PUMP CLEARANCE CHANGES WITH DEPTH: EFFECTS ON SLIPPAGE

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INTRODUCTION

Pump clearance directly affects the slippage through the pump. The clearance changes with depth due to pressure effects on the metal of the pumps. The effects are shown to be different for top hold down pumps (THD) and for bottom hold down pumps (BHD). Example on the effects on slippage are presented.

SLIPPAGE

The Patterson slippage equation is:

$$\textit{Slippage, bpd} = [\{.014xSPM) + 1]453\,\frac{DPC^{1.52}}{L\mu}$$

Where:
D = Pump diameter, inches
P = Pressure above – Pressure below the plunger (Pd-PIP), psi
C= diametrical clearance between plunger and barrel, inches
L = length of plunger, inches
μ = viscosity of fluids, cp
SPM = strokes per minute

The above relationship shows that the slip is a function of the clearance. If the clearance changes with depth, then the slippage at depth is changed. Below a model is discussed to show how clearance of the pump can change with depth and temperature.

PUMP CLEARANCE

The pump clearance is sized in the pump to account for slippage through the plunger/barrel interface. Too much clearance results in too much production lost from slippage. This can be somewhat offset if SPM is higher but this can lead to problems as well. Too little clearance may increase plunger drag due to solids and enhance galling such that it can add compression to rods above the pump. So, slippage is an important design parameter.

The industry rule of thumb for slippage (to lubricate the pump) is that the value should be around 2-5% of the production, but for very low rates this could be larger and corrected for easily by a small change in speed if desired.

However at depth the well pressure (PIP) and the pressure in the tubing above the pump (Pd) as well as BHT will change the clearance of the pump at depth from the shop measured value.

To calculate the clearance with pressure and temperature, the following equation for a cylinder is used for both the plunger and the barrel of a pump, and illustrated in Figure 1. The configuration is different for a TDH and BHD pump but the plunger and barrel are still cylinders.

$$\delta r = \left(\frac{1-\gamma}{E}\right)\left(\frac{a^2 p_i - b^2 p_o}{b^2 - a^2}\right) r + \left(\frac{1+\gamma}{E}\right)\left(\frac{a^2 b^2 (p_i - p_o)}{b^2 - a^2}\right)\frac{1}{r}$$

Where:
E = modulus for steel, psi

γ = Poisson's ratio
a = ID of cylinder
b =OD of cylinder
r = location where δr is calculated
δr = change due to pressures Po, Pi
Po = pressure on outside of the cylinder
Pi = pressure in the inside of the cylinder

The change due to temperature is calculated from:

d1 = do(dtα+1)

Where:
do = initial diameter
d1 = final diameter
α = coefficient of thermal expansion
=9.4μin/in °F

Using the above equations, the change in clearance for pumps can now be estimated. However the estimated pressures acting on the plunger and barrel need to be defined. Figures 2 and 3 show schematics of the TDH and BHD pumps considered. The change in the barrel cylinder is taken inside the barrel and change for the plunger cylinder is taken on the outside of the plunger cylinder.

Two pumps are selected for example calculations. The two example pumps used have the dimensions shown in Table 1 for thin (w) and heavy (h) wall barrels of each size.

The values for input into the cylindrical expansion equation are:

Top Hold Down: Pump Plunger

$$p_o = \left(\frac{P_d - PIP}{2}\right)$$
$$p_i = P_d$$
$$r = r_o$$

Top Hold Down: Pump Barrel

$$p_o = PIP$$
$$p_i = \left(\frac{P_d - PIP}{2}\right) P_d$$
$$r = r_i$$

Bottom Hold Down: Pump Plunger

$$p_o = \left(\frac{P_d - PIP}{2}\right)$$
$$r = r_o$$

Bottom Hold Down: Pump Barrel

$$p_o = P_d$$
$$p_i = \left(\frac{P_d - PIP}{2}\right) P_d$$
$$r = r_i$$

EXAMPLE RESULTS

Both the 1.5” and 2.00” pumps were analyzed with a 0.003” initial clearance and then the analysis was repeated with 0.006” initial clearance. The depths went to 12,000’ for the BHD pumps and to 6,000’ for the THD pumps. For the cases where the slippage was calculated, the length of the plunger was selected using the industry rule of 3’ to 3000’, proportional to depth between 3000’ and 6000’ and 6’ for deeper depths. For temperature, a surface temperature of 100^{o} F was used with a gradient of $.006^{o}$ F/1000’ to account for thermal expansion of pump components. WHP was used as 100 psi.

