MODELING AND INVESTIGATION OF STATIC FORMATION TEMPERATURE TEST (SFTT) USING NUMERICAL SIMULATION

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ABSTRACT

SFTT is one of important test in drilling operation. In Indonesia, especially in Muara Laboh and Rantau Dedap, SFTT has been used to estimate undisturbed temperature and guide the setting of production casing shoe (PCS) of the first 2-3 exploratory wells. The SFTT data are processed and analyzed to provide undisturbed formation temperature estimation by utilizing several methods, including Horner, Brennand, Ascencio, and Roux method. In the overall error rate of those methods is in the range of 10-30%, herewith they still need to be improved.

Given the high costs required and stuck-pipe risk exposures, which are associated with SFTT run, the test is expected to achieve a substantial degree of accuracy. Therefore in this study, a numerical procedure is employed to simulate a real physical condition during SFTT. That procedure is selected due to its flexibility and simplicity in understanding the heat transfer process. The TOUGH2-EOS1 software is used to carry out the numerical modeling to obtain SFTT data. Following the numerical modeling, the undisturbed temperature parameter is calculated by different methods: Horner, Brennand, Ascencio and Roux. The result proved that those methods still need to be improved to obtain a more accurate undisturbed temperature estimate. In this paper, it is proposed to have the improved estimation by creating new correlation based on Horner method. This correlation had been applied to calculate undisturbed temperature in synthetic data and Rantau Dedap, the result give the error rate less than 10%.

1. INTRODUCTION

Having accurate information from exploration wells is critical in achieving a successful geothermal drilling exploration. In the early stage of drilling exploration, there are minimum data available to determine the appropriate Production Casing Shoe (PCS) depth. SFTT provides undisturbed formation temperature estimate during drilling that is useful to assist in PCS setting.

Undisturbed temperature is the actual temperature in certain depth before disturbed by drilling activity. In geothermal drilling process, mud injection is done in conjunction with bit penetration process. The process will disturb the ambience temperature and change previous formation temperature.

Static Formation Temperature Test (SFTT) is commonly carried out during exploration drilling where there is no or very limited subsurface data. This method is used when the drilling process show the high temperature formation, given by these following indications:

- Methylene blue (MeB) consistently <10 (Methylene blue is a chemical compound for indications the content of clay).
- High mineral indication (epidote) appears consistently.
- Δ TMWD (Temperature Measurement While Drilling) vs. temperature drilling fluid-in > 10ºC.
- Temperature drilling fluid-out > 72ºC.

SFTT is conducted by running a downhole Pressure and Temperature (PT) tool using wireline logging. This tool is run inside the drill pipe along its length to record the pressure and temperature at selected depth(s). Ideally, the survey is conducted before loss circulation is encountered. However, if the loss of circulation is encountered close to the initially planned survey depth, drilling should be stopped immediately; loss should be cured before the SFTT is performed. To complete SFTT, it requires the drilling rig to standby for approximately 24-36 hours. The logged pressure and temperature data (SFTT Data) are processed and analyzed by utilizing several methods, including Horner, Brennand, Ascencio, and Roux methods, among others.

SFTT has been conducted in some geothermal fields in Indonesia such as Rantau Dedap (South Sumatra) and Muara Labuh (West Sumatra). Several methods were used to estimate undisturbed temperature, such as Roux, Brennand, Ascencio, and Horner Method. In overall the accuracy of all methods has error ranging from 10-30%. Ascencio seems to give the closest estimate to the actual temperature but still has about 10% error in average (Humaedy et al, 2016).

This paper discusses the result of numerical simulation study with an objective to understand the heat transfer process during the SFTT, in order to reduce error rates.

1.1 SFTT Methods

SFTT data are acquired from numerical models. The SFTT data then processed to determine undisturbed temperature using several methods. In this research the Horner, Brennand, Ascencio, Roux and Kutasov method are used. Summary of the equations used for the analytical models and source of those methods were listed in Table 1.

2. NUMERICAL SIMULATION

Simulation is conducted using TOUGH2-EOS1. Numerical simulation is done to model the process during SFTT. In the previous research (Afuar, 2016) the validation had been done to recognize rock properties, then the model is calibrated using actual data. The rock properties used for modelling are permeability, rock heat capacity and thermal conductivity. Numerical modelling is done in some steps as below:

- A radial model is created with 1550 m thick and divided into 31 layers. The model is simplified to have five rock types with different permeability, porosity, heat capacity, and thermal conductivity. Temperature, pressure, and saturation are assigned to each of the blocks. Input properties of rock are obtained from a previous study with an assumption that there is no loss circulation. The model is shown in Figure 1.
- Initial state run is done until the model pressure and temperature match with the well PT profile.
- Cold water is then injected at the top of wellbore blocks to simulate fluid circulation during drilling (Figure 1). This research used injection temperature and circulation time based on the previous research published in the Indonesia International Geothermal Conference (IIGCE) in 2016. Extended circulation time period (t>12 hours) and low injection circulation temperature (t<65^{o}C) will contribute to higher error of the Horner undisturbed temperature estimate. Therefore, the new model used injection temperature 60^{o}C and circulation time period is 12 hours. The procedure is similar with the actual procedure in general geothermal drilling process in Rantau Dedap and Muara Laboh.
- The injection is then stopped and the model records temperatures build up (Figure 1). SFTT method then will use temperature build up data to determine undisturbed temperature using different SFTT methods as listed in Table 1.

