Research Journal of Applied Sciences, Engineering and Technology 6(2): 320-324, 2013
DOI:10.19026/rjaset.6.4080
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: October 31, 2012 Accepted: December 22, 2012 Published: June 10, 2013

Research Article

Design and Test of Drilling and Completion Experimental System with Supercritical Carbon Dioxide

[1]Du Yu-Kun, [1]Wang Rui-He, [1]Ni Hong-Jian and [2]Yue Wei-Min
[1]School of Petroleum Engineering, China University of Petroleum, Qingdao, 266580, China
[2]Beijing Institute of Exploration Engineering, Beijing, 100083, China

Abstract: Supercritical Carbon dioxide (SC-CO_2) has many excellent properties, such as high rock-breaking efficiency, strong dissolved performance and good displacement efficiency. It is a high-efficiency fluid to exploit coal-bed methane, shale gas, heavy oil, low permeability reservoirs and other unconventional oil and gas reservoirs. Using SC-CO_2 jet to break formation rock assisted the drill bit can get several times the penetration rate of conventional drilling and effectively enhance the oil recovery while achieving an initiative reduction of greenhouse gas by storing the CO_2 underground in the proper unconventional reservoirs. The functions and process of drilling and completion experimental system are designed based on the SC-CO_2 fluid properties and the actual operation conditions. Tests find that the remote control of the system is reliable, pressurization process is steady, sealing and operating performances are excellent. The system can effectively simulate the actual drilling and completion process with SC-CO_2. The rock-breaking performance of SC-CO_2 is much better than high pressure water jet which verifies the application superiority of SC-CO_2 in rock-breaking drilling. The research lays basis for the development of SC-CO_2 drilling and completion technology.

Keywords: Carbon dioxide, completion, drilling, supercritical

INTRODUCTION

Current oil and gas exploration and development gradually shifts from integrated, high pressure, high permeability, good homogeneous oil field to the complex fault-block, low permeability, heavy oil, pressure failure reservoirs as well as shale gas, coal bed methane and other unconventional oil and gas resources. Development of new technologies to improve the exploration and development efficiency of oil and gas and ensure our energy security becomes much urgent in the current international energy situation.

SC-CO_2 has low viscosity, strong diffusion and solubility and good flow, infiltration and transmission properties (Faisal *et al*., 2009). Research found that using SC-CO_2 jet to break formation rock assisted the drill bit can not only get several times the penetration rate of conventional drilling (Kolle, 2000a), but also greatly reduce the interfacial tension, improve the mobility ratio, enhance the oil and gas discovery and recovery in the drilling and completion process (Xu *et al*., 2007). SC-CO_2 drilling and completion technology can achieve high Rate of Penetration (ROP) and meet the underbalanced condition to effectively protect the reservoir, have both advantages of efficient access to oil and gas resources and energy saving (Jiang *et al*., 2007).

However, most existing study remains in the feasibility study stage and is lack of basic experimental equipments, so the SC-CO_2 drilling and completion experimental system is developed in this study (Wang *et al*., 2011) based on the SC-CO_2 fluid properties and drilling and completion operating conditions and lays the foundation for the development of SC-CO_2 drilling and completion basic theory and technology.

METHODOLOGY

Function design: Reservoir protection drilling and completion technologies have been proven to be technical means which can effectively improve the ultimate recovery of unconventional oil and gas reservoirs. Study found that the density of SC-CO_2 is similar to liquid, viscosity and diffusion coefficient is similar to conventional gas, therefore, it has good flow, infiltration and transmission properties, small surface tension and good mass transfer property. SC-CO_2 drilling and completion technology can realize the initiative emission reduction of greenhouse gas during the exploration process (Suehiro *et al*., 1996; Bert, 2005) so that it is a reservoir protection drilling and completion fluid with great application potential. Louisiana State University hasstudied the feasibility of SC-CO_2 underbalanced drilling (Gupta, 2005), Tempress Technologies Inc proposed a SC-CO_2

Corresponding Author: Du Yu-Kun, School of Petroleum Engineering, China University of Petroleum, Qingdao, Shandong, 266580, China, Tel.: 18678417793

