ULTRA LONG STROKE PUMPING SYSTEM REDUCES MECHANICAL FAILURES, LOWERS LIFTING COST, WHILE INCREASING PRODUCTION

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ABSTRACT

Artificial lift technology advancements typically are derived through either evolution or revolutionary means. When an irrefutable lift system benefit is chosen to be enhanced, it may require a revolutionary design concept to obtain the desired feature. This is the scenario that lead to the development of the Rotaflex, an ultra long stroke pumping system we will refer to as the ULSPS.

It is widely accepted that a long, slow stroke, big bore pump is the preferred pumping parameter of many experienced artificial lift technicians. The following will examine the benefits derived from the use of a ULSPS and address the concerns stemming from the utilization of such a product. The discussion will focus on operating cost and the impact on lease operating expenses (LOE). With the exception of labor cost, electrical expenses and maintenance repair costs account for a significant portion of the yearly operating budget. As both are controllable expenses, they offer the greatest potential impact when seeking cost reduction measures.

Case histories that encompass years of gathering data by a major producer within the Permian Basin will be drawn upon for conclusions. Examination of failure frequency, comparative lift cost per barrel and other tangible features will be examined. The data will then be compared to other comparable lift systems within the same field.

Background

Over the course of the last four decades, there were numerous attempts to develop a reliable long stroke pumping system. The Alpha Unit, Lift Master, Oilwell's tower type unit, the Bender Unit, and the Lift Tronic are just a few to reflect back upon. The success of the systems were limited partially or totally by the design parameters not being of mechanical nature. In addition, several attempts to manufacture and market hydraulic rod pump units have been relatively unsuccessful. Beam units were the only reliable source of obtaining long strokes due to the design being 100% mechanical. Specifically, modified geometry and air balance units evolved to include longer 216" and 240" stroke lengths. However, structure and gearbox ratings for Class I and Class III lift systems are a function of stroke length. End results are pumping units requiring gearboxes of 1,280 to 1,824 M IN/LB and massive structural sizes.

In 1985 a totally mechanical long stroke unit was designed and placed in limited production. Ten years later, an augmented design of the original ULSPS is a proven ultra long stroke pumping system. Figures 1 and 2 illustrate one of the three available models. The systems are available with surface stroke lengths of

288" and 306". The stroke length of the units are obtained without the increased gearbox size required by beam units. This is accomplished by transmitting rotary motion from a 228 or 320 M IN/LB gearbox to a 36" chain sprocket, hence an 18" torque arm. The continuous rotational movement of the sprocket drives an enclosed chain which is directly tied to a mechanical reversing mechanism. The reversing mechanism has a totally enclosed built in counterweight box. Articulating pumping motion is created by connecting a shock absorbing load belt between the combination reversing mechanism counterweight box and the polish rod.

Introduction

The well selected for the case study was drilled in 1979 as a development well within the Midland Farms Unit (MFU) north of Odessa, Texas. Due to changing producing requirements, necessity has dictated that the lift system be revised on two different occasions. The well was initially rod pumped with a beam unit before relinquishing to an electrical submersible pump (ESP) to take advantage of higher production potential. Increased volumetric output was required to stay abreast of the responding waterflood resulting in increased lifting cost. Present fluids production and water cut is typical of many producers in a mature waterflood. Increased lease operating expenses (LOE) common with the operation of ESP's occurred as oil production declined therefore making this a marginal well. The lift system was changed again in 1988 to the ULSPS. After optimizing the subsurface pump (SSP), production was maintained at the ESP level, electrical costs were reduced and a failure frequency lower than the field average was attained.

