Modeling on Cuttings Transport in Inclined and Horizontal Well Drilling

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Abstract. In inclined and horizontal well drilling, cuttings transport is playing a very important role in obtaining a safe and efficient drilling plan. The paper presents two empirical models, namely Larsen's model and Rubiandini's model, which were considered to evaluate the cuttings transport in both inclined and horizontal well drilling in offshore Vietnam. A parametric study considering different drilling parameters such as mud weight, rate of penetration (ROP), mud rheology, etc. indicated that the two empirical models provided the same trends of the flow velocity and flow rate required for transportation of mud cuttings. It is concluded from all simulations that the flow rates predicted by both Larsen's model and Rubiandini's model are reasonably close to the actual flow rates in the drilling operation. Moreover, it is also observed from the analyses of the horizontal drilling case that the use of Rubiandini's model could generally result in larger flow rate required for cuttings transport compared to Larsen's model.

Keywords: Cuttings transport, Empirical models, Inclined and horizontal well drilling, Offshore Vietnam.

1 Introduction

Cuttings transport is one of the most common and complex subjects for drilling operations. It is also required to be monitored and properly controlled during the entire well drilling operations. Circulation of drilling fluid is an integral part of the drilling operation. The drill bit crushes the rock formation into small pieces called cuttings. The drilling fluid is pumped through pipes and then circulated back through the annulus bringing cuttings to the surface facilities. The ability of a circulating drilling fluid system to transport cuttings is known as the carrying capacity of the drilling fluid.

Cuttings transport predictions are essential for the planning of inclined and horizontal drilling. However, there are still a little limited number of works relating to the cuttings transport in deviated and horizontal wells. In this study, Larsen's and Rubiandini's models [1, 2] will be considered and compared to identify differences between them by using a calculating program written from Matlab language. The obtained simulations were based on the rheological data, drilling parameters, and cutting properties from a horizontal well drilled at offshore Vietnam.

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2 Modeling Of Cuttings Transport Process

2.1 Larsen's Model

In 1997, based on a large number of experimental studies Larsen et al. focused on cuttings size, inclination angle and mud weight that significantly affect cuttings transport in directional and horizontal wells [1]. The mud minimum rate V_{min} is a sum of velocity of the fallen cuttings V_{cut} and the slip velocity V_{slip}. Based steps to calculate the cuttings transport process from Larsen's model are shown in the following flowchart (Fig. 1).

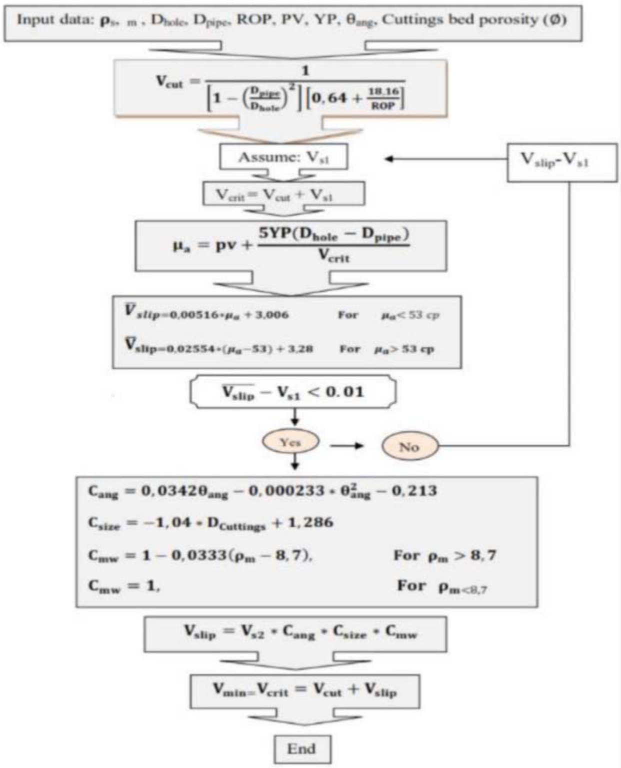

Fig. 1. Flowchart to calculate the cuttings transport from Larsen's model [3].

2.2 Rubiandini's Model

In 1999, Rubiandini presented a new equation to estimate the mud minimum rate for cuttings transport in the inclined-until-horizontal well [2]. He believed that the cuttings transport mechanisms are affected mainly by mud weight, inclination angle and rotary speed RPM. Therefore, the correction factors of these parameters played a main role in his model. Based steps to calculate the cuttings transport process from Rubiandini's model are shown in the following flowchart (Fig. 2).

