



## A comparison of Eaton's correlation and an experimental model for fracture pressure prediction for the X field of Ghana

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### Abstract

Inability to correctly estimate the fracture pressure gradient of a formation has the potential to result in downhole problems. Therefore, fracture pressure prediction is very vital in the successful drilling and cementing operations of a well. This work therefore determined the accuracy of Eaton's model using formation pore pressure, overburden stress and Poisson's ratio for predicting fracture pressure for the X field of Ghana while also comparing with an experimental linear regression model. Based on the results obtained, Eaton's fracture pressure estimate recorded a highest deviation margin of 14.92% (871.43 psi) and a lower deviation value of 0.64% (17.01 psi). Thus, Eaton's correlation overestimated the field's fracture pressures by an average of 7.13% (295.97 psi). The experimental model generated for the predicting of the fracture pressure gradient for the field recorded minimal error compared to Eaton's correlation with an accuracy of about 95.84%.

**Keywords:** fracture pressure, pore pressure, prediction, overburden stress, leak of test

### Introduction

Petroleum products continues to play major role in the world's industrialisation process as it remains the most significant primary energy source for both domestic and industrial applications [1, 2]. However, the search for the petroleum involves drilling and cementing operations where fracture and pore pressures estimations are among the principal boundary design parameters [3, 4]. For safe, economic and efficient drilling of wells required to explore and produce oil and gas, it is paramount to have pre-knowledge of the pressures in the said formation [5, 6]. The pre-knowledge of the downhole pressures helps in the prediction of pressure gradients during a well-planning stage which influence casing design and mud weight selection and other well control parameters [7, 8, 9, 10]. The methods used to estimate fracture pressure gradient can be grouped under theoretical and experimental. The theoretical methods mostly used are the Hubbert and Willis, Matthews and Kelly and Ben Eaton correlations [11]. The experimental methods, leak-off, limit and formation breakdown tests are carried out on-site to confirm the predicted values obtained from the theoretical methods [12]. A work by Contreras *et al.* [13], revealed that most values obtained from the application of these theoretical methods do not match values obtained from the experimental methods. According to them, this can lead to erroneous and improper designing of the well. It is therefore necessary to with time fine tune the theoretical with field data to established a localised model for a given field [11, 12]. In view of this, this work compared the Eaton's correlation with a generated field data model for the prediction of fracture pressure using the X field of Ghana as a case study. This is because the nation is endowed with huge hydrocarbon potentials [1].

### Methods to Predict Fracture Pressure

The most widely used equations in predicting fracture pressure gradients during the exploration phases of the oil and gas industry include the Hubbert and Willis, Matthews and Kelly and Ben Eaton's equations [11]. Among the three, the Eaton's equation is the most widely used correlation in the industry because of its higher accuracy compared with the others.

This study was carried out using three well data from the X field in Ghana. The data included True Vertical Depth, Maximum Allowable Surface Pressure (MASP), density of Leak-Off Test Mud, and pore pressure profiles of two wells. The theoretical fracture prediction method under review in this project was developed by Ben Eaton. In 1996, Yoshida *et al.* [14] published results of a study that investigated the current applied technologies used to predict, detect and evaluate the fracture pressure gradient in the earth's crust. The Ben Eaton's fracture gradient prediction equation is given by Equation 1.

$$\frac{P_{ff}}{D} = \frac{\nu}{1-\nu} \left( \frac{S}{D} - \frac{P_f}{D} \right) + P_f/D \quad (1)$$

Where

$P_{ff}/D$  = Fracture pressure in psi/ft;

$S/D$  = Overburden pressure in psi/ft;

$P_f/D$  = Pore pressure in psi/ft;

$\frac{\nu}{1-\nu}$  = Poisson's ratio.

The assumptions for implementing Eaton's equation includes the determination of the area specific overburden stress gradient, the use of an accurate pore pressure prediction for the subject well; and the estimation of the

area specific Poisson’s ratio. Equation 1 was used to compute for the fracture pressure.

**Field Description**

The X field is a sandstone cretaceous wrench modified pull apart basin residing in between the Romanche and St Paul transform fault. The basin of the field became a depositional focus resulting in the basin experiencing lots of deposition from fluvial to lacustrine environment. This provided adequate thickness required for maturity of the cretaceous source rock mainly in the central and western parts of the basin. Sandstones were stratigraphically trapped during the Albian and Cenomanian times formed the main reservoir rock for most of the field [15].

