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Development of a new hollow sucker rod family for rotating pumping (progressive cavity pump systems)

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ABSTRACT

Conventional solid sucker rods according to API 11B specification are widely used for rotating pumping, particularly to drive PCP Systems (progressive cavity pump systems) during the oil production. However, these products have been developed to work under axial alternating loads, and not under torsional loads. Thus, the use of these rods for rotating pumping has several limitations and disadvantages like a low yielding torque, insufficient backspin and fatigue resistance, showing low performance and resulting in high operative costs for artificial lift systems. Furthermore, the PCP System requires higher torque to work efficiently. For that reason, it is suitable to develop a new product with better performance to be used for this pumping system.

This paper presents the development of a family of innovative products called “Hollow Sucker Rod” as a technical solution for PCP System. The development consisted of (i) design of the connection, (ii) manufacture of prototypes, (iii) full scale lab tests, and (iv) field trials.

Some advantages of this new technology are: (i) high torque load to yielding, (ii) good fatigue resistance, (iii) high backspin resistance, (iv) less tubing wear, (v) increase in pumping rates, (vi) possibility to inject different kind of fluids by the inside of the “Hollow Sucker Rod”, and (vii) easy to make up and install (conventional pulling ring).

1. Introduction

Two of the most used artificial lift systems to produce oil in the world are alternating or beam pumping and rotating pumping (Figs. 1 and 2). In both cases, a sucker rod string is used as a “power shaft” to move a submerged pump. In the case of rotating pumping, conventional solid sucker rods manufactured according to API Specification 11B (2010) are widely used to drive Progressive Cavity Pump (PCP) systems or Moineau Pump system. However, they have been developed to work under axial alternating loads and not under torsion loads. As a consequence, a lot of money is spent on pulling, material replacement and production losses due to the use of conventional sucker rods for PCP systems.

In PCP systems, the pumping is carried out through the rotation of a progressive cavity pump installed at the well bottom. An engine is located at the wellhead, joining both of them is located a sucker rod string which has a rotating movement to transmit the torque load from the engine to the pump (Fig. 2). This type of pumping is different from the traditional beam pumping system which uses a piston pump working under alternating axial movement (Fig. 1). For rotating pumping, the sucker rod string works under torsion, tension and bending loads (the last, in case of slightly deviated wells).

This work presents the development of an innovative product called “Hollow Sucker Rod” which has been developed in order to work more efficiently during the rotating pumping, avoiding failures and reducing operative costs. Another advantage is that the interior of the hollow sucker rod could be used to produce oil, inject corrosion inhibitors and diluents for extraction of heavy and extra-heavy oils.

The following tasks were performed during the development stage: (i) design, (ii) manufacture of prototypes, (iii) full scale lab tests, (iv) field trials and (v) patens.

2. Design

The following requirements were taken into account for the design step

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Nomenclature

BHR	Bottom Hollow Rod. Connection at the well bottom
CVN	Charpy V notch
DLS	Dog Leg Severity [°/30 m]
F_a	axial load
F_b	alternating bending load
HR	hollow sucker rod
J_{Ic}	fracture toughness
M&B	Make & Break operation
M_t	torsion load
M_{t_ys}	yielding torque
N	fatigue life [cycles]
PCP	progressive cavity pump
SAGD	steam-assisted gravity drainage
SR	conventional solid sucker rod
S–N	stress vs. fatigue life curve
THR	Top Hollow Rod. Connection at the well head
σ_{max}	maximum stress
σ_{min}	minimum stress
$\Delta\sigma_b = \sigma_{max-}\sigma_{min}$	bending stress range

1. The minimum tubing size where the Hollow Rod must be operate, has to be OD 73 mm [2 7/8″] (inner diameter= 62 mm).
2. Maximum oil well curvature expressed by Dog Leg Severity, DLS: 15°/30 m
3. Maximum torque to be transmitted: 2500 ft lb.
4. Non upset and upset HR connections
5. HR must have high yield torque so that maximum torque is transmitted to the PCP pump without damage to the Hollow Rod string.
6. HR must have significant fatigue resistance better than conventional sucker rod and good backspin resistance. The backspin is a counter-rotation of sucker rod string when driving motor stops running.
7. HR has to be easy to make up and break out (assembly and disassembly of the threaded connection).
8. HR must have high resistance to jump out.
9. HR should not be welded to avoid fatigue and sulfide stress cracking damage.

2.1. Material selection

Several materials were proposed to be used in hollow sucker rods. However, after an exhaustive analysis of the mechanical and fracture mechanical properties of them as well as their manufacturing feasibility and trials, the appropriate material was a special high strength proprietary steel grade, AISI 1023 modified steel (Villasante et al., 2003b, 2007). The specified chemical composition and mechanical properties are shown in Tables 1 and 2, respectively. It can be seen that the selected material has high toughness and fracture toughness properties.

2.2. Geometry

Considering the design requirements, an optimum threaded connection was found after analyzing several connection geometry parameters such as thread height, flank angles, thread pitch, thread taper, shoulder angle, inner and outer diameters and thickness of the tube (Villasante et al., 1998; Villasante and Ernst, 2000, 2001a). Fig. 3 shows the thread geometry.

The connection is composed of a female box at the rod end which is engaged with a central male nipple (Fig. 4).

The main features of the new connection are the following:

1. Differential taper between the male threaded nipple and female threaded rod in order to reduce the stress values, particularly close to the first engaged thread.
2. The thread shape is trapezoidal non-symmetric with 8 threads per inch profile, being the thread height 1 mm. This is suitable for tubes with low thickness which are the cases of hollow sucker rods according requirements.
3. One external torque shoulder with reverse angle. This design is to avoid jump out and to increase the torque value.
4. Internal conical–cylindrical bore on the nipple. This allows the injection of different kind of fluids through inside of the hollow sucker rod.

As a second stage, after studying and analyzing the experimental results and field trial behavior, some improvements were proposed and carried out in some cases (Villasante et al., 2003c, 2010, 2011), see Fig. 5; they are as follows:

1. An internal seal zone which avoids erosion–corrosion phenomena when the oil has heavy particles and flows by the inner tube.
2. High radial thread interference which increases the yielding torque. However, a reduction of connection fatigue resistance can take place.

2.3. Hollow sucker rod family

To comply with the requirements the following family was developed

Initial family:

1. HR #1: HolloRod™ 1000,[2] it is external flush HR ⌀48 × wt 6 mm (Yield torque, M_{t_ys} = 1356 N m (1000 lbft)). To be used in 2 7/8″ Tubing.
   This product was replaced by HR #4.
2. HR #2: HolloRod™ 1500, it is HR ⌀42 × wt 5 mm + upset to 50 mm (M_{t_ys} = 2034 N m (1500 lbft)). To be used in 2 7/8″ Tubing.
3. HR #3: HolloRod™ 2500, it is HR ⌀48 × wt 6 mm + upset to 60 mm (M_{t_ys} = 3390 N m (2500 lbft)). To be used in 3 1/2″ Tubing.

2nd Stage (enhancements):

1. HR #4: HolloRod™ 1000 IF, it is external flush HR ⌀48 × wt 6 mm with modified nipple (M_{t_ys} = 1356 N m (1000 lbft)). To be used in 2 7/8″ Tubing.
   This product has an internal seal zone which is an improvement of the HR #1 (see previous item).
2. HR #5: HolloRod™ 1500F, it is external flush HR ⌀48 × wt 6 mm with modified nipple and high radial thread

[2] HolloRod™, is a trademark of TENARIS.