ROD PUMP DESIGN USING PERSONAL COMPUTERS

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INTRODUCTION

Design calculations for sucker rod pumping systems (conventional units) using the API RP 11L Recommended Practice[1] is now the "standard" for the oil industry. Prior to the RP 11L publications, the Mills, Marsh, and Coberly formulas were used. It was obvious to many designers that a more accurate method was needed. In 1954 a group of users and manufacturers undertook a study of the complex problems associated with sucker rod pumping. The services of Midwest Research Institute were retained to study these problems. Based on their correlations and test data obtained from an electrical analog study of sucker rod pumping systems, the design procedures outlined in API RP 11L were developed. Since its development, API RP 11L has become widely used. In the past two years, it has been programmed for use on the personal computers.

In general, API RP 11L gives reasonably close answers on an average for conventional units for the assumed conditions. However, the answer for a specific case can easily exceed ? percent for loads and 10 percent for peak torques. RP 11L does a good job of predicting the percentage change by altering pump conditions. Improvements that are predicted by the calculations will often be achieved in practice.

The API RP 11L method has a number of simplifications and assumptions that must be recognized. The work was based on an "average" conventional unit geometry, running with only medium slip, having complete pump fillage, and having no abnormal dampening or friction. In addition the assumptions were made that fluid acceleration was negligible and that there were no mechanical problems. For simplification, one average set of design curves were developed - regardless of the sucker rod design, dampening, actual motion, or pump fillage.

There are other design methods[2] that may be better - especially if the case does not fit the assumed conditions outlined in API RP 11L. Designs with computers using the anticipated down hole well conditions and the wave equation to calculate the surface load under stabilized pumping are used successfully by Shell Oil Company[3] and others. Such programs currently are proprietary and are generally longer and more complicated - taking more computer time to run. Such programs are commercially available and, when applicable and justified, they should be used. Also they can be used to check the validity of the API RP 11L method. The best approach is to check the calculations with good measured data.

GETTING STARTED

Computer programs can be used to do the design calculations; however, the selection of the type artificial lift, the basic equipment used and the analysis of the calculated data are still up to the designer. The designer must first come up with a priority list. Most designers plan on a system that will result in the highest present value profit after tax on the project. Production, operating cost and capital cost[4] all must be considered. An optimum pumping condition of stroke length, pump diameter and SPM needs to be selected; however, the minimum horse power, loads and peak torque do not occur at the same pumping condition. The final selection is often a compromise - using only large enough equipment to get the production without overloading the system's components. In addition a system should be selected that will operate efficiently and without causing any unusual operating problems.

It is recommended that the designer select a displacement so that the well's production can be obtained in about 18 hours each day. This practice will allow for some pump wear and for some down time without loss of production. Theory and experience show that larger pump sizes are more efficient, so they should be selected. A good selection for deeper wells is a non-dimensional fluid load (Fo/Skr) in the 0.4 to 0.6 range. Also for such wells a non-dimensional pump speed (N/NO') in the range of .3 to .4 should be chosen.

The tubing size is important in the design and should not just be the size that is currently in the well. Rod pumps are preferable over tubing pumps. Tubing pumps may be necessary in higher volume wells. On-off tools with large plungers should be used only as a last resort.

The rod selection is also very important. For shallow wells, rod loads are not the governing factor in design and API C rods are recommended in most cases. For moderately deep wells, API C or D rods are used; whereas, deeper wells (greater than 8000 feet) may require special high stress type rods. Deeper wells also require tapered rod strings. Select a rod type and combination that will fit in the tubing, will not be overloaded, and that will permit an overall efficient system.

An excellent way to get started is to use API bulletin 11L3[5] which is a print-out of many depth-rate pumping conditions. Select a rate that is 25 percent higher than the well's production capability and a depth that is approximately equal or exceeds the planned pump depth. The designer will find that a number of choices are available to pick from and must now decide what are the more important design considerations. For shallow wells, where rod loads are often low, the lowest polished rod horse power with the least expensive unit may be the best selection. In deep wells, an acceptable rod stress or a relatively low peak torque may be the most important design consideration. Longer stroke units with large pumps have the lowest polished rod horsepower; however, long stroke units require larger gear boxes and require a higher capital cost.

COMPUTER PROGRAM

Once the designer has a reasonably good idea of the type and size of the rod pumping system, the use of a computer program will simplify and speed up the design procedure. The computer program should accurately define the production and loads and should give the user enough information to make the final equipment selection. As pointed out in API RP 11L, the final solution to the design is reached through trial and error methods. Doing the design by hand is a long tedious process even with a good calculator.

A number of computer programs for sucker rod pumping system design have been developed in the past two years for use on the personal computer. The designer must select one that best fits his needs. One should know what the computer program uses to make the calculation and what assumptions are made. Also most programs have some limitations and peculiarities that eventually surface. The following is a discussion on a computer program (named "APIROD") that was donated to the Society of Petroleum Engineers and can be purchased at a reasonable price (from the SPE in Dallas) to run on the IBM personal computer. This discussion should help the designer know more about how most of such programs work.

