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Research & Development of Core Equipment for CO_2 Fracturing Technology

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ABSTRACT

CO_2 fracturing is an important measure to realize the implementation of the "carbon neutralization" policy characterized by carbon recycling. Conventional fracturing equipments is difficult to meet the technical requirements of CO_2 fracturing, so it is necessary to promote the promotion and application of this technology through the research and development of core equipment. In combination with the technical characteristics and the special nature of CO_2, The core equipment with completely independent intellectual property rights - CO_2 closed sand-mixing device and N_2 pressurization device have been developed successfully, which solved the problems of CO_2 closed sand-mixing and displacement & fluid supply".With the steady progress of the "dual carbon policy", the core equipment for large-scale CO_2 fracturing with large sand volume and sand ratio needs to be developed urgently. This article introduces the development direction of the core equipment from two aspects: closed continuous sand mixing technology and CO_2 gasification pressurization technology. The successful development of these two core technologies will greatly promote the industrial application of CO_2 fracturing technology in the future.

Keywords:CO_2, fracturing, core equipment, gasification, displacement & fluid supply

1. INTRODUCTION

Most countries or economies in the world have set carbon neutrality or net-zero emissions targets. China will achieve its carbon peak by 2030 and carbon neutrality by 2060. Now, CO_2 has become the main technical approach for implementation of the carbon neutrality plan in oil fields due to its advantages in fracturing technology, such as no residue, no water lock, strong fracture conductivity, short drainage cycle, water conservation and environmental protection, and permanent storage[1-2], and it will be more widely used in the future.

With acceleration of development process of domestic oil and gas fields, there is an urgent demand for CO_2 fracturing technology. Since 2020, the amount of CO_2 injection into reservoirs for fracturing in Changqing Oilfield has been increased year by year, and it is expected to reach 120000m^3 in 2023.The domestic CO_2 fracturing technology has gone through three development stages: CO_2 energized fracturing, foam fracturing and dry fracturing. It is impossible to resolve the problems about "CO_2 closed sand-mixing" and "displacement & fluid supply" due to lack of core equipment before 2006. Now it is necessary to carry out continuous research on CO_2 fracturing equipment[3].

2. CO_2 CLOSED SAND-MIXING DEVICE

As the core equipment of CO_2 dry sand fracturing technology, the CO_2 closed sand-mixing device is to mix the proppant and liquid CO_2 with a certain ratio under pressure and lower temperature in closed enviorment and transport the mixture to the fracturing truck. This equipment has been monopolized by foreign technology for a long time and is not sold to the outside world, which has become one of the bottlenecks restricting the development of CO_2 dry sand fracturing technology in China. Through years of tackling key problems, we have overcome many difficulties such as low temperature, pressure, dynamic sealing, sand ratio control, etc.[4]. In 2016, we successfully developed the type II product,

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and formed a CO_2 closed sand-mixing device with independent intellectual property rights.

2.1 Technical principle

In the CO_2 dry sand fracturing process, pure liquid CO_2 is used as the fracturing base fluid. In view of the problem that the conventional sand mixing device cannot add proppant to the liquid CO_2, the normal temperature proppant is pre-installed in the CO_2 closed sand-mixing device in advance, and the spiral sand adding method is adopted by designing the transmission screw in the device [5], The proppant pre-installed in the device is mixed with liquid CO_2 under closed conditions, and the amount of proppant is controlled by controlling the rotation speed of the sand conveying screw, so that the sand concentration in the main line meets the requirements of the construction process.

2.2 Technical characteristics

2.2.1 Long overhang, floating spiral sealing technology

Because the horizontal structure is adopted in CO_2 closed sand-mixing device, and the sand conveying screw is arranged at the bottom of the tank, so the spiral suspension length is large, and it is easy to deform due to the pressure of the upper proppant. In view of this harsh working condition, a new type of sand conveying screw with a new structure is designed. Combining, the "O" ring and slip ring combined seal is adopted, The sand conveying screw has good sealing performance and reliability under the condition of long suspension.

2.2.2 Stable sand transportation technology with high sand ratio

The device adopts double screw, double motor and double sand outlet symmetrical design. The sand conveying screw penetrates the whole horizontal sand mixing tank of the device, and the sand conveying has no dead angle. With low speed and large torque stepless speed regulation motor, the sand ratio can be accurately controlled, the length of single screw can be reduced, and the sand conveying speed and smoothness of the device can be improved

2.2.3 Hand-auto integrated centralized control technology

Multi-channel design can control both single device and multiple devices at the same time, monitor the operation status of the device , and realize the main process flow through the switch control of each electric valve group; According to the feedback of the proppant concentration in the pipeline in the monitoring system, the rotation speed of the sand conveying screw is automatically adjusted in real time to achieve accurate control of the proppant concentration in the pipeline.

2.3 Structure and parameters

The horizontal tank structure (as shown in fig 1) is mainly composed of tank assembly, manifold system, power system, control system, screw conveying system, etc. It has the functions of heat preservation, pressure bearing, sand transportation control, flow measurement and sand concentration detection. The specific parameters of CQ-MH-20-18 device are shown in table 1.

