Analysis on the nitrogen drilling accident of Well Qionglai 1 (II): Restoration of the accident process and lessons learned

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Abstract

All the important events of the accident of nitrogen drilling of Well Qionglai 1 have been speculated and analyzed in the paper I. In this paper II, based on the investigating information, the well log data and some calculating and simulating results, according to the analysis method of the fault tree of safe engineering, the every possible compositions, their possibilities and time schedule of the events of the accident of Well Qionglai 1 have been analyzed, the implications of the logging data have been revealed, the process of the accident of Well Qionglai 1 has been restored. Some important understandings have been obtained: the objective causes of the accident is the rock burst and the induced events form rock burst, the subjective cause of the accident is that the blooie pipe could not bear the flow burden of the clasts from rock burst and was blocked by the clasts. The blocking of blooie pipe caused high pressure in wellhead, the high pressure made the blooie pipe burst, natural gas came out and flared fire. This paper also thinks that the rock burst in gas drilling in fractured tight sandstone gas zone is objective and not avoidable, but the accidents induced from rock burst can be avoidable by improving the performance of the blooie pipe, wellhead assemblies and drilling tool accessories aiming at the downhole rock burst.

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1. The accident of Well Qionglai 1's nitrogen drilling

In general nitrogen drilling for enhancing ROP in tight gas zone whose production is none or low is safe, no risk of uncontrolled blowout or deflagration accident. This kind of nitrogen drilling has been successfully and safely applied in many wells in China, no blowout or deflagration accident ever occurred. However, a wild blowout fire suddenly occurred during nitrogen drilling in Well Qionglai 1 at 03:27 on 22 December 2011, which was the first blowout fire accident occurred in nitrogen drilling in China. In order to get a correct and systematic understanding of this accident, an experts group was organized and the studies and analysis of the accident have been done. In the paper I, all major inducement events of the accident have been speculated. This paper II will focus on the restoration of the accident process and lessons learned.

2. Possible events and sequences of the accident

The whole accident is a time series of a chain of events lined up based on causality. In some cases, the causality is one
to one, e.g., after the destruction of a sand bridge, the sticking of drilling string is consequently unfrozen, and the compression deformation of it is consequently released. In some cases, the causality is not one to one, e.g., sand bridge sticking might occur at the bit or at the centralizer, but the subsequent event evolution of them would be different. In such a case, the analytic method of event tree (or fault tree) [1] should be adopted: list various possible events and their subsequent evolution events one by one, reflect various potential evolution paths in tree structure based on causality and time sequence, allow each evolution path from its origin to terminal to correspond to a hazard level coefficient, and the greater the coefficient, the more serious the accident consequence is; if an event is followed by several possible events, allow each possible event to have its own occurrence probability, and the greater the probability, the greater the occurrence possibility is. Then, find a path with the maximum cumulative probability in the event tree, which corresponds to the most probable event sequence and its consequence of the accident.

The constitution of event tree of the accident is shown in Fig. 1.

The first bridging-off can only occur at the bit, and there is no other possibility. The second and third bridging-offs can occur either at the centralizer or at the bit. Once the bridging-off is destroyed, the compression deformation of the drilling string is consequently partially released, the bit would rush down; the down rushing bit might directly rush to the top of the settled sands and stop, or might stop before long due to the sand bridge sticking resulted during the down-moving of the centralizer and high-speed up-moving of clasts.

Besides, the total volume of clasts ejected upward at the destruction of third bridging-off is different to some extent in different cases: if the bridging-off occurs at the bit every time, the total volume of clasts ejected upward at the destruction of the third bridging-off would be the sum of sand bridge clasts of the three bridging-offs; if the second and third bridging-offs occur at the centralizer, the total volume of clasts ejected upward at the destruction of the third bridging-off would be the sum of clasts of the second and third sand bridge-offs. If there are too many settled clasts above the sticking point, it is hard to prevent sand-sticking from occurring during drilling string lifting; if there are too many clasts at the sticking point and too many settled clasts above the sticking point, the total volume of clasts during sand bridge destruction would be too large to allow them to get enough initial kinetic energy and arrive at the wellhead ahead of the natural gas; therefore, “too many settled clasts above the sticking point” is hard to be consistent with the actual performance of the accident.

