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SCALED MODEL EXPERIMENTS OF WATERJET DRILLING

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ABSTRACT

Drilling is a necessary step for petroleum exploration and production. The conventional rotary drilling technique falls short since it is costly and contaminating surrounding rock and water due to the use of toxic drilling fluids. This paper introduces the waterjet drilling as an alternative to this conventional technique. Paraffin wax samples are used to simulate the rock behavior as a result of waterjet drilling. Based on laboratory experiments, empirical models have been established to describe the waterjet–wax interaction. The results show that the depth and rate of penetration (ROP) increase with time and temperature.

Keywords: waterjet; drilling technique; paraffin wax; penetration rate.

NOMENCLATURE

A	= cross sectional area of drill bit tip, mm^2, $[L^2]$
D	= depth of penetration (DOP), mm, $[L]$
D_t	= rate of penetration (ROP), mm/hr, $[L/t]$
p	= pressure of the system, psi, $[M/Lt^2]$
q	= $A \times u$ = flow rate, cc/sec, $[L^3/t]$
T	= temperature, $[T]$, ℃
t	= time, minute, $[t]$
t_T	= thermal exposure time, minute, $[t]$
u	= waterjet velocity at the tip of the drill bit, cm/sec, $[L/t]$

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1. INTRODUCTION

Drilling is one of the oldest technologies in the world. A parameter of principal importance in any drilling process is the "weight on bit". This is the axial force acting on the bit during the cutting process. Normally this force is relatively large and may be generated by proper anchoring of the drill machine to the drilled surface. Alternatively, weight on bit may be provided by the self-weight through derrick. Waterjet drilling does not require any weight on bit. The energy loss is nominal which is quite remarkable. These are the prime advantages of waterjet drilling. This type of drilling is used as an accessory activity in many industries including the oil and gas industries. The technique is normally used to remove cuttings, rock chips, mud cake and to clean the formation of the reservoir as well as the surface.

At present, drilling technology has modernized well profiles and directions. High pressure waterjet (HPWJ) technique is now used for horizontal drilling. Horizontal wells are being drilled across the reservoir for exposing a relatively large reservoir area which is used for production or injection operations. Most of the new wells are completed without cementing or liner. Due to the long opening, acidization is used to remove mud cake. Since, this process is very costly, the HPWJ process is increasingly used. HPWJ is a cost effective and simple to handle process in drilling technology. This technology has been the topic of many researchers due to its variety usages in the industry. As a result, recently, researchers are very interested on this tropic.

Maurer et al. (1969) conducted a series of experiments by waterjet on different rock samples. They concluded that waterjets can successfully drill sedimentary rocks. They used a high pressure pump up to 13,500 psi, which can give 200 to 300 ft/hr penetration rate. They have also concluded that waterjet is economical for drilling oil wells. They found that the hydraulic jet drilling rate is influenced by nozzle size, nozzle pressure, and rock strength. Fenn (1989) investigated the use of waterjet for use in conjunction with free-rolling cutters. He conducted a series of laboratory tests with disc and button cutters to determine the effect of variations in the jet and cutting parameters on the cutter performance. His results indicate that no additional improvement in cutting performance is gained by an increase in jet pressure above 40 MPa. Ho-Cheng (1990) studied waterjet drilling to model an optimal waterjet pressure which is a function of hole depth and material parameters. He found reasonable agreement with data obtained from waterjet drilling of graphite epoxy laminate. He concluded that the predicted optimal waterjet pressure can be applied in a control scheme for maximizing the productivity of waterjet drilling of composite laminates. Hood et al. (1990) studied high-pressure waterjet for developing a better understanding of the erosion mechanisms to cut the rock materials. They developed an empirical model to describe the different parameters involved with the system. This model is described the rock erosion by a high-pressure waterjet.