**Fracture Pressure Computation**

**Pore Pressure Estimation**

In other to use Eaton’s fracture pressure equation, pore pressure, overburden stress and Poisson’s ratio of the formation were required. Data on pore pressures of the wells was used to determine the pore pressure gradients. Depth versus pore pressure relationship was fitted to a power curve as shown in Fig. 1 to generate Equation 2. Power curve gave the best fit with an R-squared value of 99.26% compared to other best fits hence its selection. The pore pressures were then computed using Equation 2.

$$Y = 0.2253X^{1.0786} \tag{2}$$

Where

Y = Depth (ft),

X = Pore pressure (psi)

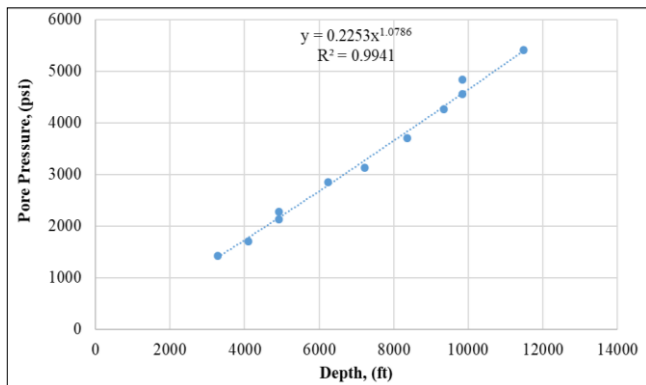


Fig 1: Pore Pressure versus Depth

**Poisson’s Ratio Estimation**

Determining the horizontal to vertical stress ratio is necessary for calculating fracture gradient [16]. The amount of horizontal stress caused by the vertical stress is a function of Poisson’s ratio of the rocks in question. Usually this horizontal-to-vertical stress ratio is considered to be constant with depth and is assumed to be one-third which corresponds to a Poisson’s ratio of 0.25 [17]. However, laboratory experiments have shown that Poisson’s ratio is a depth dependent variable and varies from well to well over 0.25 but never greater than 0.5. Poisson’s ratio for each depth was read from Eaton’s chart from Fig. 2. This is because Eaton’s Poisson ratio chart for Gulf coast can be used for some old formation, such as Cretaceous-aged and older formations [18] for which the X field is applicable.

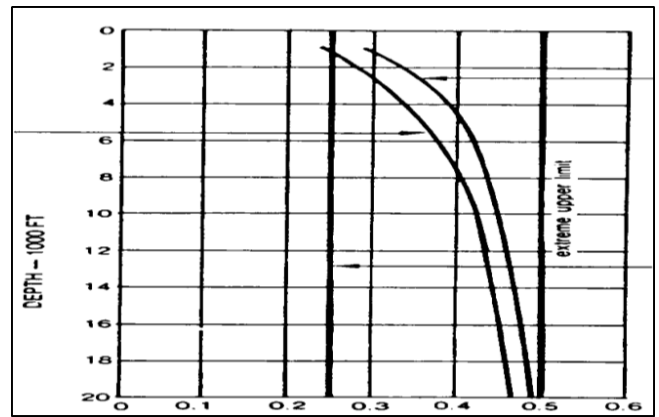


Fig 2: Eaton’s Variable Poisson Ratio Chart [19]

**Overburden Stress Estimation**

Overburden stress gradient is another important variable. Normally, overburden stress gradient is assumed to be 1 psi/ft. However, this assumption is a high average value for a non-constant variable, hence unreliable for some areas such as the Gulf Coast. For this work, the overburden stress gradient used herein was read from Eaton’s variable overburden stress chart in Fig. 3. This was developed using deepwater data from Gulf Coast similar to the X field.

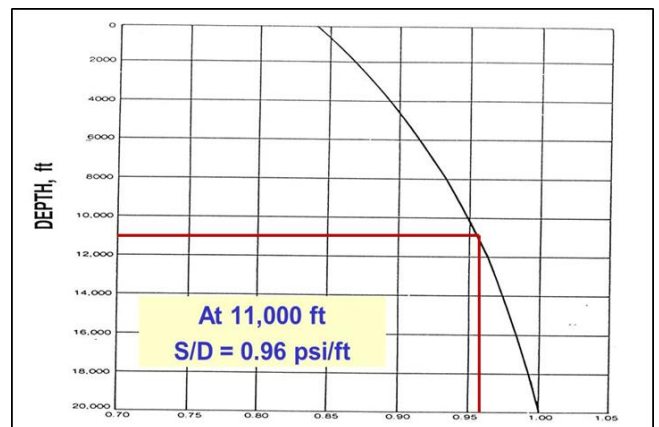


Fig 3: Eaton’s Variable Overburden Stress Chart [19]

**Hydrostatic Pressures**

The hydrostatic pressures at various depths were determined using Equation 3.

$$\text{Hydrostatic Pressure (psi)} = 0.052 * \text{mud weight (ppg)} * \text{Depth (ft)} \tag{3}$$

