A MONOGRAPH FOR PRESSURE AND PRESSURE GRADIENT ESTIMATION USING WIRELINE LOG DATA OF MAE-SOON OIL FIELD, FANG BASIN

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Received: January 25, 2012; Revised: June 19, 2012; Accepted: June 25, 2012

Abstract

In general, the pressure is directly proportional to the depth caused by the continual pressured stress of rock. From resistivity log data, a monograph indicating the relationship between increasable resistivity and depth can be created. In this study, resistivity log data of Mae-Soon oil field had been estimated its trend by applying Microsoft Office Excel 2003. This trend could be used for pressure gradient estimation by using an invented resistivity related pressure monograph. As a result, a monograph for pressure gradient estimation for Mae-Soon oil field, located in Fang basin, was created. Result from created the pressure estimation monograph testing indicated that the erroneous percentage of pressure estimation of Mae-Soon oil field was (+4.47333) to (-4.28667). Moreover, pressure gradient estimation of Mae-Soon oil field by using the created monograph was quite accurate with very low erroneous percentage as (+0.00082) to (-0.00068).

Keywords: **Monograph, pressure gradient estimation, wireline log data, Mae-Soon oil field, Fang Basin**

Introduction

In general, the formation pressure is directly proportional to the depth caused by the continual pressured stress of rock and the accumulative pressured fluid filling pore space. Trend of increasing pressure is rather stable in each reservoir. Using wireline log to explore a hole such as resistivity log, a monograph indicating the relationship between increasing resistivity and depth can be created. However, in an abnormal pressure zone, the resistivity value obviously separate from the normal resistivity trend line. This zone extremely affects on petroleum drilling because the abnormal pressure brings many serious problem, e.g. well blowout and down hole equipments stucking. Thus, there are many differently method to find the formation pressure for getting the data.

Pennebaker (1968) developed an overburden pressure gradient correlation taking into consideration the formation age. Eaton (1969) correlated the overburden pressure gradient and Poisson's ratio with depth for West Texas and the Gulf Coast areas

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of Texas and Louisiana. He derived an equation for the effective matrix stress ratio as a function of Poisson's ratio regardless of pore pressure. In his work, Eaton assumed an elastic rock behavior and a lateral strain that could be related to the vertical stress by Poisson's ratio. Constant and Bourgoyne (1988) modified Eaton's method to predict the formation fracture gradient in offshore wells where the only available variables are depth and pore pressure. Brennan and Annis (1984) with Rocha and Bourgoyne (1996) used leak-off test (LOT) data to predict fracture gradient in various geological areas around the world. All research show history of the estimated way for find pressure.

Matthews and Kelly (1967) presented the use of wireline logs for determining pore pressures by 1.) Establish a straight base line from normal pressure shale readings. 2.) Extrapolate this straight line into the abnormal pressure region. 3.) In the abnormal pressure region relate the actual log values to the normal extrapolated values. 4.) Determine formation pore pressure from empirical data that have been developed for the area or in lieu of data for the specific area relate the information to similar areas. Figure 1 shows a plot of pressure gradients versus the log ratio of observed conductivity to normal conductivity data, for well in the South Texas Gulf coast. (Figure 1)

The method to find the pressure gradient of Matthew and Kelly from the Figure 1 is to divide of resistivity and conductivity for data on X-Axis. Next, draw the linear to cross the graph line. Then, from that crossing point, draw the line to Y-Axis. As a result, the pressure gradient is shown. This is the easily and not complicated method to calculate the pressure gradient. Thus, in this research, adapted and applied the method of Matthew and Kelly by improving data on X-Axis of a monograph to estimate pressure gradient; by not dividing resistivity or conductivity, but only using an actual resistivity which be interpreted from resistivity log to plot on X-axis. As a result, we can find the pressure gradient more convenient and faster.

The objective of this study is to create a monograph based on resistivity log data for pressure gradient estimation of next drilled area for Mae-Soon oil field, located in Fang basin, which is an important onshore oil field located in Chiang Mai province, Thailand.

