RATING THE EFFECTIVENESS OF BEAM AND SUCKER ROD PUMPING MODES

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One of the most helpful and convenient aids in the successful application of conventional beam pumping units is the American Petroleum Institute bulletin, 11L-3, "SUCKER ROD PUMPING SYSTEM DESIGN BOOK".

Expanding the work of Sucker Rod Pumping Research Inc. and the Midwest Research Institute, the API produced this set of tables (11L3) containing literally thousands of different precalculated pumping options, or modes, generated by using a model of the wave equation applied to sucker rod pumping when using conventional beam units.

These API tables have been widely accepted, and though certain sections have been questioned, and in some cases revised - in general, they have made a substantial contribution to the petroleum industry in facilitating the application of conventional pumping units.

According to these tables, there are twenty API approved sucker rod sizes, eighteen approved stroke lengths, and ten different API plunger diameters. Thus, in lifting a given amount of fluid from a particular depth, with a conventional pumping unit, theoretically there could be some 3600 beam and sucker rod system options, or pumping modes, for a single, artificial lift application - not considering variation in pumping speed.

Obviously, some of these thousands of pumping modes are either impractical, uneconomical, or both - but even the elimination of 90% of them still leaves over 350 pumping modes to consider.

In the API-11L3 design tables, for a single application, i.e. lifting 400 barrels per day from 3500 feet, requires the theoretical evaluation of nearly four hundred different pumping modes. Other applications require the consideration of even more than four hundred.

But which of these hundreds of pumping modes is the most effective as regards economy, longevity, and efficiency? Theoretically, any one of them can do the job - but which one is best?

Perhaps the "best pumping mode" is in the eye of the operator - but often consideration is given to the pumping mode having the lowest torque, or lowest rod or structural loading, or highest efficiency, etc. But the pumping mode having the lowest torque, might not be the most efficient, nor the mode resulting in the lowest rod loading might not afford maximum economy, etc.

Thus, the question arises, "What is the best and most effective pumping mode, when considering all, or most, of the dominant factors involved?".

PAST RATING CONCEPTS

A significant approach to optimum pumping mode selection was made in 1975 when Manuel Estrada, an outstanding researcher at the University of Tulsa, presented a thesis on, "Design and Optimizing Tables for the Mark II Oil Field Pumping Unit".

Included in this study was a section on an Economic Index (EI) which, according to the author, "gives the most economical pumping combination when considering torsional, structural, prime mover, and lifting requirements." Estrada goes on to say, "By selecting the lowest EI number, the most economical pumping system is defined". Estrada's equation for the Economic Index is:

$$EI = 10^{-7} \frac{W_{max} T_P P_{PR}}{LE}$$

WHERE: W_{MAX} = Peak Polished Rod Load
T_P = Peak Torque (In Balance)
P_{PR} = Polished Rod Horsepower
LE = Lift Efficiency

This is a simple and direct equation, relating some of the important variables of the beam pumping system, and casting them into a series of index numbers, each associated with a particular pumping mode. (Table No. 1)

Sometime later (1980) Louis Valera M, another researcher at the University of Tulsa developed a thesis entitled, "A Technique for Determining Optimum Geometry and the Most Economical Pumping Mode for Different Beam and Sucker Rod Systems". Included in this thesis was an extension and refinement of the Estrada pumping mode index, and Valera entitled his rating number, "The Comparative Economic Index (CEI)". He states, "Since the overall economy of a beam and sucker rod pumping system is a direct function of PPRL, PT, nameplate horsepower (HPNP), the cyclic load factor, and an inverse function of lift efficiency, it is logical to combine them into a simple mathematical expression such as:

$$CEI = 10^{-9} \times \frac{PPRL \times PT \times HPNP \times CLF}{LE}$$

WHERE: PPRL = Peak Polished Rod Load (lbs.)
PT = Peak Torque in.lbs. (in-balance)
HPNP = Nameplate Horsepower
CLF = Cyclic Load Factor
LE = Lift Efficiency

Valera further states, "A weight of 1.0 was given to each of the five variables used to calculate CEI values. Wherever experience dictates, the weighting can be done empirically. For instance, in an area where power costs are excessively high, the CLF could be weighted greater than one. For a given situation, the selection of the lowest CEI assures maximum economy." (Table Nos. 2a and 2b)

In 1982, a third thesis was authored by Solomon D. Lekia, which not only expanded, but refined the work of Estrada and Valera. Lekia's thesis was entitled, "An Improved Technique for Evaluating Performance Characteristics and Economy of the Conventional and Mark II Beam and Sucker Rod Pumping Systems". The designation that Lekia used for indexing the various pumping modes was called The Performance Index (PIX) which he states is, "an important number in evaluating the overall economy of a beam and sucker rod pumping system." It is given conceptually as follows:

$$PIX = 10^{-8} \frac{PPRL \times PT \times HPNP \times CLF}{LE \times ITE}$$

WHERE: PPRL = Peak Polished Rod Load (lbs.)
PT = Peak Torque in-lbs. (in-balance)
HPNP = Nameplate Horsepower
CLF = Cyclic Load Factor
LE = Lift Efficiency
ITE = Index of Torsional Effectiveness

A power of one is given to each of the six variables to weight them equally. Peak polished rod load, peak torque, nameplate horsepower, and cyclic load factor appear in the numerator in order to keep their value as low as possible on various installations; conversely lift efficiency (LE) and index of torsional effectiveness (ITE) appear in the denominator beause high lift efficiencies (LE) and indices of torsional effectiveness (ITE) are indicative of good pumping operations.

For a given design situation or application, selection of the lowest PIX value assures maximum economy. (Tables nos. 3a and 3b)

The work of Estrada, Valera, and Lekia are important concepts, expansions, and refinements for developing a valid procedure for selecting the optimum pumping mode for a beam and sucker rod pumping application.

Often, in the past, pumping units have been applied considering one, or perhaps two major variables, such as peak torque, or peak polished rod load, etc. One virtue of the indexing of pumping modes is that most of the important variables can be considered in the formulation - not just one or two.

Although there are many different modes for the venerable conventional pumping unit, it was not until the 1920's that a significantly different beam unit geometry, the air balance unit, became popular - with its own spectrum of pumping modes.