In terms of the accident of Well Qionglai 1, no matter what the evolution path is, the consequence is all catastrophic, therefore, the hazard level coefficients were not presented in the event tree shown in Fig. 1. In addition, some impossible events in probability (e.g., fire directly triggered by the piercement on the straight segment of the blooie pipe) were also omitted in the event tree for the purpose of simplification.

Based on an integrated analysis, during down rushing of the bit, the possibility for the centralizer to be stuck is stronger than that for the bit to directly rush to the top of the settled sands. The possibility for the second and third bridging-offs to occur at the centralizer is stronger than that for them to occur at the bit. Therefore, the most probable event path is the fourth path (the bottom one) in the event tree shown in Fig. 1.

3. Restoration analysis of the accident process

3.1. Restoration of the accident process

The 2 s interval log data of a 3 minus period from 17 s before the accident to the stable blowout in the accident were played back, as shown in Fig. 2. Combined with the interview record of the accident process, the post-accident investigation data and the necessary computation and numerical simulation analysis results, important data and phenomena (represented by States A, B, C, etc.) were marked on the figure, and the sketch of each important phenomenon was shown in a Fig. 3.

The accident process as per event-time sequence is restored as follows:

1) State A: Normal drilling.

As shown in Fig. 3-b1, at that time, the bottom hole pressure (BHP) was 0.36 MPa, whereas the gas pressure in the fracture was up to 30 MPa. When the wellbore was close enough to the fracture, the strength of rock wall between the fracture and the wellbore was insufficient to resist the destructive power formed by high differential pressure between the fracture and the wellbore, the rock wall burst apart instantly, and “rock burst” occurred (point B in Fig. 2 and the state in Fig. 3-b2).

On the right side of point B in Fig. 2, as shown in Fig. 3-b2, substantial clasts were ejected into the wellbore ahead of natural gas at a very high speed and first formed blockage at the bit, forming and compacting sand bridge, called as the first bridging-off, and drilling tool being stuck. It is known from computation that the force of formation pressure acting on the sand bridge was 2400 kN. It is also known from log data that the upthrust of sand bridge acting on the bit was 745.6 kN (weight on hook dropped from 772.3 kN to 26.7 kN, the force on the bit was too much and caused the weight indicator to act up). Therefore, the self-locking friction of sand bridge was about 1650 kN. It is known from computation that the upthrust caused the bit to move up for 17 m (drill pipe compression deformation and spiral buckling) [2]. The formation of sand bridge and the upthrust of drilling string might have been
Fig. 1. Event tree of the accident process.
Fig. 2. Composite drilling logging data analysis of the accident process.

Fig. 3. Sketch of main states of the accident process (Green-Nitrogen, Yellow-Gas)

- a. Normal drilling far away from fracture
- b1. When the bottom hole was close enough to the fracture, the strength of rock wall was insufficient to resist the high differential pressure
- b2. Rock burst instantly, the first bridging-off at bit formed, the drill string was uplift
- c. The first bridging-off was destroyed and the bit ran down, the second bridging-off formed at the centralizer and loose clasts accumulated below it
- d1. The second bridging-off was destroyed and the bit ran down, the clasts were ejected upward, the third bridging-off formed and loose clast accumulation formed below it
- d2. During the period of the third bridging-off, the ejected clast began to fell and settled on centralizer
- e1. The third bridging-off was destroyed and the bit ran down, the clasts were ejected upward as the first stream of clasts. Annulus was unblocked, natural gas expanded and pushed the nitrogen in wellbore to be compressed and flow
- e2. Natural gas dragged clasts from bottom as the second stream of clasts, pushed nitrogen slug to flow with an increasingly first speed
completed within 1 s; because the sampling time of drilling logging was 2 s, the upthrust phenomenon recorded was 2 s. The evidences that “a clash sound between the swivel and the hook was heard, and the deflexion of Kelly, the rotational swing of traveling block and swivel and the violent swing of weight indicator pointer were observed” in the interview record all reflect that rock burst upthrusted and jacked up the entire drilling string.

