Developing a Casing Design for the Extraction of Petroleum in Mannar Basin, Sri Lanka

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Abstract

To develop an economical casing design program for the Mannar Basin which is safe, and risk minimized, knowledge on Pore Pressure Gradient, Fracture Pressure Gradient, Casing Performance Properties and Casing Design Criteria's are important. Previous studies present the Hottman and Johnson (1965) method and D-exponent method-Eaton (1975) as accurate methods to predict the pore pressure gradient of the Mannar Basin and the Eaton (1969) method as the most accurate method to predict the Fracture Pressure Gradient of the Mannar Basin. The data extracted from the final well reports and pressure reports of the pearl 1 well of the Mannar Basin are analyzed using the above models to accurately predict the Pore and Fracture pressure gradients of the Mannar Basin. A specific casing design program is developed to suit the conditions of the Mannar Basin by selecting the casing setting depths and sizes and calculating the casing performance properties of Burst, Collapse and Tension, concerning the predicted pore pressure and fracture pressure gradients.

Keywords: Fracture Pressure, Pore Pressure, Casing Setting Depth, Burst, Collapse, Tension.

1. Introduction

The oil and gas industry has both a direct and indirect impact on the domestic economy, as the price of oil and gas directly affects the health of the economy. Oil and gas are extremely important not only to individuals and businesses within a country, but also to the position of a country among other countries across the globe. To protect a country's economy, the oil and gas industry will need to thrive.

With the growing demand for energy and the increasing cost of supplying quality and reliable power, Sri Lanka needs to identify all available sources of energy that would be sustainable in the future.

The presence of an active petroleum system in the Mannar Basin is no longer a subject of speculation. The comprehensive exploration drilling program carried out by Cairn Lanka in 2011 provided evidence for the presence of a gas/condensate reservoir. According to the Cairn press release, the Dorado-91H/1z well was drilled to a total depth of 4741m and encountered 24m of hydrocarbon-bearing Cretaceous sandstone in three zones between the depths of 4067m and 4206m. [1] The reservoirs are predominantly gas-bearing with some additional liquid hydrocarbon potential. [1] The second well Barracuda-1G/1 was drilled to a total depth of 4741m and encountered 24m of hydrocarbon-bearing Cretaceous sandstone in three zones between the depths of 4067m and 4206m within the igneous layer. The reservoirs are predominantly gas-bearing with some additional liquid hydrocarbon potential. [1]

Casing serves several important functions in drilling and completing a well. It prevents collapse of the borehole during drilling and hydraulically isolates the wellbore fluids from the subsurface formations and formation fluids.. It provides a high-strength flow conduit for the drilling fluid to the surface and, with the blow out preventers, permits the safe control of formation pressure. Selective perforation of properly cemented casing also permits isolated communication with a given form of interest.

As the search for commercial hydrocarbon deposits reaches greater depths, the number and size of the casing strings required to drill and complete a well successfully also increase. The casing has become one of the most expensive parts of a drilling program.

Casing impairments and failures will result in a massive environment and financial losses. Control measures and damage control activities will require further financial investments. Thus, it is vital that an economical and risk minimized casing design program is prepared for the Mannar Basin of Sri Lanka.

2. Methodology

2.1 Acquisition and review of data

Data were extracted from the final well reports and the pressure reports of the Pearl I well of Mannar Basin.

A very few available actual Pore pressure and Fracture pressure gradients taken from the pressure logs of the Pearl I well, shale density, rate of penetration, overburden gradient and well data obtained from the wildcat of Pearl I were used for the initial calculations.

Out of the many available pore pressure and fracture pressure prediction models, studies have proven that the Hottman & Johnson strategy, D-exponent (Eaton) Strategy and the Eaton Strategy are the most accurate strategies for the Mannar Basin. [2]

To predict the Pore pressure gradient of the Mannar Basin, the Hottman & Johnson strategy is the most accurate when the observed interval transit time of the formation is greater than or equal to the normal interval transit time. [2]

If observed interval transit time of the formation is lower than the normal interval transit time, the D-exponent (Eaton) strategy is the most accurate to predict pore pressure gradient of the Mannar Basin. [2]

The Eaton method is the most accurate to predict the fracture pressure gradient of the area. [2]

2.2 Pore Pressure gradient prediction

2.2.1 Hottman and Johnson Method

Hottman and Johnson method of estimating pore pressure of a formation is based on its resistivity properties and acoustic properties.