Yasuda and Hoshina (1993) studied the fundamentals of the application of the ultra high pressure waterjet for rock drilling. They have developed an ultra high waterjet boring system using ultrahigh pressure waterjet. Aslam et al. (2000) have discussed the theoretical aspects of the HPWJ technology, case histories and well performance data. They have also pointed out that HPWJ can be used for steel cutting or to make holes by using abrasive materials such as sand and beads. It has been reported in the literature that the efficiency of the process depends on four factors such as (i) stand-off distance, (ii) fluid velocity, (iii) jet stream profile and (iv) rotation. Buset et al. (2001) described the penetration effects on formation zone due to waterjet technology. Lia et al. (2001) pointed out that the combined cutting effect of waterjet and polycrystalline diamond compact (PDC) is very effective in very hard rocks. They conducted experiments on waterjet and PDC for rate of penetration in hard rocks. Arangath et al. (2002) discussed the high hydraulic horsepower jetting tool which is used for scale removal. They have also shown water jetting in horizontal well drilling. Dunn-Norman et al. (2002) discussed processes for sustainable recovery of heavy oil from ultra-shallow reservoirs, using low cost, innovative horizontal drilling and completion methods. They have argued that waterjet drilling can extend for over 15,000 ft (5,000 m), which is more competitive than the conventional rotary drilling system. They also concluded that waterjet drilling methods appear most favorable for drilling horizontal wells in ultra-shallow reservoirs. Paraffin wax as a laboratory sample is used to study the waterjet drilling system. The properties of wax samples are well described by Hossain et al. (2009a). Moreover, the factors that may affect the drilling activities are also explained by Hossain et al. (2009b). In this study, a series of laboratory tests were run to know the effect of water Flow rate, the rate of penetration, and pressure. This research examines the effect of jet time and temperature on the depth and rate of penetration. In addition, the effect of change of waterjet pressure on the depth and rate of penetration is studied.

2. EXPERIMENTAL SETUP

Figure 1 shows a laboratory experimental drill bit for waterjet drilling technique. Here normal tap water is used with a maximum of 72 psig pressure to create a waterjet through a 1 mm diameter hole at the tip of drill bit. A non-return valve has been used for protecting back flow and pressure. Two grooved screws are attached with the drill bit for holding it with a stand. A pressure gauge has been set with the bit for measuring the inside pressure of the bit.

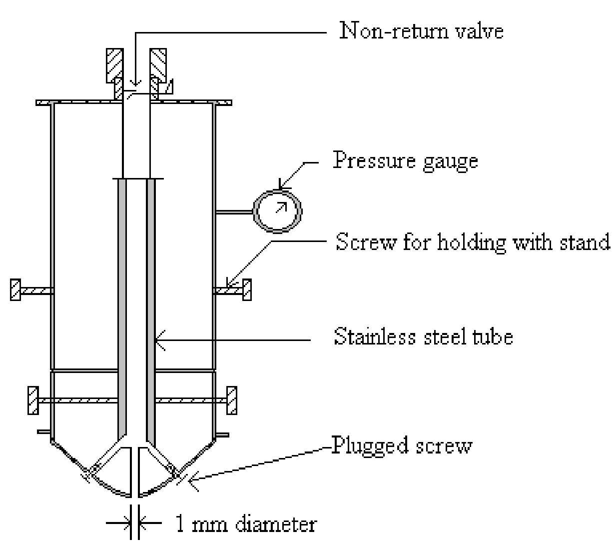

Figure 1.Stainless steel drill bit.

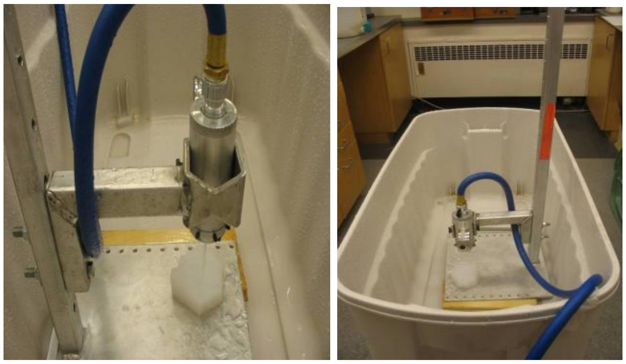

Figure 2. Experimental setup at the laboratory.

