The Cementing Quality Improvement Technology of 9–5/8" Casing in the South China Sea HPHT Gas Field

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Abstract. Poor cementing quality of 9–5/8" casing in the South China Sea high temperature and high pressure (HTHP) gas well leads to severe annular pressure, which hinders the development of HPHT gas fields in Yingqiong Basin, South China Sea. We solve this problem and comprehensively improve the cementing quality by adjusting the specific gravity of mud to increase the safe operation window and create suitable conditions for cementing, combined with preflushing technology, rheology matching technology, casing centering technology, and safe & efficient displacement technology to improve the efficiency of flushing and displacement. The practical application of two highly deviated gas wells in Yingqiong Basin of South China Sea shows that this cementing technology has strong operability, successfully overcomes the difficulties of 9–5/8" casing cementing HTHP gas wells, and effectively solves the problem of poor cementing quality of 9–5/8" casing once and for all.

Keywords: casing cementing · cementing quality · preflush · South China Sea · high temperature and high pressure gas field

Natural gas resources in the HTHP area of the South China Sea amount to 15 trillion cubic meters, accounting for 1/3 of the total resources in the South China Sea, mainly distributed in the Yinggehai-Qiongdongnan Basin [1, 2]. The reservoir temperature is 150–250 °C, and the pressure coefficient is 1.8–2.38 [3–5]. A high temperature and pressure gas field is located in Yinggehai Basin in the north of the South China Sea, in the southwest of the central mud diapir anticlinal tectonic belt of Yinggehai Basin, with a water depth of 64.0–70.0 m. The gas field mainly adopts a four-layer casing well structure of 30" riser +20" +13–3/8" + 9–5/8" + 7". The 16" section was operated with seawater/bentonite slurry and PDF-PLUS/KCL drilling fluid, while the 12–1/4" section was operated with PDF-PLUS/KCL drilling fluid at shallower depths. The 9–5/8" casing cementing slurry returns to the wellhead once, due to the long cementing section and the serious U-tube effect which commonly occurs in many high-deviated wells or horizontal wells, lead to a poor flushing and displacement efficiency. As a result, the cementing quality from the electric log is generally poor, and the annulus pressure is serious during the later production period. To solve this problem, the pre-flushing technology, rheology

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matching technology, casing centering technology, and safe & efficient replacement technology were used to improve the flushing and displacement efficiency. After our improvement, the electric log showed an excellent cementing quality for the 9–5/8" casing long open hole cementing in HTHP gas wells.

1 Technical Difficulties of Cementing

There are the following technical difficulties in the 9–5/8" casing cementing of high temperature and high pressure gas wells in the South China Sea:

1) It is difficult to clean mud cake for high density water-based drilling fluid, and the false filter cake will seriously affect the bonding quality of cement ring;
2) U-tube effect is hazardous, and turbulent flushing cannot be guaranteed, resulting in low flushing efficiency under the low flowrate;
3) The well inclination is large, the open hole section is long, the casing is difficult to center, and the displacement efficiency is low;
4) The pressure is in the transition zone, and it is difficult to prevent channeling and stabilize;
5) Long cementing section, easily leak formation;
6) Large cementing temperature difference requires high performance of cement slurry.

2 Improve Cementing Quality Process

In order to ensure the cementing quality of high temperature and high pressure gas Wells in the South China Sea, the following techniques are proposed to improve the displacement efficiency and ensure the cementing quality by summarizing the previous cementing experience.

