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COMPARING PRESSURE LOSSES AND ECD ON THE DIRECT AND REVERSE CIRCULATION SYSTEMS

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Abstract. *The cuttings cleaning at the bottom hole during drilling operations is performed through the flow of the drilling fluid in the circulation system, which can occur by the direct or reverse circulation methods. This work aims to study the pressure drop in the annular space, located between the well and drill string, during the cuttings transportation by the drilling fluid in the direct and reverse circulation systems, as well as calculate and analyze the equivalent circulating density. For this, two intervals were analyzed in a drilling operation of an onshore well, the first one using reverse circulation, and another, the conventional circulation system. The calculated pressure drops were smaller in the interval drilled with reverse circulation and this difference is mainly related to the lower flow rate used. These results show the possibility of using reverse circulation in wells whose geometry presents greater lengths, since the energy required for pumping the drilling fluid will be substantially lower than in the direct circulation.*
Keywords: *pressure losses, equivalent circulating density, reverse circulation, direct circulation*

1. INTRODUCTION

A successful drilling operation depends, among other factors, on the cleaning of the cuttings from the drilled formation. This function is performed by the circulation system, which is a closed path covered by the drilling fluid. The most common method used is the direct circulation. On this method the drilling fluid is pumped from tanks and displaced by surface equipment down through the drill string towards the bit nozzles (MACHADO, 2002; THOMAS, 2001). In this case, the fluid returns to the surface through the annular space, carrying the cuttings drilled. On the other hand, in the reverse circulation system, which is a recent innovation, the drilling fluid makes the opposite way, being injected in the annular space and returning to the surface through the drill string.

Regardless the circulation method used, the flow of the drilling fluid during its course in the well experiences pressure losses due to the friction between the fluid and the contact surface, also known as pressure losses. The pressure losses occur throughout all the flow path of the fluid in the circulation system, including the inside of the drill string, bit and annular space. In this way, the pumps must provide a minimum differential pressure, capable to compensate the pressure losses suffered by the fluid as it flows in the well. Thus, accurate prediction of the pressure losses in a circulation system, as well as the distribution of these along the well sections, play a key role in the planning and monitoring of drilling operations (MINTON and BERN, 1988).

The pressure losses in the annular space influence the dynamic pressure that the fluid exerts against the formation to a certain depth and is therefore related to the safety and stability of the well. This relationship is expressed by the calculation of equivalent circulating density (ECD), which comprises a density measurement equivalent to the increase in pressure due to the pressure losses in the annular space with the flow of the fluid (COSTA, 2006). Thus, the calculation of this indicator is based on the sum of two pressure components: the hydrostatic pressure, exerted by the fluid column at a given depth, and the pressure loss due to the fluid flow between that depth and the surface (MACHADO, 2002). The ECD value is compared to the pore and fracture gradients, so that the stability and safety of the well is guaranteed (QUEIROZ JÚNIOR, 2013).

According to McCann (1993), the ECD calculation more clearly demonstrates the overall impact of the annular pressures losses. Bailey and Penden (2000) argue that an adequate quantification of the system pressure losses improves the accuracy of the calculated ECD, as well as advantages such as maintenance of underbalance conditions, prevention of circulation losses, indications of kick probability and improvements in the efficiency of the drilling operation generally through proper well cleaning performance.

The objective of this study is to study the pressure losses in the annulus, comparing the methods of direct and reverse circulation, as well as to relate these losses to the equivalent circulation density (ECD) of the drilling fluid.

2. METHODOLOGY

2.1 Well studied and interval analyzed

The analyzes carried out on this study considered the drilling of the 12,25-inch-diameter phase of an onshore directional well, between 1105 and 2830 meters. For the drilling of this phase the direct and reverse circulation systems were used alternately. Table 1 shows the initial and final depth of each interval drilled, as well as weight on bit (WOB), rotation (RPM), flow rate, and circulation method used.