Figure 4 shows calculated clearances for the 1.5” pumps. Note the clearances for this model show the THD pump clearances increase a little or stay about the same with depth and the clearances for the BHD pumps are predicted to decrease with depth.

Figure 5 shows the calculated slippage for 1.5” pumps. Note the slippage for the BHD pumps become more constant for depth with the differential pressure across the pump plunger going up and the clearance going down. The THD pumps show increasing slippage as the pressure drop and the clearance increases with depth.

Figure 6 show predicted slippage but with constant length of the plunger. This makes results smoother with depth.

Figure 7 shows calculated clearances with the 2” pumps with the .003” shop clearances.

Figure 8 shows the predicted slippage with the 2” pump with the .003” shop clearance. The BHD slippage is less than the constant .003” slippage curve but again the THD slippage is little more than the constant .003” predicted slippage.

Figure 9 through 12 are all for shop clearances of .006”.

Figures 9 and 10 are for the 1.5” pump showing clearance and slippage. Note with the bigger initial clearance the slippage increases with depth for all pumps even with reduced clearances for the BHD pumps.

Figures 11 and 12 are for the 2” pumps showing clearances and slippage.

Figure 13 shows how water viscosity can change with temperature and pressure. For all the cases presented here the water viscosity if referenced to 1 cp. Since water at higher temperatures can have a lower viscosity, then the leakages shown here can be quite a bit higher if lower viscosities are entered into the leakage equation.

SUMMARY

A possible model is presented for THD and BHD pump clearances and resultant slippage. It depends on the assumptions for what the average pressures are on the barrel and plunger of the pumps during the upstroke.

For the THD pumps the clearances are predicted to increase with depth and for the BHD pumps the clearances are predicted to decrease with depth.

For calculated slip, the slip becomes fairly constant with depth for the .003” shop clearance calculations but with the .006”shop clearances the slip increase with depth for all cases.

The equations and assumptions are presented such that if one would want to explore the effects of modifying any of the assumptions, it would be easy to do.

REFERENCES

1. Reference for the cylindrical expansion equation:
   http://www.engr.mun.ca/~katna/5931/Thick%20Walled%20Cylinders(corrected).pdf

Table 1. Dimensions for example pumps

Box End Pumps	Plgr ID	Plgr OD	BBL ID	BBL OD
BHD W	1.25	1.497	1.5	1.75
THD W	1.25	1.497	1.5	1.75
BHD H	1.25	1.497	1.5	2.253
THD H	1.25	1.497	1.5	2.253
BHD W	1.5	1.997	2	2.25
THD W	1.5	1.997	2	2.25
BHD H	1.5	1.997	2	2.753
THD H	1.5	1.997	2	2.753
*take more off the plunger for .006 clearance				

