DESIGNING AN ENERGY EFFICIENT SUCKER ROD PUMPING SYSTEM

By R. H. Gault
Consultant

There are a number of important considerations in the design of any sucker rod pumping system. To get the best design for a specific application each of these variables must be evaluated in terms of the particular requirements of that specific system. A system which might be ideal for the operating conditions of one area might be a very poor selection for use in another area with different operating conditions.

The individual parts of a sucker rod pumping system are:

1. The size of the bottom hole pump.
2. The size, strength and taper of the sucker rods.
3. The stroke length, load and torque capacity, and the geometry of the pumping unit.
4. The type and efficiency of the prime mover.
5. THE ENERGY USAGE OF THE SYSTEM.

All of these items are interrelated so that a change in one of them affects each of the others. Good design practice dictates that the specific requirements of each well or lease be evaluated for each of the variables so that the final design will be best one possible for that particular lease.

The best starting point for an examination of these variables is the API RP11L3 manual. There are about 60,000 individual well applications listed in this manual and so it is possible to quickly see the effects that a change in one of the variables will have on the other design criteria. A quick scan of possible systems in the RP11L3 will show how each of design items influence energy usage. For example refer to pages 338 and 339 in the API RP11L which are reproduced as EXHIBITS A and B.

Several systems which would produce at the rate of 500 BPD from 6000 feet are listed. Of all of the systems listed on these two pages only the systems for Rod No.s 75, 76, 85, and 86 will be used. These are the only systems which would be considered by an experienced designer.

An examination of the polished rod horsepower requirements of these systems shows that changes in rod size, pump size, stroke length, and strokes per minute all affect the polished rod horsepower required to do the same work of lifting 500 BPD from 6000 feet. The system which requires the greatest polished rod horsepower is:

Rod No. 86   Pump Dia. 1.25   Stroke 192   SPM 13.7   PRHP 54.6

The system which requires the least polished rod horsepower is:

Rod No. 86   Pump Dia. 2.75   Stroke 120   SPM 7.9   PRHP 22.8

These are startling differences. One system requires almost two and one half times as much horsepower at the polished rod as another. Total energy usage is directly related to the work done at the polished rod plus horsepower losses in the pumping unit and motor. It is plain that any design must include consideration of the energy consequence.

The importance of the energy requirement is in porportion to the cost of energy. When the API RP11L3 was first published, eighteen years ago, electricity was selling for about \$0.006 / kwh (6 mills per kilowatt hour) and gas was selling for about \$0.25 / mcf (twenty five cents per thousand cubic feet) the energy bill was so small that it was not even considered in the design of the system.

Today the average cost of electricity is about seven cents per kilowatt hour (\$0.07 / kwh) and the average lease value of natural gas is about three dollars per thousand cubic feet (\$3.00 / mcf). Now the energy bill is usually the largest operating cost item on the lease and it has become a most important design consideration.

A base for the discussion of energy usage and energy cost should start with hydralic horsepower. This is the <u>theoretical</u> work that is required to lift the pounds of well fluid from the net depth. The formula for calculating hydralic horsepower for a fluid weighing 8.34 pounds per gallon (sp. gr. = 1.0) is:

$$\text{HYD. HP.} = \frac{\text{ft.lb.}}{} \times \frac{(\quad 1 \quad)}{(\ 33{,}000\ )}\ \text{min.}$$

$$\text{HYD. HP.} = \text{NET LIFT} \times \frac{(\text{BPD} \times 42 \times 8.34)}{1440} \times \frac{(\quad 1 \quad)}{(\ 33{,}000\ )}$$

$$\text{HYD. HP.} = 0.00000736 \times \text{BPD} \times \text{NET LIFT}$$

The theoretical hydralic horsepower to lift 500 BPD of fluid with a specific gravity of 1.0 from 6000 feet would be:

0.00000736 X 500 BPD X 6000 FT. = 22.08 hydralic horsepower

Converting this to kilowatts:

22.08 HP X .746 KW/HP = 16.47 KW

The annual power bill with \$0.07 \$/KWH electricity would be:

0.07 \$/KWH X 16.47 KW/HR X 24 HR/DAY X 365 DAYS/YEAR = \$10,100

This is the <u>theoretical</u> cost to do the work of lifting 500 BPD from 6000 feet.

Polished rod horsepower starts with this theoretical work at the pump and includes the other downhole horsepower requirements of the system. The other downhole horsepower requirements of the system consist of the horsepower required to dynamically move the sucker rod string and the frictional losses between the sucker rods and the tubing.

The dynamic horsepower requirements are related to the weight of the sucker rod string and the pumping speed (SPM X Stroke Length). The pumping speed for a given stroke length and producing rate is primarily determined by the size of the bottom hole pump.

In the first example, where maximum polished rod horsepower was required, a small diameter pump was used with a heavy rod string. To get the required amount of fluid (500 BPD) it was necessary to use a long stroke at a fast speed (1 1/4" pump at 13.7 - 192" strokes per minute). This system has very large dynamic horsepower requirements. In the second example, where the minimum polished rod horsepower was required, a large pump was used with a slow pumping speed (2 3/4" pump at 7.9-120" strokes per minute). This system has very small dynamic horsepower requirements. Note that the polished rod horsepower (22.8 HP) of this system is only slightly greater than the theoretical hydralic horsepower (22.08 HP).

The polished rod horsepower requirements listed in the RP11L3 just include the work that must be performed <u>at the polished rod</u>. The total energy requirements of the system must also include the horsepower requirements of the surface system. These additional horsepower requirements are mechanical friction losses in the pumping unit and sheave system. This will be called motor shaft horsepower because it is the horsepower needed at the motor shaft.

