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Study on the mechanism of sand-carrying ability of gas well bore

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Abstract

The loose sandstone gas reservoirs at home and abroad are widely distributed, and there is more or less sand production. If the gas cannot carry the produced formation sand to the wellhead, the formation sand will accumulate at the bottom of the well, causing sand blockage. In this paper, the three-phase flow mechanism of gas, water and sand in the wellbore and the sand-carrying capacity of the gas well have been studied. The influencing factors of gas-liquid two-phase flow are studied through experimental methods, and by observing the phenomenon of sand-carrying suspension and settlement of gas wells and the flow pattern of gas-water two-phase flow, it is more intuitive to reflect the different influencing factors for gas wells impact. On the basis of two-phase flow, a three-phase flow experiment of gas, water and sand is carried out to study the influencing factors of sand carrying capacity, and the influence of water on the sand carrying capacity of gas wells under different conditions.

Keywords

Gas well bore; Sand carrying capacity; experimental method; mechanism research.

1. Introduction

Sand production in gas well wellbore is one of the more common problems in the process of gas production in loose sandstone gas reservoirs. To solve the problem of sand production in gas wells, gas well sand control can ensure normal production of gas wells, but many sand control methods can not achieve the expected results, especially For some weakly cemented rock layers, the phenomenon of sand production is more serious, and it is often impossible to completely control the sand after taking certain sand control measures. Therefore, the current gas wells generally carry out sand-carrying production. After entering the wellbore, if the gas flow reaches a certain value, the natural gas can carry the sand to the wellhead, and the high-speed two-phase flow of gas-sand will erode the surface equipment at the wellhead; if the flow is too low, the gas flow will not be able to carry the sand. , causing it to accumulate at the bottom of the well, causing serious accidents such as sand plugging of oil pipes, sand buried oil layers, and lying wells. For unconsolidated sandstone gas reservoirs, when the flow velocity of the reservoir fluid reaches a certain level, the sandstone near the wellbore or the bottom of the well is easily damaged due to its looseness, leading to sand production in the gas well.

The way the sand particles move in the wellbore fluid is related to the impact velocity of the fluid. When the fluid flow velocity is less than the free settlement final velocity of the sand grains, the sand grains exhibit a settling motion; when the fluid flow velocity is greater than the sand grains free settlement final velocity, the sand grains exhibit upward motion; when the fluid flow velocity is equal to the sand grains free settlement final velocity , the sand particles are in a suspended state, so the final sedimentation velocity of the sand particles can be regarded as the critical point of the sand-carrying capacity of the fluid. Based on the law of mixing motion of gas and liquid, this paper studies the gas-liquid-solid three-phase flow mechanism, and then discusses the sand-carrying capacity of water-producing gas wells. Methods The sand-carrying law of wellbore of water-producing gas wells was studied.

2. Research progress on sand-carrying capacity of gas wells

In the 1960s, some scholars put forward the theory of liquid-carrying in gas wells. Through experimental research, a large number of calculation models for calculating the critical liquid-carrying of gas wells were proposed, which can be divided into three categories: droplet model, liquid film model, and minimum kinetic energy model. In the 20th century, influenced by the development of computer research, many experts engaged in multiphase flow research gradually used numerical simulation methods to numerically simulate the gas-liquid-solid mixed flow law.

2.1. Numerical simulation of sand-carrying capacity of gas well boreholes

In recent years, with the development of computer technology, some researchers have begun to use numerical simulation methods to simulate the gas-liquid-solid three-phase flow in order to improve the design and develop new equipment. At present, the sand-carrying models of gas wells are mostly established based on the force analysis of sand particles or the results of laboratory experiments.

