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Experimental study on the performance of sand control screens for gas wells

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Abstract Based on the sand control mechanism, similarity criterion and factors affecting the stability of borehole plastic region, a large-scale laboratory test apparatus for simulating the performance of sand control screens for gas wells was developed. A series of sand control simulation experiments were performed. Based on the particle size analysis of formation sand and geological conditions, parameters of sand control screen, such as sand retention efficiency, were investigated. By simulating formation conditions, such as pressure gradient and gas flow rate, the performance of several types of screens, including slotted screen, wire wrapped screen and premium composite screen that are commonly used in oilfield, was evaluated. Experimental results were discussed and premium composite screen was found to be most efficient for sand control among all the tested screens. This study provides a sound experimental method for evaluating the performance of sand control screens for gas wells.

Keywords Gas well · Sand control simulation experiment · Sand control screen

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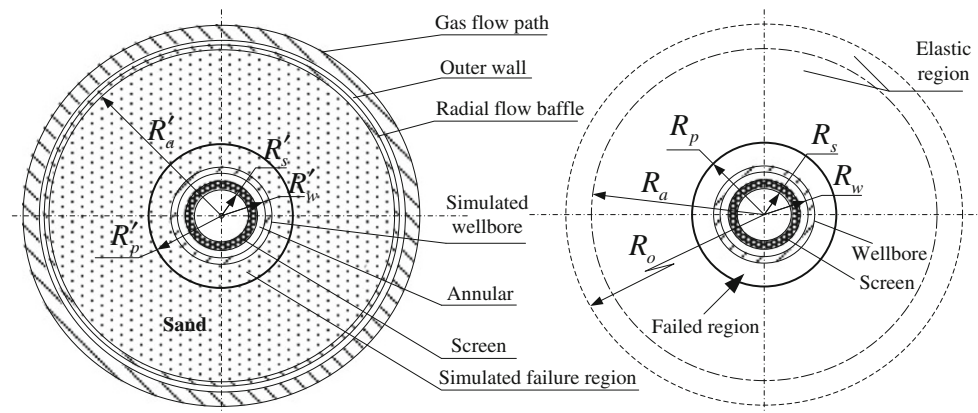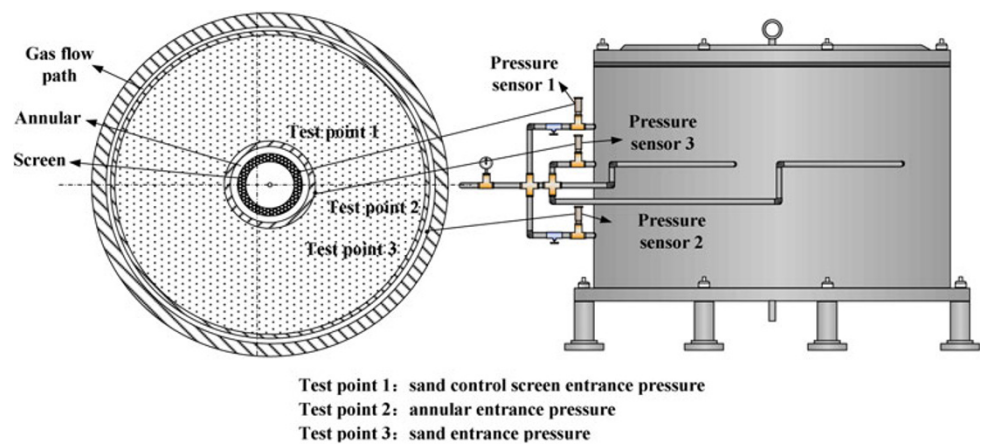Sinopec Research Institute of Petroleum Engineering,
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Introduction

Sand production can pose serious problems to normal field production. Hence, numerous methods have been proposed to perform effective sand control. Laboratory sand control simulation experiment has been considered as a good way to select appropriate sand control screens. Schulien et al. (1997) designed and constructed a small-scale laboratory test apparatus for investigating screen plugging. With this test apparatus, the influence of scale sensitive parameters on the performance of a single wire wrapped screen was studied. Ballard et al. (1999) developed a laboratory method to evaluate the performance of various sand control screens, which was applied in a North Sea oilfield to select the most appropriate screen. Underdown et al. (1999) evaluated sand control efficiency for different screens and defined performance factor and sand control factor. The higher the sand control factor, the better the sand control performance of a screen. For the performance factor, the higher the value, the longer the screen occurs sand plugging. Zhu et al. (2000) conducted laboratory sand control simulation experiments for heavy oil reservoir of Shengli oilfield, China. They investigated the adaptability of different sand control methods in different geological conditions and established an optimal sand control screen selection model. Zeng et al. (2004) designed a sand control simulation apparatus and conducted simulation experiments for shallow loose heavy oil reservoir in the Bohai Sea, China. They came to conclusion that the studied reservoir is not suitable for gravel packing, while using metal cotton fiber for sand control is more preferable. Qi (2004) designed a large-scale experimental apparatus for simulating sanding during radial flow. The relationship between fluid viscosity, flow rate and sanding was obtained. Nouri et al. (2005) used field sand to make poorly cemented
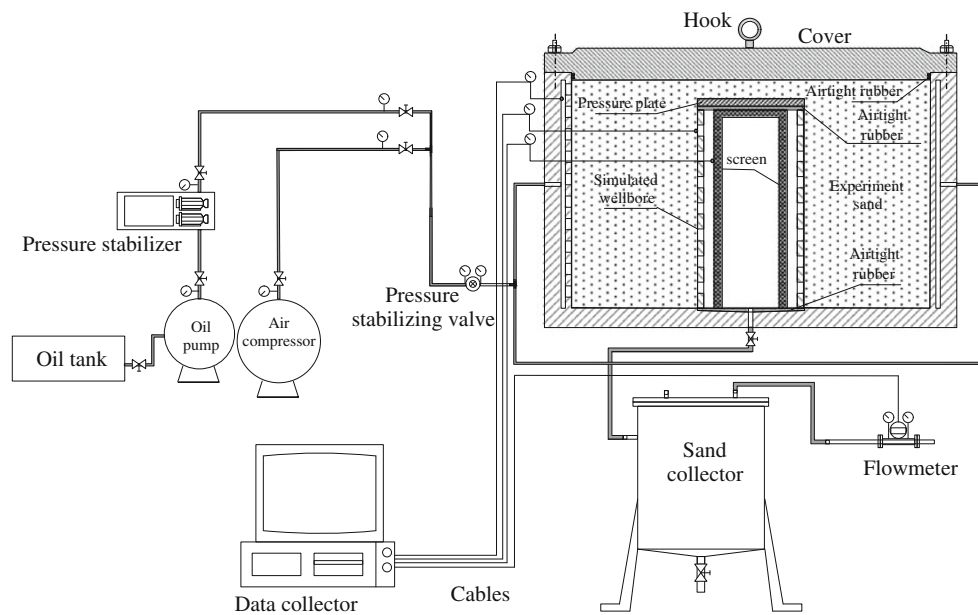
Fig. 1 Schematic diagram of sand control simulation experimental apparatus