The following formulas summarize the discussion so far:

HYDRALIC HORSEPOWER = 0.00000736 X BPD X NET LIFT

POLISHED ROD HP = HYD. HP + DYNAMIC HP + ROD FRICTION HP

MOTOR SHAFT HP = POLISHED ROD HP + UNIT LOSS HP

$$= \frac{\text{POLISHED ROD HORSEPOWER}}{\text{UNIT EFFICIENCY}}$$

The unit efficiency value would include the losses in the belts and sheaves. It has been shown that the efficiency of a pumping unit and sheave system is dependent on its age, geometry and percentage of load. The average values for this efficiency are about 0.70 to 0.90. Using an efficiency of 0.8 the motor shaft horsepower would be:

$$\text{MOTOR SHAFT HP} = \frac{\text{POLISHED ROD HORSEPOWER}}{0.8}$$

MOTOR SHAFT HP = 1.25 X POLISHED ROD HORSEPOWER

NOTE: Motor shaft horsepower should not be confused with motor nameplate horsepower. To determine motor (nameplate) size it is common practice to use 2 X POLISHED ROD HORSEPOWER and then use the next larger motor size. The motor selected by this method will be large enough to start the unit and service the unit but the actual motor load will only be about 1.25 X polished rod horsepower.

To find the energy cost of the system it is necessary to include the motor efficiency and to convert horspower to kilowatts. NEMA D motors used in sucker rod pumping duty will have average efficiencies from about 50 percent under light loads to about 85 percent under optimum load conditions. An average value of 74.6 percent will be used for ease of calculations. The formula for determining kilowatts from polished rod horsepower is:

$$\text{KILOWATTS} = \frac{1.25 \text{ X POLISHED ROD HORSEPOWER X } 0.746 \text{ KW/HP}}{0.746 \text{ MOTOR EFFICIENCY}}$$

KILOWATTS = 1.25 X POLISHED ROD HORSEPOWER

This defines the billing kilowatts since it includes all of the energy requirements to the meter. The formula for calculating the kilowatt hours per year for one polished rod horsepower would be:

KW HRS PER YEAR = 1.25 X PRHP X 24 HRS/DAY X 365 DAYS/YEAR

= 10950 X POLISHED ROD HORSEPOWER

The annual power cost of one polished rod horsepower at various rates would be:

RATE $ / KWH	ANNUAL POWER COST (1 PRHP)
0.05	$548
0.06	$657
0.07	$767
0.08	$876

As a "rule of thumb" ONE POLISHED ROD HORSEPOWER COSTS $110 PER YEAR PER ONE CENT PER KWH.

Now that the cost of a polished rod horsepower per year has been determined it will be applied to the examples mentioned previously.

Rod No. 86 Pump Dia. 1.25 Stroke 192 SPM 13.7 PRHP 54.6
Annual power cost at $0.07 per kwh = 767 X 54.6 = $41,878

Rod No. 86 Pump Dia. 2.75 Stroke 120 SPM 7.9 PRHP 22.8
Annual power cost at $0.07 per kwh = 767 X 22.8 = $17,488

The difference between the worst system and the best system, from an energy stand point would be $41878 - $17488 = $24,390. This demonstrates quite clearly that a good system design <u>must</u> include consideration of the cost of energy.

To get a complete picture of how each of the system variables affect the cost of energy refer to Figures 1 through 7. These charts were prepared using the tables for Rod No.s 75, 76, 85, 86.

Figures 1 through 3 illustrate how sucker rod size affects energy costs. Each of the rod strings under consideration was applied with each of three pump sizes. Refer to Fig. 1. using a 1 1/2" pump. Note that, in general, the energy requirements for the 1" rod tapers are greater. With the shorter strokes the four way tapered 1" string (85) and the three way tapered 7/8" string (75) require more energy than the stiffer rod strings of the same size. This is because they lose more of their stroke to stretch. Notice also that there is a sharp break in energy cost starting with stroke lengths longer than the 120" stroke unit. The energy cost of the 1" tapers get relatively flat after the 144" stroke but the 7/8" tapered strings do not flatten until the stroke length is greater than 168". The worst system shown requires about 37 percent more energy than the best case shown.

In Fig. 2, with a 1 3/4" pump the same general pattern is apparent except that the sharp drop in energy usage occurs with stroke lengths longer than 100" and continues until the 144" stroke unit is used. Note also the reduction in energy usage with all rod sizes when compared with the requirements of the 1 1/2" systems.

In Fig. 3 the same basic patterns continue except that with a 2" pump the drop in energy usage starts with the 86" stroke and continues with all strings, except the 75 rod string, to the 120" stroke. With the 75 rod string the drop in energy continues until the stroke length reaches 144".

The conclusion that must be reached from these charts is that the heavier rod strings use more energy. In addition there is an optimum minimum stroke length which must be reached with any particular rod size and pump size if minimum energy usage is to be attained.

While energy cost is an important parameter, the basic criteria of rod design must be the rod stresses and fatigue endurance of the rods. The energy value of high strength and fiberglass rods, which permit lighter rod strings, is quite apparent from these charts. Especially if they are used with the proper minimum stroke length.

Figures 4 through 7 are based on a single rod size and show the energy consequences of various pump sizes. These charts illustrate clearly that pump size does affect energy usage. The difference in energy cost is quite substantial.