In this method, a relationship is established between the logarithm of transmit time or resistivity and depth for the hydrostatic pressure formation.

Generally, the transmit time and depth curve is having a linear correlation while the resistivity and depth have a nonlinear relationship.[3]

$$\frac{PF}{D} = f\left(\frac{dT_{ob(sh)}}{dT_{n(sh)}}\right) \quad ..(1)$$

Where;

PF - Formation fluid pressure

D - Depth

$dT_{ob(sh)}$ - Observed Acoustic travel time for shale

$dT_{n(sh)}$ - Normal Acoustic travel time for shale

2.2.2 D Exponent (Eaton) Strategy

Rate of Penetration (ROP) is one such parameter which describes the speed of drilling and is measured in ft./hr.

Since the ROP is affected by several parameters, changes in ROP can also be resulted due to changes in such parameters. Therefore, a correcting or normalizing ROP for such changes of related parameters is important to use it as a pore pressure indicator. The D exponent is one such normalized parameter developed by Bingham (1965) and Jordan and Shirley (1967). [4]

$$d = \frac{\log \frac{ROP}{60 \times RPM}}{\log \frac{12 \times WOB}{10^6 \times B}} \quad ..(2)$$

This equation was modified by Rehm et al (1971) to correct the D Exponent for the effect of changes in mud weight. The modified equation for the corrected D Exponent (dc) is as follows: [4]

$$d_c = d\left(\frac{NPPG}{ECD}\right) \quad ..(3)$$

Where;

d - D Exponent, in d-units

ROP - Penetration rate (ft./hr.)

RPM - Rotary speed (rpm)

WOB - Weight on the bit (lbs.)

B - Diameter of the bit, inch

dc - Corrected D Exponent (dimensionless)

NPPG - Normal pore pressure gradient (ppg)

ECD - Equivalent circulating density (ppg)

When calculating the pore pressure from dc exponent data, the following procedure was followed.

Dc Value vs. Depth was plotted in a semi-log paper and a normal pressure trend line through dc values corresponding to known clean, normally pressured shale was established. Actual dc values alongside the trend line were plotted.

The Eaton Method is a method to calculate the pore pressure from d exponent data. The Eaton Method is generally used in most sedimentary basins. Under Eaton method, the following equation is used for the pore pressure calculation. [5]

$$PP = \sigma_{ov} - (\sigma_{ov} - P_n) \times \left(\frac{d_{co}}{d_{cn}}\right) \quad ..(4)$$

Where,

PP -Pore pressure gradient (ppg)

σ_{ov} -Overburden gradient (ppg)

P_n -Normal pore pressure gradient (ppg)

d_{co} -The observed value of dc at depth of interest

d_{cn} -Normal trend line value of d_c at depth of interest

2.3 Fracture Pressure gradient prediction

2.3.1 Ben Eaton Method

Ben Eaton's fracture pressure gradient prediction strategy is considered as the most widely used strategy worldwide. Eaton developed the concepts proposed by Matthews and Kelly and introduced the Poisson's ratio into the fracture pressure gradient prediction equation.

Eaton (1969) explored that, both the overburden stress and Poisson's ratio vary with the depth [6]

$$P_{FF} = \frac{v}{1-v}\left(\frac{\sigma_{ob}}{D} - \frac{P_F}{D}\right) + \frac{P_F}{D} \quad ..(5)$$

The specific overburden stress can be determined using the equation below and it can be converted into a gradient easily. [6]

$$\sigma_{ob} = \int \rho_b * dD \quad ..(6)$$

The following equation of Eaton can be used to calculate the Poisson's ratio (Eaton, 1969). [6]

$$\frac{v}{1-v} = \frac{\frac{P_{FF}}{D} - \frac{P_F}{D}}{\frac{\sigma_{ob}}{D} - \frac{P_F}{D}} \quad ..(7)$$

