Determination of Formation Temperature

by

Noor Farhana Bt Musiran

Dissertation submitted in partial fulfillment

of the requirements for the

Bachelor of Engineering (Hons)

Petroleum Engineering

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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In partial fulfillment of the requirement for the

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Approved by,

(AP Wan Ismail B Wan Yusoff)

Date :

UNIVERSITI TEKNOLOGI PETRONAS

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January 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I, Noor Farhana Bt Musiran, I/C No : 880209-01-5034, am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

In the name of Allah, The Most Gracious, The Most Merciful

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Special thanks to Mr. Aizuddin Bin Sa'lman for helping me on developing the program using Visual Basic 6.0. He helped me to use the software from the beginning until the completion of the program.

Last but not least, I would like to express my gratitude to my parents and family for their love and support. Same goes to my friends who helped me throughout this project directly or indirectly.

"At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us."

-Albert Schweitz

ABSTRACT

This report was written to present a study to determine formation temperature. It will be divided into three main sections which are introduction, literature review and methodology. In the introduction, the author will discuss the background of study, problem statement, objectives, relevancy and feasibility of the study. In the literature review, the author will state the studies done in the past and related to this study. Lastly, the author will explain on how this study will be conducted in the methodology. Raw bottom-hole temperature (BHT) measured during drill-stem test on oil and gas wells are usually lower than the true formation temperature. There are several factors affecting the readings of formation temperature such as the circulation time of drilling mud, flow of formation fluid and thermal conductivities. There are a lot of studies done in the past to correct the raw BHT. This study will have a review on those studies and focus on developing a program that will yields the corrected formation temperature for each depth, if given elapsed time between the drilling stop, raw BHT and mud-circulation time, by using Visual Basic 6.0. Based on this study, the Effective Cooling Method had been identified as the most suitable method to be used.

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NOMENCLATURES

AAPG	American Association of Petroleum Geologist
BHT	Bottom-hole Temperature
DST	Drill-stem Test
GOM	Gulf of Mexico
HP	Horner-plot
LWD	Logging while drilling
MWD	Measurement while drilling
TSC	Time since circulation

1.0 INTRODUCTION

1.1 Background of study

Temperature of formation is a vital parameter in geothermal studies. It is measured by lowering down temperature logging tools to the bottom of borehole. During drill-stem test, the actual temperature measured is the temperature of the drilling fluid and not the formation. The drilling mud is circulated during drilling and it is colder than the formation. It will eventually invade the formation and cools it down by heat convection. During circulation of the drilling fluid, the temperature of the borehole reached equilibrium which is defined by the cooling effect of the drilling fluid and the heating effect of the formation. When the circulation of the drilling stops, the drilling fluids will equilibrates with the formation and slowly regains the true formation temperature. However, this process is very slow because it occurs by heat conduction which is less efficient compared to conduction. In most cases, equilibrium could only be achieved after several months of stopping the circulation of the drilling fluid.

The measurement of temperature during drilling (LWD and MWD) usually yields unreliable data because drilling mud is being circulated. Temperature measurements made on wireline logs, which is a while after the circulation of drilling fluid has stopped, could produce better data as the formation is now in the process of reheating the borehole.

However, the rate of the process of reheating the borehole would be varied from one area to another. It could be affected by the thermal conductivities, flow of formation water and drilling activities.

1.2 Problem Statement

Temperature is a very important thermal property. It is used as an indicator for thermal conductivity and geothermal gradient. Geothermal gradient will only be constant if everything in the formation is constant which only happen in an ideal case and unlikely to happen in real field. This is why accurate reading of temperature is very crucial. Temperature readings by logging are often affected by circulation of drilling mud and flow of formation fluids. Correction methods had been introduced from time to time and the most common one is the Horner-Plot method. However, in some fields, the Horner-Plot method does not yield the best approximation. Therefore, in this study, the author will compare several types of correction methods with the actual formation temperature and come out with a software program.

1.2.1 Problem identification

Before developing the program, the author should understand the basic principle of this study such as the main factors that affecting the temperature reading and how to correct it. After mastering the topic, the author will have to learn on how to use the Visual Basic since it is not taught in the class. Only then, the author can develop the program for this study.

1.2.2 Significant of the project

A good estimation of true formation temperature will helps a lot in determining the heat flow a region which is a very important parameter in geothermal studies.

Besides that, well tests were carried out to determine the properties of the reservoirs. Usually people will use pressure transient to carry out well tests but recently temperature transient are quite important in well tests for gas wells. Therefore, it is vital for us to have a program that will give us the real formation temperature so that well tests and geothermal studies could be conducted easily.

1.3 Objectives and Scope of Study

The objectives of the study are:

i) to study on the factors that affected the reading of formation temperature
ii) to study on the methods used to correct the raw bottom-hole temperature
iii) to come out with a program that will gives a corrected temperature.

The scope of study for the first semester will understand the topics by doing literature review from journals and books. Research on the topic will be furthered by studying the factors affecting the reading of formation temperature and the methods to correct the raw data.

The scope of study for the second semester will be developing the program by using Visual Basic and do a case study based on real field data.

1.4 The Relevancy of the Project

This project is relevant to the study of reservoir engineering. Temperatures can help in reservoir characterizing especially in gas wells, instead of using pressure. There are new methods that had been developed in well tests interpretation for temperature transient analysis (H.Bahrami, 2007). It shows that temperature is as important as pressure to determine reservoir properties. Temperature is also required for calculations of hydrocarbon recovery factors, including pressure-volume-temperature relationships, and gas-oil ratios (S.Prensky, 1992).

1.5 Feasibility of the Project within the Scope and Time frame

The project is to be done in two semesters. The first five months to study on the topics, understands the basic principle and come out with the best solution. Another five months is to come out with a program as the product of the project and a case study. The author feels that the project could be completed within the given time.

2.0 LITERATURE REVIEW

2.1 General Overview

In order to develop good estimates on the heat content of a geothermal reservoir and its formation resistivity, and for various drilling and completion decisions one needs, an accurate estimate of the formation temperature (B.Roux, S.K.Sanyal and S.L.Brown, 1980).

Accurate knowledge of undisturbed formation temperature essential for numerous applications in drilling, completions and production. Applications include 1) drilling fluid and cement slurry design, 2) log interpretation, 3) corrosion in tubing and casings, 4) thermal stress assessment, 5) hydrocarbon reserve estimation, and 6) geothermal energy extraction (S.V.Kashikar, 1991).

In most cases, bottom-hole temperature surveys are mainly used to determine the temperature of the earth's interior. The drilling process, however, greatly alters the temperature of formation immediately surrounding the well. The temperature change is affected by the duration of drilling fluid circulation, the temperature difference between the reservoir and the drilling fluid, the well radius, the thermal diffusivity of the reservoir and the drilling technology used. Given these factors, the exact determination of formation temperature at any depth requires a certain length of time in which the well is not in operation. In theory, this shut-in time is infinitely long to reach the original condition (I.M.Kutasov and L.V.Eppelbaum, 2010).

It should be noted that Horner method for obtaining the formation equilibrium temperature from the bottom-hole temperature is widely applied in oil and gas industry (Cao et al., 1988; Deming and Chapman, 1988; Kutasov, 1989; Nielsen et al., 1990; Kutasov, 1999; Mcaleese, 2000; Förster, 2001; Andaverde et al., 2005; Kutasov and Eppelbaum, 2005; Zschocke, 2005; Verma et al., 2006; Pasquale et al., 2008; Espinosa-Paredes et al., 2009).