Fig. 2 Profile of experimental cylinder and test positions

Test point 1: sand control screen entrance pressure
Test point 2: annular entrance pressure
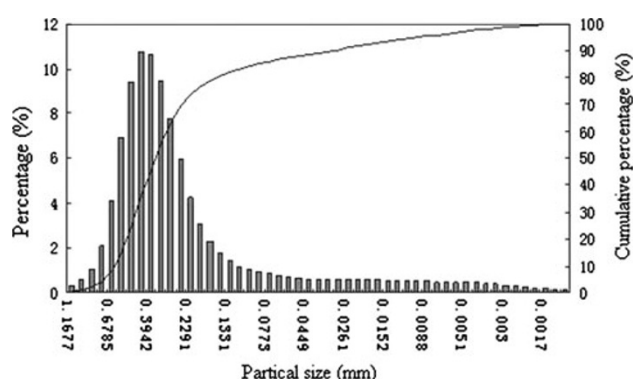Test point 3: sand entrance pressure

Fig. 3 Structure of experimental cylinder and dimensions of sand-filling model and field formation

thick-walled cylinder samples. Laboratory sanding simulation experiments were conducted for both open hole completion and sand control screen completion. Sand control performance of expandable screen was analyzed as well. The experimental equipments include fluid injection system, axial loading system and sand collection system.

Numerous studies on laboratory simulation of the performance of sand control screens used in poorly consolidated reservoirs have been reported. The fluids used in the experimental simulation are most often refined oil and water. Our study focuses on the evaluation of the performance of sand control screen for gas wells. With a large-scale laboratory test apparatus designed by ourselves, it is aimed to provide a sound experimental method.
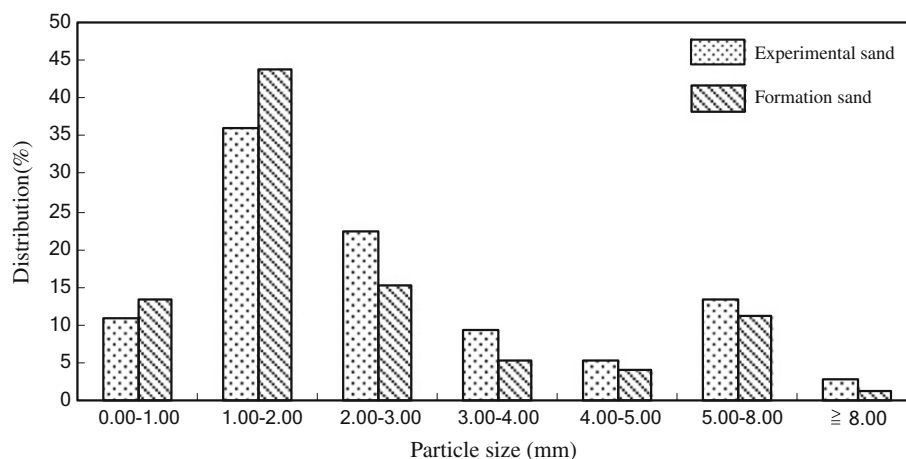
Experimental apparatus for sand control simulation of gas wells

The experimental study in this paper simulates sand production for gas wells, aiming to evaluate the performance of various sand control screens. The experimental study does not involve mechanical failure analysis of wellbore. Instead, this paper focuses on the study of when and on what conditions sand production occurs and the evaluation of the performance of several sand control screens.

The experimental apparatus consists of power system, pressure measurement system, flow rate measurement system, data acquisition system, experimental cylinder, sand collection system, simulated wellbore and auxiliary equipments, as is illustrated in Figs. 1 and 2.

Determination of experimental conditions of sand control simulation for gas wells

Simulating field conditions by conducting laboratory experiment require geometric similarity (composition of experimental and formation sand; diameter, slot height, slot length of experimental and field screen), physical similarity (production pressure difference and gas flow rate), boundary similarity. In order to establish the relationship between the performance of sand control screen, production pressure difference and flow rate utilizing experimental results, experimental conditions are determined through similarity criterion.

In this paper, letters without superscript "'" represent field parameters, whereas letters with superscript "'" represent laboratory parameters. For convenience of derivation, corresponding diagram of laboratory sand-filling model and field formation is shown in Fig. 3.