Table 1. Intervals and operational parameters related to the drilling of the 12.25 in. phase of the well.

Interval	Starting (m)	Ending (m)	WOB (Klbs)	RPM	Flow Rate (gpm)	Circulation Method
1	1105	1188	40	100	850	DIRECT
2	1188	1480	40	90	100,5	REVERSE
3	1480	1495	35	100	100,5	REVERSE
4	1495	1498	35	100	850	DIRECT
5	1498	1507	35	100	850	DIRECT
6	1507	1528	45	100	100	REVERSE
7	1528	1847	40	100	750	DIRECT
8	1847	1890	40	100	100	REVERSE
9	1890	1987	38	110	130	REVERSE
10	1987	2012	32	110	130	REVERSE
11	2012	2020	37	110	140	REVERSE
12	2020	2215	47	100	100	REVERSE
13	2215	2830	10	126	900	DIRECT

The interval 2, which uses reverse circulation and 13, which uses direct circulation, were selected for the analysis of the pressure losses along the path of the drilling fluid in this study. Additional operational parameters related to each interval used for the calculations of the pressure loss are summarized in Tables (2) and (3), which present data regarding to the depths and diameters of the interval and the previous casing, as well as properties of drilling fluids.

Table 2. Operational parameters related to intervals 2 and 13.

	Interval 2	Interval 13
Wellbore Depth (m)	1480	2830
Wellbore Diameter (in)	12,25	12,25
Casing Depth (m)	1098,5	1098,5
Casing Diameter (in)	13,375	13,375

Table 3. Drilling fluids properties used in intervals 2 and 13.

	Interval 2	Interval 13
Density (lb/gal)	10,1	9,8
Plastic Viscosity	65	53
Yield Strenght	45	44

2.2 Division of annular subsections

The composition of the bottom hole assembly (BHA) was considered to divide the annular into subsections, depending on the casing depth, total depth of the phase and length of drill pipes, heavy weights and drill collars. Each subsection was named according to the acronyms presented in Table 4. The abbreviations represents the initial letter of the internal component (drill pipe, drill collar or heavy weight) and external component (open hole or cased hole) limiting the subsection. From this division, each subsection had its length and internal and external diameters defined.

Table 4. Subsections on the anular space.

Subsection	Abbreviation
Drill Pipe/Open hole	DP/OH
Drill Pipe/Cased hole	DP/CH
Heavy Weight/Open hole	HW/OH
Heavy Weight /Cased hole	HW/CH
Drill Colar/Open hole	DC/OH
Drill Colar/Cased hole	DC/CH

2.3 Pressure drop calculation

After the division of the annular subsections, the pressure losses on the annulus were calculated according to Eq. (1).

$$\Delta P_{anullus} = \frac{L \text{ x } YS}{68{,}58 \text{ x } (\emptyset_o - \emptyset_i)} + \frac{L \text{ x } PV \text{ x } V}{24730 \text{ x } (\emptyset_o - \emptyset_i)^2} \quad (1)$$

For this equation, the variables L, $\emptyset o$ and $\emptyset i$ are related to each subsection of the annular. L corresponds to the length, in meters, $\emptyset o$ is the diameter of the component that limits the annular externally (open hole diameter or inner diameter of the casing) and $\emptyset i$ is the diameter of the drill string component that establishes the inner limit of the annulus (outside diameter of the drill pipe, heavy weight or drill collar). All diameters are considered in inches (in). The variables PV and YS correspond to the plastic viscosity and yield strength of the fluid, given in cP (centipoise) and lb / 100ft^2, respectively. V corresponds to the flow velocity of the drilling fluid in ft / min, calculated through Eq. (2).

$$V = \frac{24{,}51 \ x \ Q}{(\emptyset_o^2 - \emptyset_i^2)} \quad (2)$$

On Eq. (2), $\emptyset o$ and $\emptyset i$ assumes the same value than for Eq. (1), and Q corresponds to the flow rate used to drill the subsection.