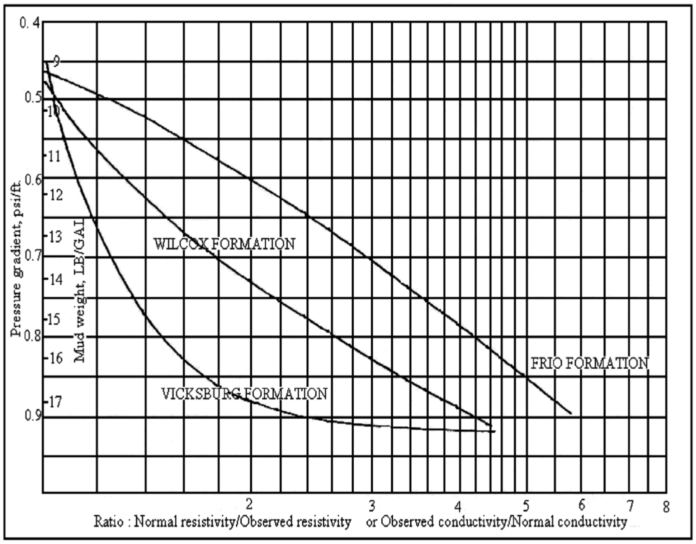

Figure 1. Pressure gradient versus resistivity or conductivity ratios, South Texas gulf coast (modified the resolution of image after Moore, 1974)

Resistivity and Pressure

In petroleum industry, types of drilling pressure are loosely determined as follows;

Pore pressure is the pressure which is constituted by accumulation of fluid in pore space.

Hydrostatic pressure is the pressure in a hole which is constituted by mud weight.

Overburden pressure is the pressure which is constituted by accumulation of rock matrix and pressure of fluid in pore space at any level.

As mentioned above, the pore pressure is increasable proportional to the pressured stress of rock and pressured fluid filling pore space. This increasable accumulation is so-called "pressure gradient". Normally, the accumulative pressure in the formation of rock is stable but sometimes it is imposed by another external force and pressure making formation collapse. The last pressure cause formation collapse is so-called "fracture gradient".

Generally, the increase of pore pressure tends to be stable except some zone; there is a jumping of pore pressure. This is because fluid in formation which is contained, not independently flow constituting long accumulation of pressure. The pressure in this area is higher than a normal one and it is so-called an "abnormal pressure zone". In contrast, some area when drilling, the pressure is lower than a normal scale causing the accumulative fluid flow out of formation. This zone is so-called "subnormal pressure zone".

If using the data of pressure to plot with depth in each level, it be found out that the increasing pressure tend to be almost linear. This is because the increasing pressure of each level is high. But, if using pressure gradient to plot in each level, it be found out that the trend lines of the increasing is not tend to be a linear; it is the curve line which gradually increasing little by little. This is because the increasing pressure gradient of each level is not much. However, in different places, the trend line is different depending on geographical characteristic of that place.

For the in general data of resistivity, it tends to be increase, when the depth increases. This is because mostly mineral composition is insulator. Only few of them are conductivity. However, the resistivity of rock formation also depends on type of fluid which be contained in rock layer. This fluid is contained in porous of rock. Thus, the porosity of rock is the important factor in the change of resistivity of rock to be abnormal. The porosity of rocks depends on many factors such as characteristic of deposition, grain size, sorting, cementing, etc. These factors determine porosity of rock layers; much or less. If the porosity is much, the resistivity is high. If the porosity is less, the resistivity is low. But, it also depends on the fluid which be contained in rock layers.

Geological Information of Mae-Soon Oil Field

The lithology of Mae-Soon oil field is divided into 2 formations as follows:

Mae Fang formation : The Mae Fang formation is the upper unit of Fang Basin. It is an alluvial deposits, mostly composed of loose arkosic sand and conglomeratic sand, grey, coarse-very coarse grain, subangular-subround, interbedded with thin layer of clay. The thickness of this unit is approximately 1200-1400 ft.

Mae Sod formation : The Mae Sod formation is the lower unit of Fang Basin It is a fluviolacustrine to lacustrine, mostly composed of grey, grey brown, dark brown shale and claystone interbedded with medium-coarse, subanggular grey sand.

Materials and Methodology

Materials

To create a monograph indicating correlation between pressure gradient and normal trend of resistivity, Microsoft Office Excel 2003 was used to find a line of normal trend of resistivity. In this study the correlation between resistivity and pressure gradient of Fang basin was determined for Mae-Soon.

Required resistivity log data from three wells including FAMS5280, FAMS4874, and FAMS5179 were collected from virgin zone by resistivity logging equipment (Electrical and Spontaneous potential logs) and analyzed to make a monograph for pressure gradient estimating.