The following table summarizes the differences:

	BEST SYSTEM			WORST SYSTEM			
ROD SIZE	PUMP SIZE	STRK LGTH	ENERGY DOL/YR	PUMP SIZE	STRK LGTH	ENERGY DOL/YR	COST DIFF.
75	2	144	19,000	1.5	86	30,500	11,500
76	2	120	19,000	1.5	120	29,200	10,200
85	2	120	20,100	1.5	86	33,400	13,300
86	2	120	20,100	1.5	100	32,600	12,500

These charts are intended to illustrate that larger pump sizes can make an important difference in the annual energy cost. This advantage is the result of the slower pumping speeds needed with the greater displacement of the larger bore pumps. These slower pumping speeds generate less dynamic horsepower losses and therefore are more energy efficient. Another benefit of the slower pumping speeds possible with the larger pumps is the reduced number of wear strokes per year.

The formula for calculating the number of strokes per year for each stroke per minute is:

$$\frac{\text{STROKES}}{\text{YEAR}} = \frac{\text{STROKES}}{\text{MINUTE}} \times \frac{\text{MINUTES}}{\text{DAY}} \times \frac{\text{DAYS}}{\text{YEAR}}$$

$$= \frac{\text{STROKES}}{\text{MINUTE}} \times 1440 \times 365$$

$$= 525{,}600 \times \text{SPM}$$

This can be expressed by a "rule of thumb": ONE STROKE PER MINUTE IS EQUAL TO A HALF MILLION STROKES PER YEAR.

In the cases presented above for the 75 rod string the "worst case" 1 1/2 inch system was pumping at 21.1-86" strokes per minute and the "best case" 2 inch system was pumping at 9.2-144" strokes per minute. This is:

525,600 X 21.1 = 11,090,160 strokes per year
525,600 X 9.2 = 4,835,520 strokes per year

It has been estimated that the average wear life of a bottom hole pump is about 5 million strokes and that the average life of a sucker rod string is about 20 million cycles. The first case would require about 2 pump changes per year and a string of sucker rods every other year. In the second case the pump would last about one year and the rod string would last about 4 years. The large pump and the long stroke have monetary benefits in addition to the energy savings.

In spite of these obvious benefits there are a number of reasons why larger pumps would not be used in a system. First, the casing size often limits the largest pump that can be run. For instance the largest tubing that is usually run in 4 1/2" casing is 2 3/8" O.D. This limits the maximum pump size to a 1 3/4" tubing pump. Second, tubing pumps require that the tubing be pulled to service the pump barrel. This adds substantially to the cost of servicing. Third, the larger fluid loads and the greater range of load present with the larger pump bores require larger or stronger rods. Often the maximum rod diameters that can be used are limited by the maximum tubing size that can be installed in the well. In any case, the rod string for the larger diameter pump will be more expensive.

Now that the bottom hole equipment has been evaluated it is well to consider the application of the pumping unit. Refer to Figures 8 and 9 and the following table.

86 ROD STRING

PUMP	STROKE	SPM	PRHP	ENERGY DOL/YR	CONV UNIT PEAK TORQ	SPEC GEOM PEAK TORQ
1.5	74	22.2	41.3	31677	360	284
1.5	86	20.4	42.2	32367	430	423
1.5	100	18.6	42.5	32597	523	480
1.5	120	16.5	42.0	32214	657	578
1.5	144	13.2	36.7	28148	746	624
1.5	168	11.3	35.8	27458	824	659
1.5	192	10.1	36.5	27995	905	720
1.5	216	9	35.7	27381	977	764
1.5	240	8.1	34.6	26538	1048	798

PUMP	STROKE	SPM	PRHP	ENERGY DOL/YR	CONV UNIT PEAK TORQ	SPEC GEOM PEAK TORQ
1.75	74	19.5	35.4	27151	343	314
1.75	86	17.6	34.7	26614	401	368
1.75	100	15.9	34.3	26308	492	436
1.75	120	13.1	31.5	24160	612	492
1.75	144	10.5	28.9	22166	717	541
1.75	168	9	28.7	22012	798	597
1.75	192	7.9	28.3	21706	861	633
1.75	216	7	29.1	22319	919	667
1.75	240	6.3	29.5	22626	956	699

PUMP	STROKE	SPM	PRHP	ENERGY DOL/YR	CONV UNIT PEAK TORQ	SPEC GEOM PEAK TORQ
2	74	17.7	32.1	24620	344	307
2	86	15.8	31.9	24467	405	365
2	100	14	30.5	23393	478	430
2	120	10.7	26.2	20095	577	465
2	144	8.8	25.7	19711	712	534
2	168	7.4	25.8	19788	827	586
2	192	6.4	25.4	19481	890	620

Observe that for any given pump size the torque increases as a function of stroke length. However, from the previous discussion and from the table below it is apparent that a certain minimum stroke length is required to obtain lowest energy cost. It is apparent that sometimes it will be necessary to buy a larger unit to achieve the benefits of lower energy consumption. Evaluate the additional cost of the larger unit in terms of the savings in energy and savings in rod and pump servicing costs.

With a conventional unit a 912 gear reducer is needed with the 1 1/2 inch and 1 3/4 inch pumps, and a 640 gear reducer is needed with a 2" pump to handle a stroke length long enough to approach the lowest operating cost.

With special geometry units like the Torqmaster, a 640 gear reducer can handle all of the pumps with a stroke length long enough to reach the most economical operating level and if 1 3/4 and 2 inch pumps are used it can handle up to a 192" stroke. It has long been recognized that these long slow strokes are desirable for a number of reasons in addition to the energy saving. Peak rod loads are reduced and minimum rod loads are increased to give longer rod life. The number of wear strokes are reduced and the life of the pump and rods is lengthened.