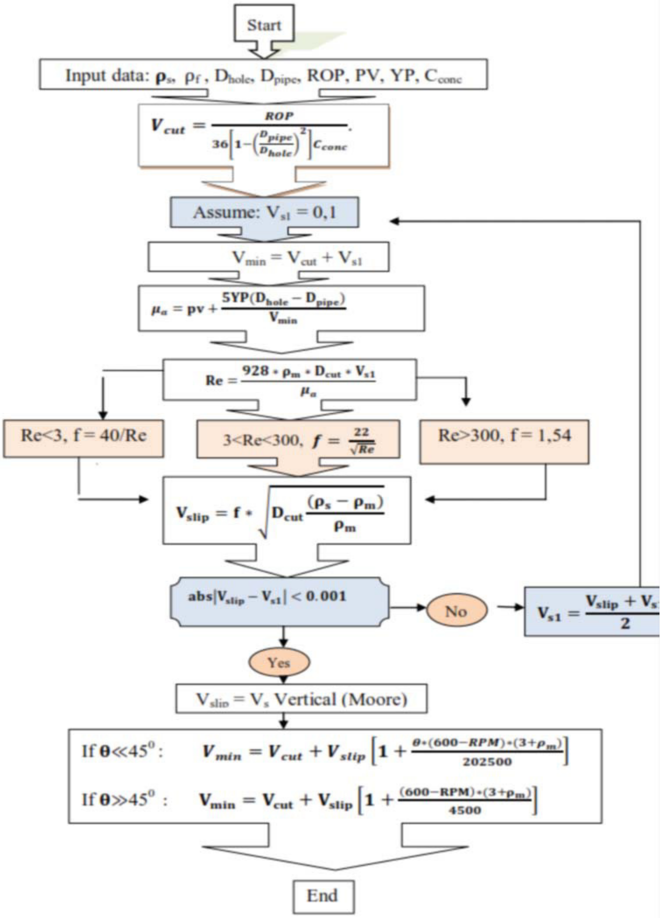

Fig. 2. Flowchart to calculate the cuttings transport from Rubiandini's model [3].

3 Case study for a horizontal well drilling at offshore Vietnam

3.1 Input data

In this study, predictive calculations for the case study well are carried out with drilling parameters as:

D_{pipe} = 5.5 inch; D_{hole} = 8.5 inch;

Drilling fluid: ρ_m=1.16 – 1.26 g/cm^3 ± 0.02;

PV = 25 cp; YP = 25 lbf/100ft^2;

D_{cutt} = 0.1 mm = 0.004 inch;

ROP = 40 m/h or 131.234 ft/hr;

RPM = 120 rpm.

3.2 Results and discussions on the required flow rate

Using the Matlab computer program, predictive curves are drawn from the experimental data set. In the simulations, the following variables were used for both Larsen's and Rubiandini's models and only one of these parameters is varied in each simulation. The predictive curves of the required flow velocity or flow rate versus with variation of parameters, which includes mud weight, rate of penetration ROP, mud rheology, etc. as a varying parameter, for both Larsen's and Rubiandini's models are shown in Fig. 3, 4, 5.

Mud weight as a varying parameter

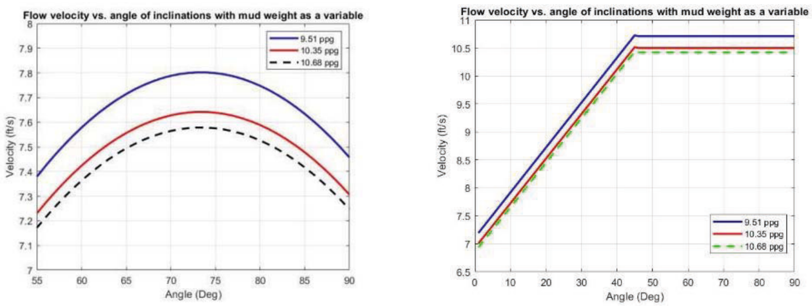

Fig. 3. Flow velocity vs. angle of inclination with mud weight as a variable (from Larsen's model on the left and from Rubiandini's model on the right).

