Geomechanical Simulation of Core Microfractures While Pulling Out Of Hole

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ABSTRACT
When the core is retrieved to the surface, it undergoes pressure and temperature drop. Due to pressure and temperature drop, some micro fractures may be created in the core if the pressure and temperature change occurs too rapidly. This is because basically the hydrocarbon inside the core cannot exit the core fast enough and thus pressure inside the core cannot drop as fast as the pressure outside. This causes a pressure difference between the inside and outside of the core. If the pressure difference is excessively high, it can simply cause creation of microfractures throughout the core.
Therefore, in this paper, the effect of stress changes outside of the cylindrical core while retrieval is simulated in order to obtain the inside core pressure, difference between inside and outside pressure, and the induced circumferential stresses in a time based manner. In this work, geomechanical poroelastic models have been modified and merged with finite element modeling and thus a new model has been reached. Having inserted the inputs into the developed model and interpretation of outputs, the creation of tensile microfractures is simulated. Thus, initiation time of microfractures and their radial locations in the core can be reported.

INTRODUCTION
Microfractures in cores are known as small cracks with high fracture length to width. Microfractures can be natural or induced. Induced microfractures occur while coring, core retrieval, recovery or handling. The aperture of microfractures is considered in the order of 0.1 mm in geophysics and petroleum engineering.
Induced microfractures created during core retrieval can be severe (as typically shown in **Figure-1**) if safe tripping procedures for core quality is disregarded. If core tripping speed is too high, the pore pressure does not reach equilibrium with outside pressure fast enough. This can cause stress-release induced microfractures.

Indeed, microfractures cause irreversible damage to the core, but there is little knowledge about their creation time and their locations. Obtaining this knowledge contributes to preventing induced microfractures in some cases (e.g. by controlling tripping rate). It can also contribute to the detection and discrimination in the core.

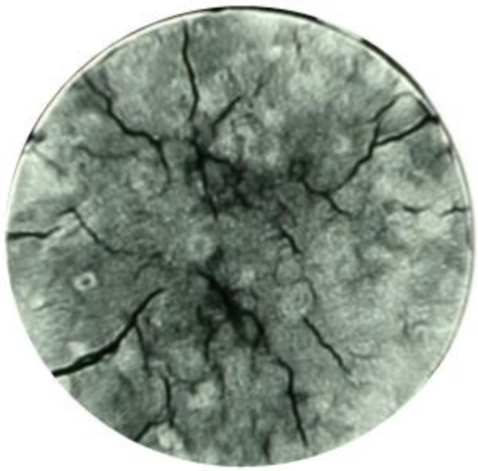

Figure 1: Typical large sized microfractures created in the core during tripping

Poroelastic Modeling and Solution

In elasticity modeling of cores, the effect of pores is ignored. Poroelastic models are modeling the effects of change in induced stress and pore pressure. Based on solid to fluid coupling, a change in stress causes a resultant change in pore pressure and also fluid volume. Conversely, a change in pore pressure causes a change in effective stress and rock mass volume. Poroelasticity depicts the interactive effects of pore pressure, increment of fluid content, strain and effective stress as follows (*Wang, 2000*):

$$\zeta = \alpha\epsilon + \frac{\alpha}{K_u B} p \qquad (1)$$

The parameters in equation-1 are named in .

While core retrieval to the surface, outside pressure is reduced from bottomhole to atmospheric pressure gradually depending on retrieval speed. The same effect occurs for temperature.

The following equation depicts the relation between the Laplace transform of increment of fluid content (ζ) with radius and time (*Wang, 2000, Detournay and Cheng, 1993*):

$$\frac{d^2L(\zeta)}{dr^2} + \frac{1}{r}\frac{dL(\zeta)}{dr} - \frac{s}{c}L(\zeta) = 0 \qquad (2)$$

The above equation is solved to yield the solution of increment of water content in Laplace form ($L(\zeta)$). Then, using Stehfest algorithm, the inverse of Laplace is taken to yield water content. Unlike many other geomechanical works, in this paper the compressive and tensile stresses are respectively considered positive and negative.