If multiple BHT measurements from successive logging runs are available, the Horner plot correction procedure can be used. The accuracy of the Horner plot is limited by simplifying assumptions made in its derivation, and by the common lack of information on parameters such as duration of mud circulation (D.Deming, 2003).

2.2 Disturbance of Drilling

Jessop (1990) stated that during the process of drilling, there were some disturbances happened to the temperature of formation, both by friction of the drilling and heat exchange from the drilling fluid. The heat of friction usually will be absorb by the drilling fluid due to its heat capacity.

The drilling fluid will be pumped through tubing and will first reach the bottom of the hole. The drilling fluid will had direct contacts with the formation, equilibrated thermally and will then moved upward through the annulus and equilibrated with the formation further. This is why the drilling fluid at the bottom is colder. After the circulation of the drilling fluid stopped, heat transfer will occurred between the drilling fluid and formation until the original temperature restored. However, when this happened, the drilling fluid also has invaded the formation and this made the recovery of the true temperature became much slower. As a rough approximation the recovery is completed to within the accuracy of most measurements in a period that is ten to twenty times greater that the time of drilling (Bullard, 1974).

Drilling process by using a diamond driller bit normally took no more than 1 year to achieve equilibrium temperature. However, a large rotary-drilled hole will take many years and a system of extrapolation of observed data is essential. This extrapolation is achieved by plotting the observed temperature against T, a logarithmic function of the time elapsed since end of drilling and the time of duration of the drilling. The time function is given by

$$T = \ln [(t + t_I) / t] \qquad (2.0)$$

where t is the duration of drilling and t_I is the time elapsed since completion. The function T will become zero if the time elapsed is too big, and thus the temperature extrapolated o the axis gives the equilibrium temperature of the well and the formation.

2.3 Disturbance of Formation Water Flow

Water was contained in most pore spaces of the formation. During drilling process, water will flows into the borehole if the pressure of the water is higher than the hydraulic pressure. The borehole acted like a new channel for the water to flow. If the water is moving in some direction before the drilling, it might change the flow pattern. While the flow pattern is changing, the formation temperature nearby the well will equilibrates with the water temperature. If the flow is continuous, it seems like impossible to get the equilibrium temperature. The temperature should be taken as soon as possible after the drill has passed each spot (Jessop, 1990, p.240).

2.4 Borehole Temperature Correction

Temperature from DST with high flow rates and low pressure drawdown can be expected to yield values close to 'true' formation temperatures (Vik and Hermanrud, 1993).

2.4.1 AAPG Empirical Correction

The borehole temperature correction could be divided into two which are based on mathematical model of the temperature buildup in a well, and empirical corrections (D.Deming, 1989). One of the famous empirical corrections is the correction proposed and used by the American Association of Petroleum Geologist (AAPG). The correction arose as an outgrowth of the AAPG geothermal survey of North America in the early 1970s. The AAPG correction is based upon a comparison between BHTs and equilibrium temperatures measured in 602 wells in the states of Lousiana and West Texas, and has been used in geothermal studies by Speece et al. (1985) and Bodner and Sharp (1988). The temperature difference between a BHT and equilibrium temperature was used to derive a geothermal gradient difference for that depth (Kehle, 1972).

$$\Delta T = az + bz^2 + cz^3 + dz^4 \qquad (2.1)$$

Where ΔT is the temperature correction in degrees Celsius, and z is the depth in kilometers. The correction coefficients are not generally available and are varied from one area to another. The correction is zero at zero depth, increases in a nearly linear manner to a maximum of 14.1°C at 4574m depth and then decreases to 9°C at 6km depth. This is probably due to the time taken by the logging tools to reach deeper bottom of borehole, permitting the borehole temperature to equilibrate longer with the temperature of formation.

Table 1 : AAPG correction coefficients.

Area	**a**	**b**	**c**	**d**
West Texas	-1.169e-3	-4.690e-7	6.609e-10	-8.312e-14
Louisiana	4.926e-3	2.164e-6	-7.628e-10	4.950e-14
Average	1.878e-3	8.476e-7	-5.091e-11	-1.681e-14

2.4.2 Horner Plot

The relationship between true formation temperature and DST temperature is unknown for any single temperature measurement (Ben Dhia, 1988, p.1480). Bullard (1947) and Lachenbruch and Brewer (1959) derived the so-called Horner plot for temperature buildup in the bottom hole which is the oldest method based upon mathematical models. It's called Horner plot because it is identical to an equation developed by Horner (1951) to predict reservoir pressure recovery. The simplified equation was given by (Bullard, 1947)

$$Tf = BHT + A \log \left[\frac{t + t_{circ}}{t}\right] \qquad (2.2)$$

where t_{circ} is the duration of mud circulation, t is the shut-in time, or time elapsed between the end of mud circulation and BHT measurement, Tf is the equilibrium temperature in the borehole, and A, the slope of the Horner plot, is an unknown constant.

In order to apply the correction, it is necessary to have time-temperature set of two or more BHTs, measured in the same well, at the same depth, but at different shut-in times. In practice, there are two drawbacks to application of the Horner plot: it cannot be applied to single BHTs, and although shut-in time is usually found on log headers, information on the duration of circulation times is often not found. The more serious of these problems is that time-temperature sets are frequently not available for most wells (D. Deming, 1989).

Table 2 : Horner plot calculation example.

Time	Operation	Temperature (°C)	T (hours)	*t* (hours)	*T/(t/T)* (-)
00:00	Circulation started	-	-	6	
06:00	Circulation stopped	-	0	6	
13:00	Run IEL log	100	7	6	0.538
17:30	Run Sonic log	105	11.5	6	0.671
01.30	Run FDC-CNL log	108	19.5	6	0.765

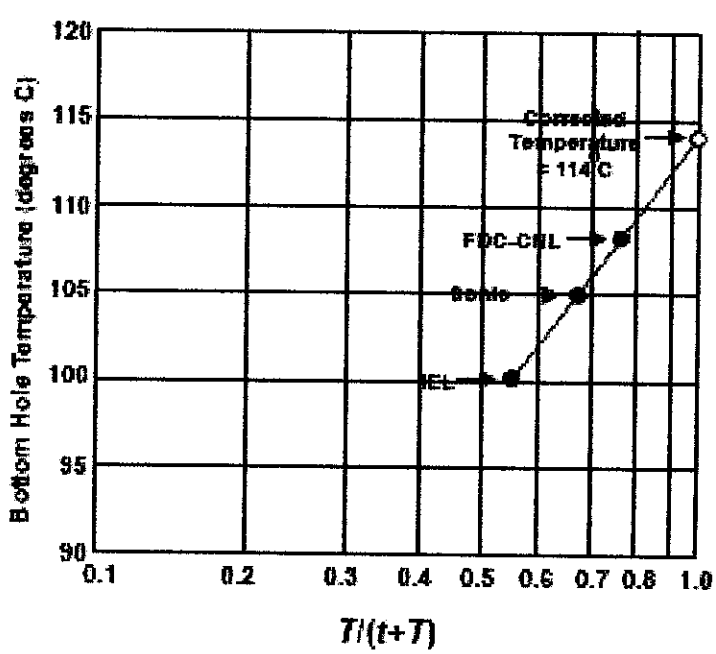


Figure 1 : The Horner plot for correction of BHT at 3200 m in a well using data in Table 1.