There are five methods used in this research, with each method has different error rate. The next step is comparing the accuracy of those methods and creating a new correlation with higher accuracy rate. Figure 2 presents this the workflow of this study.

3. RESULT AND ANALYSIS

The main objective of this research is to build a more accurate SFTT method to determine undisturbed temperature. To be able to build the more accurate correlation, this research compares and analysis some general method that broadly used for SFTT procedures.

3.1 Comparison of SFTT Methods

SFTT data acquired from numerical modelling is 3 months temperature build up (Figure 3). The data is then processed using equation (1), (2), (3), (5) and (6) in Table 1 to calculate undisturbed temperature profile for all methods. Figure 4 shows undisturbed temperature for 8 hours of build-up temperature data that were processed using the Horner method. The undisturbed temperature is Horner intercept, the value is 163^{o}C.

By an interval of one hour, every 8 hours build-up temperature data is used to calculate the undisturbed temperature. Figure 4 shows a graph of temperature extrapolation per 8-hour undisturbed temperature using Horner's method. By using the same steps with Horner's method, the undisturbed temperature is determined using the Brennand, Ascencio, Roux and Kutasov method.

The calculations are done with an interval of one year. It is started at t=10 hours and limited to t= 50 hours. For each interval, 8 hours temperature buildup data are used in the calculation. Figure **5** shows the temperature extrapolation profile from various methods and also their error compared to the actual temperature. The light pink bar indicates the time region when SFTT usually takes place, and it's called SFTT Region

The results suggest that Horner, Brennand, and Roux, always underestimate the actual temperature with the errors getting smaller with time, from 20-30% down to around 4-10%. Roux underestimates the actual temperature until t~36 hours where the error reaches a minimum value or closes to zero. On the other hand, the Ascencio reaches its minimum error at t~25 hours before it starts overestimating the actual temperature.

Under the SFTT time region, Ascencio gives the smallest error, which is consistent with the field experiences (Humaedy et al, 2016). The error is however still significant, in the range of 10-20%. If the SFTT duration could be prolonged up to 10 hours, higher accuracy of temperature estimate would be obtained. Extending the SFTT duration is unfortunately not recommended, besides more expensive it would be risky to leave the hole without circulation for such a long time. Therefore, a solution that can offer a more accurate undisturbed temperature estimate under the SFTT time region is required.

3.2 Development of New Correlation (Improved Horner).

There are some methods to determine undisturbed temperature. Comparing those methods guide to conclude that all methods underestimated actual data. Figure 3 show that only Horner that have similar trends with actual temperature. The new correlation based on the Horner method and numerical simulation is built on this research. There are 7 models that have been constructed using different rock temperature to generate synthetic data of the reservoir temperature versus time. Formation temperature or actual data used as input model are 120^{O}C, 140^{O}C, 160^{O}C, 180 ^{O}C, 200 ^{O}C, 220 ^{O}C, and 250 ^{O}C (Figure 6).

Running the model resulted SFTT (build up temperature) for each model as shown in Figure 6. The SFTT data are then processed to determine undisturbed temperature using the Horner method. Figure 7 displays extrapolated undisturbed temperature versus time. The light pink area is SFTT time measurement. The SFTT region shows that for all data, it has an error rate range from 20 to 30%.

A new temperature correlation is built using an error graph and Horner graph for various inputs and using regression of 3 variables (Figure 8). It is a function of Horner temperature (T_{HM}), Horner's time (t_{HM}), and Horner's gradient (B_{HM}) has been generated to fit the synthetic data

$T = 2.855512*T_{HM}-0.58481*B_{HM}-0.04448*B_{HM}*t_{HM}-108.34$………..$R^2$=0.9957 (6)

The correlation is applicable with condition injection temperature 50-60^{0}C and circulation time around 12 hours and the undisturbed temperature in range 120-250^{O}C.

Applying the new correlation using synthetic data is shown as a red line in Figure 9a, while the blue dot is the actual data. The proposed correlation can decrease the error from

20-30% (Horner) to <10%. This correlation had been applied to calculate undisturbed temperature in Rantau Dedap. The result is in Figure 9b. It showed that applying the new correlation give better error rate. A calculation used in this research gives the error rate less than 10%.