Where,

P_{FF} - Formation fracture pressure gradient, psi/ft
D - Depth, ft
V - Poisson's ratio
σ_{ob} - Overburden stress, psi
P_F - Pore pressure, psi
ρ_b - Formation bulk density

2.4 Selection of casing setting depth

In selecting the casing setting depths, the graphs of Formation Pore Pressure and Fracture Pressure (With safety margins) vs. the depth is plotted in one graph. [7]

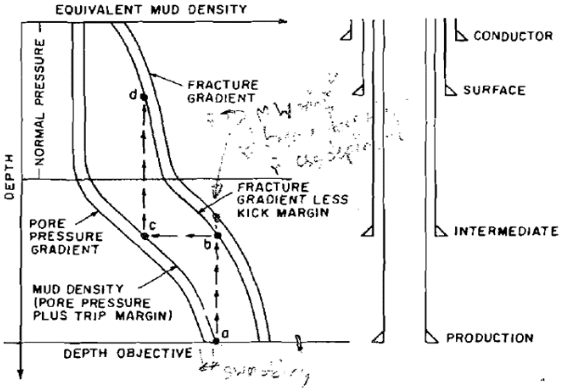

Figure 1 - Sample relationship among casing-setting depth, formation pore-pressure gradient, and fracture gradient.

To reach the depth, the effective drilling fluid density at a point is chosen to prevent the flow of formation fluid into the well (i.e., to prevent a kick). [7] However, to achieve this drilling fluid density without exceeding the fracture pressure gradient of the weakest formation exposed within the borehole, the protective intermediate casing must extend at least to the depth at a point, where the fracture gradient is equal to the mud density needed to drill to that point. [7]

2.4.1 Surface Casing shoe point correction

Surface casing often subjects to the Kick at shoe point. Therefore, in casing shoe depth selection the kick imposes pressure at the casing shoe is mainly considered. As surface casing protect shallow depth aquifer formation depths also considered in section process. The depth obtained for the surface casing shoe should double confirmed by calculating the kick-imposed pressure at that depth as given in equation 8. [7]

$$P_k * D_s = (SM * D_i * D_s) + G_{pf} \quad ..(8)$$

Where,

P_k - Kick-imposed pressure at depth Ds, psi.
D_s - Setting depth for the surface casing, ft.
D_i -Setting depth for the intermediate casing, ft.
G_{pf} -Formation fluid gradient at depth Di, psi/ft.
SM -Safety margin

2.4.2 Conductor Casing shoe point selection

A graph was drawn with depth starting from the rotary table vs. mud fluid pressure. The conductor casing shoe depth is where the overburden pressure graph and mud fluid pressure line intersect. The Conductor Casing setting depth was selected under the following relationship. [7]

$$P_{mw} = P_{ob} + P_{sw} \quad ..(9)$$

Where,

P_{mw} – Pressure due to mud weight
P_{ob} - Pressure due to overburden
P_{sw} - Pressure due to seawater

2.5 Selection of Casing Sizes

The size of the casing strings is controlled by the Internal Diameter of the production string and the number of intermediate casing strings required to reach the desired depth. To enable the production casing to be placed in the well, the bit size used to drill the last interval of the well must be slightly larger than the Outer Diameter(OD) of the casing connectors. [7] The bit used to drill the lower portion of the well also must fit inside the casing string above. This, in turn, determines the minimum size of the second-deepest casing string. With similar considerations, the bit size and casing size of successively more shallow well segments were selected.