Fig. 1: SC-CO_2 drilling and completion experimental system

coiled tubing drilling program (Kolle, 2002) and conducted exploratory test which found that SC-CO_2 drilling fluid can increase the ROP (Kolle and Marvin, 2000b) and promote the development of SC-CO_2 drilling technology. However, most existing study remains in the feasibility study stage and is lack of basic experimental research equipments, so the SC-CO_2 drilling and completion experimental system is developed based on the SC-CO_2 fluid properties and drilling and completion operating conditions as is shown in Fig. 1. The system can be used to carry out the wellhole fluids flow characteristics analysis and SC-CO_2 jet rock-breaking experiments. The cuttings-carrying, formation fracturing and reservoir flooding effect of SC-CO_2 fluid can also be studied by selecting appropriate simulation wellbore and the experimental study covers the drilling and completion field.

Process design: The experimental system takes a modular design approach in the design process which is divided into several units such as storage unit, pressurization unit, heating unit, wellhole unit, separation unit and cooling unit, in which the wellhole unit can be replaced to effectively simulate SC-CO_2 jet drilling, completion and other exploration and development process (Liao *et al*., 2002; Wang, 2008).

The experimental process is as shown in Fig. 2. There are sufficient liquid CO_2 stored in the CO_2 storage tank before the test, the requirement pressure can be met after the booster pumps pressurizing (the No. 1 booster pump can pressurize to 100 MPa, the No. 2 booster pump can pressurize to 50 MPa, the two pumps may run separately or in parallel according to the test requirement, the fluid can be modulated to 50 MPa and 125 L/min in parallel). The fluid flows into the simulation wellbore after heating to the test requirement temperature through the heater (maximum temperature to 120°C). The test fluid flows out of the simulation wellbore after acting on the simulation core, it first passes through the solid separator in which the cuttings is removed and then flows through the liquid separator in which the water vapor is removed and finally the pure CO_2 fluid is cooled down to storage tank temperature by the refrigerator and returns to CO_2 storage tank.

Experimental apparatus:

Storage tank of carbon dioxide: The CO_2 storage tank is designed to maintain CO_2 in liquid state before the booster pumps and is adequate for experimental process. If fluid CO_2 in the tank is insufficient, the pipeline cycle will delay, the tank pressure will reduce and even lead to the phase change, so the liquid CO_2 storage tank requires enough volume to meet the normal cycle of the system which is designed to 200 L which is greater than all the pipeline and cavity volume. Three sets of overvoltage protection devices include the safety valve, solenoid valve and overpressure rupture disc are installed on the tank to ensure the safety of the system. The principles are automatic machine control, signal control and overpressure unrecoverable blast respectively, a small refrigerator is used to cool the tank to maintain the CO_2 in liquid state.

Booster pumps: The variable speed piston pump is selected as a power source to modulate continuously the SC-CO_2 flow combined with the existing SC-CO_2 extraction pump features. In addition, the cooling equipment is installed around the pump head to further

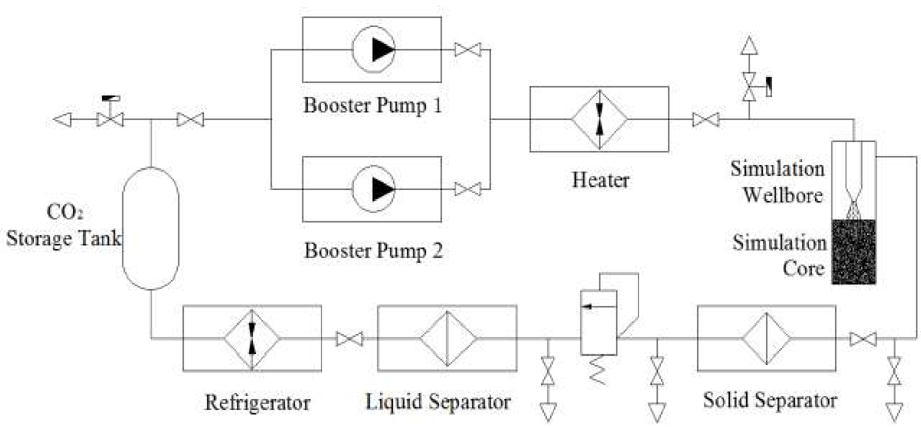

Fig. 2: Flow chart of experimental system

ensure the normal operation and steady pressurization of pumps and the liquid CO_2 condensed before the pumps will not regasify for the friction and heat of pistons which may result in pressurization not smooth.