4. CONCLUSION & FURTHER WORK

From this study the following conclusion can be drawn:

1. There are some broadly used SFTT methods at present, those are: Horner, Brennand, Ascencio, Roux and Kutasov. Application of these methods gives underestimated results compare to the actual temperature, with error rate ranging from 10 to 30%.
2. Ascencio provides a good approximation within the SFTT time period with undisturbed temperature error ranging from 10-20%, which is supported by field experience
3. Within the SFTT time region (light pink bar), Ascencio gives the smallest error (10-20%), which is consistent with the field experiences. Horner, Brennand, and Kutasov always underestimate the actual temperature with the errors getting smaller with time, from 20-30% down to around 4-10%. Roux underestimates the actual temperature until t~36 hours where the error reaches a minimum value or closes to zero.
4. The Horner methods is chosen as the basic method in this research because it gave similar trend with the actual data
5. A new correlation has been generated to obtain more accurate of an undisturbed temperature estimate. Applying the new correlation using synthetic data and data from the Rantau Dedap field can decrease the error from 20-30% (Horner) to <10%.

The research needs further work to test the proposed correlation with more testing data obtained from the field.

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Methods	Equation	Information	Sources
Horner	$BHT\ (t) = T_{HM} + (b_{HM}) * \log\{\frac{(t_c+t)}{t}\}$ (1)	Log $\{\frac{(t_c+t)}{t}\}$ = Dimensionless Horner Time (DHT) t_c and t = the circulation time before shut-in and time elapsed since the circulation stops (s) B_{HM} = Horner's gradient (^{O}C /s) T_{HM} = Undisturbed temperature using Horner's method (Horner's intercept) (^{O}C)	Dowdle and Cobb (1975)
Brennand	$BHT(t) = T_f - \frac{m}{\Delta t + p * t_c}$ (2)	Based on data from Philippines geothermal field p = 0.785 tc = circulation time (s) Δt = the total duration of the test (s)	Anthony W Brennand (1984)
Ascencio	$BHT(t) = T_{SRM} + (b_{SRM}) * \left(\frac{1}{\sqrt{t}}\right)$ (3)	t = the shut-in time elapsed since the circulation stops (s)	Ascencio et al. (1994)
Roux (improved Horner)	$BHT(t) = T_{HM} + H_s * t_{DB}$ (4)	T_{HM} = Undisturbed temperature using Horner's method (Horner's intercept) (^{O}C) H_s = Horner Slope t_{DB} =correction time depend on circulation fluid time and rock properties (s)	*Roux* et al (1980)
Kutasov (improved Horner)	$BHT(t) = T_i + m * lnX$ (5)	lnX Is a Dimensionless Horner Time correction by circulation time, shut-in time and rock properties	Kutasov and Eppelbaum (2005)

