Experimental Investigation on Sand Production during Non-Diagenetic Hydrate-Bearing Sediments Depressurization Production in Vertical Well with Crustal Stress

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1. Introduction

Nature gas hydrate mainly exists in non-diagenetic strata, and it is easy to appear the sand production and subsidence during the mining. It restricted the safe efficient and long-term production of gas hydrate.

Objective: Investigation on sand production during hydrate exploitation

Key factors: Crustal Stress, Hydrate Saturation, 3D Pore Pressure, 3D Temperature, Sand Production Mechanism, Water Production, Gas Production Types & Volume and Stimulation.

2. Experiment--Experimental Materials and Apparatus

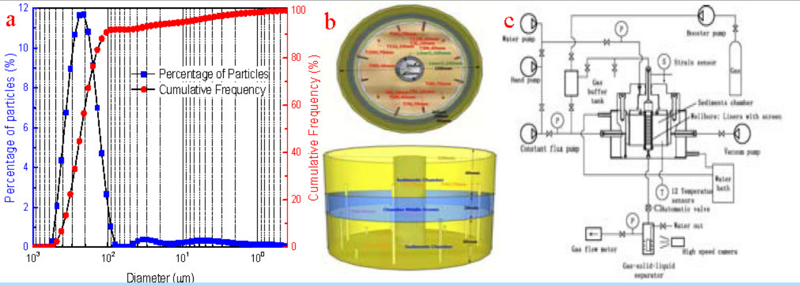


Fig.1 (a)The Particles size of sand;(b) Top view and Flat view of sediment chamber;(c) Schematic of methane hydrate sand production and sand prevention facility.

Table 1. The Facility properties.

P	0 to 30 MPa, 3 layers Pore Pressure, Overburden Pressure, Accuracy 0.01 MPa
T	253.15 to 313.15 K, 3 layers* 4 directions temperature sensors (Accuracy 0.1 K)
Sample	ø159 mm×130 mm, wellbore: ø24-32 mm×135 mm, subsidence: -0 to -30 mm.
Sand Production	Record visual window by video, weighed dry Time-interleaved samples
Water Production	Weighed weight Time-interleaved samples
Gas Production	Monitored by gas flow meters

Fig.2 The sample chamber before and after experiment

Table 2. The Experimental Details.

Periods	NO.	1	2	3	4	5
Sample Preparation	Dry sand/kg	2	2	2	2	2
	Water/g	250	350	250	250	250
	Water in Pore/%	11.11	14.89	11.11	11.11	11.11
	Ideal Hydrate Saturation/%	46.71	65.40	46.71	46.71	46.71
	Water injection /ml	806.68	855.31	725.55	653.86	673.86
Production	Max gas rates/sccm	400	1000	1000	500	231
	Samples Time Point/min	1,1.25,1.75,30.33,85.67,305.33,Bottom	0.82,0.5,62.5,63.3,165.5,173.25,Bottom	0.5,1,1.82,8.15,16.27,44.89,Bottom	0.5,1.27,1.6,12.4,51.93,Bottom	20,60.58,122,300,Bottom
	Stimulation time/min	N	349	N	N	314
Production Results	Production Time/min	1100	400	179	288	347
	Produced Gas Volume/SL	72.9	113.2	78	77	50.9
	Hydrate Volume/mol	0.41	0.63	0.44	0.43	0.28
	Hydrate Saturation/%	61.84	95.86	67.01	65.32	43.18
	Wet Sand Production/g	640.87	682.58	905.13	887.39	527.42
	Dry Sand Production/g	1.14	7.91	7.05	6.63	6.21
	Subsidence/mm	-1.93	-2.28	-1.88	-1.96	-1.77

Fig.3 The water-sand samples in beakers by time

Table 3. The time,T and subsidence details of Fig.4(i).