The threshold pressure of common formation rocks during drilling process is as shown in Table 1. The maximum output pressure of booster pump is identified as 100 MPa for a comprehensive effect study of SC-CO_2 on different rocks, while the system maximum output flow is preferred as 125 L/min in order to meet the need of SC-CO_2 completion tests.

Heat exchanger: CO_2 in the drill pipe can be converted to supercritical state in about 800 m well depth during the actual drilling and completion process due to the influence of the formation temperature. The heater is developed to effectively simulate actual drilling and completion working conditions by which the CO_2 phase in the simulation wellbore can be adjusted among liquid, supercritical and gaseous states. The design heating power is 114 kW according to the flow calculation and heating temperature requirement. Because the temperature of CO_2 fluid is very high after flowing out of simulation, it needs to be cooled down to liquid state and returns the storage tank to ensure the recycle of whole system, so the refrigerator unit is developed whose thermal power is also 114 kW. The volume of heater and refrigerator are both designed to 4000 L.

Simulation wellbore: The simulation wellbore can adjust fluid parameters, jet structure and bottom-hole parameters in a wide range so as to effectively simulate the actual conditions as shown in Table 2.

The SC-CO_2 jet rock-breaking simulation wellbore as shown in Fig. 3 is a core component of the experimental system, mainly includes the bottom-hole environment simulation unit, jet time control unit, pressure & temperature control unit and data acquisition unit. Bottom-hole environment simulation unit can adjust the ambient pressure, pore pressure and formation parameters such as formation temperature

Table 1: Threshold pressure of formation rocks

Rock type	Threshold pressure (MPa)
Most hard sandstone	137
Marble, dolomite	98
Limestone, sandstone	78
Sandy shale, bedded sandstone	58
Hard clay shale	39

Table 2: Wellbore adjustment parameters

Parameters	Adjustment range
Pump pressure	0~100 MPa
Pump flow	0~125 L/min
Fluid temperature	0~120°C
Jet distance	0~50 mm
Bottom-hole pressure	0~20 MPa
Bottom-hole temperature	0~120°C
Formation ambient pressure	0~40 MPa
Formation temperature	0~120°C

which effectively simulate the bottom-hole actual working conditions. Jet time control unit can precisely control the jet rock-breaking time through the baffle controller. Pressure and temperature control unit can effectively control the pressure and temperature of SC-CO_2 in the experimental process. Data acquisition unit can real-timely collect test data and control the test process correctly.

The simulation wellbore adjusts the jet standoff distance through the continuous adjustment the axial position of the nozzle. The jet nozzle includes the forms of direct jet, swirl jet, pulse jet and abrasive jet. The wellbore pressure is adjusted by controlling the opening pressure of the back pressure valve (5~10 MPa) and the ambient pressure around the simulation core is applied by pressurized to the plastic tube. The pressure and temperature test points at the bottom radial, wellbore axial and rock wall are used to measure the flow state in the wellbore and the propagation law in the core.

Solid separator: The cuttings carried out of the simulation wellbore after SC-CO_2 jet breaking rock should be timely and effectively separated in order to ensure the normal operation of the circulatory system. One kind of cyclone separator is designed according to the characteristics of fluid medium and impurities