Table 1: Summary of SFTT Methods

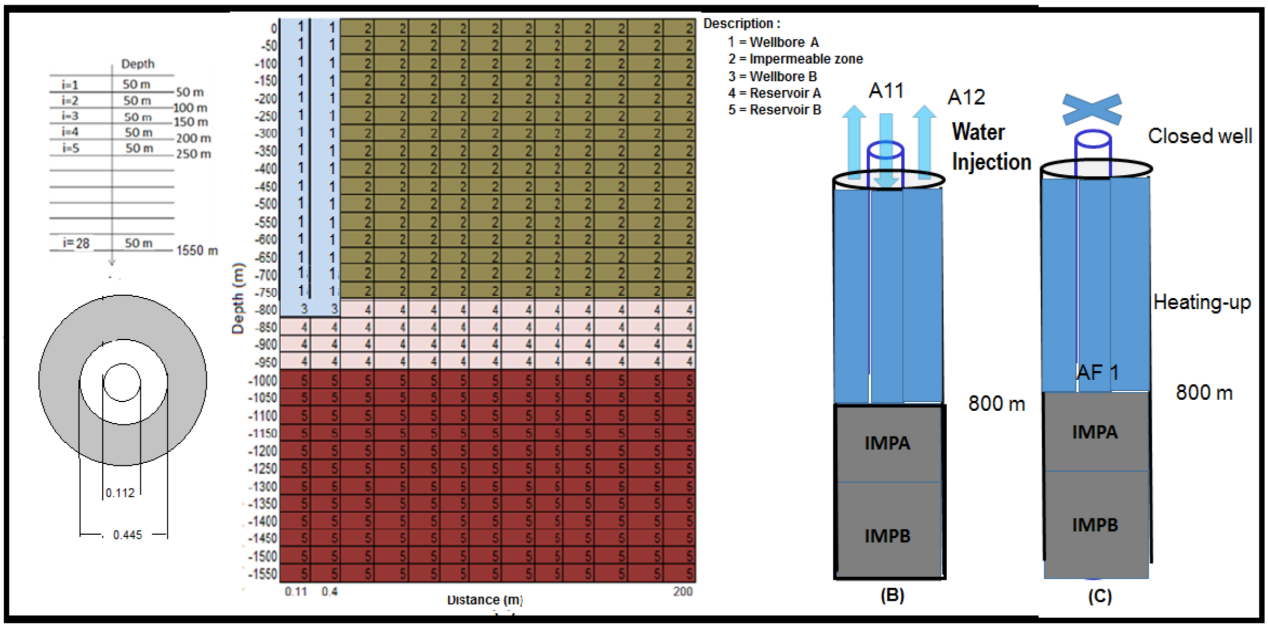

Figure 1: Step of SFTT modelling

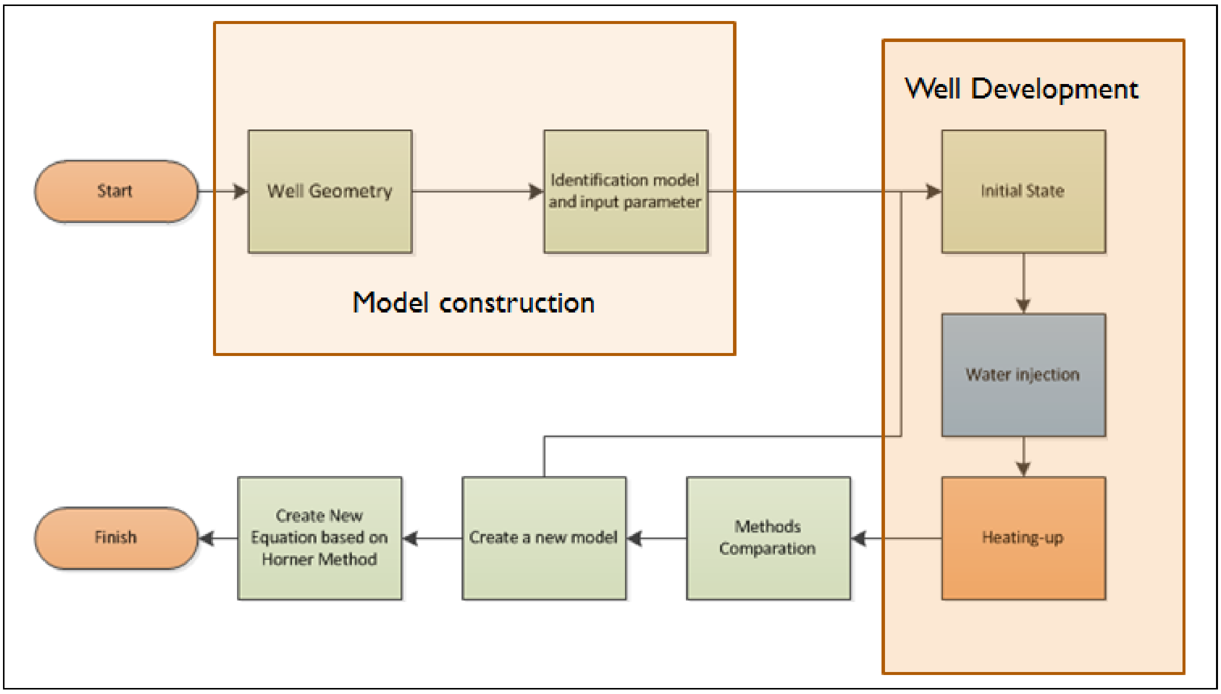

Figure 2: Workflow of this study

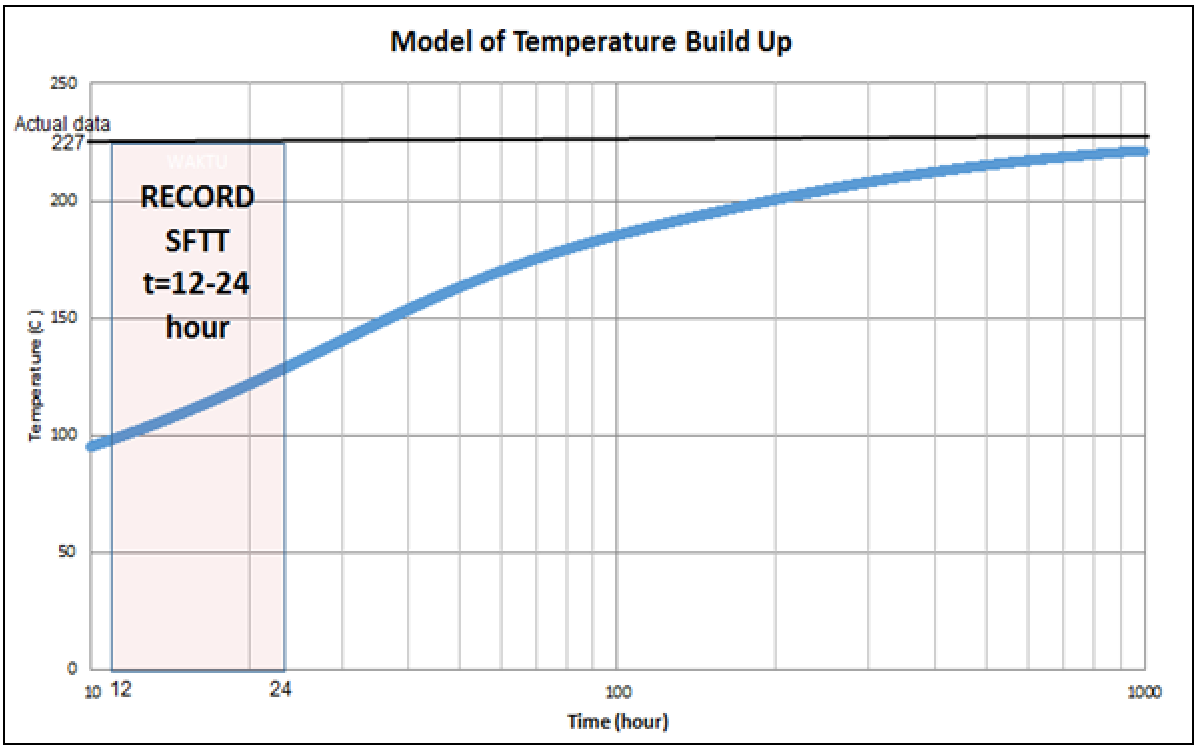