2.4.3 Statistical Method

Waples and Mahadir Ramly (2001) stated that for individual log-derived temperatures the correction factor f_s, which is applied to the difference between the measured temperature and the surface temperature, is given by

$$f_s = [-0.1462 \ln (TSC) + 1.699] / [0.572 - Z^{0.075}] \qquad (2.3)$$

where TSC is the time since end of mud circulation in hours and Z is the depth in metres. For temperatures that have already been corrected by extrapolation using Horner plots, f_{HP} is given by

$$f_{HP} = 0.1321 \ln (TSC) + 1.52 \qquad (2.4)$$

where TSC is the maximum time since circulation stopped (hours) in the Horner plot set. Uncertainties in f_S decrease markedly as TSC and depth increase as shown in Figure 2. Uncertainties in f_{HP} decrease as maximum TSC and the number of consistent temperature measurements at a given depth increase.

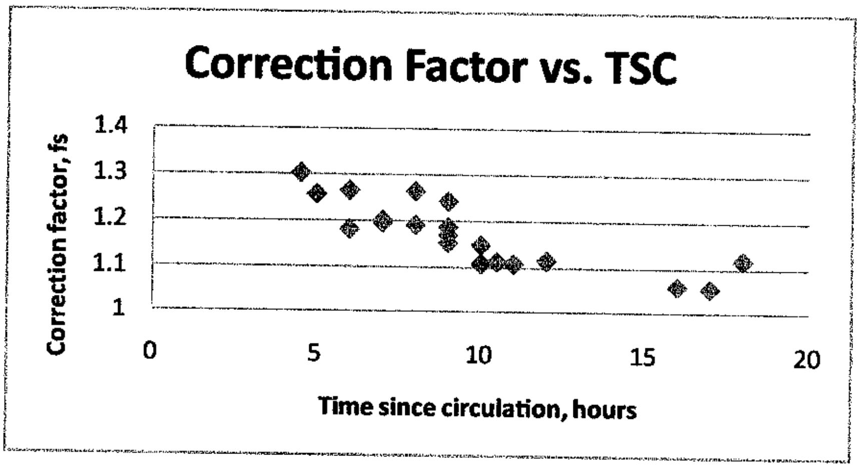


Figure 2 : Correction factor, fs over maximum time since circulation

Their study confirmed earlier observations (Beck and Balling, 1988; Dowdle and Cobb, 1975; Hermanrud, 1988) that Horner plots systematically underestimate true formation temperatures. They suggested that some modification should be made in the Horner plot as a function of maximum TSC:

$$Tf = (-0.132 \ln Tbhmax + 1.52) * (Thp - Tsurf) + Tsurf \qquad (2.5)$$

Waples et al. (2004) have developed a method for correcting log-derived temperatures in deep wells (3500-6500 m) by comparing log temperatures from the Gulf of Campeche (Mexican Gulf of Mexico) with DST temperatures in the same wells. The equations developed in this study are modified slightly from those of Waples & Mahadir Ramly (2001), which were calibrated using data from depths <3500 m in Malaysia. The correction depends strongly on time since end of mud circulation (TSC) and, to a much lesser degree, on depth. The corrected subsurface temperature (Celsius) is given by

$$T_{true} = T_{surf} + f \cdot (T_{meas} - T_{surf}) - 0.001391(Z-4498) \qquad (2.6)$$

where T_{meas} is the measured log temperature in Celsius, Z is depth below sea floor in meters and T_{surf} is the sea floor or land surface temperature. The correction factor, f, is a function of TSC given by

$$f = 1.3433e^{-0.0059TSC} \qquad (2.7)$$

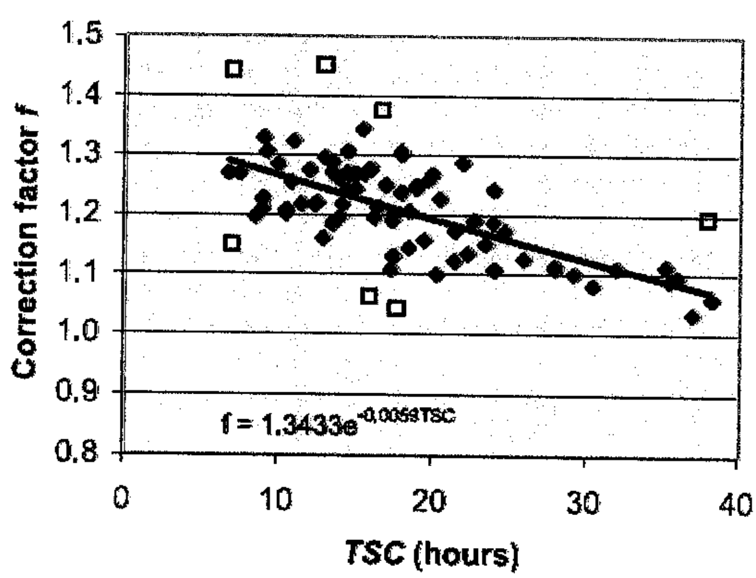


Figure 3 : Correction factor, f over TSC (time since circulation)

Figure 2 shows the amount of correction strongly depends on time since end of mud circulation (TSC). The scatter is typical of BHT data and gives a good sense of the error bars associated with such a correction (Waples et al., 2004).

2.4.4 Simple BHT Correction

If time-since-circulation information is available, but the data are unsuitable for a Horner correction, a correction method based only on the time-since-circulation information has been developed. Teq estimate uncertainties (1 sigma) are on the order of ±10-20 °F at a post-circulation time of 10 hours, decreasing to ±5-10°F at a post-circulation time of 30 hours.

The plot below shows the data set and model fits for the time since circulation method used here. The plot shows the difference between equilibrium temperature (taken to be equivalent to high-graded DST temperature measurements) and adjacent (±500 ft) BHT measurements versus time since circulation (N = 983 DST-BHT pairs). The solid line represents the best fit for the equation shown in the box. Dashed lines are standard error estimates.

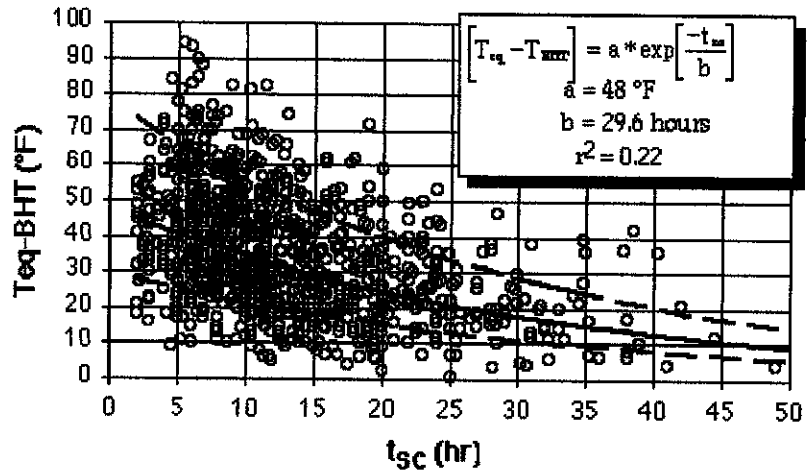


Figure 4 : Simple BHT Correction Plot

2.4.5 Effective Cooling Time Method

There is cooling time in Horner-plot equation but the data is not always available because the circulation time of the mud is not measured during logging. To encounter that, many workers have estimated it to be between 1 to 6 hours (Thamrin, 1985; Majorowicz et al., 1990; Brigaud et al. 1992). Jessop (1990) suggested that the cooling time interval is the time of drilling operation before recording the first temperature reading.

$$Tf = BHT + A \ln((1+tc)/te) \qquad (2.8)$$

Where Tf is the true formation temperature, BHT is the bottom-hole temperature, A is the slope, tc is the estimated cooling time or drilling time and te is the elapsed time between the end of drilling and logging started.