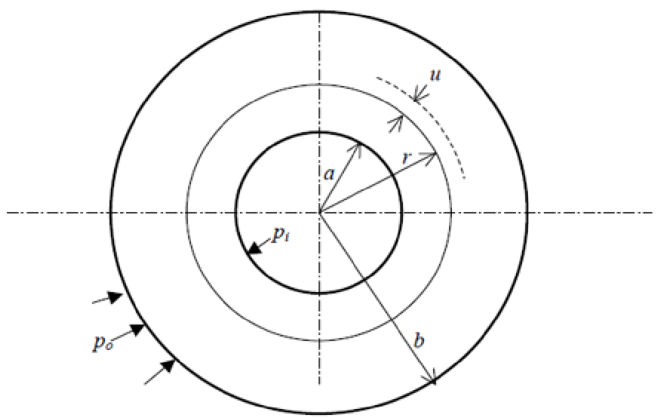

Figure 1. Nomenclature for the cylindrical expansion equation

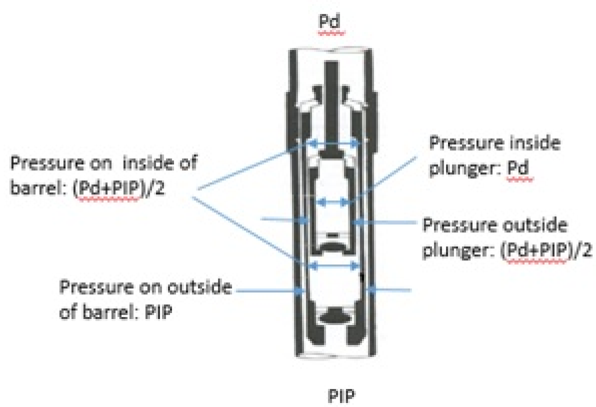

Figure 2: Schematic of THD Pump. Upstroke Pressures

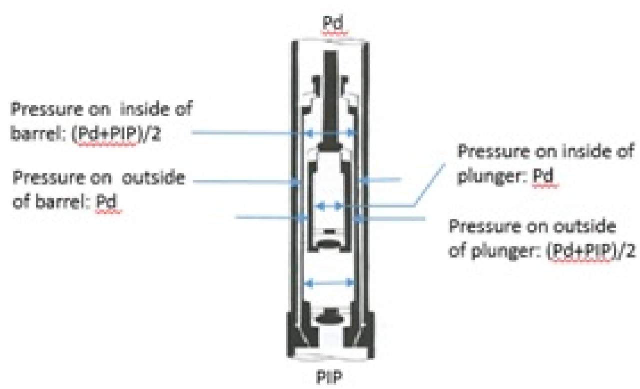

