CHAPTER IV
RESULTS AND DISCUSSION

4.1 Study of Torque and Drag Model

The below results were calculated from the data from Pan Orient Energy Siam Company (POES) at the onshore directional well A which is located in Nakornphatom Province, Thailand. This well produced oil and water.

4.1.1 Well Trajectory

Figures 4.1 and 4.2 show well trajectories of well A in vertical and side views, respectively. The measured depth of this well is 1,610 meters. There are 88 data points from the survey file to generate the well trajectories and calculated friction data. The well trajectories in this model were illustrated by balanced tangential method. which the kick of point is 100 meters. This well begins with vertical section and follows by build section with the left turn. The last section is a hold section in the average angle of 45 degrees.

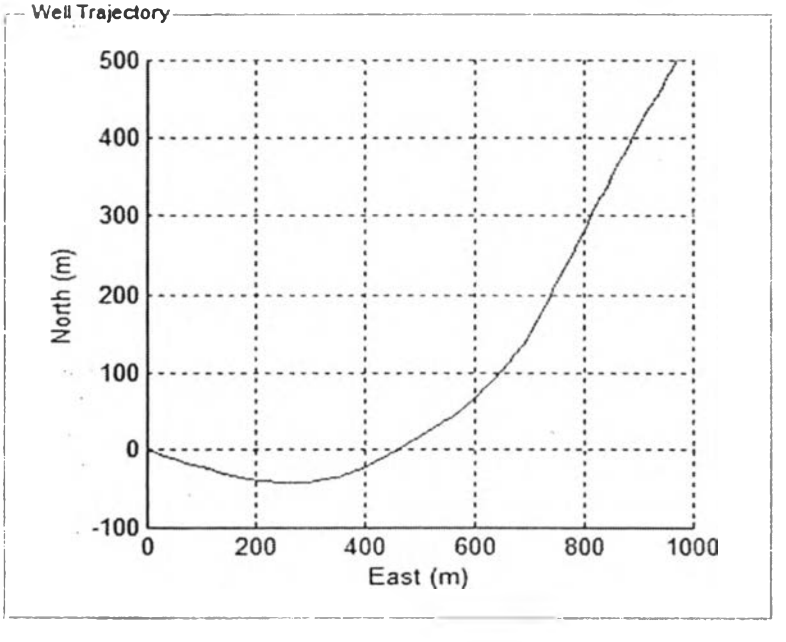

Figure 4.1 Well A trajectory in vertical view.

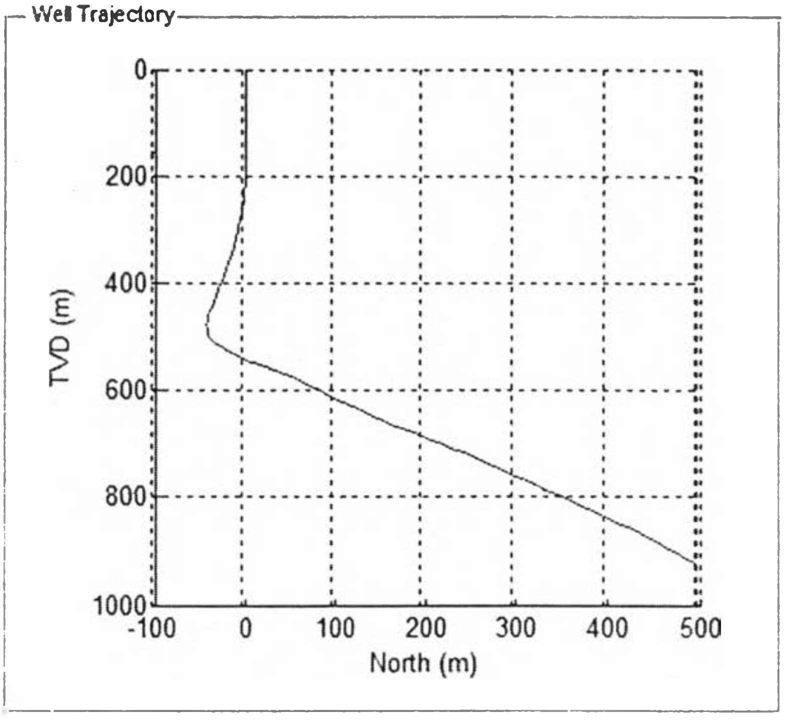

Figure 4.2 Well A trajectory in side view.

4.1.2 Fazaelizadeh's Model

The initial guess of the friction coefficient in this model is 0.4. The values of 0.05 and 0.95 are set as the lower and upper limits. The upper and lower limits are set for breaking the calculation in the program. The friction coefficient was varied until the difference between hook load from the calculation and field hook load is within three percentages window range. The calculation of hook load was done by back calculation method. The method is the summation of axial force from the bottom of drill string, which is the bit through the surface, which is hoisting systems. If the value of friction coefficient reaches the limit point, it means that there is an error in calculation at that point. Then the program changes the down-hole weight on bit (DWOB) by itself, and recalculates the friction coefficient from the initial guess. Thus, the acceptable friction model does not give the results at the limit values. The results in Figure 4.3 show almost of the friction coefficient values are at 0.05, 0.4 and 0.95. The value of friction coefficient at 0.05 and 0.95 are error points and 0.4 are the initial value. The friction coefficient at initial value means the change of DWOB making calculated hook load equal to field hook load. Thus, the point, which has value of friction coefficient at the initial guess, may not sensitive to friction coefficient. In other word, the friction has less contribute to hook load than axial force at this point. The errors in calculation come from the friction angle (Ψ), which separates the friction force into two directions, axial and rotational. When the data is the reaming operation, which there are both axial and rotational movements, will reduce the axial friction largely. Thus, the effect of friction on hook load from this operation is very small, that brings the friction coefficient into only three values, which are 0.05, 0.4 and 0.95. Then, the friction coefficient becomes the non-adjustable variable, so the program has to vary DWOB data to match the calculated hook load with the actual field hook load. In conclusion, this model is very difficult to adjust a friction coefficient in the reaming operation. That is why this model is not suitable for the friction calculation.

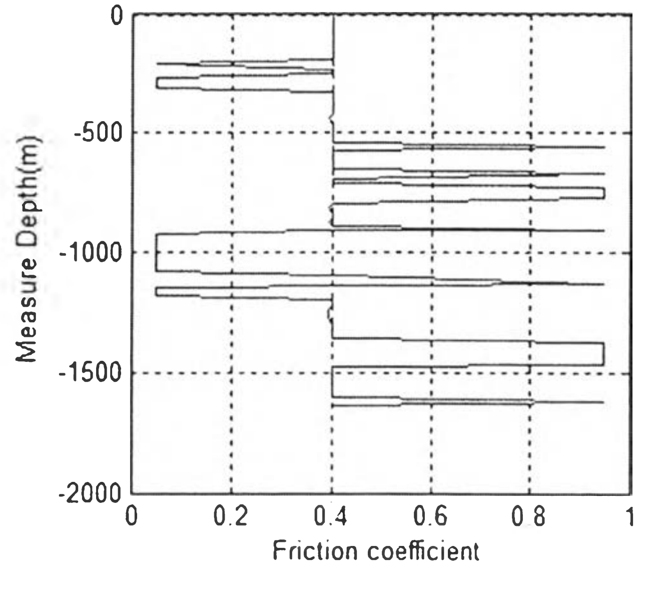

Figure 4.3 The results of Fazaelizadeh's model.

4.1.3 <u>Prurapark's Model</u>

The initial guess, limits and methodology in this model are the same as previous model. The results of this model in Figure 4.4 show, the friction coefficient values look better than previous model because of the lesser points at the limits. Thus, this model can be adjustable better than the previous model because there is no the friction angel (Ψ) in the calculation. However, there still have the error points with the friction coefficient at 0.05 and 0.95. The errors come from the assumption of the model, which is the well planning operation. This operation assumes the drilling in certain direction, which means that it is not small direction change of the drilling from the operation planning. For example, the build up section is the section, which the lower point has more inclination than the upper point for entire section. However, the real drilling it is difficult to maintain this condition for a long length. Thus, the large build up section also has both small build up and drop off sections inside. The small build up and drop off inside the long build or drop sections bring the errors in the calculation because these small-unpredicted sections have small radius value (R_{turn}) in the calculation. Moreover, this model is sensitive to small turning wellbore in horizontal direction, which always occurs with small build up and drop off section (left and right turn). The small turning wellbore has small turning radius (R_{turn}). The small R_{turn} increases too much friction (see the term $\frac{F_{n+1}}{R_{turn}}$ in the friction equation, if R_{turn} is very small, thus the value of friction becomes greater because R is very large than R_{turn}). Thus, this model has the sensitivity on small direction changed, which occur normally in the drilling operation. In conclusion, this model is better than the previous model but it is not suitable model for the calculation.