In addition to the energy benefits detailed above there is one additional energy benefit when special geometry units are used. The principle difference between the conventional units and the special geometry units is that they reduce the torque peaks and smooth the torque curve. With any prime mover this allows the prime mover to operate continuously in a more efficient manner. Head to head comparisons of special geometry units with conventional units, operating with identical operating conditions, show energy savings of up to 25% because the special geometry unit uses the motor more efficiently.

In summary: Consideration of the energy requirements of a sucker rod pumping system is very important. The benefits of using the largest possible pump with the lightest, strongest, rod string and with special geometry units can have enormous economic benefits.

BIBLIOGRAPHY

1. API BULLETIN RP11L3, Sucker Rod Pumping System Design Book, May 1970

ROD NO. 64 | PUMP DEPTH 6000. | PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.25	192.	14.3	15382.	730.	34800.	747.	39.9	8167.	484.6	6111.
1.25	216.	12.7	15118.	1037.	34205.	799.	38.6	8167.	486.5	6111.
1.25	240.	11.4	14972.	1405.	33873.	846.	38.2	8167.	487.7	6111.
1.25	300.	9.3	14723.	1991.	33310.	986.	38.3	8167.	489.9	6111.
1.50	168.	12.1	15765.	2342.	35667.	637.	30.1	9365.	472.7	6540.
1.50	192.	10.7	15708.	2723.	35538.	710.	29.7	9365.	476.0	6540.
1.50	216.	9.5	15589.	2904.	35270.	767.	29.6	9365.	478.5	6540.
1.50	240.	8.6	15381.	3056.	34798.	814.	29.1	9365.	480.7	6540.
1.50	300.	6.9	14966.	3821.	33859.	911.	29.8	9365.	484.6	6540.
1.75	168.	9.7	17229.	3654.	38979.	645.	25.9	10782.	470.8	7048.
1.75	192.	8.4	17167.	3531.	38839.	739.	26.0	10782.	474.7	7048.
1.75	216.	7.4	17000.	3815.	38462.	811.	26.0	10782.	477.7	7048.
1.75	240.	6.6	16779.	4307.	37962.	855.	25.8	10782.	480.1	7048.

ROD NO. 65 | PUMP DEPTH 6000. | PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.25	300.	9.1	16349.	2034.	36988.	1110.	41.2	8932.	490.2	6833.
1.50	168.	11.9	16614.	2483.	37587.	668.	30.7	9809.	473.2	6959.
1.50	192.	10.4	16513.	2939.	37360.	734.	30.1	9809.	476.8	6959.
1.50	216.	9.3	16388.	3072.	37077.	796.	30.3	9809.	479.1	6959.
1.50	240.	8.4	16146.	3286.	36530.	844.	29.8	9809.	481.0	6959.
1.50	300.	6.7	15664.	4167.	35440.	936.	30.7	9809.	484.8	6959.
1.75	168.	9.7	17341.	3673.	39233.	650.	25.9	10848.	471.0	7110.
1.75	192.	8.4	17271.	3547.	39075.	745.	26.1	10848.	474.9	7110.
1.75	216.	7.4	17095.	3877.	38675.	813.	26.0	10848.	477.8	7110.
1.75	240.	6.6	16875.	4366.	38178.	857.	25.8	10848.	480.2	7110.

ROD NO. 66 | PUMP DEPTH 6000. | PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.50	300.	6.6	18186.	5200.	41146.	1076.	33.3	11495.	485.2	8549.

ROD NO. 75 | PUMP DEPTH 6000. | PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.25	192.	13.8	19187.	1153.	31925.	900.	45.5	10274.	485.4	8099.
1.25	216.	12.4	18979.	1484.	31579.	969.	45.1	10274.	486.9	8099.
1.25	240.	11.3	18881.	1887.	31416.	1042.	45.4	10274.	488.1	8099.
1.25	300.	9.1	18445.	2670.	30691.	1219.	44.6	10274.	490.1	8099.
1.50	86.	21.1	20786.	2936.	34585.	353.	39.9	11339.	453.4	8403.
1.50	100.	19.1	20104.	2802.	33452.	420.	38.8	11339.	457.2	8403.
1.50	120.	17.1	19915.	2531.	33136.	542.	39.4	11339.	461.9	8403.
1.50	144.	14.2	19383.	2747.	32252.	659.	35.7	11339.	468.0	8403.
1.50	168.	11.6	18706.	3474.	31125.	714.	31.9	11339.	473.8	8403.
1.50	192.	10.4	18726.	3832.	31158.	793.	32.6	11339.	476.8	8403.
1.50	216.	9.3	18518.	4071.	30812.	854.	32.4	11339.	479.1	8403.
1.50	240.	8.4	18199.	4389.	30281.	903.	31.7	11339.	481.2	8403.
1.50	300.	6.7	17676.	5267.	29411.	1018.	32.5	11339.	485.0	8403.
1.75	74.	20.4	20470.	4222.	34059.	289.	33.5	12595.	439.7	8758.
1.75	86.	18.5	20495.	3924.	34101.	350.	34.7	12595.	445.4	8758.
1.75	100.	16.6	20677.	3781.	34404.	414.	33.7	12595.	450.6	8758.
1.75	120.	14.6	20616.	183.	34302.	527.	32.8	12595.	456.7	8758.
1.75	144.	11.1	19772.	4506.	32899.	619.	27.7	12595.	466.8	8758.
1.75	168.	9.4	19692.	4743.	32765.	729.	27.4	12595.	471.7	8758.
1.75	192.	8.2	19472.	4788.	32399.	800.	27.2	12595.	475.4	8758.
1.75	216.	7.3	19220.	5348.	31980.	852.	27.0	12595.	478.3	8758.
1.75	240.	6.5	18956.	5882.	31541.	893.	27.1	12595.	480.6	8758.
2.00	74.	18.6	21860.	4765.	36373.	287.	30.1	14052.	406.4	9177.
2.00	86.	16.6	22172.	4675.	36891.	365.	30.6	14052.	417.3	9177.
2.00	100.	14.8	21891.	1523.	36424.	416.	30.2	14052.	425.3	9177.
2.00	120.	12.0	21668.	4774.	36053.	498.	28.2	14052.	438.5	9177.
2.00	144.	9.2	21335.	5599.	35499.	621.	24.8	14052.	452.9	9177.
2.00	168.	7.8	21258.	5638.	35370.	739.	24.7	14052.	460.1	9177.
2.00	192.	6.7	21015.	6135.	34967.	833.	24.5	14052.	465.8	9177.
2.25	120.	10.4	23754.	6041.	39524.	516.	24.8	15695.	413.8	9643.
2.25	144.	8.1	23602.	6167.	39271.	665.	23.8	15695.	434.1	9643.
2.25	168.	6.7	23434.	6767.	38992.	801.	24.0	15695.	445.4	9643.