With the advent of the Mark II pumping unit in the mid 1950's, a third menu of pumping mode possibilities was added. As the Mark II patents expired in the late '70's, other beam pumping geometries appeared with their own unique series of modes, further adding to the vast number of pumping mode possibilities to be reckoned with.

Each pumping mode would have a different kinematic or performance output, and the most desirable pumping mode for one beam unit might be different from the optimum mode of another type of geometry.

Thus, evaluating the possible pumping modes for a single application, considering two or three different geometries, could become a sizeable task.

For instance, in comparing two different unit geometries for an application, one might be superior in reducing structural load, rod load range, and lift efficiency - while a second might lower torque peaks, the cyclic load factor, and surface efficiency, etc. Which is the more effective pumping mode?

Obviously, the substantial number of physical constraints on the typical well often makes the number of pumping mode options manageable - but which one is best?

To further illustrate the performance disparity of conventional unit pumping mode options, some practical, others impractical, reference is made to API bulletin 11L3 for several dramatic examples which underscore the need for some kind of rating index in addition to the regular, comprehensive, predictive survey.

EXAMPLE No. 1

On page 370 of these tables, a pumping mode using API-75 rods and pumping 8.0-300 in. SPM with an 1 1/2" plunger, the peak polished rod load is given as 20,366 lbs. To handle this same pumping application (page 373), a conventional unit using API 98 rods and pumping 11 - 100 inch SPM with a 2.75 inch plunger, will develop a peak polished rod load of 40,403 lbs. - almost exactly twice the structural load requirement when using the pumping mode employing API 75 rods. Thus, the conventional unit performs the same amount of work per day in each case, i.e. lifting 600 BFPD from 6500 feet, but by selecting the proper pumping mode, the unit structural load can be cut in half.

EXAMPLE No. 2

On page 372 of the API bulletin, it can be seen that a pumping mode of 10.4 - 300 inch SPM driving a 1.25 inch pump, with API 97 rods, develops a peak torque of 2,358,000 in-lbs to lift this same application of 600 BFPD from 6500 feet. On the preceding page (371), using API 87 rods, a conventional unit, pumping 19.9 - 64 inch SPM and driving a two inch plunger develops a peak torque of but 346,000 in-lbs.

Thus, selecting the previous pumping mode, requires a speed reducer to accommodate nearly seven times as much peak torque as is required with a second mode to handle the same pumping job. In one case, peak torque slightly overloads an API 320 in-lb reducer, while in the second case, the same pumping job requires nearly the largest beam pumping speed reducer manufactured - a 2,560,000 in-lb box. In both cases, the same amount of work is performed per day - i.e., lifting 600 barrels from 6500 feet. In this conventional unit application, one pumping mode developed a peak torque about 700% greater than that of the second pumping mode.

EXAMPLE No. 3

The desirability of selecting an optimum pumping mode is strikingly demonstrated on page 148 of the API 11L3 tables. To lift 400 b/d from 3500 feet with an API 77 rod string, lists among others, two different pumping modes, one requiring a polished rod horsepower of 57.4, another needs but 10.7. Assuming these figures are correct, rod string losses would be 118 times greater in the former pumping mode compared to the latter, and over five times as much polished rod power would be consumed by the higher horsepower mode. Furthermore, as regards only lift efficiency, which is but one of the factors involved in total system efficiency - in the 57.4 horsepower mode, about 20% of the polished rod input energy is devoted to fluid elevation, while 80% is wasted as heat loss. In the contrasting pumping mode, about 96% of the polished rod work is devoted to beneficial fluid lift, and only 4% to heat loss. This should be adequate justification for the further understanding and exploration of different beam pumping modes.

EXAMPLE No. 4

One of the most important aspects of proper pumping mode selection involves prime mover horsepower requirements.

On page 372 of the API tables, using API 97 rods and driving 10.4 - 300 in. SPM, with an 1 3/4 in. plunger, the resulting polished rod horsepower is 89.9. This number is a direct function of the size of the prime mover required. With the same API 97 rod string, it can be seen that using a 2.75 in. pump and driving 9 - 120 in. SPM, the polished rod horsepower required is 30.7 - or approximately one third the amount needed in the preceding example. Obviously, if the API 11L3 figures are correct, this means a prime mover three times as large would be required to perform the same job, when lifting 600 BFPD from 6500 feet with a conventional beam pumping unit.

Though misapplications of the magnitude of the four examples listed above seldom, if ever, occur - such disparity, even theoretical, emphasizes the fact that proper pumping mode selection can significantly increase the effectiveness and the economy of lifting fluid with a beam and sucker rod pumping system.

THE PERFORMANCE EFFECTIVENESS RATING SYSTEM (PE)

The following simple and direct mathematical model seeks to consider, balance, and harmonize most of the dominant factors concerned with performance effectiveness in lifting fluid with a beam and sucker rod system.

In this new, modified approach, called the PE model, an attempt has been made to recognize; (1) rod and structural loading; (2) rod loading alone; (3) torsional loading; (4) lift efficiency; (5) surface efficiency of the prime mover, belts, drive train and structural bearings; (6) prime mover size requirement; and (7) power consumption.

PERFORMANCE EFFECTIVENESS (PE)

$$PE = \left[\frac{Wr_f + W_f}{PPRL} + \frac{Wr_f + W_f}{PPRL - MPRL} + \frac{(HP_{PR})(378{,}150)}{(SPM)(PT_{BAL})}\right]\left(\frac{HHP}{HP_{PR}}\right)\left(0.90\,\frac{\Sigma_{0^\circ}^{360^\circ}(746 \times \text{Output } HP_{INST})}{\Sigma_{0^\circ}^{360^\circ}\dfrac{(746 \times \text{Output } HP_{INST})}{(EFF_{MOTOR})_{INST}}}\right)$$

$$+ M_X + (1.5)\,\frac{\dfrac{(t_1 + t_2 + t_3 \ldots + t_n)}{n}}{\sqrt{\dfrac{t_1 + t_2 + t_3 \ldots + t_n}{n}}}$$

WHERE:

Wr_f = Weight of rods in fluid

W_f = Weight of fluid

PPRL = Peak polished rod load

MPRL = Minimum polished rod load

HP_{PR} = Polished rod horsepower

SPM = Strokes per minute

PT_{BAL} = Peak torque in balance

HHP = Hydraulic horsepower

HP_{INST} = Instantaneous horsepower

EFF $MOTOR_{INST}$ = Instantaneous motor efficiency

$$M_X = \frac{\text{Lift Efficiency x Surface Efficiency}}{\text{Cylic Load Factor}}$$

$t_1, t_2, t_3, \ldots t_n$ = Instantaneous torque or instantaneous motor current

n = Number of crank stations considered

In a more condensed form, the equation becomes:

$$PE = (P_X + R_X + T_X) \quad L_X S_X + M_X + C_X$$

WHERE:

$$P_X = \frac{Wr_f + W_f}{PPRL}$$

$$R_X = \frac{Wr_f + W_f}{PPRL - MPRL}$$

$$T_X = \frac{(HP_{PR})(378,150)}{(SPM)(PT_{BAL})}$$

$$L_X = \frac{HHP}{HP_{PR}}$$

$$S_X = \left(.90 \frac{\sum_{0°}^{360°} (746 \text{ x Output HP Inst.})}{\sum_{0°}^{360°} \frac{(746 \text{ x Output HP Inst.}}{(\text{Eff.}_{\text{Motor Inst.}})}}\right)$$

$$M_X = \frac{(L_X)(S_X)}{CLF}$$

$$C_X = \frac{(t_1 + t_2 + t_3 .... + t_n)}{\sqrt{\frac{(t_1 + t_2 + t_3 .... + t_n)}{n}}} \, (1.5)$$

Following is a list and rationale of the various PE equation components.

1. P_X, is the structural and rod load factor, relating the dead weight of rods and fluid to the peak polished rod load. This is the reciprocal of the impulse factor used in earlier peak polished rod load formulation.

2. R_X, simply ratios the weight of rods and fluid to the load range of the system in operation.

3. T_X, is a mathematical relationship of the ratio of average torque to peak torque, modified by a constant to account for a fundamental differential in ranges between P_X, R_X, and T_X as well as attempting to balance torsional considerations properly to rod and structural factors.

4. L_X, is simply the ratio of hydraulic horsepower to polished rod horsepower, and is the quantity known as Lift Efficiency (LE).

5. S_X, is the surface efficiency of the machinery from the input of the Nema "D" motor to the output of the pumping unit. This equation for surface efficiency not only covers the mechanical efficiency of the pumping unit proper at rated capacity, or thereabouts, but also considers prime mover and belt efficiency as well.

6. M_X, is a factor based on lift efficiency, surface efficiency, and the cylic factor, giving appropriate credit to a smaller prime mover adequately handling the required hydraulic work load.

7. C_X, is the inverse of the cyclic load factor times a 1.5 multiplier, which is a direct index of the power consumed.

Although the PE concept is primarily a performance effectiveness index, a prime mover size factor and a power consumption factor were arbitrarily added to the equation. No attempt has been made to consider either the first cost of the pumping unit and prime mover or their maintnance costs.

The larger the PE index number, the more effective the pumping mode.

Several important application functions in the optimizing of beam pumping modes can be facilitated by using the new Performance Effectiveness System (PE), or perhaps one of the three earlier optimizing versions. Because of differences in the mathematical models used, similar, though not exact correlation should be expected from the various tables.

Unfortunately, the PE system tables are not now available - but hopefully will be, sometime in the near future.

Pumping mode optimizing tables can come in at least two different arrangements, (1) having an Index number included in the regular arrangement of the tables, such as the examples in tables 1, 2, and 3; or (2) arranging the tables in either ascending or descending order according to the Indexing system used.

Pumping mode indexing tables can perform several useful functions; (1a) comparing the existing pumping mode to the optimum pumping mode to see if they are the same or similar; (2a) comparing two different pumping unit geometries using the same pumping mode to determine the difference in performance effectiveness; (3a) comparing the optimum performance effectiveness mode of one geometry to the same pumping mode of a second non-optimized geometry; (4a) to compare the optimum pumping mode of one geometry to the optimum pumping mode of another geometry, etc.

Since the new PE tables are not currently available, in the following examples, a combination of the PE model and the Lekia optimizing tables have been substituted.

Example 1a

To produce 400 barrels per day from 4000 ft. with API 76 (Grade D) rods employing a Class III beam pumping unit. The operator, using his own experience, selected a pumping mode of 16.5 - 54 inch SPM with a 2 1/2 in. plunger and 76 rods. Was this selection, based on the operator's experience, similar to the optimum pumping mode?

EXPERIENCE SELECTION	OPTIMUM SELECTION
16.5 - 54 in. SPM x 2 1/2 in.	13.6 - 74 in. SPM x 2.0 in.
$P_X = .765$	$P_X = .7080$
$R_X = .996$	R_X - .8780
$T_X = 1.536$	$T_X = 2.296$
$L_X = .923$	$L_X = .773$
$S_X = .767$	$S_X = .750$
$M_X = .366$	$M_X = .407$
$C_X = .776$	$C_X = 1.053$
PE = 3.476	PE = 3.711

Obviously, the PE's of both pumping modes are reasonably close, showing that the operator's experience has resulted in a good pumping effectiveness mode, and an economical pumping arrangement. Changing the existing pumping mode should provide a 5% or 6% improvement, which is significant enough to be considered.

Example 2a

To produce 400 B/D from 8500 ft. with API 86 Grade "D" rods. The pumping mode selected is: 12.7 - 120 in. SPM with a 1.5 in. plunger. In this case, which pumping unit geometry is the most effective - Unit "E" or Unit "F"?

Unit "E"	Unit "F"
12.7 - 120 in. SPM x 1.5 in. plunger	12.7 - 120 in. SPM x 1.5 in. plunger
$P_X = .695$	$P_X = .702$
$R_X = 1.151$	$R_X = 1.162$
$T_X = 1.852$	$T_X = 2.351$
$L_X = .719$	$L_X = .710$
$S_X = .779$	$S_X = .751$
$M_X = .339$	$M_X = .407$
$C_X = .909$	$C_X = 1.145$
PE = 3.319	PE = 3.798

The PE for unit "F" appears to be some 13% better than the effectiveness of unit "E", both operating with the same pumping mode. Presumably the PE is not optimum for either geometry.

