FLOW VELOCITY AS A FACTOR OF EROSIVE WEAR OF MUD PUMP VALVES

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This paper aims to develop a theoretical model in order to study the influence of the drilling fluid flow velocity on mud pumps valves wear.

Mud pumps are operated at a high flow rate of the drilling fluid. The mud pumps valves come under the action of the abrasive drilling mud, which leads to their early wear.

For the analysis of the velocity field in the flow area of the interspace between valve body and seat is used the finite element method.

Research has shown that the maximum velocity zones can be correlated with the wear appearance on the same areas.

Keywords: mud pump, valve body, valve seat, wear, finite element method.

1. Introduction

The drilling rigs are used to drill in different environments to realize the extraction of oil and gas from hydrocarbon reservoirs.

The mud pump of the drilling rig circulates the drilling fluid (mud) at high pressures into the drill string and back up through the annulus. The suction and discharge valves are important elements in the mud pump operation, their construction and their state largely influencing normal operation of the pump. [1]

A modern mud pump (triplex) is operated at high flow velocities of the drilling fluid, containing solid particles and detritus. This leads to abrasive wear of the mud pump components. The most affected parts are the mud pump valves.

The mud pump valves are manufactured in different constructive forms that can influence their wear resistance and therefore their service life.

Erosive wear of the mud pump valves influence the correct operation of the other pump parts and can result in mud pumps failure.

The paper presents a numerical analysis of the mud velocity field in the interspace between valve body and valve seat using the finite element method.

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The study was performed by using a simulation software ANSYS, a proprietary computational fluid dynamics program.

The drilling fluid velocity profile in the valve-seat interspace varies during suction/ discharge phases. It was calculated for different relative positions of the valve body and seat during mud pump operation. There were also considered different values for the valve seat angle.

2. Types of valves

Modern mud pump valves and seats can be divided into three categories according to their constructive form: [2, 3, 4]

2.1. Full-open valve

The full open constructive form of the valve is considered to be the most performant type of valve for present drilling conditions. The complete full open valve is shown in Fig. 1, in a cross section view.

The valve body and seat are usually made of alloyed steel, forged, with heat treatments. The valve body construction is solid, rigid, in one-piece, in order to withstand the high drilling pressures (34.5-51.7 MPa).

The valve seat has a fully open construction, without the support webs present at other types of valves. The pressure is uniformly distributed on the tapered surface of the valve, thus reducing the appearance of valve seat wear and increasing the valve assembly life. The simplified guide legs of the valve reduce turbulent flow through the valve thus increasing valve performance. This type of construction offers the possibility to remove the suction valve seats without removing first the discharge valve seats. If only a suction valve seat must be replaced, the costs associated to replacement times are reduced.

The valve insert can be made of different materials, depending on the requested drilling conditions. The standard insert can be replaced in the field and is usually made of polyurethane/ rubber. The polyurethane used commonly for valve inserts can withstand drilling temperatures up to 82°C (180°F). For higher temperatures, up to 93°C (200°F), valve inserts can be made of special compounds. Also, for high pressure drilling conditions, valves can be equipped with bonded inserts, non-replaceable, with better adherence and with longer wear life.

The standard valve spring is made of carbon steel. For a longer operating life and better performance, the valve spring can be made also of stainless steel.

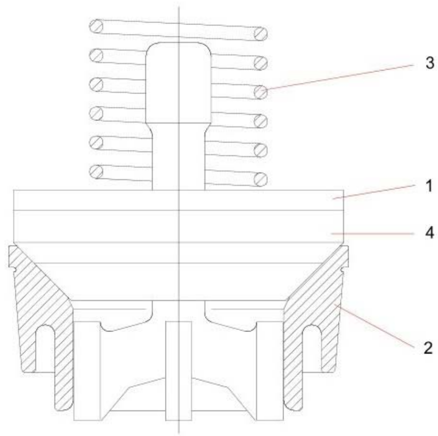

Fig. 1. Full open valve: 1. Valve body; 2. Valve seat; 3. Valve spring; 4. Valve insert.

2.2. Three web valve

The three-web valve is considered to be the most popular valve type used in the oil sector. This is a standard valve, commonly used for a variety of drilling conditions.

The three-web design is center guided, providing the support during pressure application for the valve body. During mud pump operation, the valve body is supported by the seating cone of the valve seat and the center upper part of its webs. This large support area for the valve, reduces the appearance of tensions in the valve components and increases their working life.