Figure 2 shows a schematic view of the experimental setup used in the laboratory test. Continuous flow of water was achieved by connecting the drill bit with tap water with a flexible extra-strength plastic tubing. Figure 3 shows the paraffin wax that is used as a rock sample in the experiment.

3. RESULTS AND DISCUSSION

Figure 4 shows the dependence of different influential parameters such as depth of penetration (DOP), ROP, Flow rate, pressure of the drilling fluid system and temperature with time. The graph shows that the depth increases with time nonlinearly. ROP is more complex to describe because it fluctuates with time. The penetration rate is decreased as the DOP is increased. This trend is decreasing with time. The Flow rate was maintained within 5% of 20 ml/s. This variation was unavoidable because of the pressure change during the drilling operation.

Figure 3. Paraffin wax for experiments.

The pressure profile during the course of the experiment is reported in Figure 4. This variation was due to the direct use of tap water in the system. There is no temperature variation during the experiment in this case. So the trend is constant with time.

The trend line for DOP with time is shown in Figure 5. The empirical relationship between these two parameters has been derived by best fit regression analysis.

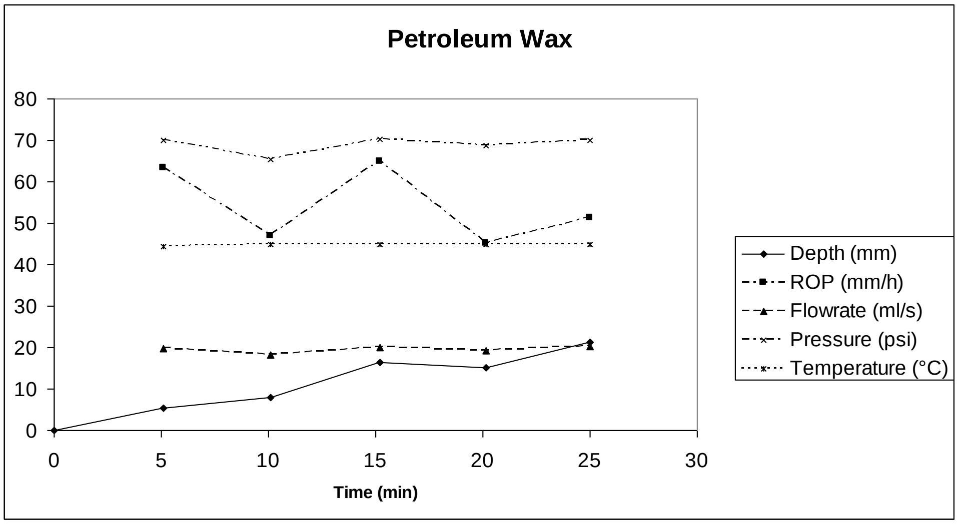

Figure 4. Dependence of different parameters on time.