Wan Ismail (1994) said that to estimate the most effective cooling time, we need to calculate the instantaneous warming-up rate and determine the thermal recovery type of the formation. Instantaneous warming-up rate is given by ($Tbh_{max} - Tbh_{min}$) / ($te_{max} - te_{min}$) / depth in meter.

Table 3 : Summary of the limit of instantaneous warming-up rate of each type of thermal recovery for Bottom-Hole Temperature

Thermal Recovery Type	**Instantaneous Warming-up Rate (°C/hr/m)**	
	>	< or =
Rt1		0.0004595
Rt2	0.00046	0.0006095
Rt3	0.00061	0.00085
Rt4	0.00085	0.001188
Rt5	0.001188	

After defining the types of thermal recovery of the formation, effective cooling time could be estimated using this equation:

$$tc_{emp} = (b)(m1)^{D}(m2)^{temin}(m3)^{temax}(m4)^{Tmin}(m5)^{Tmax}(m6)^{tec}(m7)^{Tc} \quad (2.9)$$

Where D is the depth at logging in kilometers, te_{min} is minimum elapsed time after mud circulation prior stopped, te_{max} is the maximum elapsed time after mud circulation prior stopped, Tmin is the minimum temperature measured, Tmax is the maximum temperature measured, te_c is the time interval between the measurement of Tmin and Tmax, T_c is increase in the measured temperature after time te_c and m1 to m6 is the coefficient of the independent variables.

The values of m1 to m7 are depending on the types of thermal recovery and are given in the table below.

Table 4 : Values of m1 to m6 due to respective thermal recovery types.

Coefficient	Thermal Recovery Type				
	Rt1	Rt2	Rt3	Rt4	Rt5
b	2.88E+03	4.39E+06	6.27E+04	6.07E+02	9.03E+05
m1	1.00	1.00	1.00	1.00	1.00
m2	0.81	0.06	0.21	0.44	0.22
m3	0.96	13.39	1.82	1.58	2.57
m4	0.09	01.61	1.06	0.89	0.88
m5	10.69	0.55	0.85	1.05	1.00
m6	1.29	0.08	0.61	2.54	0.31
m7	0.06	1.37	080	0.62	1.43

3.0 METHODOLOGY

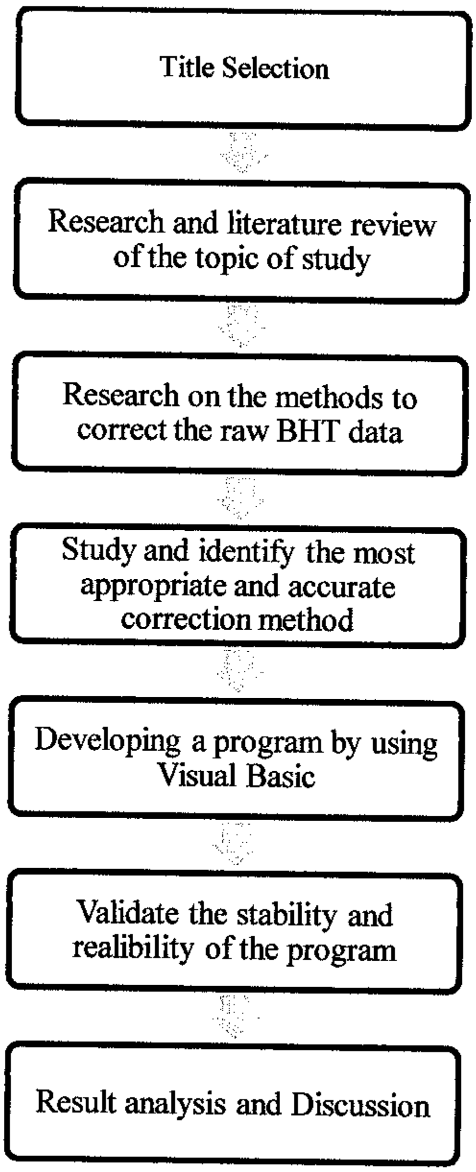


Figure 5 : Process flow diagram

3.1 Research Methodology

All the research on this study will be mainly based on a book entitled "Thermal Geophysics" by A.M. Jessop, other books and journals related to the topic. Research will also be conducted by asking or interviewing the experts of the topics which are either lecturers or people from the industry.

After identifying the correction methods to be studied, calculations will be made by using excel. Based on the result, the author will select the correction method(s) to be used to develop a program.

3.2 Tools Required

In order to complete this project and come out with a program, the author will need software which is Visual Basic 6.0. However, in the early stage of this study, the author will have to use Microsoft Office Excel to test and do initial simulation.