Both valve body and seat are obtained in the same way as the full open valve. The valve is made of alloyed steel, forged, heat treated. The one solid piece construction of the valve provides strength and durability at high pressures.

The valve insert has a special design that allows maintaining the drilling fluid above the valve, even when the pump is not functioning and there is no pressure to perform sealing. The insert channel of the valve body features special lips for keeping the gasket in place. This design decreases the potential for washing and loss circulation or for other solid particles to enter the sealed cavity.

As for the previous model of valve, the standard valve insert is field replaceable, but to ease the process, the manufacturers provide and recommend special installation tools. Valves are usually equipped with polyurethane/ rubber seals. For more demanding drilling conditions, the valve inserts can be made of a high temperature polyurethane.

Standard valve springs are made of carbon steel. There are also available valve springs made of stainless steel, with a longer operating life.

2.3. Four web valve

The four-web valve design is a profitable one for drilling applications in low and medium pressure range. This construction type is center guided and provides a large bearing area for the valve that increases its working life.

The valve insert is standard made of polyurethane/ rubber and for high pressure drilling, the valve can be equipped with a high resistant urethane seal. This design features a pre-charged insert, secured with a threaded retaining washer for easy disassembly. This characteristic make the valve inserts to be changed rapidly and decreases downtime. This valve type is suitable to drilling operations at low and medium pressures due to the assembly of two parts of the valve body.

The four web design, as the previous three webs, provides the valve body good support during pressure loads with the upper part of the webs, in addition to the seating cone of the valve seat. This design allows the existence of a large area to support the valve that reduces tensions and increases the valve lifetime.

The valve springs are made usually of carbon steel, for normal drilling operations. As an upgrade to the standard springs, there are also available springs made of stainless steel.

In Fig. 2 it is presented a cross section through the three/ four web valve design, highlighting the main components. The main mud pump valve designs used in modern rotary drilling are shown in Fig. 3.

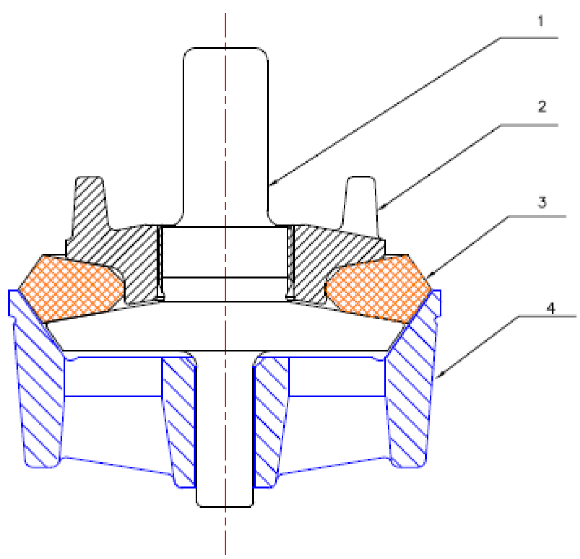

Fig. 2. Three/ Four web valve: 1. Valve body; 2. Valve nut; 3. Valve insert; 4. Valve seat

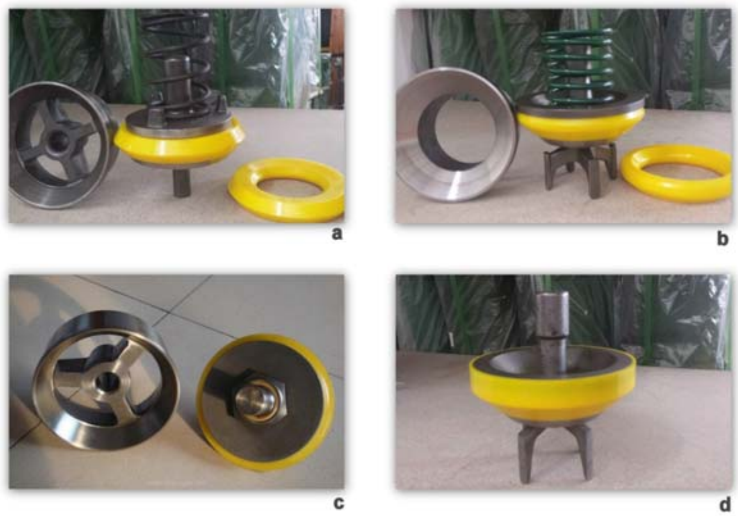

Fig. 3. Mud pump valve designs: a. four web valve; b. full open valve; c. three web design; d. bonded insert valve.