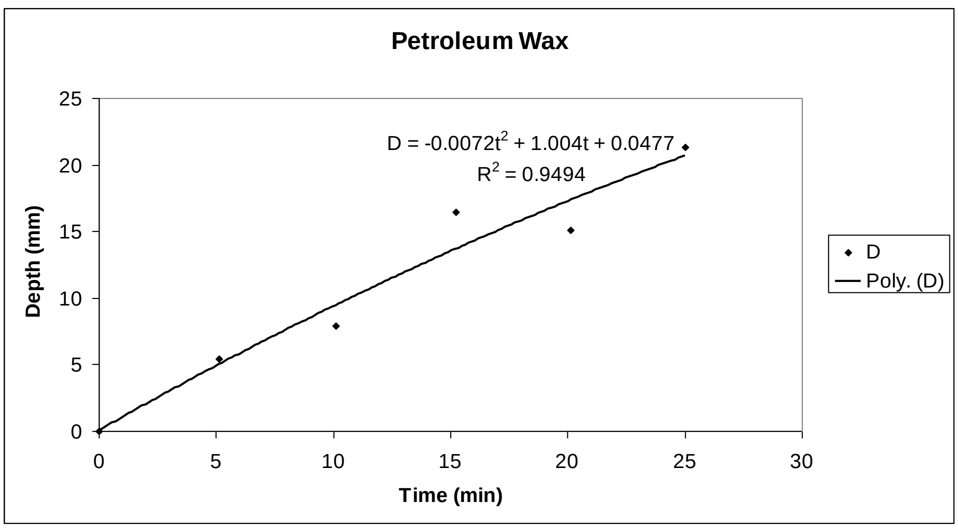

Figure 5. Dependence of depth on time for empirical relation.

The relationship is represented by equation 1;

$$D = -0.0072\,t^2 + 1.1004\,t + 0.0477 \text{ and } R^2 = 0.9494 \quad (1)$$

The trend line for ROP with time is shown in Figure 6. The empirical relationship between these two parameters has been derived by best fit regression analysis which shows in equation 2. However,

$$D_t = -0.5233\,t + 62.219 \quad (2)$$

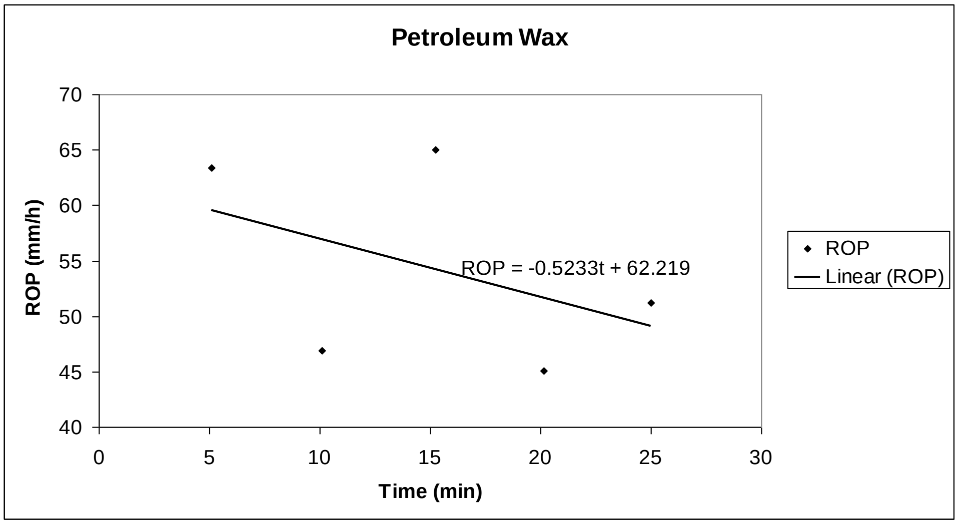

Figure 6. Dependence of rate of penetration on time for empirical relation.

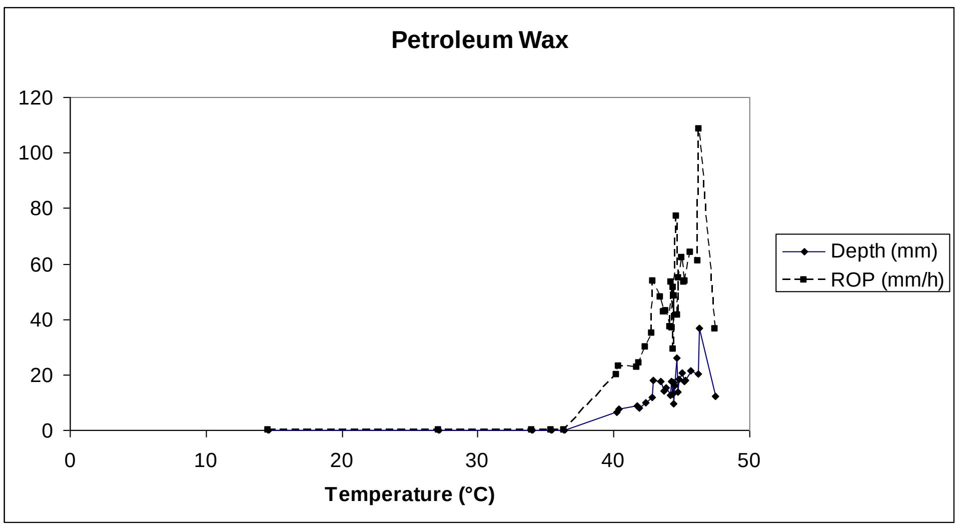

Figure 7. Effects of temperature on depth and rate of penetration.