3.3 Gantt Chart for first semester

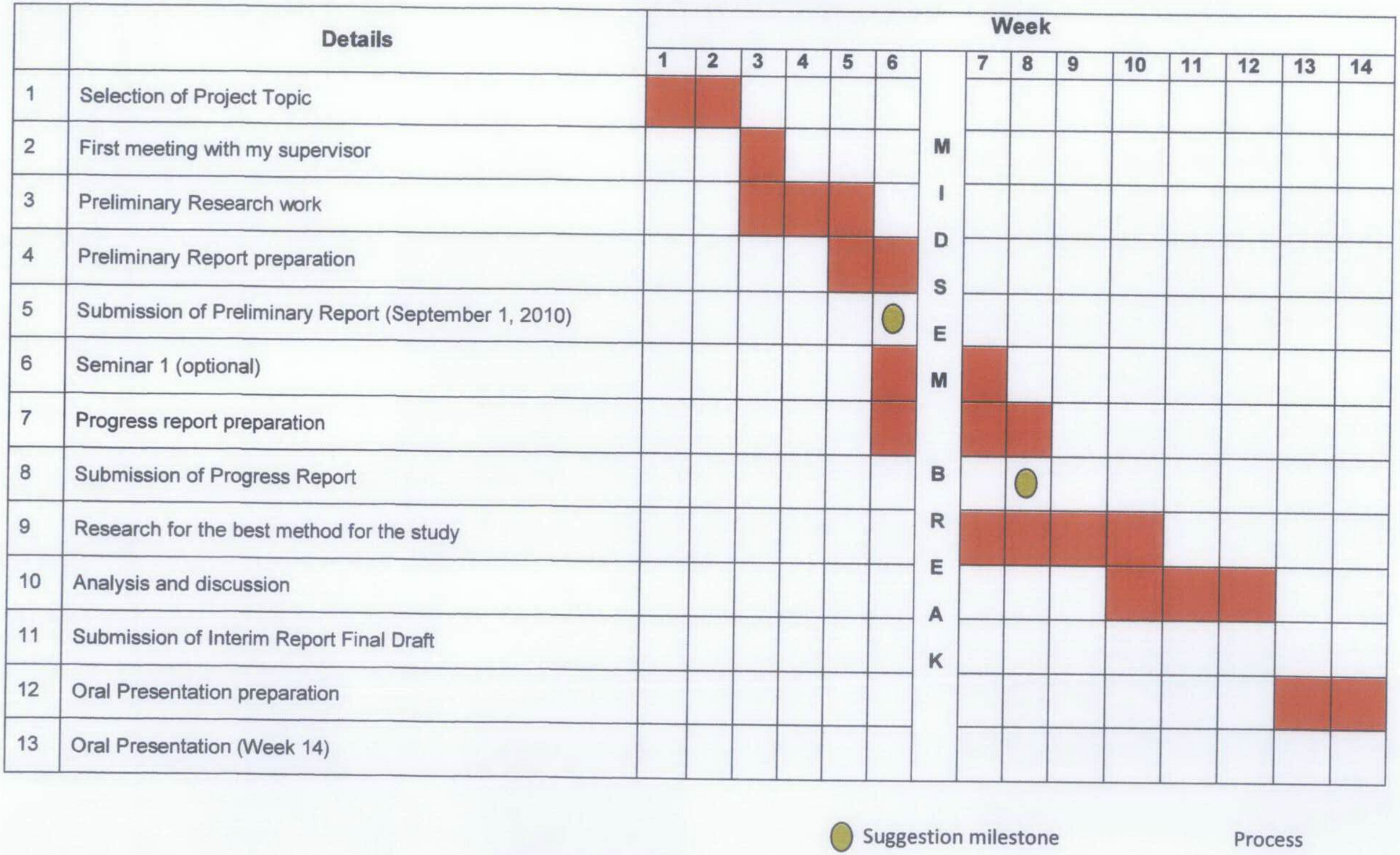
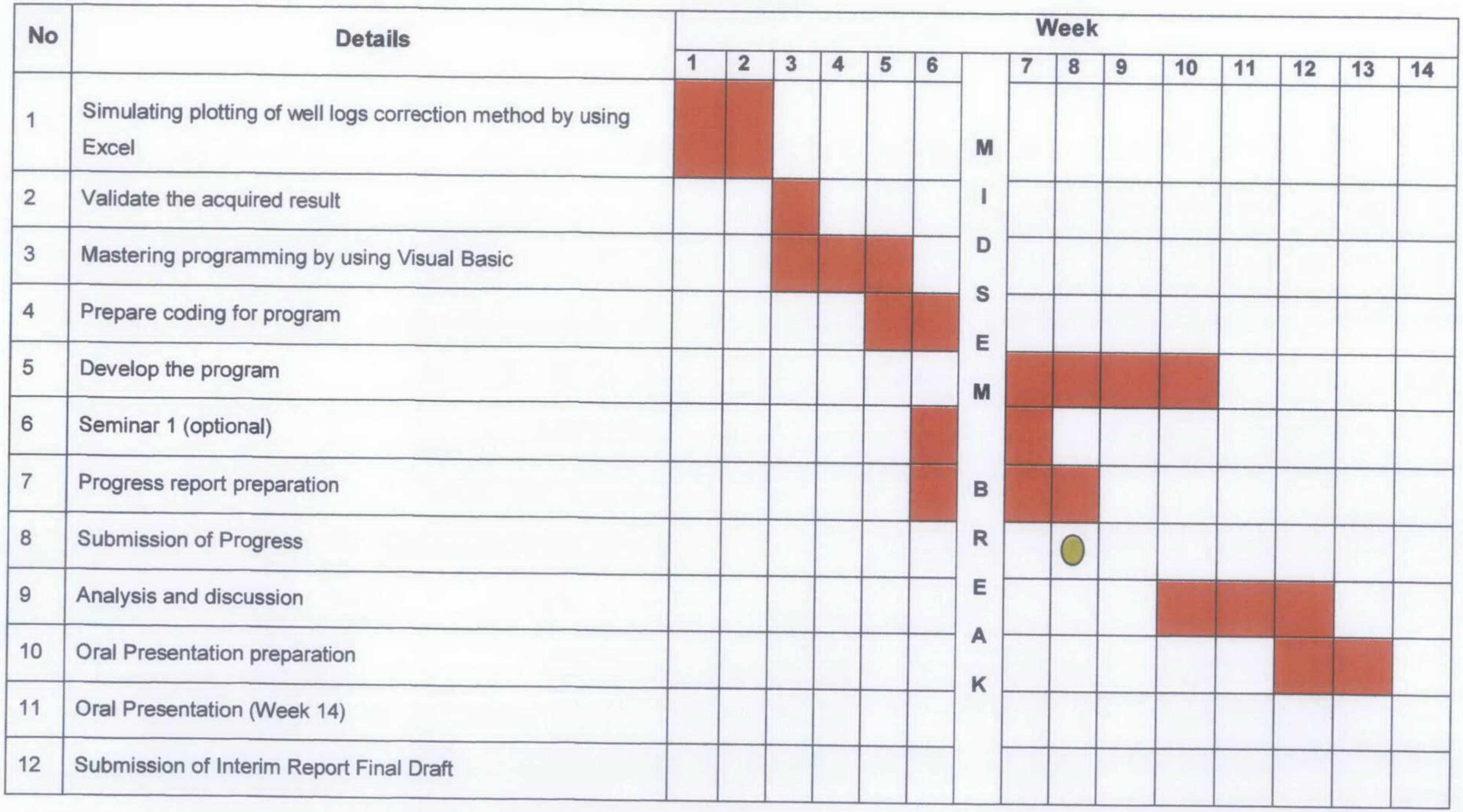