**Results**

Estimates from fracture pressure prediction is used in selection of appropriate mud weight and casing design. From Table 1 and Fig. 4, quantitative comparison between the predicted fracture pressure and the measured fracture pressure at depth 4,370.08 ft shows a reasonable match. At this depth, Eaton’s correlation underestimates the fracture pressure value by about 0.64% (17.01 psi) deviation from the measured fracture pressure from field. It is evident from Table 1 and Fig. 4 that Eaton’s prediction strategy overestimates to a very high deviation margins as depth increased. For example, at a depth of 5,540 ft, the predicted fracture pressure was in excess of 466.23 psi which is equivalent to a deviation of -13.44%. The highest

overestimated predicted pressure occurred at a depth of 8,704.07 ft with a deviation margin as high as -871.43 psi (-14.92%). Thus, Ben Eaton’s correlation overestimates the fracture pressures by an average of 7.13% (295.97 psi) with a lower deviation value of 0.64% (17.01 psi) an upper deviation value of 14.92 (871.43 psi). Also as shown in Fig. 4, both the LOT values and the estimated values were fitted to a linear regression curve in excel and it revealed that both curves follow the same linear trend and remained relatively parallel to each other.

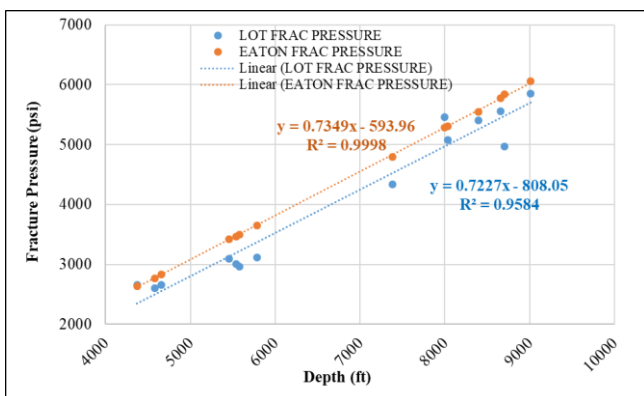
Another trend that is evident in Fig. 4 was that as depth increased, the measured fracture pressures from the field did not necessarily increase, whereas Eaton’s fracture pressures

continuously increased with increasing depth. This trend for the predicted pressures is only logical considering the fact that the overburden stress and Poisson’s ratio used increased as depth increased. However, the assumption that overburden stress and Poisson’s ratio increases with depth is relatively not always applicable for this formation. Therefore, the fields linear regression model generated for predicting fracture pressure with an R-squared of 95.84% as shown in Equation 4 is recommended for the prediction of the X field fracture pressure:

$$y = 0.7227x - 808.05; \quad R^2 = 0.9584 \quad (4)$$

**Table 1:** Results from Eaton’s Model and Measured Pressures

Depth (ft)	Poisson Ratio	Overburden Stress (psi/ft)	Pore Pressure (psi)	Eaton Frac. Pressure (psi)	LOT Frac. Pressure (psi)	Deviation (psi)	Deviation %
4370.08	0.38	0.88	1902.80	2641.09	2658.10	17.01	0.64
4579.20	0.38	0.88	2001.19	2772.02	2608.26	-163.76	-5.91
4654.88	0.38	0.89	2036.89	2837.16	2659.95	-177.21	-6.25
5459.65	0.40	0.90	2419.17	3416.98	3091.51	-325.46	-9.52
5540.36	0.40	0.90	2457.77	3469.19	3002.96	-466.23	-13.44
5582.02	0.40	0.90	2477.71	3496.15	2968.40	-527.76	-15.10
5785.43	0.41	0.90	2575.23	3654.21	3111.86	-542.35	-14.84
7382.55	0.42	0.92	3349.72	4795.45	4330.82	-464.64	-9.69
7998.69	0.43	0.93	3652.22	5280.44	5455.90	175.46	3.32
8039.21	0.43	0.93	3672.18	5308.02	5072.76	-235.26	-4.43
8395.74	0.43	0.93	3848.14	5550.90	5405.56	-145.33	-2.62
8661.09	0.43	0.94	3979.49	5769.12	5552.21	-216.91	-3.76
8704.07	0.44	0.94	4000.79	5840.45	4969.02	-871.43	-14.92
9011.62	0.44	0.94	4153.47	6053.15	5853.38	-199.77	-3.30



**Fig 4:** A Plot of Estimated versus Field Fracture Pressures

**Conclusions**

Based on the fracture pressure prediction analysis done using both theoretical and experimental data, it can be concluded that;

1. Eaton’s correlations recorded the highest fracture pressure prediction deviation margin of 14.92% (871.43 psi) and a lower deviation value of 0.64% (17.01 psi) when compared with field data. Thus, Eaton’s correlation overestimated the field’s fracture pressures by an average of 7.13% (295.97 psi);
2. The field data model generated for the predicting of the fracture pressure gradient for the field recorded minimal error compared to Eaton’s correlation with an accuracy of about 95.84%.

Further work could be done in other fields in Ghana to develop a holistic fracture gradient for the country.

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