Wen Jianping et al. [1] used the quasi-homogeneous research method, regarded the solid as a part of the liquid, applied the gas and liquid flow model to the gas-liquid-solid three-phase flow, and added relevant parameters to adjust it. Take into account the inevitable connection of the interactions between phases. Mitra-Majundar D et al. [2] regarded solid particles as fluids with fluidity, and regarded gas, liquid and solid as fluids with the characteristics of mutual penetration, and deduced the three-fluid model. Wen Jianping [3] used the two-fluid model to express the interaction between gas and liquid according to the flow law of gas and liquid; and studied the trajectory law of solid in the Lagrange coordinate system, and coupled the influence of solid on gas and liquid. In the two-fluid model, the Eulerian/Eulerian/Lagrangian model is proposed. In 2011, Leidenson et al. [4] based on the liquid-solid two-phase steady-state flow theory, the flow regime was sequentially combined from a heterogeneous suspension flow plus a fixed bed or a fluidized bed to a single heterogeneous suspension flow. In 2018, Feng Wei et al. [5] studied the force of sand particles in a vertical wellbore based on the gas-solid two-phase flow theory, and established a mechanical model during the sand lifting process.

Scholars' theoretical research on the sand-carrying capacity of wellbore with moderate sand production mainly starts from the two-phase flow model, and studies the sand-carrying capacity of the wellbore by establishing a layered model. At present, there are few studies on the motion state of sand particles in the process of wellbore lifting, and the studies are rarely combined with practice.

2.2. Experimental study on sand-carrying capacity of gas well bore

In recent years, domestic and foreign scholars have carried out a series of experimental studies on the flow of wellbore carrying sand (cuttings). In 2014, Dong Changyin et al. [6] conducted a systematic experimental study on the gas-water-sand three-phase flow mechanism and gas-water sand-carrying capacity under different water-gas ratios and sand-containing volume fractions in vertical wellbores. In 2016, Dong Changyin et al. [7] proposed three characteristic flow rates of solid-liquid sand-carrying flow in the wellbore, namely hydrostatic settling velocity, suspension velocity and sand-carrying velocity, and gave their definition methods. In 2017, Gao Hong et al.[8] carried out the three-phase sand-carrying flow experiment of oil, gas and water based on a large-scale wellbore oil, gas, water, sand multiphase complex flow physical simulation experimental device, and analyzed the viscosity, liquid phase mainstream flow, and gas mainstream flow. The influence of other parameters on the wellbore pressure

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drop and sand carrying capacity. In 2018, Tong Shaokai et al. [9] designed a double-spiral hydraulic jet fracturing string, and conducted an indoor sand-carrying flow evaluation experiment using a visual experiment method. Zeng Sirui et al.[10] used the sand-carrying law simulation experiment device to conduct the wellbore inclination angle of 0°~90°, fluid viscosity of 1~50 mPa s, and particle size of quartz sand and ceramsite. The comparison experiment of wellbore sand-carrying flow velocity under the conditions of 0.08-0.4 mm and wellbore inner diameter of 40-100 mm, obtained the sensitivity relationship between sand-carrying flow velocity and fluid viscosity, particle size, particle density, wellbore inner diameter and sand-carrying flow velocity under different wellbore inclination angles. changing laws.

At present, scholars have done more research on liquid-carrying in gas wells, but few on sand-carrying in gas wells. The study of sand-carrying in gas wells plays a guiding role in production and secondary sand control. Theoretically, although the research on particle settling in static fluid and sand settling in simulated vertical wells has been quite complete, there is still a lack of research on the motion law under gas-liquid two-phase flow conditions, especially for the sand-carrying law in horizontal wells. Even less research.

3. Experimental analysis of sand-carrying capacity of vertical gas wells

3.1. Force analysis of sand particles

The way the sand particles move in the wellbore fluid is related to the impact velocity of the fluid. When the fluid flow velocity is lower than the free settlement final velocity of the sand grains, the sand grains exhibit a settling motion; when the fluid flow velocity is greater than the sand grains free settlement final velocity, the sand grains exhibit upward motion; when the fluid flow velocity is equal to the sand grains free settlement final velocity , the sand particles are in suspension. Therefore, the free sedimentation terminal velocity of sand particles can be taken as the starting point of the research, and the sedimentation terminal velocity of sand particles can be regarded as the critical point of the sand-carrying capacity of the fluid[11].

Because the natural gas is in a high temperature and high pressure state in the wellbore, the properties of the natural gas in the wellbore and the annulus are different from those under atmospheric pressure, so it cannot be simply studied according to the situation of liquid-solid two-phase flow. In the following, we will study the sand-carrying situation of natural gas in the gas well bore, and analyze the force of the sand particles.

