Engineering Failure Analysis xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure and integrity analysis of casings used for oil well drilling

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A R T I C L E   I N F O

Article history:
Received 16 September 2016
Received in revised form 4 November 2016
Accepted 7 November 2016
Available online xxxx

Keywords:
Casing drilling
Fatigue cracking
In-service integrity
Material optimization

A B S T R A C T

Drilling with casing (DwC) is an innovative method particularly widespread in deep shale plays, that reduces the time and cost of drilling stages. However, casings are not designed for this purpose, and still the pipes and connections are required to remain sealed in the well after sustaining a large amount of drilling cycles and possible damage. The investigations presented in this article were triggered by the failure of a 9 5/8″ diameter K55 seamless casing during drilling an oil well. Fractographic analyses identified fatigue crack nucleation and growth in the tube/coupling (T/C) transition zone. The failure analysis included physical and chemical material tests and numerical stress analyses at the T/C threaded joints when subjected to the loads logged during drilling.

Fatigue cracks were found in other pipes that, although did not lead to fast fracture, would have caused leaking during subsequent well completion and production. The most relevant conclusion is that future integrity of casings used for drilling could not be assured. Reducing cyclic drilling stresses below the actual fatigue strength of pipes and connections is not easy task; the industry tendency is to go to slim-hole DwC, with ever increasing operating loads. Therefore, the economic feasibility of using heat treated casing and more sophisticated DwC designs are highlighted. Large grained tube steels and premium connections are found to be the most cost-effective alternatives to ensure the casing would survive the cyclic torque and compression stresses without serious damage.

1. Introduction

Drilling with Casing (DwC) is an innovative method particularly widespread in deep shale plays, that reduces the time and cost of drilling stages. Traditional drill pipes that transmit torque and compression to the drilling bit are replaced by the same tube that will later become the well casing [1].

The applicability of the concept of Drilling with Casing, also called Casing while Drilling (CwD) or simply Casing Drilling (C–D), has been extensively proven in vertical, horizontal and deviated wells. This process eliminates the conventional drill string by using the casing itself as the hydraulic conduit and means of transmitting mechanical energy to the drill bit. A short wireline-retrievable Bottom Hole Assembly (BHA) consisting of at least a drill bit and an expandable under-reamer are used to drill a hole of adequate size to allow the casing to pass freely.

DwC has been employed in many countries as an effective method of reducing the overall drilling costs by reducing drilling time and drill string problems encountered during conventional drilling process [2]. In addition to the productive drilling time

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http://dx.doi.org/10.1016/j.engfailanal.2016.11.008
1350-6307/

lost to tripping, unscheduled events during tripping can make the drilling process even more inefficient and even lead to losing the well. While the potential savings from reducing drill-string tripping and handling times are important, the savings from reducing hole problems may be more significant [3].

There are many situations where problems such as loss of circulation, well control incidents, and borehole stability problems are directly attributed to tripping the drill-string and other situations where these problems prevent the drill-string from being tripped. Since the CwD process provides a continuous ability to circulate the well, it is inherently safer than leaving the well static without a means of circulating it while a conventional drill-string is tripped. Reduced pipe tripping with CwD should also reduce surge and swab pressure fluctuations.

There are two basic methods of drilling with casing [4]:

1. a latched retrievable Bottom Hole Assembly (BHA) inside the casing that incorporates a mud-motor to drive a conventional bit and reamer
2. a surface system that rotates the hole casing, and a drillable "cement in place" drilling BHA. This drill bit is cemented and drilled out with the next drilling assembly.

DwC systems have been designed primarily for multi-well offshore platforms, multi-well operations on land, deep-water operations, and for situations requiring operators to drill through and place casing across problem formations quickly. This technology was applied successfully to drill through depleted zones showing wellbore instability problems and mud losses, as an alternative to underbalanced drilling.

However, casings have originally not been designed for this purpose and still, the pipes and connections are required to remain sealed in the well after sustaining a large amount of drilling cycles and possible damage [5]. This is particularly true in the case of rotating casings, and the parts that are prone to fatigue failures the threaded connections between individual tubes.

Casing drilling is one of the examples in which excessive torque and wear must be added to the casing design stage in order to obtain good well integrity. Fatigue is not an unknown failure mode for mechanical components, but it was considered as being un-important for well tubulars such as casing or tubing. With the advent of CwD, especially in deviated wells with small -radii deviations (or "doglegs"), rotating bending is the primary source for cyclic (mostly axial) tensile stresses in the casing walls.

Most recent casing connection evaluation test programs are based on ISO 13679 requirements [6], while, API RP 7G is the dominant testing program for drill stem applications [7]. With the evolution of casing drilling technology, connections are subjected to increasingly stringent well conditions. These conditions include higher pressures, higher temperatures, and higher mechanical loads for longer drilling periods. As a result, the performance of the connections under these conditions is of increasing concern.

Drilling with casing applications combine both, drilling and casing damage mechanisms. As a result, new test programs were required to adequately characterize connection performance when used in casing drilling applications [8].

Casing failure is among the foremost concerns associated with oil & gas drilling operations. The rate of casing failure, causing fluid or gas leakage, rises sharply as wells age [9]. Tubing-less hydraulic fracturing compounds the risk by exposing weakened areas of the casing to very high pressures that could create pathways to other formations causing potential environmental issues. As of yet, the risks associated with horizontal wells are unclear. Besides, 90% of casing failures occur at the connecting points that link each individual steel pipe together.

Based on the increased demand upon OCTG (Oil Country Tubular Goods) to serve the new technologies, many of the OCTG manufacturers are developing new systems in which the fatigue aspects are considered. The increase in non-typical uses of OCTG makes the design and selection criteria for these new applications more difficult than conventional well usage During the life of a well the fatigue load of a casing string may change from simple fatigue (high cycle) to low cycle fatigue.

Based on these changes, fatigue tests and damage accumulation calculations were applied in order to estimate and extend the total life of the casing. As high resistance to fatigue loading together with high overtorque and compression capacities are at the top of a list of required features for connections to be used in DwC techniques. Special connections with enhanced performance need to be developed. This led to the development and evaluation of "premium" connections for casing which were designed to stand cyclic loads and reach an extended number of cycles under such conditions. The development process of an integral connection for casing sizes targeting very demanding applications comprised Finite Element Analysis (FEA) and Full Scale Fatigue Test (FSFT) leading to Stress Concentration Factors (SCF) lower than 2 [10]. In addition, semi-premium connections are notably cheaper, and cover less demanding applications, with SCF lower than 3, good enough when low doglegs are present.

2. Drilling conditions of the failed casing

A cracked 9″ 5/8 diameter, # 40 lbs/ft, K55 casing failed during "drilling with casing" an oil well, when the drill bit reached a depth of 752 m, causing a costly string break. The threaded joints are API Buttress connections with internal shoulder. The failure analysis carried out includes physical and chemical material tests, and a numerical stress analysis at the T/C threaded joint when subjected to the operation loads, as actually logged during drilling.

Fig. 1a is an image of the failed casing at the broken section, on the side that was in the well and had to be fished. Fig. 1b is an image of the broken section, in the upper side. Fig. 2 shows a sketch of the threaded part of the casing, the circle indicates the

Please cite this article as: P.G. Cirimello, et al., Failure and integrity analysis of casings used for oil well drilling, Engineering Failure Analysis (2016), http://dx.doi.org/10.1016/j.engfailanal.2016.11.008