Development of Rod Guides for Progressing Cavity (PC) Pumps

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Introduction

Even though progressing cavity (PC) pumps have been used by the industrial world for many years on liquids containing abrasive fluids, PC systems are a relatively new means of artificial lift in the oil field. One of the more obvious differences between the newer PC and the traditional beam pump is that the rod string rotates rather than reciprocates.

PC pumps are now being used on increasingly deeper wells and on a wider variety of production fluids following their introduction in shallow wells to produce heavy, sand-laden oil. As a result, PC pumps are earning a place in the market and oil field equipment manufacturers are beginning to develop products for PC systems. One example is rod guides which, until recently, have been designed solely for reciprocating rod strings in beam pumped wells.

Lower initial investment, less power per unit of production, more tolerance for sand-laden fluids, and greater production capacities are some of the advantages touted by PC systems. However, maintenance can be more expensive. One reason, which is the driving force behind this study, is that tubing wear opposite rod couplings is more concentrated because the rod string rotates in a stationary position.

If well bores were truly vertical and crude oil was free of abrasives and water, rod and tubing wear in either beam or PC pumping systems would be of little consequence. However, in the real world, rods and tubing never hang perfectly concentric and few wells, if any, produce crude oil with undiluted lubricity. Consequently, in both reciprocating and rotating systems, rod and tubing wear accelerates as production rates, hole deviations, water/oil ratios, and sand concentrations increase. As these variables increase, the need for rod guides also increases.

When PC's were first installed, operators had no choice but to rely on guides which had been developed for reciprocating pumps to centralize rod strings inside the tubing. Two examples are Huber's New Era Turbulence Breaker (NETB) and Patco's Double Plus (DP) shown in Figures 1 and 2, respectively. Both are the end result of years of research and development. Each guide has fins with an O.D. close to the I.D. of the tubing. The fins have been designed to achieve maximum standoff between the rod couplings and tubing with minimum pressure drop.

A third example is the cylindrical unfinned poly guide shown in Figure 3. The poly guide has a smaller O.D. than either the NETB or DP, otherwise pressure drop increases beyond acceptable limits. Because the O.D. is smaller, standoff between the rod couplings and tubing is less. Consequently, the unfinned design is at a disadvantage because it has less erodible wear volume (EWV), as defined in Figure 5, to prevent metal-to-metal contact between the rod couplings and the tubing.

In all three examples, the guides are bonded to the sucker rod. In fact, the quality of guides for reciprocating rod strings is frequently judged on the basis of bonding power--the more, the better. However, evidence in this study suggests the past practice of bonding guides to the sucker rod is not best for rotating rod strings.

Even though the NETB and DP have proven to be effective in reducing rod and tubing wear in both PC and beam pumping applications, an extensive research effort, which is still in progress, is beginning to show that characteristics of guides for rotating rod strings should resemble those of Huber's spin-through design shown in Figure 4. The most striking difference has been the elimination of the bond between the guide and the rod. As a result, the fins remain stationary and the rod, which has a permanent sleeve molded to it, spins inside the guide.

Allowing the fins to remain stationary has preserved the best possible EWV and pressure drop features while reducing unwanted hydraulic resistance and turbulence generated when guides are rotated. A more obvious benefit is that tubing wear is eliminated because the guide no longer rotates against the tubing. This would be particularly true in situations where production fluids contain abrasive solids.

Rationale behind the spin-through design is the basis of this presentation. The project has not been completed. However, work has progressed to the point that the merits of the spin-through concept have been identified and measured.

Research

It was concluded that the power required to operate a PC system has to overcome three primary sources of resistance to rotate the rod string. If power can be reduced at constant production volume, then production efficiency increases.

1. **MECHANICAL(COULOMB) FRICTION** - When two surfaces are rubbed together as illustrated in Figure 6, the resistance to movement increases as the force pressing the surfaces together increases. Theoretically, the force of resistance is independent of the areas of interference and a function of only the normal force and coefficient of friction. Because the frictional resistance is closer to the center of the sucker rod, the spin-through design has less resisting torque than a guide fixed to the sucker rod as shown in Figure 7. Less torque translates to less power required to operate the pump. Measurements for mechanical friction have not been taken but calculations in Figure 7 indicate torque will decrease by a factor of 2.5 to1 if a 1" rod spins through a 21/2" guide rather than the guide turning against the tubing. This improvement alone would justify the spin-through design.