1) Increase safety density window: Under the premise of ensuring downhole safety, the drilling fluid for the drilling and casing operations should be maintained a specific gravity as low as possible to provide a larger safety window for the subsequent cementing operation and ensure a higher displacement flowrate.
2) Pre-flushing technology: 1. During the circulation period, pump in 25.44 m^3 seawater and ensure the contact time is not less than 10 min, then pre-clean the borehole wall with a large circulation flowrate (2.385–2.544 m^3/min). 2. Determines the amount and concentration of cleaning fluid from the mud cake flushing experiment to ensure the turbulent flushing time of cleaning fluid is more than 10 min. Use the mud pump to pump the spacer fluid at a high speed to replace the flushing fluid, achieve turbulent flushing of the open hole, and "pre-flush" of the whole hole and before cementing.
3) Casing centering technology: By optimizing the centralizer, ensure that the integrated rigid and elastic centralizers are alternated in the 500 m section above the 9–5/8" casing shoe. One centralizer is added every other casing; From the upper 500 m section of 9–5/8" casing shoe to the upper 800 m section of 13–3/8" casing shoe, rigid and elastic centralizers are alternated, and one centralizer is added every three casing pipes. Using this solution, the software simulation indicates the casing centering degree is above 67% for critical sections.

4) Rheology matching technology: Control the cementing fluid rheology to satisfy the 10% increments of the shear stress on the wall surface among the following fluids: fast solidification tail slurry > slow solidification tail slurry > head slurry > spacer fluid > mud slurry, to improve the displacement efficiency under different flowrates.
5) Safe and efficient displacement technology: Strictly control the displacement pump rate. The software simulation indicates that the equivalent density of the bottom hole, the upper casing shoe, and the weak layers are lower than that of the formation leakage equivalent density. Never increase or decrease the pump speed too fast, to prevent pressure excitement and leakage of the formation. The maximum displacement flowrate should not exceed the maximum mud of the circulating rate before cementing.

3 Application Examples

Two high temperature and high pressure and highly deviated gas wells A1 and A2 in Yingqiong Basin, South China Sea, the 9–5/8" casing depth is 3500 m and 4585 m, respectively, the formation temperature is about 151 °C. The pressure coefficients are 1.76–1.82 g/cm^3 and 1.72–1.78 g/cm^3 respectively; the biggest well inclination of A1 is 35.24°, the one of A2 is 65.4°; The rupture pressure equivalent density at the 9 5/8" casing shoe is greater than 2.10 g/cm^3.The cementing scheme for the two Wells is shown in Table 1.

Table 1. 9-5/8" casing cementing schemes for high temperature and high pressure gas wells A1 and A2 in South China Sea

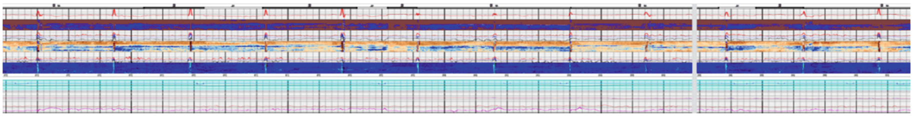
Cementing scheme	Well A1	Well A2
Preflush	Pump 30 m^3 seawater with a large displacement of 2.5 m^3/min (contact time 10–15 min) for pre-cleaning	Pump 30 m^3 seawater with a large displacement of 2.5 m^3/min (contact time 10–15 min) for pre-cleaning
Slurry column structure	Head slurry: drift bead cement slurry, specific gravity of 1.45 g/cm^3, sealing to wellhead, appending 20%, ensure that the pure cement slurry returns to the wellhead; hyper elastic cement slurry: specific gravity of 1.90 g/cm^3, cementing the casing overlap section of 200 m, no appending; Self-healing cement slurry: specific gravity of 1.90 g/cm^3, cementing the casing overlap section of 200 m, no appending; Slow solidification tail slurry: specific gravity of 1.90 g/cm^3, return from the 9–5/8" tube shoe 300 m to the 13–3/8" tube shoe, appending 10%; Fast solidification tail slurry: specific gravity of 1.90 g/cm^3, cementing 9–5/8" shoe above 300 m, no appending	Head slurry: drift bead cement slurry, specific gravity of 1.45 g/cm^3, return from the upper 400 m of the 13–3/8" shoe to the wellhead, appending 15%; Self-healing cement slurry: specific gravity of 1.90 g/cm^3, seal the 13–3/8" casing 400 m above, no appending; Slow solidification tail slurry: specific gravity of 1.90 g/cm^3, return from the 9–5/8" tube shoe 300 m to the 13–3/8" tube shoe, appending 15%; Fast solidification tail slurry: specific gravity of 1.90 g/cm^3, cementing 9–5/8" shoe above 300 m, no appending