3) State C: The first bridging-off at the bit was destroyed, resulting in the formation of the second bridging-off at the centralizer.

As shown in Fig. 3-c and at B—C time interval in Fig. 2, the sand bridge at the bit was in a stable state for about 16 s. During that period, the rotary table rotated at a constant rate of 30 rpm for 12 s (torsional deformation for 6 circles in total), and a rotary torque was generated at the sand bridge. Under the coaction of the shearing force generated by the torque and vertical differential pressure, the sand bridge at the bit was suddenly destroyed [3]. The “gas cannon” effect made the compression energy of high-pressure gas under the bridge be converted into kinetic energy of sand bridge clasts, causing high-speed upward ejection of sand bridge clasts accompanied by drill pipe release (instant release of torsional deformation, exhibiting sudden jump of rotation rate, on the left side of point C in Fig. 2, and instant release of compression deformation, exhibiting bit and centralizer suddenly moved down). The clasts ejected upward formed bridging-off at the centralizer, i.e., the second bridging-off, and the drilling string was stuck once more (exhibiting sudden drop of rotation rate, on the right side of point C in Fig. 2). At that time, substantial clasts exhibited loose accumulation above and below the bit. It is known from log data that at that time, the weight on hook rose from 76.3 kN to 311.8 kN, the upthrust acting on the centralizer was 504 kN (at that time, the display of weight indicator was restored). It is also known from computation that the drill string deformation displacement resulted from drilling tool upthrust was 8.8 m [2]. In the interview record that “a clash sound between the swivel and the hook was heard, ... another clash was heard before long”, the second clash should be the reflection of the second upthrust of the drilling string.

4) State D: The second bridging-off at the centralizer was destroyed, resulting in the formation of the third bridging-off at the centralizer.

At C—D time interval in Fig. 2, as shown in Fig. 3-d1, the second bridging-off was in a stable state for 12 s. During that period, the drill string suffered 6 circles of torsional deformation in total, and a torque was generated at the sand bridge. Under the coaction of the rotary torque and vertical differential pressure, the bridging-off at the centralizer was suddenly destroyed, causing a high-speed upward ejection of sand bridge clasts due to the resulted “gas cannon” effect and being accompanied by drill pipe release, and instant release of torsional deformation (exhibiting a sudden jump of rotation rate) and compression deformation (the centralizer suddenly moved down). When the high-concentration sloughing matter below the centralizer moved upward and the centralizer moved downwards, a self-locking effect around the centralizer happened by the chips between the centralizer and the well wall, bridging-off was formed once more, which was called the third bridging-off, as shown at C—D time interval in Fig. 2, and the drilling tool was stuck once more (exhibiting sudden drop of rotation rate, on the left side of point D in Fig. 2). It is known from drilling logging data that the weight on hook was restored from 312.50 to 450 kN, the upthrust displayed on weight indicator was 366 kN (at the centralizer). It is estimated by computation that the deformation displacement resulted from the upthrust was about 5.6 m [2].

After the second bridging-off was destroyed, the clasts at the centralizer were ejected upward at a very high speed, simultaneously, a few high-pressure gas below the centralizer expanded and entered the space above it; however, the third bridging-off was formed and compacted instantly at the centralizer, and the tight sand bridge again formed a bridging-off state with low pressure above the centralizer (weight of static nitrogen column) and high pressure below it (formation pore pressure). After the second bridging-off was destroyed, although the clasts at the centralizer were ejected upward into the wellbore at a very high speed, because the nitrogen above the centralizer in the wellbore was still, these particles, decelerating rapidly due to the impedance of nitrogen and the collision with each other and sidewall, started to fall after having moved upward for about hundreds of meters and settled on the centralizer, forming loose accumulation, as shown in Fig. 3-d2.

5) State E: The third bridging-off was destroyed, making the whole annulus unblocked and gas carrying rock burst clasts start to move up.