Example 3a

To produce 400 B/D from 3500 ft. with API 77 rods.

The optimum pumping mode for unit "G" is; 14.6 - 64 in. SPM with a 2.0 in. plunger. A comparable unit "H" (different geometry) employs essentially the same pumping mode, except it is not known if this mode is optimum for geometry "H".

Unit "G"	Unit "H"
14.6 - 64 in. SPM x 2.0 in. plunger	14.4 - 64 in. SPM x 2.0 in. plunger
$P_X = .692$	$P_X = .746$
$R_X = .835$	$R_X = .973$
$T_X = 3.002$	$T_X = 1.735$
$L_X = .764$	$L_X = .828$
$S_X = .775$	$S_X = .785$
$M_X = .398$	$M_X = .393$
$C_X = 1.008$	$C_X = .906$
PE = 4.148	PE = 3.544
(OPTIMIZED)	(NOT OPTIMIZED)

In this comparison, Unit "G" optimized appears to be about 15% more effective than Unit "H", not optimized.

Example 4a

To lift 500 B/D from 4500 ft. with API 87 rods - optimumly - with unit Geometry "I", suggests a pumping mode of 17.1 - 54 in. SPM x 2.5 in. plunger, with its accompanying PE number.

Also a second PE number is desired for geometry "J" when it is operating in the identical (though non-optimized) pumping mode as Geometry "I".

And finally, a third PE number is calculated for geometry "J" when it is operating in its optimum pumping mode, and compared to Unit "I" when also optimumly driven.

Unit "I" Optimized 17.1 - 54 in. SPM x 2.5 in. plunger	Unit "J" with "I" pumping mode	Unit "J" optimized 11.8 - 86 in. SPM x 2.25 plunger
P_X = .749	P_X = .754	P_X = .720
R_X = 1.008	R_X = 1.009	R_X = .924
T_X = 1.961	T_X = 1.768	T_X = 2.667
L_X = .815	L_X = .780	L_X = .796
S_X = .776	S_X = .773	S_X = .774
M_X = .395	M_X = .347	M_X = .418
C_X = .938	C_X = .863	C_X = 1.017
PE = 3.684	PE = 3.339	PE = 4.091

Although Unit "I", optimized, shows a 9.5% greater effectiveness than Unit "J" in the same pumping mode - when Unit "J"'s mode is optimized, its PE becomes 10% greater than Unit "I"'s optimized mode, and 18.5% more effective than its own non-optimized mode.

This example illustrates that a rigorous comparison of the PE for different pumping unit geometries, over a given application cannot be finally evaluated until the optimum PE for both geometries is determined and compared.

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Obviously, use of the PE procedures and other pumping mode rating systems is impractical without adequate tables.

Following are some limitations of the PE procedures: (1) it does not consider the first cost of unit, prime mover, or rod string; (2) it assumes the prime mover to be a standard, Nema D, oil field motor; (3) it does not signal overloading of the system components; (4) it assumes pumping a full barrel of incompressible fluid, off bottom each stroke.

On the other hand, if used properly, the PE system can assist in determining the optimal and most economical performance in the application of different pumping unit geometries applied to any artificial lift requirement.

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to M. Estrada, L. Valera, and S. Lekia for their pioneering effort in this area; to, Dr. Kermit Brown and Dr. John Day for their guidance and assistance; to Lufkin Industries, Inc. for its gracious support; and to Dr. Phil Narmore, Executive Dean, Georgia Institute of Technology, whose kindness and compassion over half a century ago helped salvage a young, confused, and very marginal engineering student.

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Table 1
Unit Geometry "N"

PUMP DEPTH
7500.

PRODUCTION = 250.