Fig. 1. Type II CO_2 closed sand-mixing device

Table. 1 CQ-MH-20-18 device Parameters

Working medium	liquid CO_2 and proppant
Design pressure (MPa)	3.5
Rated working pressure (MPa)	3.5
Total volume (m^3)	20
Maximum sand volume (m^3)	15
Maximum sand conveying speed（m^3/min）	1.0

2.4 Field application

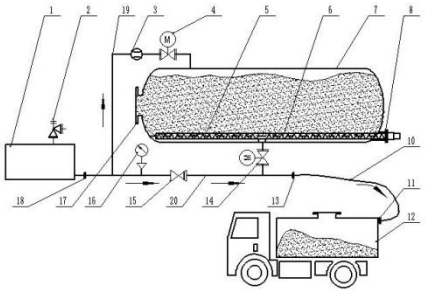
The CO_2 closed sand-mixing device has been applied in 17 wells in Changqing Sulige Gas Field and Yanchang Oilfield, with cumulative time of safe operation reaching 2370 minutes and accuracy of sand ratio control over 95%. The best performance for this technology: maximum well depth 3352m, maximum volume of sand injection for single layer 30m3 , maximum average sand ratio 15.3%, and maximum instantaneous sand ratio 25%(table 2).

In view of the problems of the existing manual sand cleaning method, such as poor working conditions, high labor intensity and slow sand cleaning speed, an automatic sand cleaning system is designed for the device. The gas-driven sand cleaning method is adopted. The CO_2 closed sand-mixing device is not only the sand cleaning object but also the sand cleaning tool (as shown in Fig 2). The air compressor provides the sand cleaning power, and the sand cleaning pipeline is used as the sand cleaning channel, forming a positive pressure in the device, which plays the role of gas drive for the ceramsite

Table 2 Field Application of CQ-MH-20-18 Device

number	displacement (m^3/min)	Sand volume(m^3)	Average Sand ratio(%)	Liquid volume(m^3)	Milestone nodes
1	3.0	9.6	7.9	350.5	large-scale on-site testing
2	4.0	10.0	4.5	385	The first land-based shale gas well
3	4.2	5.0	4.1	217.6	The first fixed string layered CO_2 dry sand fracturing well
	4.5	8.8	5.2	244.2	
4	4.0-6.0	30	15.3	413	Refresh records of single well,single layer sand addition volume and sand ratio

sand in the tank, Realize efficient automatic sand cleaning and greatly reduce the labor intensity of sand cleaning.



1. Air compressor; 2. Safety valve; 3. Flow meter; 4. Pressure compensating valve; 5. Reverse blade; 6. Positive blade; 7. CO_2 closed sand-mixing device; 8. Sand conveying spiral; 10. Wear-resistant transparent tube; 11. 13, 18. Quick connector; 12. Sand tanker; 14. Sand outlet valve; 15. Check valve; 16. Pressure sensor; 17. Manhole; 19. Make-up pipeline; 20. Sand cleaning pipeline

Fig. 2. Flow of automatic sand cleaning system

3. N_2 PRESSURIZATION SYSTEM

In the early application of CO_2 fracturing technology, conventional CO_2 transport tanker and CO_2 booster pump truck are used as the fluid supply combination equipments of the fracturing truck. Through the field test of multiple wells in the early stage, it is found that there are two problems in this way of liquid supply:

(1) The pumping effect of booster pump truck and pipeline friction lead to serious gasification of liquid CO_2 in the ground liquid supply pipeline[6], leading to the fracturing truck emptying the pump; The displacement is difficult to increase and extremely unstable, which is easy to cause sand plugging [7].

(2) In order to ensure that the liquid level in each tank car drops at the same speed, each tank car must be manually operated by a specially-assigned person, which greatly increases the risk factor and coordination difficulty of on-site construction.

In view of the above problems, through research and development of N_2 pressurization technology, the development of special N_2 pressurization device, the development of automatic liquid supply control system, and the formation of a complete set of liquid supply system have completely solved the problem of liquid supply in CO_2 fracturing construction.

3.1 System structure

3.1.1 N_2 pressurization device

In response to the problem of vaporization of liquid CO_2 during fracturing, a N_2 pressurization device suitable for CO_2 fracturing is developed through the integration of technology such as tank pressure and liquid level centralized control, which has effectively increased the displacement and ensures that the fracturing truck can receive continuous and stable liquid supply(fig 3).

Fig. 3. N_2 pressurization device

3.1.2 High-efficency surface liquid supply system

The system consists of five parts: CO2 storage system, N2 pressurization system, closed sand-mixing system, tackifier injection system and high-pressure injection system.Equipped with N_2 pressurization system, high-power pump truck, CO_2 storage tanks and other equipment to ensure liquid CO_2 supply during high

displacement operation and improve utilization efficiency of liquid CO_2.