	a	b	c	d	e
1	0 m, S=0%, 0.41 mol, Sh=61.84%	18 m, S=-0.15%, 0.37 mol, Sh=56.58%	125 m, S=-0.7%, 0.18 mol, Sh=27.99%	325 min, S=-1.23%, 0.04 mol, Sh=5.85%	600 m, S=-1.79%, 0.001 mol, Sh=0.09%
2	0 m, S=0%, 0.63 mol, Sh=95.86%	10 m, S=-0.25%, 0.58 mol, Sh=88.23%	150 m, S=-1.52%, 0.11 mol, Sh=16.97%	343 m, S=-1.81%, 0.02 mol, Sh=3.39%	362 m, S=-2.23%, 0 mol, Sh=0%
3	0 m, S=0%, 0.44 mol, Sh=67.01%	13 m, S=-0.24%, 0.38 mol, Sh=57.69%	80 m, S=-1.62%, 0.006 mol, Sh=0.85%	170 m, S=-1.87%, 0 mol, Sh=0%	189 m, S=-1.88%, 0 mol, Sh=0%
4	0 m, S=0%, 0.43 mol, Sh=65.32%	10.17 m, S=-0.38%, 0.4 mol, Sh=61.08%	110.83 m, S=-1.26%, 0.12 mol, Sh=18.66%	200 m, S=-1.66%, 0.02 mol, Sh=2.54%	287.17 m, S=-1.96%, 0 mol, Sh=0%
5	0 m, S=0%, 0.28 mol, Sh=43.18%	25 m, S=-0.27%, 0.26 mol, Sh=39.25%	312 m, S=-1.58%, 0.04 mol, Sh=5.89%	339 m, S=-1.75%, 0.01 mol, Sh=0.98%	355 m, S=-1.76%, 0 mol, Sh=0%

3. Results and Discussion

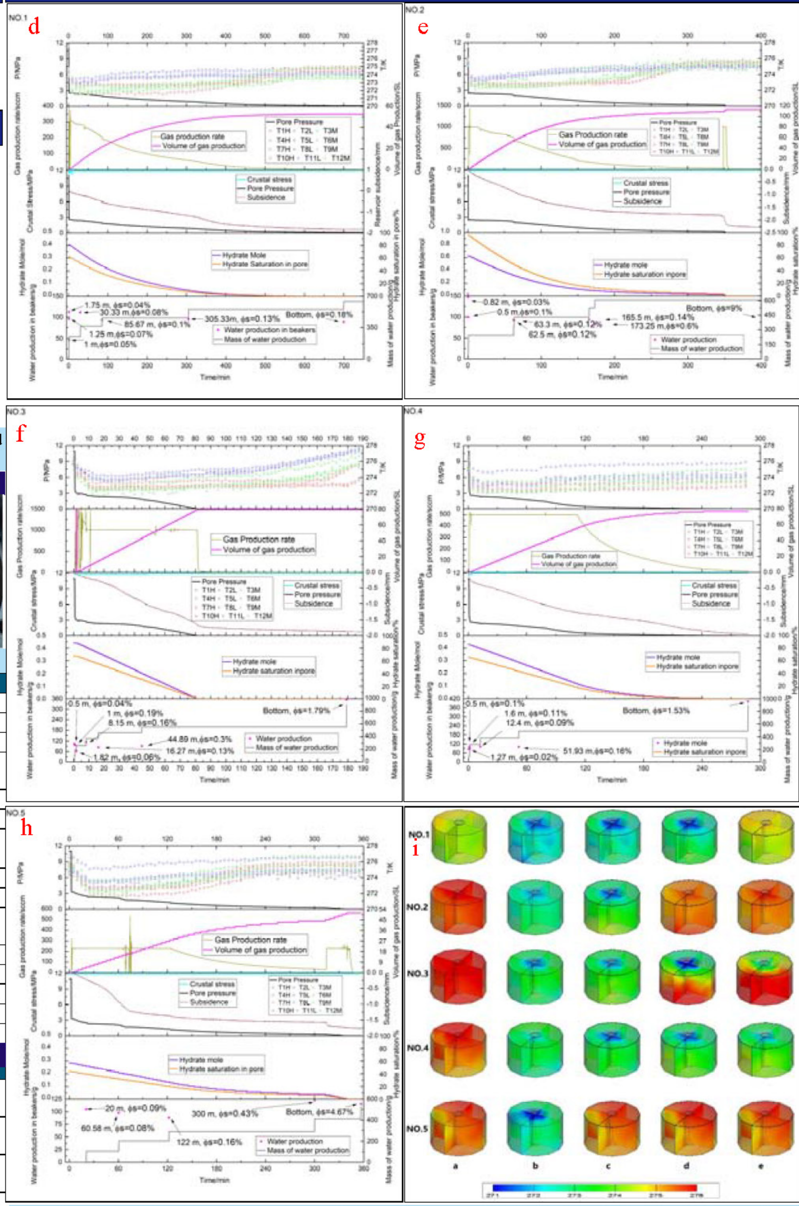


Fig.4 The experiential details of five experiments(d-h) and (i) 3D temperature distribution and subsidence(Here, T indicates temperature, 1–12 indicates the alignment of the temperature sensors; H, L and M mean the height of temperature sensors in layers H, M and L; Øs indicates the sand rates in produced water.)

