SPE Paper 76759

Improved Means of Reducing Drag in ERD Applications

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This paper was prepared for presentation at the SPE Western Regional/AAPG Pacific Section Joint Meeting held in Anchorage, Alaska, U/S.A., 20-22 May 2002.

Abstract

The increasing number of difficult Extended Reach Drilling (ERD) applications in recent years has emphasized the need for reducing drill string drag. Drill string drag can substantially limit weight on bit and negatively effect directional control.

An improved type of drill pipe deployed Non-Rotating Drill Pipe Protector (NRDPP) has been developed that was found, both in laboratory tests and in actual down-hole drilling/sliding applications, to reduce drag inside casing up to 50% of that for bare drill pipe. This new tool incorporates existing NRDPP fluid bearing technology for torque reduction along with a modified geometry and the use of low-friction wear pads to reduce drag.

This paper describes the design and testing of the new “Low-Drag” NRDPP and provides a detailed discussion of three different wells that were drilled using this new tool for the purpose of providing drag, torque, and casing wear reduction. The wells, drilled by major oil companies in different regions of the world, were of varying profiles and possessed a unique set of operational circumstances.

Introduction

ERD has become a common practice throughout the world as a means to reach a maximum number of targets from a single location. In recent years there have been increasing demands on operators to drill farther and deeper, while maintaining a higher degree of directional control than ever before. There are many factors which can limit the success of difficult ERD wells, among the most important are the ability to manage torque, drag, and casing wear.

One effective means of managing torque and casing wear, which has been developed over the last ten years and is utilized throughout the drilling industry, is the drill pipe deployed NRDPP. Moore[1] et al. has described the development and testing of this technology and has detailed field case studies where such technology was utilized by major operators to achieve torque reductions of 10-30% as well as prevention of casing wear in ERD applications.

In many ERD applications, long horizontal or high angle hole sections must be drilled, requiring slide drilling (drilling with motor only) for extensive sections of the hole. In these applications, drill string drag can become a significant problem and may even result in the abandonment of a well short of the planned TD. Excessive drill string drag can limit weight-on-bit, contribute to drill string buckling, cause “stick-slip” effect along the drill string, and substantially reduce directional control.

For these reasons, an improved type of NRDPP has been developed that can, along with reducing torque and preventing casing wear, significantly reduce drill string drag. This new type of Low-Drag NRDPP has been tested extensively both in laboratory and actual down-hole applications for performance as well as durability. The Low-Drag NRDPP has been found to substantially reduce drill string drag inside casing (up to 50% of that for bare drill pipe) and has shown exceptional durability.

To date, Low-Drag NRDPPs have been run successfully on over 10 wells for major oil companies in the Gulf of Mexico, Offshore California, Western and Eastern Canada, South America, and the North Sea.

Design

The low drag NRDPP consists of three primary components: the “sleeve”, which is free to rotate with respect to the drill pipe, and two thrust bearing “collars” that are fixed to the drill pipe holding the sleeve in place axially with respect to the drill string. (See Figure 1). The Outer Diameter (O.D.) of the sleeve is designed to be larger than the drill pipe tool joint, providing stand-off between the tool joint and casing wall.

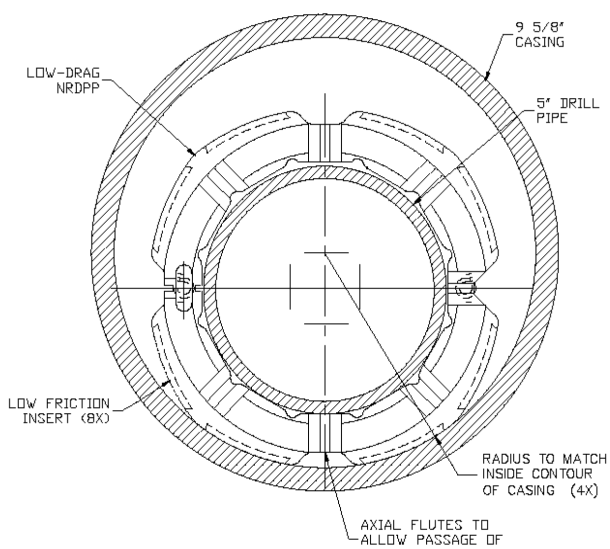
The two collars, top and bottom, are identical designs constructed of aluminum. The collars have a thrust bearing surface, which faces inward toward the sleeve, and a tapered lead-in facing away from the sleeve.