Field Conditions

The MFU located within the center of the Permian Basin produces oil from two intervals. The upper formation is a mature waterflood in the Grayburg formation . Average well depth is approximately 4700 feet. Corrosion is considered moderate to heavy due to high concentrations of H_2S. The unit contains approximately 86 wells on beam lift and another 85 wells produced by ESP's. A ULSPS was installed on MFU # 401 which had 7" casing. Due to the corrosive environment, the producer decided against using bottle necked big bore pump and 2.875" tubing. Thus, a 2.75" tubing pump was run on a special alloy, API 97 tapered sucker rod string. The tubing consisted entirely of 3.50", J-55, 8Rd EUE pipe. The tubing pump has a nickel carbide barrel, modified plunger and oversized balls and seats.

Comparative Analysis

There have been a number of excellent papers presented at the SWPSC on the subject of determining overall system efficiency of particular artificial lift methods. The system efficiency of the subject MFU wells were previously discussed by J. Lea and J.D. Minissale[1] and by Wright and Adair[2]. Subsequently, their data will be drawn upon as a reference where comparable lift and production conditions exist.

J. Lea and others used the following formula for determining overall system efficiency for his subject wells when comparing ESP to beam lift overall system efficiency.

$$\text{OVERALL SYSTEM EFFICIENCY} = \text{HHP} / \text{INPUT HP}$$

To continue the paradigm, analytical data acquired by Nabla from the MFU Well No. 401 will be compared to the previous studies (refer to Table 1). As indicated by the data, the ULSPS (61% efficiency) surpassed the overall system efficiency of the ESP (32% efficiency) by a 48% margin. Even with the beam units analyzed by Lea and Minissale operating significantly above their expected efficiencies, the average 55% efficiency remains 10% less than the ULSPS. The improved system efficiency would translate into a significant savings opportunity. To get a better understanding of exactly how the ULSPS extracts more work out of input energy, we need to analyze the surface and sub-surface components separately.

Nabla performed several electrical/mechanical studies on a large number of wells in the MFU. The subsequent data was used to compare beam units to ESP'S, beam units to ULSPS, beam units with steel sucker rods versus beam units with ribbon rods and others. Two ULSPS wells (MFU #401 and MFU #549) and three beam pumped wells were selected after qualification by production. The mechanical/electrical analysis, an extension of the service provided by Nabla, uses the difference between input horse power (IHP) and polish rod horse power to define the mechanical friction losses within the ULSPS.

$$IHP = PRHP + HP_{(\text{mechanical friction losses})}$$

$$\text{Mechanical Efficiency} = 1 - [(IHP - PRHP) / IHP]$$

These losses stem from friction within the gearbox, bearings, chains, belts sheaves and the electric motor. The mechanical efficiency of the surface equipment for the ULSPS on MFU #401 was measured and determined to be 81.2%. This indicates there was a 18.8% loss within the surface equipment components. Table 2 illustrates the mechanical losses for a randomly selected set of Class I and III beam units on the MFU with an average loss 23%.

As evidenced by measured surface dynamometer card on MFU #401, the improved geometry of the ULSPS provides a preferred shaped rectangular surface card when matched with a 168" air balance unit (refer to Figures 4 and 5). Near constant polish rod velocity and reduced unit speed has reduced peak load spikes, hence the prime mover is allowed to operate more efficiently at a continuous output. The actual work performed at the polish rod is the area contained within the surface dynamometer card. By distributing the work more evenly through reduction of peak load spikes, a smaller prime mover can be used.

The subsurface portion of the Nabla analysis depicts the correlation of polish rodhorsepower (PRHP) to hydraulic horsepower (HHP) required to deliver the flow (Q) given a differential pressure (Delta P). The following formulas will be useful for this analysis.

$$HHP = Q \times \text{Delta } P / 58800$$

$$PRHP = HHP + HP_{(\text{sucker rod friction})} + HP_{(\text{fluid friction})}$$

In the preceding equations, $HP_{(\text{sucker rod friction})}$ is lost work resulting from friction between the rods and tubing and $HP_{(\text{fluid friction})}$ is lost work resulting from friction between the rods, tubing and fluids.