Figure 3: Heating-up simulation of well WA

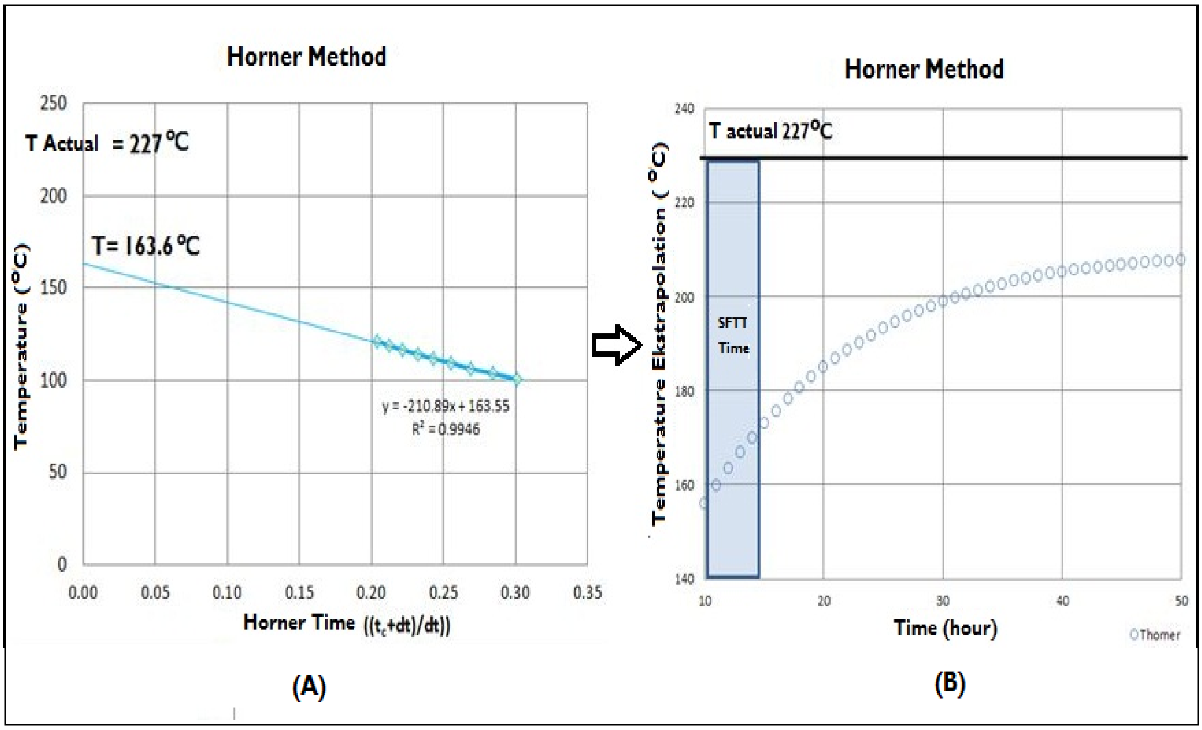

Figure 4 : Undisturbed temperature using Horner method (A) and extrapolation of undisturbed temperature per 8-hour using Horner's method (B).