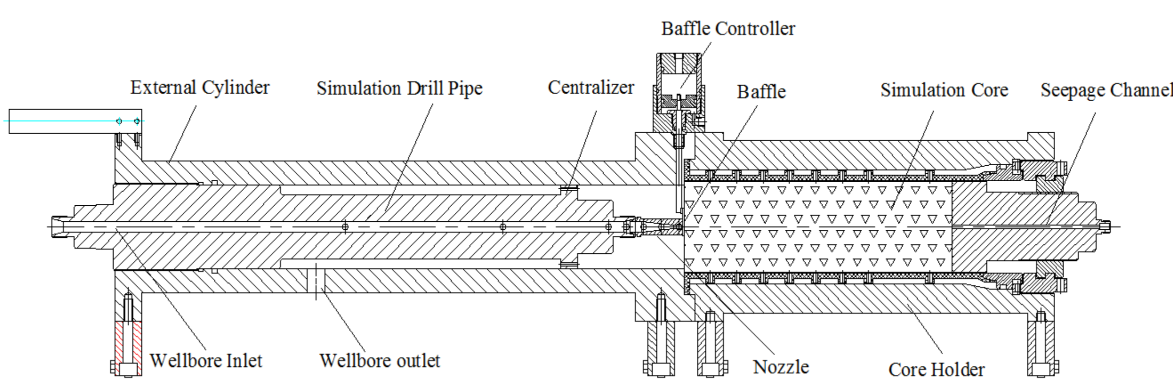

Fig. 3: Simulation wellbore

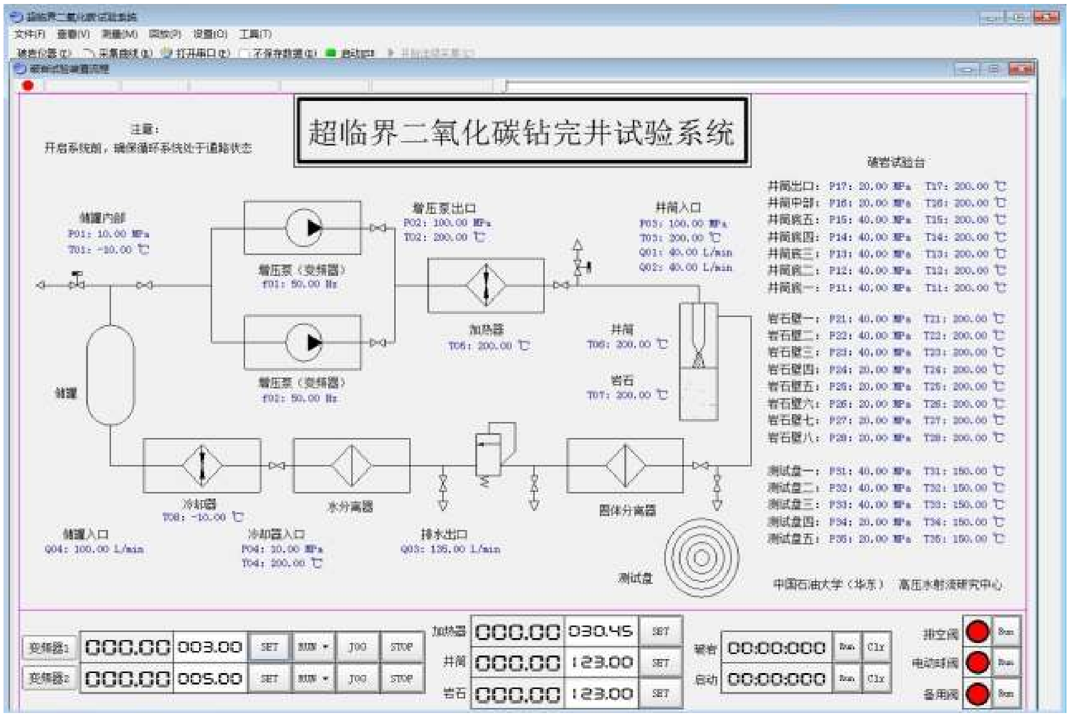

Fig. 4: Data acquisition and control system

required to be separated. Multi-layer filters are installed at the exit of cyclone separator to ensure the separation accuracy. The collector is installed at the separator bottom to accurately measure the solid quality.

Liquid separator: The water exists in simulation core and air can be brought into the circulatory system during the experiment, the hydrate or ice will form if it is combined with CO_2. Then the circulatory system will not operate normally while the pipe plugged, or even accidents may happen. Therefore, the water in CO_2 fluid is separated using adsorption means in this circulatory system. The silica gel is selected as the desiccant which does not affect the stability of CO_2.

Data acquisition and control system: A data acquisition and control system is developed as shown in Fig. 4 because there are 86 groups of parameters needed to be tested, stored and analyzed as well as eleven equipments to be controlled in the SC-CO_2 drilling and completion experimental system. The system can remotely control the experiment process and carry out real-time data acquisition and storage to ensure safe and orderly conduct of the experiment and the validity of data analysis.