The third bridging-off was in a stable state for 8 s, as shown by D—E time interval in Fig. 2. At 03:27:57, the driller started to gear down and lift the drilling string. Under the coaction of the rising drilling tool, rotary torque and high differential pressure, the third bridging-off was destroyed, corresponded by point E in Fig. 2. As shown in Fig. 3-e1, the “gas cannon” effect made the sand bridge particles at the centralizer be ejected upward at a very high initial velocity, simultaneously, the upthrust at the centralizer disappeared, accompanied by the release of drilling string compression deformation, the bit down-rushing and approaching the bottom hole; the weight indicator showed that the force on the bit and the centralizer was zero.

The low-pressure nitrogen slug (green in the figure) above the centralizer was connected to the high-pressure gas slug (yellow in the figure) below it. The natural gas compressed at high pressure below the centralizer started to expand, and pushed the low pressure nitrogen above the centralizer to be compressed and move. Because the drilling string was in a continuously rising state, fixed bridging-off would not be formed due to the self-unlocking effect around the centralizer,
thus, the natural gas continuously pushed the nitrogen above it to move in a slug mode, the gases (nitrogen and natural gas) in the whole annulus started to be in a flow state, and the flowing velocity gradually increased, as shown in Fig. 3-e2.

After the third bridging-off was destroyed, the clasts moving upward in the annulus could be divided into two parts. The first part was composed of the centralizer sand bridge particles formed during the third bridging-off destruction and the particles generated during the second bridging-off destruction and then settled on the top of the centralizer, which was called the first stream of clasts; these particles obtained very high initial velocity at the sudden collapse of the sand bridge, which made these particles rise for hundreds of meters instantly; afterward, the gases in the whole wellbore flew at a very high speed, and then carried these particles to go on moving upward. The second part was composed of the particles loosely accumulated below the centralizer during the third bridging-off destruction; the high-pressure natural gas in the formation fracture passed them and formed blowdown flow; when the flow rate was large enough to form large enough dynamic differential pressure, the loose sand bridge was carried away layer by layer, which was called the second stream of clasts. The distance between the first stream of clasts and the second stream of clasts was hundreds of meters away.

So the flowing matters in the wellbore in the order from top to bottom were following: a long slug of nitrogen, the first stream of clasts in nitrogen, a nitrogen slug again, a short slug of natural gas, the second stream of clasts in natural gas, a long slug of natural gas. The first stream of clasts is shorter and denser, the second stream of clasts is longer and sparser.

This period corresponds to the E–F time interval in Fig. 2. The pressure in the wellbore gradually reduced, and the weight on hook gradually increased (at that time, some external forces still acted on the drilling tool and counteracted partial weight on hook: one was the pressure in the wellbore, and the second was the impact force of transient flow of gas and solid mixed fluid to the drilling tool).

6) State F: The blooie pipe was partially blocked, resulting in pressure rise in the wellbore.

14 s after the third bridging-off was destroyed, the first stream of clasts arrived at the wellhead, making the first 9" T joint with a cecum-end on the blooie pipe partially blocked, which is corresponded by point F in Fig. 2. At F–G time interval of Fig. 2, because the blooie pipe was partially and gradually blocked, the flow resistance caused the pressure in the wellbore to rise gradually, and thus caused the weight on hook to stop rising, or even start to drop gradually. Due to the partly blocked, the velocity of the gases flow in the wellbore decreased gradually, but the moving clasts were still moving fast because of their inertia.

7) State G: The 6" T-joint on the RCD was pierced.

The irrational structure of the 6" T-joint made it suffer severe erosion in the long-term of normal drilling; when the first stream of high-concentration sand particles arrived at the wellhead at high speed, the erosion at this point was aggravated, so the eroded part became very thin, but was not completely pierced. After the first 9" T-joint with a cecum-end on the blooie pipe was partially blocked, the pressure in the wellbore increased rapidly, and ultimately caused the weakest point to be pierced in a burst mode at high pressure, which is corresponded by point G in Fig. 2. The “everted perforation edge” photo (see Fig. 8 in the paper I) is the evidence of burst under high pressure, and the interview record that “piercing sound was heard at the wellsite, below the drill floor dust was observed” is the direct proof of piercement. After the piercement, nitrogen in the wellbore was quickly released, causing the pressure in the wellbore to drop, and thus causing the weight on hook to stop dropping and start to rise, as shown on the right side of G point of Fig. 2. With the second stream of clasts in the wellbore arriving at the wellhead, substantial clasts and dusts suddenly came to the partially-blocked 9" T-joint, and were rapidly accumulated and compacted there, which caused the partial blockage to suddenly become complete blockage, causing the pressure in the wellbore to rapidly and sharply rise once more; the fact that the weight on hook stopped rising and started to drop again, as shown in the G–H time interval in Fig. 2, is an evidence of pressure rise in the wellbore.