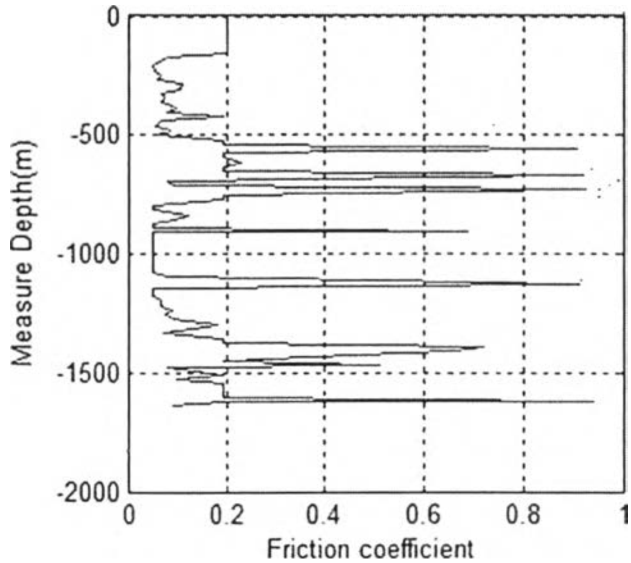

Figure 4.4 The results of Prurapark's model.

4.1.4 Hareland's Model

The two previous models are not suitable for the down-hole parameters calculation because of their limitations, which are mentioned before. This model is more sensitive to friction coefficient than two previous models. Thus, the upper and lower limits were set at 0.05 and 0.5. The initial guess was set at 0.2. This model also uses the back calculation method to calculate friction coefficient and DWOB. The results of this model as shown in Figure 4.5, there is only one friction coefficient at the lower limit (0.05) and zero point at upper limit (0.5). Thus, this model is more suitable than two previous models. The hook load corrections (see Chapter 2) and no friction angle are the reasons, which bring this model to the most accurate model. Moreover, this model was tested with the commercial sensor. The testing results show that it is compatible with the sensor information. Therefore, this model is suitable to use in the calculation of down-hole parameters in this research.

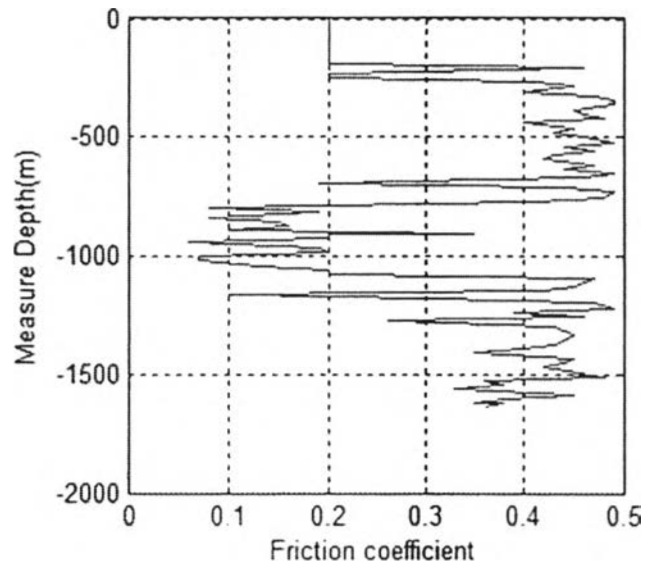

Figure 4.5 The results of Hareland's model.

4.2 Effect on Number of Intervals

This is the next step of numerical methods. As seen in section 4.1, the number of calculation data is too low. The total survey data is 88 data. Thus, this section studied the effect of intervals in a calculation. The intervals mean the number simulates from the gap between each elements of survey data. Figure 4.6 shows the real and simulated gaps between element n and n+1. Element n and n+1 refer to measured depth number n and n+1, respectively. The above box in Figure 4.6 means the real gap and simulated gap for the below box. The real gap between element n and n+1 is one. The simulated gap in Figure 4.6 shows there are four simulated gaps between element n and n+1, which is four intervals. The elements A, B and C are the simulated elements from the program, all of them have equal sizes. The simulated gaps were calculated from linear-interpolation of element n and n+1, which has four intervals (four small gaps inside). This method can increase the number of measured depth from two (n and n+1) to five measured depths. The reason of having more intervals is to increase the accuracy of specific energy to predict a potential zone. Although increasing intervals data points are benefit, it also requires a much more calculation time. The results of intervals are shown in Figures 4.7, 4.8, 4.9, which plotted hook load versus measured depth for four, nine and 14 intervals, respectively. The nine intervals case is chosen in this research for two reasons. The first reason is a suitable calculation time. The change in number of intervals from nine to 14 may requires three or more times longer than nine intervals calculation time. The second reason is that nine intervals can cover the scattered data the same as that of 14 intervals. Moreover, the hook load from nine and 14 intervals are in the same trend, which cover the fluctuations of hook load such as 600-800 and 1,000-1,200 meters.

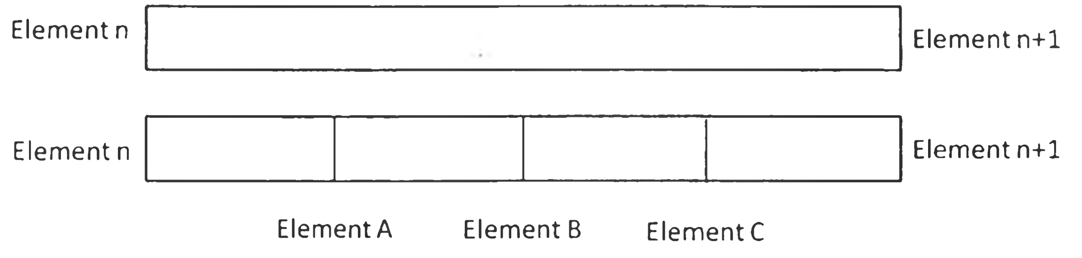

Figure 4.6 Real and simulated gaps.

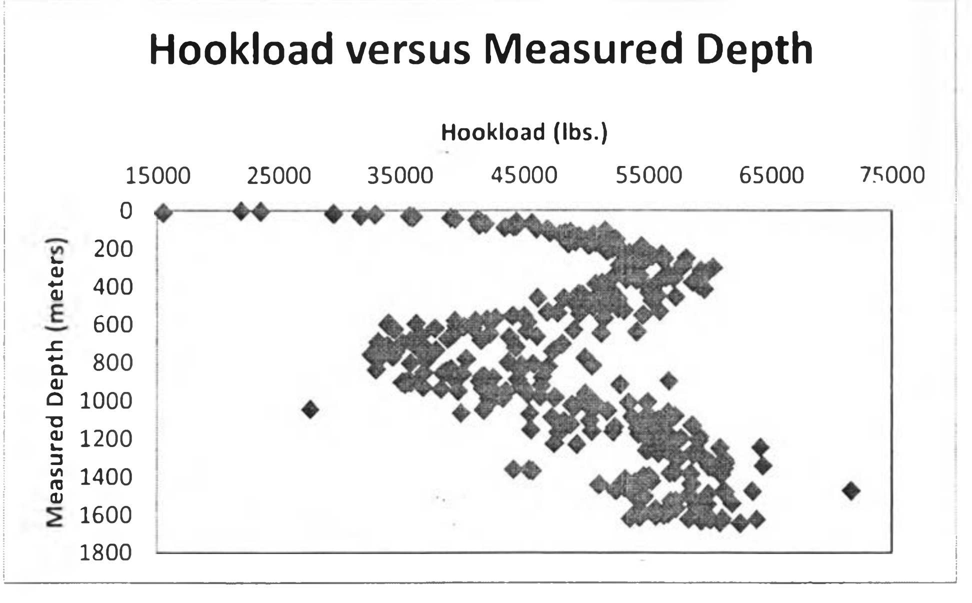

Figure 4.7 Hook load versus measured depth for four intervals.

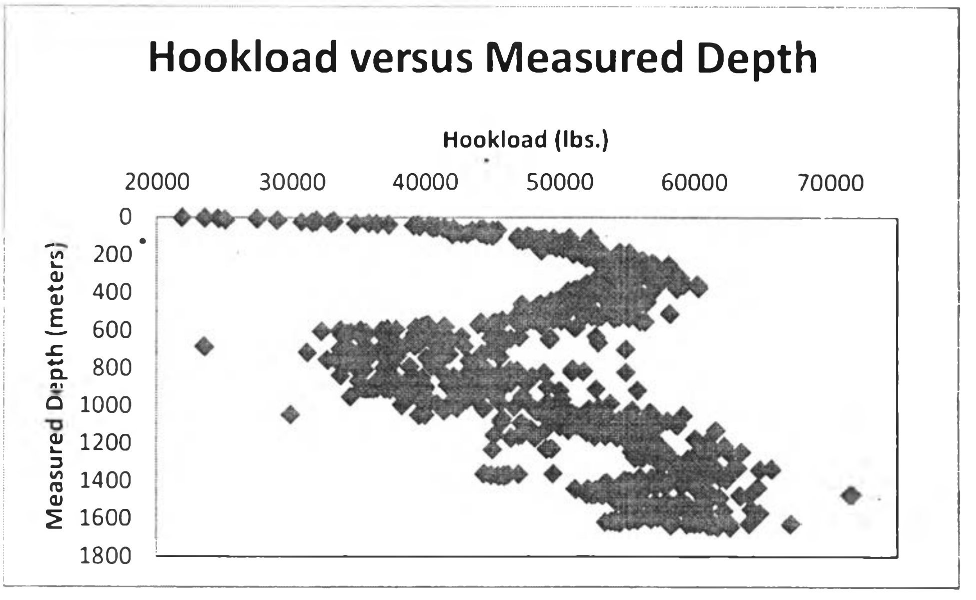

Figure 4.8 Hook load versus measured depth for nine intervals.