Methodology

Resistivity log data of three drilled holes from Mae-Soon oil fields (FAMS5280, FAMS 4874, FAMS5179) were read, recorded and interpreted at each five-feet interval.

To find a normal trend of resistivity based on data from interpretation in last step, the following steps were conducted;

1. Data which was in the range of abnormal pressure zone was deleted (Geology section, Defense Energy Department, Fang, Chiangmai, 2005-2009). This is because these data are not correspond to the normal trend of resistivity value. (Table 2)

2. Resistivity data located in normal pressure zone was then studied and analyzed statistically, e.g. its standard deviation (SD). The SD study is normally used for testing the unity of a data set. In mathematics, SD is found by equation below.

$$SD = S = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \overline{X})^2}{N}} \qquad (1)$$

where S = standard deviation of sample
X = random variable
X = mean value of these observations
N = Numbers of sample

This study used Microsoft Office Excel 2003 to calculate SD of each data set by its statistic function; STDEV, which the SD and mean of resistivity data of each hole were showed in the table below. (Table 3)

Results from SD and mean of resistivity analysis indicated that within the same oil field the SD and mean of resistivity of selected holes were quite the same. This is because the similarity of geological characteristics of Mae-Soon oil field has an influence on recorded resistivity which has been generated in the same condition.

Resistivity data recorded in normal pressure zone then were plotted with its corresponding depth by Microsoft Office Excel 2003 to create a line of normal resistivity trend. The results of plotting were showed in the following graphs. (Figure 3)

Table 1. Number of resistivity values measured for each hole

Resistivity (Ohm-m)	FAMS5280 (amount of resistivity)	FAMS4874 (amount of resistivity)	FAMS5179 (amount of resistivity)
10-19	12	9	7
20-29	85	74	80
30-39	73	77	83
40-49	33	48	51
50-59	22	15	18
60-69	11	10	12
70-79	10	8	4
80-89	5	8	2
90-99	4	8	3
100-109	7	7	5
110-119	2	2	3
120-129	0	3	2
130-139	2	1	1

Program created trend was then so-call "normal resistivity trend". The normal resistivity trend of Mae-Soon oil field had its own corresponding equation as follows;

Mae-soon oil field's normal resistivity trend

$$y = 57.524x \quad (2)$$

where y = depth (ft)

x = resistivity value (ohm-m.)

In general, linear equation is in the form = ax+b but in the second equation, 'b' is zero. According to making a starting point of normal trend resistivity started from zero, the Axis-crossing is set equally zero. This is because normal resistivity trend should start since on the soil surface; at the soil surface, the depth is zero. That's why 'b' is zero.