Composition of experimental sand

Field core samples were collected and their particle sizes were analyzed (Fig. 4), then experimental sand was prepared accordingly (Fig. 5; Table 1).

Fig. 4 Analysis of core particle sizes for Well Dabei 3 (well depth 7,066–7,067 m)

Fig. 5 Comparison of particle sizes between experimental and formation sand

Determination of experimental pressure difference and gas flow rate

Driven by pressure gradient, formation fluid flows towards wellbore. The pressure gradient is related to formation permeability, fluid viscosity, reservoir thickness, flow rate and model outer/inner radius. For convenience, assumptions are made as: (1) reservoir physical parameters do not change due to the small deformation of reservoir, (2) fluid viscosity is constant, (3) fluid pressure is considered as linearly distributed.

Formation pressure at position R_a can be expressed as:

$$P_a = \left(P_{po} - P_w\right)\frac{R_a - R_w}{R_o - R_w} + P_w = \frac{\mu Q \ln\frac{R_o}{R_w}}{2\pi k h}\frac{R_a - R_w}{R_o - R_w} + P_w. \quad (1)$$

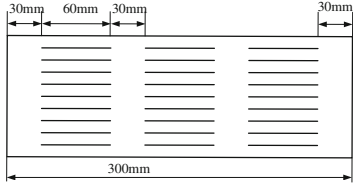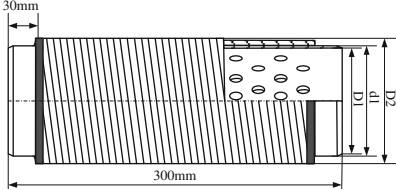Corresponding pressure difference between fluid and wellbore is:

Table 1 Composition of experimental sand

Well no.	Interval (m)	Ratio of experimental sand		
		20–40 mesh	80–120 mesh	150 mesh
Well Dabei 3	7,058–7,090.87	2	2	1

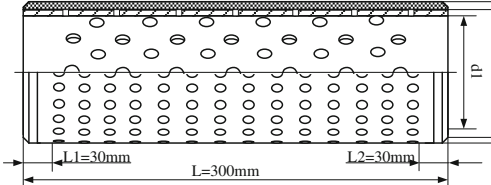**Table 2** Determination of experimental gas flow rate and pressure gradient

Item	Wellbore radius (R_w, (mm)	Outer boundary (R_a, mm)	Effective reservoir thickness (mm)	Pressure gradient (MPa/m)	Gas flow rate (at wellbore, m/s)
Well Dabei 3	50.8	225	9,500	2.37	0.053
Experimental conditions	50.8	225	450	1.6–4	0.051–1.5

Table 3 Experimental sand control screens and their parameters

Screen type	Schematic of screens and their structure	Parameters	
Slotted screen	A: screen with slot width 0.3mm B: dimension of slotted screen	Slot width (mm)	0.3
		Slot length (mm)	60
		Number of slots in a single line	20
		Total number of slots	60
		Slot configuration	Axially parallel
		Slot geometry	Rectangle
		Steel grade	P110
		Distance between two slot lines (mm)	30
		Length of side tube (mm)	30
		Outer radius of base tube (mm)	73
		Inner radius of base tube (mm)	62
		Thickness of base tube (mm)	5.51
Wire wrapped screen	A: 0.3mm wire wrapped screen B: schematic of structure and dimension of wire wrapped screen	Gap (mm)	0.3
		Maximum outer radius D2 (mm)	74
		Number of layers	1
		Outer radius of base tube D1	
		Inner radius of base tube d1	
		Thickness of base tube	
		Steel grade	P110/N80

Table 3 continued

Screen type	Schematic of screens and their structure	Parameters	
Premium composite screen		Outer radius of base tube D1 (mm)	60.32
	A: 0.3mm premium composite screen	Thickness of base tube (mm)	4.86
		Inner radius of base tube d1 (mm)	50.6
		Material quality of base tube	J55
		Length of base tube L (mm)	300
		Maximum outer radius of screen D2 (mm)	74
	B: 0.225mm premium composite screen	Screen length (mm)	240
		Side tube L1, L2 (mm)	30
		Diameter of base tube hole (mm)	8
		Hole density of base tube (hole/m)	320
		Number of filter screen layers	1 layer
		Type of filter screen	Mat shaped
		Diameter of filter screen hole (mm)	0.3
			0.225
	C: schematic of structure and dimension of premium composite screen	Type of leak screen	Square hole shaped
		Diameter of leak screen mesh (mm)	0.45
		Number of leak screen layers	2 layers
		Thickness of cover (mm)	1.2
		Hole area percentage of cover	30%

$$\Delta P_a = P_a - P_w = \left(P_{po} - P_w\right)\frac{R_a - R_w}{R_o - R_w}$$
$$= \frac{\mu Q \ln\frac{R_o}{R_w}}{2\pi k h}\frac{R_a - R_w}{R_o - R_w}. \tag{2}$$

For laboratory simulation, pressure difference can be expressed as:

$$\Delta P'_a = P'_a - P'_w = \frac{\mu' Q' \ln\frac{R'_a}{R'_w}}{2\pi k' h'}. \tag{3}$$

The ratio of these two pressures is:

$$\frac{\Delta P_a}{\Delta P'_a} = \frac{P_a - P_w}{P'_a - P'_w} = \frac{\mu}{\mu'}\frac{Q}{Q'}\frac{k'}{k}\frac{h'}{h}\frac{\ln\frac{R_o}{R_w}}{\ln\frac{R'_a}{R'_w}}\frac{R_a - R_w}{R_o - R_w}. \tag{4}$$

Let $\Delta P'_a = \Delta P_a$, we have:

$$P'_a = \left(P_{po} - P_w\right)\frac{R_a - R_w}{R_o - R_w} + P'_w \tag{5}$$

Based on the above analysis, pressure gradients in these two conditions should be similar:

$$\varpi_{td} = \frac{\Delta P'/\Delta r'}{\Delta P/\Delta r} \approx 1, \tag{6}$$

where pressure gradient in laboratory experiment is: $\frac{\Delta P'}{\Delta r'} = \frac{P'_a - P'_w}{R'_a - R'_w}$.

