Journal of Natural Gas Science and Engineering 35 (2016) 686–694

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Real-time optimization of drilling parameters based on mechanical specific energy for rotating drilling with positive displacement motor in the hard formation

Xuyue Chen [a, c, *], Deli Gao [a, **], Boyun Guo [b], Yongcun Feng [c]

[a] MOE Key Laboratory of Petroleum Engineering, China University of Petroleum-Beijing, Beijing 102249, China
[b] Department of Petroleum Engineering, University of Louisiana at Lafayette, Lafayette, LA 70504, USA
[c] Department of Petroleum and Geosystems Engineering, The University of Texas at Austin, Austin, TX 78705, USA

ARTICLE INFO

Article history:
Received 30 May 2016
Received in revised form
2 August 2016
Accepted 7 September 2016
Available online 9 September 2016

Keywords:
Mechanical specific energy
Positive displacement motor
Drilling parameters optimization

ABSTRACT

Mechanical specific energy (MSE) has been widely used to quantify drilling efficiency and maximize rate of penetration (ROP) in oil and gas wells drilling. Given currently there are few effective MSE models to precisely model the actual downhole drilling for rotating drilling with positive displacement motor (PDM), in this work a new MSE model for rotating drilling with PDM is established based on the analysis of PDM performance. Meanwhile a method for real time optimization of drilling parameters based on MSE for rotating drilling with PDM in the hard formation is also presented. Field data presented in this paper indicate that when drilling with a high efficiency and free of drilling complications, the MSE(min) estimated by the new MSE model is roughly equal to the confined compressive strength (CCS) of the formation along the well depth, it can meet the needs of applications in the field. It also shows that ROP is sensitive to high weight on bit (WOB) for rotating drilling with PDM and the optimum WOB is low, increasing WOB does not always increase ROP but is more likely to decrease ROP. The method for optimizing drilling parameters can real time estimate optimum WOB values with different RPM to drill a specific formation interval with PDM. It can be used to maximize ROP and allow operators to drill longer and avoid unnecessary trips.

1. Introduction

Maximizing ROP to reduce drilling cost in oil and gas1 development is the permanent objective of drilling researchers (Chen et al., 2016a, 2016b; Li et al., 2015). Numerous methods have been developed for optimizing drilling parameters to maximize ROP, and they are similar to drill rate and drill-off tests in that they observe trends in performance and attempt to identify the founder point, which is the point at which the ROP is maximized (Dupriest and Koederitz, 2005). Although these methods have enhanced drilling performance, they do not provide an objective assessment of the true potential ROP, only the founder point of the current system. Actually the process of optimizing drilling parameters should be not only drilling system specific but also formation specific. Mechanical specific energy (MSE) is defined as the mechanical work done to excavate a unit volume of rock, it could provide an objective assessment of the drilling efficiency and an objective tool to identify the bit founder. The initial MSE model for rotating drilling system was proposed by Teale (1965). In this model, as the majority of field data is in the form of surface measurements, which results in MSE's calculation containing even large sources of error. Then numerous investigators were motivated to develop more accurate models. These models include those presented by Pessier and Fear (1992), Dupriest and Koederitz (2005), Armenta (2008), Mohan et al. (2009), Meng et al. (2012), Cherif (2012), Chen et al. (2014), Mohan et al. (2015), Wei et al. (2016), and they have been widely used in bit selection, drilling efficiency quantification, drilling performance monitoring, drilling parameters optimization, ROP improvement and so on.

* Corresponding author. College of Petroleum Engineering, China University of Petroleum-Beijing, 18 Fuxue Road, Changping, 102249 Beijing, China.
** Corresponding author. College of Petroleum Engineering, China University of Petroleum-Beijing, 18 Fuxue Road, Changping, 102249 Beijing, China.
E-mail addresses: chenxuyue2011@163.com (X. Chen), gaodeli@cup.edu.cn (D. Gao).

http://dx.doi.org/10.1016/j.jngse.2016.09.019
1875-5100/

In recent years, positive displacement motor (PDM) has gained widespread use in the hard formation drilling to improve ROP. In rotating drilling with PDM, the power section of PDM converts hydraulic energy of mud flow into mechanical rotary power (Samuel and Miska, 1997a; Motahhari et al., 2007), the surface rotation is superimposed on downhole motor rotation. During slide drilling, bit rotation is generated only from the PDM as drilling fluid is pumped through the drill string. However, the PDM's performance is controlled by the combination of the rotor/stator lobe configuration, and the direct measurement of PDM rotary speed and torque in down hole has proven difficult (Macpherson et al., 2001; Motahhari et al., 2010). Therefore, currently there are few effective MSE models to precisely model the actual downhole drilling for rotating drilling with PDM.

In this paper, a new mechanical specific energy model for rotating drilling with PDM is established based on the evaluation of key MSE models and the analysis on PDM performance, meanwhile a method for real time optimization of drilling parameters based on MSE for rotating drilling with PDM in the hard formation is also presented.

