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THE PROBLEM OF LIQUIDATION OF THE OPEN ERUPTION BY DRILLING TOOLS

1. DRILLING FAILURES DURING OIL WELL DRILLING

Drilling of deep wells consists of a number of processes and procedures. Their obeying may guarantee safe and trouble-free drilling of wells.

If any of the elements of drilling procedure is neglected or violated, a failure situation may occur.

A drilling failure can be defined as an abnormal state of the borehole in which an undesired and sudden event occurs due to direct or indirect geologic, technical and organizing reasons. This state creates an obstacle for the correct and fluent operation of the well, and can be done away with the use of specialist procedures and equipment.

The most dangerous drilling failures are connected with uncontrollable formation fluid outflow during wellbore drilling. This type of failure frequently leads to material losses and sometimes fatal accidents among the crew, especially when ignition of the outflowing medium or its blowout take place. Statistics of occurrence and scientific analyses reveal that the most common causes of such failures are:

- break-downs and failures of major rig subassemblies and well outlet,
- insufficiently recognized geological-drilling conditions in the course of well prospecting,
- erroneous drilling procedures and violating procedures by drilling crews at the first stage of blowout liquidation.

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The appearance of an outflow and the subsequent blowout of reservoir fluids may in normal conditions lead to the following effects, depending on the type of performed operations in the well:

- blowout while performing drilling operations,
- blowout during hoisting operations in a well,
- blowout in a well without the string.

2. SIGNS OF BUILD-UP PRESSURE IN A WELL AND THEIR LIQUIDATION

The problems with pressure symptoms, theory and ways of liquidating them have been considered by a number of authors (1–5) and also groups specializing in blowout liquidation (e.g. Wild Well Control, USA).

Under the notion of pressure signs we understand a spontaneous outflow of formation fluids from the well. This effect takes place in a situation when the pressure equilibrium has been disturbed. Such an effect can be evoked by a drop of mud's hydrostatic pressure, e.g. as a consequence of drop of mud level in the well or higher pressure in the reservoir layer and inflow of reservoir fluids lowering mud density. The pressure equilibrium is disturbed when the well is drilled, when tripping in/out the string, or during other well operations, e.g. geophysical logging when mud does nor circulate in the well. Outflows should be treated as a chain reaction; the reservoir fluid has naturally lower density than drilling mud. Due to the mixing of these fluids the specific weight of the mud is lowered. Consequently reservoir fluid inflows to the well, and the volume of lower density fluid increases in the well causing a difference between reservoir pressure and hydrostatic pressure, with domination of the former. The rate of this effect depends on the properties of the collector layer, especially permeability, reservoir pressure and mechanical properties of layer.

After the outflow or blowout has been tamed, various procedures are used, depending on the current situation in a wellbore. Initially, the liquidation of outflow or blowout lies in closing the well followed by its regulated reopening with the simultaneous injection of loaded mud. This action is aimed at reaching a pressure equilibrium between formation pressure and hydrostatic pressure.

The lack of equilibrium during hoisting operations in a well, when the string is tripped down or up, is a specific case. The most dangerous situation is encountered when the drill string column is open. In this case the blowout preventer has to be installed to prevent the outflows through the mud pipes. The biggest problem for the rescue teams is to mount it on the string while the fluid is outgoing.

A solution to this problem could be found thanks to the cooperation of HBZS, MND S.A. Hodonín with VSB – Technical University of Ostrava consultations with the FDOG AGH-UST academic staff. As a result of this corroboration a specialist device called FIB-1 (from the name of the inventor eng. Jaroslav Fibinger) was worked out. With this device a BOP can be disposed on a string without using heavy equipment.

In 2013 a prototype of a system preventing high-pressure outflows through the drill string was worked out at the laboratory of the Institute of Geological Engineering, Faculty of Geology and Mining TU-Ostrava (fig. 1). The principle lies in plastic crushing of mud pipes with a system of wedges. One of them is fixed and acts like a matrix, and the mobile one assumes the role of a stamp. The objective of this operation is closing the inner diameter of mud pipes and reducing or cutting off the outflow, which would advantageously elongate time for preparing a successive stage of blowout liquidation.