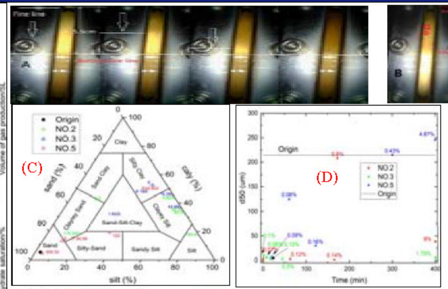
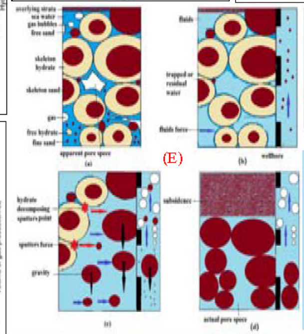


Fig.5 Sand production in the visual window (A) fine sand as a whole and (B) sand grains; (C)Particle size classification of sand production at different time; (D) sand content in water and median granularity over time



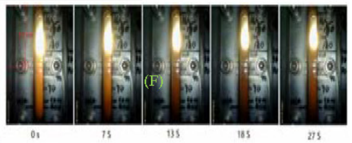


Fig.6 (E)Mechanism for hydrate sand production in the three production period, (a) the initial state of hydrate-bearing-sediments; (b) the fine sand production in the first production period; (c) hydrate decomposition and sand production in the second period; (d) the final state hydrate-bearing-sediments in the third production period. (F) The increase the sand carrying ability by water production at moment of stimulation operation. (S means seconds)

4. Conclusions

(1) Three hydrate production stages were observed; depressurization by drainage gas production, high gas production carrying liquids, and low gas production. The sand production of hydrate reservoir during production were mainly in the first two stages. Production of whole fine sand and sand grains was noted in the first and second stages, respectively, and no significant amount of sand was produced in the third stages. The sand rates and sizes in water were gradually increased with production process. The concept of sand prevention by grades and stages was put forward.

(2) Sputtering unique to hydrate decomposition may provide the driving force for sand migration. The flowing gas bubbles and water from hydrate decomposition enhanced the sand carrying capacity and reduced the strength of hydrate-sand cementation and skeleton solids, and conducted the sand production increasing.

(3) Increasing the gas production rates in hydrate fine sand reservoir would bring more water and sand. Thus, the critical flow rate of sand grain migration by gas flow carrying water should be considered. Increasing the gas production rate would increase of temperature drop and the possibility of ice phase formation, which would increase the wellbore ice plugging and the risk of blockage by secondary hydrate formation.

(4) From the experiments, the subsidence of hydrate-bearing-sediments could be over 10% with sand production. Thus, higher sand production led to the higher subsidence. The loss of crustal stress may increase the subsidence. The dynamic subsidence of the hydrate layers and sand production alter the seepage characteristics, thermal properties and material balance of the hydrate layers. The subsidence process was stable in depletion gas production mode. The subsidence of hydrate bearing reservoir is significantly correlated with hydrate saturation in reservoir. The reservoir pressure and gas production rate had significant correlation with reservoir sedimentation in depletion gas production mode, however the correlation was not significant in stable gas production mode. After the gas production, the stratum would still have slow settlement, but settlement rate was low and gradually stabilized.

(5) The stimulation operation in middle and late stages of hydrate mining would increase the risk of reservoir sand production and reservoir subsidence, because the increase gas production rates would increase the water production which increased the sand carrying ability, thus conducted the sand production in the hydrate cementation weakening reservoirs. Based on the experiments, we made the further discussed on the speculation of sand production in Japan's First marine hydrate production test in 2013 and thought that the stimulation operation after 4 days production was the cause of large scale whole sand production. For stimulation methods such as heat injection method and huff-puff method, it is necessary to balance the relationship between production capacity and sand production near wellbore. According to characteristics of sand production in hydrate exploitation, it suggested the layered at different granularity in different production stages sand prevention could be applied in the hydrate reservoir.

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