3. Mud pump valve wear

One of the typical failure of a mud pump is wear, which increases the delay between piston and cylinder and damages the suction and discharge valves. The valves wear, while drilling is intensive, can lead quickly to mud pump failure.[5]

The appearance of wear to suction and discharge valves is difficult to identify, because the leaks caused by the valve insert wear are not visible. They can only be detected in an advanced stage of deterioration, when keeping constant the discharge pressure becomes difficult. In such cases, the mud pump must be stopped immediately and the damaged valves should be replaced. [6] The difficulty is, however, to identify the valve is damaged or malfunctioning. One of the methods for assessing the condition of the valve is "the listening method". Unfortunately, this method is not accurate, safe and requires a comparison between acoustic effects of the different work units, approximately every fifteen minutes.

A common cause for valve assembly wear is caused by high operating pressure, as shown in Fig. 4. [7] The abrasive drilling fluid, containing solid particles and detritus, is circulated at high velocities and pressures which can damage all the mud pump components. [8]

Fig. 4. Valve assembly affected by erosive wear (offshore platform)

4. Drilling fluid flow velocity influence on valve assembly lifetime

In order to emphasize the velocity profile in the interspace between valve body and seat in triplex mud pumps, a numerical analysis based on the finite element method was performed. [9] For this purpose it was used FLOTRAN CFD module in ANSYS software.

The model consisted of the flow passage in a valve assembly size API 7.

In the performed analysis it was considered that the drilling fluid has the following hydrodynamic characteristics: density: $\rho = 1200\ kg/m^3$ and dynamic viscosity: $\eta = 20 \cdot 10^{-3}\ Pa \cdot s$. [10]

For a certain stroke of the valve body, that means a particular interspace between valve body and seat, the flow was considered to be stationary, in a turbulent regime. The drilling fluid was considered a Newtonian incompressible fluid.

Regarding the flow parameters of the drilling fluid, in order to validate the model it was considered that, at maximum flow rate, the input speed is v = 4 m/ s. Actually, the flow velocity varies, depending on the valve body position relative to the valve seat. The smaller is the interspace between valve body and seat, the higher are pressure and flow rates, implicitly the velocity rate. In our future research, the test will be made for different velocity values.

The analyzed situations correspond to the following valve strokes: j = 5; 10; 15; 22 mm, and the inclination angle was, according to drawings, $\alpha = 45°$. This value was changed by ±5° to study the influence on drilling fluid flow velocity.

The geometric model design was based on the dimensions of the valve assembly. An approximation of the model consisted in disregarding the three webs of the valve seat, therefore resulting in an axial-symmetric model. So, in the finite element analysis it was used FLUID141 element from ANSYS software library.

In the following figures (Fig. 5-10) are presented the drilling fluid speed distributions for different valve strokes and seat inclination angles.

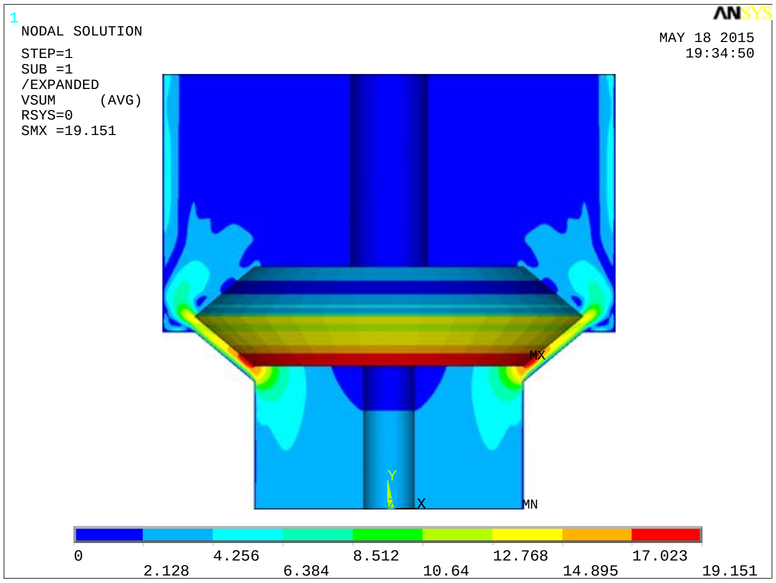

Fig. 5. Velocity field for the valve stroke of j = 5 mm and the seating angle α= 40°.