ROP as a varying parameter

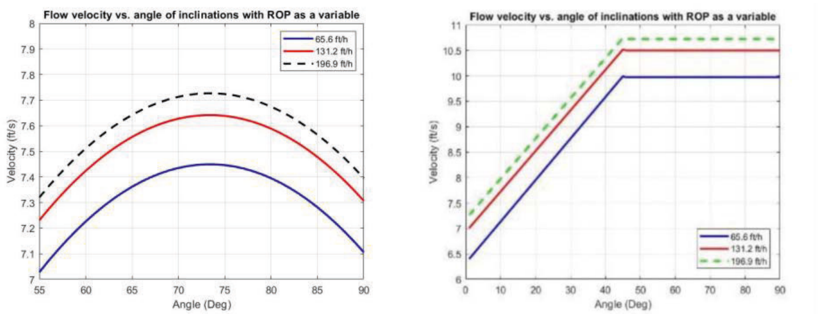

Fig. 4. Flow velocity vs. angle of inclination with ROP as a variable (from Larsen's model on the left and from Rubiandini's model on the right).

Mud rheology as a varying parameter

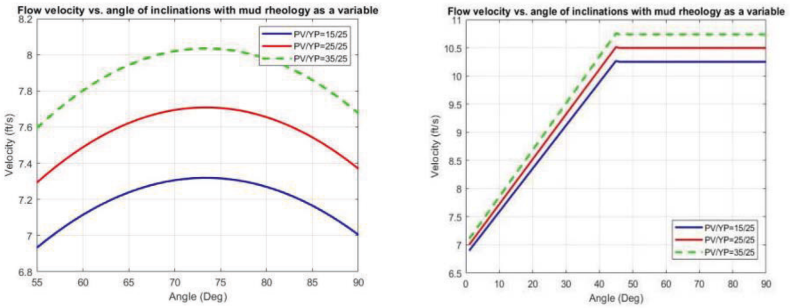

Fig. 5. Flow velocity vs. angle of inclination with mud rhelogy as a variable (from Larsen's model on the left and from Rubiandini's model on the right).

Moreover, at inclination angle of 75 deg. the obtained results on the required flow rate from using Larsen's and Rubiandini's models are compared in the following tables. The error equation [2] was used in order to identify the distinctions or similarities between Larsen"s and Rubiandini"s models:

$$Error = \left| \frac{V\min, Rubi - V\min, other}{V\min, Rubi} \right| \quad (1)$$

Table 1. Flow velocity value vs. inclination angle with mud weight as variable parameter.

Mud weight (ppg)		9.51	10.35	10.68
Flow rate (l/s)	Larsen's Model	51	50	49
	Rubiandini's Model	69	68	67
Error of flow rate (%)		26.1%	26.5%	26.9%

Table 2. Flow velocity value vs. inclination angle with ROP as variable parameter.

ROP (ft/hr)		65.6	131.2	196.9
Flow rate (l/s)	Larsen's Model	48	49	50
	Rubiandini's Model	65	68	70
Error of flow rate (%)		26.1%	28.0%	28.6%

Table 3. Flow velocity value vs. Inclination angle with mud rheology as variable parameter.

Mud Rheology (PV/YP)		15/25	25/25	35/25
Flow rate (l/s)	Larsen's Model	47	50	52
	Rubiandini's Model	67	68	70
Error of flow rate (%)		29.9%	26.5%	25.7%

By analyzing flow rate results from both Larsen’s and Rubiandini’s models, the differences between these two models and how various drilling parameters affecting cutting transport can be observed as following:

- *Mud weight as a variable:* both models showed the same trend, namely the flow velocity decreases as mud weight increases. This means that high mud weight improves cuttings transport. The difference between these two models increases slightly as mud weight increases (mean error of 26.5%).
- *ROP as a variable:* both models also showed the same pattern, namely high ROP values generated high flow velocity. The difference between these two models was rather significant (26.1%, 28.0% and 28.6%).
- *Mud rheology as a variable:* both models indicated the same trend, namely higher mud rheology produced higher flow velocity. However, the difference between these two models decreases as mud rheological parameter increases (29.9%, 26.5% and 25.7%).

4 Conclusions

Based on all simulation scenarios performed by using Larsen’s and Rubiandini’s models, it could be concluded that the flow rates for cuttings transport predicted by both Larsen's model and Rubiandini's model are reasonably close to the actual flow rates in the drilling operation. Moreover, it is also observed from the analyses of the horizontal drilling case that the use of Rubiandini's model could generally result in larger flow rate required for cuttings transport compared to Larsen's model.

In practice, it is recommended using both these models to predict the critical mud flow rates, then comparing and monitoring actual data obtained from the cuttings transport process to select the appropriate model at every given inclination angle in inclined and horizontal well drilling.

References

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