The sleeve is constructed primarily of a polyurethane body molded to a hinged steel reinforcing cage. The Internal Diameter (I.D.) of the sleeve incorporates the same "fluid bearing" geometry which has been used in previous designs of NRDPPs to successfully reduce drill string torque in hundreds of ERD applications around the world.

Figure 1: 3-1/2" Low-Drag NRDPP Inside 7" Casing

In addition, the Low-Drag NRDPP sleeve utilizes low-friction composite wear pads on the O.D. to significantly reduce the Coefficient Of Friction (COF) between the sleeve and casing wall. The sleeve's O.D. also incorporates a multi-radius geometry that allows maximum and uniform contact area between the low-friction wear pads and the casing wall, while ensuring adequate passage for drilling fluid flow in order to minimize hydraulic pressure loss across the sleeve. (See Figure 2).

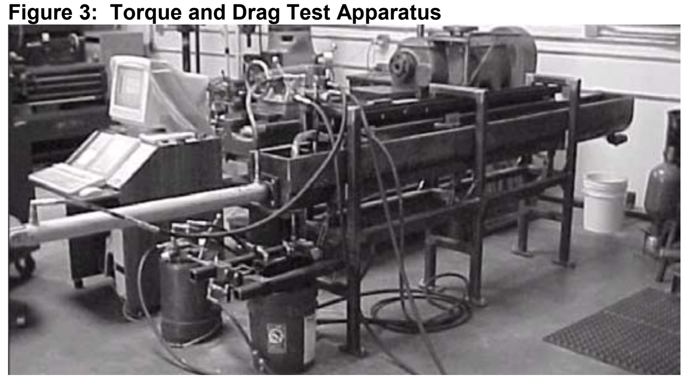
Figure 2: 5" Low-Drag NRDPP Inside 9 5/8" Casing.



Testing

Laboratory Testing. Prototypes of the low drag NRDPP were tested for performance and wear characteristics using a specially-designed test fixture. This test fixture is capable of simultaneously sliding a protector assembly down a section of casing filled with drilling mud while rotating drill pipe inside the NRDPP sleeve and applying side load between the casing and the protector sleeve. (See Figure 3). During this process rotary torque, axial load, and side load are simultaneously measured and recorded via data acquisition system, thus providing the sliding and rotating COFs. The tests were run over a range of side loads from 1,800 – 2,400 lbs, sliding velocities of 60 - 80 fpm, and Revolutions Per Minute (RPM) of 80 - 100. All of the tests were run in 11 ppg Water Based Mud (WBM). This testing was also repeated using a section of steel drill pipe without a NRDPP for comparison.

Figure 3: Torque and Drag Test Apparatus



These tests were conducted in an actual segment of 9-5/8" x 47 ppf casing. The casing was new with the I.D. surface left in stock condition/roughness with no polishing or other surface modifications. The data from the series of tests described above was combined providing the average rotational and sliding COFs shown in Table 1:

Table 1: Average Rotational and Sliding COF's.

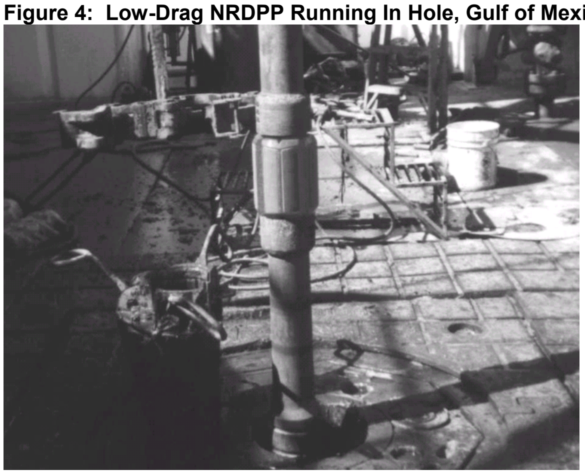
RESULTS	Low Drag NRDPP	Bare Drill Pipe
Average Sliding COF	0.11	0.21
Average Rotational COF	0.03	0.20

Field Testing. After quantitative laboratory testing had verified performance, ten Low-Drag NRDPP prototypes were manufactured for use in preliminary down-hole field trials. These were sent out to two separate offshore drilling operations in the Gulf of Mexico for the purpose of evaluating the durability of the new prototypes. (See Figure 4).