Figure 3. Schematic of BHD Pump: Upstroke Pressures

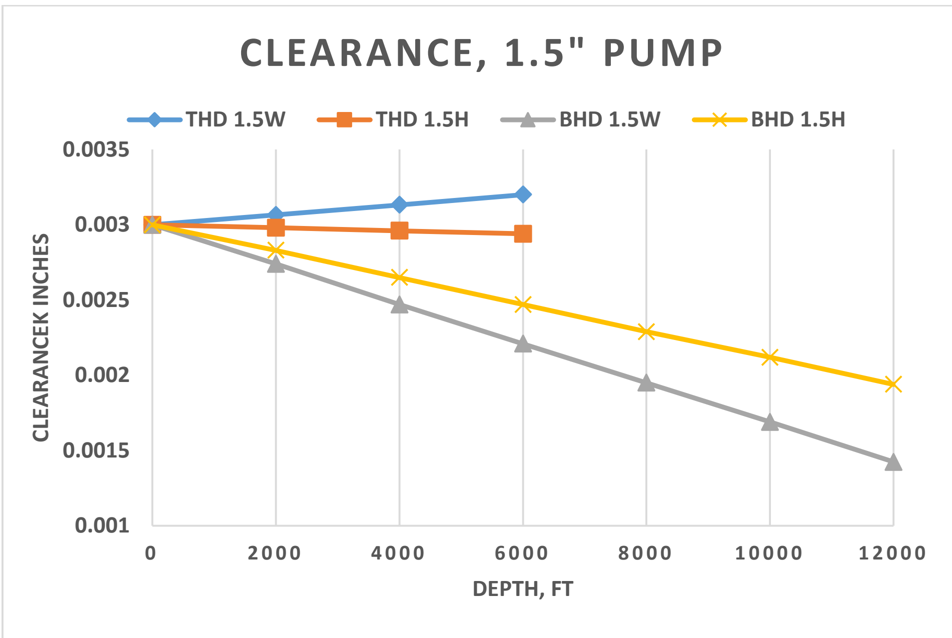

Figure 4. Calculated Clearances: Initial Shop Clearance .003

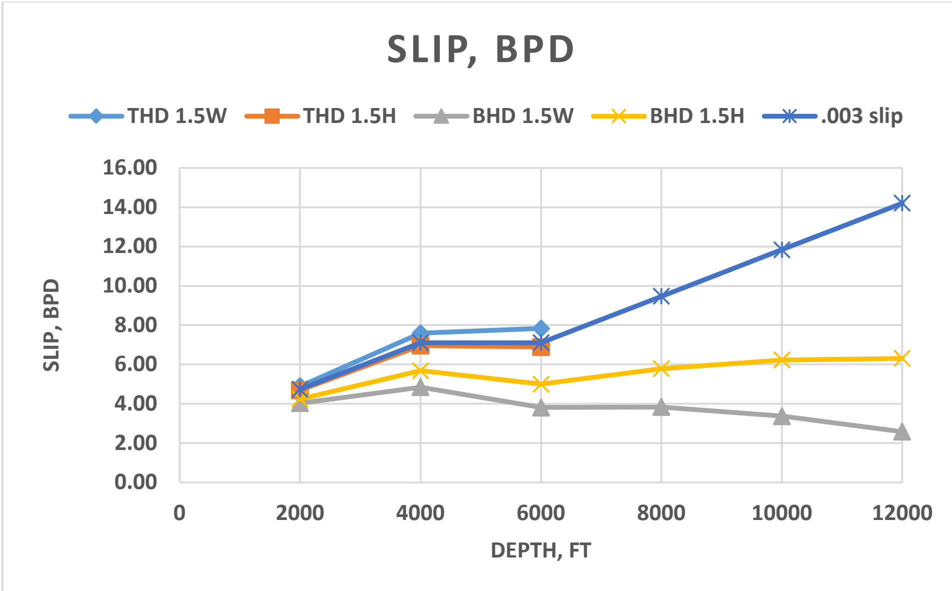

Figure 5. Calculated Slippage: 1.5” Pump: Surface clearance .003”

