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ANALYSIS OF CAUSES OF DEEP-WATER BLOWOUT AND ITS SUSTAINABLE HYDROSTATIC PRESSURE

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KeyWords.
Well-plan, pore pressure, fracture, spudding, well control, well depth

ABSTRACT

The events surrounding deep-water disasters have changed the face of deep-water operations around the world. Before spudding a well in any environment, proper delineation of the reservoir and correct well plan must be made to avoid drilling problems. The following information about the environment must be known: the water and formation depths, the formation and fracture pressures, the types of fluid present in the reservoir, etc. This information will guide a drilling engineer on how to select the right type of drilling fluid, mud weights and pressures to use among other things. This research focuses on analyzing the causes of deep-water blowouts and determination of appropriate mud weights and pressures necessary to drill a well safely without causing a well control failure. The data used were obtained from three wells. A mathematical approach was used to determine the appropriate mud weights, pore pressures (from pore pressure gradients), fracture pressures (from fracture pressure gradients), mud weights and hydrostatic pressures. Plots of well depths versus pore pressures, mud hydrostatic pressures and fracture pressures were obtained graphically using Microsoft Excel. The graphs showed points of kick and fracture and their possible causes. The results show that with the correct knowledge of pore pressures and fracture pressures of a formation, including the well depths, appropriate mud weights and pressures can be determined and used for safe well drilling.

INTRODUCTION

There are two types of environment where oil and gas wells can be drilled: ***onshore*** and ***offshore*** environment. Onshore environment is land while offshore is water. Offshore constitutes both the ***continental shelf*** and ***deep-water***. Technically, deep-water refers to water depths greater than “normal” for the time and current technology in offshore operations. Although various organizations have their own definitions of deep-water, a general definition has been given by Bureau of Safety and Environmental Enforcement, BSEE as water depth greater than 1000ft (Labelle and Lane, 2001).

A number of problems are associated with deep-water drilling because of the great water and reservoir depth. Such problems include a combination of low temperature, high seabed pressures, presence of gas and water for hydrate formation, greater risk of blowouts, and harsh weather conditions to which the drilling rig and a long section of riser are exposed. Others are narrow pressure windows resulting from young and unconsolidated formations at shallow formation depth, high pressure and high temperature formation, etc. To mitigate these problems, a proper well plan must be made. This will include the type of drilling rig and drilling equipment required to drill the well, mud type selection, etc.

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Several blowouts have occurred throughout the years since the inception of drilling. Notable ones among them are *IXTOCI* well (Mexico, 1979), *Enchova field* (Brazil, 1984 and 1988), *Piper field* (north-east of Aberdeen, the Netherlands, 1988) *Funiwa well 5* (Rivers, Nigeria, 1989), *Adriatic IV* (in the Mediterranean Sea, Egypt, 2004) and the most popular one among others, *Macondo well* blowout (Gulf of Mexico, 2010). A *blowout* is an uncontrolled release of formation fluid; crude oil and/or natural gas from an oil well or gas well after pressure control systems have failed. According to The Foundation for Scientific and Industrial Research, SINTEF, a blowout is an incident where formation fluid flows out of the well or between formation layers after all the predefined technical well barriers or the activation of the same have failed (SINTEF, 2012). While a *well release* can be said to have occurred if oil or gas flowed from the well from some point were flow was not intended and the flow was stopped by use of the barrier system that was available on the well at the time the incident started (Per Holland, 1999). Offshore drilling is similar in many ways to drilling on land. Like their onshore counterparts, offshore rig crews use *drilling fluids* and rotary drill bits to bore a hole into the earth. Drillers pump the mud down through a *riser* which is connected to the drill string (Helgeland et al, 2012). The mud flows out of the hole in the bit and then circulates back to the rig through the space between the drill pipe and sides of the well, *annulus*. As it flows, the mud cools the bit and carries cuttings away from the bottom of the well to the surface. When the mud returns to the surface, rig equipment sieves the cuttings out and pumps the mud back down to the drill string. Thus, the mud travels in a closed loop (Barkim, 2000).