8) State H: The wired hose burst and the 6" T-joint fell off.

Because fluid-structure coupled vibration occurred at the wired hose in the long-term normal drilling, and the alternate load of vibration caused the wires in the hose to suffer fatigue fracture and damage, thus significantly reducing the bearing capacity of the wired hose. After the blooie pipe was blocked, the pressure in the wellbore ceaselessly rose, and finally exceeded the residual bearing capacity of the wired hose, resulting in the hose burst; simultaneously, the tremendous recoil made the 6" T-joint subjected to the action of sudden bending moment; under the coaction of recoil bending moment and pressure in the wellbore, the thread of the 6" T-joint suffered asymmetric deformation and elastic slip, and the T-joint was separated from the 9" to 6" bell joint on the RCD, which is corresponded by point H in Fig. 2. There is such a description that “piercing sound was heard at wellsite, and dust pervaded below the drill floor.···A dull blare was heard a few seconds later (the time for a logger to run more than 20 m)” among the interview evidences collected by the expert panel, “dull blare” should be the common sound of the hose burst and the 6" T-joint falling-off, which occurred about 10 s after piercement. After the hose burst, the driller stopped the rotation of the rotary table.

9) State I: Natural gas deflagrated at the wellsite.

After the 6" T-joint falling-off, the wellbore was instantly unblocked; the high-pressure nitrogen carrying particles blew out of the side outlet of the rotary control head substantially; pressure in the wellbore stopped rising and turned to dropping.
so the weight on hook stopped dropping and turned to rising; this state is corresponded by H—I time interval in Fig. 2. Gases in the wellbore rapidly flew out; after the residual nitrogen in the wellbore was exhausted, the natural gas started to flow out of the wellhead at high speed, and instantly permeated the lower part of the drill floor; simultaneously, the high-speed gas flow mixed with the sand particles collided with the steel, and the resulted spark triggered the deflagration of natural gas. The sudden deflagration made a pressure jumping in the wellbore which caused a dropping of the weight on hook, as shown as the section I–J of Fig. 2.

10) State J: Relatively stable blowout and combustion.

After the deflagration of natural gas at the wellsite, the driller stopped hoisting the drilling tool, and all the personnel evacuated. The natural gas carrying the residual clasts in the wellbore went on blowing out of the 9" to 6" bell joint on the side outlet of the RCD and burning, forming a relatively stable blowout state. The gas produced from the well was flowing out to air, the clasts remained in the wellbore were gradually cleaned out, the pressure in the wellbore decreased slightly and the weight on hook increased gradually and slightly, as shown as right side of the point “J” of Fig. 2. At the time of 3:29:10, the fire damaged the logging sensors, the logging data was unobtainable.

Until the clasts in the wellbore were evacuated clearly, the unsteady flow of gas—solid two phase was weakened to a steady single phase flow of pure gas in the wellbore, the flow rate of the natural gas was about $1 \times 10^6$ m$^3$/d, which was the situation of hours later, not shown in the logging data.

3.2. Secondary evidences of the “wellbore bridging-off and blooie pipe bridging-off”

When the total hydrocarbon gas (for short TG, Total Gas) logging in the course of the accident was played back, which is shown in Fig. 4: the total hydrocarbon had been about 4% in the normal drilling before the rock burst, and had all along been maintained about 4% in the whole course of the accident; it did not change obviously until 1 min after the wellsite had been on fire and dropped to zero 3 min later. What does this phenomenon show?