Gas flow rate in the field (gas passes through effective wellbore area) should be approximately similar to the gas flow rate in simulation experiment (gas passes through simulated wellbore area):

$$\frac{V_{jb}}{V'_{jb}} = \frac{Q/2\pi R_w h}{Q'/2\pi R'_w h'}, \tag{7}$$

where V_{jb}, Q, R_w, h are field gas flow rate, gas production, wellbore radius and effective reservoir thickness, respectively, V'_{jb}, Q', R'_w, h' are laboratory simulated gas flow rate, gas production, wellbore radius and effective reservoir thickness, respectively.

Let $\frac{V_{jb}}{V'_{jb}} = 1$ and $R'_w = R_w$.

Thus, $\frac{h}{h'} = \frac{Q}{Q_w}$.

It is evident that gas flow rate (at wellbore) is controlled by effective reservoir thickness and gas production (Table 2).

**Table 4** Sand production for several types of screen (2.25 MPa compressor output pressure)

| Screen type	Sand production (g)
0.3 mm slotted screen	5.363
0.3 mm wire wrapped screen	0.7622
0.3 mm premium composite screen	0.6315
0.225 mm premium composite screen	0.2731
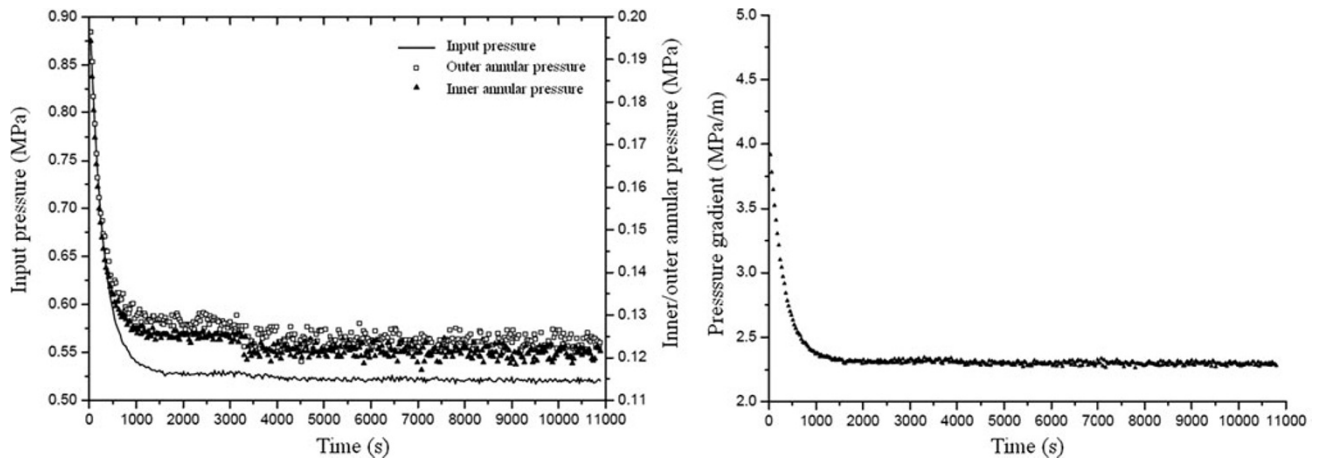
Fig. 6 Input pressure, annular pressures and pressure gradient (0.3 mm premium composite screen and compressor output pressure 2.5 MPa)