ROD	DIA.	STROKE	SPM	PPRL	MPRL	STRESS	GRD	PT	CBM	ITE	PRHP	LE	PMHPO	PMHPC	EI	N/NO	WF/SK	WRF
65	1.06	120	13.7	14851	4645	33600	92	282	773	34.2	21.0	65.8	28.2	38.9	.13+3	.3940	.2069	8442
	1.06	144	12.4	14896	4227	33702	96	338	914	33.6	22.3	61.9	29.5	40.8	.18+3	.3562	.1724	8442
	1.25	86	14.8	15514	5759	35101	92	226	505	32.5	17.2	80.1	22.4	31.0	.76+2	.4230	.3954	8540
	1.25	100	13.5	15502	5622	35073	93	201	657	41.2	17.8	77.5	23.0	31.8	.72+2	.3858	.3401	8540
	1.25	120	11.8	15084	5313	34127	89	298	781	32.4	18.1	76.5	25.2	34.8	.11+3	.3369	.2834	8540
	1.25	144	10.4	15322	4940	34667	97	383	1002	29.7	18.8	73.4	28.9	39.8	.15+3	.2973	.2362	8540
	1.50	100	11.8	16672	6226	37721	108	281	719	30.6	16.2	85.3	23.4	32.2	.89+2	.3355	.4815	8697
	1.50	120	10.4	17191	6151	38893	119	355	899	28.9	17.1	81.0	27.0	37.2	.13+3	.2961	.4013	8697
	1.50	144	8.8	16972	5692	38398	120	364	1070	33.2	16.9	81.9	26.8	37.0	.13+3	.2482	.3344	8697
66	1.06	120	13.1	17306	6249	39155	121	346	898	31.8	22.9	60.2	30.2	41.6	.23+3	.4096	.1589	10685
	1.25	86	13.8	17881	7369	40457	121	210	598	40.3	18.6	74.4	23.9	32.9	.94+2	.4324	.3068	10685
75	1.06	120	13.6	16997	5436	28282	66	229	840	44.7	22.2	62.2	28.1	38.8	.14+3	.3651	.1853	9881
	1.06	144	12.2	16949	5376	28201	65	362	1025	33.2	23.4	59.0	33.6	46.4	.24+3	.3277	.1544	9881
	1.25	74	16.1	17366	7031	28896	60	219	494	31.2	17.5	78.8	22.7	31.4	.85+2	.4264	.4062	10123
	1.25	86	14.6	17396	6851	28945	61	224	559	35.2	18.3	75.4	23.6	32.6	.95+2	.3865	.3496	10123
	1.25	100	13.3	17404	6616	28959	62	231	707	38.6	18.9	73.1	24.2	33.4	.10+3	.3530	.3006	10123
	1.25	120	11.7	17209	6445	28634	62	389	859	26.5	19.1	72.3	29.2	40.3	.18+3	.3095	.2505	10123
	1.25	144	10.3	17493	6081	29106	66	373	1066	31.9	19.4	71.1	29.5	40.7	.18+3	.2720	.2088	10123
	1.50	86	12.9	18916	7829	31474	69	308	583	26.2	16.5	83.7	23.7	32.7	.11+3	.3398	.4849	10502
	1.50	100	11.5	19350	7638	32197	74	387	758	24.1	17.1	80.8	27.0	37.3	.16+3	.3042	.4170	10502
	1.50	120	9.9	19203	7165	31953	76	381	940	28.9	17.4	79.5	27.3	37.7	.16+3	.2620	.3475	10502
	1.50	144	8.0	19033	7241	31669	74	455	1170	28.8	16.6	83.1	26.5	36.6	.17+3	.2104	.2896	10502
	1.75	120	8.8	21632	8138	35994	97	512	1022	22.9	16.5	83.9	29.1	40.2	.22+3	.2340	.4510	10947
76	1.06	120	13.3	19949	6406	33194	89	347	947	32.5	23.8	58.0	31.1	42.9	.28+3	.3904	.1479	11686
	1.06	144	11.9	19451	5974	32364	86	482	1105	27.4	24.9	55.4	35.2	48.5	.42+3	.3500	.1232	11686
	1.25	86	14.0	19604	7815	32619	76	266	635	32.2	19.0	72.5	26.2	36.2	.14+3	.4103	.2842	11758
	1.25	100	12.8	19705	7443	32787	79	217	796	44.5	19.8	69.9	25.2	34.7	.12+3	.3762	.2444	11758
	1.25	120	11.3	19254	7287	32037	76	383	943	29.4	20.2	68.3	30.4	41.9	.22+3	.3319	.2037	11758
	1.25	144	9.9	19444	7091	32354	79	385	1181	33.6	20.3	68.2	30.4	42.0	.22+3	.2896	.1698	11758
	1.50	74	13.8	20881	8984	34745	82	238	586	31.0	16.2	85.3	21.3	29.4	.94+2	.4012	.4716	11876
	1.50	86	12.2	20497	8597	34105	80	251	659	33.7	16.5	83.9	23.6	32.6	.10+3	.3557	.4058	11876
	1.50	100	11.0	20552	8521	34197	81	361	841	27.6	17.3	79.6	27.3	37.7	.16+3	.3195	.3490	11876
	1.50	120	9.6	21210	8137	35292	91	301	1068	39.1	17.9	77.3	25.1	34.6	.15+3	.2786	.2908	11876
	1.50	144	7.7	20753	7956	34531	87	437	1301	31.8	16.9	81.6	26.9	37.1	.19+3	.2233	.2423	11876
	1.75	100	10.1	22969	9246	38217	106	379	952	27.4	16.6	83.3	26.5	36.5	.17+3	.2912	.4703	12007
	1.75	120	8.4	22707	8810	37783	106	428	1118	28.6	16.4	84.1	26.3	36.3	.19+3	.2442	.3919	12007
77	1.06	120	12.9	22209	8632	36954	100	441	1102	28.6	26.0	53.2	36.2	49.9	.48+3	.4045	.1168	14544
	1.06	144	11.6	22683	8554	37742	108	481	1371	30.5	27.0	51.1	37.3	51.4	.58+3	.3627	.0973	14544
	1.25	86	13.5	22287	10264	37084	89	260	760	36.8	20.5	67.5	27.7	38.2	.18+3	.4211	.2255	14544
	1.25	100	12.2	23206	9759	38613	106	249	948	43.0	20.9	66.2	26.5	36.5	.18+3	.3825	.1939	14544
	1.25	120	11.0	23249	9249	38685	110	315	1125	40.0	22.0	62.8	29.2	40.3	.26+3	.3435	.1616	14544
	1.25	144	9.6	23107	9432	38448	107	318	1412	44.6	21.8	63.4	29.0	40.0	.25+3	.3013	.1347	14544
	1.50	64	13.8	23953	11017	39856	107	223	573	33.6	16.4	84.3	21.5	29.7	.10+3	.4302	.4364	14544
	1.50	74	12.6	23966	10819	39877	105	241	649	35.3	17.0	81.2	22.2	30.6	.12+3	.3929	.3774	14544
	1.50	86	11.4	23708	10524	39448	107	311	742	31.0	17.5	78.7	24.7	34.1	.16+3	.3575	.3247	14544
	1.50	100	10.3	23702	10410	39438	108	398	948	27.5	18.0	76.9	28.0	38.6	.22+3	.3225	.2793	14544
	1.50	120	9.0	24349	10204	40515	120	297	1193	42.7	18.1	76.1	25.3	34.9	.17+3	.2816	.2327	14544
	1.50	144	7.2	23930	10183	39817	113	478	1455	31.8	17.4	79.6	27.3	37.7	.25+3	.2245	.1939	14544

Table 2a
Unit Geometry "K"

PUMP DEPTH (FT)
3000.

PUMP DISPLACEMENT (B/D) = 500.