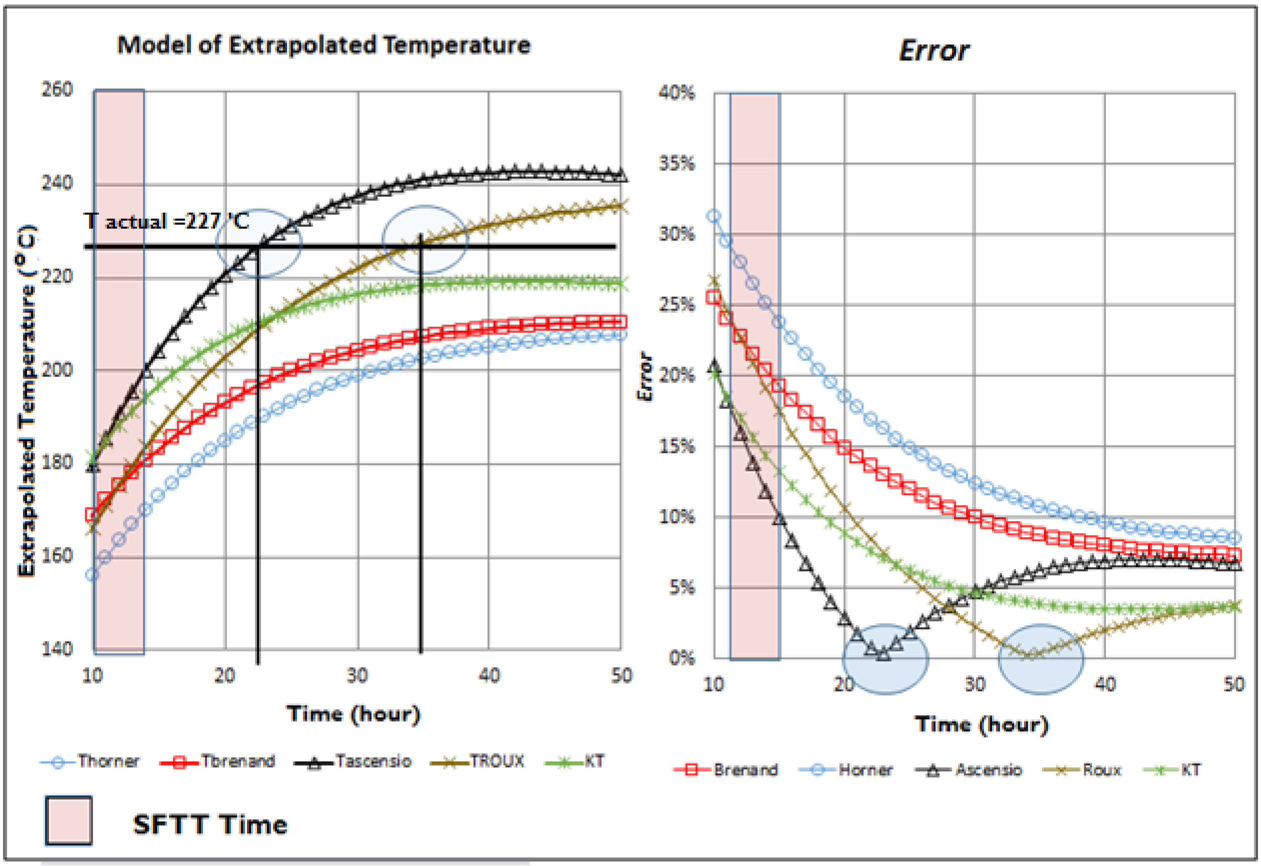

Figure 5: Graph of undisturbed temperature extrapolation (per 8 hours) with various methods and error

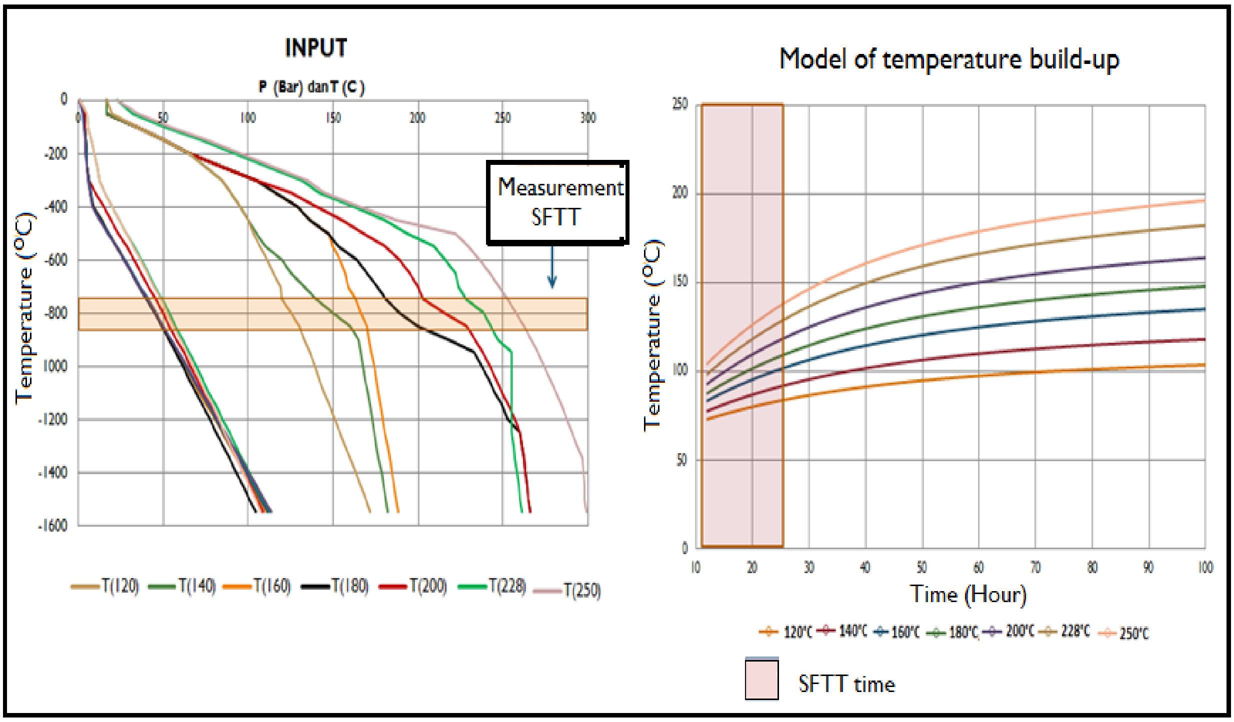

Figure 6: SFTT Input (A) and model of temperature build up (B)