Figure 7 shows how the temperature of the drilling fluid affects the DOP and ROP. There is no temperature effect up to 36.4^0C. DOP and ROP increase with the increase of temperature. For both cases, the trend of variation is chaotic since there is no definite trend of variation for these two parameters. In addition, the depth and ROP are affected by other parameters such as side effect (Figure 8), thermal exposure, waterjet pressure and wax composition. To investigate the side effects, sets of experiment have been completed marking the sample in 1” interval from each other and each side (Figure 8). Figure 8 shows the orientation and DOP at different places within the sample. Each of holes has an interval of 1” between each others and side. It should be noted that, green color at the location of holes are used to visualize clearly.

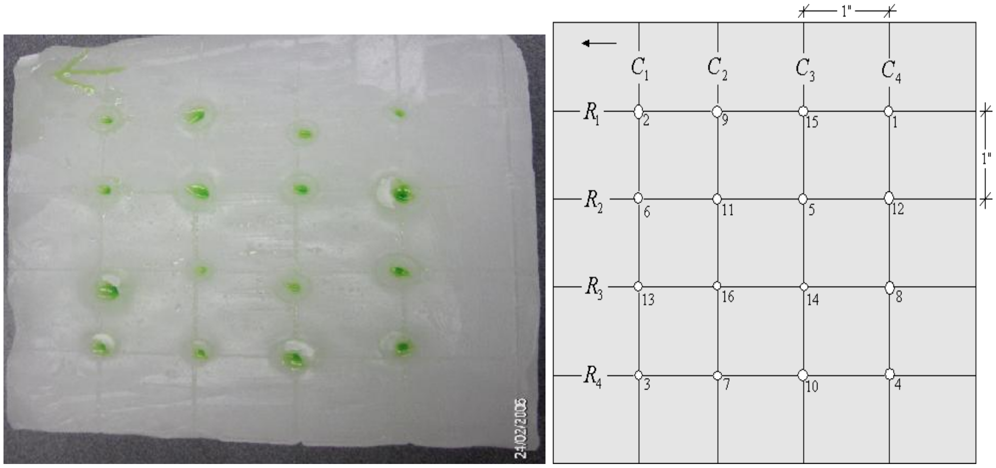

Figure 8. Systematic drilling to investigate side effects.

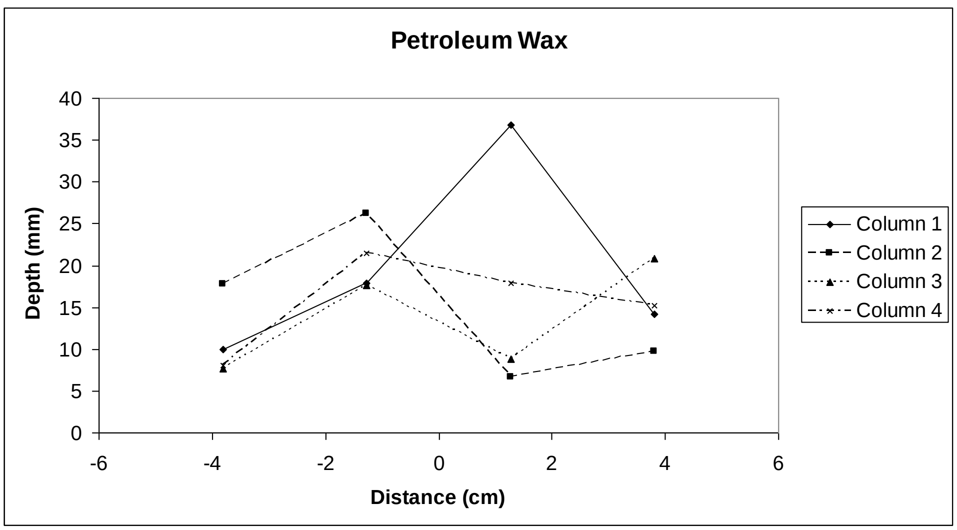

Figure 9. Side effects on depth of penetration (column wise).

