Segment Milling Technology in Field Application and Optimization of Gas Storage

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Abstract. This paper mainly introduces the application and optimization of segment milling technology in the old well plugging project of H gas storage. Based on the analysis of mud properties, segment milling tool structure, and optimization of construction technology. It ensures the safe and efficient completion of the plugging work of HU2010 well, and opens up a new field for the safe and effective operation of the technology in H gas storage.

1. Introduction
Segment milling is a technology that uses segment milling tools to cut the casing from the predetermined position, and then mill the casing for a segment. In the early stage of segment milling technology, the window is mainly opened in the process of sidetracking. With the maturity of segment milling technology, the application field is gradually expanding. In the old well plugging, segment milling a segment of casing and sweeping away the cement outside the casing, and then replugging the segment milling well, so that the cement directly contacts with the formation, achieving a better plugging effect [1].

The key technology of HU2010 well is casing segment milling plugging, and the segment milling length is required to be at least 35.0m. Through technical improvement, process optimization, and parameter control in the process of process implementation, the well plugging was completed successfully, and the long-term safe operation of H gas storage was ensured.

2. Process principle of segment milling
When the casing segment miller is lowered to the predetermined position, the rotary table is started first, and then the pump is started. At this time, the mudflows through the piston nozzle to produce a pressure drop, and the pressure pushes the piston downward so that the piston rod pushes the blade outward, and the blade gives a transverse force to the casing wall to cut the casing. When the casing is cut off, the blade gradually expands outward, and finally reaches the maximum limited position. At this time, the casing segment milling can be carried out under pressure. After the completion of the construction, stop the pump and wait for the pressure drop to disappear, the piston will reset under the action of the return spring. The blade will be retracted back into the tool slot by its own weight and external force, and then stop the rotary table for tripping operation [2].
3. Technical difficulties of segment milling

3.1. Basic information about gas well
HU2010 is a development well with a finished drilling depth of 3710.0m. At present, the artificial bottom hole is 3695.0m.

1) In the 664-2368.0m segment, the casing wall thickness changes, and the casing is corroded to a certain extent.
2) The damage and deformation of 3418-3440m casing are serious.
3) Through gadolinium neutron logging, there are channeling channels between the perforated layer and its upper and lower water layers.

According to the technical requirements of the old well plugging in the gas storage, it is determined that the segment milling process is adopted to implement the plugging operation.

**Figure 1.** Well structure

**Figure 2.** Engineering log interpretation diagram
3.2. Technical difficulties
1) The well is 139.7mm * 9.17mm casing, and the milling footage is 35.0m. It belongs to slim hole segment milling of medium-deep well. The well segment is relatively long, which is prone to downhole complications.
2) The casing steel grade is P110. The high steel grade requires high quality of segment milling tool body and cutter.
3) The production time of this well is more than 10 years. The casing deformation is serious, which brings difficulties to segment milling.
4) It is the first time that segment milling technology is applied to gas wells in H oilfield, which needs to be explored in mud performance, tool adaptability, field technical parameter control, and effect evaluation.

4. Optimization of segment milling process

4.1. Mud performance optimization
According to the technical requirements of segment milling, the mud density is 1.15g/cm³, the viscosity is 90-120s, and the dynamic cutting is kept above 18. However, in the process of segment milling operation, it is found that the fluidity of high viscosity mud is poor, which is easy to cause the blockage of casing segment Miller and cause the construction complexity. During segment milling, the viscosity of mud is gradually reduced. It is found that when the viscosity is 70-80s, it can meet the requirements of carrying iron chips and enhance the fluidity of mud. Therefore, the viscosity of mud is selected between 70-80s in the later segment milling operation.

4.2. Tool structure optimization

4.2.1. Optimization of pressure drop generation mode. When the drilling tool in HU2010 well was lowered to the window opening position, it is not possible to open the pump and wash the well. There was a problem with the structure of the segment mill. The throttle needle was in the inner diameter of the piston, and the circulation clearance was too small, which was only 3 mm. It result pump choking. The tool could not be fully opened when opening the window. Solution: by changing the original thimble rod into a shunt valve, changing the way of pressure drop, effectively reducing the pump pressure during operation, it is not easy to hold the pump.

![Optimization of segment milling machine](image)

**Figure 3.** Optimization of segment milling machine

4.2.2. Add single flow valve. During segment milling, the iron chips in the drilling fluid cannot be completely washed out. In the process of running in, the drilling fluid enters into the drilling tool, and the iron chips in the drilling fluid are blocked in the piston of the segment mill, accumulating more and more, causing the blockage. Solution: a single flow valve at the lower part of the segment mill.
4.3. Optimization of construction technology

4.3.1. Drilling fluid circulation: During segment milling, the static time of drilling fluid is long, and it is easy to form the paste, resulting in washing failure. During the construction process, the Run in speed is increased to reduce the static time of workover fluid. If the workover fluid in the wellbore is stationary for a long time, it is necessary to wash the well by segments in the process of running in. Pay special attention not to move the rotary table or move the drilling tool up and down.

