **The exploitation effects comparisons of 10 well-types were made:** The sequence of exploitation effects for different well-types ranging from good to poor is: horizontal well, 60°-fishbone well, 90°-fishbone well, 30°-fishbone well, 4-lateral Well, snaky well, radial well, 3-lateral Well, 2-lateral Well , vertical well.
- **The conception of radio of production is proposed:** For the specific reservoir, the radio of production changes little by changing the voltage value with the same resistivity. Utilizing the conclusion, the production of the well transformed from vertical well can be calculated under the conditions of specific reservoir.

NOMENCLATURE

L = Geometric dimension of formation or well, m
Q = Production of well, m^3/d
R_m = Resistance of solution
R_f = Resistance of formation fluid
ΔU = Potential drop in the modeling, V
ΔP = Pressure drop in the reservoir, MPa
K = Permeability of reservoir, $10^{-3}\mu m^2$
ρ = Resistivity of solution, μs/cm
μ = Viscosity of crude oil, mPa/s
I = Current through solution, mA
C_p = Pressure similarity coefficient
C_q = Flux similarity coefficient
C_l = Geometrical similarity coefficient
C_ρ = Flow similarity coefficient

Subscripts:

m = Parameters of modeling
o = Parameters of reservoir

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