Figure 9 shows the column wise side effects on DOP where distance from the centre of the wax sample has been considered as benchmark. Side effect is more effective in column 1 especially in reference point 13 (Figure 8). This is due to thermal effect on samples. Reference point 9 of column 2 is more affected than reference point 2 of column 1. It is interesting that Reference point 11 is more affected than 9 or 7 in column 2. It seems unrealistic because intuitively Reference 11 should be less affected than 9 or 7. Reference point 5 shows more affected than reference point 15 in column 3. Column 4 shows the same trend reference number 12. This apparent anomaly can be explained through thermal effects. The thermal effect on the interior side reference points are more affected than that of the side. It is true that for a paraffin wax, temperature is more influential parameters than side effects. Therefore, these chaotic behaviors appear.

Figure 10 shows the row-wise side effects on DOP. Distance from the centre of the wax sample has been considered as the reference. The side effect is more effective in Row 2 especially in Reference points 6 and 12 (Figure 8). However, Reference point 11 is more affected due to thermal effect. The behavior of Row 3 is quite interesting where the trend of the line makes sense of side affects. Reference point 13 is the most effected point by side effect in the system. Figure 11 shows the column wise side effects on ROP. Distance from the centre of the wax sample has been considered as the reference. The trend of all the columns is same as explained for Figure 9.

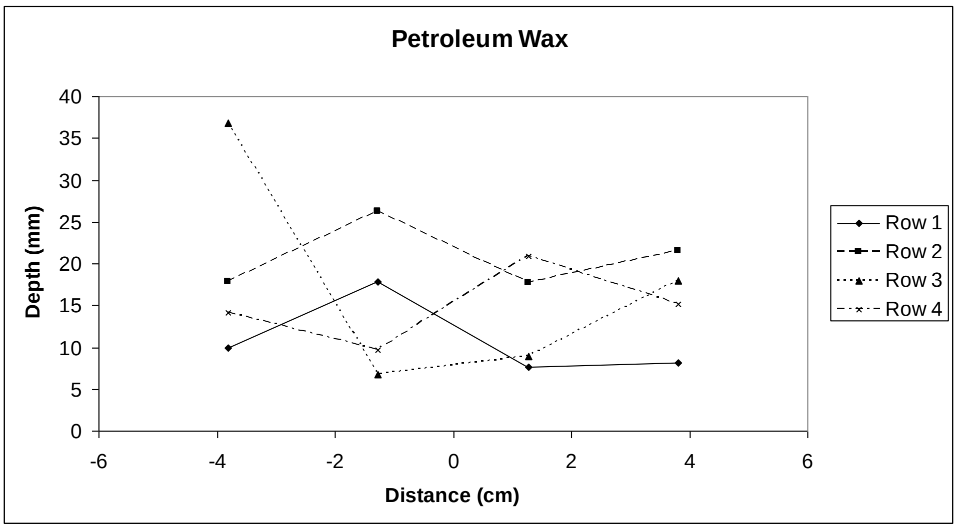

Figure 10. Side effects on depth of penetration (row wise).