2. **HYDRAULIC FRICTION** - Hydraulic friction occurs as a guide rotates in a fluid--much like the paddle wheel on a riverboat. This results in lost energy. The energy losses are less if the guide remains stationary and the rod rotates inside the guide. This concept is illustrated in Figures 8 and 9. The magnitude of hydraulic resistance is more difficult to calculate, so one important aspect of this study was to measure the amount of hydraulic resistance associated with various rod guides. These measurements are illustrated in Figures 12 through 20.
3. **PRESSURE DROP** - A PC pump must receive enough power through the rod string to overcome the hydrostatic pressure of the fluid column plus the pressure drop resulting from fluid flowing through the tubing and around the rod string. Power decreases if the pressure drop generated by the fluid flowing through this annulus decreases. Therefore, guides which generate the least amount of pressure drop will reduce power and improve production efficiency.

The test apparatus used in the project is shown in Figure 10. The assembly is horizontal to negate the effect of hydrostatic head on the pressure drop readings. Pressure drops were measured in inches of water. Tap water was used as the flowing medium in all tests. A 1" diameter hollow, aluminum rod was used as the rotating member.

Acrylic tubing with an I.D. equal to 6.5 lb/ft, 2 1/2" tubing was used in order to photograph turbulence associated with the various rotating elements. No work has been done with 2" or 3" tubing at this point in the project. Small amounts of compressed air were introduced into the flowing water in order to make the streamlines visible for photographs. Air bubbles were not introduced when measurements were taken but experience showed that the small amounts used had negligible effects on the data.

Flow rates ranging from 0 to 2400 BPD were studied with rotational speeds of the rod varying from 0 to 900 RPM. Power required to rotate the rod was calculated from the electrical current and voltage to the variable speed motor.

Tests included pressure drops on bare rotating rods as well as rod guides and rod couplings, including the wrenching flats and upsets. To date, almost all the rod guide designs on the market have been tested. For the sake of brevity, not all the tests have been reported in this paper. Results of other tests are available by contacting Huber.

The first power consumption tests, which are shown in Figures 12 through 20, had no sideloads. Therefore, the normal force causing mechanical friction was zero except for the deflection of the 1" hollow, aluminum rod which was neglected. As a result, the tests measured only hydraulic resistance.

Subsequent runs will involve inducing incremental sideloads. The difference between secondary tests and the initial tests will be the torque resistance generated by mechanical friction. Based on the calculations in Figure 7, the differences between the spin-through and other guides are expected to increase dramatically as sideloads are induced.

Conclusions are based on differences between the various rods, rod guides, and rod couplings rather than absolute values. Therefore, there is no reason to believe if one design outperformed another on the test stand that the same improvement would not occur in an actual installation.

Conclusions

Pressure drop was much less of a factor than anticipated. With the exception of the poly guide, pressure drop was not significant below 2000 BPD on any of the guides. Rotational speed had negligible effects on pressure drop. Therefore, the values shown in Figure 11 are the same for any speed up to 900 RPM.

One inch rods with slim hole couplings generated more pressure drop than any of the rod guides. Measurable values began to appear at 350 BPD and increased exponentially above 1000 BPD.

As expected, the poly guide had about the same pressure drop as a 1" rod with a slim hole coupling. The pressure drop for a rotating 1" bare rod was so low that it could not be measured. As a result, it is not shown in Figure 11.

The erratic nature of the data on all hydraulic tests at 100 RPM (Figure 12) is believed to be the result of the experimental accuracy of the test equipment. In reality, the hydraulic resistance below 100 RPM is probably not a significant design criteria for any of these rod guides. However, as rotational speeds increase, hydraulic resistance increases and becomes increasingly important in design considerations.

Hydraulic resistance of a bare 1" rod was essentially constant at slightly above 185 watts at 100 RPM as shown in Figure 13. Between 100 and 400 RPM, as shown in Figures 12 through 15, the power required to rotate the bare rod increased significantly. This increase is attributable to the whipping action that resulted from its longer, unsupported length. Had the apparatus been vertical and the rod in tension, this dramatic increase would probably not have occurred. More than likely, the bare rod would be less than the spin-through guide which proved to have the least amount of hydraulic resistance of any guide tested. No values for the bare rod were recorded above 400 RPM (Figure 15).