3. THE FIRST STAGE OF LABORATORY EXPERIMENTS – CRUSHING OF MUD PIPE

The FIB-1 makes use of a servo with two crushing rams. One of the ram is stable and the other moves along the rods of regulated length (fig. 1). This system turned out to be inconvenient for analytical purposes as the replacement of rams takes relatively too much time vs. time of crushing. A laboratory press SHREK HL-100T was used for the effect of accelerating the tests, selecting the best type of crushing rams and finding appropriate pressure and force values to crush the mud pipes. The results of crushing were verified during the tests made for various shapes of rams, i.e. wedge-wedge, spherical cap - spherical cap, spherical cap -plate.

At the first stage of the test mud pipes of nominal diameter 5" (0.127 m; 127 mm) and inner diameter 0.106 m (106 mm) underwent crushing with the press SHREK HL-100T. The press allowed for continuous recording of pressure and measurement of deformations at the crushing stage and at the piston rod return stage. On the whole, three crushing tests were performed on mud pipes with the use of various types of rams. During the first two tests the wedge-wedge rams (fig. 2) were used, whereas the third test was performed with a spherical cap a-wedge ram. The test wedges were provided by HBZS Hodonín. In the third test original crushing wedges of FIB-1 and a spherical cap of own design 60 mm of diameter and 19 mm high were used.

Fig. 1. System controlling mud outflow and blowout from mud pipes (prototype performed by HBZS Hodonín)

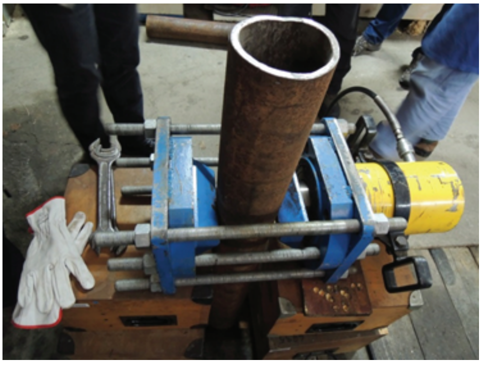

Fig. 2. Press SHREK HL-100T during compression tests with wedge-wedge rams

Fig. 3. Press SHREK HL-100T during compression of pipe with spherical cap - spherical cap rams

Fig. 4. Deformation of mud pipe with visible cracks after wedge-wedge rams have been used

4. THE SECOND STAGE OF LABORATORY TESTS – CRUSHING OF MUD PIPES, CASING AND PRODUCTION PIPES

Analogously, the second stage was also realized with the use of a laboratory press SHREK. This stage was based on the results from the first stage. It lied in crushing tests on various types of pipes with the use of different crushing elements. A total of 12 crushing tests were performed for mud pipes, casing and production pipes and for different crushing elements (spherical cap -plate, spherical cap, wedge-wedge).

5. RESULTS OF LABORATORY CRUSHING TESTS OF MUD PIPES, CASING AND PRODUCTION PIPES – SUMMING UP OF STAGE I AND II

The tests with the use of a press SHREK HL-100T reveal that the rams have to be approached individually, depending on the type of the crushed pipe (tests no. 1 to 9).

As far as pressure exerted on pipes of inner diameter 106 mm is concerned, the spherical cap crushing set turns out to be most effective (fig. 3.). A pressure of 180 bar was needed for this combination of rams, giving about 90 kN (test no. 5). In the case of wedge-wedge rams the pressure had to be higher (250 bar), corresponding to 125 kN (test no. 8); in another test the pressure equalled to 210 bar, i.e. 105 kN (test no. 2). From the point of view of the pressure needed for crushing a pipe the least desired ram combination is the **spherical cap** -plate variant (test no. 4).

The results for the particular tests are presented in fig. 5.