(*continued*)

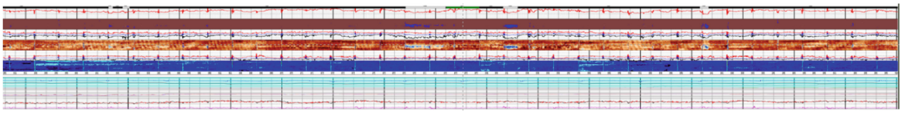
Table 1. (*continued*)

Cementing scheme	Well A1	Well A2
Prepad fluid structure	15.9 m^3 weighted flushing fluid 1.40 g/cm^3 + 79.5 m^3 weighted spacer fluid 1.40 g/cm^3 + 10 m^3 seawater 1.03 g/cm^3 + 79.5 m^3 weighted spacer fluid 1.40 g/cm^3	31.8–63.6 m^3 low viscosity and shear mud 1.38 g/cm^3 + 8 m^3 flushing fluid 1.0 g/cm^3 + 23.8 m^3 weighted flushing fluid 1.40 g/cm^3 + 270 m^3 weighted spacer fluid 1.43 g/cm^3 + 16 m^3 hybrid hydraulic rubber plug
Centralizer placement and casing centering degree	9–5/8" casing shoes above 500 m: According to the one-piece rigid and elastic centralizers alternate, add 1 centralizer every other casing; the upper 500 m section of 9–5/8" tube shoe to the upper 800 m section of 13–3/8" tube shoe: Alternating between rigid and elastic centralizers, 1 centralizer is added every 3 casing pipes	9–5/8" casing shoes above 1000 m: One-piece elastic centralizer, add 1 centralizer every other casing; the upper 1000 m section of 9–5/8" tube shoe to the upper 1000 m section of 13–3/8" tube shoe: According to the rigid centralizer, add 1 centralizer every 2 casing pipes
Pressure stability check	According to the pressure coefficient of 1.40, the whole cementing process can be stabilized. Considering the weight loss of cement slurry, the pressure stability coefficient of 1.114 is calculated to be greater than 1.0	According to the pressure coefficient of 1.40, the whole cementing process can be stabilized. Considering the weight loss of cement slurry, the pressure stability coefficient of 1.134 is calculated to be greater than 1.0
Displacement scheme	Displacement 0.64–1.9 m^3/min to replace the original well slurry	Firstly, displacement is carried out according to the maximum displacement of 2.39 m^3/min. When the tail slurry is discharged from the tube shoe, the displacement is reduced to 1.59–1.90 m^3/min. The displacement is gradually reduced according to the equivalent circulating density, and the last 100 bbls is replaced with 0.64 m^3/min until the bumping

Cementing was carried out according to the cementing design scheme of the above two wells, and electrical cementing quality logging was carried out after 98 h of hardening. The logging evaluation results are shown in Fig. 1. From the log evaluation results, it can be seen that the cementing quality of A1 is mainly medium and poor. Most of the well sections have grooves, and only some sections may have certain sealing. The cementing quality evaluation results of A2 well all showed excellent cementing quality.



a) Electrical measurement of cementing quality in well A1



b) Electrical measurement of cementing quality in well A2

Fig. 1. Electric logging well cementing quality evaluation results of well A1 and A2

By comparing the cementing schemes of the two wells, the following differences can be founded:

1. The casing centering technology are different: The placement of the centralizer in well A1 is inappropriate, resulting in a casing centering degree of less than 67%, and there is a serious edge attachment; The centralizers in well A2 were properly placed, and the casing centering degree reached 85% (as shown in Fig. 2).