Figure 6: Gantt chart for first semester

3.4 Gantt Chart for second semester



Suggestion milestone Process

Figure 7 : Gantt chart for second semester

4.0 RESULTS AND DISCUSSIONS

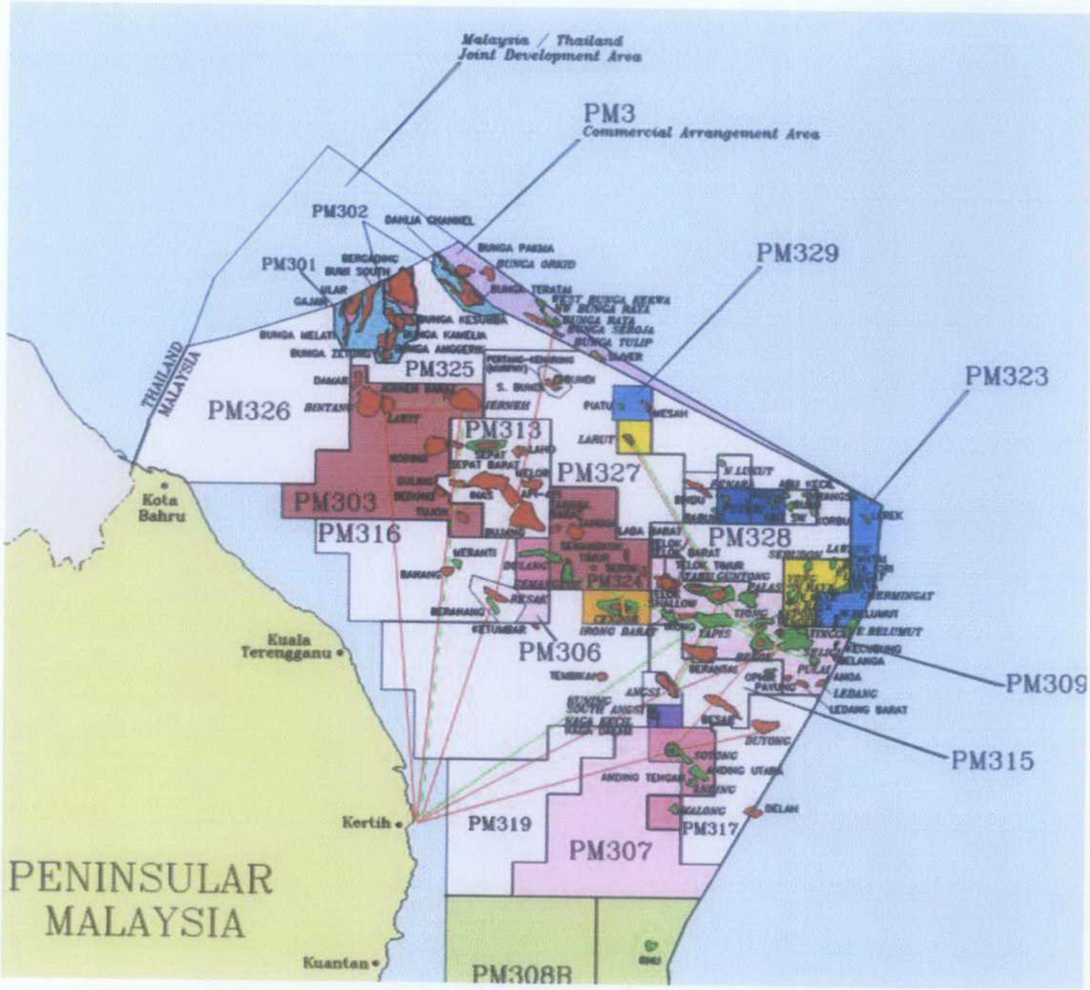


Figure 8 : Map of the Malay Basin

This study was conducted using data from the Malay Basin as shown in Figure 8. Temperature data from 18 different wells were collected and became the subject of this study. Six different correction methods were used and the results were compared to the true formation temperature. Table 5 shows the error of the corrected temperature yielded by each method. The summary for all the corrected temperatures and true formation temperature will be in Table 6.

Table 5 : Summary of error yielded by each method.

WELL	ERROR					
	HORNER PLOT ANALYSIS	STATISTICAL CORRECTED BHT	EFFECTIVE CIRCULATION TIME ANALYSIS	WAPLES GOM 2004	MAHADIR RAMLY & WAPLES 2001	AAPG
	%	%	%	%	%	%
BEKOK-8	5.24	14.54	3.41	16.36	4.19	4.13
DULANG-3	3.31	3.96	4.63	4.69	8.58	11.13
GUNTONG-4	7.82	0.10	10.46	5.18	11.51	16.75
INAS-2	3.27	1.67	10.85	0.86	0.93	14.56
IRONG BARAT-1	2.37	13.59	0.35	8.61	4.89	8.79
IRONG BARAT-3	3.98	16.21	5.68	11.82	6.48	6.71
IRONG BARAT-9	2.32	10.76	1.29	9.13	5.76	8.69
IRONG-1/1A	0.63	9.76	1.59	13.56	7.91	2.66
OPHIR-1	5.56	13.83	3.42	20.24	4.57	4.49
PALAS-1	4.53	5.64	6.26	7.89	11.50	5.15
PALAS-2	7.06	6.09	7.87	6.52	14.19	4.11
PALAS-4	5.43	5.04	6.94	8.71	13.04	5.09
SELIGI N W-1	3.79	1.58	2.57	3.19	7.73	16.54
SEMANGKOK-2	8.24	1.11	8.36	2.68	11.29	18.83
TABU-3	7.10	1.03	2.57	1.40	0.03	11.10
TAPIS-3	2.60	10.25	1.73	12.57	4.32	3.24
TINGGI-1	1.94	18.10	0.51	18.33	3.34	1.75

Table 6 : Summary of Corrected Temperature and True Formation Temperature

WELL	LOG DATA (CORRECTED TEMPERATURE)							PRODUCTION TEST DATA (MEASURED TEMPERATURE)	
	DEPTH	HORNER PLOT ANALYSIS	STATISTICAL CORRECTED BHT	EFFECTIVE CIRCULATION TIME ANALYSIS	WAPLES GOM 2004	MAHADIR RAMLY & WAPLES 2001	AAPG	DEPTH	TEMPERATURE MEASURED
	m	°C	°C	°C	°C	°C	°C	m	°C
BEKOK-8	2372.3	130.40	141.92	128.12	144.17	118.71	129.02	2143.4	123.9
DULANG-3	1525.5	102.88	110.61	101.47	111.39	97.27	94.56	1428.9	106.4
GUNTONG-4	1308.8	91.62	99.50	89.00	94.25	87.95	82.75	1482.9	99.4
INAS-2	1564.5	100.38	98.83	107.75	98.03	96.30	83.05	1550.2	97.2
IRONG BARAT-1	1006.8	77.23	89.85	78.82	85.91	75.23	72.15	933.6	79.1
IRONG BARAT-3	972.3	74.71	90.41	73.38	87.00	72.76	72.58	921.4	77.8
IRONG BARAT-9	1251.2	85.08	96.47	88.22	95.05	82.08	79.54	1116.8	87.1
IRONG-1/1A	1985.2	114.87	126.88	113.76	131.27	106.46	112.52	1833.1	115.6
OPHIR-1	2571.6	137.22	147.98	134.44	156.31	124.06	135.83	2314.4	130.0
PALAS-1	2324.1	114.57	126.77	112.48	129.47	106.20	113.82	2206.1	120.0
PALAS-2	2424.1	114.60	130.81	113.60	131.34	105.80	118.23	2242.2	123.3
PALAS-4	2356.1	120.29	133.62	118.37	138.28	110.61	120.73	2188.9	127.2
SELIGI N W-1	1730.4	97.27	99.50	98.51	97.88	93.28	84.37	1616.4	101.1
SEMANGKOK-2	1262.2	87.53	94.34	87.43	92.85	84.63	77.44	1226.2	95.4
TABU-3	2013.8	124.99	117.90	119.70	118.34	116.74	103.75	1898.9	116.7
TAPIS-3	1855.6	112.85	121.27	111.91	123.82	105.25	106.43	1743.8	110.0
TINGGI-1	1702	94.60	109.60	93.27	109.81	89.70	94.42	1313.4	92.8