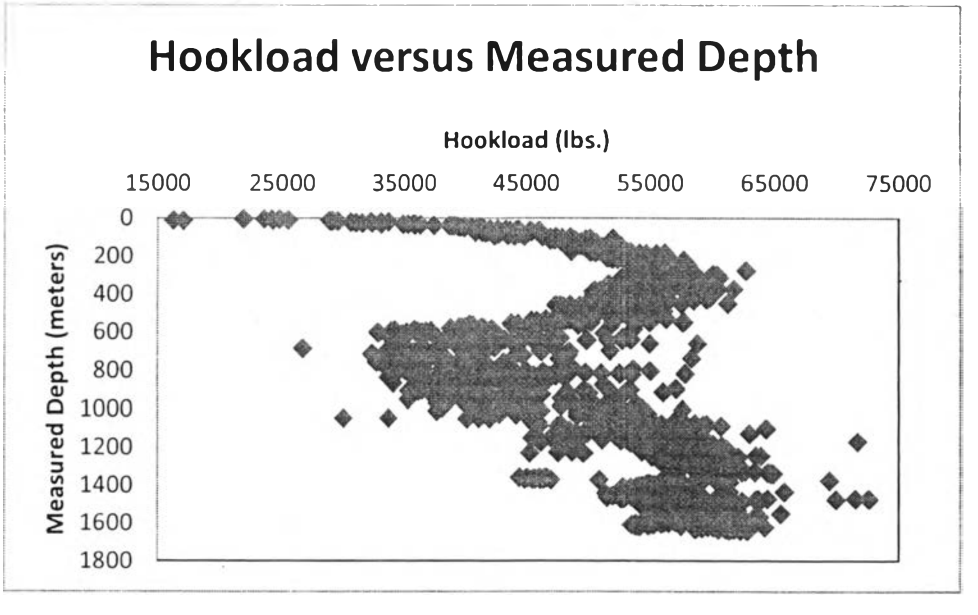

Figure 4.9 Hook load versus measured depth for 14 intervals.

4.3 Data Screening

The data that received from POES are depth log data. However, there are a lot of scattered data and noises as shown in Figure 4.10. For example, at 600-800 meters measured depth, the hook load seems to split into two values, which are about 60,000 and 35,000 lbs. Moreover, the actual hook load for drilling operation should not fluctuate. This scattered hook load may come from the errors in collecting surface parameters. Thus, the screening of data is necessary for the accurate down-hole parameters. The key parameters for screening are rotation of drill string (N), mudflow rate, surface weight on bit (SWOB) and rate of penetration (ROP). The rotation of drill string RPM should be zero for build up section due to the sliding drilling and should not be zero for drop off section because of down-hole mud motor. The average mudflow rate for this well is about 667 gallon/minute (GPM), thus the overflow mud (>1,000 GPM) and the starting up mud pump (<400 GPM) should be screened. The negative SWOB is screened, which means the bit is off bottom. The showing high ROP (>150 meters/hr.) is tripping in or tripping out operation also screened. The results after screened data (removed noises) are shown in Figure 4.11, many data were screened at 600-1,300 meters measured depth from the above conditions. The screened hook load is acceptable because the hook load is like a trend (low fluctuation).

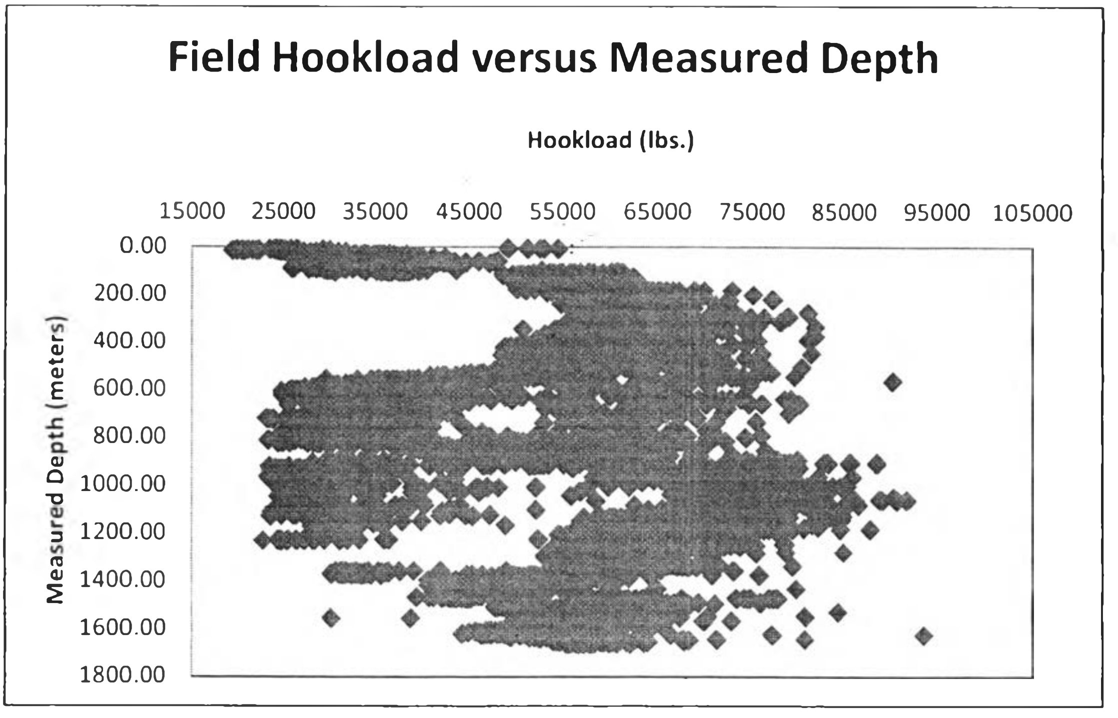

Figure 4.10 Field hook load from depth log.

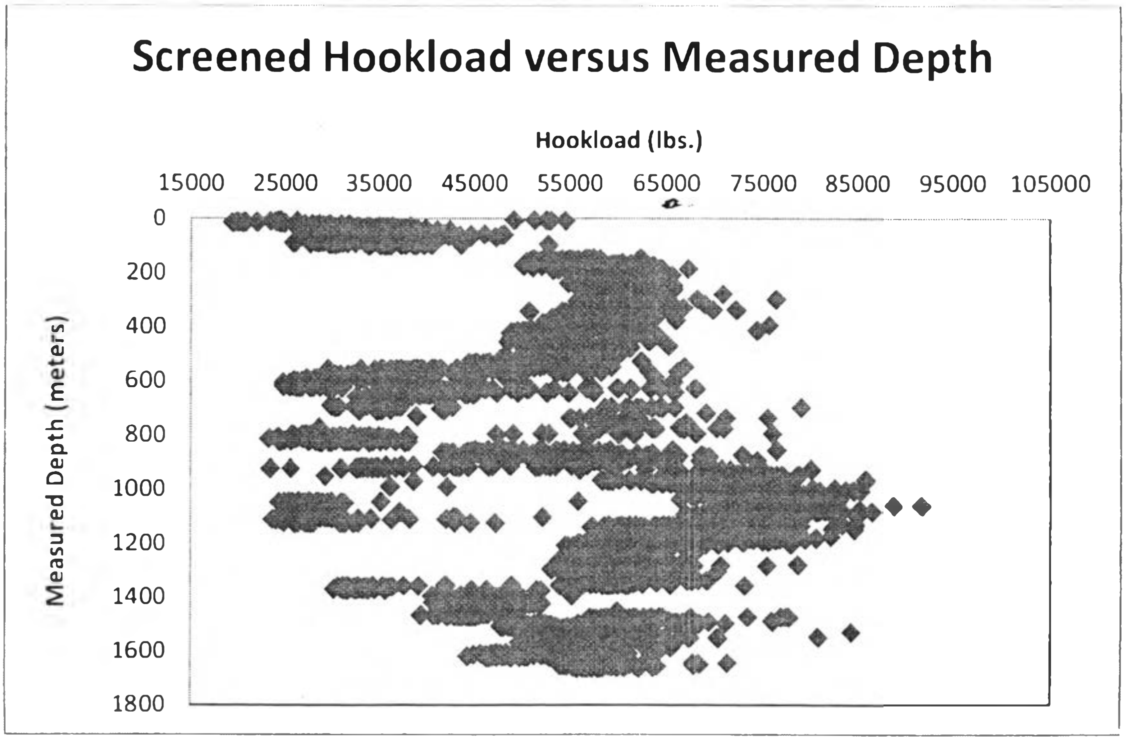

Figure 4.11 Hook load after data screening.

4.4 Results from Field Data

The calculation of down-hole parameters based on Harealand's model with nine intervals and data screening. Two onshore oil wells as filed data were wells A and B belonging to POES in Nakorn Phatom province, Thailand. The results are separated into four parts, which are well trajectories, down-hole parameters, Down-hole drilling specific energy (DSE) and DSE interpretation information.