ROD	DIA.	STROKE	SPM	PPRL	MPRL	STRESS	CLF	PT	CBM	ITE	PRHP	LE	S.EF	HPNP	CEI	GRD	N/NO	WF/SK
76	1.50	74	25.4	14144	1873	23535	1.998	253	268	26.52	27.06	40.83	78.2	69.1	1.211	62	.2875	.0748
	1.50	86	21.7	13852	1754	23048	1.728	273	301	28.49	26.89	41.08	78.2	59.5	.949	60	.2458	.0644
	1.50	100	19.1	13748	1615	22875	1.646	309	344	29.51	27.66	39.94	78.4	58.1	1.020	60	.2157	.0554
	1.50	120	15.9	14166	1418	23571	1.610	381	477	28.66	27.55	40.10	72.9	60.8	1.320	64	.1797	.0461
	1.50	144	13.2	13880	1321	23095	1.483	429	578	31.50	28.45	38.84	73.5	57.4	1.307	63	.1498	.0384
	1.75	54	27.1	13895	1331	23120	1.983	197	183	24.35	20.65	53.50	78.8	52.0	.528	63	.3048	.1380
	1.75	64	21.9	13779	1357	22926	1.676	220	212	26.01	19.91	55.50	78.5	42.5	.390	62	.2462	.1164
	1.75	74	19.1	13575	1257	22588	1.606	246	228	27.13	20.30	54.43	78.7	41.5	.409	61	.2154	.1007
	1.75	86	16.9	13702	1303	22799	1.584	284	276	27.23	20.76	53.22	74.3	44.3	.513	61	.1902	.0866
	1.75	100	14.5	13886	1486	23105	1.519	325	362	27.84	20.93	52.78	74.4	42.7	.556	62	.1636	.0745
	1.75	120	12.1	13718	1679	22825	1.434	365	468	30.56	21.51	51.35	67.9	45.5	.637	60	.1365	.0621
	1.75	144	10.1	13738	1814	22859	1.384	419	594	33.00	22.24	49.68	68.5	44.9	.722	59	.1138	.0517
	2.00	54	21.0	13880	1817	23095	1.628	187	189	27.03	16.87	65.49	76.5	35.9	.232	60	.2349	.1779
	2.00	64	17.9	13869	1700	23077	1.552	220	213	27.56	17.20	64.22	76.8	34.8	.256	61	.2003	.1501
	2.00	74	15.9	13902	1767	23132	1.516	253	248	27.22	17.41	63.44	70.8	37.3	.314	60	.1782	.1298
	2.00	86	13.4	13951	2022	23214	1.448	279	306	29.23	17.40	63.51	70.8	35.6	.317	60	.1502	.1117
	2.00	100	11.5	13867	2084	23074	1.410	313	365	30.74	17.63	62.66	71.1	35.0	.342	59	.1290	.0961
	2.00	120	9.5	13882	2250	23098	1.369	360	482	33.15	18.08	61.12	64.3	38.5	.431	58	.1068	.0801
	2.00	144	7.9	13891	2438	23113	1.336	409	615	36.37	18.65	59.23	65.0	38.4	.493	57	.0883	.0667
	2.25	54	17.8	14180	2058	23595	1.497	186	189	29.08	15.35	71.96	74.9	30.7	.169	61	.1990	.2220
	2.25	64	15.4	14458	2107	24058	1.473	227	223	27.94	15.55	71.07	75.2	30.5	.207	63	.1724	.1873
	2.25	74	13.2	14568	2280	24240	1.438	256	270	29.16	15.64	70.62	68.6	32.8	.249	63	.1474	.1620
	2.25	86	11.2	14538	2400	24190	1.400	289	315	30.74	15.76	70.09	68.8	32.1	.270	62	.1248	.1394
	2.25	100	9.5	14493	2517	24116	1.370	324	387	32.69	15.98	69.12	69.0	31.7	.296	61	.1060	.1199
	2.25	120	7.8	14511	2703	24145	1.342	373	512	35.33	16.34	67.63	62.4	35.1	.378	60	.0871	.0999
	2.50	54	15.9	15319	2414	25490	1.446	198	205	29.03	14.50	76.21	73.9	28.4	.163	68	.1773	.2706
	2.50	64	13.4	15442	2470	25694	1.436	234	239	29.46	14.67	75.33	74.1	28.4	.197	69	.1491	.2283
	2.50	74	11.1	15386	2623	25601	1.398	268	284	30.73	14.57	75.83	67.1	30.3	.231	68	.1242	.1975
	2.50	86	9.4	15375	2770	25583	1.374	304	338	32.22	14.68	75.26	67.3	30.0	.256	67	.1054	.1699
	2.50	100	8.0	15369	2902	25573	1.353	343	415	34.13	14.83	74.51	67.5	29.7	.285	66	.0889	.1461
	2.75	54	14.3	16431	2707	27340	1.420	204	216	30.19	13.96	79.13	73.2	27.1	.163	76	.1597	.3218
	2.75	64	11.7	16470	2795	27405	1.402	244	252	30.87	14.05	78.63	73.3	26.9	.193	76	.1312	.2715
	2.75	74	9.8	16495	2924	27446	1.380	284	302	31.76	14.05	78.64	66.4	29.2	.240	75	.1098	.2349
	2.75	86	8.2	16512	3053	27475	1.363	326	361	33.11	14.14	78.14	66.5	29.0	.272	75	.0923	.2021

Table 2b
Unit Geometry "L"

PUMP DEPTH (FT)
4500.

PUMP DISPLACEMENT (B/D) = 300.