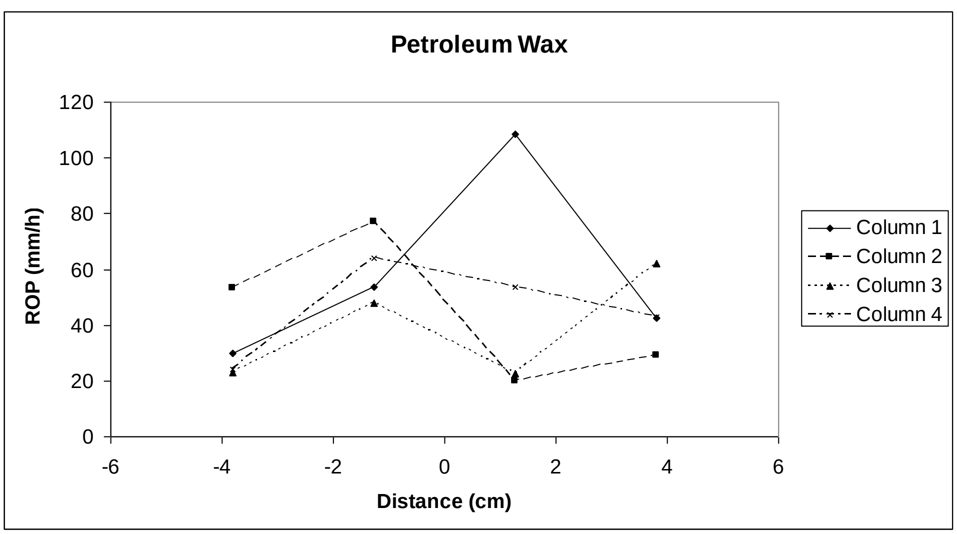

Figure 11. Side effects on rate of penetration (column wise)

The influence of side effects on ROP is represented by Figure 12. The behavior of the curves is almost same as DOP described for Figure 10. Figure 13 explains more clearly the effects of side on the paraffin wax sample. First point has been generated by averaging all the reference points of Row 1, Row 4 and Column 1, and Column 4 (Figure 8).

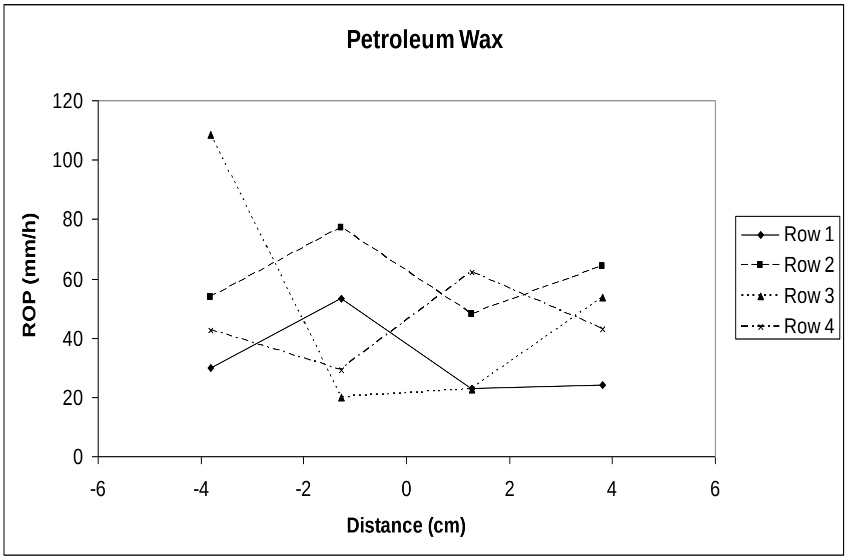

Figure 12. Side effects on rate of penetration (row wise).