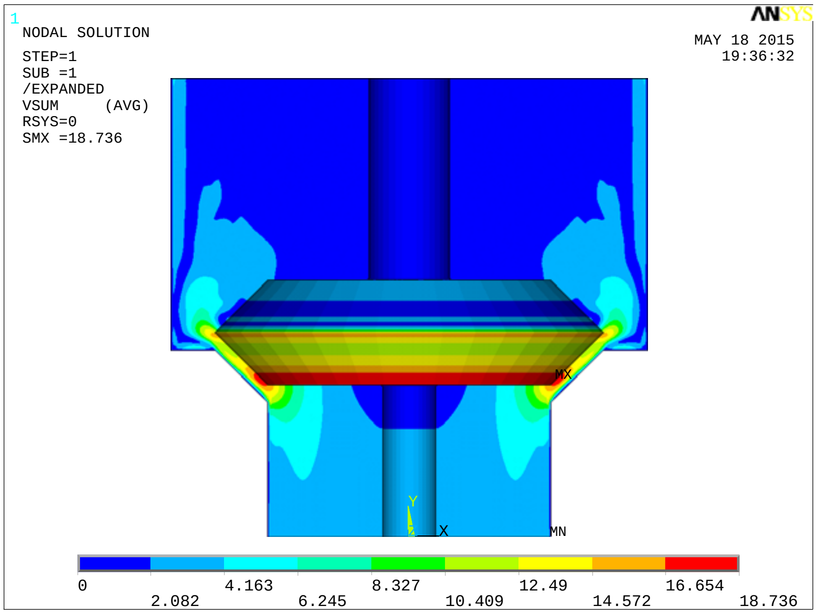

Fig. 6. Velocity field for the valve stroke of j = 5 mm and the seating angle α= 45°.

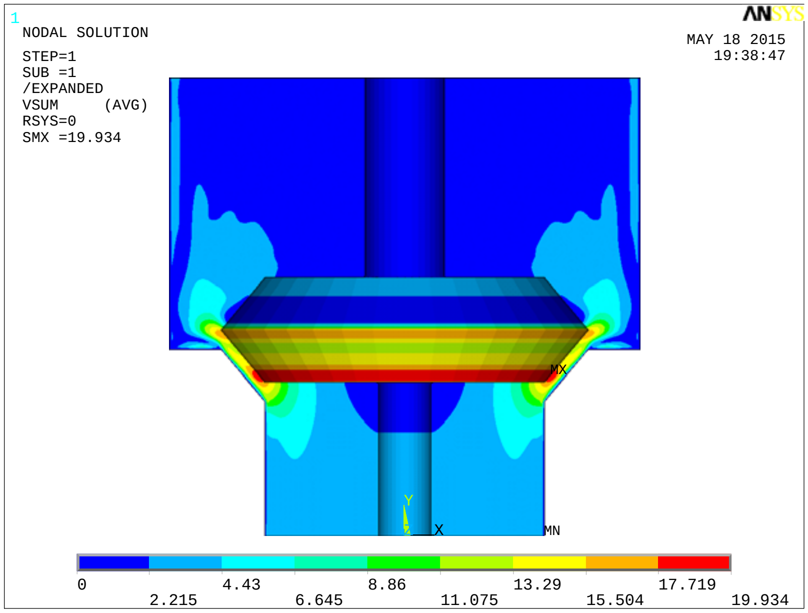

Fig. 7. Velocity field for the valve stroke of j = 5 mm and the seating angle α= 50°.