Overall system efficiency (motor input to down hole pump) was calculated to be 61.2% for subject well. The efficiency calculation indicates an additional 20% of input HP is lost to friction along the rod string, within the pump and to fluid friction. More work will be lost to friction resulting in decreased system efficiency if the well bore is deviated, rod guides are installed or if the produced fluids are viscous. MFU

#401 is not deviated, rod guides or scrapers are not installed and produced fluids viscosity is approximately 1 centipoise.

Gibbs and Nolen[3] presented data on the relationship of sucker rod friction to miles traveled in one day of pumping. They concluded it is best to use the largest bore pump possible within loading constraints of surface and subsurface equipment. Hence, the SSP design that allows the least amount of travel in the rod string reduces the effects of fluid friction losses and sucker rod drag upon the system. It is worth noting that fluid friction is known to increase proportionally with sucker rod velocity whereas sucker rod drag on the tubing is rather independent of velocity.[3] The reduction in subsurface friction is seen in the comparison between an ULSPS (288" stroke length) to air balance units (168" stroke length) producing similar volumes (refer to Table 2). The ULSPS with a big bore pump delivers more production while traveling 26 miles less per day than beam units for comparable producing rates (MFU beam lift wells #119 and #66). The 33% less distance traveled contributes to a 14% reduction in HP wasted to friction translating into approximately $431 per year savings per well. It is also worth noting maximum gear box torque is 64% less with the ULSPS. The air balance unit required 536M IN/LBS average torque whereas the ULSPS register only 194M IN/LBS.

Reducing Maintenance Repair Cost

Surface equipment repair, sucker rod and subsurface equipment replacement costs constitute the largest portion of a field's maintenance budget. If corrosion is eliminated as a factor, operating conditions can be altered to reduce the failure frequency. Specifically, a long slow stroke will reduce surface and subsurface equipment fatigue resulting from fewer rod reversals, less metal loss, decreased system loading and gearbox torque. Table 2 and Figures 6 through 9 illustrate the relationship between stroke length and unit speed with rod reversals, rod loading and gearbox torque.

The API Modified Goodman Stress Diagram is a useful design tool in predicting the number of reversals a sucker rod string can sustain before experiencing a fatigue failure. The fatigue endurance limits of steel can be defined as that maximum stress level at which it will operate without failure in complete reversals of loading from tension to compression for a minimum of ten million cycles.[5] As previously discussed, increasing the stroke length permits the unit speed to be reduced if all other design parameters are held constant. From this rudimentary exercise, given constant rod loading we can safely predict the sucker rod string will last longer if reversals are reduced. Table 2 shows a 62% reduction in cycles with the use of a ULSPS compared to the 168" air balance units operating at 10.4 SPM.

It is not as well documented, but one could theorize that the same cyclic forces act upon the tubing especially in systems where the tubing is not anchored. Any reduction in cyclic loading would contribute to decreased fatigue failures. More note worthy, is the reduction in holes in the tubing that can be contributed to the longer surface stroke length. Wear is a function of load over a given area during a given time period. In evaluating the virtues of a long, slow, big bore pump, the load will undoubtedly be increased from the increased fluid load. However, the contact area between the rods and tubing will increase approximately 43%, and the time the area is exposed to wearing surfaces is reduced by over 60%. The case study well has not experienced any holes in the tubing.

Costs associated with pump failures add up very rapidly when everything is taken into consideration (i.e. rig cost, pump repair, tubing anchor repair, safety equipment, etc..). This does not even include lost production. Metallurgy technology has significantly improved subsurface pump life; however, the pump operates in one of the most hostile environments imaginable. Corrosive fluids and gases combined with the abrasives produced within the MFU require all pump connections be manufactured of 316 stainless or monel alloy steels with nickel carbide barrels. The balls and seats are manufactured from silicon nitrate. Our case study well, MFU # 401, obtained a continuous run of 1,087 days. It was only eight days away from completing a three year run without any type of failure. Equally remarkable, the failure was due to a loose connection within the standing valve assembly. The pump was reported to be in good condition; therefore, it was repaired and placed back in service. In order to comprehend the significance of the run, the average failure frequency in the Midland Farms Field is 1.74 failures per year for wells producing 500 BFPD or more. As each well is different, we can only hypothesize that the long slow stroke contributed to the above average run time. The assessment is drawn from the fact the balls within the pump impact the seats 62% less frequently due to fewer reversals. With a 272" net pump stroke length at 4.25 SPM , we can also surmise wear is reduced proportionately over the closest comparable air balance unit with 162" of net pump stroke length operating at 10.49 SPM.