4.4.1 <u>Well Trajectories</u>

The well trajectories of well A and B are shown in Figure 4.12 and 4.13, respectively. The survey definitions are shown in Appendix C. Well A has a measured depth 1,610 meters and 1,060 meters for well B. These wells are directional oil wells. The average inclination of wells A and B are 60 and 45 degrees, respectively. The kick of points for wells A and B are 100 and 90 meters, respectively.

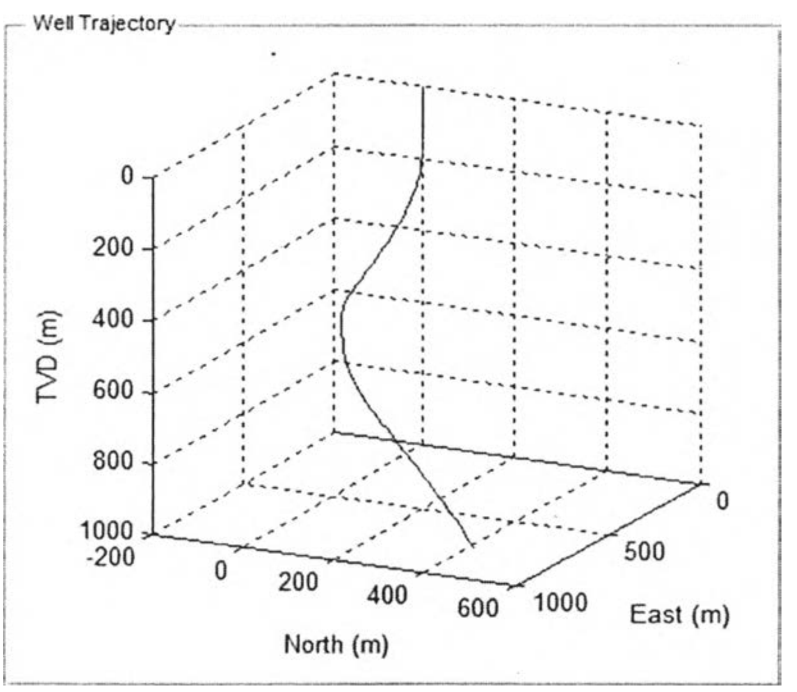

Figure 4.12 Well trajectories of well A.

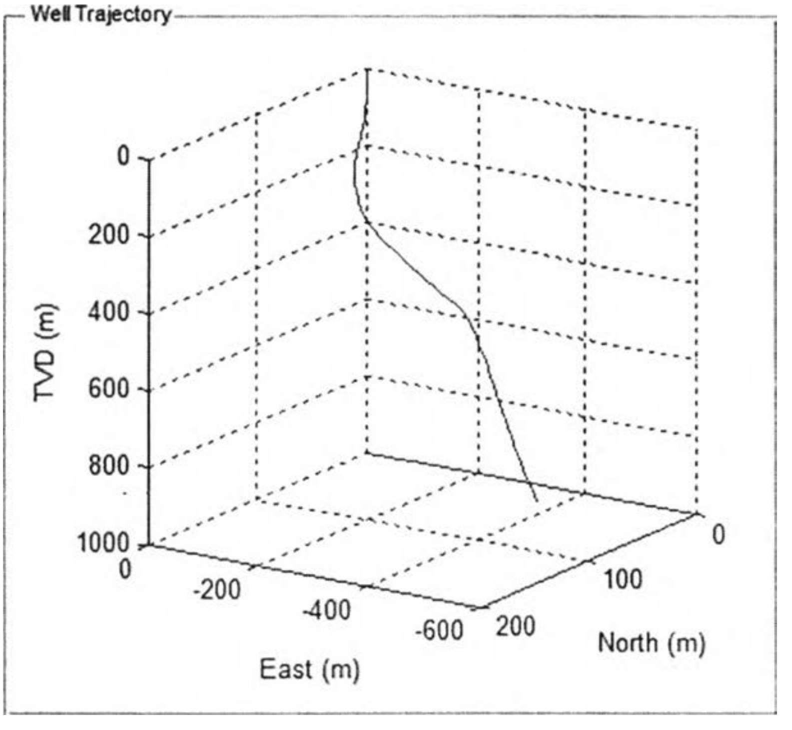

Figure 4.13 Well trajectories of well B.

4.4.2 Down-hole Parameters

The DWOB results from the friction model analysis for wells A and B are shown in Figures 4.14 and 4.15, respectively. Friction coefficient for wells A and B are in Figures 4.16 and 4.17, respectively. DTOR for wells A and B are in Figures 4.18 and 4.19, respectively.

The DWOB of well A from Figure 4.14 quite be an increasing trend between DWOB and Measured Depth (MD) but there are some fluctuation points around 550, 700 and 1,100 meters. The fluctuations may come from the problems in the drilling operation and the delayed drilling rate. At 1,000 – 1,200 meters measured depth, there are many fluctuation points, which may come from the delayed drilling rate. The delayed drilling rate is the operation that slow down the rate of penetration (ROP), when the bit reaches the soft formation an excessive DWOB increases ROP rapidly. The very high ROP caused the damage to the bit, which reduces the bit efficiency. Thus, the driller has to slow down the ROP by reducing the SWOB, which it will bring DWOB decrease.

For well B, there are less fluctuation points than well A. DWOB of well B seems likely an increasing trend comparing with well A. Thus, the drilling well B may be more effective well than well A, where the drilling rate is optimized. However, the drilling problems, which bring the fluctuation in DWOB at some points, can from inlet pressure. This inlet pressure may come from water, oil or gas, which it will reduce ROP and then driller will counteract by increasing WOB.

The friction coefficient is the parameter, which tell the quality of contact area between wellbore and drill string. The high value of friction coefficient could be poor-hole cleaning and low value means the wellbore surface is smooth. The friction coefficient of well A is in the range between 0.05 and 0.45.The upper and lower limits were set at 0.05 and 0.5 (from the section 4.1). The reason of changing upper limit is the sensitivity of this model to friction coefficient value. The results show, there are some error at around 900 meters and most of friction coefficient value are in the range between 0.25 and 0.4. This range is the same result, which is observed by Lesage et al. (1988) (see Chapter 2).

For well B, this well has more problems than well A because many friction coefficient above the limit value. However, the results from DWOB show the DWOB of well B is practical because it is in the range between 5,000-10,000 lbs. Thus, the real friction coefficient of well B may close to the limit value. That brings the results of friction coefficient reach the limit. Therefore, the conclusion of well A and B from friction coefficient is wellbore surface of well A may smoother than well B. Normally, the friction coefficient depending on formations, inclination and hole cleaning. In this case, these two wells are in the same area also an inclination does not different much, thus the friction coefficient will be affected by the roughness of wellbore surface.

Most of DTOR for wells A are in range of 1,000 to 2,000 lbs.-ft. and 300-2,000 lbs.-ft. DTOR were calculated from the Pessier and Fear (1992) (see Chapter 2). However, there still has fluctuation in some points for both wells A and B. The explanation of DTOR is likely as DWOB because the DTOR calculated from DWOB and friction coefficient but the main effect comes from DWOB. The variation of DTOR is the same as DWOB, which is increasing when the bit reaches the hard formation or there is the inlet pressure at the bit.

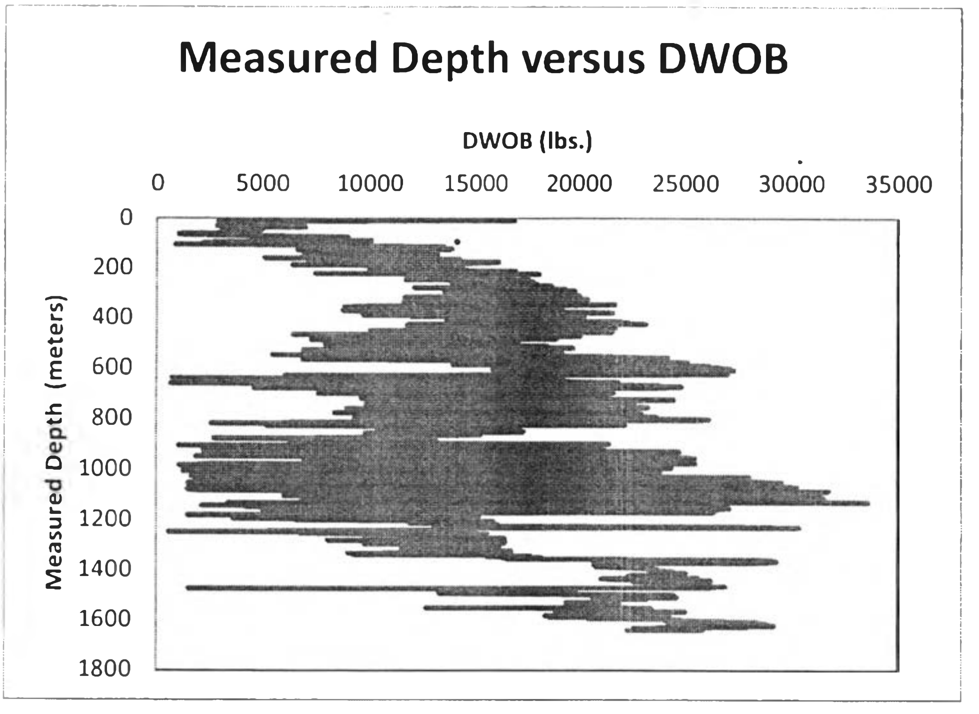

Figure 4.14 DWOB for well A.