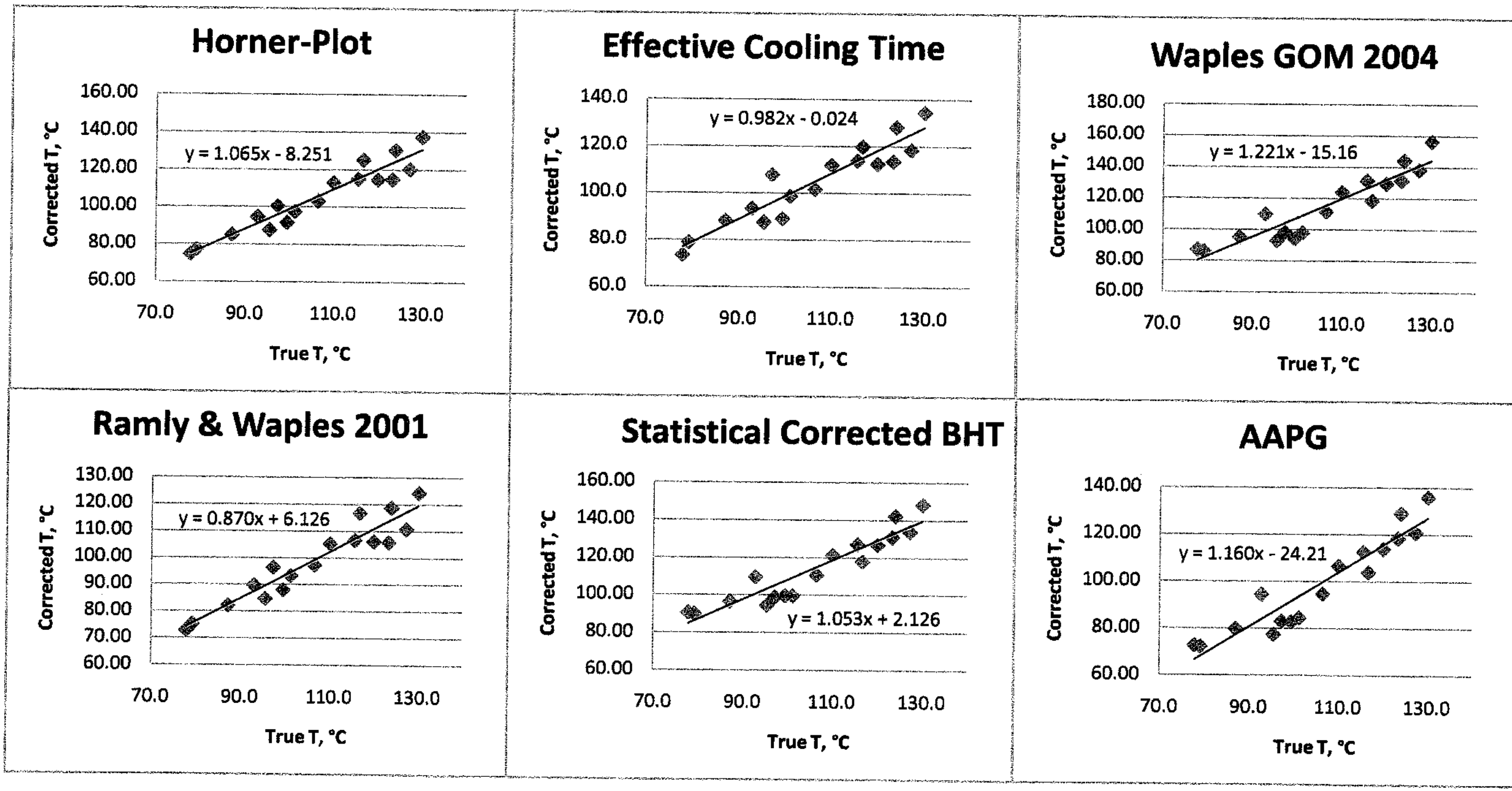


Figure 9 : Corrected Temperature vs. True Temperature for all correction methods

Figure 10 : Histograms showing the frequency of certain ranges of temperature (70-90°C, 90-110°C, 110-130°C, 130-150°C).

Figure 8 shows the distributions of six same set of temperature data but with different methods of BHT correction. From the figure, we could see that almost all correction methods yielded consistent results except for AAPG. This might be caused by different geological setting. The study for AAPG was carried out in United State while all the data used in this study were from the Malay Basin. This figure was further explained by Figure 9.

In Figure 9, we could see the frequency of the corrected temperature compared to the true formation temperature. For Horner -plot, we could see that the temperature frequencies are quite comparable for all ranges of temperature. Horner-plot considers the general factors that contribute to the temperature reading and yielded a quite consistent result. The average errors were also smaller compared to other methods. All Tc was set for 6hours in this study.

Effective cooling time was matched with the true temperature for the range of 110°C and above. Temperature readings usually were taken from sandstone zone which is often to be at lower depth and have higher temperature. The temperature data used in the study of effective cooling time may consist of this kind of readings only and did not take into account lower temperatures. The range 90-110°C did not give a good match probably because of the content of shale. The details will be in Appendix.

Correction made by Ramly and Waples 2001 were also a bit off although the study was done on the same basin. This is possible because the study was done based on statistical method and it did not consider the type of formation, etc.

Statistical Corrected BHT also gave inconsistent results. It's the same as Ramly and Waples 2001 which used statistical method in their study. The Statistical Corrected BHT used regression analysis that calibrated the first-run BHT with selected production test data. So it will only be accurate for certain wells.

The Waples GOM 2004 overestimated the temperature for range 130°C and above. Although the study was done in Gulf of Mexico and was meant for depth more than 3500 metres, the corrected temperature somehow matched the BHT ranged 90-110°C. The geological pattern in shallower depth might not vary too much for both basins.

5.0 CONCLUSION

5.1 Conclusion

From the research done, the author has realized the importance of determining the undisturbed formation temperature. There are a lot of factors or parameters could affect the reading of the temperature but different areas have different concerns. The wellbore cooling time is one of the most important parameter. As we can see in the result, good estimation of cooling time will give us a good corrected temperature. To get a good estimation of cooling time, the thermal facies should be determined correctly as the warming up rate will depend on it.

The author will developed a program based on Effective Cooling Method since it gave the most consistent results. It has the potential to be improved and with further studies it would be able to yield a desired result. The interface and coding for the program are in APPENDIX B and APPENDIX C.

5.2 Recommendation

The effective cooling method considers a lot of factors such as the type of formation and the warming-up rate but the study were conducted by using real data only which usually were taken at sandstone region. To be able to use it at every basin and every depth, further study and some adjustment should be done. The study should be conducted in laboratory so that some simulation could be done.

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APPENDIX A : *List of estimated circulation time by comparing with known temperature, tc, and log parameters used to predict effective cooling time, tcemp.*

WELL	Depth	Depth	temin	temax	Tbhmin	Tbhmax	tec	Tc	Rt	Inst. Warming rate	tcemp
	m	km	hours	hours	°C	°C	hours	°C	type	°C/hr/m	hours
BEKOK-8	2374	2.374	8	17	113	121	9.00	8	Rt1	0.000374	0.021
DULANG-3	1524	1.524	5	9	83	90	4.00	7	Rt4	0.001148	3.645
GUNTONG-4	1309	1.309	10	18	71	79	8.00	8	Rt3	0.000764	0.001
INAS-2	1565	1.565	4	5	74	78	1.20	4	Rt5	0.002367	15.711
IRONG BARAT-1	1013	1.013	6	9	67	69	3.00	3	Rt4	0.000914	12.059
IRONG BARAT-3	976	0.976	4	8	67	70	4.00	3	Rt3	0.000768	1.089
IRONG BARAT-9	1251	1.251	3.5	6	72	76	2.50	4	Rt5	0.001279	15.255
IRONG-1/1A	1985	1.985	6	9	102	106	3.50	4	Rt2	0.000560	3.171
OPHIR-1	2572	2.572	6.5	10	123	127	3.50	4	Rt1	0.000444	0.025
PALAS-1	2326	2.326	8	11	103	106	3.50	3	Rt1	0.000369	0.130
PALAS-2	2424	2.424	9	16	107	110	7.00	3	Rt1	0.000164	0.151
PALAS-4	2357	2.357	7	10.5	110	113	3.50	3	Rt1	0.000337	0.096
SELIGI N W-1	1731	1.731	5	7	74	79	2.00	5	Rt5	0.001445	7.707
SEMANGKOK-2	1254	1.254	4	4.5	73	74	0.50	1	Rt5	0.001772	5.817
TABU-3	2014	2.014	8	12	87	97	4.00	11	Rt5	0.001310	1.071
TAPIS-3	1855	1.855	5	10	92	101	5.00	8	Rt4	0.000898	4.323
TINGGI-1	1743	1.743	6	9	87	89	3.00	2	Rt1	0.000382	0.846

APPENDIX B : *Program developed using Visual Basic 6.0 to determine the corrected temperature by Effective Cooling Time Method.*