As mentioned in the paper I, in the course of the first, second and third bridging-offs in the wellbore, the spaces below and above the sand bridges were isolated; apart from hundreds of milliseconds of gas shock wave, the space above the sand bridge was filled by still nitrogen column with 4% TG. After the third bridging-off was destroyed, the first rise of the first stream of clasts (inclusive of the particles of the third bridging-off and the particles of the second bridging-off settled on the top of the centralizer) resulted from an upward ejection of clasts at very high initial velocity after kinetic energy was obtained due to the release of the high-pressure gas under the bridging-off; the second rise of the first stream of clasts resulted from the carrying kinetic energy of annulus moving nitrogen. During the second rise of the first stream of clasts, the flowing natural gas carrying the second stream of clasts (particles settled below the centralizer due to gravity) started to move upward. Therefore, the distance between the first stream of clasts and the second stream of clasts was hundreds of meters away.

14 s after the third bridging-off was destroyed, the first stream of clasts arrived at the wellhead and immediately resulted in the blockage of the first 9" T-joint with a cememont on the blooie pipe. So gases in the wellbore stopped flowing and became compressed. Besides, the interface of natural gas and nitrogen also stopped moving upward, but the second stream of clasts still moved up at high speed by inertia, and moved from the natural gas slug into the nitrogen slug. Another 4 s later, the 6" T-joint was pierced, resulting in ejected nitrogen with 4% TG. The pressure in wellbore started to drop. At this time, the interface of natural gas and nitrogen moved upward slowly due to the blowing of nitrogen out of the perforation. 10 more seconds later, the second stream of clasts successively arrived at the wellhead due to inertial motion and made the first 9" T-joint to be blocked from partly to totally, the pressure in the wellbore started to rise again. 28 s after the third bridging-off was destroyed, the wired hose burst and the 6" T-joint fell off, so the wellbore was instantly unblocked. The gases in the wellbore rapidly flew out of the 9" to 6" bell joint, and the interface of natural gas and nitrogen moved up rapidly; about 2–4 s later, the residual nitrogen in the wellbore was exhausted, so the natural gas started to flow out of the wellhead at high speed, and instantly permeated the lower part of the drill floor. Simultaneously, the sands mixed with the high-speed natural gas flow collided with the steel, generating spark and triggering natural gas deflagration.

Obvioulsy, during the period from the occurrence of rock burst to the blockage of the blooie pipe, natural gas in the wellbore did not flow out of the wellhead, therefore, the gases at the gas logging sampling point of the blooie pipe was always the original nitrogen with 4% TG. After the blooie pipe was blocked, it broke before long; thereafter, although the natural gas in the wellbore blew out of the wellhead and permeated the wellsite, because the blooie pipe had already been broken and still blocked, the natural gas at the wellsite
could not enter the blooie pipe; therefore, during the period from the blocking of the line to the fire-catching of the wellsite, the gas at the gas logging sampling point of the blooie pipe was always the nitrogen with 4% TG. Therefore, from the starting of rock burst to the fire-catching of the wellsite, the gas logging TG value was always about 4%. After the wellsite caught fire 2 min later, because the concentration difference of methane on the wellsite and in the blooie pipe resulted in diffusion and convection, the methane concentration in the blooie pipe started to drop, another 3 min later, the methane concentration in the blooie pipe dropped to zero. This indirectly proves the rationality of such speculation as “wellbore bridging-off and blooie pipe blocked”.

4. “Rock burst” and gas drilling safety

The “rock burst” phenomenon similar to that occurred in Well Qionglai 1 has not been reported in any available foreign literature, or has not been talked about by the foreign counterparts, either. Then, whether the rock burst accident in Well Qionglai 1 is an awfully peculiar isolated event? The answer should be no.