ROD	DIA.	STROKE	SPM	PPRL	MPRL	STRESS	CLF	PT	CBM	ITE	PRHP	LE	S.EF	HPNP	CEI	GRD	N/NO	WF/SK
77	1.06	86	21.3	17430	3732	29001	1.661	207	430	44.19	30.99	32.08	80.7	63.8	1.194	79	.3916	.0587
	1.06	100	19.5	17161	3489	28555	1.624	246	599	42.94	32.84	30.27	81.0	65.8	1.495	78	.3588	.0504
	1.06	120	17.5	17829	3141	29666	1.625	310	736	41.60	35.83	27.75	79.7	73.0	2.368	87	.3209	.0420
	1.06	144	15.1	17875	2799	29742	1.649	346	911	44.00	36.46	27.27	79.8	75.4	2.819	89	.2771	.0350
	1.25	64	21.2	16387	3323	27266	1.393	174	290	36.15	21.20	46.90	80.6	36.7	.311	72	.3893	.1091
	1.25	74	19.5	16842	3200	28023	1.432	205	353	35.28	22.41	44.38	79.0	40.6	.453	77	.3582	.0943
	1.25	86	17.8	16804	2913	27961	1.443	236	391	35.58	23.76	41.85	79.4	43.2	.592	78	.3272	.0812
	1.25	100	16.1	17096	2916	28446	1.479	251	554	38.48	24.72	40.23	77.1	47.4	.748	81	.2961	.0698
	1.25	120	13.7	16976	3267	28246	1.453	260	715	43.46	24.65	40.35	77.1	46.5	.740	78	.2520	.0582
	1.25	144	11.4	16790	3277	27937	1.387	310	884	44.42	25.00	39.78	77.3	44.9	.814	76	.2100	.0485
	1.50	54	19.6	16610	4304	27637	1.272	142	245	37.44	16.58	59.97	79.4	26.6	.133	69	.3605	.1862
	1.50	64	17.5	16218	4069	26986	1.287	157	281	39.33	17.18	57.89	79.5	27.8	.157	67	.3219	.1571
	1.50	74	15.8	16528	3940	27501	1.364	182	345	37.91	17.38	57.22	76.9	30.8	.222	70	.2906	.1359
	1.50	86	13.9	16826	4095	27997	1.388	202	424	38.81	17.36	57.26	76.9	31.3	.259	72	.2558	.1169
	1.50	100	11.7	16770	4098	27904	1.423	207	593	45.17	17.44	57.00	77.0	32.2	.280	71	.2153	.1005
	1.50	120	10.0	16714	4130	27810	1.427	226	752	50.37	18.14	54.80	77.5	33.4	.329	71	.1839	.0838
	1.50	144	8.3	16806	4298	27964	1.410	245	955	56.76	18.39	54.06	77.7	33.4	.359	70	.1531	.0698
	1.75	54	16.8	16837	4820	28015	1.395	139	242	38.53	14.31	69.48	78.7	25.4	.119	68	.3092	.2534
	1.75	64	14.7	17561	4641	29220	1.435	164	327	37.33	14.30	69.54	78.7	26.1	.155	75	.2694	.2138
	1.75	74	12.6	17448	4528	29032	1.469	129	419	55.15	14.32	69.42	78.7	26.7	.128	75	.2318	.1849
	1.75	86	10.7	17181	4708	28587	1.499	165	471	51.38	14.47	68.74	78.8	27.5	.170	71	.1973	.1591
	1.75	100	9.4	17487	4641	29096	1.542	210	627	47.63	14.99	66.32	74.5	31.0	.266	75	.1728	.1368
	1.75	120	7.8	17347	4896	28863	1.533	218	796	55.99	15.08	65.92	74.6	31.0	.274	72	.1427	.1140
	2.00	54	14.8	18222	5251	30320	1.694	81	342	67.10	12.95	76.81	79.8	27.5	.090	78	.2727	.3310
	2.00	64	12.7	18410	5075	30633	1.662	120	383	54.11	13.08	76.05	79.8	27.2	.132	81	.2326	.2793
	2.00	74	10.5	18221	5226	30318	1.673	154	414	50.63	13.01	76.42	77.8	28.0	.173	78	.1922	.2415
	2.00	86	9.0	18447	5171	30694	1.712	197	485	46.72	13.23	75.17	72.1	31.4	.261	81	.1656	.2078
	2.25	54	14.1	19655	5880	32704	2.057	92	352	62.68	12.97	76.68	79.8	33.4	.163	89	.2583	.4189
	2.25	64	11.3	19807	5560	32957	1.954	141	400	49.77	12.63	78.76	77.4	31.9	.222	93	.2073	.3535
	2.25	74	9.2	19560	5530	32545	1.938	179	426	47.67	12.46	79.81	70.9	34.1	.290	90	.1687	.3057

Table 3a
Unit Geometry "L"

ROD NO. 76 — PUMP DEPTH (FT) 5000. — PUMP DISPLACEMENT (B/D) 600.

DIA.	STROKE	SPM	PPRL	MPRL	STRESS	GRDC	GRDD	CBM	PT	PRHP	LE	S.EF	CLF	ITE	HPNP	PIX	N/NO	WF/SK
1.50	100	19.8	19037	3748	31676	165	96	661	314	36.5	60.5	72.2	1.459	37.02	73.8	.2873	.3730	.1538
1.50	120	17.9	16992	3629	31602	165	96	792	343	38.0	58.1	70.4	1.472	38.93	79.5	.3372	.3385	.1281
1.75	64	22.9	17614	3211	30472	161	94	346	250	32.3	68.4	73.4	1.269	35.40	55.9	.1369	.4302	.3234
1.75	74	20.6	18891	3153	31442	168	98	402	279	32.7	67.6	72.0	1.287	35.69	58.5	.1646	.3872	.2797
1.75	86	19.0	18757	2831	31209	168	98	442	317	32.9	67.1	76.2	1.292	34.52	55.8	.1853	.3555	.2406
1.75	100	17.0	18833	2626	31336	172	100	579	335	33.0	67.0	77.2	1.309	36.40	55.9	.1896	.3188	.2069
1.75	120	15.0	19318	2399	32143	187	107	720	405	33.8	65.4	74.9	1.387	34.98	62.6	.2978	.2813	.1725
1.75	144	12.3	19480	2277	32413	193	110	923	462	33.4	66.1	75.9	1.401	37.12	61.7	.3175	.2302	.1437
2.00	64	20.6	19396	4466	32274	166	95	366	233	28.8	76.8	77.1	1.359	37.70	50.7	.1078	.3840	.4170
2.00	74	18.7	19437	3917	32341	173	99	413	271	28.6	77.3	79.1	1.304	35.36	47.1	.1188	.3499	.3607
2.00	86	16.8	20113	3373	33466	199	111	464	322	29.2	75.7	75.3	1.356	33.94	52.5	.1795	.3139	.3103
2.00	100	15.0	20477	3034	34072	215	117	625	381	29.5	74.9	72.0	1.403	32.47	57.5	.2594	.2802	.2669
2.00	120	12.6	20497	2769	34106	218	119	783	452	29.8	74.1	77.0	1.415	33.07	54.8	.2935	.2346	.2224
2.00	144	10.3	20233	3017	33667	207	114	977	499	30.2	73.1	74.9	1.403	37.18	56.6	.2956	.1914	.1853
2.25	74	17.1	21651	4848	36025	233	121	470	295	26.6	83.0	74.9	1.509	33.24	53.7	.1881	.3179	.4501
2.25	86	15.6	22000	4225	36607	256	130	535	361	27.2	81.3	76.5	1.550	30.45	55.1	.2745	.2899	.3873
2.25	100	13.6	21685	3687	36083	250	129	681	418	27.0	81.8	74.9	1.556	30.01	36.1	.3222	.2524	.3331
2.25	120	10.6	21863	3851	36379	256	131	817	426	27.3	81.0	74.1	1.513	38.16	55.7	.2544	.1966	.2776
2.25	144	8.8	21613	3626	36295	257	132	1110	534	27.3	80.9	76.4	1.544	36.74	55.2	.3344	.1634	.2313
2.50	86	14.4	23450	4615	39026	321	149	593	397	24.6	89.9	78.1	1.798	26.96	56.5	.3914	.2684	.4719
2.50	100	12.6	23424	4627	39808	355	159	762	465	25.2	87.6	76.6	1.790	27.17	58.9	.4940	.2337	.4059
2.50	120	9.4	23449	4262	39017	330	153	1015	397	25.3	87.2	74.9	1.715	42.57	58.1	.2499	.1758	.3382
2.50	144	7.8	23587	4158	39246	341	157	1258	541	25.1	88.2	77.9	1.704	37.47	54.8	.3609	.1449	.2819
2.75	100	12.2	26096	5166	43421	559	200	836	524	24.1	91.6	78.8	2.093	23.75	64.1	.8434	.2279	.4828
2.75	120	6.8	25766	4677	42872	527	197	1118	446	23.8	92.9	77.0	1.937	38.23	59.8	.3752	.1639	.4023
2.75	144	7.0	25724	4710	42802	521	196	1333	611	23.9	92.5	78.9	1.879	35.16	56.8	.5168	.1305	.3352