Conclusions

In conclusion, large bore pumps combined with a slow, ultra long stroke pumping system will undoubtedly deliver a lower energy cost per barrel than ESP's or comparative size beam units. Test data indicates the primary factor affecting the wasted energy in any artificial lift system is the efficiency of the subsurface pump; however, system designs using a long and slow stroke offer significant savings when compared to the operation of ESP's and beam units. Other tangible benefits that enhance the systems performance contribute to lowering maintenance and operating expenses as well. These benefits can significantly contribute to extending the life of aging fields where higher volumes and lower oil cuts are produced.

Opportunities For Optimization of ULSPS

Prior discussions regarding prime mover specifications for ULSPS's suggest using the "oil field pumper" (a 1200 RPM Nema D rating). However, due to the reduction of high load peaks the use of a high torque motor such as the Nema D may not be required. Future ULSPS installation will recognize the benefits of using a Nema B or C motor due to greater mechanical efficiencies. Independent studies suggest there may be as much as 5% gain in mechanical efficiency.

It is acknowledged the 3.5" tubing in the MFU # 401 contribute to the overall system efficiency. Due to constraints in placing 3.5" tubing in 5.5"casing, not to mention the added cost of purchasing the larger tubing, it is not practical to use 3.5" tubing in all applications. The reduction in fluid friction gained by using 3.5"tubing could be achieved by eliminating sucker rod couplings. Two products currently being marketed provide this feature. One is manufactured of carbon fiber, the other of steel. Both products have tremendous potential once the service issues are addressed. If a high strength continuous rod is developed, 1,000 through 1,500 BFPD systems with 2.875" tubing
in similar depths as our case study well will be common.

Acknowledgement

The authors would like to thank Amoco Production Company and Highland Artificial Lift Systems for their cooperation in making this paper possible. Special recognition is given to Mr. Sam Gibbs, Mr. Ken Nolen of the Nabla Corporation and Mr. Earl Baldridge of Highland Artificial Lift Systems for their assistance.

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Table 1

Well Name	Lift Spec's Type	Lift Spec's Model or Size	Lift Spec's SPM x St	Depth	Delta P	Tubing	Production Oil	Production Water	Input KW-Hr	HHP	Input KW-Hr Per BBL Per Net Lift	Mechanical Efficiency	Pump Efficiency	Overall System Efficiency
Lea Study[1]														
MFU #557	ESP	DN-1000		4750	1998	2 875	33	800	62 97	28 3	0 00003784		53 0%	34 0%
MFU #168	ESP	DN-800		4650	1881	2 375	110	575	49 58	21 9	0 00003847		57 0%	33 0%
MFU #168	ESP	DN-800		4785	2002	2 875	25	500	44 21	17 9	0 00004206		52 0%	30 0%
Case Study[2]														
MFU #119	A640-305-168	2" Steel Rods	10 49 x 168	4760	1516	2 875	7	770	33.4	21 4	0 00002835	76 2%	97 0%	47 9%
MFU #66	A640-335-168	2" Steel Rods	10 42 x 168	4808	1370	2 875	12	753	28.4	18 1	0 00002709	76.3%	98 0%	47 5%
MFU #687	A640-305-168	2" FG Rods	9.47 x 168	4825	1917	2.875	30	623	35.3	20 3	0.00002819	75.4%	N/A	45 0%
MFU #401	RF320-360-288	2.75" Steel Rods	4 25 x 291	4827	1722	3 5	43	770	37 4	30 7	0 00002671	81 2%	80 0%	61 2%
MFU #549	RF320-360-288	2 75" Steel Rods	3 87 x 291	4650	1908	3 5	28	766	38.94	30 6	0 00002571	78.4%	87 0%	58 6%