As it was stated earlier, deep-water environment is characterized with increasingly high pore pressures, low fracture pressure and low temperature because of its depth. This makes it complex for drilling safely in such environment. Therefore, a drilling fluid of high density that is equal to or slightly greater than the pore pressure and less than the fracture pressure of the formation must be used to drill an oil and gas well in order to prevent a kick and a blowout. Now, the problem lies in the determination of this mud density and pressure (Bourgoyne et al,1991).

METHODOLOGY

The mathematical formulae used to solve the problem was executed using Microsoft Excel Spreadsheet. The steps are given below.
STEP1: fill up the uppermost cells in the first row of the spreadsheet with the symbols of the parameters required for the calculation. These symbols and parameters have been identified in the Excel sheet as shown in table 3.1.

Table 1 Illustration of Calculation

TVD(ft.)	G_p (psi/ft.)	P_{res} (psi)	M_w (psi/ft.)	M_w (ppg)	P_{mud}(psi)	G_f (psi/ft.)	P_{frac} (psi)

Where, TVD=true vertical depth, G_p=pore pressure gradient, P_{res}=reservoir or pore pressure, M_w= mud density, P_{mud}=mud hydrostatic pressure, G_f=formation fracture gradient, P_{frac}=formation fracture pressure, M_{wmax}=maximum mud weight.
STEP2: input the field data in the required cells of the each column of the spreadsheet. These data are TVDs, G_p, and G_f.
STEP3: input the formulae needed to do the necessary calculations in the second row of the required cells. The calculations are performed automatically by the software to determine the pore pressures, minimum mud weights, mud hydrostatic pressures, formation fracture pressures and maximum allowable mud weights at each depth in the appropriate spreadsheet.
In this work, the descriptive and analytical approach were used to determine the objectives. The descriptive approach involved the explanation of certain concepts like causes of kicks and blowouts, etc. With the analytical approach, mathematical formulae, models, tables, pictures and graphs were used for data presentation, analysis and interpretation.

SOURCES OF DATA

The data used in this research work were collected and collated from secondary sources for analysis and interpretation. They were sourced from textbooks, internet and a research paper. Specifically, the field data such as, pore pressure gradients, fracture pressure gradients and depths were culled and modified from a research paper, Pore and Fracture pressure Determination written by Theja Kankanamge.

SAMPLING PROCEDURE

The samples collected for this research were culled from an offshore field. The data were simply obtained from the internet by typing "pore and fracture pressures in deep-offshore fields" on a search engine. They were then converted to API units before their deployment for calculations.

METHOD OF DATA ANALYSIS

This involved the derivation of mathematical formulae, use of engineering models and statistical techniques to analyze the data. The mathematical formulae and engineering models are presented here (derivation of formula), while the statistical techniques are presented in chapter four of this paper.

Derivation of Formulae

Minimum Mud Density: the density of mud is its mass divided by its volume. The density is usually calculated (in psi/ft.) from formation pressure as formation pressure gradient plus overbalance. The unit is then converted to API unit, pounds per gallon (ppg).The conversion is done using a factor of 0.052.

Imagine a cube with $1ft$ sides (length, breadth and height)

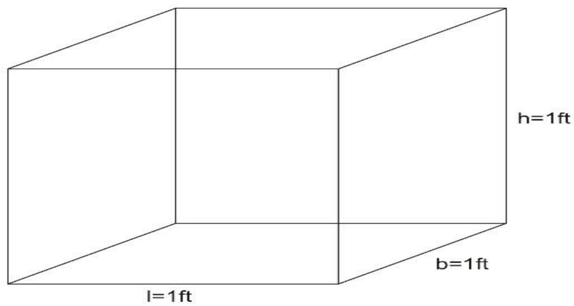

Figure 1i a cube

Its volume would be $1ft^3$ or $7.48gals$

Because $v = l \times b \times h$ and $1ft^3 \equiv 7.48gals$ **(3.1)**

If the cube is filled with a fluid of density $1ppg$ the total weight of the fluid would be$7.48pounds$. That is $1\,{}^{Ib}/_{gal} \times 7.48gal = 7.48Ibs$ **(3.2)**