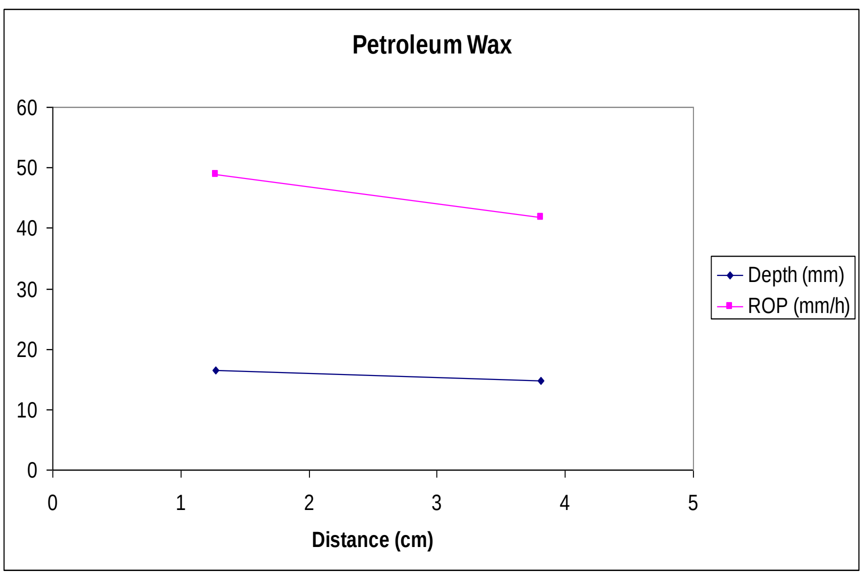

Figure 13. Side effects on depth and rate of penetration (towards centre from edge of the wax sample).

The second point is the average of the central four points such as Reference points 11, 5 and 16, 14 of Row 3 and Row 4. The trend is decreasing for both depth and ROP. It indicates that there is a side effect during the laboratory experiment. This error can be eliminated if every experiment is conducted by an individual sample keeping sufficient distance from the edges i.e. at the center point. Thermal exposure time of the wax sample is investigated by comparing various cases at different temperatures (Figure 14).

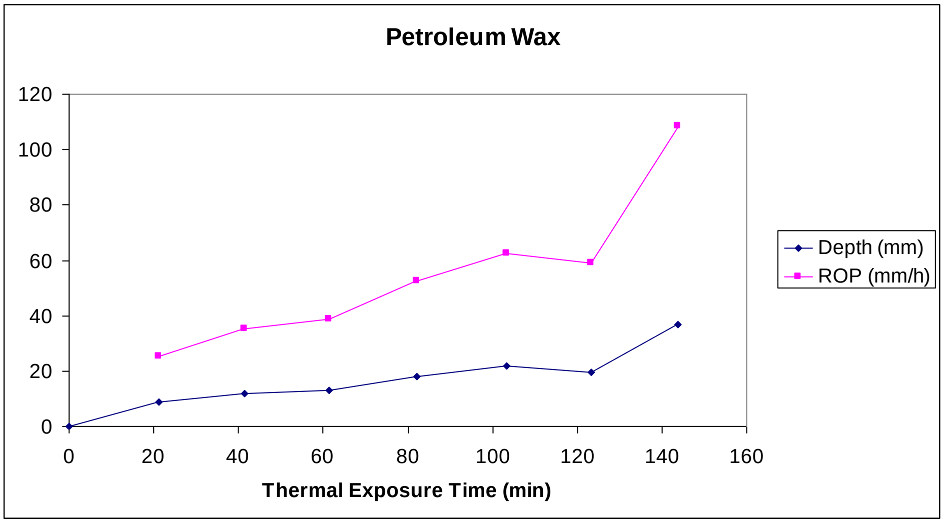

Figure 14. Variation of depth and rate of penetration with thermal exposure time.

As the thermal exposure time increases, the depth and ROP increase with time. It is obvious that there is a thermal effect during any hot water action. To soften the rock matrix, thermal action is helpful during waterjet drilling. As long as time progresses, thermal action plays a role in the rock matrix system shown in this figure.

Conclusions

The conventional practice in the oil industry is to use different drilling techniques for which large capital expenses are involved. The technology is also more complicated to handle. In this regard, waterjet drilling is simpler and needs less capital involvement. Experiments show that the DOP and ROP depend on pressure, temperature and flow rate of the waterjet. ROP decreases with time, however DOP increases with time. Both depth and ROP increase with thermal exposure time and temperature after 36.4°C. There is a side effect during the experiment. It decreases from the edge towards the centre of the sample. Empirical models are developed to describe the depth and ROP with time.

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