Table 3b
Unit Geometry "M"

ROD NO. 77 — PUMP DEPTH (FT) 5000. — PUMP DISPLACEMENT (B/D) 600.

DIA.	STROKE	SPM	PPRL	MPRL	STRESS	GRDC	GRDD	CBM	PT	PRHP	LE	S.EF	CLF	ITE	HPNP	PIX	N/NO	WF/SK
1.50	100	19.5	22251	2234	37023	297	149	522	607	43.8	50.4	76.2	2.018	23.28	115.9	2.6935	.3980	.1241
1.50	120	17.7	23543	2184	39240	375	172	704	776	47.1	47.0	73.5	2.127	21.53	136.1	5.2398	.3622	.1034
1.50	144	15.7	24037	1996	39995	412	183	894	950	48.2	45.8	64.6	2.220	20.44	165.7	8.9756	.3194	.0862
1.75	74	19.8	21676	4461	36067	239	124	406	385	34.4	64.3	74.8	1.787	28.32	82.1	.6733	.4045	.2283
1.75	86	18.3	22476	3756	37398	285	141	466	489	36.2	61.0	74.4	1.903	25.53	92.7	1.2476	.3728	.1964
1.75	100	16.6	22668	3685	38050	306	148	566	583	36.6	60.5	72.1	2.022	23.72	102.6	1.9315	.3395	.1689
1.75	120	14.2	23792	4074	39588	356	161	773	714	36.6	60.4	74.3	2.036	22.72	100.2	2.5289	.2900	.1408
1.75	144	11.7	22803	4361	37942	292	142	933	782	37.1	59.6	77.8	1.780	25.57	84.8	1.7679	.2381	.1173
2.00	64	19.1	22109	5278	36788	245	124	363	310	30.6	72.2	74.8	1.654	32.44	67.7	.3288	.3905	.3448
2.00	74	17.4	22816	4953	37964	263	137	418	395	31.0	71.4	75.1	1.775	28.39	73.2	.5785	.3548	.2982
2.00	86	15.8	23514	4510	38792	318	149	482	485	31.5	70.1	74.6	1.941	25.97	82.0	.9894	.3215	.2566
2.00	100	14.2	23883	4721	39738	350	157	586	564	32.1	68.9	76.5	1.950	25.18	81.8	1.2409	.2902	.2207
2.00	120	11.2	23235	5170	38660	302	142	763	653	31.0	71.2	77.2	1.763	26.78	70.9	.9951	.2280	.1839
2.00	144	9.5	23951	5068	39852	348	156	977	813	31.5	70.2	76.3	1.692	25.79	69.7	1.2685	.1930	.1532
2.25	64	17.2	23666	5752	39411	319	145	366	324	28.8	76.6	78.1	1.631	32.51	60.2	.3029	.3515	.4364
2.25	74	15.7	24251	5170	40351	368	160	423	390	29.2	75.6	77.3	1.790	30.02	67.7	.5058	.3208	.3774
2.25	86	14.2	24052	5143	40021	358	157	479	462	29.4	75.2	77.4	1.811	28.18	68.8	.6537	.2897	.3247
2.25	100	12.7	24724	4878	41138	412	172	565	560	30.3	73.0	77.7	1.837	26.84	71.5	.9295	.2588	.2793
2.25	120	9.5	24271	5475	40384	364	158	756	670	28.1	78.6	77.3	1.676	27.74	61.0	.7628	.1946	.2327
2.25	144	8.1	24454	5656	40690	374	160	967	812	28.8	76.6	75.8	1.647	27.59	62.7	.9697	.1654	.1939
2.50	74	14.6	25269	5587	42046	448	177	396	339	26.8	82.5	77.4	1.674	33.97	57.9	.2964	.2989	.4659
2.50	86	12.9	25758	5482	42659	506	189	438	422	28.3	78.0	77.4	1.729	32.72	63.3	.4675	.2636	.4009
2.50	100	11.3	25921	5491	43129	526	193	538	525	28.2	78.3	76.9	1.737	29.97	63.8	.6432	.2304	.3448
2.50	120	8.5	25736	5931	42822	492	185	773	700	26.9	82.2	77.8	1.647	28.50	56.9	.7200	.1732	.2873
2.50	144	7.0	25965	5956	43203	520	190	973	849	27.5	80.5	75.9	1.630	29.09	59.0	.9055	.1429	.2394
2.75	66	11.9	27329	5856	45471	771	226	468	433	27.3	81.0	77.1	1.691	33.41	59.8	.4429	.2422	.4851
2.75	100	10.4	27632	5671	45976	861	238	493	499	27.2	81.1	78.1	1.696	32.93	59.1	.5184	.2129	.4172
2.75	120	7.8	27546	6135	45867	824	230	771	723	26.0	85.1	76.1	1.643	29.18	56.0	.7396	.1582	.3477