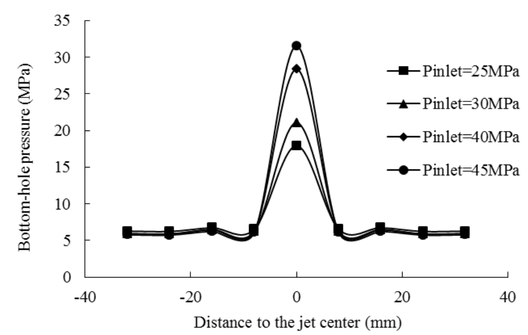

Fig. 5: Test of bottom-hole pressure

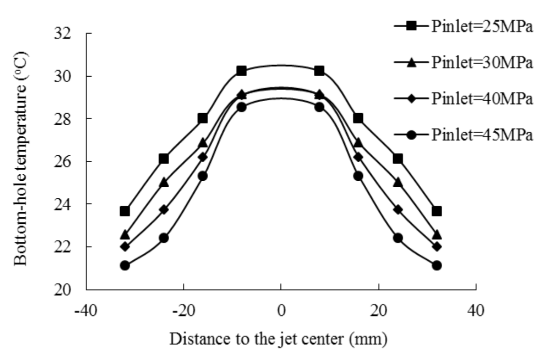

Fig. 6: Test of bottom-hole temperature

TEST OF SYSTEM

The SC-CO_2 wellbore flow and rock-breaking properties are carried out to test the performance of the SC-CO_2 drilling and completion experimental system. Take the bottom-hole radial test results for example, the radial pressure and temperature distribution on the bottom-hole are shown in Fig. 5 and 6 when the fluid temperature at the wellbore inlet is 70°C, direct jet conical nozzle diameter is 2 mm and standoff distance

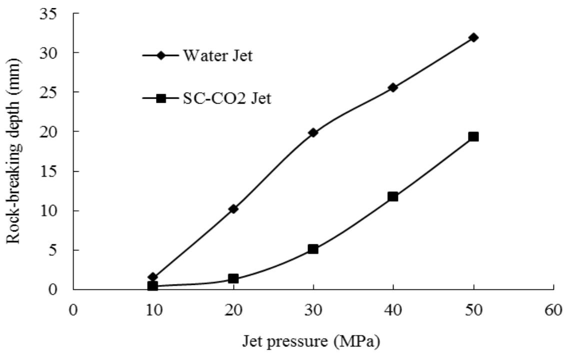

Fig. 7: Comparison with water jet

4 mm. Results found the bigger the pressure at the wellbore inlet is, the higher pressure and lower temperature at bottom-hole will obtain, but the greater pressure consumption and temperature drop will take place during the jet process. The reason is that the fluid speeds up when the pressure at the wellbore inlet grows larger, the fluid phase changes dramatically during the jet process and the role of phase change is much severer while the initial pressure of fluid is bigger. The pressure and temperature quickly releases during the phase change process and the internal energy can be converted into a large number of rock-breaking energy in the jet impact process.

High pressure water jet assisted mechanical rock-breaking technology has become an important ROP-increasing method. SC-CO_2 jet rock-breaking experiments are carried out compared with water jet to test the rock-breaking performance of this now drilling and completion fluid as shown in Fig. 7. Results found the rock-breaking performance of SC-CO_2 is much better than high pressure water jet which verifies the rock-breaking drilling superiority of SC-CO_2.

CONCLUSION

The SC-CO_2 drilling and completion experimental system is developed based on the SC-CO_2 fluid properties and actual conditions. The CO_2 storage tank, heat exchanger, experimental wellbore, solid separator, liquid separator and other equipment are designed and calibrated.

The wellbore flow properties and rock-breaking experiments are carried out and results found that the pressure and temperature of CO_2 fluid rapidly release with the phase change during the jet process. The rock-breaking performance of SC-CO_2 is much better than high pressure water jet.

Results found that the remote control of system built is reliable, pressurization process steady, sealing and operating performance excellent. The research provides important basis for the development of SC-CO_2 drilling and completion technology.

ACKNOWLEDGMENT

Financial supports from the Natural Science Foundation of China (50974130/51034007), the Major State Basic Research Development Program of China (2010CB226700), the excellent PhD thesis training fund of China University of Petroleum and the Fundamental Research Funds for the Central Universities of China (11CX06021A) are greatly acknowledged.

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