2.4 Equivalent Circulating Density (ECD) Calculation

Considering the pressure losses to be overcome by the fluid, calculated according to the equations already presented, the equivalent circulation density, ECD, was calculated at two depths of the annular: at the casing shoe, which corresponds to the depth at which the casing was seated, and at the bottom of the well. The ECD calculation was performed according to Eq. (3).

$$ECD = \frac{P_h + \Delta P_a}{0{,}17 \text{ x } D} \quad (3)$$

Where P_h is the hydrostatic pressure of the fluid, in psi; ΔPa is the pressure drop on the annular section due to fluid flow between the depth D, measured in meters, and the surface.

The hydrostatic pressure exerted by a column of fluid at a depth D, in meters, is given by Eq. (4).

$$P_h = 0{,}17 \ x \ \rho x D \quad (4)$$

ρ is the density of the drilling fluid, in lb / gal.
In this way, the equivalent circulating density can be calculated using Eq. (5).

$$ECD = \rho + \frac{\Delta P_a}{0{,}17 \text{x } H} \quad (5)$$

3. RESULTS AND DISCUSSION

The division of the annular subsections are presented in Tables 5 and 6, for the intervals 2 and 13, respectively. The tables show the inner and outer diameter and lengths of each subsection.

Table 6. Annular subsections on interval 2.

Subsection	Outside Diameter (in)	Inside Diameter (in)	Length (m)
DC/OH	12,25	6,75	102,35
HW/OH	12,25	5,5	56,53
DP/OH	12,25	5	222,62
DP/CH	13,375	5	1098,5

Table 7. Annular subsections on interval 13.

Subsection	Outside Diameter (in)	Inside Diameter (in)	Length (m)
DC/OH	12,25	6,75	93,74
HW/OH	12,25	5,5	56,53
DP/OH	12,25	5	1581,23
DP/CH	13,375	5	1098,5

For each of the subsections defined in Tables 6 and 7 the flow velocity of the fluid was calculated. The values obtained are set out in Tables 7 and 8 for intervals 2 and 13, respectively.

Table 7. Flow velocities on interval 2 subsections.

Subsection	Velocity (ft/min)
DC/OH	23,57
HW/OH	20,56
DP/OH	19,70
DP/CH	16,00

Table 8. Flow velocities on interval 13 subsections.

Subsection	Velocity (ft/min)
DC/OH	211,10
HW/OH	184,11
DP/OH	184,11
DP/CH	148,40

As can be seen, the flow velocities along the annular are considerably greater in the range 13, which was drilled using direct circulation. This result is attributed to the low flow rate in the reverse circulation, which was about nine times lower than that used in direct circulation. It is noteworthy that the lower flow velocities in the reverse circulation do not cause operational problems related to well hydraulics. According to Sansoni (2005) the reverse circulation provides higher velocities during the flow of the fluid inside the drill string, due to the smaller diameters in that region. In this way, those higher velocities enable a proper well cleaning.

From the fluid flow velocity values in each of the subsections, presented above, the respective pressure losses were calculated. The calculated pressure loss values for the subsections of the two intervals are shown in Table 9 and in the graph in Fig. 1. The last line of the Table 9 and two first columns of the graph correspond to the total pressure losses at the annulus for each interval, being obtained by the sum of the pressure loss in each subsection.

Table 9. Pressure drops on intervals 2 and 13.