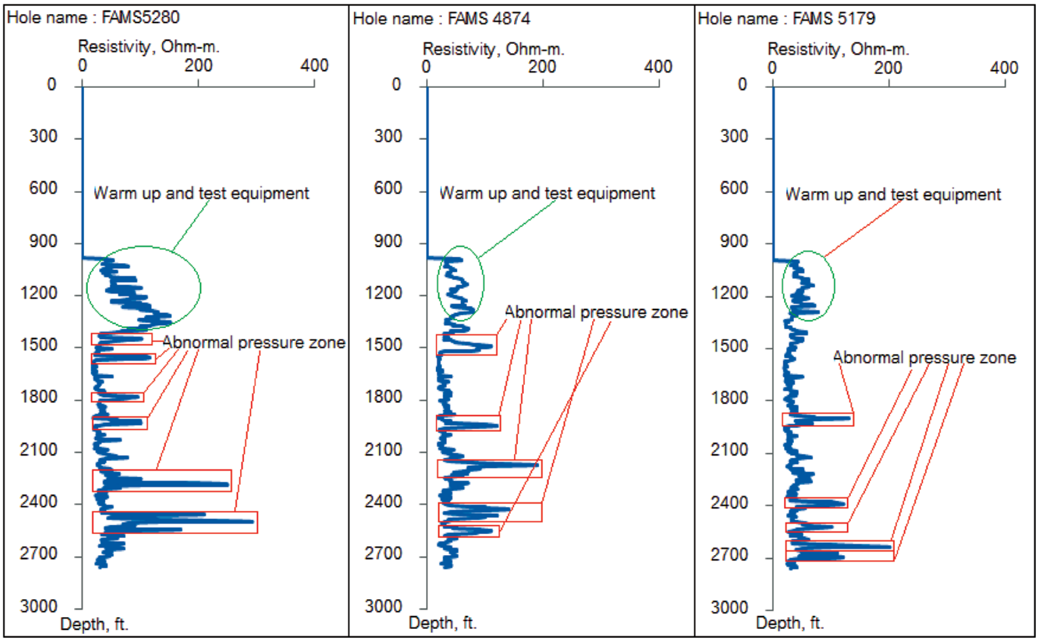

Figure 2. Resistivity value plot with depth of each hole

Table 2. Number of abnormal pressure data for the Mae-Soon oil field-Wells and which has been deleted for the monograph determination

Hole name	Total Data (Number)	Deleted Data (Number)	Deleted Data (%)
FAMS5280	266	57	21.42
FAMS4874	270	45	16.66
FAMS5179	271	24	8.85
Total	807	126	15.61

Based on this empirical equation, normal resistivity at any depth could be calculated by varying "y" parameter. This study used variation with depth of every five-feet interval (The feet is a unit of depth and pressure gradient used in this research regarding popularity and reference style of The Society of Petroleum Engineering, SPE)

In the next step, calculated normal resistivity of every five-feet depth interval was plotted with pressure at this corresponding depth. Then, a monograph showing correlation between pressure and normal resistivity at the same corresponding depth could be created.

Results and Discussion

From methodology, created monographs for pressure and pressure gradient estimation of Mae-Soon oil field were presented in Figure 4 and 5 respectively.

From these created monographs of Mae-Soon oil filed, the corresponding linear equation of the monograph could be created as below.

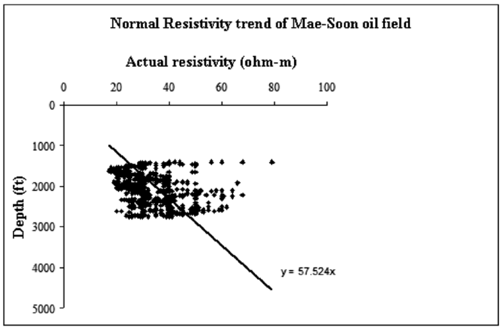

Figure 3. Normal resistivity trend of Mae-Soon oil field

In case of normal resistivity versus pressure plotting;

Mae-Soon oil field

$$P = 28.417x - 0.1 \quad (3)$$

where x = resistivity value (ohm-m.)

P = pressure (psi)

In case of normal resistivity versus pressure gradient plotting;

Mae-Soon oil field

$$PG = (10^{(-9)}x^3) - ((2)10^{(-7)}x^2) + ((9)10^{(-6)}x) + 0.493825 \quad (4)$$

where x = resistivity value (ohm-m.)

PG = pressure gradient (psi/ft)

The second and the third equation are linear but the fourth equation is non- linear. This is because resistivity and pressure more increasing at each lower depth, whereas pressure gradient less increasing at each lower depth.

In this step the created monograph was tested for checking its accuracy. Resistivity log data of well FAMS4874 was selected for this testing the created monograph of Mae-Soon oil field. (The data which interpret in Figure 2 is used. Regarding there are many massively data, the data has been shown in the Figure instead of Table. However, some resistivity recorded in the abnormal high pressure zone of this well had been erased as reasons mentioned above. The excluded resistivity data of well FAMS4874: the resistivity data at depth 1940-1970 ft, 2240-2275 ft, and 2500-2540 ft, respectively.

Next, monograph of Mae-Soon oil field was used to estimate pressure at every five-feet depth interval. After that, estimated

Table 3. Mean and SD of resistivity data of selected holes in Fang Basin

Hole name	Resistivity (Mean)	Resistivity (SD)
FAMS5280	33.02	10.35
FAMS4874	32.66	9.65
FAMS5179	34.31	10.64

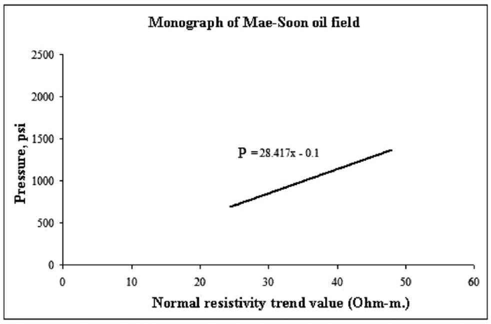

Figure 4. Monograph for pressure estimation of Mae-Soon oil field (All area)