During these two field trials, the prototypes were subjected to more than 500 hours of down-hole operation. On both jobs, back-reaming operations were conducted, exposing the NRDPPs to side-loads well in excess of the rated 2,000 lb per protector side load.

The Low-Drag prototypes were returned from the field in excellent condition, with the low-friction inserts in tact and showing little wear. Although, the number of prototypes run was insufficient to create a measurable reduction of drag, these initial field trials were successful in demonstrating the durability and ruggedness of the new type of NRDPP.

Figure 4: Low-Drag NRDPP Running In Hole, Gulf of Mexico



Operational Experience

Case History 1 - Western Canada, August 2000. Case History 1 is an L-shaped well with a TD of 16,960 ft (5,169m). This well contained a 'jog' with dogleg severities of greater than 4deg/100ft(30m) high in the vertical section, producing high contact forces between the drill string and casing during the drilling of the 8 ½" hole section. (See Figure 5). These contact forces created excessive torque and drag, which inhibited the ability of the rig to rotate or slide the drill string effectively.

An initial quantity of 150 - standard NRDPPs were installed in the high contact force area of the drill string. (The protectors were installed on 5" drill pipe). This provided a significant torque reduction, allowing the rig to rotate the drill string at 25,000 ft-lb and also reducing drag to 101 kips (45 kdaN). During the following pipe trips the number of NRDPPs was increased to 300 (the area of NRDPP coverage is shown as the gray shaded region in Figure 5). This further reduced torque to 21,000 ft-lb and drag to 56 kips (25 kdaN). The 8-½" hole section was successfully completed using 300 - standard NRDPPs.

After completion of the 8-½" hole section, additional drag reduction was desired. For this purpose 100 of the standard NRDPPs were replaced by Low-Drag NRDPPs after the first bit run of the 6" hole section. Since the quantity of Low-Drag NRDPPs available for this application was limited, they were positioned in the areas of highest contact force (marked by "◊" in figure 5). Prior to installation of the Low-Drag NRDPPs, drag was measured at 61 kips (27 kdaN). After their installation, drag was reduced to 51 kips (22 kdaN). This equates to 17% additional drag reduction due to the installation of the Low-Drag NRDPPs.

Based on the recorded field data, COFs for the drill string inside cased hole were back-modeled using torque and drag software. This analysis yielded a COF of 0.09 for the areas of the drill string where Low-Drag NRDPPs were installed, and a COF of 0.20 for areas where they were not. These values correspond very closely to those observed in laboratory testing.

Figure 5: Contact Force Graph (Case History 1)

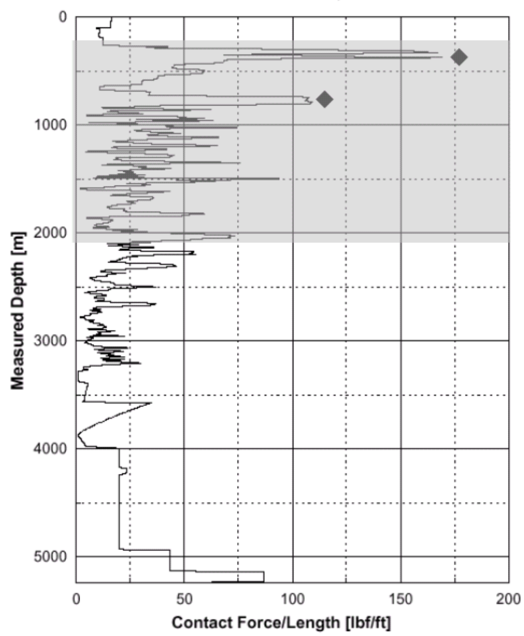
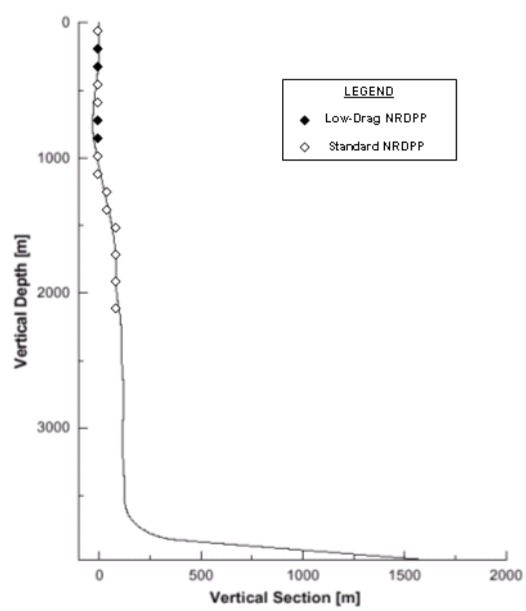