Fig. 7 Gas flow rate versus time and premium composite screen after experiment (0.3 mm premium composite screen and compressor output pressure 2.5 MPa)
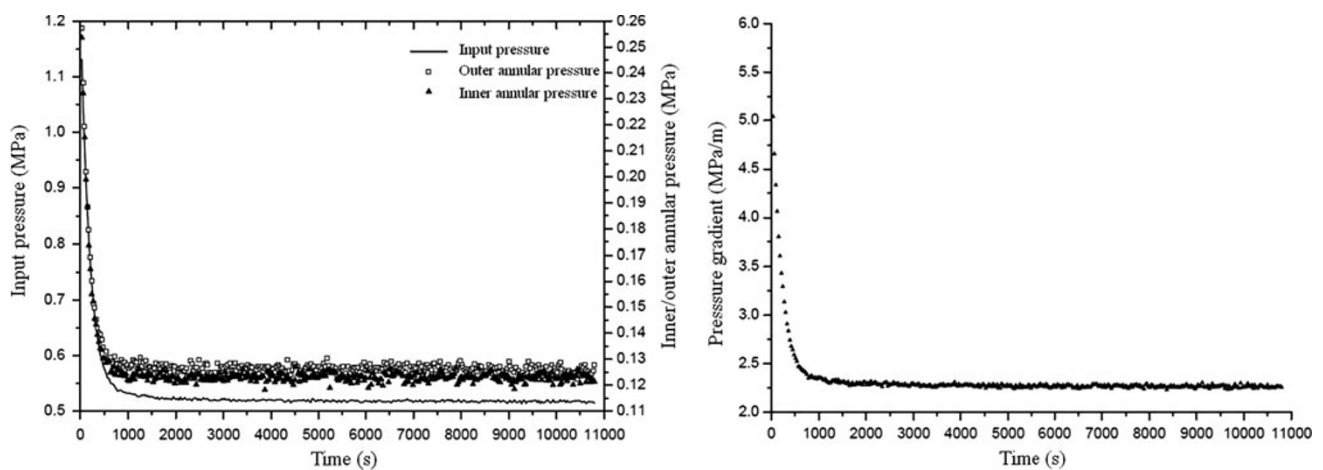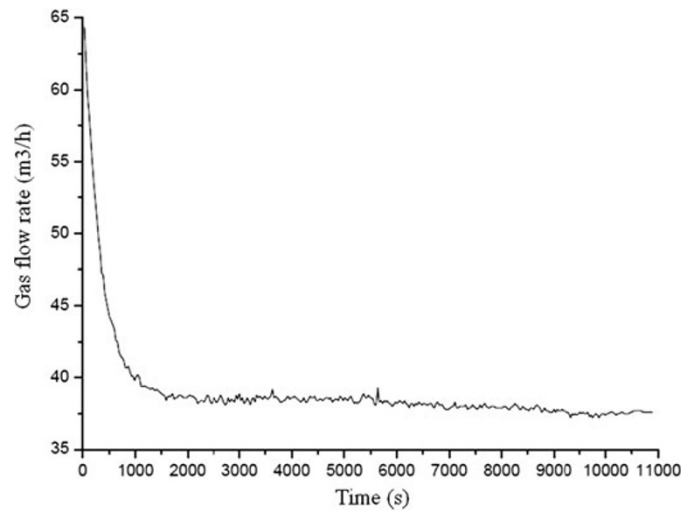
Fig. 8 Input pressure, annular pressures and pressure gradient (0.225 mm premium composite screen and compressor output pressure 2.5 MPa)
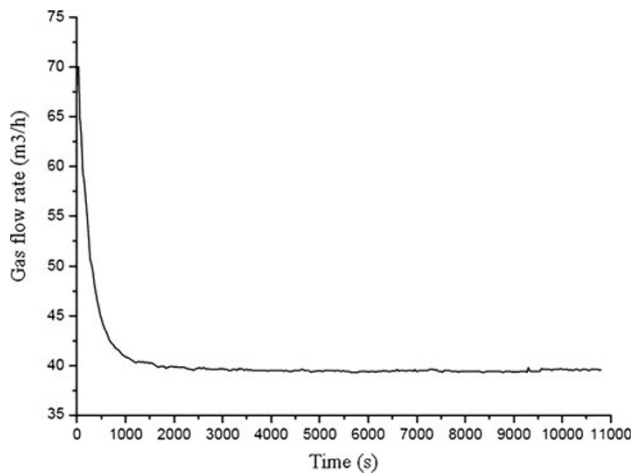
Fig. 9 Gas flow rate versus time (0.225 mm premium composite screen and compressor output pressure 2.5 MPa)

Experimental results and discussion

Sand control screens and their parameters

The most commonly used sand control screens in oilfields include slotted screen, wire wrapped screen and composite screen. Therefore, simulation experiments were conducted on these types of screens and their parameters are listed in Table 3.

Experimental results

We first conducted sand control simulation experiments to evaluate the performance of 0.3 mm slotted screen, 0.3 mm wire wrapped screen, 0.3 mm and 0.225 mm premium composite screens under 2.25 MPa compressor output pressure. The corresponding sand production is listed in Table 4.

It is apparent that the sand control performance of premium composite screen is the best among all the tested screens. Therefore, we focus on the evaluation of two types of premium composite screens under different compressor output pressures.
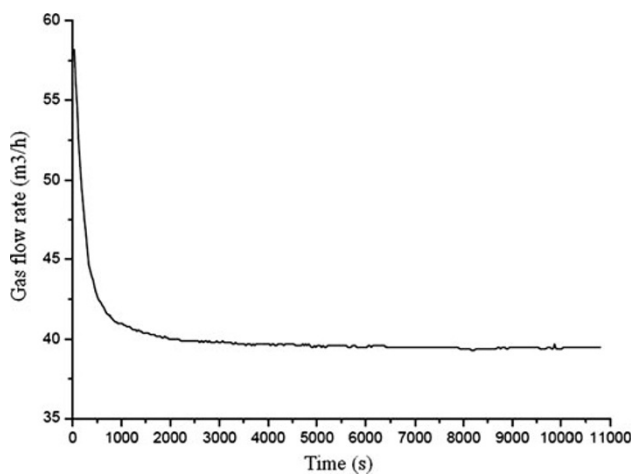
1. Experimental results for 0.3 and 0.225 mm premium composite screens under 2.5 MPa compressor output pressure.

    Figures 6 and 7 illustrate the input pressure, inner/outer annular pressure and gas flow rate for experiments using 0.3 mm premium composite screen under compressor output pressure 2.5 MPa. We can see that both input pressure and inner/outer annular pressures stay stable for a time interval of 1,500–3,500 s while the sand is stable. After 3,500 s, three pressures decreased simultaneously, indicating partly sand instability occurs. Some sand passed through 40-mesh screen and entered into simulated wellbore while some adhered to screen. Those sand that entered into simulated wellbore was blocked by composite screen, and some would block screen and reduce both pore area and gas flow rate. As a result, the pressure difference between annular and screen increased and fine sand was more easily carried out of screen. At last, some fine sand (0.6315 g) passed through 0.3 mm premium composite screen.