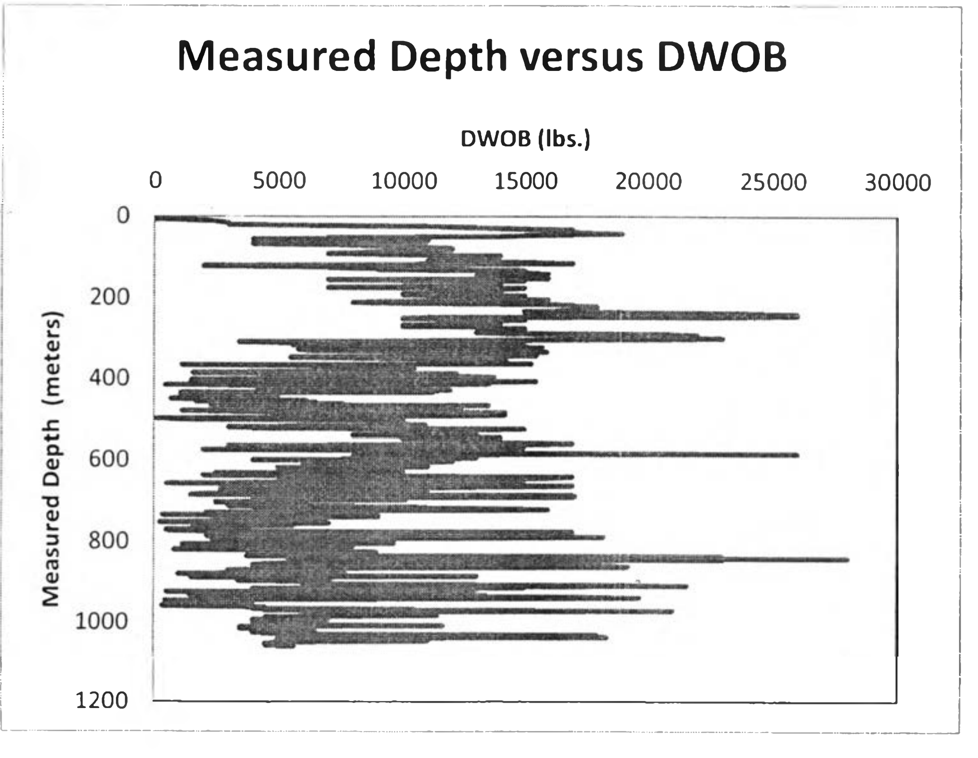

Figure 4.15 DWOB for well B.

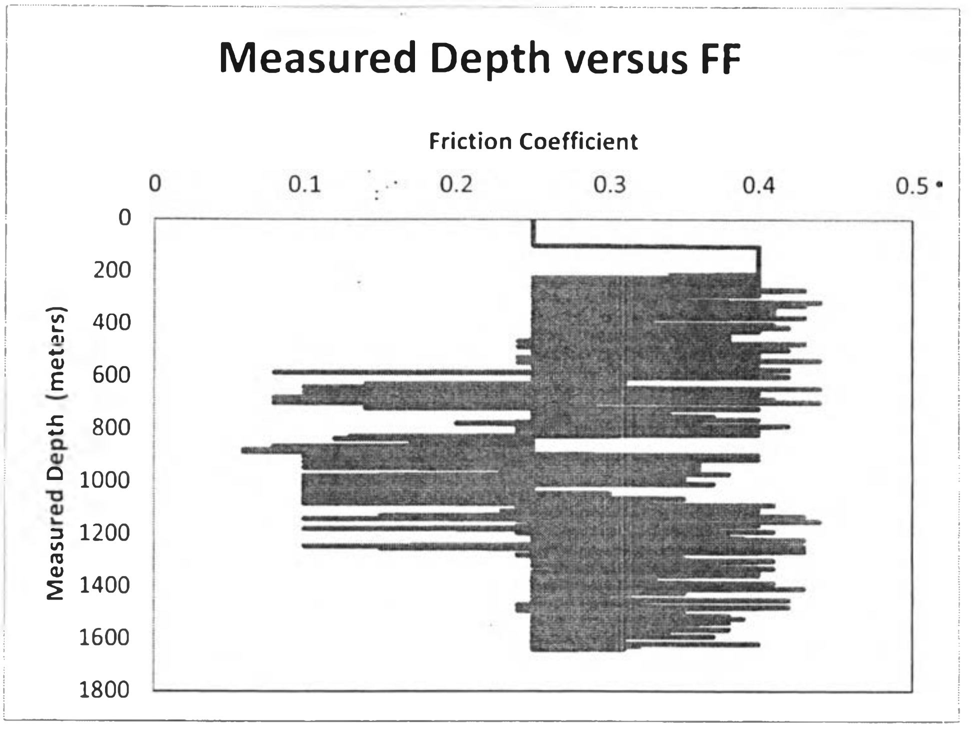

Figure 4.16 Friction coefficient for well A.

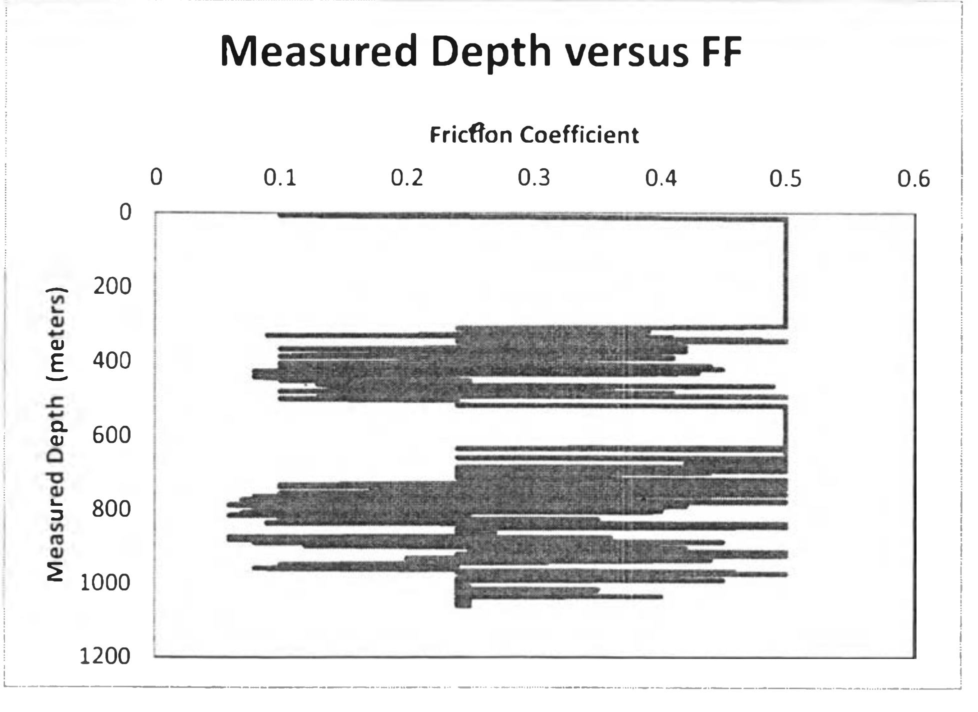

Figure 4.17 Friction coefficient for well B.

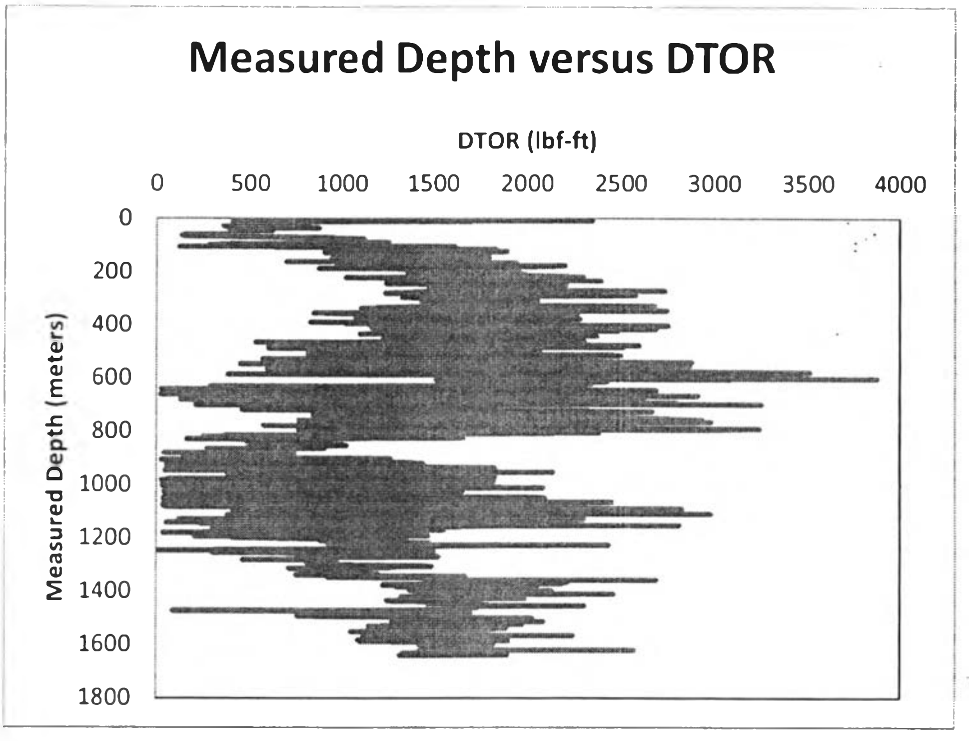

Figure 4.18 DTOR for well A.