Subsection	***Pressure drop (psi) Interval 2***	***Pressure drop (psi) Interval 13***
DC/OH	12,09	12,73
HW/OH	5,42	6,03
DP/OH	19,86	168,85
DP/CH	84,63	97,76
Annulus	122	285,37

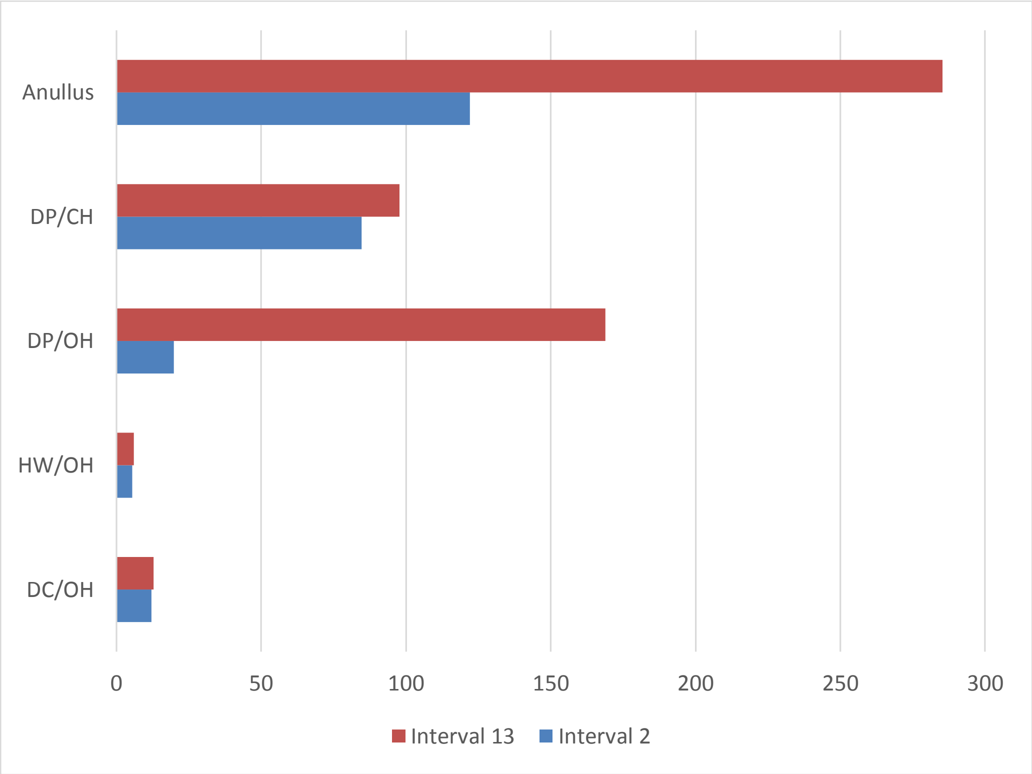

Figure 1. Pressure losses for each subsection and total pressure loss on the annulus.

As can be noticed, the pressure losses in the interval 2 are always smaller than in the interval 13. However, this difference is more significant when comparing the subsection of the annulus between the drill pipe and open hole (DP / OH), which has a length considerably greater in the interval 13. Thus, the differences between the calculated pressure losses in this section may be largely related to the difference in lengths between them, and not necessarily to the circulation method used.

The pressure drop at the section between the drill collar and the open hole (DC / OH) points out the advantages of the operating parameters used in reverse circulation. In this case, even with a longer length on the subsection of the interval 2, the pressure loss calculated was smaller. For the subsections with the same length in the two intervals (DP / OH and HW / OH) the pressure losses in the interval drilled with reverse circulation were also smaller, presenting a reduction of approximately 11% and 15%, respectively, in relation to the calculated values with the direct circulation method.

These results confirm the advantages of using the reverse circulation method proposed by Torres (2006), which emphasizes the possibility of using smaller flow rates and drilling fluids with simpler rheological properties. It is expected that these factors will allow the reduction of the annular pressure losses, as observed in this study, as well as in the other well regions. This fact guarantees the possibility of using smaller pump pressures, and, as a result, the application of reverse circulation to drill oil wells whose geometry has a great length, such as the directional ones. For these cases, the drilling using the conventional method is often prevented due to the high energy demanded by the pumping system.