ROD NO. 76 | PUMP DEPTH 6000. | PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.25	216.	12.2	21780.	1556.	36240.	1114.	49.8	11661.	487.1	9407.
1.25	240.	11.0	21648.	2125.	36020.	1194.	50.0	11661.	488.4	9407.
1.25	300.	9.1	21399.	2731.	35605.	1444.	51.3	11661.	490.4	9407.
1.50	74.	21.6	22724.	3644.	37811.	326.	36.9	12504.	452.1	9501.
1.50	86.	20.0	22175.	3365.	36897.	390.	37.9	12504.	456.4	9501.
1.50	100.	18.2	21755.	3214.	36199.	473.	38.0	12504.	460.1	9501.
1.50	120.	16.1	21654.	2934.	36030.	600.	38.1	12504.	464.1	9501.
1.50	144.	13.5	21209.	3208.	35290.	708.	35.9	12504.	469.5	9501.
1.50	168.	11.3	20729.	3939.	34491.	773.	33.7	12504.	474.8	9501.
1.50	192.	9.9	20535.	4508.	34169.	840.	33.5	12504.	477.6	9501.
1.50	216.	9.0	20345.	4739.	33852.	912.	33.8	12504.	479.7	9501.
1.50	240.	8.1	19971.	5101.	33229.	974.	32.8	12504.	481.6	9501.
1.50	300.	6.6	19586.	5856.	32589.	1141.	34.7	12504.	485.2	9501.
1.75	64.	21.2	21853.	4872.	36360.	264.	31.3	13493.	437.6	9606.
1.75	74.	19.1	21653.	4677.	36028.	311.	32.0	13493.	443.4	9606.
1.75	86.	17.3	21824.	4436.	36312.	370.	31.8	13493.	448.5	9606.
1.75	100.	15.6	21836.	2731.	36333.	441.	31.0	13493.	453.3	9606.
1.75	120.	13.6	21791.	2385.	36257.	567.	31.5	13493.	459.2	9606.
1.75	144.	10.5	21101.	5176.	35109.	667.	27.5	13493.	468.3	9606.
1.75	168.	9.1	20962.	5267.	34879.	759.	27.6	13493.	472.7	9606.
1.75	192.	8.0	20731.	5490.	34494.	828.	27.6	13493.	476.1	9606.
1.75	216.	7.1	20469.	6075.	34058.	881.	27.9	13493.	478.8	9606.
1.75	240.	6.4	20191.	6622.	33596.	922.	28.2	13493.	481.0	9606.

EXHIBIT A

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
2.00	74.	17.7	22735.	5133.	37828.	308.	29.2	14646.	412.6	9737.
2.00	86.	15.6	22700.	3742.	37770.	368.	28.4	14646.	420.1	9737.
2.00	120.	11.4	22466.	5316.	37381.	534.	27.0	14646.	441.5	9737.
2.00	144.	8.9	22196.	5884.	36932.	654.	24.8	14646.	454.4	9737.
2.00	168.	7.5	22057.	6037.	36700.	770.	24.8	14646.	461.4	9737.
2.00	192.	6.5	21817.	6551.	36301.	863.	24.8	14646.	466.7	9737.
2.25	120.	10.2	24027.	6308.	39978.	530.	24.5	15944.	416.2	9878.
2.25	144.	7.8	23849.	6430.	39766.	677.	23.4	15944.	435.5	9878.

ROD NO. 77 — PUMP DEPTH 6000. — PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.50	192.	9.8	24119.	5618.	40131.	957.	37.4	14767.	478.4	11636.
1.50	216.	8.8	23774.	5930.	39558.	1047.	36.8	14767.	480.4	11636.
1.50	240.	7.9	23350.	6361.	38851.	1124.	35.9	14767.	482.1	11636.
1.50	300.	6.5	22881.	7293.	38071.	1326.	37.7	14767.	485.5	11636.
1.75	144.	10.0	24001.	6676.	39935.	724.	28.1	15645.	469.9	11636.
1.75	168.	8.8	23830.	6780.	39651.	815.	28.7	15645.	473.8	11636.
1.75	192.	7.7	23494.	7271.	39091.	882.	28.8	15645.	476.9	11636.
1.75	216.	6.9	23191.	7897.	38588.	934.	29.5	15645.	479.4	11636.
1.75	240.	6.2	22880.	8480.	38070.	975.	30.3	15645.	481.4	11636.
2.00	120.	10.4	24943.	7169.	41503.	598.	25.8	16659.	446.5	11636.
2.00	144.	8.5	24814.	7087.	41289.	731.	25.5	16659.	456.8	11636.
2.00	168.	7.2	24549.	7588.	40847.	834.	25.6	16659.	463.2	11636.