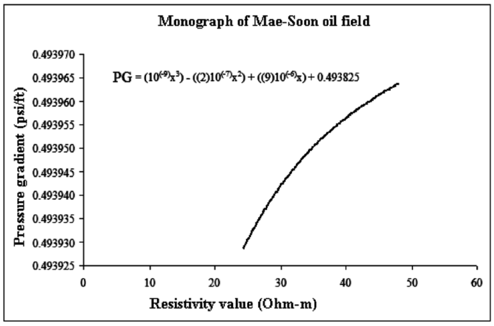

Figure 5. Monograph for pressure gradient estimation of Mae-Soon oil field

Table 4. Normal trend resistivity value of FAMS

Depth	Resistivity	Depth	Resistivity	Depth	Resistivity
1295	22.51234	1510	26.24991	1725	29.98748
1300	22.59926	1515	26.33683	1730	30.0744
1305	22.68618	1520	26.42375	1735	30.16132
1310	22.7731	1525	26.51067	1740	30.24824
1315	22.86002	1530	26.59759	1745	30.33516
1320	22.94694	1535	26.68451	1750	30.42208
1325	23.03386	1540	26.77143	1755	30.509
1330	23.12078	1545	26.85835	1760	30.59593
1335	23.2077	1550	26.94528	1765	30.68285
1340	23.29462	1555	27.0322	1770	30.76977
1345	23.38155	1560	27.11912	1775	30.85669
1350	23.46847	1565	27.20604	1780	30.94361
1355	23.55539	1570	27.29296	1785	31.03053
1360	23.64231	1575	27.37988	1790	31.11745
1365	23.72923	1580	27.4668	1795	31.20437
1370	23.81615	1585	27.55372	1800	31.29129
1375	23.90307	1590	27.64064	1805	31.37821
1380	23.98999	1595	27.72756	1810	31.46513
1385	24.07691	1600	27.81448	1815	31.55205
1390	24.16383	1605	27.9014	1820	31.63897
1395	24.25075	1610	27.98832	1825	31.72589
1400	24.33767	1615	28.07524	1830	31.81281
1405	24.42459	1620	28.16216	1835	31.89973
1410	24.51151	1625	28.24908	1840	31.98665
1415	24.59843	1630	28.336	1845	32.07357
1420	24.68535	1635	28.42292	1850	32.16049
1425	24.77227	1640	28.50984	1855	32.24741

Table 4. Normal trend resistivity value of FAMS (con)

Depth	Resistivity	Depth	Resistivity	Depth	Resistivity
1430	24.85919	1645	28.59676	1860	32.33433
1435	24.94611	1650	28.68368	1865	32.42125
1440	25.03303	1655	28.7706	1870	32.50817
1445	25.11995	1660	28.85752	1875	32.59509
1450	25.20687	1665	28.94444	1880	32.68201
1455	25.29379	1670	29.03136	1885	32.76893
1460	25.38071	1675	29.11828	1890	32.85585
1465	25.46763	1680	29.2052	1895	32.94277
1470	25.55455	1685	29.29212	1900	33.02969
1475	25.64147	1690	29.37904	1905	33.11661
1480	25.72839	1695	29.46596	1910	33.20353
1485	25.81531	1700	29.55288	1915	33.29045
1490	25.90223	1705	29.6398	1920	33.37737
1495	25.98915	1710	29.72672	1925	33.46429
1500	26.07607	1715	29.81364	1930	33.55121
1505	26.16299	1720	29.90056	1935	33.63813

Table 5. Values of normal resistivity, pressure and pressure gradient of Mae-Soon oil field

Depth, ft	Normal resistivity value, Ohm-m	Pressure, psi	Pressure gradient, psi/ft
1510	26.24991	746	0.493934
1515	26.33683	748	0.493934
1520	26.42375	751	0.493934
1525	26.51067	753	0.493934
1530	26.59759	756	0.493935
1535	26.68451	758	0.493935
1540	26.77143	761	0.493935
1545	26.85835	763	0.493935
1550	26.94528	766	0.493935
1555	27.0322	768	0.493936
1560	27.11912	771	0.493936
1565	27.20604	773	0.493936
1570	27.29296	775	0.493936
1575	27.37988	778	0.493937
1580	27.4668	780	0.493937
1585	27.55372	783	0.493937
1590	27.64064	785	0.493937
1595	27.72756	788	0.493937