Pump Efficiency Calculations Are Based on Net Pump Stroke
[1] Calculations for HHP Do Not Include Crude Shrinkage
[2] Calculations for HHP Include Crude Shrinkage

Table 2

Well Name	Lift Spec's Type	Lift Spec's Model or Size	Lift Spec's SPM x St	GB Torque	PPRL	PR Travel Mile/Day	Reversals #/Day	Production	Pump Eff	HHP	PRHP	HP Loss Rod Friction	% Loss PRHP	KW-Hr Lost Per Yr	Annual Cost Wasted HP @ $.04/KW-Hr
Case Study															
MFU #119	A640-305-168	2" Steel Rods	10 49 x 168	555 M	21633	80 11	30211	777	97%	21 4	34 1	12 7	37.0%	83000	$3,300
MFU #66	A640-335-168	2" Steel Rods	10 42 x 168	517 M	20269	79.57	30009	765	98%	18 1	29 1	11 0	38 0%	154000	$6,200
MFU #687	A640-305-168	2" FG Rods	9 47 x 168	795 M	21957	72 31	27273	653		20 3	35 7	15 4	43 0%	101000	$4,000
MFU #401	RF320-360-288	2 75" Steel Rods	4 25 x 291	196 M	29106	56 22	12240	813	80%	30 7	40 7	10 0	25.0%	65000	$2,600
MFU #549	RF320-360-288	2 75" Steel Rods	3 87 x 291	191 M	29665	51 19	11145	794	87%	30 6	40.9	10 3	25 0%	67310	$2,692