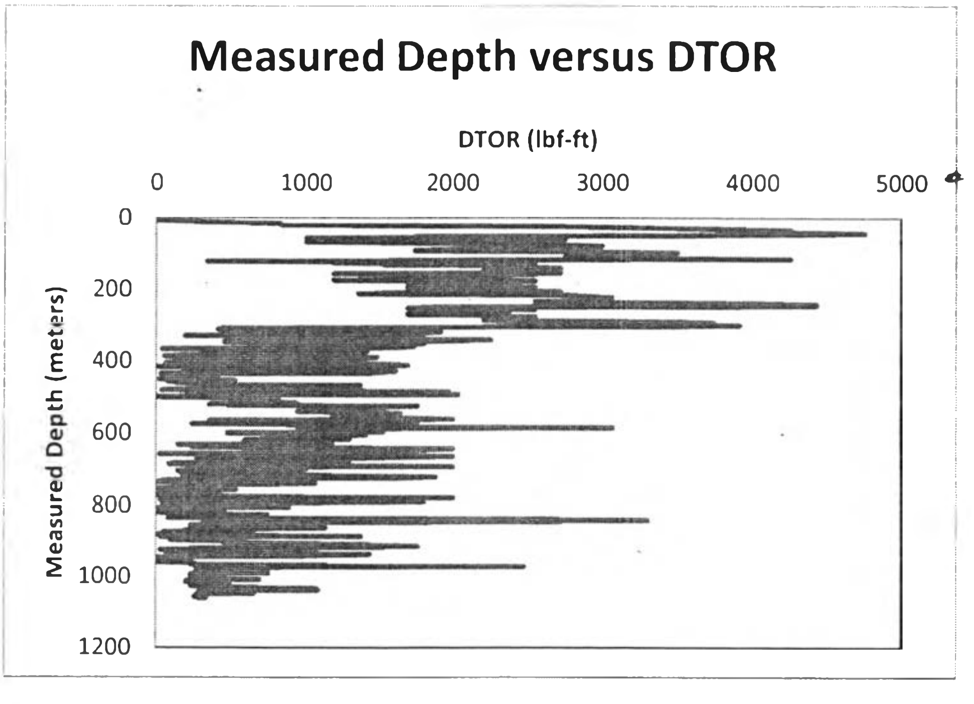

Figure 4.19 DTOR for well B.

4.4.3 Down-hole Drilling Specific Energy (DSE)

The DSE of wells A and B are shown in Figures 4.20 and 4.21, which were calculated every two meters. This length comes from nine intervals and the survey point normally collected every stand (20 meters). Thus, the length of data is 20 divining by 10 (number of intervals+1). The values of DSE are not constant because the DSE refers to rock strength, which is depended on type of the rock. Thus, the different formations give the different DSE value. Moreover, DSE is also depended on the drilling problems such as inlet pressure, which increase the DSE value.

The DSE value for well A quite be an increasing trend which is depended on measured depth (DSE increase when measured depth increase). For well A, this well has a lot of drilling problems. For example, these problems can see the fluctuation of DSE around 750, 1,100 and 1,300 meters measured depth.

For well B, there are drilling problems around 550 and between 800 – 1,000 meters. However, the drilling problems cannot interpret alone because the drilling problem from non-reservoir zone is not inlet pressure only. Thus, the interpretation requires the well logging data to indicate the probable reservoir zone. The interpretation discusses in section 4.4.4.

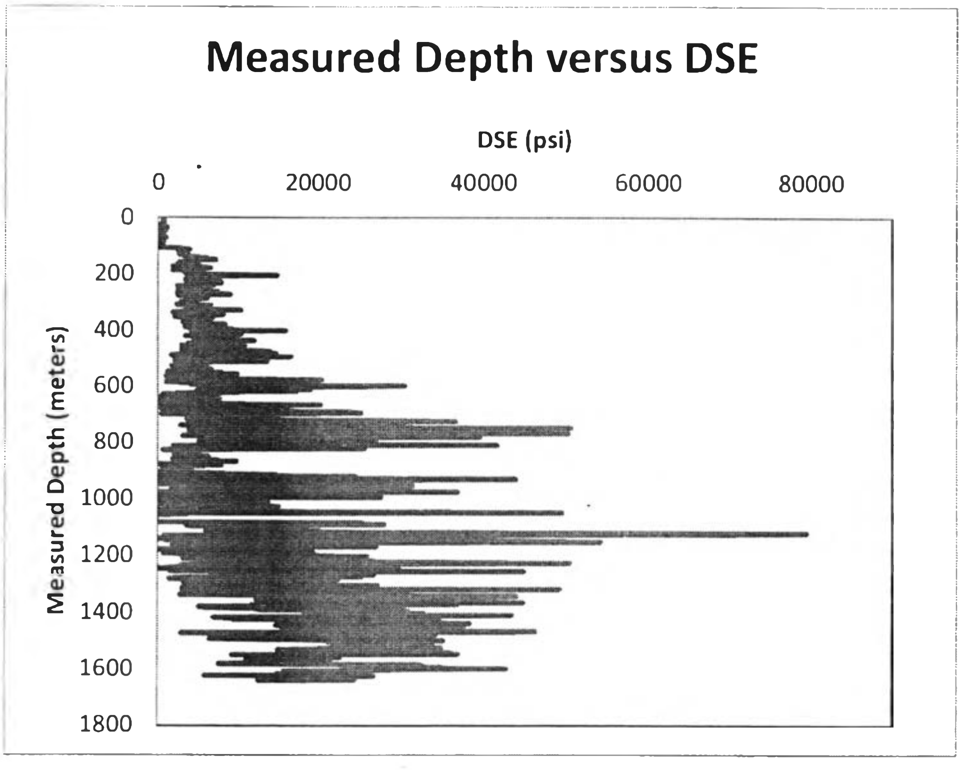

Figure 4.20 DSE for well A.

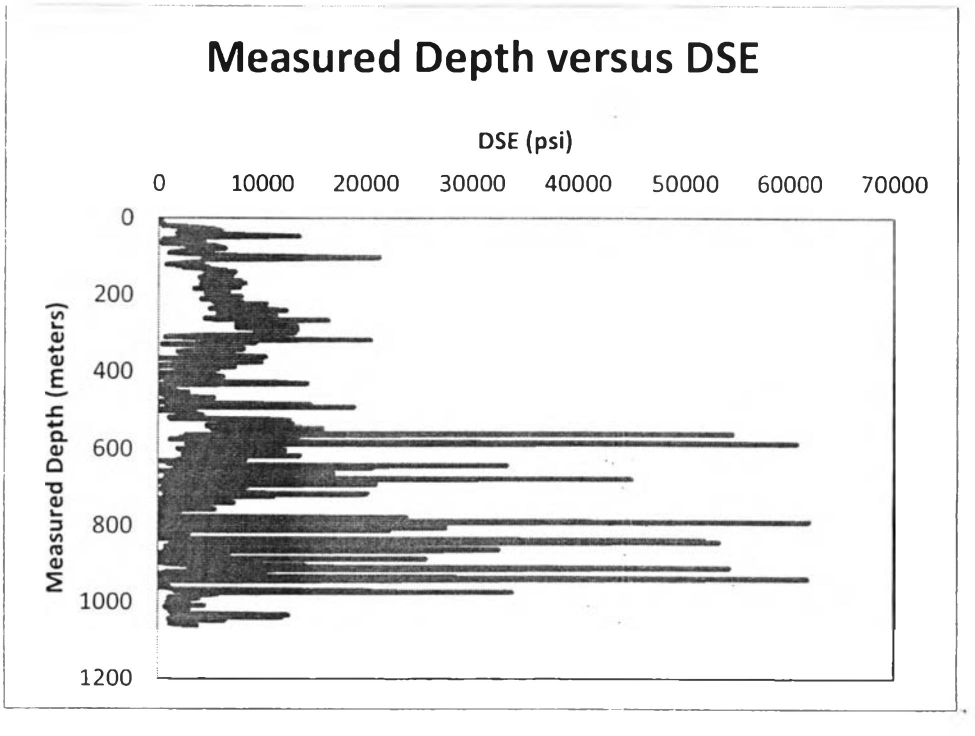

Figure 4.21 DSE for well B.