In 2008, when nitrogen drilling was being conducted in Well Longgang 001-12 in the Sichuan Basin, downhole burst accident with undefined causes occurred, and it resulted in the burst and break of the blooie pipe. After the burst and break of the blooie pipe, the well was immediately shut in and killed, so no subsequent accidents occurred. In the course of drilling, nitrogen generation equipment was in good condition, so the accident should not have been resulted from the deflagration of natural gas in the wellbore. The blooie pipe of the well was similar to that of Well Qionglai 1, i.e., there was a T-joint right angle bend with bune cap, therefore, it is speculated now that downhole rock burst might have occurred, and the resulted high pressure due to the rock burst clast blockage at the T-joint, and caused the blooie pipe to burst.

It is also noticed that in Well Qionglai 1, when nitrogen drilling was conducted to a well depth of 1003.1 m, the total hydrocarbon content rose suddenly from 4% to 40%, so the blooie pipe was ignited successfully, with flame being 7–8 m high; simultaneously, the standpipe pressure rose from 1.4 to 7.6 MPa; after POOH, one of the nozzles of the air hammer bit was blocked which was obviously also a slight rock burst accompanied by a small gas flow. In 2012, in the nitrogen drilling of Well Niudong 102 in the Huabei oilfield, accompanied by a small flowing out of gas, about 40 kN upthrust impact force occurred on the bit, so this should also be a slight rock burst. It was said by a counterpart that in the nitrogen drilling of Well Gushen 3 of the Daqing oilfield in 2012, during the producing of a small flow of gas, the bit nozzle was blocked. In retrospect, such phenomena as a small gas flow rate simultaneously accompanied by bit bouncing, sticking, jumping and nozzle blocking are relatively universal in gases drilling in the western Sichuan Basin, especially the downhole accident occurred in gases drilling of Well Xin 3 in 2006. All these were paid attention to by people at that time, but because the existence of rock burst was not identified, the wellbore instability accompanied by a sudden gas flow was boiled down to fluid and solid coupling sidewall spalling due to formation gas production [4]. Now it seems that all these should be the results of different degrees of rock burst.

Therefore, slight rock burst should universally exist in the implementation of gas drilling in tight sand gas zones, and severe rock burst similar to those occurred in Well Longgang 001-12 and Well Qionglai 1 would also take place occasionally. Simply because severe rock burst resulting in great hazards has never been encountered before, it is not paid enough attention to. After the fatal accident in Well Qionglai 1, a close investigation and analysis on it was immediately organized; it is fortunate that various data and 2 s log data of the relevant well interval are complete, so the rock burst phenomenon and a series of events resulted from it can be analyzed.

After the accident in Well Qionglai 1, gas drilling safety has been questioned, and the application of gas drilling has also been reduced largely. Is gas drilling definitely unsafe and bound to be forbidden under the circumstances of potential rock burst? It is conceivable that if the blooie pipe of Well Qionglai 1 had been upgraded by some anti-blocking technical measures, the pipe would not have been blocked in rock burst, and the subsequent hose burst, uncontrolled blowout of natural gas and deflagration of the wellsite would not have occurred. If the blooie pipe of Well Qionglai 1 had been upgraded by some anti-erosion technical measures, the pipe would not have been eroded and pierced in drilling, the accident potential of gas leakage and fire at the wellsite would not have existed. It can also imagine that if the shape of the downhole hammer bit had not packed the wellbore like mill shoe, but rather had relatively smooth flow channel, blockage would not have been easily formed at the bit by rock burst clasts; if there were no centralizer or the centralizer had fluent flow channel, blockage would not have been easily formed at the centralizer either; in this way, the state in the wellbore would be smoother in rock burst, and state on the ground would be gentler. Furthermore, if relevant studies had been conducted on the occurring mechanism, condition and law of rock burst, and then the downhole tool, operating procedure, wellhead equipment and blooie pipe would have been improved, and the means like surface monitoring and early warning aiming at rock burst would also have been increased. Ultimately the safety of gases drilling under rock burst circumstances would be certain to be guaranteed. Therefore, the existence of rock burst is objective and inevitable, but the accident induced by rock burst is not inevitable, and can be overcome by means of human effort.

Then, why has the rock burst in drilling never been reported in the literature of foreign drilling industry?