ROD NO. 85 — PUMP DEPTH 6000. — PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.25	192.	13.8	21185.	1696.	26987.	970.	48.4	11561.	485.3	9313.
1.25	216.	12.5	20927.	2068.	26659.	1043.	47.9	11561.	486.9	9313.
1.25	240.	11.4	20946.	2347.	26683.	1136.	49.3	11561.	488.0	9313.
1.25	300.	9.1	20337.	3370.	25907.	1311.	47.4	11561.	490.1	9313.
1.50	86.	21.4	23707.	3483.	30200.	391.	43.6	12931.	452.8	9904.
1.50	100.	19.4	22838.	3375.	29093.	470.	43.1	12931.	456.9	9904.
1.50	120.	17.0	22276.	3303.	28377.	602.	41.8	12931.	461.8	9904.
1.50	144.	13.6	21322.	3858.	27162.	694.	35.5	12931.	469.4	9904.
1.50	168.	11.6	20932.	4416.	26665.	768.	33.9	12931.	473.9	9904.
1.50	192.	10.4	20960.	4812.	26701.	852.	34.9	12931.	476.8	9904.
1.50	216.	9.3	20663.	5160.	26322.	912.	34.4	12931.	479.2	9904.
1.50	240.	8.3	20284.	5552.	25840.	965.	33.4	12931.	481.3	9904.
1.50	300.	6.6	19735.	6412.	25140.	1106.	34.0	12931.	485.1	9904.
1.75	64.	22.3	23858.	5454.	30392.	286.	35.2	14553.	434.1	10605.
1.75	74.	20.2	23502.	5310.	29939.	335.	36.9	14553.	440.2	10605.
1.75	86.	18.2	23470.	5004.	29898.	384.	36.1	14553.	445.6	10605.
1.75	100.	16.4	23503.	4836.	29940.	462.	35.3	14553.	451.0	10605.
1.75	120.	13.4	22804.	3757.	29050.	576.	31.1	14553.	459.8	10605.
1.75	144.	10.7	22326.	5956.	28441.	691.	28.5	14553.	467.7	10605.
1.75	168.	9.3	22203.	6120.	28285.	782.	28.7	14553.	472.3	10605.
1.75	192.	8.1	21877.	6377.	27869.	847.	28.2	14553.	475.9	10605.
1.75	216.	7.1	21583.	7000.	27495.	897.	28.3	14553.	478.7	10605.
1.75	240.	6.4	21281.	7574.	27110.	935.	28.6	14553.	481.0	10605.
2.00	64.	19.9	25268.	6363.	32188.	285.	32.4	16420.	401.2	11411.
2.00	74.	17.9	25291.	6149.	32218.	343.	32.6	16420.	410.9	11411.
2.00	86.	15.9	25416.	5247.	32377.	405.	32.3	16420.	418.9	11411.
2.00	100.	14.1	25163.	1640.	32055.	475.	30.6	16420.	428.1	11411.
2.00	120.	10.8	24470.	6974.	31172.	574.	26.2	16420.	444.6	11411.
2.00	144.	8.8	24385.	7106.	31064.	709.	25.8	16420.	455.0	11411.
2.00	168.	7.4	24161.	7366.	30779.	823.	25.7	16420.	462.0	11411.
2.00	192.	6.4	23810.	8130.	30331.	889.	25.4	16420.	467.2	11411.

ROD NO. 86 — PUMP DEPTH 6000. — PRODUCTION 500.