    Figures 8 and 9 illustrate the input pressure, inner/outer annular pressure and gas flow rate for experiments using 0.225 mm premium composite screen under compressor output pressure 2.5 MPa. Three pressures stayed stable during experiment with occasional fluctuate due to partly sand instability. The pressure gradient between inside and outside cylinder kept constant at 2.26 MPa/m. Moreover, gas flow rate kept stable as well, which indicates good sand control
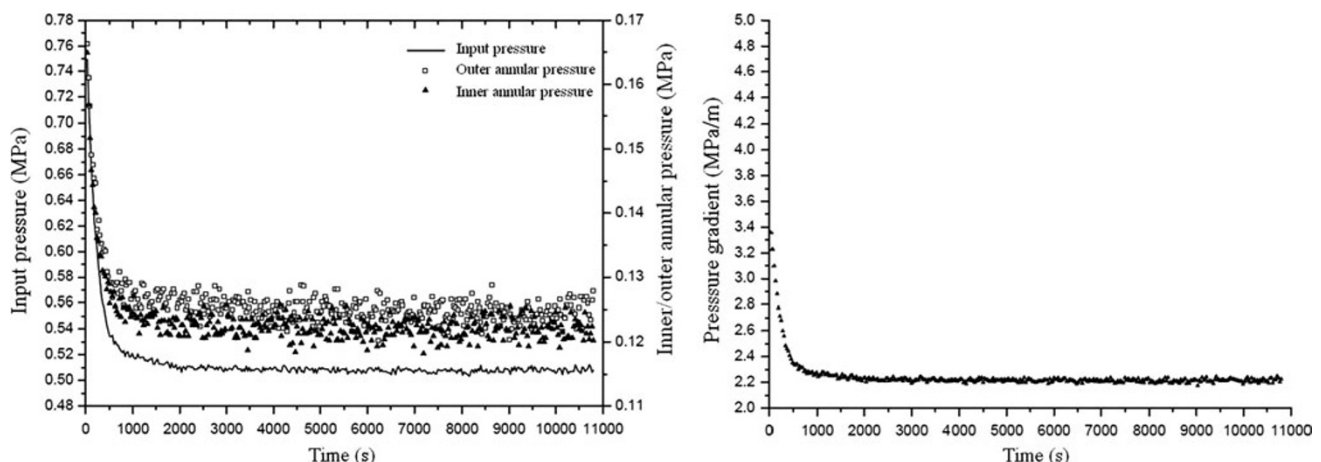
Fig. 10 Input pressure, annular pressures and pressure gradient (0.3 mm premium composite screen and compressor output pressure 2.0 MPa)

Fig. 11 Gas flow rate versus time (0.3 mm premium composite screen and compressor output pressure 2.0 MPa)

performance. At last, very fine sand (0.2731 g) was collected.

2. Experimental results for 0.3 and 0.225 mm premium composite screens under 2.0 MPa compressor output pressure.

The input pressure, inner/outer annular pressure and gas flow rate for experiments using 0.3 mm premium composite screen under compressor output pressure 2.0 MPa are illustrated in Figs. 10 and 11. It can be seen that input and annular pressures fluctuate, which indicates partly instability occurs. Because of great overlying pressure, fine sand entered into wellbore and had little impact on whole sand stability. Therefore, pressure gradient between inside an outside cylinder and gas flow rate roughly stayed stable. Fine sand (0.2635 g) was collected from sand collector, which

also indicates sand instability occurs in such experimental conditions.

The input pressure, inner/outer annular pressure and gas flow rate for experiments using 0.225 mm premium composite screen under compressor output pressure 2.0 MPa are illustrated in Figs. 12 and 13. Three pressures fluctuated and input pressure decreased during experiment. After 5,000 s, inner and outer annular pressures slightly increased which indicates screen blocking by produced sand. While gas flow rate stayed stable and indicated screen blocking was not severe. This can also indicate that sand instability leads to sand production. Fine sand (0.1516 g) was collected at last.

3. Experimental results for 0.3 and 0.225 mm premium composite screens under 1.5 MPa compressor output pressure.

Figures 14 and 15 are for 0.3 mm premium composite screen under compressor output pressure 1.5 MPa. We can see that three pressures roughly stayed stable and both pressure gradient (approximately 2.25 MPa/m) and flow rate were constant. Probably partly sand instability occurred but sand production failed to occur. There was not any produced sand in the sand collector. Moreover, screen was found to be clean after experiment, and there was very few sand between screen and wellbore. Above phenomenon indicates sand was stable in such experimental conditions.