Original poroelasticity has an innate assumption that stress change occurs instantly. Thus, the core is instantly retrieved for the core retrieval case. This questions the validity of the model. Therefore, in this paper, finite element modeling is merged with poroelastic models. Thus, the incremental values are calculated and summed up to yield the final inside pore pressure at each stage, and circumferential stress.

Fracture Criteria

The creation of microfractures while core is being retrieved is considered tensile. Basically, tensile fracture occurs when the effective tensile stress across a plane in the core becomes greater than the rock critical tensile strength (T_0).

Table 1: Geomechanical Parameters Used and their Values

Parameter	Relation	Values
α (Biot's Coefficient):		0.74
c1 (initial hydraulic diffusivity):	$c = \frac{K}{\mu S}$, $c = (4.083e-7)\frac{K}{\emptyset \mu C_t}$	6e-8 m^2/s (Shale)
μ (dynamic viscosity) at downhole conditions:		0.02 cp
S (uniaxial specific storage):	$S = \frac{1}{K_v} + \varphi \frac{1}{K_f}$	
K_f (fluid bulk modulus):	$K_f = \frac{1}{C_f}$	
C_t (total compressibility) at reservoir conditions:	$C_t = (4.083e-7)\frac{K}{\emptyset \mu c}$	85.06 1/Pa (Shale)
UCS (Uniaxial Compressive Strength):		20 MPa
Estimated Tensile Strength (T_0):	$T_0 = \frac{1}{8} UCS$	2.5 MPa
υ (Poisson's Ratio):		0.18
υ_u(undrained Poisson's Ratio):	$\upsilon_u = \frac{3\upsilon + \alpha B(1-2\upsilon)}{3 - \alpha B(1-2\upsilon)}$	0.28
B (Skempton's coefficient):	$B = \frac{3(\upsilon_u - \upsilon)}{\alpha(1-\upsilon)(1+\upsilon_u)}$	0.49

To detect the time and location of microfractures created in the core, two criteria are conceived in this paper to be effective:

1) Griffith criteria (*Griffith 1921*):

$$\sigma'_{\theta\theta} = -T_0 \tag{3}$$

2) When difference between inside pore pressure ($P_{p,c}$) and outside pressure exceeds critical tensile strength (T_0):

$$P_{p,c} - P_m > -T_0 \tag{4}$$

The second criterion was utilized by Zubizarreta et. al. (2013) to simulate microfractures created while core retrieval using computational fluid dynamic modeling.

Case Study

To evaluate the developed model function, one typical case study is investigated in this paper. The parameters and their corresponding values are given in **Table-1.** The controlling variables are pull-out-of-hole time or speed, hydraulic diffusivity (*c*), and mud cake pressure drop which have been simulated.

Results and Discussion

After inserting the input data in the developed model, the two mentioned criteria of initiation of microfractures (***equation-3 and 4*** respectively) are considered to detect the time and location of microfractures. The results of the simulation for a typical *shale gas formation* case have been shown in **Table 2**. The simulation results using the two tensile failure criteria respectively for the time and location of fracture initiation have been plotted in **Figure 2**. As can be seen in **Figure 3**, the time of creation of microfractures in shales is almost instant. As can be seen in **Figure 3**, most microfractures are concentrated near the boundary.