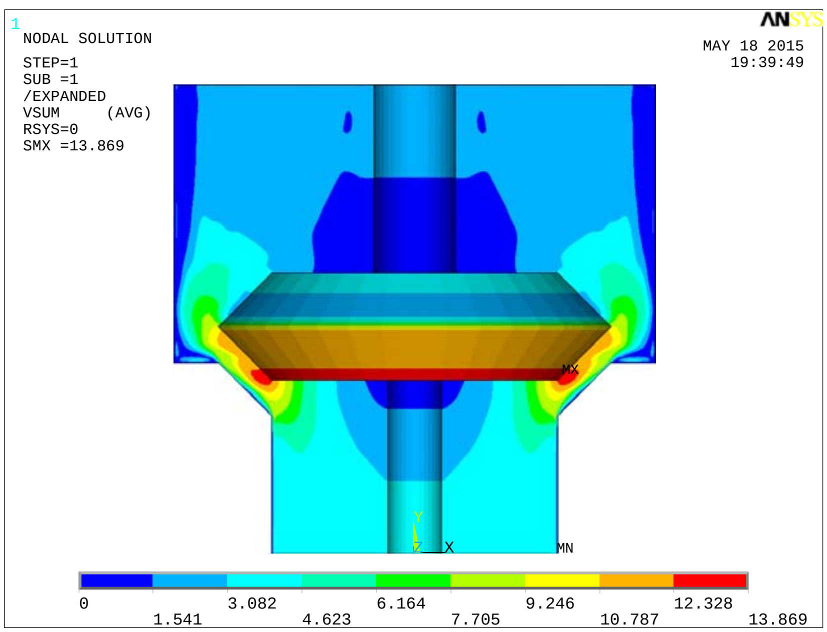

Fig. 8. Velocity field for the valve stroke of j = 10 mm and the seating angle α= 45°.

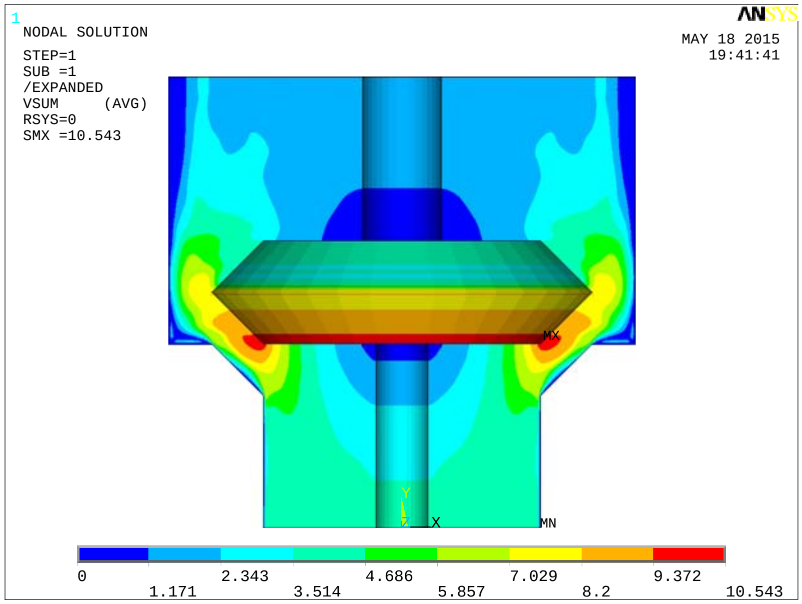

Fig. 9. Velocity field for the valve stroke of j = 15 mm and the seating angle α= 45°.

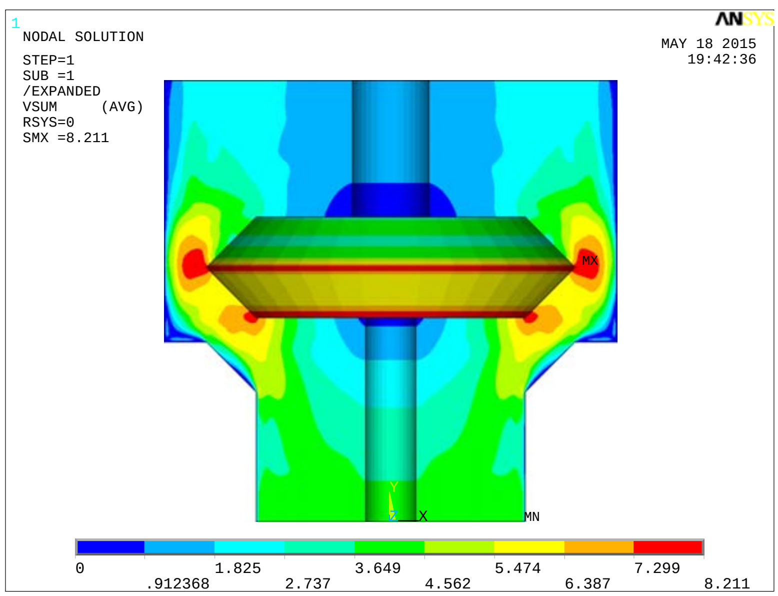

Fig. 10. Velocity field for the valve stroke of j = 22 mm and the seating angle α= 45°.