4.3.2. Requirements for running in: Strictly control the speed of running in speed, and the running time of each column is required to be 4-5min to prevent blade damage. Stop running in case of resistance in the following drilling process, and the resistance shall not exceed 10kN. Slowly move the drilling tool up and down to make it pass smoothly. It is strictly forbidden to turn the drilling tool and start the pump at will during running in, to prevent the blade from opening and damaging casing and milling tools.

4.3.3. After the casing is cut off, the displacement should be gradually increased from small to large to normal. If the displacement is suddenly increased, the drilling tool elongation is too large, resulting in a sudden increase in Drilling pressure, increasing in the load of the rotary table, resulting in serious choking, and even cause the rotary table to stop running. The light tool will be damaged, and the heavy tool will be stuck.

4.3.4. The driller's operation must be stable, the drilling must be delivered evenly, the drilling must not slip, and the Drilling pressure must be kept at 10kn-20kn. Special attention should be paid to the segment milling operation before the first single piece is connected. The Drilling pressure must be small to prevent the blade deformation caused by excessive Drilling pressure from retracting into the tool groove, resulting in that the milling tool cannot enter the upper window and connect the single piece during the drilling lifting period. Therefore, the segment milling operation cannot be continued, and the drilling tool sticking accident may be caused.

4.3.5. The performance of the drilling fluid should be stable. In case of fluid pollution, the performance of drilling fluid should be adjusted in time.

4.4. Complicated problem treatment
Scrap iron treatment: Under normal conditions, the returned scrap iron is about 0.5-0.2mm thick, 400-800mm long and curly. If the scrap iron is too thick, it means that the Drilling pressure is too high. If the scrap iron is too thin, it means that the Drilling pressure is too small. In the process of segment milling, the iron chips may form a "sand bridge" around the drill string, resulting in that the segment milling machine cannot add drilling pressure and the tool cannot be retracted. The solution is: during segment milling, the drilling tool is often moved to wash the iron chips accumulated around the tool. Generally, the drilling tool is moved every half meter, or when the number of iron chips returned from the outlet suddenly decreases. The drilling tool is moved to wash the iron chips, and the iron chips are carried in time. In addition, the iron filings at the return pipeline and vibrating screen shall be removed in time to prevent blocking the mud channel and ensure continuous and smooth operation [3].
Figure 4. Shape and size of scrap iron

After tripping out, the tool wear must be analyzed. If the tool is grinded into an "inverted hook" shape. It means that the tool is milling effectively. If the tool is grinded into a "cone" shape, it means that the pressure is too high. The milled casing must have "peeling" phenomenon. If the wear is large and the tool is tapered, the blade should be replaced. At the same time, the effective milling speed should be controlled by rotating speed of 60-70 rpm and the drilling pressure of 0-10kn.

Shape and size of iron chips: there are three main forms of sticking. First, the cutter is not retracted when lifting the drill, the segment Miller body is stuck in the upper window position. Second, the drilling tool is stuck in the lower window position due to excessive pressure during segment milling. Third, the iron chips form a "sand bridge" around the cutter, causing sticking.

Solution: The drilling tool cannot be forced to pull hard pressure. The correct method is to lift and lower 200kn on the basis of the weight of the original drilling tool, and move the drilling tool repeatedly to release the sticking [4-5].

5. Implementation effect
1) Through mud performance adjustment, tool structure improvement and construction process optimization, the adaptability of the process was greatly improved, and the segment milling operation of HU2010 well was successfully completed, with the segment milling length of 35.7m and the segment milling depth of 3529.7m.

2) The technology accumulation of HU2010 well provides technical support for the subsequent operation of hu001 well. It ensure the successful milling operation of HU10 well in the 47m long segment, which is the first case in China. The construction efficiency is increased from 0.7m/d to 0.85m/d.

3) The successful implementation of the two wells ensures the quality and safety of plugging the old wells in the gas storage, and ensures the long-term and effective safe operation of H gas storage.

6. Conclusion
The successful application of casing segment milling technology in the plugging of old wells in gas storage indicates that the technology has opened up a new application field. However, this technology is a special workover technology.
(1) The mud performance is high-quality, which cannot only ensure the formation stability, but also carry out the milled iron chips. Especially for slim hole wells, the mud viscosity should not be too high. The mud performance should be adjusted in time according to the amount of retured iron chips.

(2) According to the actual situation of casing, the well entry tools are selected to prevent frequent tripping due to tool problems, which will affect the construction progress. The solid control equipment is selected to ensure the purification of mud, and filter device can be added at the circulation outlet.

(3) Technicians and drillers should constantly analyze the downhole situation and pay close attention to the parameter changes, especially the torque and pump pressure. If the torque increases and the pump pressure increases, it analyze the downhole situation, move the drilling tool in time and do not increase the hard pressure to prevent the occurrence of drilling accident.

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