As expected, the hydraulic resistance increased with rotational speed and flow rate. The spin-through guide proved to have less resistance than all other designs. This advantage progressively improved as flow rate and rotational speed increased (Figures 13-20).

Summary

1. Rod Guides should be used to reduce rod and tubing wear.
2. Guides should not be bonded to the rod in rotating rod strings.
3. 1" rods and poly guides began to generate significant pressure drops at production rates over 350 BPD.
4. Pressure drop is negligible for the NETB, DP, and spin-through guides below 2000 BPD.

5. Hydraulic resistance is significantly less for the spin-through guides.
6. Spin-through guides will significantly reduce torque generated by mechanical friction.
7. Spin-through guides will improve PC pump efficiency.

EXAMPLES OF RECIPROCATING AND ROTATING ROD GUIDES

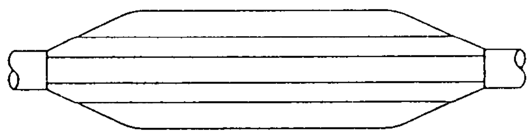


Figure 1 - Huber - NETB

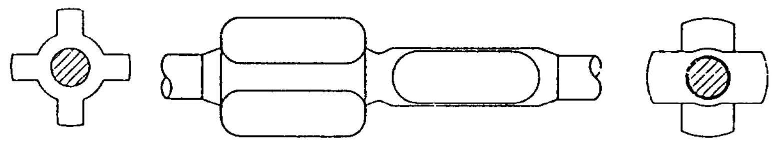


Figure 2 - Patco - double plus

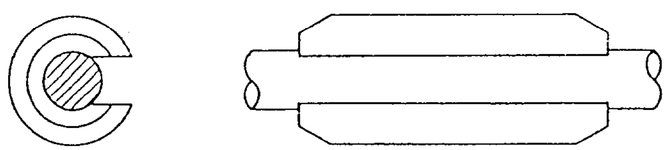


Figure 3 - Poly guide

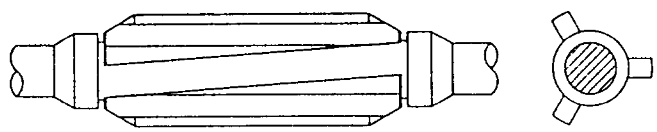


Figure 4 - Huber - spin-through

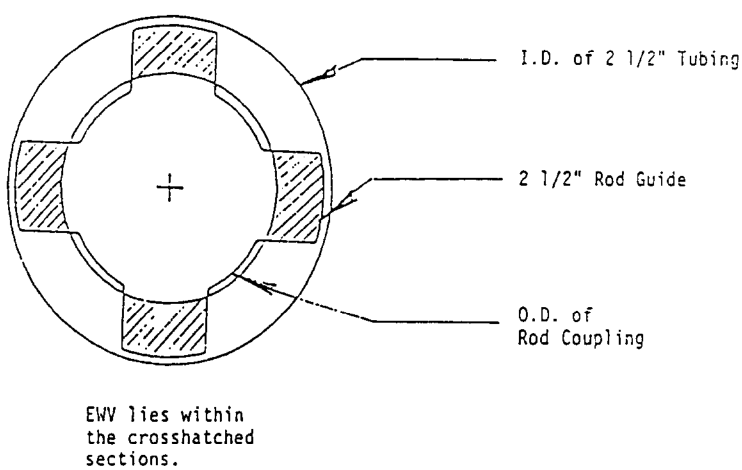
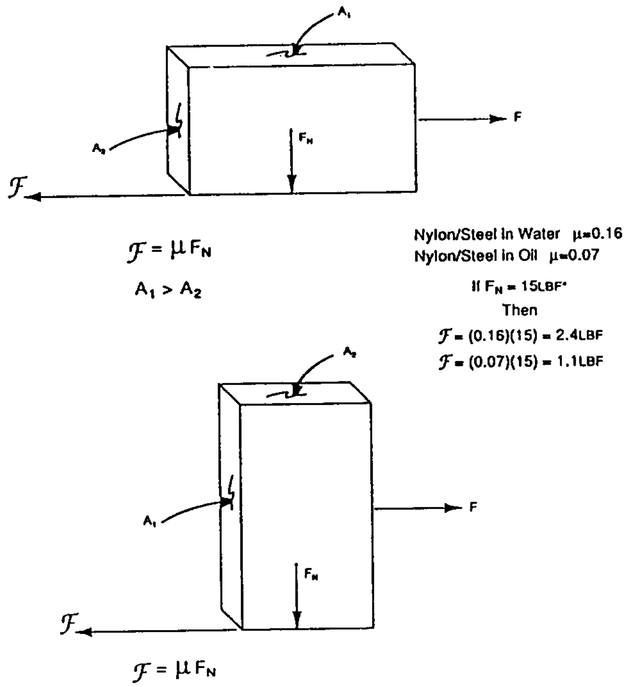
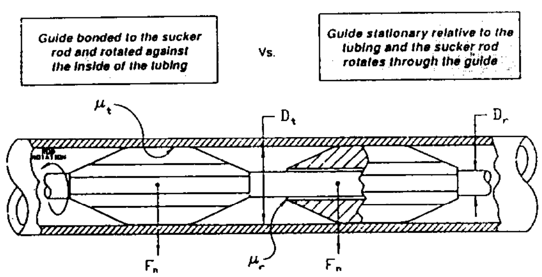