Figures 16 and 17 are for 0.225 mm premium composite screen under compressor output pressure 1.5 MPa. Sand stayed stable and three pressures kept roughly stable as well, indicating no blocking in the experiment. The pressure gradient (1.81 MPa/m) in this experiment was slightly smaller than that of
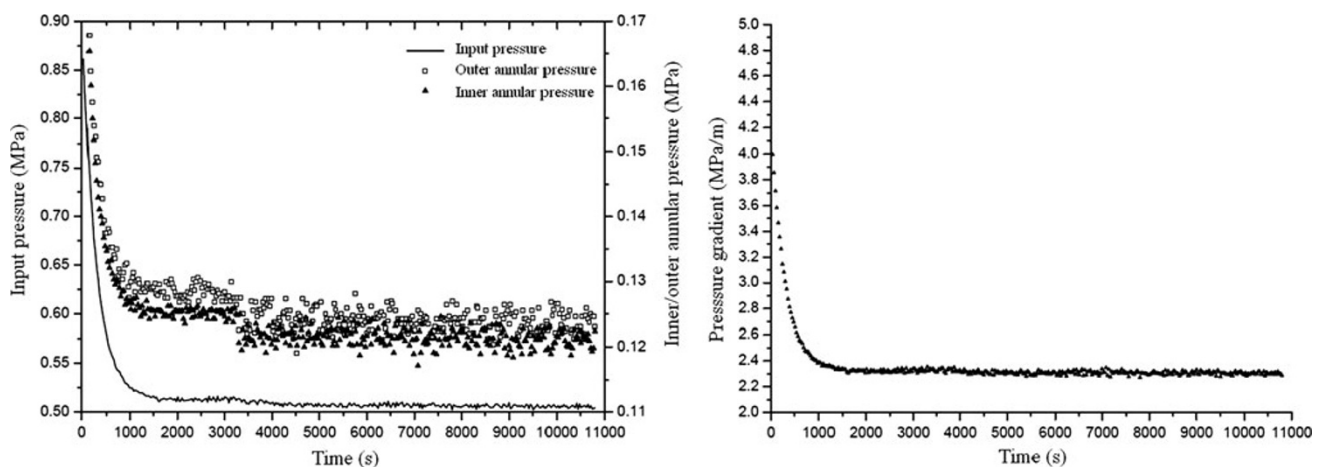
Fig. 12 Input pressure, annular pressures and pressure gradient (0.225 mm premium composite screen and compressor output pressure 2.0 MPa)
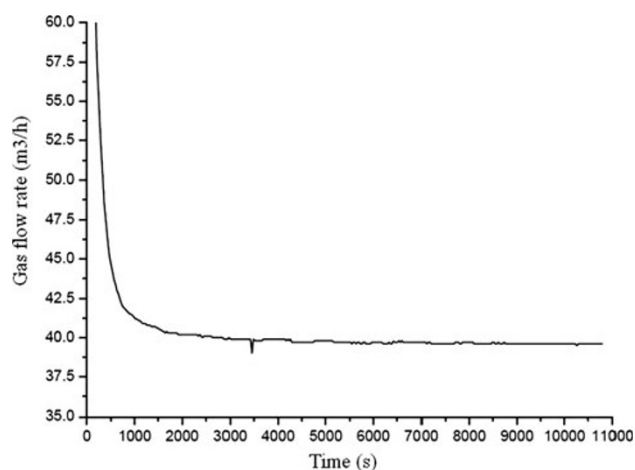
Fig. 13 Gas flow rate versus time (0.225 mm premium composite screen and compressor output pressure 2.0 MPa)
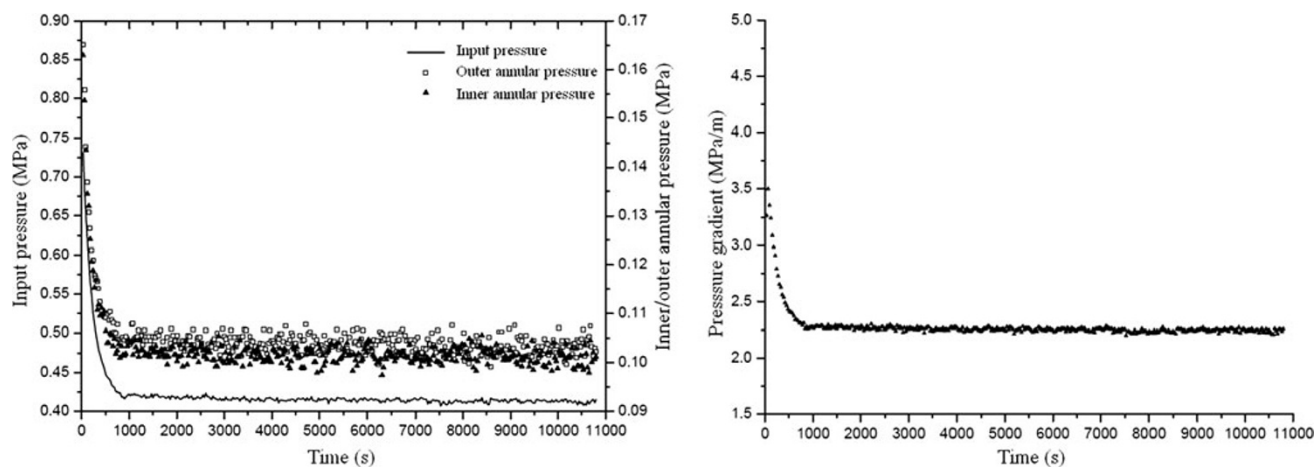
0.3 mm premium composite screen. This also indicates that gas flow rate increases with open area but would result in greater pressure difference.