Note: Calculations for HHP do not include crude shrinkage factors

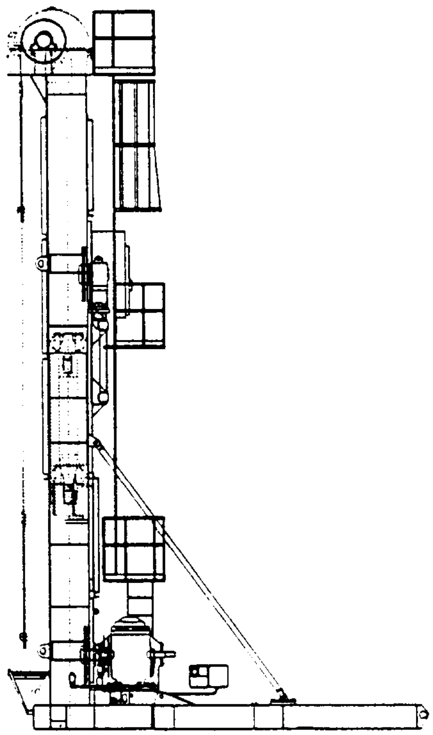

Figure 1

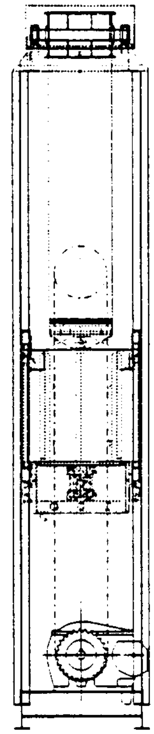

Figure 2

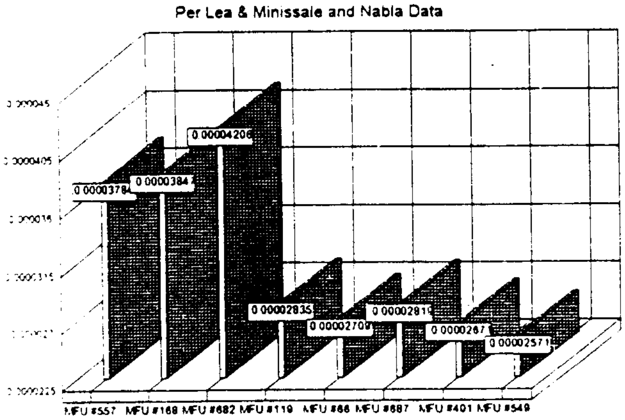

Figure 3 - Input KW-Hr / BBL / Net Lift