Figure 5 - Erodible wear volume



* 15LBF is a value that was arbitrarily selected but that could be typical in wells with relatively straight and vertical holes. F_N values can easily exceed 200LBF in deviated wells

Figure 6 - Forces from mechanical friction are independent of the contact area between the rubbing surfaces



Given:

- D_t = Tubing I.D.
- D_r = Diameter Sucker Rod
- F_n = Normal force acting to deflect the sucker rod toward the I.D. of the tubing
- μ_r = Coefficient of dynamic friction between the guide and the sucker rod
- μ_t = Coefficient of dynamic friction between the guide and the I.D. of the tubing
- $\mathcal{F}_t$ = $(F_n)(\mu_t)$ Frictional resistance between the guide and tubing
- $\mathcal{F}_r$ = $(F_n)(\mu_r)$ Frictional resistance between the guide and sucker rod

Required:

What is the torque required to turn the sucker rod when the guide is locked on the sucker rod and is rotating relative to the tubing as compared to the torque generated when the guide is stationary and the sucker rod rotates through the guide?

Solution:

$T_t = (F_n)(\mu_t)(D_t/2)$ Resisting torque when guide rotates

$T_r = (F_n)(\mu_r)(D_r/2)$ Resisting torque when guide is stationary

IF

$\mu_r = \mu_t$

THEN

$T_t/T_r = D_t/D_r$

For 1" rods inside 2 1/2" tubing:

$T_t/T_r = D_t/D_r = 2.5$

Figure 7 - Resisting torque ratio resulting from mechanical (coulomb) friction

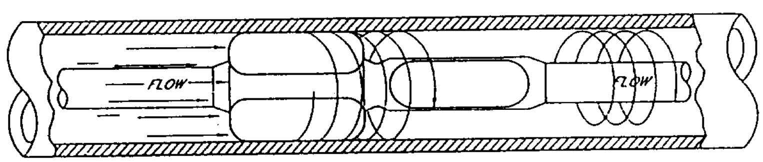


Figure 8 - Hydraulic resistance for finned guide

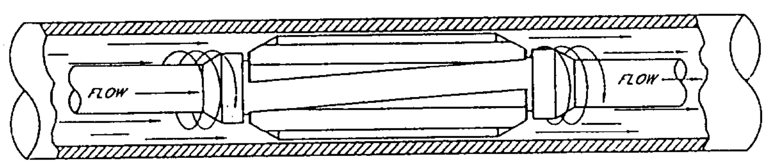


Figure 9 - Hydraulic resistance for spin-through guide

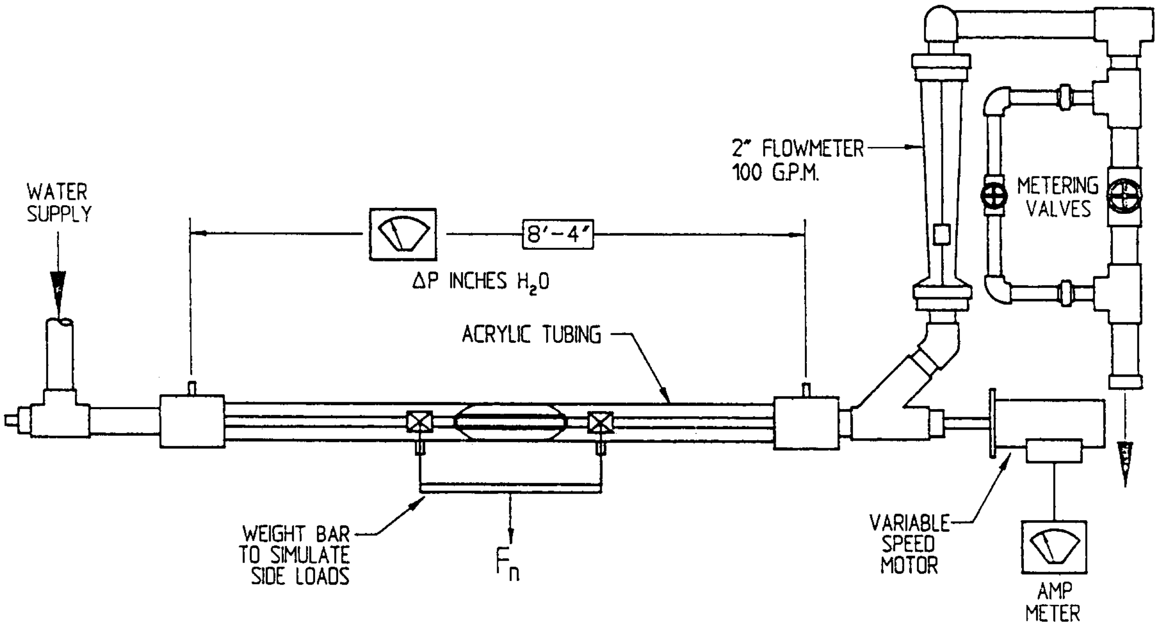


Figure 10 - Test apparatus for the development of rotating rod guides

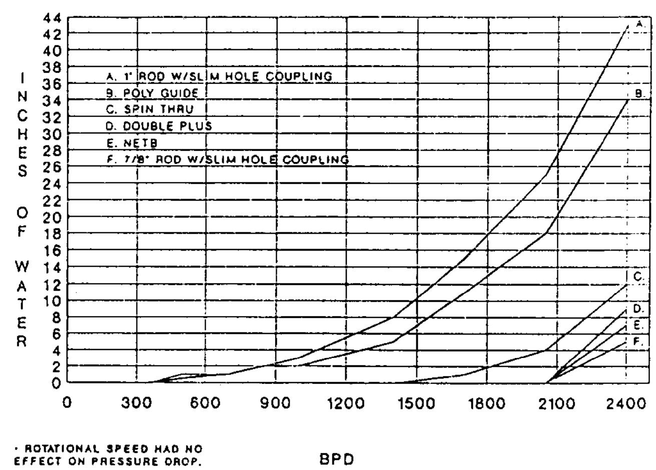


Figure 11 - Pressure drip in inches of water for rod couplings and guides at rotational speeds* between 0 and 900 RPM in 2-1/2 in. tubing using fresh water as the flowing medium

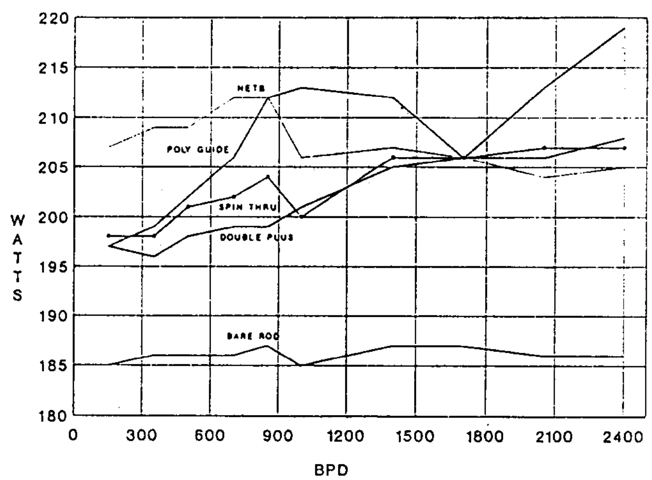


Figure 12 - Power (watts) required to turn a 1 in. rod @ 100 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.