High-efficency surface liquid supply system mainly including the gas booster manifold (as shown in the blue line in Figure 4) and the upper liquid manifold (as shown in the green line in Figure 4). The medium in the gas pressurization manifold is energy increasing gas, which pressurizes the CO_2 storage tank in parallel; The medium in the upper liquid manifold is liquid CO_2, which supplies fluid for the fracturing truck.

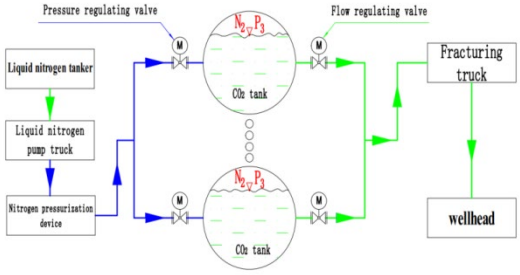


Fig. 4. High-efficency surface liquid supply system

3.2 System functions

3.2.1 Booster function

It is the N_2 pressurization device that pressurizes the CO_2 storage tank by using the stable physical characteristics of the energy increasing gas, so that prevents the fracturing truck from running out of pump due to gasification during the transportation of liquid CO_2 from the storage tank to the fracturing truck; N_2 is used to displace the liquid CO_2 in the CO_2 storage tank, so that the fracturing truck can get continuous and stable liquid supply.

3.2.2 Stable liquid supply

(1) Collect the pressure parameters of each CO_2 storage tank, and automatically control the opening of the output pressure valve based on the CO_2 storage tank with the largest pressure value to stabilize the maximum pressure within a certain range.

(2) The system collects the liquid level parameters of each CO_2 storage tank, and controls the flow regulating valve of the CO_2 storage tank to the appropriate opening through calculation and comparison to ensure that the liquid level of each storage tank decreases synchronously .

(3) The control system will transmit the collected electrical parameters of the device, the pressure and liquid level of the CO_2 storage tank to the instrument car.

3.3 Field application

The high-efficiency surface liquid supply system has been applied for over 50 layers on wellsite in Changqing area, Yanchang Oilfield, Southwest Oil and Gas Field, etc. After continuous improvement and optimization, the optimal solution has been found, which integrates N2 pressurization device , tank level and pressure control, and surface liquid supply system. In 2022, it was used in 26 layers with a total injection of nearly 2600 cubic meters of liquid CO_2

(1) Liquid supply capacity: increased from 3.5m^3/min to over 6m^3/min.

(2) Cooling efficiency: Reduce cooling time by 20 minutes and reduce CO_2 consumption by 30m^3.

(3) Scope of application: It can be applied to CO_2 dry sand fracturing, foam fracturing and pre energy boosting fracturing.

4. DEVELOPMENT TREND OF CORE EQUIPMENT

The CO_2 fracturing technology of CCDC has reached the international leading level. Leading the development of techology as engine of development, we will continue to conduct independent core technologies and equipment research, founding sulutions for improving operational capabilities and reducing operational costs and preparing for its widespread use in the future.

The proppant is filled into the CO_2 closed sand-mixing device before construction, the device is pressurized with gaseous CO_2 until the pressure of the sand mixing tank is the same as that of the CO_2 storage tank, and then the device is filled with liquid CO_2(-20℃). The low temperature liquid CO_2 enters the device with normal temperature proppant, and the proppant is cooled by liquid CO_2 to the same temperature as liquid CO_2, After the preparation, the following two problems need to be solved for "closed sand-mixing technology" to "continuous sand-mixing technology":

(1) The proppant at atmospheric pressure is in the process of continuous addition and continuous pressurization, and there is no separate step to pressurize the proppant in advance, so how to realize the solid particles from atmospheric pressure(0MPa) to high pressure (8MPa-13MPa) is the key technical problem to be solved urgently.

(2) CO_2 closed sand-mixing technology cannot achieve continuous cooling. After the problem of continuous transportation of proppant from normal pressure to high pressure is solved, the high pressure and normal temperature proppant needs to be continuously cooled to the same temperature as liquid CO_2. Due to the continuity of the whole process,how to make solid particles continuously and rapidly cool from normal temperature (25 ℃) to low temperature (- 20 ℃) is also a key technical problem to be solved urgently.

5. CONCLUSIONS

(1) The CQ-MH-20-18 CO2 closed sand-mixing device can meet the requirements of CO2 dry sand fracturing and closed sand injection. The maximum sand injection capacity of one unit is 15m3, and the maximum sand conveying speed is 1 m^3/min.

(2) The N_2 pressurization device can meet the demand for stable fluid supply with high displacement during CO2 fracturing, and the maximum displacement during operation can reach over 6m3/min.

(3) High-efficiency surface liquid supply system can effectively improve operation efficiency and liquid CO2 utilization efficiency.

(4) CO2 fracturing technology has a significant effect on the stimulation of unconventional oil and gas reservoirs such as tight gas, shale gas and coal-bed gas, and on their clean and efficient development, the CO2 storage rate exceeds 40%, so it has broad application prospects.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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