But the area of the base= $1ft^2 \equiv 144\ square\ inches$. Because$1ft = 12inches$. **(3.3)**

Hence, the pressure exerted by 1foot of that fluid is $7.48/144 = 0.052$ psi **(3.4)**

The gradient of $1ppg = 0.052psi/ft$ **(3.5)**

Now the required ***minimum mud density*** to drill a well and maintain overbalance (all other factors remaining constant) is given as: ${}^{(pore\ pressure + overbalance)}/_{TVD}$ **(3.6)**

Mathematically,

$$\rho_m = \frac{P_{res} + P_{ob}}{0.052 \times TVD}$$

Where, $\rho_m = mud\ density, ppg$

$P_{res} = formation\ pressure, psi$

$P_{ob} = overbalance\ pressure, psi$

$TVD = true\ vertical\ depth, ft$

$0.052 = converting\ factor$

Mud Hydrostatic Pressure: this is expressed mathematically as,

$$P = 0.052 \times \rho_m \times TVD \quad \textbf{(3.7)}$$

Maximum Mud Weight: the maximum mud density is dependent on fracture gradient. It is expressed mathematically as:

$$\rho_{mmax} = \frac{P_{frac}}{0.052 \times TVD} - S_f \quad \textbf{(3.8)}$$

Where, $\rho_{mmax} = maximum\ allowable\ mud\ weight, ppg$

$P_{frac} = fracture\ pressure, psi$

$S_f = safety\ factor, about\ 0.5ppg$

Therefore, mud hydrostatic pressure is given as,

$$P = 0.052 \times \rho_{mmax} \times TVD \quad \textbf{(3.9)}$$

Table 2 INPUT DATA

Well #H08

TVD(ft)	Gp(psi/ft)
0	0.000
1115	0.016
1430	0.533
1447	0.533
2133	0.690
2789	0.674
3445	0.706
4278	0.706
4311	0.706
4757	0.706
5413	0.706
6726	0.706
7710	0.706
9022	0.706
10177	0.737

Well #F70

TVD(ft)	Gp(psi/ft)
0	0
1264	0.428
1591	0.428
3166	0.423
4084	0.428
5807	0.446
7119	0.441
8267	0.446
8874	0.446
9186	0.446
9987	0.450

Well #D41

TVD(ft)	Gf(psi/ft)
0	0.000
1115	0.016
1430	0.533
1447	0.533
2133	0.690
2789	0.674
3445	0.706
4278	0.706
4311	0.706
4757	0.706
5413	0.706
6726	0.706
7710	0.706
9022	0.706
10177	0.737

Well #08

TVD (ft)	Gp(psi/ft)	Gf (psi/ft)
0	0.000	0.000
1050	0.394	0.702
1263	0.405	0.726
1854	0.416	0.769
2887	0.431	0.799
3133	0.431	0.804
3281	0.435	0.806
3543	0.437	0.808
4035	0.437	0.814
4331	0.435	0.817
4495	0.439	0.819
5249	0.442	0.825
5905	0.442	0.832
6562	0.442	0.84
7132	0.442	0.842
7605	0.442	0.847

RESULTS

Well #08

Pres(psi)	Mw (psi/ft)	Mw (ppg)	Pmud(psi)
0	0.000	0.000	0
414	0.584	11.24	614
512	0.563	10.83	712
771	0.524	10.07	971
1244	0.500	9.62	1444
1350	0.495	9.52	1550
1427	0.496	9.54	1627
1548	0.493	9.49	1748
1763	0.487	9.36	1963
1884	0.481	9.25	2084
1973	0.483	9.30	2173
2320	0.480	9.23	2520
2610	0.476	9.15	2810
2966	0.480	9.23	3150
3459	0.480	9.23	3423
3803	0.480	9.23	3650