Table 5. Values of normal resistivity, pressure and pressure gradient of Mae-Soon oil field (con)

Depth, ft	Normal resistivity value, Ohm-m	Pressure, psi	Pressure gradient, psi/ft
1600	27.81448	790	0.493938
1605	27.9014	793	0.493938
1610	27.98832	795	0.493938
1615	28.07524	798	0.493938
1620	28.16216	800	0.493938
1625	28.24908	803	0.493938
1630	28.336	805	0.493939
1635	28.42292	808	0.493939
1640	28.50984	810	0.493939
1645	28.59676	813	0.493939
1650	28.68368	815	0.493939
1655	28.7706	817	0.49394
1660	28.85752	820	0.49394
1665	28.94444	822	0.49394
1670	29.03136	825	0.49394
1675	29.11828	827	0.49394
1680	29.2052	830	0.49394
1685	29.29212	832	0.493941
1690	29.37904	835	0.493941
1695	29.46596	837	0.493941
1700	29.55288	840	0.493941
1705	29.6398	842	0.493941

Table 6. Comparison between the pressure which was estimated by using a monograph and the actual pressure which was found in FAMS hole

Depth	Real Pressure (1)	Resistivity of FAMS4874	Pressure from Graph (2)	% Error ((1-2)x100)/1
1400	692	24	660	4.555315
1405	694	24	660	4.895024
1410	696	23	631	9.396359
1415	699	25	708	-1.300600
1420	701	25	708	-0.943850
1425	704	24	660	6.230021
1430	706	25	708	-0.237850
1435	709	22	605	14.643270
1440	711	26	738	-3.759530
1445	714	27	766	-7.323500
1450	716	27	766	-6.953360

Table 6. Comparison between the pressure which was estimated by using a monograph and the actual pressure which was found in FAMS hole (con)

Depth	Real pressure (1)	Resistivity of FAMS4874	Pressure from graph (2)	% Error ((1-2)x100)/1
1455	719	30	852	-18.552300
1460	721	26	738	-2.337960
1465	724	25	708	2.157239
1470	726	25	708	2.490084
1475	729	24	660	9.409100
1480	731	23	631	13.682250
1485	733	26	738	-0.614870
1490	736	28	795	-8.022180
1495	738	30	852	-15.379900
1500	741	28	795	-7.301930
1505	743	26	738	0.722386
1510	746	25	708	5.073474
1515	748	26	738	1.377771
1520	751	25	708	5.698074
1525	753	27	766	-1.692670
1530	756	29	822	-8.770440
1535	758	30	852	-12.372900
1540	761	27	766	-0.702020
1545	763	26	738	3.293017
1550	766	24	660	13.793100

pressures from monograph was compared with recorded pressure at the same depth of this oil fields to see the different. There were both unary plus and unary minus erroneous percentage, depended on higher or lower pressure, had been estimated by these monographs comparing with recorded pressure.

Both results (unary plus and unary minus) were calculated as erroneous percentage by comparing with the actual pressure which was recorded at the same corresponding depth. The followed table shows an example of comparison between the pressure which was estimated by using created monograph and recorded pressure of Mae-Soon oil field at depth 1400-1550 ft. (Table 6)

As a result, the average accuracy erroneous percent both in unary plus and unary minus of the created monograph testing were listed in below table. (Table 7)

For the pressure gradient estimation, the created monograph was tested for checking its accuracy by using resistivity log data from the last step and it was applied same methods as in pressure estimation testing. For pressure gradient estimation testing, Figure 5 was used. (Table 8)

As a result, the average accuracy erroneous percent both in unary plus and unary minus of created monograph testing were also listed in Table 7.

For FAMS5280 and FAMS5179, to prove the accuracy of the monograph, the same method with FAMS4874 is used. Casing the amount of data is excessive, only the result has been shown in Table 7.