Figure 6: Vertical Section / NRDPP Placement (Case History 1)

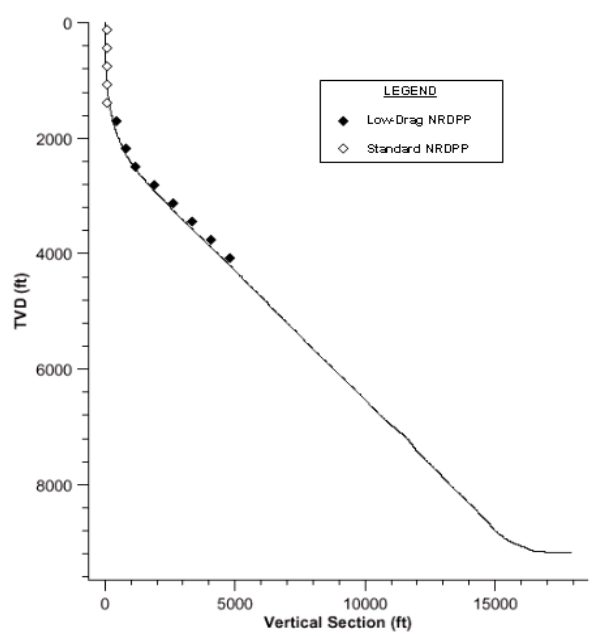


Torque and drag remained at acceptably low levels throughout the drilling of the 6” hole section from 13,990 – 16,960 ft (4,265 to 5,169m). After successfully reaching T.D. for this well, an ultrasonic logging tool was run to determine the condition of the casing. This log showed that no new casing wear had occurred during the drilling of the 6” hole section in areas where either Low-Drag or standard NRDPPs were installed.

Case History 2 – North Sea, January 2001. This case study involves the drilling of an ERD well in excess of 21,000 ft (MD). The well profile consisted of a build section high in the well followed by a long high angle tangent section and finally becoming horizontal to T.D. This well was the second side track through the original surface casing, therefore prevention of additional casing wear was of concern. For this reason, coupled with anticipated high torque, standard NRDPPs were run for the drilling of the 12-¼” and 8-½” hole sections. These hole sections were completed successfully while protecting casing and constraining torque within manageable levels.

Prior to the start of the 6” hole section, torque and drag analyses predicted that the drill string drag would become a problem in the horizontal section near T.D. It was decided that 171 of the 310 – 5-½” standard NRDPPs on the string be replaced with Low-Drag NRDPPs in order to minimize the drag and assure that the rig would be able to achieve sufficient weight-on-bit to reach the planned T.D. It was decided that the optimum placement of a limited number of Low-Drag NRDPPs was to run them starting at the end of the build section, whereby they would move out into the tangent section as the 1,600 ft bit runs were drilled. (See Figure 7).

Figure 7: Vertical Section / NRDPP Placement (Case History 2). NRDPPs shown mid way through 1,600 ft bit run.