PUMP DIA.	STROKE	SPM	PPRL	MPRL	STRESS	PT	PRHP	CBE	PROD UNANCH.	WRF
1.25	192.	13.7	24415.	1428.	31101.	1132.	54.6	12975.	485.6	10647.
1.25	216.	12.2	23884.	2056.	30425.	1198.	53.1	12975.	487.1	10647.
1.25	240.	11.1	23903.	2474.	30449.	1303.	54.6	12975.	488.3	10647.
1.25	300.	9.1	23463.	3346.	29889.	1550.	54.7	12975.	490.3	10647.
1.50	74.	22.2	25780.	3978.	32840.	360.	41.3	13963.	450.9	10877.
1.50	86.	20.4	24890.	3763.	31707.	430.	42.2	13963.	455.3	10877.
1.50	100.	18.6	24332.	3695.	30996.	523.	42.5	13963.	459.0	10877.
1.50	120.	16.5	24135.	3454.	30746.	657.	42.0	13963.	463.2	10877.
1.50	144.	13.2	23133.	4126.	29469.	746.	36.7	13963.	470.3	10877.
1.50	168.	11.3	22811.	4772.	29059.	824.	35.8	13963.	474.8	10877.
1.50	192.	10.1	22741.	5296.	28970.	905.	36.5	13963.	477.4	10877.
1.50	216.	9.0	22376.	5645.	28504.	977.	35.7	13963.	479.7	10877.
1.50	240.	8.1	21967.	6014.	27984.	1048.	34.6	13963.	481.6	10877.
1.50	300.	6.6	21515.	6876.	27408.	1225.	36.3	13963.	485.3	10877.
1.75	64.	21.4	24695.	5721.	31459.	296.	35.0	15124.	436.8	11144.
1.75	74.	19.5	24435.	5487.	31127.	343.	35.4	15124.	442.3	11144.
1.75	86.	17.6	24410.	5244.	31096.	401.	34.7	15124.	447.5	11144.
1.75	100.	15.9	24328.	4349.	30991.	492.	34.3	15124.	452.6	11144.
1.75	120.	13.1	23762.	4774.	30270.	612.	31.5	15124.	460.8	11144.
1.75	144.	10.5	23273.	6269.	29647.	717.	28.9	15124.	468.5	11144.
1.75	168.	9.0	23032.	6469.	29340.	798.	28.7	15124.	472.8	11144.
1.75	192.	7.9	22675.	6872.	28885.	861.	28.3	15124.	476.2	11144.
1.75	216.	7.0	22445.	7422.	28592.	919.	29.1	15124.	478.9	11144.
1.75	240.	6.3	22121.	8019.	28179.	956.	29.5	15124.	481.2	11144.
2.00	64.	19.7	25268.	6411.	32189.	285.	31.8	16470.	402.1	11458.
2.00	74.	17.7	25341.	6205.	32282.	344.	32.1	16470.	411.6	11458.
2.00	86.	15.8	25438.	5005.	32405.	405.	31.9	16470.	419.6	11458.
2.00	100.	14.0	25252.	1747.	32168.	478.	30.5	16470.	428.4	11458.
2.00	120.	10.7	24552.	7012.	31276.	577.	26.2	16470.	444.8	11458.
2.00	144.	8.8	24461.	7122.	31161.	712.	25.7	16470.	455.2	11458.
2.00	168.	7.4	24236.	7396.	30873.	827.	25.8	16470.	462.1	11458.
2.00	192.	6.4	23878.	8177.	30418.	890.	25.4	16470.	467.3	11458.
2.25	74.	16.5	27269.	6807.	34737.	355.	29.9	17991.	369.1	11809.
2.25	86.	14.3	26509.	2506.	33769.	402.	28.3	17991.	381.9	11809.
2.25	100.	12.4	26873.	6323.	34233.	458.	29.0	17991.	398.5	11809.
2.25	120.	9.3	26355.	7912.	33574.	580.	24.0	17991.	423.4	11809.
2.25	144.	7.5	26307.	8109.	33512.	737.	24.2	17991.	438.1	11809.
2.50	86.	13.4	29186.	4736.	37180.	400.	26.9	19702.	384.0	12211.
2.50	100.	11.6	29350.	7548.	37388.	483.	26.8	19702.	398.9	12211.
2.50	120.	8.6	28829.	8402.	36725.	612.	23.6	19702.	425.8	12211.
2.75	120.	7.9	31799.	8942.	40508.	641.	22.8	21570.	399.2	12635.