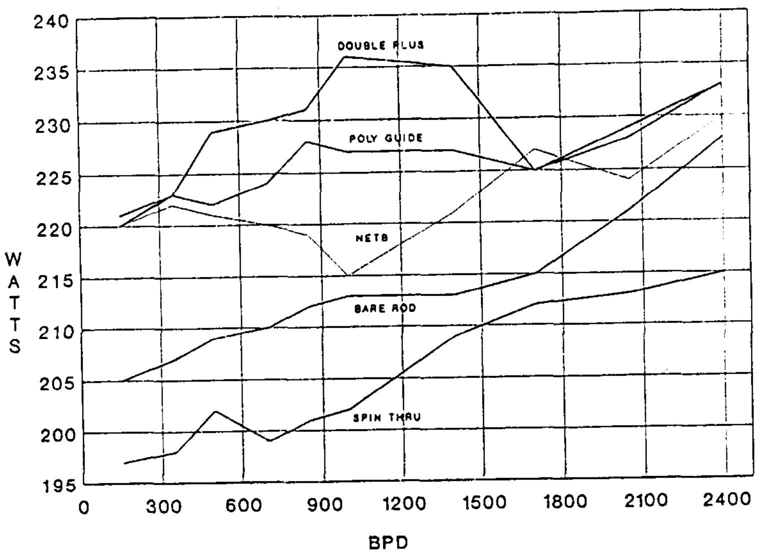


Figure 13 - Power (watts) required to turn a 1 in. rod @ 200 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.

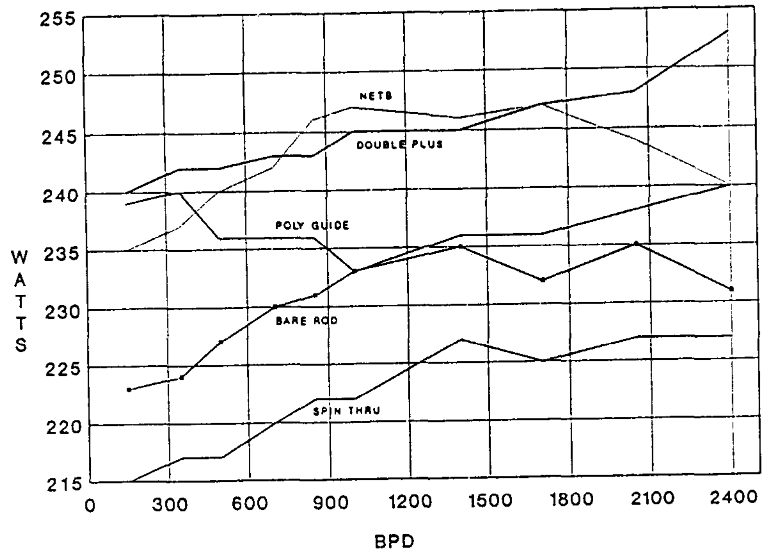


Figure 14 - Power (watts) required to turn a 1 in. rod @ 300 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads