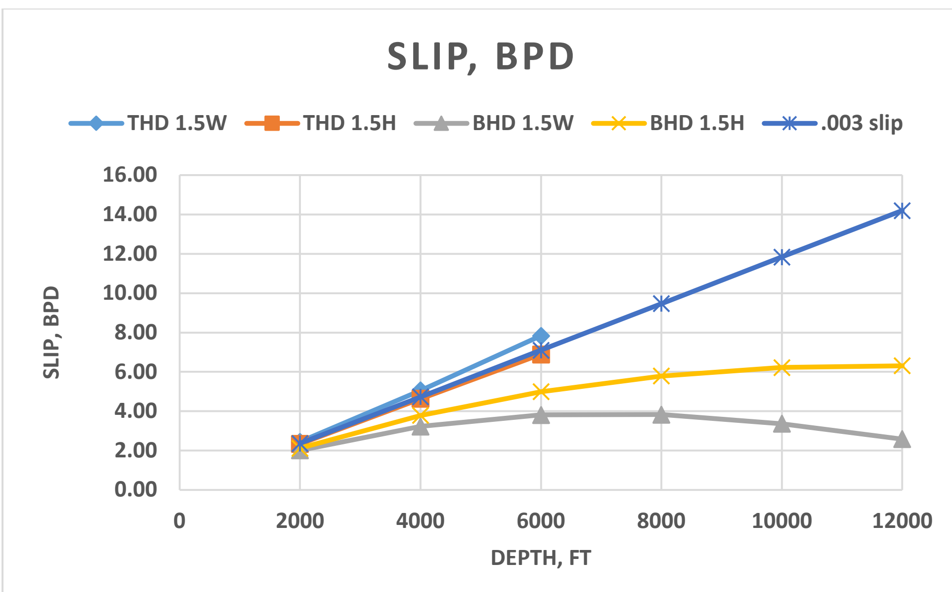

Figure 6. Slip, 1.5” pump, with constant plunger length of 72 inches

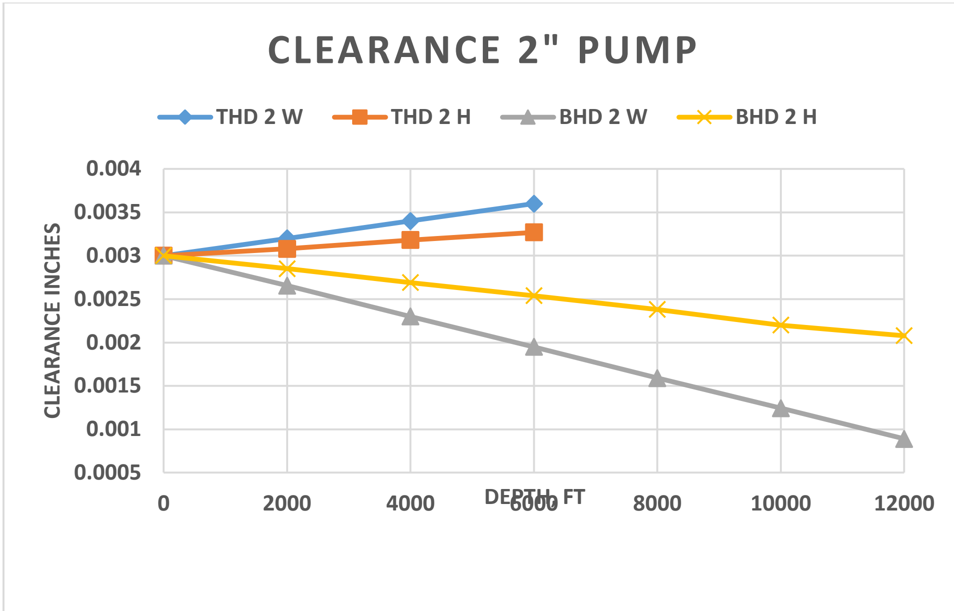

Figure 7. Clearances for 2” pump: Shop clearance .003”

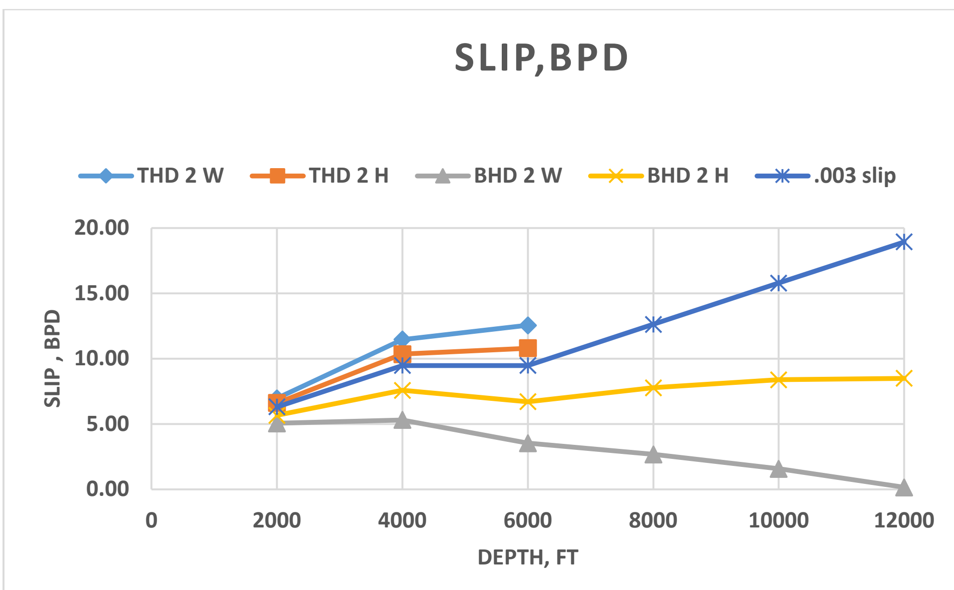

Figure 8. Calculated Slip: 2” Pump: Shop Clearance .003”