Conclusions, Limitations and Recommendations

Result from created the pressure estimation monograph testing indicated that

Table 7. Erroneous percent of the created pressure and the created pressure gradient estimation comparing to the recorded pressure at the same depth

Hole name	Pressure		Pressure gradient	
	+	-	+	-
FAMS4874	+4.21000	-4.24000	+0.00067	-0.00056
FAMS5280	+4.47000	-3.97000	+0.00093	-0.00083
FAMS5179	+4.74000	-4.65000	+0.00087	-0.00065
Average	+4.47333	-4.28667	+0.00082	-0.00068

Table 8. Comparison between the pressure gradient which was estimated by using a monograph and the actual pressure gradient which was found in FAMS hole

Depth	Real pressure gradient (1)	Resistivity of FAMS4874	Psi/ft from graph (2)	% Error ((1-2)x100)/1
1400	0.493929	24	0.493928	0.000116
1405	0.493929	24	0.493928	0.000167
1410	0.493929	23	0.493925	0.000826
1415	0.493929	25	0.493931	-0.000340
1420	0.493930	25	0.493931	-0.000290
1425	0.493930	24	0.493928	0.000369
1430	0.493930	25	0.493931	-0.000190
1435	0.493930	22	0.493921	0.001886
1440	0.493931	26	0.493933	-0.000490
1445	0.493931	27	0.493936	-0.001050
1450	0.493931	27	0.493936	-0.001010
1455	0.493931	30	0.493942	-0.002170
1460	0.493932	26	0.493933	-0.000300
1465	0.493932	25	0.493931	0.000150
1470	0.493932	25	0.493931	0.000197
1475	0.493932	24	0.493928	0.000851
1480	0.493932	23	0.493925	0.001505
1485	0.493933	26	0.493933	-0.000069
1490	0.493933	28	0.493938	-0.001040
1495	0.493933	30	0.493942	-0.001800
1500	0.493933	28	0.493938	-0.000940
1505	0.493934	26	0.493933	0.000112
1510	0.493934	25	0.493931	0.000562
1515	0.493934	26	0.493933	0.000201
1520	0.493934	25	0.493931	0.000650
1525	0.493934	27	0.493936	-0.000320
1530	0.493935	29	0.49394	-0.001090

Table 8. Comparison between the pressure gradient which was estimated by using a monograph and the actual pressure gradient which was found in FAMS hole (con)

Depth	Real pressure gradient (1)	Resistivity of FAMS4874	Psi/ft from graph (2)	% Error ((1-2)x100)/1
1535	0.493935	30	0.493942	-0.001450
1540	0.493935	27	0.493936	-0.000190
1545	0.493935	26	0.493933	0.000461
1550	0.493935	24	0.493928	0.001515

the erroneous percentage of pressure estimation of Mae-Soon oil field was (+4.47333) to (-4.28667). Moreover, pressure gradient estimation of Mae-Soon oil field by using the created monograph was quite accurate with very low erroneous percentage as (+0.00082) to (-0.00068). Percentage error of pressure gradient is very low because pressure gradient has been changed in each depth at the five decimal places. (Please see pressure gradient in Tables 5 and 8). As a result, when calculate the percentage error, the error is quite low.

The most important factor for the degree of estimating accuracy is the similarity of geological characteristics within the study area. The more complex geology, the less accuracy of the pressure and/or pressure gradient estimation accuracy.

To use monograph of each oil field to estimate pressure or pressure gradient, some limitations are listed as follows;

1. The created monograph both of pressure and pressure gradient estimation can only use in its own oil field. This is because the differences of geological characteristics of each oil field play an important role to its existed pressure directly and differ from place to place.

2. This monograph cannot be used to estimate pressure or pressure gradient of the abnormal high zone. This is because in the area of abnormal high zone the pressure is abnormally high and it is not follow the normal pressure trend.

3. The most important factor affecting this monograph to estimate pressure or pressure gradient is the similarity of geological characteristics of interesting area. The more different of geological characteristics, the less accuracy in pressure estimating. The variety of geological characteristics may be inspected from the degree of resistivity data distribution.

Some recommendations for further study are listed as follows;

1. The created monographs should be modified if there are some more resistivity data collected in the same area.

2. Other wireline logs, e.g. sonic log and density log should be used and tried to create this kind of monograph by using the same procedures.

Acknowledgement

I am grateful and indebted to Defense Energy Department for giving all data in this research. I am, as always, grateful to Geotechnology research unit, Suranaree University of Technology for giving me access computer (Microsoft excel 2003), helpful and good advise, and various documents and information.

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