4.4.4 Interpretations

This section discusses the results from DSE with the real field data for both wells A and B. The DSE in this section were combined with the well logging data for interpretation. The verification of DSE was done by comparing the real production data from POES. The interpretations were done on Figure 4.22, 4.23, 4.24 and 4.25. The contents in the figures from top to bottom are production data, specific energy, well logging data (Neutron Porosity (NPRL), Density (RHOB), DT35 (Sonic Log), Resistivity (DDLL and DSLL), Gamma Ray (GRGC)) and lithology.

The interpretations focused on finding high DSE in reservoir zone, which is occurred from inlet pressure. The inlet pressure means the pressure from inlet water, gas or oil. When the bit reaches the water, gas or oil reservoir, the fluid inside the reservoir will come through the wellbore called inlet pressure. The result of inlet pressure is likely a force, which exerts on the bit to push the bit back. Then, the rate of penetration (ROP) decreasing, thus the driller has to increase DWOB to against the pressure force ROP. The increment on DWOB brings DTOR and DSE higher. Normally, DSE should be the same value for the same formation. When the same formation has very different DSE value, the drilling problems occur. The drilling problems refer to many problems such as struck pipe, damaged bit, inlet pressure etc. If the drilling problems occur in the zone, which should be the reservoir, it may come from the inlet pressure of petroleum itself. Generally, the well logging data can show the reservoir zone but cannot show the real production zone. The real production zone means the zone, which has the petroleum and suitable pressure for the commercial production. Thus, some zones may have petroleum but they are not suitable for the production. If expected reservoir zone has high DSE, it is the potential zone. The potential zone is the zone, which can be the commercial production zone. The commercial production zone must have high pressure, suitable permeability and large size. However, the DSE cannot be used alone to interpret the potential zone because DSE can only tell the drilling problems, which occur in that zone but cannot tell the types of the problem. Thus, the interpretation of the potential zone requires the well logging data and DSE value.

4.4.4.1 Well A

This well is a directional well which has measured depth of 1,610 meters and an average inclination about 60 degrees. The perforation plan included seven stages. There are five stages, stages one, two, four, five and six, which are production zones and other two stages, stages three and seven, are dry zones. Table 4.1 shows the perforation stages of well A.

Table 4.1 Perforation stages of well A

Stage	Measured Depth (meters)
1	897-979
2	1,258-1,265
3	1,292-1,295
4	1,306-1,314
5	1,348-1,353
6	1,367-1,372
7	1,503-1,516

The results of DSE from the program are interpreted with well logging and real production data, which are shown in Figure 4.22-4.24. These three figures show only the DSE in the perforation sections because the interpretations need to zoom in to see the change and value of DSE. There is not a benefit to focus on finding the problems outside an expected production zone.

Figure 4.22 shows the results of stage one perforation. This stage consists of five interval zones. These zones produced only little amount of water. The results of DSE show, third and fourth zones may have the drilling problems because of high DSE than the nearby formations. However, the product from this stage is only water. The product may come from third and fourth zones, which have high DSE. The error in production only water come from the interpretation of geologists because DSE can only tell the problems occurred during the drilling operation. It cannot tell the type of the problem. Thus, the drilling problems in this zone may be inlet pressure of water from the water reservoir.

Figure 4.23 shows the perforation of stages two, three, four, five and six which all of them are production zones. These stages produced both water and oil in different ratio. The oil to water ratio is highest at stage two and lowest at stage six. The production data show second, fourth stages produced the largest amount of oil, and stage six produced the lowest amount of oil. The results of DSE show there are high fluctuation in DSE value at the boundary of second and fourth stages. The value of DSE in these zones is higher than the DSE in other nearby zones, which have the same lithology. That can be interpreted second and fourth stages have drilling problems, which is inlet pressure. Thus, second and fourth stages are the potential zone from both DSE and well logging data. Moreover, the result of interpretation from DSE value and the production data of second and fourth stages are in the same way. That can be confirmed the application of DSE on determination of potential zone. For sixth stage, there is high DSE in the middle of the zone. However, the value of it looks the same DSE in nearby zone but when taking into account the lithology of this zone, it is different from the nearby zone. This zone contains only sandstone and clay stone. The nearby zones contain sandstone, clay stone and shale. The strength of the shale formation is more than sandstone formation and clay stone. Thus, the DSE value of nearby zones should be higher than sixth stage for the normal case, which has not the drilling problem. Therefore, the sixth stage could be a potential zone due to the same DSE as the harder formations. Unfortunately, sixth stage produced high amount of water but low amount in oil. The errors come from the interpretation of well logging data as mentioned before. For third and fifth stages, the DSE values are quite the same to nearby formations. It is difficult to interpret from DSE value due to the low pressure of the reservoirs, which brings low in DSE changed. Moreover, the production data from these two zones also show, there are very low production rate. From this case, DSE is not suitable for the small reservoirs.

Figure 4.24 shows the perforation of seventh stage. The results of DSE in this stage are the same as nearby zones (1,490-1,520 meters measured depth), which have the same lithology. It can infer that there is no drilling problem around this stage. Thus, this zone is not the potential zone. However, there still has the probability to be a small reservoir zone as mentioned in an above paragraph.

In the conclusion of this well, the DSE value can indicate only the large reservoirs, which are second, fourth and sixth stages, and cannot indicate for the small reservoirs, which are third and fifth stages. Thus, DSE plays a great benefit to confirm the logging data for the large reservoirs. This can increase the accuracy of perforation, which reduce the cost of production. Moreover, this technology may fit with unconventional gas reservoirs such as shale gas and tight gas, which have high pressure.

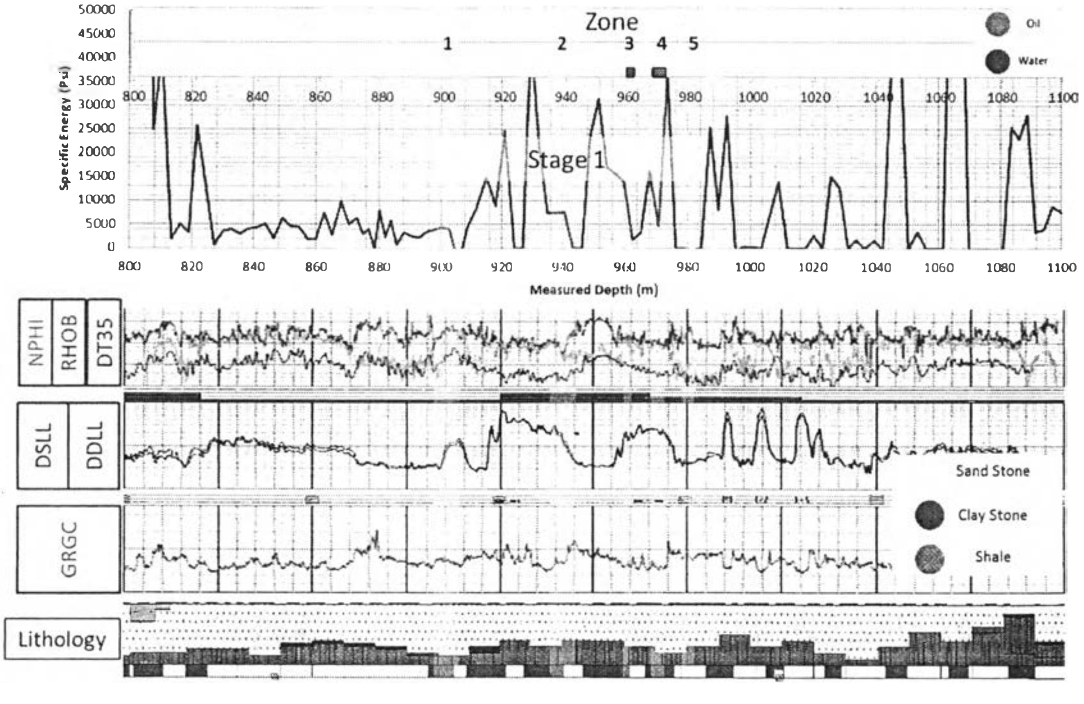

Figure 4.22 DSE interpretation for well A, 800-1,100 meters.