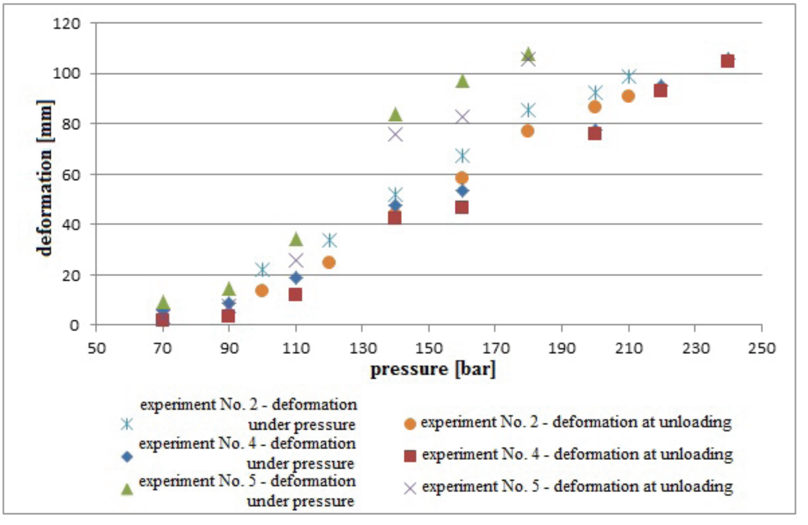

Fig. 5. Comparison of deformation and crushing pressure for various ram variants: wedge-wedge (test no. 2); spherical cap -plane (test no. 4); spherical cap (test no. 5)

For smaller diameters of tested pipes the required pressures were definitely lower, therefore the wedge-wedge ram setup was used in the tests.

In the case of the casing 5 ½” the pipes could be crushed at a pressure of 130 bar, i.e. 65 kN. The production pipe 3 $^5/_8$” required a pressure of 100 bar, which corresponds to the crushing force of 50 kN. The production pipe 2 $^7/_8$” could be crushed at ca. 65 bar, i.e. 32.5 kN. The tests were performed with the use of an experimental press allowing for the measurement of crushing parameters, therefore the recorded pressure values are expected to be free of methodological and measurement errors.

The tested prototype device by HBZS Hodonin easily reached the demanded working pressure values therefore is fit for severing casing and production pipes.

6. EVALUATION OF CRUSHING ELEMENT PROFILES

Apart from the required crushing pressure used for particular types of pipes it was also the inner profile of the crushed pipes which was evaluated. Particular rams had a unique impact on the shape of the crushed pipes.

In the further design works aimed at improving the efficiency of the prototype press FIB-1 for drill pipes one should consider the way of controlling the crushing of the pipe's interior: whether it is better to change the radius of **the spherical cap, or increase** the diameter of the piston rod in the prototype. Figures 6 to 8 illustrate the inner shape of the crushed element in relation to the type of the applied rams.

Fig. 6. Inner profile of crushed string after spherical cap -plane rams have been used

Fig. 7. Inner profile of crushed string after spherical cap - spherical cap a rams have been used

Fig. 8. Inner profile of crushed string after wedge-wedge rams have been used

Fig. 9. Location of crushed mud pipes in FIB-1 with wedge-wedge ram

Mud pipes of inner diameter 106 mm crushed by the spherical cap – spherical cap rams in test no. 5 and wedge-wedge rams in test no. 8 were damaged in the place of the maximum narrowing due to the disrupted continuity of the material in the outer wall.

The tests also proved that the pipe walls cracked in the place where the rams were acting (fig. 4.). Therefore, prior to using this solution in drilling industry, the device needs to be evaluated for its safety. Any break in the pipe creates hazard. The breaks are a place through which the pressurized medium can penetrate creating a real hazard for the rescue crew. However, in the case of a quick liquidation of pressurized flow such cracks do not have to be classified as particularly hazardous. The bendings visualized in fig. 8 do not have cracks in the outer surface which would mean that fast injection does not have to end up in cracked pipes. In this case the geometrical size of both crushing and crushed elements plays an important role.

Basing on the analysis of data obtained from laboratory tests it is recommended that the hydraulic servos capable of producing injection pressure of 700 bar, i.e. 350 kN, were used in the modernized version of the FIB-1 device for stopping pressurized outflow through the inner part of the pipes. This value stems from the fact that pressure in the pipes and elasticity of materials were accounted for. The most advantageous ram combination has not been confirmed by analyses, though the wedge-wedge system turned out to have the best results in tests. This assumption needs proving by a series of further tests of various shapes of wedges in the experimental press SHREK HL-100T, followed by a control system regulating outflows through the drill pipes.

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