Firstly, rock burst would not occur in the conventional drilling of wellbore filled with fluid. Because the fluid column pressure in the wellbore is balanced with the pore pressure in formation, there is no differential pressure between them; furthermore, even if underbalanced drilling is adopted, and there is differential pressure, the differential pressure is not high enough to induce the rock burst. Therefore, rock burst
would not occur in either overbalanced or underbalanced liquid drilling.

Secondly, air drilling has been popular in North America since the 1950s, why is there no rock burst ever reported? Could it be that gas drilling in North America has never encountered rock burst? Now that at the time of encountering the fracture of tight sand gas zones in gas drilling, rock burst is an inevitable phenomenon of objective existence, gas drilling in North America must have encountered many times of rock burst, then, why is there no relevant report? The probable reason is that when gas drilling occurred in North America in the 1950s, air drilling was avoided for drilling in the formation of natural gas, as a result, rock burst was avoided. At the beginning of the 21st century, with the application of nitrogen generation technique of membrane separation, nitrogen drilling was used to drill out the hydrocarbon formations. However, large, straight, open and steady blooie pipe were recommended and applied in North America at the very start [5], as shown in Fig. 5.

The basic requirements of this type of blooie pipe are as follows: large — the flow channel area of the pipe should not be 1.1 times smaller than annular area; straight — the pipe should decline at $10^\circ-15^\circ$, and should be straight and un-bending; open — the flow channel should be open and unblocked inside; and steady — the bracket should be steady. When this type of blooie pipe is applied, it would not be blocked when encountering rock burst, therefore, accidents would not occur. Although rock burst might have occurred in gas drilling in North America, no hazards and accidents have ever taken place, so rock burst has never been paid attention to, and there is no studies and reports on rock burst. This is nothing but a speculation, and the specific reasons remain to be further studied.

Fig. 5. The blooie pipe for gas drilling recommended by the American Gas Research Institute.

5. Conclusions

1) The accident process was completely restored mainly based on the 2 s log data in the accident, the interview record of the accident process, the post-accident investigation data, and the necessary computation and numerical simulation analysis results.

2) The restored accident process as following: Firstly, downhole “rock burst” suddenly occurred in normal drilling. Secondly, rock burst clasts formed bridging-offs and sticking at the bit or at the centralizer; under the circumstances of continuous rotation and action of drilling tool, the bridging-offs were destroyed. Thirdly, the bridging-off was formed and destroyed repeatedly, until it was no longer formed in the whole annulus, and the clasts and gas flew upward in the unblocked annulus. Fourthly, some clasts arrived at the wellhead ahead of the natural gas; large stream of clasts suddenly coming to the wellhead blocked the blooie pipe, so the wellhead pressure increased rapidly, and caused the wired hose to burst and the outlet 6\(^{th}\) T-joint to fall off. And finally, the nitrogen in wellbore was instantly exhausted, the gas in the wellbore rapidly blew out of the outlet of the RCD and triggered deflagration.

3) The objective causes of the fatal accident in nitrogen drilling of Well Qionglai 1 lie in that infrequent fracture was encountered in gas drilling of the tight sandstone formation, and severe “rock burst” occurred; whereas the subjective causes lie in that the blooie pipe was inadaptable to the large stream of clasts resulted from “rock burst”, and was blocked, so high pressure was formed, which caused the blooie pipe to break, resulting in uncontrolled blowout and fire.

4) The lessons and inspirations obtained from the accident are as follows: if bridging-off had not occurred at the bit and the centralizer, the violent solid load impact in ground blooie pipe would not have been exerted; if the blooie pipe had not been blocked, hose burst and break would not have occurred, and such type of fatal accidents would not have occurred, either; if the outlet T-joint had not been eroded and pierced, the risk of natural gas leakage and fire at the wellsite would not have existed. Therefore, it is the fundamentality of preventing such type of rock burst induced accidents to improve the performance of blooie pipe, wellhead assemblies and drilling tool accessories aiming at the downhole rock burst.

5) In gas drilling in fractured tight sandstone gas zones, the existence of rock burst is objective and inevitable, but the accident induced by rock burst is not inevitable, and can be avoided by means of improving the performance of blooie pipe, wellhead assemblies and drilling tool accessories aiming at the downhole rock burst.

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