Discussion

Based on the above analysis of experimental results, conclusions can be drawn as follows.
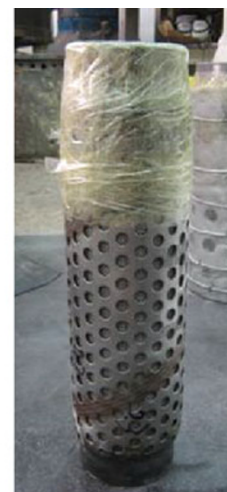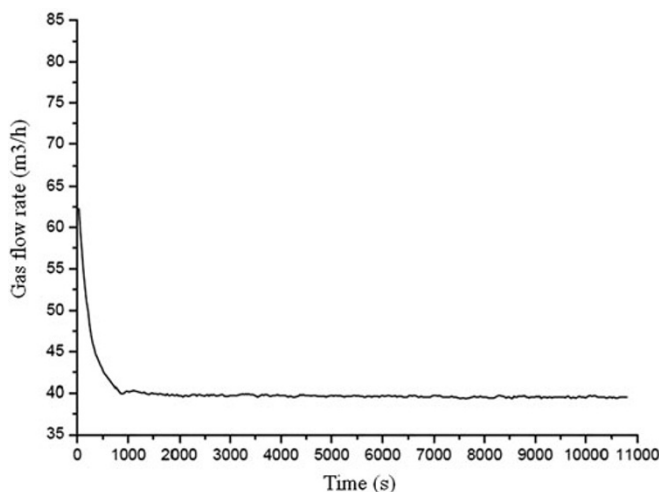
For compressor output pressure 2.5 MPa, the pressure gradient between inside and outside sand-filling cylinder was 2.26 MPa/m and gas flow rate was 40 m^3/min, and sand instability occurred.
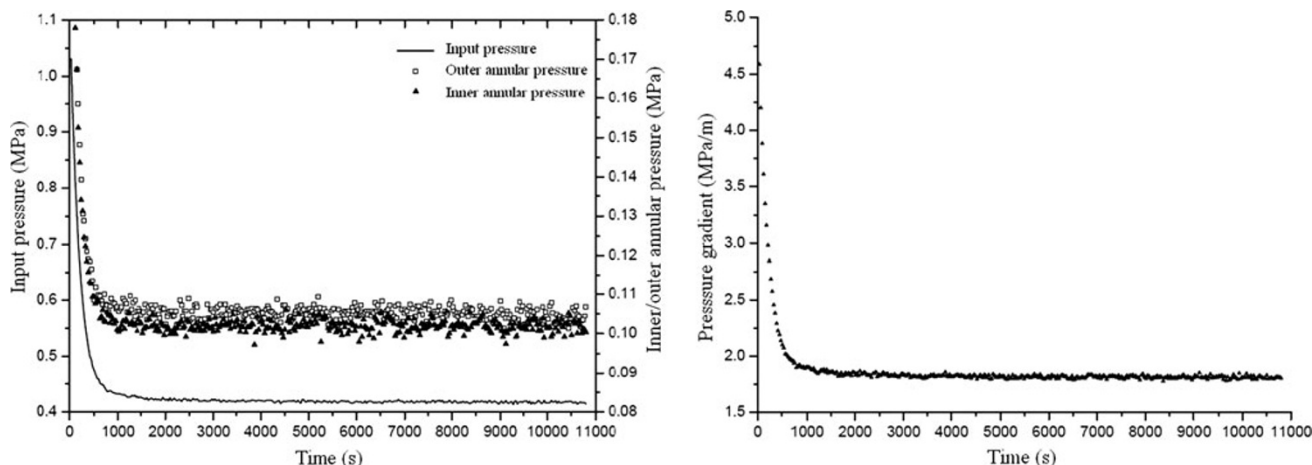
For compressor output pressure 2.0 MPa, pressure gradient decreased and gas flow rate was equal to that of output pressure 2.5 MPa, partly sand instability and sand production occurred in cylinder, but the amount of
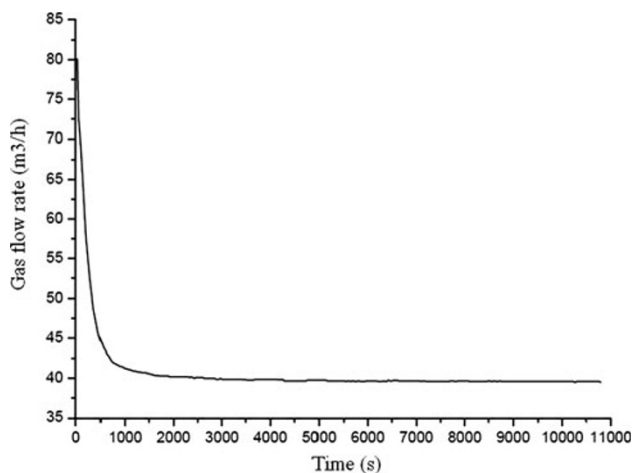

Fig. 14 Input pressure, annular pressures and pressure gradient (0.3 mm premium composite screen and compressor output pressure 1.5 MPa)

Fig. 15 Gas flow rate versus time and premium composite screen after experiment (0.3 mm premium composite screen and compressor output pressure 1.5 MPa)

Fig. 16 Input pressure, annular pressures and pressure gradient (0.225 mm premium composite screen and compressor output pressure 1.5 MPa)

Fig. 17 Gas flow rate versus time and premium (0.225 mm premium composite screen and compressor output pressure 1.5 MPa)

produced sand was significantly less than that of output pressure 2.5 MPa.

For compressor output pressure 1.5 MPa, pressure gradient fell between 1.81 snf 2.25 MPa/m and gas flow rate was same with two former experiments, sand production failed to occur, which indicates sand is stable.

Under same conditions, sand control performance of premium composite screen is the best while slotted screen the worst.

Based on the above analysis, we know that the greater the pressure difference between inside and outside cylinder, the more instable the sand. With field pressure gradient, sand production was severe, which is consistent with field condition. By reducing pressure difference, sand tends to be stable. Therefore, once reasonable production pressure difference is adopted, wellbore plastic region can be maintained and sand production would be avoided.

Summary

A large-scale experimental apparatus for evaluating the performance of various sand control screens was developed and a series of experimental conditions can be satisfied. In the experiment, failed formation was simulated by sand-filling cylinder according to formation particle size distribution. Gas radial flow and wellbore can be simulated. Through real time measurement of input pressure, inner/outer wellbore pressure and gas flow rate, the effect of pressure and flow rate changes on sand stability was analyzed.

Sand control simulation experimental apparatus for gas wells still needs to be further improved, especially the stability of power system, since experiment for various similarity conditions needs to be conducted accurately. Moreover, it is also advisable to develop real time sand production monitoring system in the future.

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