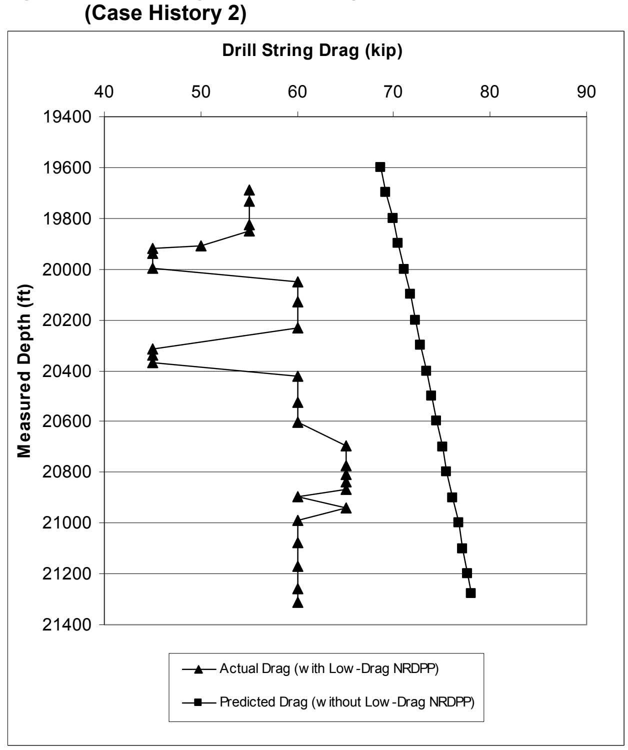


The protectors were installed while running-in-hole to drill out the shoe at the start of the 6” hole section. Because the protectors were installed on the initial bit run of the 6” section, it was impossible to achieve a direct comparison of torque and drag with and without the protectors installed for the same drill string at the same depth. For this reason, the actual torque and drag data recorded while drilling this well was compared to the theoretical torque and drag predictions made prior to drilling this well based on computer analysis and back-modeling the COFs from previous wells in the area with similar configuration.

The COFs used to calculate the predicted drag for the 6” hole section were 0.17 and 0.24 for cased and open hole, respectively. It is important to note that these values were an optimistic estimation, given the KCL polymer water based mud system used for this hole section. (COFs in this range are typically used to modeling wells using oil based mud systems).

Figure 8 shows both ‘actual’ and ‘predicted’ drag for the 6” hole section plotted versus measured depth. This data suggests that the Low-Drag NRDPPs produced an average drag reduction of approximately 23% for the 6” hole section.

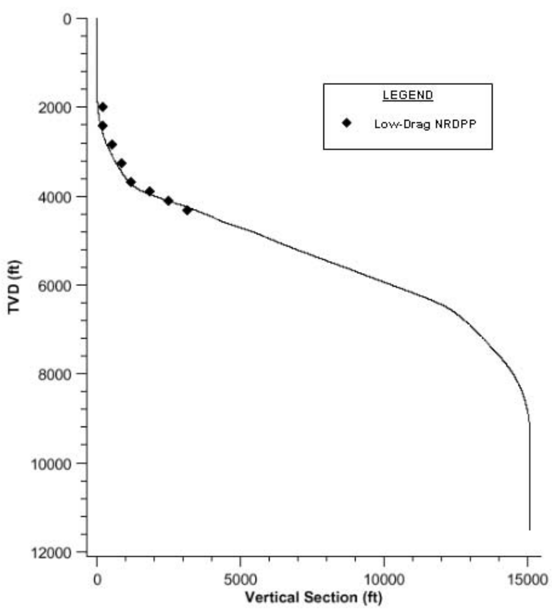
Figure 8: Drill String Slack-Off Drag, Actual vs. Predicted (Case History 2)



The 6” hole section was drilled successfully from 19,687ft to a final T.D. of 21,314 ft (MD) with the same configuration of standard and Low-Drag NRDPPs shown in Figure 7. Lower than expected torque and drag were experienced throughout the entire section, and casing logs confirmed that no additional wear had occurred in areas where protectors were used.

Case History 3 – Offshore California, June 2001. The well in this case history is an S-Shaped well drilled to a T.D. of over 20,000 ft. Drag, torque, and casing wear were expected to become significant factors during the drilling of the 8-½" and 6-1/8" hole sections of this well. For this reason, 266 Low-Drag NRDPPs were installed on the drill string at the start of the drilling of the 8-½" hole section. (The NRDPPs were installed on 5-1/2" drill pipe). Similar to the installation program described in "Case History 2", the Low-Drag NRDPPs were installed in the upper build section of the well, and allowed to run out into the tangent section as the bit runs were drilled. (See Figure 9).

Figure 9: Vertical Section / NRDPP Placement (Case History 3)