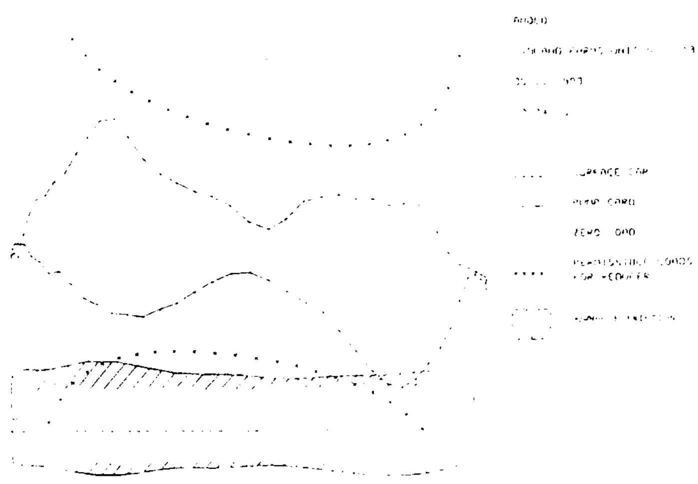

Figure 4 - Class III Beam Unite Dynamometer

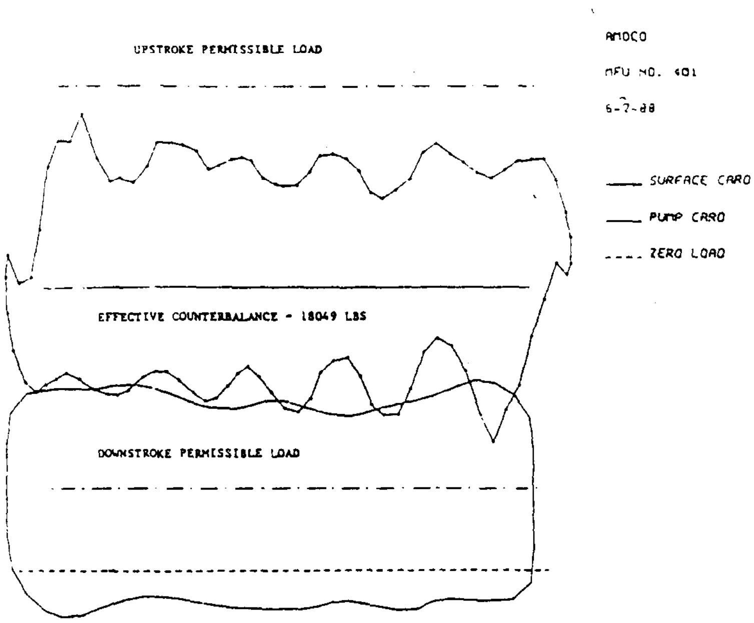

Figure 5 - ULSPS Dynamometer

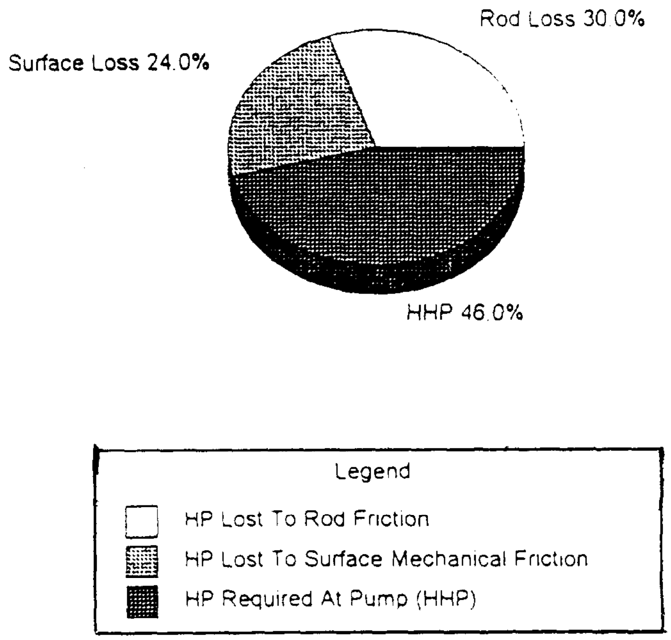

Figure 6 - System Input HP
Average 43.4 HP for Beam Units