2.6 API casing performance properties

2.6.1 Burst Criterion

The predictable internal pressures and the external pressures of the casing that contribute to Burst was calculated and the Burst pressure differentials at the top and the bottom of each casing was obtained using the following equations. [7]

Burst pressure differential = $P_{In} - P_{EX}$

$$P_{In} = P_i - (GG * D) \quad ..(10)$$

$$P_{Ex} = PP * D \quad ..(11)$$

Where,

P_{In} -Internal Pressure

P_i -Injection Pressure Opposite the lost circulation zones

GG -Gas Gradient

D -Depth

P_{Ex} -External Pressure

2.6.2 Collapse Criterion

The predictable internal pressures and the external pressures of the casing that contribute to Collapse was calculated and the Collapse pressure differentials at the top and the bottom of each casing was obtained. [7]

Collapse pressure differential = $P_{EX} - P_{In}$

$$D_m = \frac{MD - \left(\frac{PP}{0.052}\right) * D_{Sh}}{MD} \quad ..(12)$$

$$P_{Ex} = 0.052 * MD * (D_{set} - D_m) \quad ..(13)$$

Where,

MD -Mud Density

D_{Sh} -Depth of next casing seat

D_{set} -Casing Setting Depth

2.6.3 Tension Criterion

The maximum tensile force a casing will undergo was computed by using equations 14 to 18 presented bellow. [7]

$$T_{Tot} = W_B + T_{PT} + F_{Ben} + SL \quad ..(14)$$

$$W_B = W_{Tot} * BF \quad ..(15)$$

$$T_{PT} = A * 60\% * BP_{Weak} \quad ..(16)$$

$$F_{Ben} = 63 * d * CWG * \theta \quad ..(17)$$

$$SL = 3200 * CWG \quad ..(18)$$

Where,

T_{Tot} -Total tensile force

W_B -Buoyant weight

W_{Tot} -Total Weight of casing

BF -Buoyancy factor

A -Cross-sectional area

BP_{Weak}-Burst pressure of weakest casing

F_{Ben} -Bending Force

d -Diameter

CWG -Casing weight grade

θ -Angle

SL -Shock Loading

If Design factor for tension < Tension safety factor - The casing should be selected again

2.6.4 Biaxial Effect

The combination of stresses due to the weight of the casing and external pressures are referred to as biaxial stresses. Biaxial stresses reduce the collapse resistance of the casing and must be accounted for when designing deep wells or combination strings. [7] following equation were used to calculate the biaxial effect,

$$T_r = W_{Weak} / \sigma_{yield} \quad ..(19)$$

$$C_R = C_r * C_{Weak} \quad ..(20)$$

Where,

T_r -Tensile Ratio

W_{Weak} -Weight carried by weakest joint

σ_{yield} -Yield Strength

C_R -Remaining collapse resistance

C_r -Collapse ratio

C_{Weak} - Collapse at the top joint of weakest casing

If Collapse design factor < Collapse Safety factor - Casings need to be selected again

2.6.5 Compressional Effect

Compression loading occurs in casings which carry inner strings where the weights of inner strings are bared by the larger supporting casing. Production casings do not carry inner casing strings and do not develop any compression. This is critical for conductor casing. [7] Therefore, to calculate the compressional effect on casing equation 21 was used.

$$W_B = W_{Tot/Carried} * BF \quad ..(21)$$

Where,

$W_{Tot/Carried}$ -Total weight carried by the conductor pipe

If Compression design factor < Compression Safety factor - Casing should be selected again

3. Results

3.1 Formation Pore Pressure, Fracture Pressure gradients and setting depths

The pore pressure and fracture pressure gradients of the formations were modelled from the afore-mentioned strategies and plotted against the graph along with kick and trip margin allocation. Conductor casing setting depth was calculated and the other setting depths were obtained from the graph illustrated in figure 2. Calculated casing setting depths are presented in table 1 and the outer casing sizes for each casing type are given in table 2.