Well #70

Pres(psi)	Mw(psi/ft)	Mw(ppg)	Pm(psi)
0	0.000	0.00	0
541	0.586	11.27	741
681	0.554	10.65	881
1339	0.486	9.35	1539
1748	0.477	9.17	1948
2590	0.480	9.24	2790
3139	0.469	9.02	3339
3687	0.470	9.04	3887
3958	0.451	8.67	4002
4097	0.442	8.50	4060
4494	0.470	9.04	4694

Well #D41

Pfrac(psI)	Mwmax(ppg)	Mwmax (psi/ft)	Pm (psi)
0	0.00	0.000	0
18	0.35	0.018	20
762	9.25	0.481	688
771	9.25	0.481	696
1472	12.27	0.638	1361
1880	11.96	0.622	1735
2432	12.58	0.654	2253
3020	12.58	0.654	2798
3044	12.58	0.654	2819
3358	12.58	0.654	3111
3822	12.58	0.654	3540
4749	12.58	0.654	4399
5443	12.58	0.654	5042
6370	12.58	0.654	5900
7500	13.17	0.685	6971

Well #08

Pres(psi)	Mwmax (psi/ft)	Mwmax (ppg)	Pmud(psi)	Pfrac (psi)
0	0.000	0.00	0	0
414	0.624	12.00	655	737
512	0.648	12.46	818	917
771	0.691	13.29	1281	1426
1244	0.721	13.87	2082	2307
1350	0.726	13.96	2275	2519
1427	0.728	14.00	2389	2644
1548	0.730	14.04	2586	2863
1763	0.736	14.15	2970	3284
1884	0.739	14.21	3201	3538
1973	0.741	14.25	3331	3681
2320	0.747	14.37	3921	4330
2610	0.754	14.50	4452	4913
2900	0.762	14.65	5000	5512
3152	0.764	14.69	5449	6005
3361	0.769	14.79	5848	6441

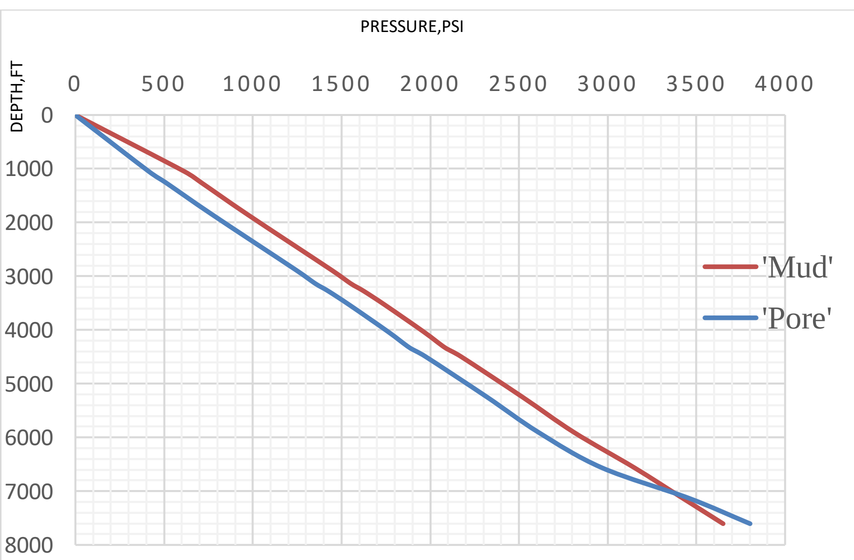

Fig 2a Pore and Hydrostatic Pressure versus Depth Plot

CASE1: In figure 2a, pore pressure increases almost linearly with depth up to a point (2,966, 6,562) where there is a sharp increase (overpressure). Mud gradient remained almost constant. At point (3,149, 7132) pore pressure equals mud pressures, and then exceeds it. Point (3149, 7132) is a point of kick. This indicates an over pressure zone.