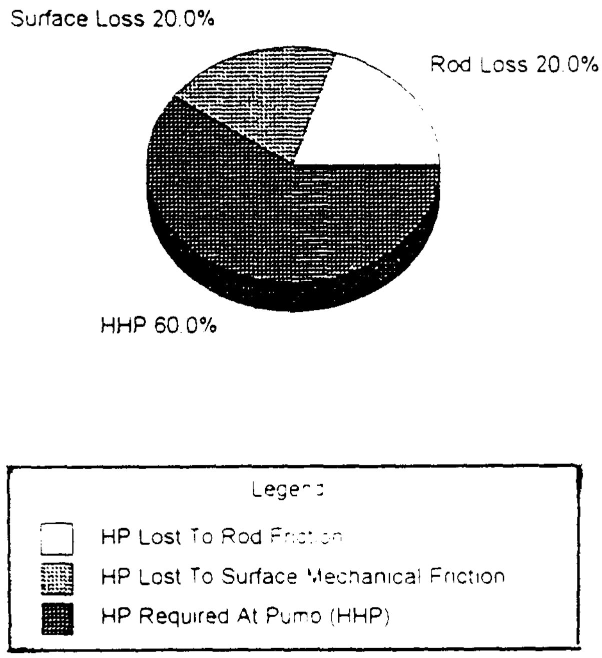

Figure 7 - System Input HP
Average 51.2 HP for ULSPS Units

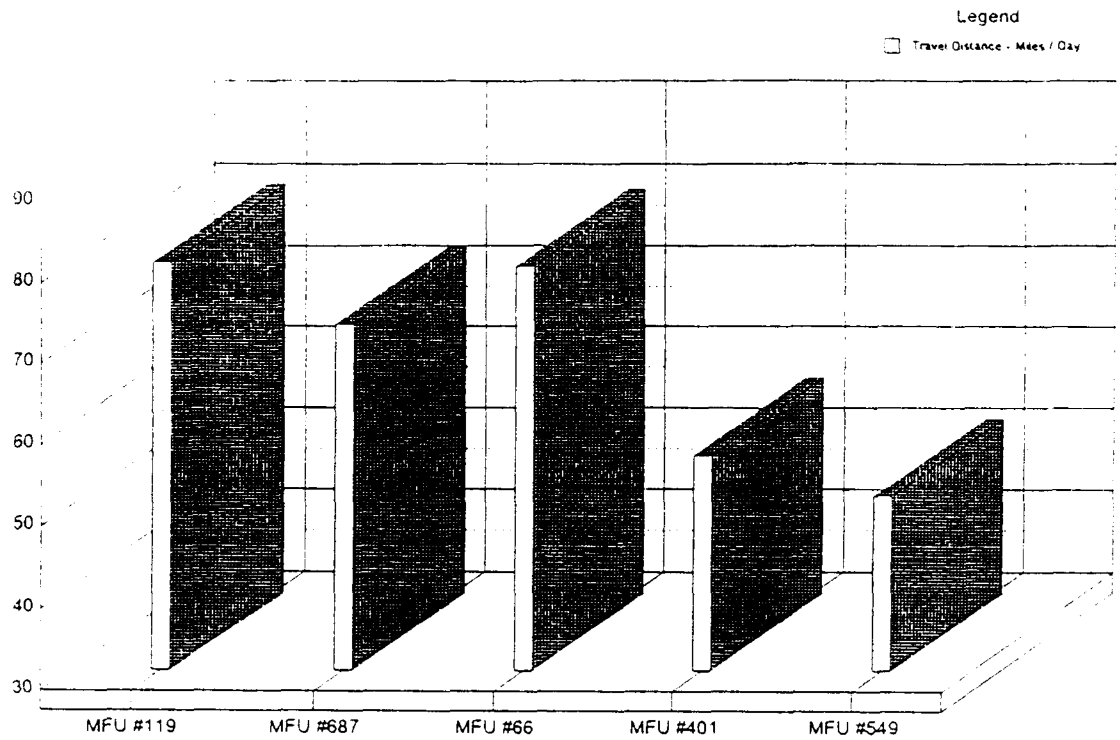

Figure 8 - Polished Rod Travel

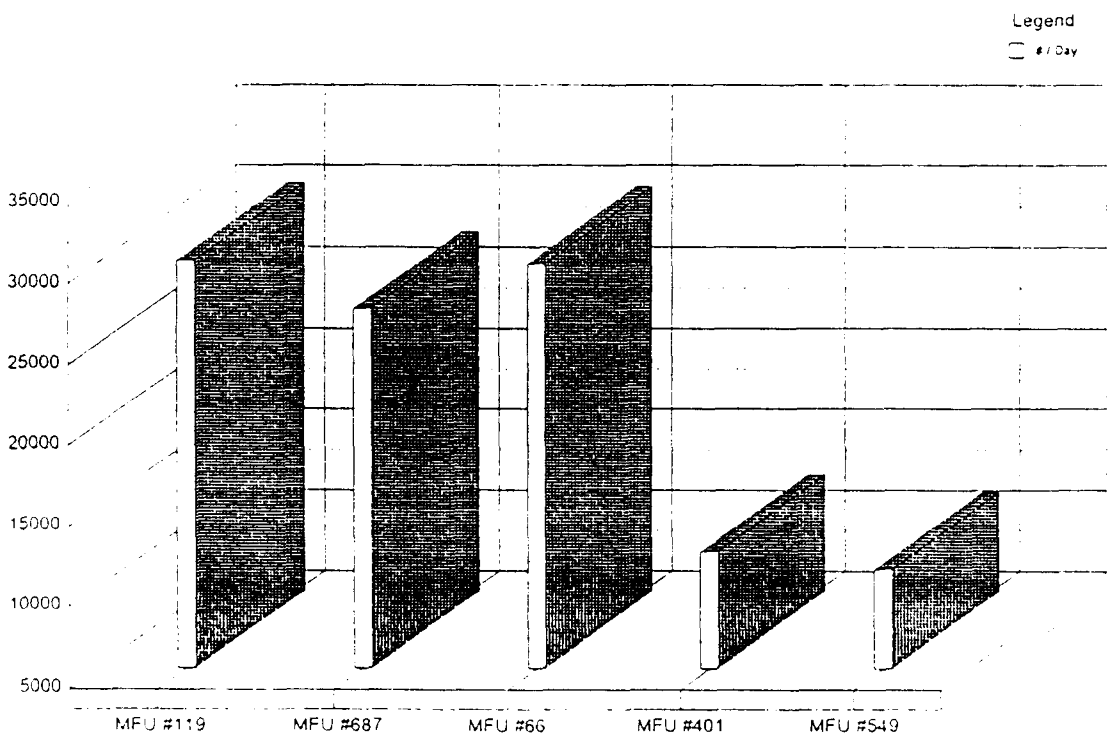

Figure 9 - Rod Reversals