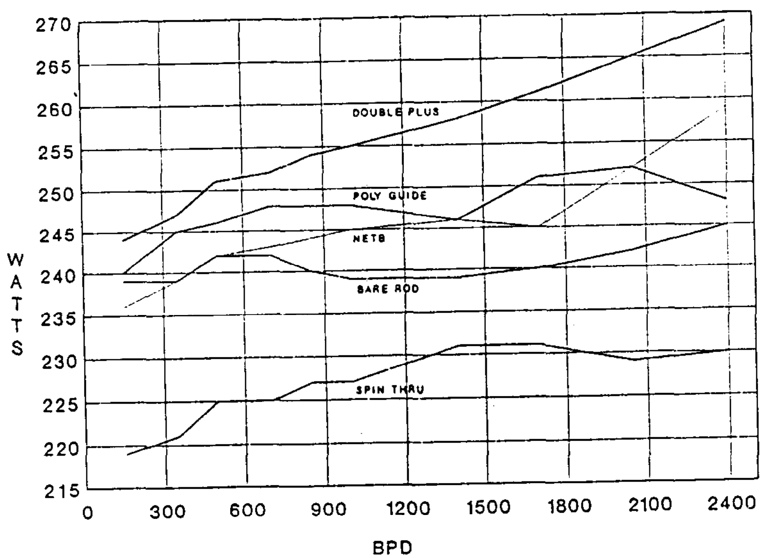


Figure 15 - Power (watts) required to turn a 1 in. rod @ 400 RPM in 2-1/2 in.tubing with fresh water as the flowing medium with no induced wide loads.

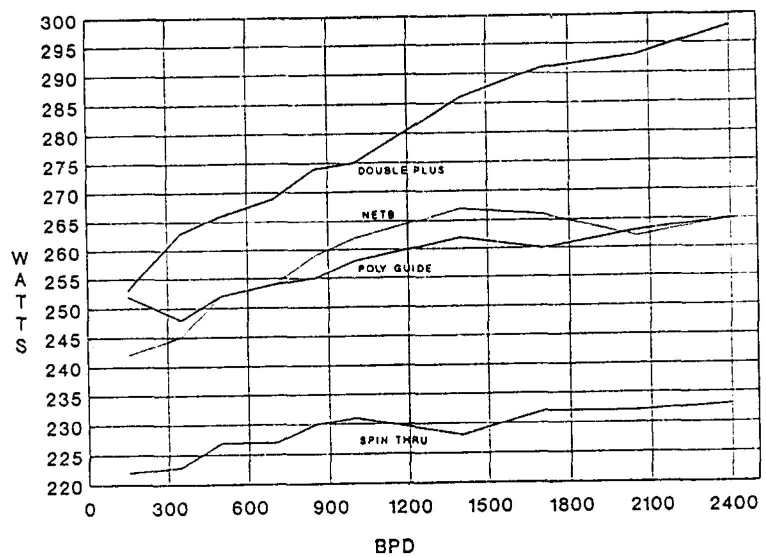


Figure 16 - Power (watts) required to turn a 1 in. rod @ 500 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.

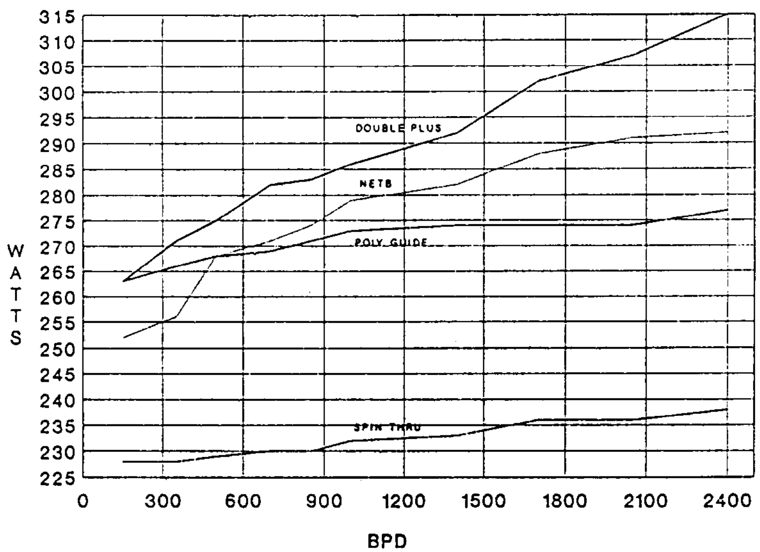


Figure 17 - Power (watts) required to turn a 1 in. rod @ 600 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.