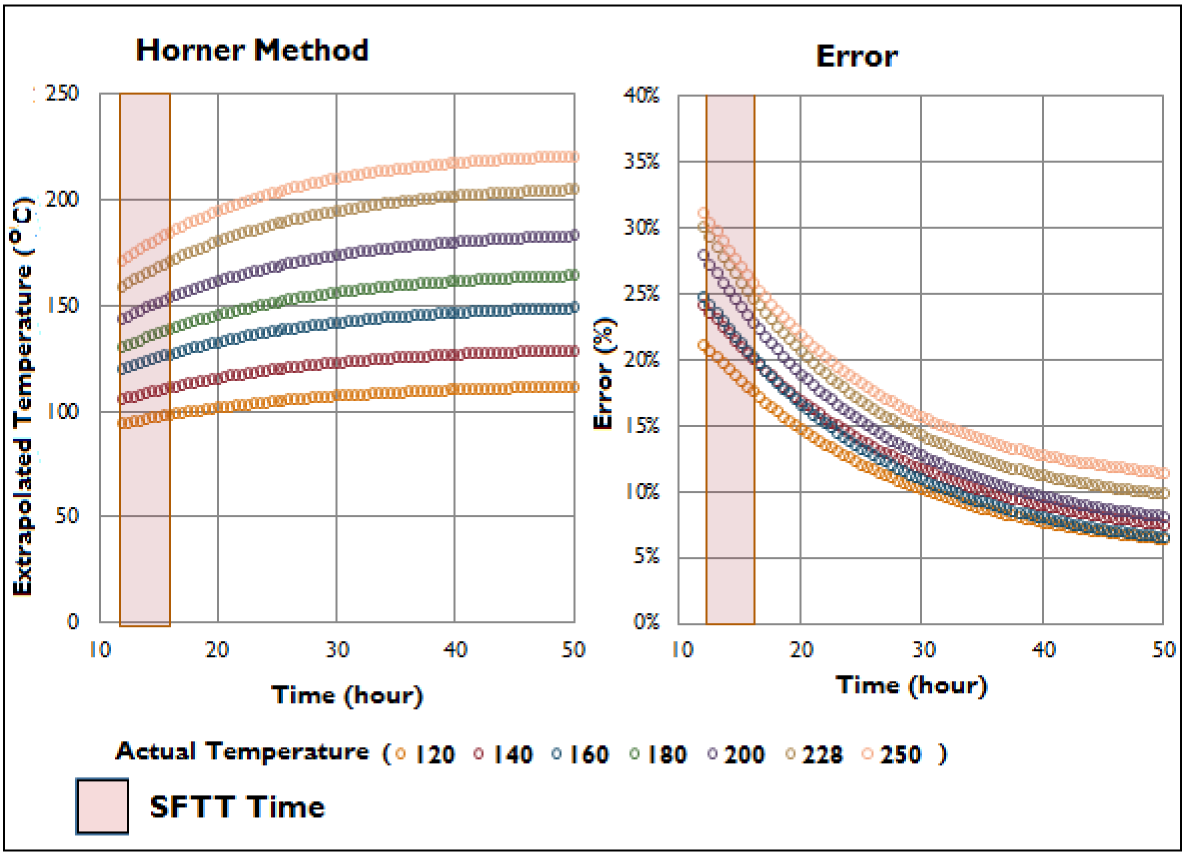

Figure 7: Graph of undisturbed temperature extrapolation (per 8 hours) with Horner method and error