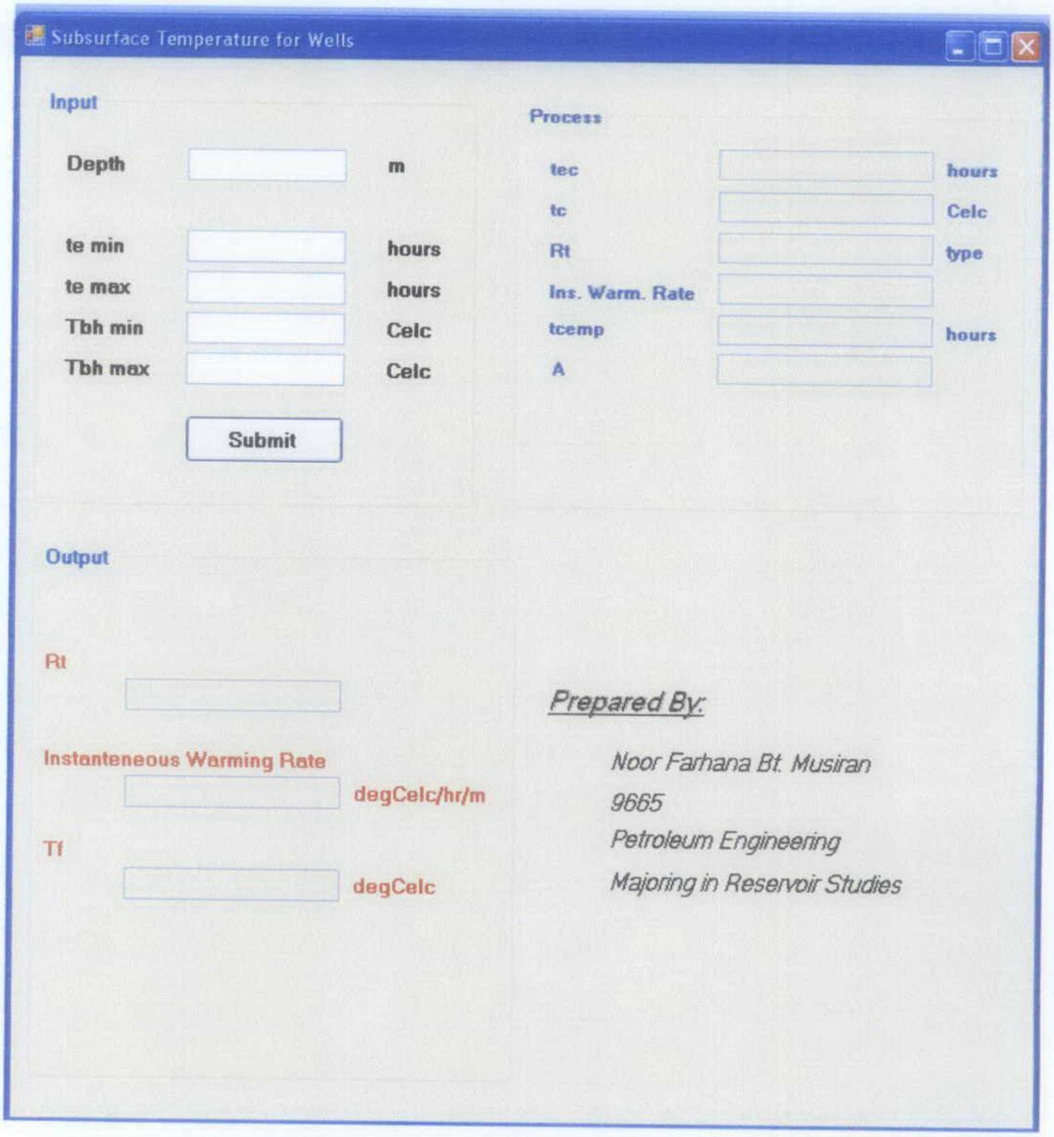

Figure B.1 : The Interface of the program.

APPENDIX C : Coding for *program developed using Visual Basic 6.0 to determine the corrected temperature by Effective Cooling Time Method.*

```
Imports System.Math

Public Class frmSub

    Dim m As Integer
    Dim km As Decimal
    Dim temin As Integer
    Dim temax As Integer
    Dim tbhmin As Integer
    Dim tbhmax As Integer
    Dim IWR As Decimal
    Dim tec As Double
    Dim tc As Integer
    Dim rt As String
    Dim LNmin As Double
    Dim LNmax As Double


 Private Sub btnSubmit_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnSubmit.Click
        m = Val(txtDepth.Text)
        km = m / 1000
        txtDepth2.Text = km
        temin = Val(txtTemin.Text)
        temax = Val(txtTemax.Text)
        tbhmin = Val(txtTBHmin.Text)
        tbhmax = Val(txtTBHmax.Text)


        txtTec.Text = temax - temin
        tec = Val(txtTec.Text)
        txtTc.Text = tbhmax - tbhmin
        tc = Val(txtTc.Text)

        IWR = tc / tec / m
        txtIWR.Text = Math.Round(IWR, 6)


        If IWR <= 0.0004515 Then
            txtRt.Text = "RT1"
        ElseIf IWR <= 0.0006095 Then
            txtRt.Text = "RT2"
        ElseIf IWR <= 0.00085 Then
```

```
    txtRt.Text = "RT3"
  ElseIf IWR <= 0.001188 Then
    txtRt.Text = "RT4"
  Else
    txtRt.Text = "RT5"
  End If

  Dim b As Decimal
  Dim m1 As Decimal
  Dim m2 As Decimal
  Dim m3 As Decimal
  Dim m4 As Decimal
  Dim m5 As Decimal
  Dim m6 As Decimal
  Dim m7 As Decimal
  Dim tcemp As Decimal = 0.0


  If IWR <= 0.0004515 Then
    b = 2880.9029998939
    m1 = 1.00324956883585
    m2 = 0.81337657178096
    m3 = 0.961312419213176
    m4 = 0.0868610176906944
    m5 = 10.690627360619
    m6 = 1.28625610577932
    m7 = 0.0610128356113378

  ElseIf IWR <= 0.0006095 Then
    b = 4394301.69382224
    m1 = 1.00126683771811
    m2 = 0.058817404453177
    m3 = 13.3890954752188
    m4 = 1.61314717574345
    m5 = 0.551194655522182
    m6 = 0.0806313755633812
    m7 = 1.37102769992824

  ElseIf IWR <= 0.00085 Then
    b = 62742.455199091
    m1 = 1.00398607259569
    m2 = 0.210929784674323
    m3 = 1.8173896838813
    m4 = 1.06456140399456
    m5 = 0.853917234033961
    m6 = 0.610852577515805
    m7 = 0.795648841383418

  ElseIf IWR <= 0.001188 Then
    b = 607.382067229823
    m1 = 1.00105364054779
```

```
        m2 = 0.441038981412485
        m3 = 1.58113357273865
        m4 = 0.885858046479806
        m5 = 1.05107355899644
        m6 = 2.54317500534263
        m7 = 0.623679277374385

      Else
        b = 903219.854024274
        m1 = 1.00025507431636
        m2 = 0.215928663521156
        m3 = 2.56623694401489
        m4 = 0.876522230602927
        m5 = 0.996160807918849
        m6 = 0.308402660739299
        m7 = 1.43452725480995

      End If

      tcemp = b * m1 ^ km * m2 ^ temin * m3 ^ temax * m4 ^ tbhmin * m5 ^ tbhmax *
      m6 ^ tec * m7 ^ tc
      txtTcemp.Text = Math.Round(tcemp, 6)

      LNmin = Log(1 + tcemp / temin)
      LNmax = Log(1 + tcemp / temax)

      txtLNmin.Text = Math.Round(LNmin, 9)
      txtLNmax.Text = Math.Round(LNmax, 9)

      txtRTO.Text = txtRt.Text
      txtIWRO.Text = txtIWR.Text


      Dim c As Decimal
      Dim A As Decimal

      A = (tbhmax - tbhmin) / (LNmax - LNmin)
      txtA.Text = A
      c = tbhmax - (A * LNmax)
      txtTFO.Text = Math.Round(c, 1)


    End Sub


End Class
```