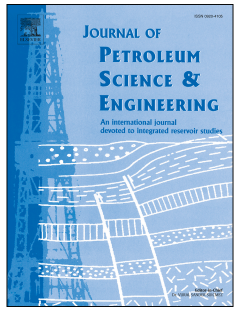

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Modeling and Analysis of Coupled Thermal-Hydrologic-Mechanical Processes during Lost Circulation

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ABSTRACT: Wellbore stability remains as one of the major challenges to drilling engineers. Results of recent survey showed about one third of non-productive time of drilling operation is classified as borehole problem, where a significant part is attributed to borehole instability. The thermal regime of a formation in the vicinity of a wellbore affects the stability of the well significantly during drilling operations, especially in High pressure High Temperature (HPHT) wells. This paper describes how the thermal behavior of a tubular-wellbore-reservoir system is altered during mud loss, as well as its consequent impact on near-wellbore state of stresses and critical mud weights. A fully coupled three dimensional thermal-poro-elastic model, integrated with a transient tubular-wellbore-reservoir heat flow model, is developed to evaluate near-wellbore stresses and pore pressure redistribution during mud loss. The forced convective heat transfer coefficients in both conduits- drillpipe and annulus- are rigorously determined as a function of local flow and fluid properties.

The results reveal that continuous mud loss destabilizes the wellbore as the pressure window shifts considerably over time. Critical mud weights for both tensile and compressive failures decrease during mud loss over the entire length of the wellbore, in addition to the point of loss. During severe losses, the fracture gradient at the bottom of the well can decrease by over 1 ppg within the first hour. This can intensify the existing fracturing condition and allow the development of new fractures at other locations, which leads to further losses as time progresses. This model enables prediction of a more realistic operating window during lost circulation by taking additional thermally-induced effects into account. In addition, failure indexes during mud loss considering P-ρ-T coupling effect on a compressible mud column in the annulus are investigated with the proposed model.

During drilling operations, especially Managed Pressure Drilling (MPD) and offshore applications with moderate to severe mud loss, the operation window should be modified by taking mud loss-induced thermal stresses into account. The mud type, wellbore geometry, circulation rate, and other parameters affect the magnitude of shift in critical mud weight during mud loss, hence evaluations should be based on specific cases.

1. INTRODUCTION

Wellbore instability is a major source of additional costs to drilling operations, and is therefore of paramount importance to avoid when drilling for petroleum production. It is more likely to occur when drilling in hostile environments, such as weak and/or reactive formations; formations with tectonically active beddings [1]; formation with unfavorable lithology sequences; and formation with high pressures and temperatures [2]. In addition, the increasing use of directional drilling and extended-reach drilling (ERD)[3], as well as underbalanced drilling and multilateral drilling[4], has increased the difficulty of maintaining stability of the wells significantly[5,6].

Wellbore stability problems have been extensively studied during the last few decades. Many wellbore stability models have been developed to describe the physics of the systems by considering multiple effects, including but not limited to mechanical effects, pore pressure effects, chemical effects, and thermal effects. Based on the effects that have been taken into account, the wellbore stability models can be categorized as: pure elastic model[7,8,9]; poro-elastic models[10,11]; thermal-poro-elastic models [2,12,13,14] ; chemo-poro-elastic models [15, 16,17]; thermo-chemo-poro-elastic models [18,19], etc.

Under most circumstances, drilling fluids in the wellbore have a temperature that is different from the formation temperature as a result of the thermal gradient down the borehole. Thermal expansion and contraction leads to volume changes in the rock matrix and pore fluid, which results in effective stresses and pore pressure changes. It has been observed that thermo-osmosis modifies the pore pressure field near the wellbore significantly at early times [20].

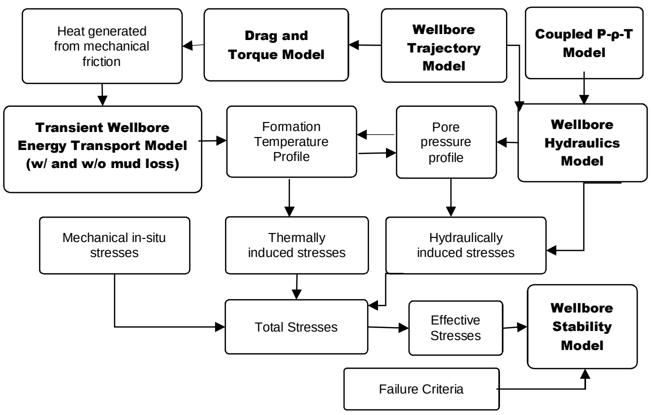

Fig. 1. Diagram of coupled Thermal–hydrologic–mechanical Processes modeling in wellbores

However, previous models did not consider the redistribution of fluid flow and heat transfer in the wellbore and near-wellbore formations during lost circulation events, which would lead to incorrect estimations of temperature profile along the wellbore and stress states in near-wellbore formations during mud loss. The model developed in this