EXHIBIT B

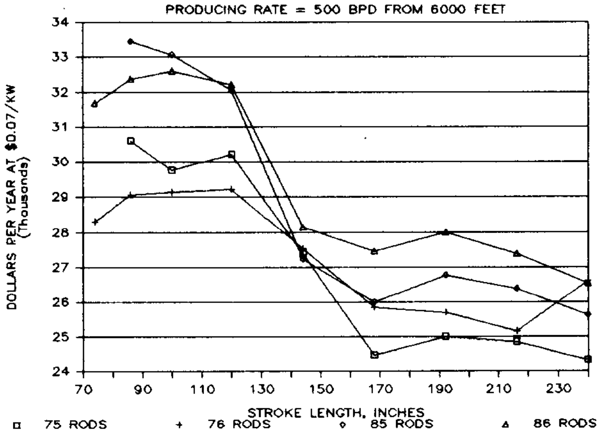

Figure 1 - 1½" pump with various rod sizes

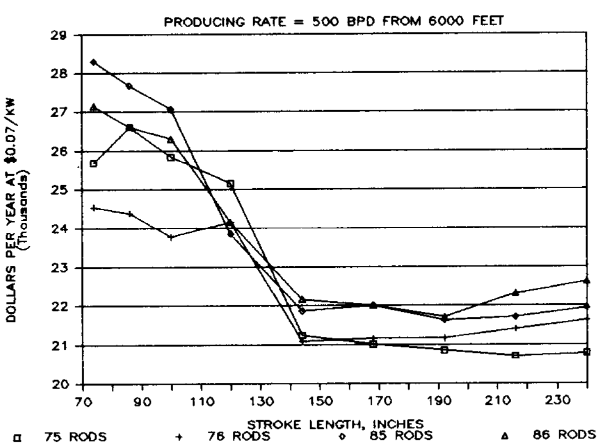

Figure 2 - 1¾" pump with various rod sizes

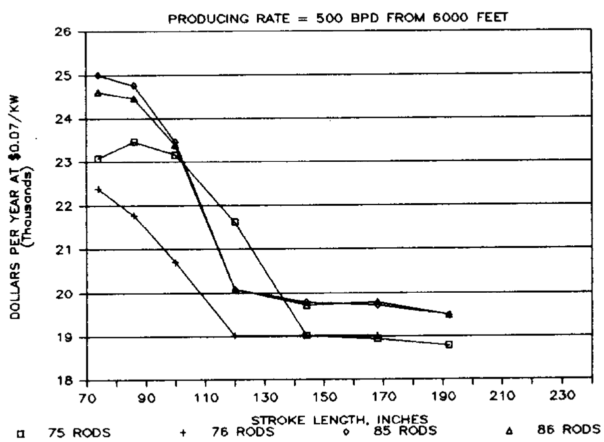

Figure 3 - 2" pump with various rod sizes

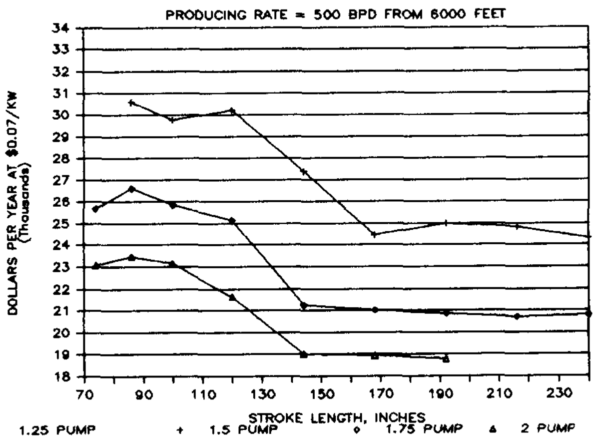

Figure 4 - 75 rods with various pump sizes

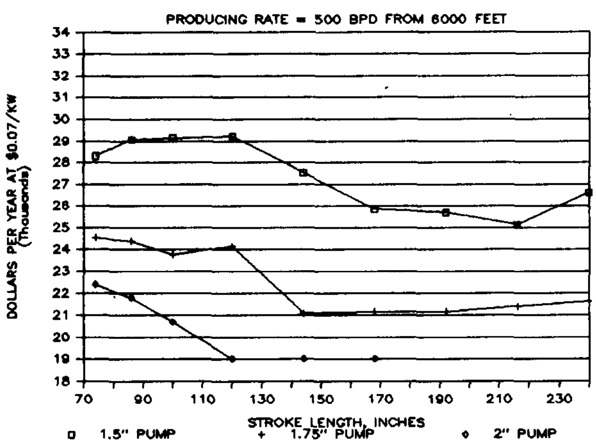

Figure 5 - 76 rods with various pump sizes

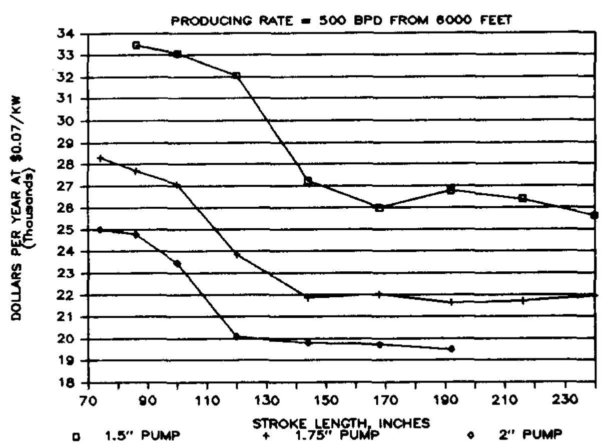

Figure 6 - 85 rods with various pump sizes

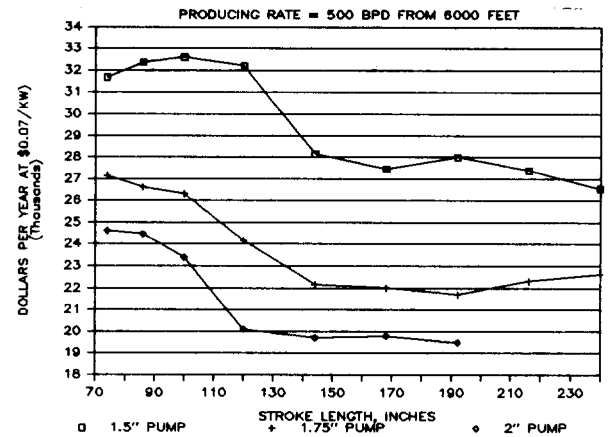

Figure 7 - 86 rods with various pump sizes

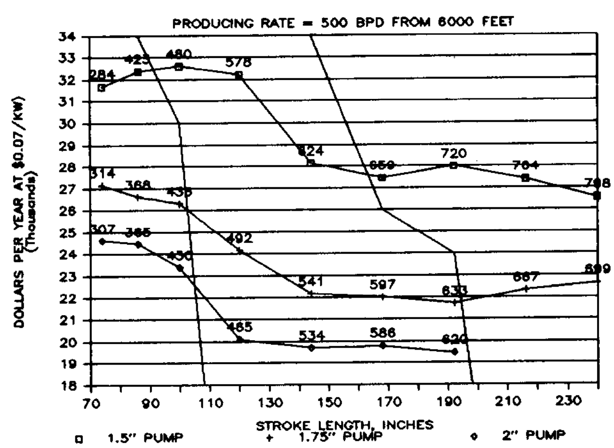

Figure 8 - 86 rods with various pump sizes - Torqmaster special geometry

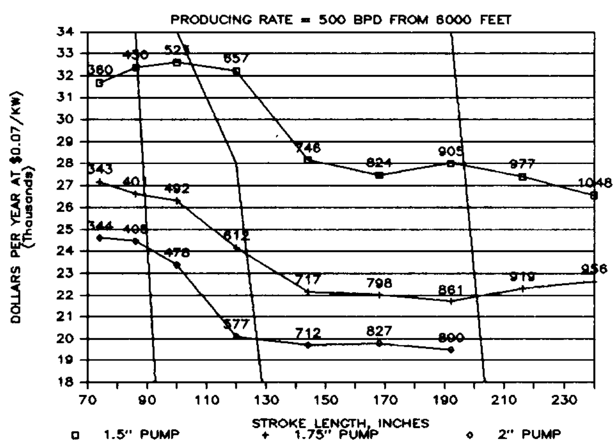

Figure 9 - 86 rods with various pump sizes - conventional geometry unit