Axes
X – Pressure gradients
Y - Depth

Legend
— Pore pressure gradient
- - - Pore pressure gradient + safety margin
— Fracture pressure gradient
- - - Fracture pressure gradient – safety margin

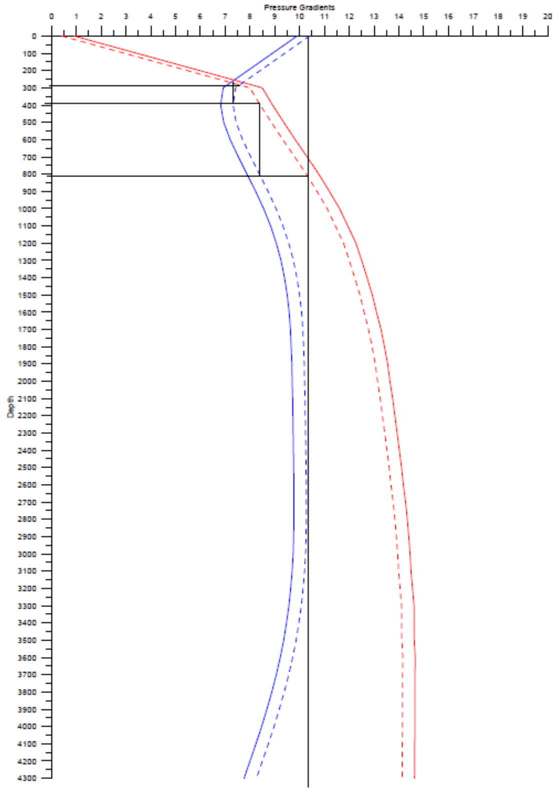

Figure 2 – Variation of formation pore pressure and fracture pressure gradient with depth and casing setting depths.

As per the figure 2, the calculated pore pressure gradient is higher than the calculated fracture pressure gradient between the depths of 0 – 300 ft. This may indicate an unconsolidated subsurface within this depth interval.

Table 1 – Depth Intervals for each casing

Casing	**Depth Interval (ft)**
Conductor Casing	0 – 1300
Surface Casing	0 – 300
Intermediate I	300 – 630
Intermediate II	630 – 1070
Production Casing	1070 - 4206

3.2 Casing Sizes

Table 2 – Outer diameters and bit sizes for the casings

Casing	**OD (In)**	**Bit Size (In)**
Conductor Casing	20	24
Surface Casing	18.625	22
Intermediate I	13.375	17.5
Intermediate II	9.625	12.25
Production Casing	7	8.625

3.3 Burst and Collapse Differentials

The internal and external pressures, burst and collapse differentials were plotted with the depth to identify the suitable casings.

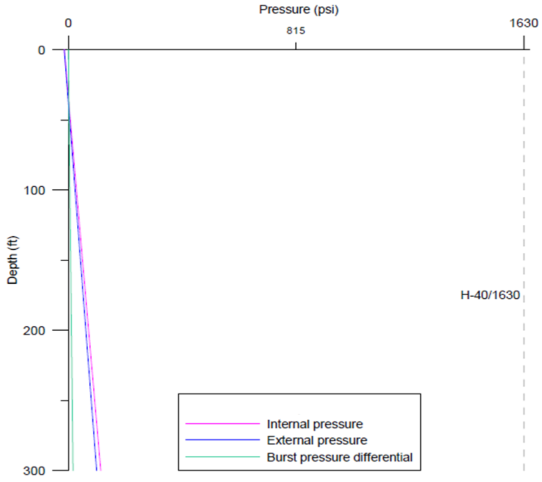

Figure 3 – External Pressure, Internal Pressure and the burst pressure differential for the Surface Casing.

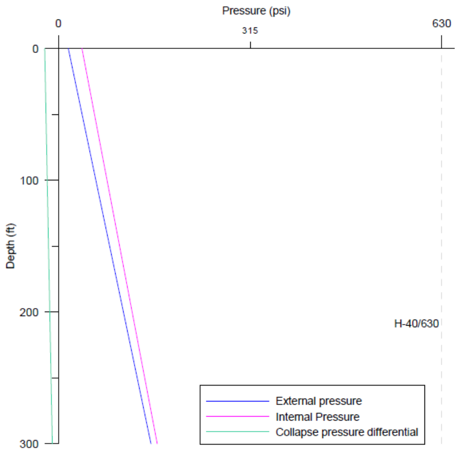

Figure 4 - External Pressure, Internal Pressure and the collapse pressure differential for the Surface Casing.