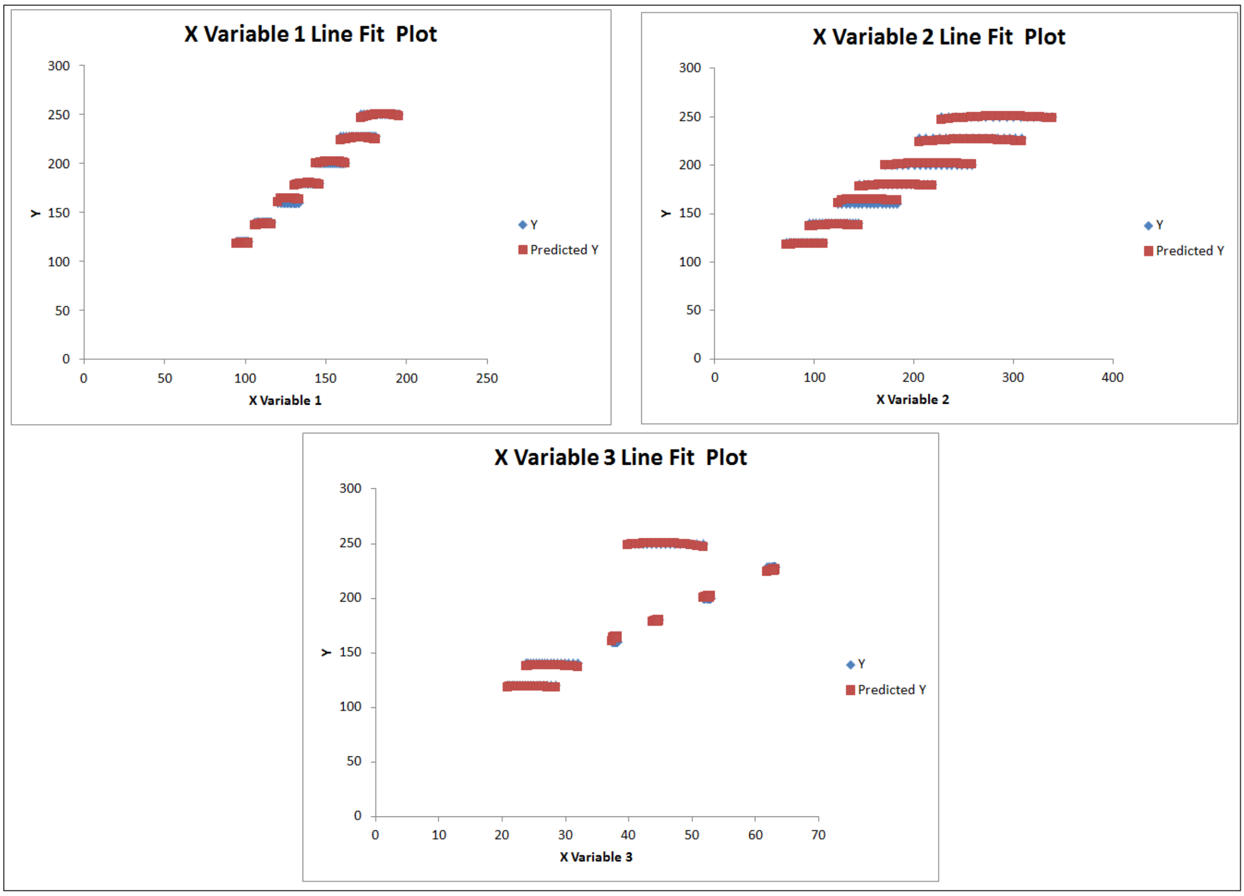

Figure 8: Regression of 3 (three) variables

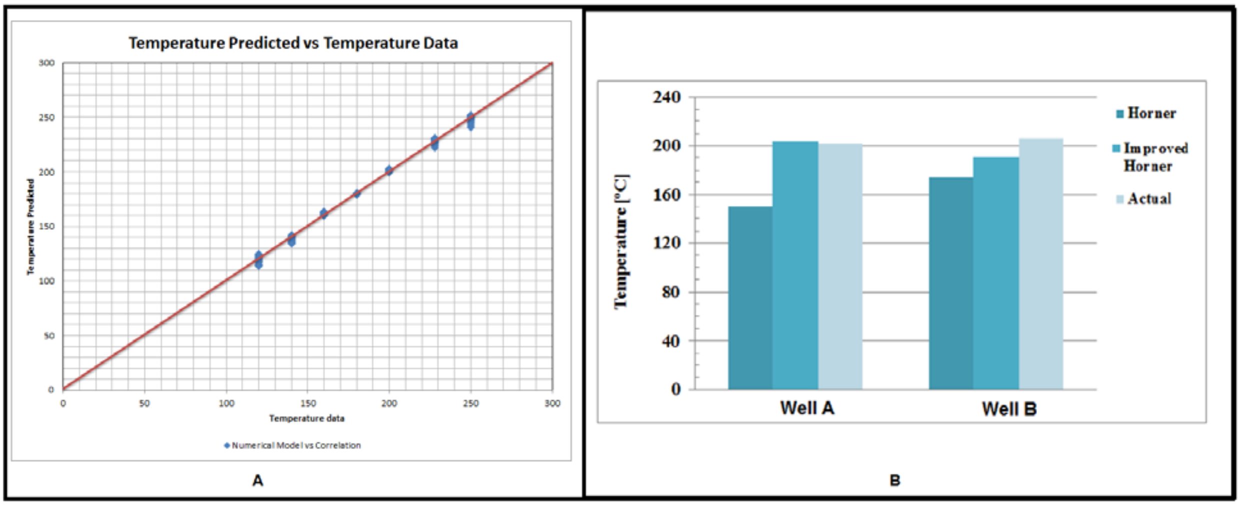

Figure 9: Applying the new correlation using synthetic data (A) and Rantau Dedap (B)