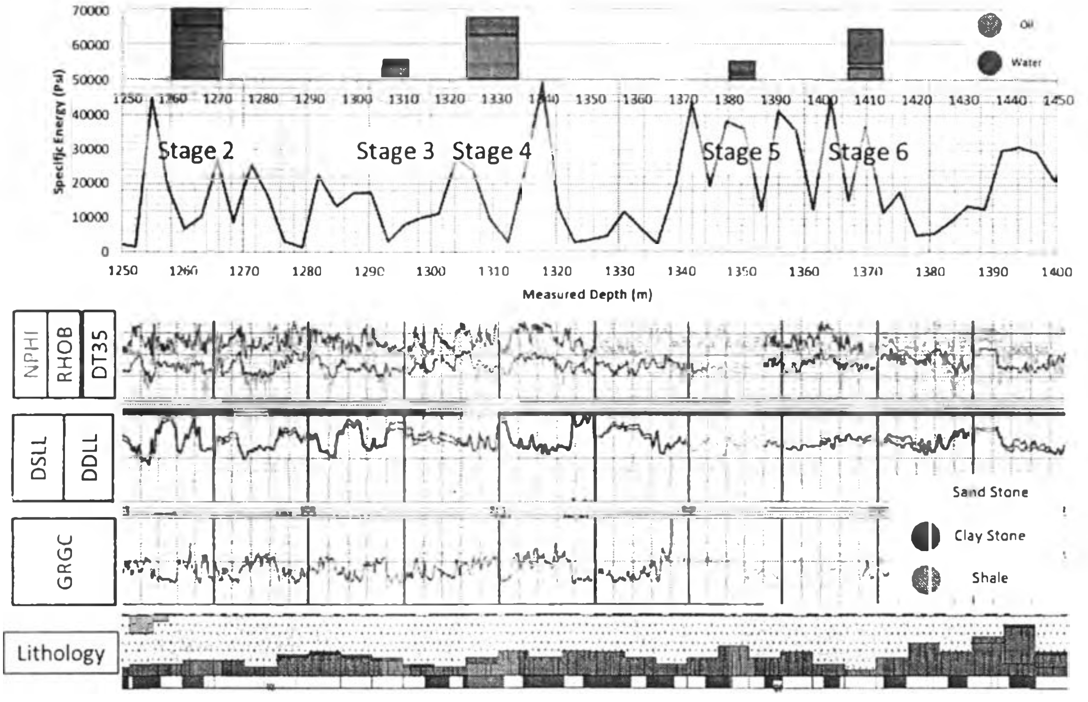

Figure 4.23 DSE interpretation for well A, 1,250-1,450 meters.

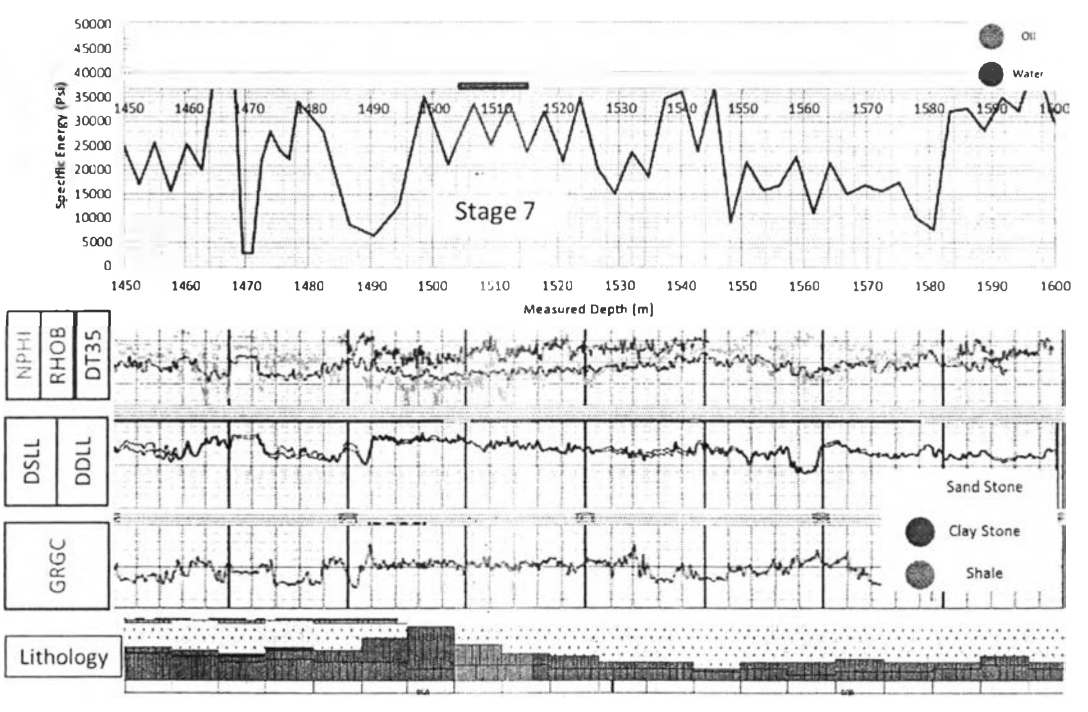

Figure 4.24 DSE interpretation for well A, 1,450-1,600 meters

4.4.4.2 Well B

This well is a directional well which has measured depth of 1,060 meters and an average inclination around 45 degrees. The perforation plan included two stages. There is only second stage, which is a production zone and first stage is a dry zone. Table 4.2 shows the perforation zone stages of well B.

Table 4.2 Perforation stages of well B

Stage	Measured Depth (meters)
1	727-759
2	777-788

The results of DSE from the program are interpreted with logging and production data, which are in Figure 4.25. This figure shows only the DSE in the perforation sections because the interpretation needs to zoom in to see the changed value of DSE. There is not a benefit to focus on finding the problems from outside an expected production zone.

There are two perforation stages for well B. The first stage consists of four interval zones and one interval zone for stage two. The results of DSE show, stage one has the very low value of DSE, which are as same as nearby formations. This can be inferred, there is no inlet pressure at stage one. Thus, this stage is not a potential zone. However, the geologists decided to perforate at this stage and found only few amount of water. The results of perforation are the same as the DSE results, which there may have only small and low-pressure reservoir.

For second stage, there are water and oil productions at this stage, which are very high quantities when compared to total water production from first stage. This stage was perforated for three times. The results from well logging data indicated, this stage has very high probability to find the oil. The well logging shows this stage has very high resistivity (DSLL and DDLL), low gamma ray (GRGC) and high porosity (NPHI). Thus, the geologists decided to perforate this stage from the well logging results. Unfortunately, the first of perforation zone there was nothing been found. However, the second perforation also applied to this stage, then oil and water showed for production. After the depletion of second perforation, the third perforation also applied again and found oil and water again. The amount of production from the second and third perforations is quite the same. The reason, why the first perforation did not produce any water and oil, can be expressed by the results of DSE. The results show, there are high DSE value at the front (777 meters measured depth) and the back (788 meters measured depth) of the stage two. Thus, the high-pressure zones are at the front and the back of this stage. However, the fractures from first perforation did not reach to these zones. Therefore, there was nothing found from first perforation. The second perforation might extend the first fractures length a little, which reached the high-pressure zone and thus the oil and water were produced. For the third perforation, the fractures were extended again and then the production was continued at this stage. The results of second and third perforations can confirm the real high-pressure zones may be at the front and the back of this zone.

In conclusion, this well is a good example of the DSE interpretation. Moreover, if this technology was applied during the decision of perforation step, the perforation cost can be reduced. The geologists can remove the perforation of first stage and perforate only second stage. However, the study of DSE should be done on the large reservoirs and unconventional reservoirs in the future. The good decision in perforation plays an important role to reduce a drilling operation and sustainable the world energy.

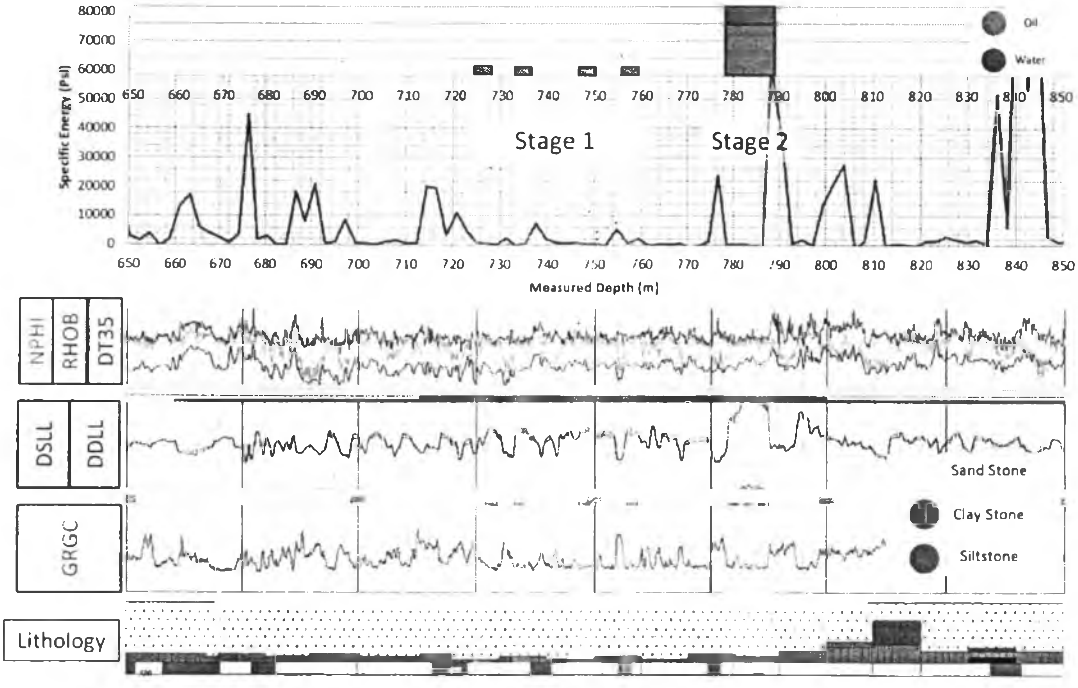

Figure 4.25 DSE interpretation for well B, 650-850 meters