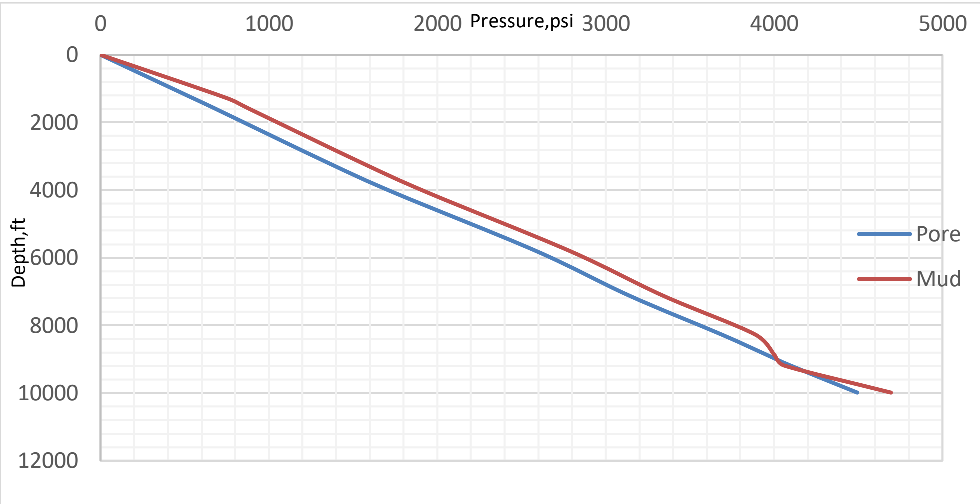

Fig 2b Pore and Hydrostatic Pressure versus Depth Plot

CASE2: In figure 2b, pore pressure increases almost linearly with depth as mud pressure does. At point (3887, 8267), there is a slight decrease in mud pressure. At point (4060, 9186) pore pressure exceeds mud pressure. Point (4060, 9186) is a point of kick caused by a reduction in mud weight. This could be as a result gas cut, solid removal or excessive mud dilution.