2. Model development

2.1. Key models of mechanical specific energy (MSE)

Mechanical specific energy (MSE) has been defined as the mechanical work done to excavate a unit volume of rock. Teale (1965) initially proposed the MSE model for rotating drilling system.

$$MSE = \frac{WOB}{A_b} + \frac{120\pi \cdot RPM \cdot T}{A_b \cdot ROP} \quad (1)$$

In the above model, torque at the bit is a main variable. Although torque at the bit can be easily measured in the laboratory and with Measurement While Drilling (MWD) systems in the field, the majority of field data is in the form of surface measurement (Pessier and Fear, 1992). While in the absence of reliable torque at the bit measurements, the calculation of MSE based on this model contains even large sources of error. Therefore, it is only used qualitatively as a trending tool.

In 1992, Pessier and Fear provided a simple method of the calculation of torque at bit while in the absence of reliable torque measurements and optimized Teale's model.

$$\begin{aligned} MSE &= WOB \cdot \left(\frac{1}{A_b} + \frac{13.33 \cdot \mu_b \cdot RPM}{D_b \cdot ROP}\right) \\ \mu_b &= 36\frac{T}{D_b \cdot WOB} \end{aligned} \quad (2)$$

The above model's parameters are easy to be obtained on the ground, and its calculation precision has been improved, as a result, it has a common usage in the drilling industry. In this model, the torque of bit is calculated through WOB. However, WOB is always read in the weight indicator on the ground, which is not the bottom hole actual WOB. As for directional and horizontal drilling, there is a big difference between the WOB of surface measurement and the bottom hole actual WOB (Chen et al., 2014). And in the actual drilling process, the bit has a certain mechanical efficiency, thus Pisser's model has a limited application and also exists a certain error in MSE calculation.

In 2014, Chen et al. formulated a relationship between the bottom hole weight on bit (WOB_b) and the surface measured *WOB* and presented a method to calculate the torque of bit in directional and horizontal drilling. Based on the relationship and given the mechanical efficiency of bit, Chen et al. (2014) developed a new mechanical specific energy model for directional and horizontal drilling.

$$\begin{aligned} MSE &= E_m \cdot WOB_b \cdot \left(\frac{1}{A_b} + \frac{13.33 \cdot \mu_b \cdot RPM}{D_b \cdot ROP}\right) \\ WOB_b &= WOB \cdot e^{-\mu_s \gamma_b} \\ \mu_b &= 36\frac{T}{D_b \cdot WOB \cdot e^{-\mu_s \gamma_b}} \end{aligned} \quad (3)$$

Chen's model is suitable for both vertical and horizontal drilling, and its calculation precision is high in the absence of reliable torque measurements, so it can be widely used in the drilling industry.

In the above MSE models, hydraulic energy is ignored as it is hardly aid in actual rock-broken in conventional rotary-drilling. Recently some researchers think that hydraulic energy also aids in actual drilling for certain formations (Mohan et al., 2009, 2015), then they add the hydraulic term to the MSE function as

$$MSE = \frac{WOB}{A_b} + \frac{120\pi \cdot RPM \cdot T}{A_b \cdot ROP} + \frac{\beta \cdot \Delta P_b \cdot Q}{A_b \cdot ROP} \quad (4)$$

Hydraulic energy has a great influence on drilling efficiency, but its role is complex. In conventional rotating drilling, bit hydraulics mainly accounts for the removal of cuttings from the bottom hole by jet-erosion, and the jet from bit nozzles could hardly aid in rock-broken especially in the deep and hard formations. Therefore, the MSE model is suitable for high pressure jet drilling and soft formation drilling.

Actually the bit's mechanical rotary energy has a much higher efficiency on rock breaking than the hydraulic energy. If the hydraulic energy of mud flow is converted into mechanical rotary power, it could improve ROP greatly. In the field, positive displacement motor (PDM) has gained widespread use in the hard formation drilling to improve ROP. In rotating drilling with PDM, the power section of PDM converts hydraulic energy of mud flow into mechanical rotary power, the surface rotation is superimposed on downhole motor rotation (see Fig. 1). Moreover, during slide drilling, bit rotation is generated only from the PDM as drilling fluid is pumped through the drill string. Due to the direct measurement of PDM rotary speed and torque in down hole has proven difficult,

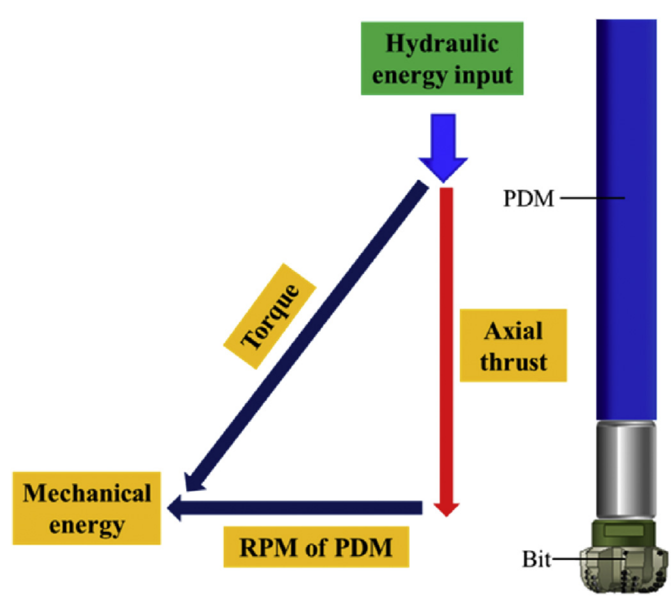

Fig. 1. PDM converts hydraulic energy of mud flow into mechanical rotary power.