It is assumed that the shape of the sand particles is an ideal spherical particle, and the individual sand particles do not interfere with each other. When the sand particles are lifted in the wellbore, the drag force F_R, the differential pressure force F_p and the buoyancy force Ff of the gas to the particles are the driving force, and the particle's own gravity F_g is the resistance [6].

The gravity, buoyancy, differential pressure and drag force of the sand particles are:

$$F_g = -\frac{1}{6}\pi d_p^3 \rho_p g \tag{1}$$

$$F_f = \frac{1}{6}\pi d_p^3 \rho_f g \tag{2}$$

$$F_p = \frac{1}{6}\pi d_p^3 \frac{dp}{dx} \tag{3}$$

$$F_R = \frac{1}{8}\pi d_p^2 \rho_f C_D \left| v_f - v_p \right| \left(v_f - v_p \right) \tag{4}$$

In addition to the above-mentioned forces, there may also be particle-to-particle and particle-to-pipe collision forces, but these forces are difficult to calculate. Therefore, in order to facilitate the research and consider the universality of the problem, some acting forces such as the

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additional mass force, Basset force, Magnus force, and Saffman force can be ignored according to the actual situation of sand carrying in the wellbore of gas wells.

3.2. Sand-carrying experiment and capability analysis of single-phase gas

The critical sand-carrying flow rate of single-phase gas wells is studied by experimental and theoretical analysis methods. The experimental method is to place the sand sample at the bottom of the simulated gas well, and observe and study the sand-carrying state and phenomenon of the gas phase under different gas flow rates. The experimental device is composed of an air compressor, a gas flow meter, a vertical wellbore plexiglass pipe section, a sand collecting tank, a sand adder, a camera, supporting pipelines and other accessories. The sand samples used are artificially prepared formation fine silt sand, quartz sand, ceramsite sand, etc., a total of 15 groups, and the particle size of the sand samples is between 0.05 and 0.9 mm.

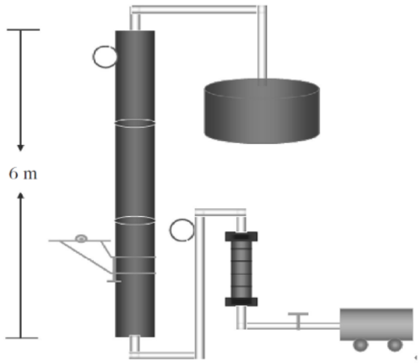

Fig.1 Schematic diagram of experimental simulation of wellbore sand carrying law

According to the experimental data, the relationship between formation sand particle size and critical sand-carrying flow rate and critical sand-carrying flow rate is obtained.

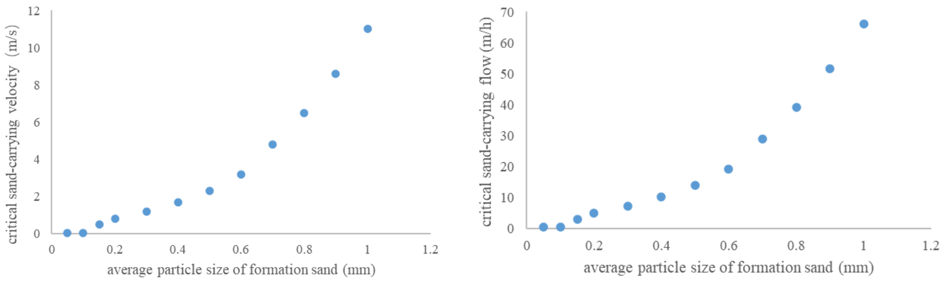

Fig.2 Relationship between critical sand-carrying velocity, flow rate and formation sand particle size

Under dry conditions without water, it is relatively easy for single-phase gas to carry sand, and the critical sand-carrying flow rate increases with the increase of sand particle size; for finer sand particles (<0.2~0.3 mm), the required critical sand-carrying velocity The flow rate is very low, and the critical sand-carrying flow rate is not very sensitive to the sand particle size; under the condition of coarse particle size, the critical sand-carrying flow rate increases significantly with the increase of particle size.