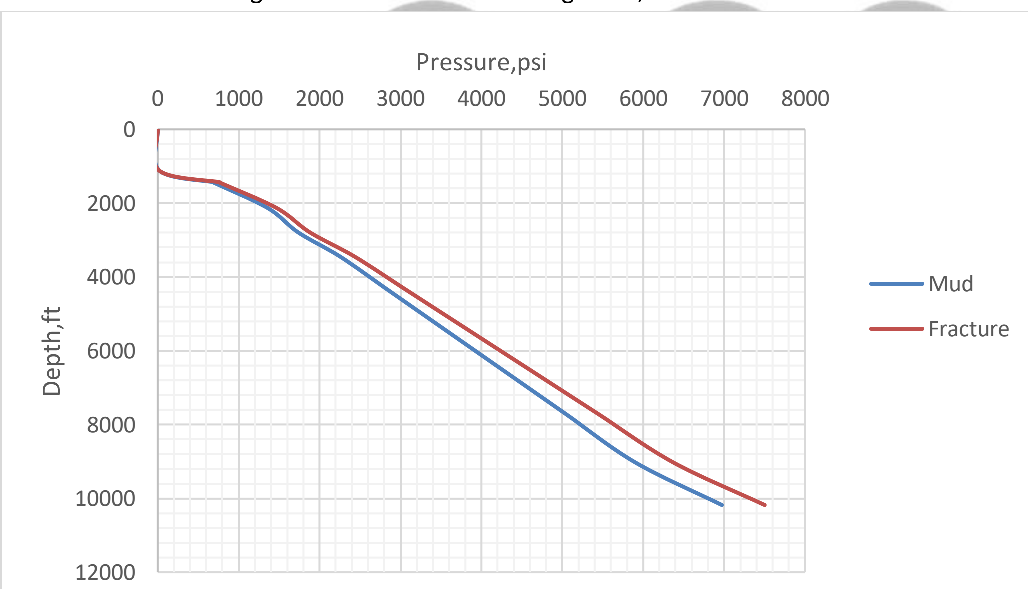

Fig 2c Fracture and Hydrostatic Pressure versus Depth Plot

CASE3: In figure 2c, there is a very low fracture pressure from point (17.84, 1115) to point (762.19, 1430) and hence equal or slightly greater mud pressure. Beyond that point, both pressures increase almost linearly with depth. Points (17.84, 1115) and (762.19, 1430) are points of formation fracture. These points are at shallow depths where the formations are highly unconsolidated in offshore regions.

CASE4

In figure 2d, all the pressures increase almost linearly with depth at all points but tend to be closer at initial points. At shallow depths, pore and fracture pressures tend to be very close, but become further apart at greater depths. Here, there is neither a kick nor a fracture.

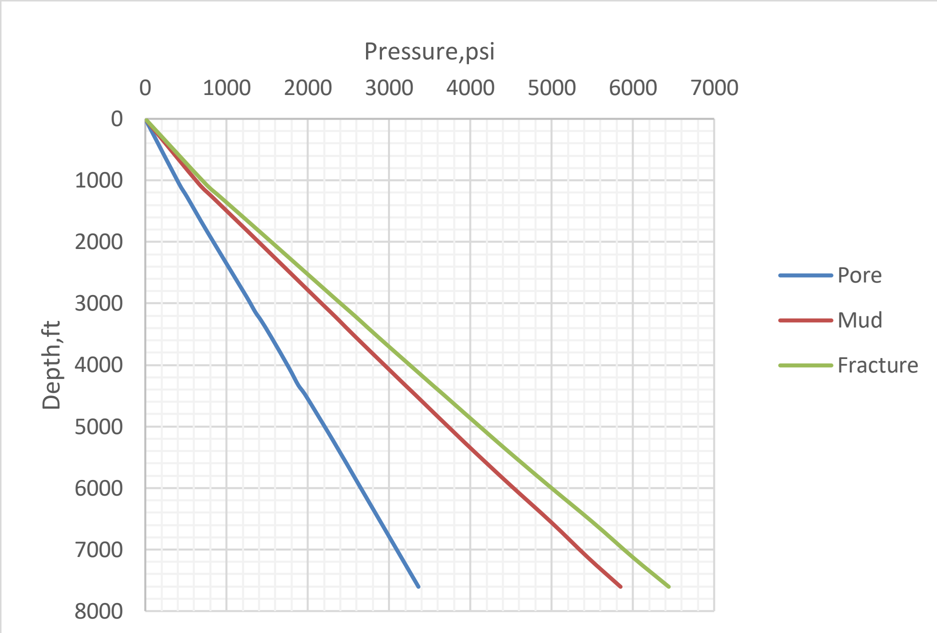

Fig 2d Pore, Hydrostatic and Fracture Pressure versus Depth Plot

CONCLUSION

In this research work, the author has been able to establish the causes of blowout in deep-water environment, identified and reviewed the type of drilling fluid required for safe drilling, required BOP closing pressures, and calculate the safe mud weights and pressures. It can be seen from the work that knowledge of the geology of the area is needed. The reservoir must be delineated to check for overpressures, shallow gas sands, HPHT, etc. This will enable the management make a proper well design prior to drilling a well.

RECOMMENDATIONS

- Data can be obtained from more wells for a more comprehensive analysis.
- More elaborate work can be done in future to determine the appropriate composition of mud required for drilling each section of a well.
- Another area of research is in the calculation of BOP closing pressures required to close in BOP in the event of loss of primary well control.

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