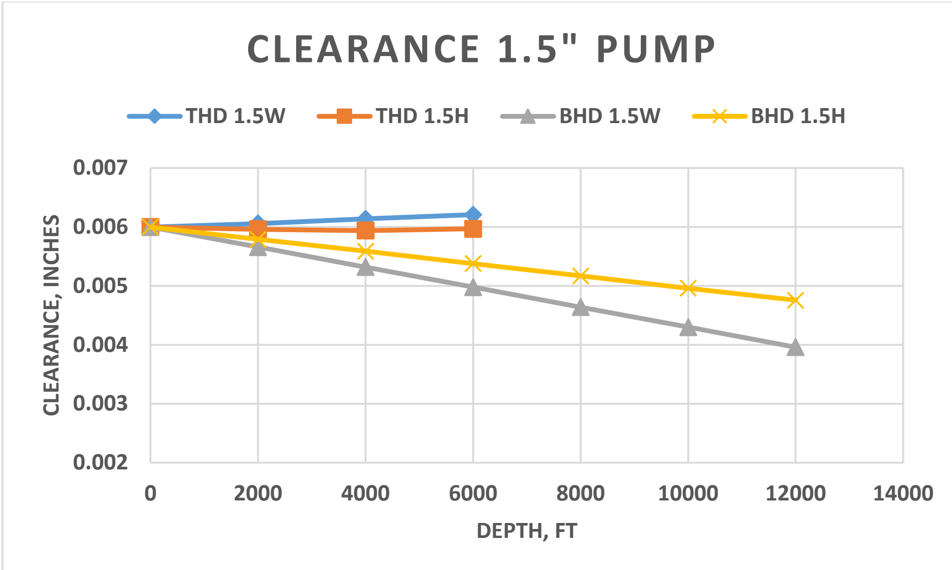

Figure 9. Clearances for 1.5” Pump: .006” Shop Clearance

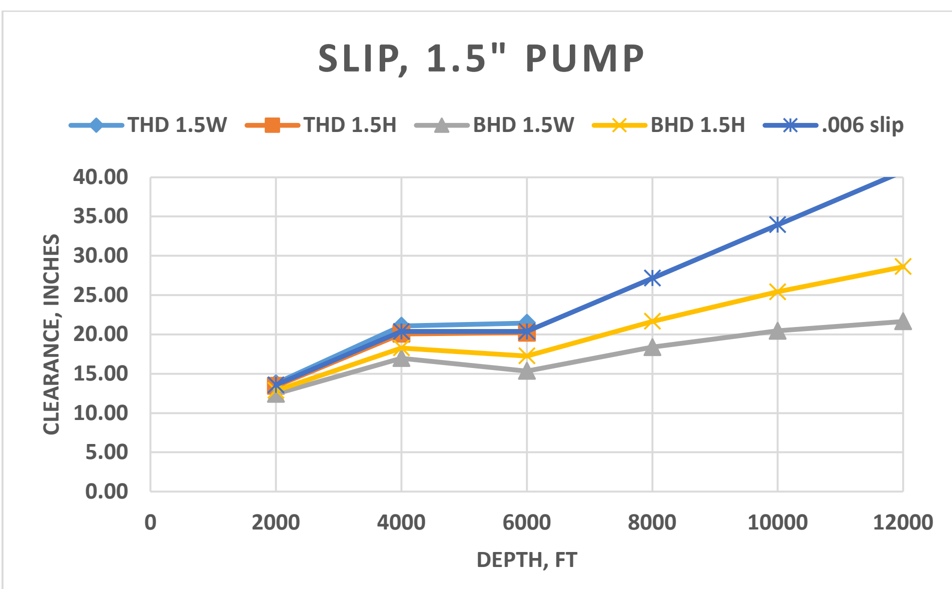

Figure 10. Calculated Slip 1.5” pump. Shop Clearance .006”

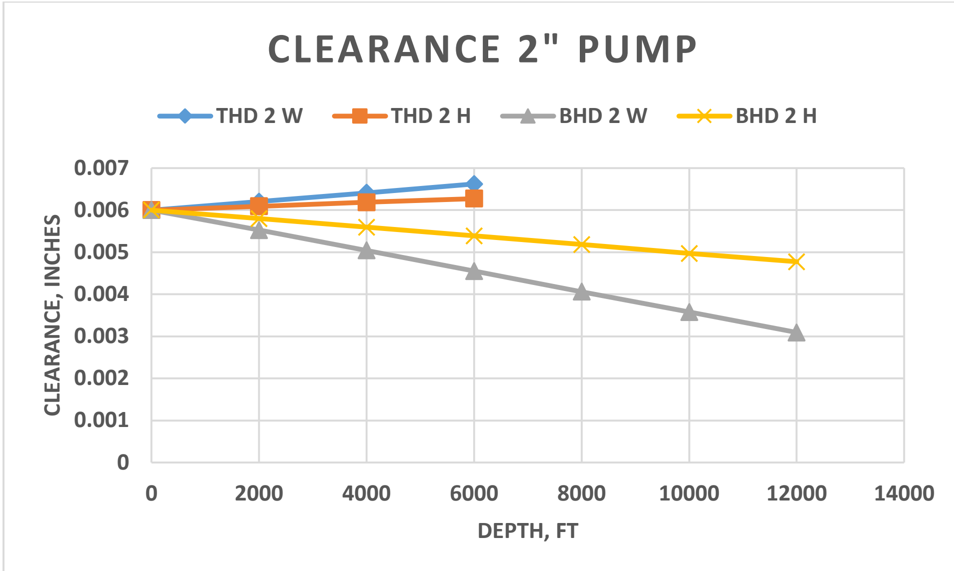

Figure 11. Clearances 2” Pump: Shop Clearance .006”