3.3. Experiment and mechanism analysis of gas-water two-phase carrying sand

For water-producing gas wells, gas-liquid two-phase flow occurs in the wellbore, and its sand-carrying mechanism is different from that of single-phase gas wells. 16 sets of gas-liquid two-phase fluid sand-carrying experiments were carried out. The sand-carrying phenomenon, flow pattern and mechanism of wellbore under water production conditions of gas wells are summarized. Mud-like flow occurs under the condition of very little water, and the flow pattern is the same as that of gas-liquid two-phase flow under other conditions. According to the observed flow pattern variation law, the sand-carrying law and influencing factors of water-producing gas wells are researched and summarized.

For the sand-carrying gas-liquid two-phase fluid in the case of water production, it is found through experiments that the water production amount or the water-gas ratio directly affects the flow mechanism and flow pattern. As the water-air ratio changes, the following phenomena and flow patterns will appear:

(1) Muddy flow: Under the conditions of very little water volume and very low water-gas ratio, the formation sand is unsaturated cement-like and sticks to the pipe wall. No matter how much air volume, it is difficult to carry.

(2) As the water-gas ratio increases, the water flow increases, and the formation sand is in a flowing state. The flow pattern changes basically follow the gas-liquid two-phase flow pattern: as the gas-liquid ratio increases, slug flow, annular flow and annular mist flow gradually appear.

(3) Bubble flow occurs only when the inlet pressure is high, but at this time, the flow is essentially non-gas, liquid-carrying and sand-carrying.

According to the experimental analysis of gas-water sand-carrying, the main influencing factors of sand-carrying in water-producing gas wells are as follows:

(1) Under the conditions of very little water and very low water-gas ratio, the formation sand forms muddy sticking to the pipe wall. It is difficult to carry even a large air volume (>10 m3/h);

(2) With the increase of water flow, the formation sand is in a flowing state, and the gas carrying liquid, liquid carrying sand, and wellbore sand carrying capacity depend on the liquid flow rate;

(3) Under the circumstance of the annular mist flow when the water vapor is relatively low, it is possible to carry sand only after the liquid-carrying condition is reached. Due to the low flow velocity of the annular liquid flow on the pipe wall, it is difficult to carry sand and the amount of sand carried is low;

(4) The water-gas ratio is extremely high, and a large amount of sand can be carried only under the condition of gas-liquid slug flow;

(5) Compared with pure gas wells, the water production of gas wells is not conducive to carrying sand. After the gas well produces water, the critical sand-carrying gas production is significantly higher than the critical liquid-carrying gas production.

4. Conclusions and recommendations

(1) In the single-phase gas sand-carrying experiment, the critical sand-carrying flow rate increases with the increase of sand particle size; for finer sand particles (<0.2~0.3 mm), the required critical sand-carrying flow rate is very low, and the critical sand-carrying flow rate is very low. The sand-carrying flow rate is not very sensitive to the sand particle size; under the condition of coarse particle size, the critical sand-carrying flow rate increases significantly with the increase of particle size.

(2) From the gas sand-carrying experiment in the static water state, it can be concluded that when the gas flow rate is small, a small amount of liquid exists, and the solid-liquid two phases form a muddy mixture, which is not conducive to gas-carrying sand; when the gas flow rate is large, the The carrying ability of gas to sand depends on the carrying ability of gas to liquid; the carrying ability of gas to sand has obvious relationship with the ratio of solid to liquid;

(3) Pure gas wells that do not produce water are relatively easy to carry sand, and it is not conducive to wellbore sand carrying after gas wells produce water. For water-producing gas wells, it is almost impossible for the wellbore to carry sand under the condition of extremely low water-gas ratio; sand-carrying in the wellbore becomes more and more easy with the increase of water-gas ratio, but it is more difficult to carry than when no water is produced. The sand conditions are harsh.

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(4) Different from the vertical section, the horizontal section is a variable mass flow. Due to the formation inflow, the wellbore velocity gradually increases from the toe end to the heel end. Studying the fluid velocity distribution in the horizontal section is helpful to understand the sand-carrying dynamics of the horizontal section.

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