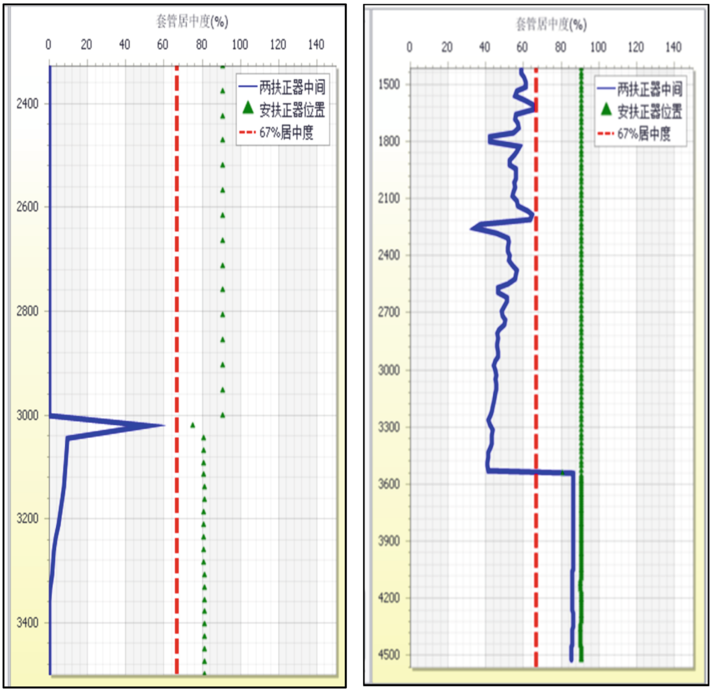


Fig. 2. Casing centering simulation results for wells A1 and A2

2. The pre-flushing technology are different:
   a. The amount of spacer fluid of well A1 is low, the spacer fluid fails to return to the upper pipe shoe before pumping in cement slurry. Well A2 increased the amount of spacer fluid and the spacer fluid had returned to the upper casing shoe before pumping in cement slurry, and achieved "pre-flushing" of the entire open hole.
   b. Well A2 increased the amount of flushing fluid by pumping 8 m^3 of dilute flushing fluid before the weighted flushing fluid. The amount of weighted flushing fluid was increased to 23.8 m^3 and longer turbulent flushing was achieved.
   c. If the wellbore volume is calculated based on 30% diameter enlargement, during displacement the turbulent flow rate needs to reach 1.9 m^3/min. However, the critical turbulent flow rate will increase to 2.02 m^3/min after the cleaning fluid is contaminated by 10% mud; The pre-flushing displacement of well A1 was 1.9 m^3/min, the one of well A2 was 2.39 m^3/min; In the actual operation, the flushing fluid of well A1 is likely to fail to achieve turbulent flushing, while well A2 can achieve turbulent flushing. The electrical cementing quality logging can prove the flushing efficiency of the two wells.
3. Rheology matching technology are different:
   a. Cementing preflush (flushing fluid and spacer fluid) of well A1 adopt 1.40 g/cm^3, without the specific gravity difference, affecting the displacement efficiency. Well A2 increased the spacer fluid density to 1.43 g/cm^3, greater than the drilling fluid density 0.03 g/cm^3.
   b. 9.5 m^3 seawater was injected into the middle of the cement spacer fluid of well A1, which impacts on the performance of the upper spacer. No seawater was injected into the middle of the cement spacer fluid of well A2.
   c. When the displacement of A1 well was in place, the return density of 1.43 g/cm^3 was measured at the wellhead, which left 17.5 m^3 before the bumping. A total of 13.5 m^3 cement slurry was added to the cementing, which further indicates that the displacement efficiency of well A1.

4 Conclusion

(1) The "pre-flushing" technique can effectively solve the problem of wellbore flushing in wells with serious U-tube effect.
(2) Pumping low viscosity and shear mud before cementing reduces annular friction while ensuring that the mud is more easily replaced.
(3) It is necessary to place the centralizers properly to ensure that casings are in the middle, prevent casings from sticking to the edge, and improve the displacement efficiency for wells with large deviation.
(4) The displacement efficiency can be effectively improved by adjusting the structure of the preset slurry column to meet the turbulent flow flushing of the cementing section and ensure the turbulent flow contact time is more than 10 min.

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