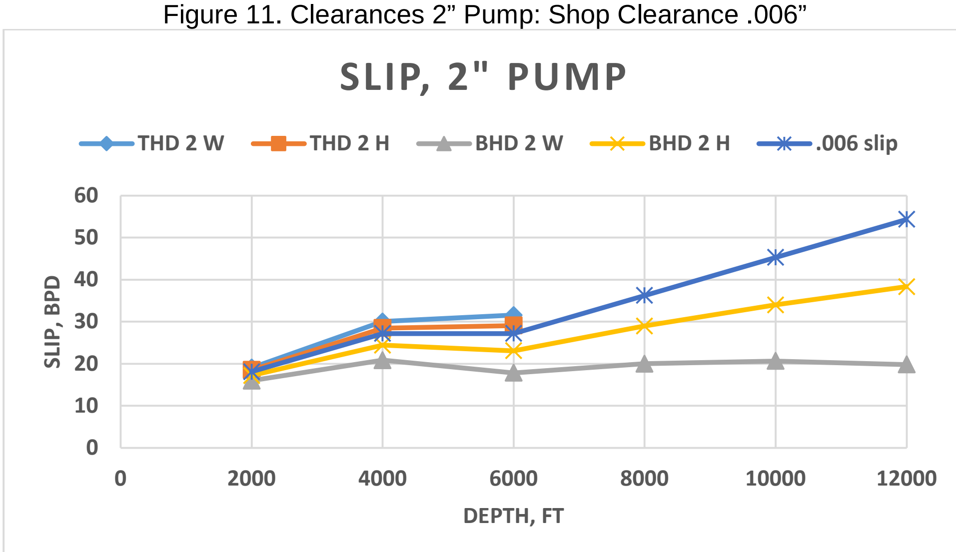

Figure 12: Calculated Slip: 2” pump: Shop Clearance .006”

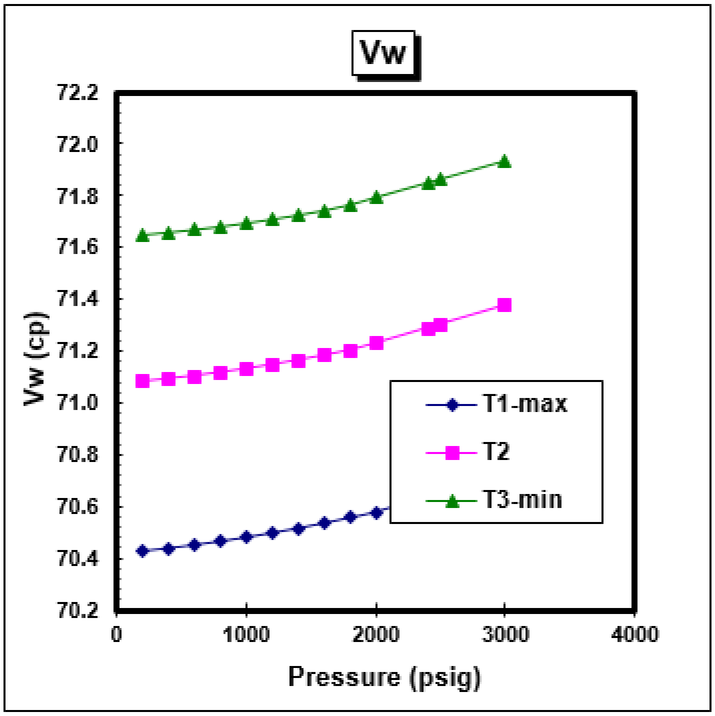

Figure 13: Water Properties (T1,T2,T3, 140,105,70F)