Table 3 – Burst and Collapse pressure differentials

Depth (ft)	Burst Pressure Differential(ft)	Collapse Pressure Differential(ft)
Conductor Casing		
0	000	16.17
1300	84.82	86.47
Surface Casing		
0	0.00	-22.52
300	16.52	-10.16
Intermediate Casing I		
300	16.52	185.93
630	113.96	526.70
Intermediate Casing II		
630	113.96	504.40
1070	173.17	526.70
Production Casing		
1070	173.17	1,020.90
4206	1,78.54	1,196.53

3.4 Tensile Forces

The tension safety factor taken as per the industry standards is 1.6.

Table 4 – Calculated tension design factors

Casing	Design Factor
Conductor Casing	2.51
Surface Casing	3.04
Intermediate I	2.79
Intermediate II	2.51
Production Casing	1.62

3.5 Biaxial Effect

The collapse safety factor taken as per the industry standards is 1.1.

Table 5 – Calculated design factors

Casing	Design Factor
Intermediate I	3.86
Intermediate II	2.58
Production Casing	1.12

3.6 Compressional Effect

The compression safety factor taken as per the industry standards is 1.6.

Table 6 – Design Factor

Casing	Design Factor
Conductor Casing	8.26

4. Discussion

Although there have been gas discoveries in the two wells Dorado and Barracuda in the Mannar Basin, production well testing has not yet been carried out in these wells. Therefore, the well testing data of the Well pearl I of the same basin was used to develop the casing program.

required parameters to calculate the fracture pressure and pore pressure of the Mannar Basin were not available for some depths and the data had to be interpolated using a trend line, using the software Grapher.

The safety factors were selected according to the industry standards and a safety factor of 1.1 was used for the burst and collapse pressures and a safety factor of 1.6 was used for the tension and compression forces.

The selected casings are the casings with the minimum properties for the given diameter.

The effect of burst and collapse of pressure on the casings is less because the casing with the minimum strength itself has a significant design factor

The only risk factor is the effect of an earthquake. The forces acting on the casing at a time of an earthquake should be further studied.

5. Conclusions

According to the results obtained, the following casings can be used for the Mannar Basin.

Table 7 – Casing Specifications

Casing	Grade	Weight (lbm/ft)
Conductor Casing	H-40	94.00
Surface Casing	H-40	87.50
Intermediate Casing I	H-40	48.00
Intermediate Casing II	H-40	32.30
Production Casing	H-40	17.00

The pore pressure and the fracture pressure gradients of the Mannar Basin are comparatively low.

Acknowledgements

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References

[1] Premarathne, U., Suzuki, N., Ratnayake, N., & Kularathne, C., “Burial and thermal history modelling of the Mannar Basin, offshore Sri Lanka” J. Petroleum Geology, Vol. 39, No. 02, March 2016, pp. 193-213.

[2] Jayasinghe, J & Kurukulasuriya, A & Jayasinghe, W & Wickrama, Madmg & Damith, A & Senadhira, M & Ratnayake, N. (2016). Pore-Pressure and Fracture Pressure Gradient Prediction Model for Few Exploration Blocks in Mannar and Cauvery Basins, Sri Lanka.

[3] Hottmann, C. and Johnson, R., 1965. Estimation of Formation Pressures from Log-Derived Shale Properties. Journal of Petroleum Technology, 17(06), pp.717-722.

[4] Francis, N. I., Oriji, A. B., and Dosunmu,A.,“Study of abnormally-high pore pressure prediction

methods in regions with nonequilibrium compaction Insight of Niger Delta fields", The International Journal Of Engineering And Science, Vol. 5, No. 2, 2016, pp. 01-10.

[5] Eaton, B. A., "The equation for geopressured prediction from well logs". In Fall Meeting of the Society of Petroleum Engineers of AIME, 5544, January, 1975.

[6] Eaton, B., 1969. Fracture Gradient Prediction and Its Application in Oilfield Operations. Journal of Petroleum Technology, 21(10), pp.1353-1360.

[7] Bourgoyne, A., 1991. Applied Drilling Engineering. Richardson, TX: Society of Petroleum Engineers, pp.246-348.