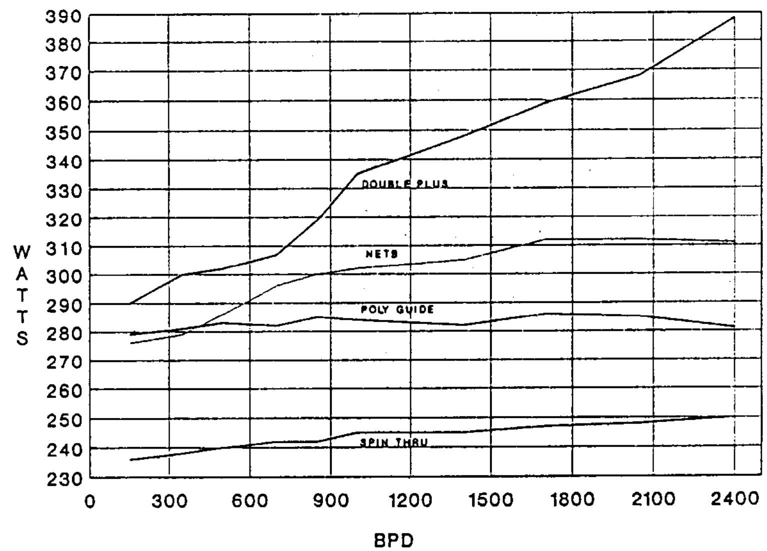


Figure 18 - Power (watts) required to turn a 1 in. rod @ 700 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.

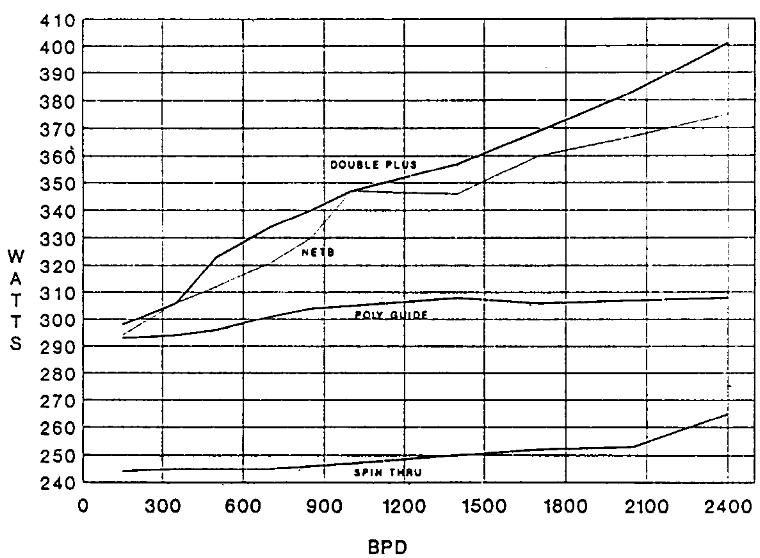


Figure 19 - Power (watts) required to turn a 1 in. rod @ 800 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.

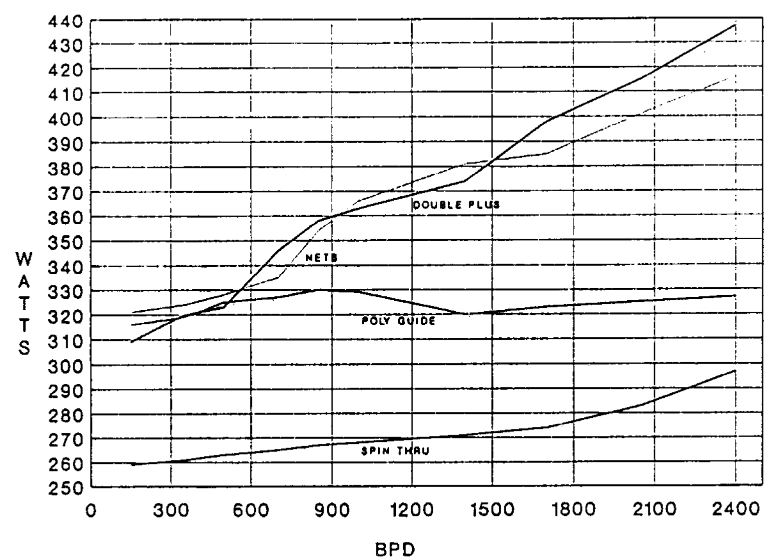


Figure 20 - Power (watts) required to turn a 1 in. rod @ 900 RPM in 2-1/2 in. tubing with fresh water as the flowing medium with no induced side loads.