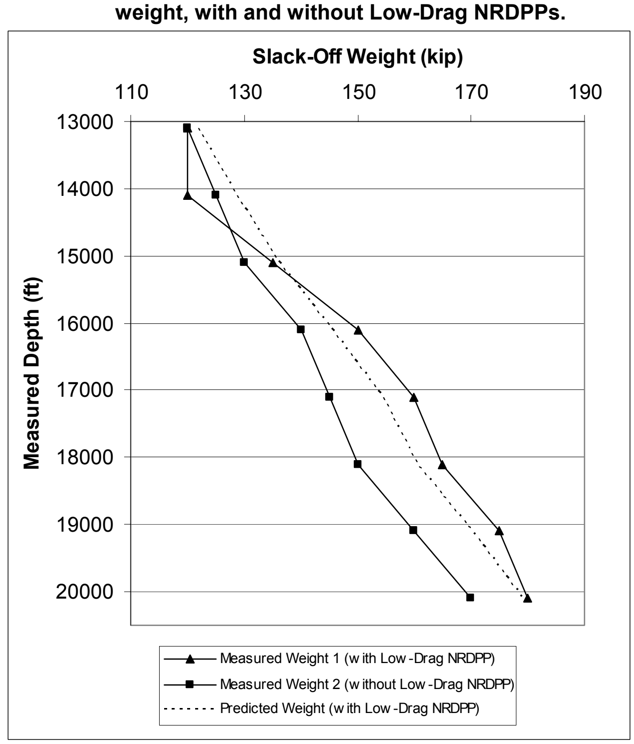
The 8-½" and 6-1/8" hole sections were successfully completed and the well reached final T.D. in December 2001. Drill string drag, torque, and casing wear were maintained within acceptable operating limits throughout the nearly six months of drilling, in which time the Low-Drag NRDPPs had accumulated over 3,000,000 rotational cycles without failure.

After reaching T.D. and setting the 5" production liner, the operator conducted a comparative test of drill string drag with, and without the Low-Drag NRDPPs installed. Pick-up, slack-off, and rotating weights were recorded by the driller every 1,000 ft while tripping out of the hole with the NRDPPs installed. The NRDPPs were then removed and the same string was run back into the well without the Low-Drag NRDPPs installed. The same measurements were again recorded on the following trip. (Figure 10 shows the actual measured slack-off weights for these two trips). Given a rotating string weight at T.D. of 230 kip, the weights shown in Figure 10 yield a drill string drag of 50 kip with the Low-Drag NRDPPs installed and a drag of 60 kip with them removed. This equates to a drag reduction of 17% at T.D. with the Low-Drag NRDPPs installed.

It is also important to note that the graphs for 'with' and 'without' NRDPPs converge as the bit depth nears 14,000 ft (MD). This is due to the fact that at T.D. the Low-Drag NRDPPs were positioned from 2,095 – 6,306 ft. Therefore as the drill string was pulled out of the hole, the number of Low-Drag NRDPPs in the well began to decrease above a bit depth of 18,000 ft. After the bit had reached a depth of 13,800 ft., no Low-Drag NRDPPs remained in the well.

Figure 10 also contains a graph of "Predicted Weight (with Low-Drag NRDPP)". This theoretical model was calculated based on the sliding COF of 0.11, which was derived from the laboratory testing of the Low-Drag NRDPP. As can be seen from this illustration, the predicted weight follows the actual weight quite closely when using the laboratory derived value for sliding COF. This data also suggests that the Low-Drag NRDPPs performed slightly better in this actual down-hole application than in the laboratory. This is likely due to the fact that an oil-based-mud system was used in this application, whereas water-based-mud was used for the laboratory testing.

Figure 10: Slack-Off Weight. Actual measured drill string weight, with and without Low-Drag NRDPPs.



Conclusions

The conclusions of this paper are as follows:

- Drill string drag can be reduced by 17 – 23% through the use of Low-Drag NRDPPs.
- The sliding Coefficient Of Friction (COF) for the Low-Drag NRDPP running inside casing was established at 0.11 (half of that for bare drill pipe) through extensive laboratory testing. This

performance has been validated in actual down-hole drilling applications.

- Low-Drag NRDPPs can be incorporated into computer torque and drag models to accurately predict drag reduction that can be achieved in a particular application.
- Low-Drag NRDPPs achieve the same torque reduction and casing wear prevention performance as the standard fluid bearing type NRDPPs that have been used throughout the drilling industry for the past ten years.
- Low-Drag NRDPPs can be positioned strategically along with standard type NRDPPs to successfully achieve substantial torque, drag, and casing wear reduction in a variety of ERD applications.

References

1. Moore, N.B., Mock, P.W., Laule, R.B., Krueger, R.E., “Reduction of Drill String Torque and Casing Wear in Extended Reach Wells Using Non-Rotating Drill Pipe Protectors”, paper SPE 35666 presented at the 1996 SPE Western Regional Meeting, Anchorage, May 22-24.