Table 2: Results of Model on the Case Study

	Controlling Variables		**Results**	
Shale Core	POOH schedule:	T1=2 min/stand T2=12 min/stand T3=18 min/stand	Microfractures?	Yes
	Hydraulic diffusivity (c):	6e-8	Time(s):	t≥0.5e3 s
	Mud cake pressure drop (psi):	0%	Location(s):	0≤r/R≤1
	Total time (hr):	25.55 hr	Damage:	Severe
	Tensile strength (MPa):	2.5 MPa	Effect:	+

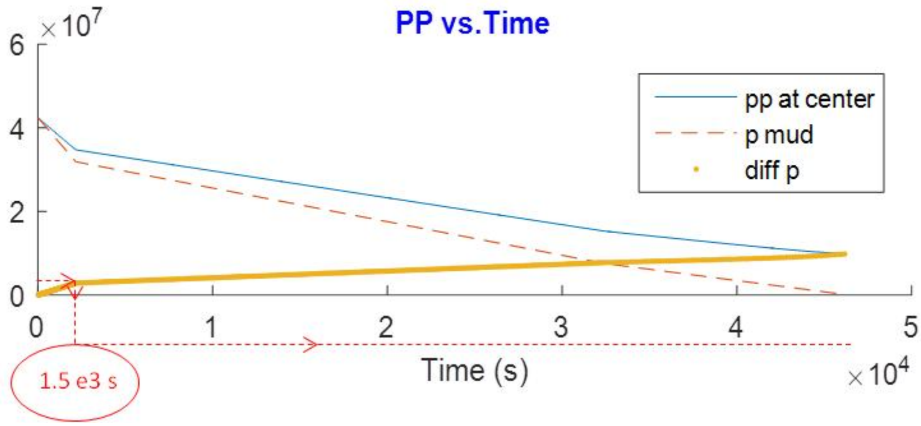

Figure 2: Results of application of the First Tensile Failure Criterion for Detection of Microfracture Initiation Time (Equation-3)

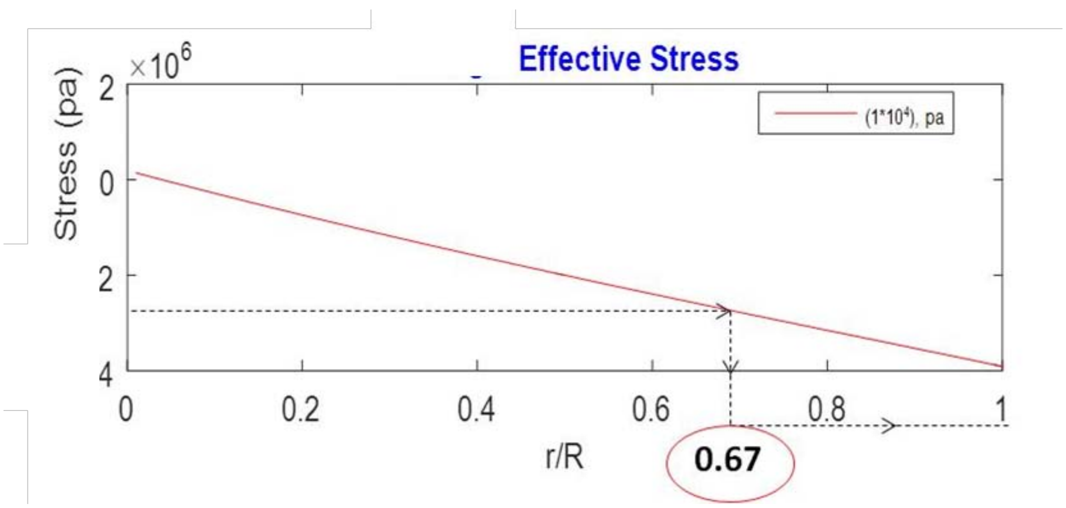

Figure 3: Results of application of the Second Tensile Failure Criterion for Detection of Radial Locations of Microfractures in the Core (Equation-4)

CONCLUSION

In this paper, it is attempted to detect the initiation time and radial locations of microfractures created in the core when it is retrieved to the surface. Using poroelastic modeling of stress change and merging it with finite element modeling, it is possible to evaluate inside pore pressure and circumferential stresses around the core while retrieval. For shale cores, the microfractures are created almost instantly due to their minimal permeability and hydraulic diffusivity. In addition, most microfractures are distributed near the boundary.

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