In figure 11 is shown the velocity variation of the drilling fluid along the area inclined at 45° of the valve body for an opening interspace of *j* = 5 mm.

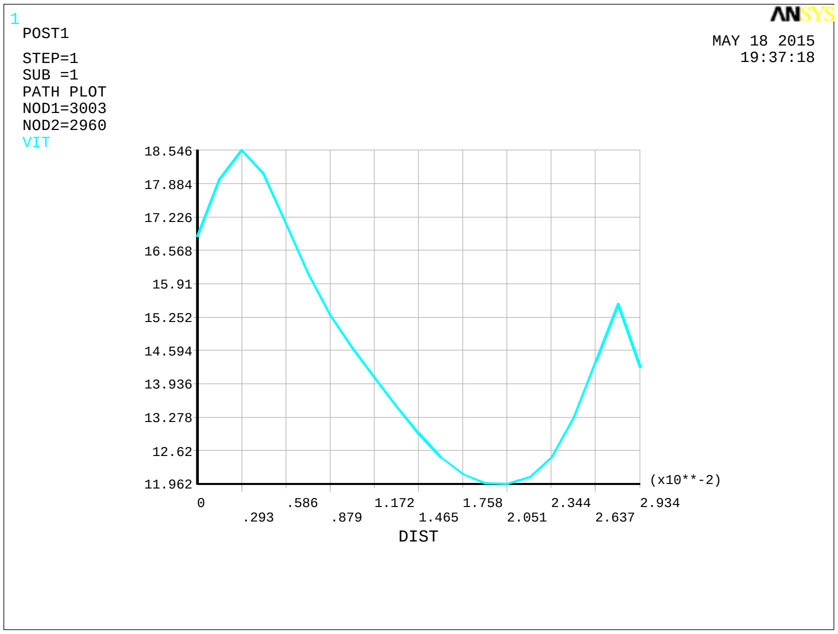

Fig. 11. Flow speed variation of the drilling fluid along the inclined area of the valve body for j = 5 mm and α = 45° (see Fig. 6).

The results show that, in the interspace between valve body and seat, the speed varies between v = 8.2 m/ s for j = 22 mm and v = 18.7 m/ s for j = 5 mm.

In Table 1, the influence of the inclination angle on the drilling fluid velocity rate is presented.

Table 1

Influence of the valve angle on the drilling fluid velocity

Valve stroke j [mm]	Inclination angle α [°]	Max. velocity v_{max} [m/s]
5	40	19,1
	45	18,7
	50	19,9

It is also observed that the variation of the angle α = 45° with ± 5° is not changing in a significant way the velocity value, and for the same valve opening, the minimum velocity corresponds to α = 45°.

For all the studied cases, the maximum velocity area is located at the bottom of the valve body which can be correlated with the occurrence of wear in this area.

6. Conclusions

Mud pump valves are affected by the abrasive drilling fluid circulating at high flow velocities, resulting on wear appearance.

Flow velocity in the interspace between valve-seat varies, depending upon the valve position in its ascending stroke:

- v = 8.2 m/ s for j = 22 mm
- v = 18.7 m/ s for j = 5 mm

The inclination angle has a small influence upon flow velocity values.

The flow velocity of the drilling fluid depends on the valve stroke (j). The smaller is the valve lift height, the higher is the flow rate.

For all the studied cases, the maximum velocity areas are located at the bottom of the valve body and at the top of the valve seat which can be correlated with the occurrence of wear in these areas.

Improving the lifetime of drilling mud pump valves leads to cost reduction (replacement or repairs of valves) and downtime reduction.

Acknowledgements

The experimental research work was performed using the equipment acquired with the financial support of European Union in the framework of the POSCCE Program “Regional Center for Determination of the Characteristics and Monitoring the Technical State of OCTG-Oil Country Tubular Goods” in Petroleum-Gas University of Ploiesti, Romania. The work has been funded by the Sectoral Operational Program Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132395 in “Politehnica” University of Bucharest, Romania.

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