The ECD values for each of the ranges are shown in the graphs of Fig. (2) and (3). The ECD calculated on the casing shoe and at the bottom of the well was compared to the original density value of the fluid used.

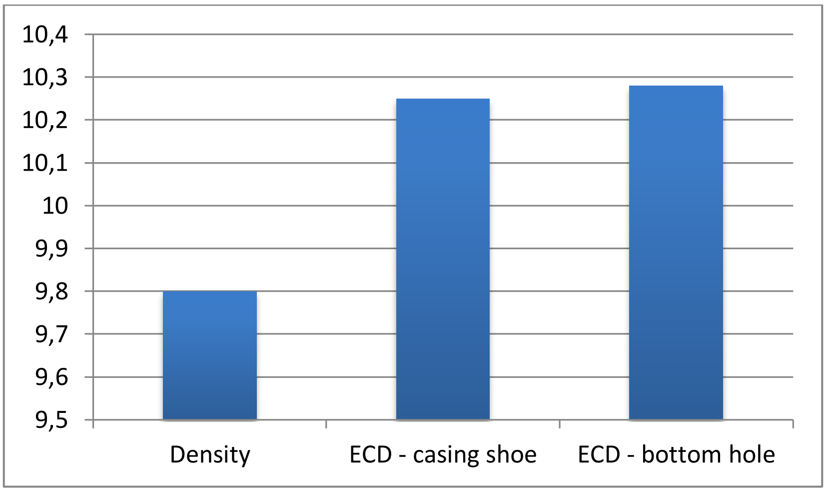

Figure 2. ECD calculated for interval 2.

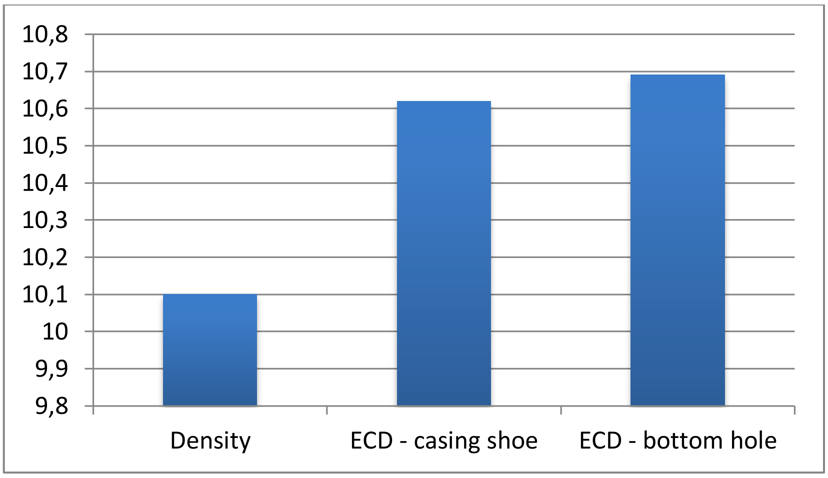

Figure 3. ECD calculated for interval 13.

The equivalent circulation densities obtained represented percentage increases of approximately 4% and 5% for the intervals drilled using the reverse or direct circulation method, respectively. The absolute values meet the operational window of the well studied, ensuring the stability and safety of the well for both methods.

4. CONCLUSION

The objective of this work was to compare the pressure losses in the annular space, in the systems of direct and reverse circulation, as well as the calculation and the analysis of the equivalent density of circulation - ECD. From the obtained results we conclude that:

i) In all subsections of the annular space the reverse circulation method presented moderate reductions in the pressure losses compared to the values obtained in the interval drilled using direct circulation;

ii) The operating conditions of the reverse circulation system make it possible to drill wells whose geometry has a longer length due to the lower pumping pressures required to overcome the drilling fluid's pressure losses.

iii) The predicted ECD values represent increases of 4% and 5% in relation to the initial fluid density for the reverse and direct circulation methods, respectively.

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6. RESPONSIBILITY NOTICE

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