"APIROD" is a program to make design calculations for sucker rod pumping systems (conventional units) using the method outlined in API RP 11L. In general, the same nomenclature is used and the method outlined in API RP 11L is closely followed. The program can be used for design or for surveillance. (A flow chart for the program is shown in Figure 1.) As compared to API RP 11L there are some minor changes and some enhancements - but the same answers should be obtained. Oil field units are used throughout.

The program requires the same basic input data as required for API RP 11L. The original program was conversational and required line by line answers to data questions. The new modified version is a full screen that allows user to step rapidly through the data - changing items as needed (see Fig. 2). The program does five pumping speeds at one time. The program permits overall pump efficiencies less than 100%. The modified version asks for tubing head pressure and if no rods lengths are input, then the program assumes that the API percentages for a given API rod number are desired. The user has a option to edit and change any or all input items.

The program calculates the factors that must normally be looked up and then calculates the non-dimensional variables. Non-dimensional fluid loads (Fo/Skr) greater than 0.6 are assumed equal to 0.6 and the calculations are probably in error. Also non-dimensional pumping speeds (N/No') greater than 0.5 are not allowed and the program assigns any N/No' greater than .5 to .499.

After doing these preliminary calculations, APIROD calculates the down hole stoke (Sp) and then the down hole displacement in barrels per day. (A typical print-out of these calculations is shown in Fig. 3.) As in API RP 11L the user can continue or can change one or more input variables to obtain a different displacement or more reasonable variables.

Next the program determines various parameters. The rod weight in air is calculated and to that value 100 pounds mass is added to account for the polished rod and the pump plunger. The 100 pound addition is not done in API RP 11L. This is a minor program enhancement. This change will result in a slight increase to the standing valve weight (Wrf) and to the traveling valve weight (Wrf + Fo). Also this addition will increase the value of Wrf/Skr.

One of the best features of the program is the finding of the non-dimensional factors (F1/Skr, F2/Skr, 2T/S2kr, F3/Skr, Ta) that normally require look-up on a graph. In the computer program, a table look-up is used and a linear interpolations first between non-dimensional speed and then between non-dimensional fluid loads are made. These findings prove to be very close to those picked off the API RP 11L graphs by an experienced designer. Additional non-dimensional fluid curves were added for Fo/Skr values of 0 and .6. The addition of the Fo/Skr values for 0.6 were relatively easy but for zero caused some problems. More about this under shallow pumping.

The adjustment for peak torque graph shown in API RP 11L Figure 4.6 was re-plotted for use with the APIROD program. The re-plot is shown in Figure 5.. The graph was done similarly to other graphs plotting the adjustment factor vs the non-dimensional speed for various non-dimensional fluid loads. The data were then altered slightly to make the curve relatively smooth. This graph is linear and linear interpolation can be used.

After finding the non-dimensional parameters, the program solves for the operating characteristics. Peak polished rod loads (PPRL), minimum polished rod load (MPRL), polished rod horsepower (PRHP), counter-balance (CBE), and peak torque (PT) are calculated using API RP 11L formulas. (A typical print-out of these calculations is shown in Figure 3.) In addition a load peak torque (LPT) is calculated using the formula:

$$LPT = \frac{(STROKE)}{2} * \frac{(PPRL - MPRL)}{2} * 1.10$$

This peak torque approach assumes that the peak and minimum loads occur near the center of the stroke. The unit torque factor at mid-stoke is assumed equal to half the stroke length and the well is ideally counter-balanced. A 10 percent safety factor is applied. The load peak torque (LPT) should be relatively close (but slightly on the high side) to the API peak torque and is a check.

The program continues and will find the rod stress for K, C, or D type API rods as well as for the Oilwell E rod. Input the type rod and the program calculates the maximum and minimum stress in the top rod. APIROD also finds the allowed stress based on the API modified Goodman diagram[6] - assuming an SF equal to 1.0 for the API rods. A load ratio is calculated to aid in the analysis. (A typical print-out of the calculation is shown in Figure 4.)

The program will next calculate the approximate characteristics for the Mark II and the air-balanced units. These equations used are those recommended by Lufkin[7] and are not in API RP 11L. This approach alters the peak polished rod load down slightly and the minimum polished rod load downward. Peak torques are generally decreased for the air balanced unit and are significantly reduced for the Mark II unit. The designer can compare these results with those for the conventional unit (see Fig. 4).

The user can get a list of the input data. Next the program allows the input data to be edited or to run another case. Often it is desirable to change one or more items and find out if a better overall design is achieved.

Any computer program to be worthwhile must get the right answers. A comparison of the results is shown in Table A. For the API RP 11L example and the Gipson-Swaim[8] example design problems, only minor differences occur. The program API ROD is accurate for API RP11L calculations.

PROBLEM AREAS

There are a few problems that arise in the design of rod pumping systems with API RP 11L. Mostly these are for conditions different from those assumed by RP 11L. What should the designer do for high slip prime movers, special geometry units, deviated wells, and shallow wells?

As pointed out in API RP 11L, a higher slip prime mover normally results in a slight decrease in maximum loads and a slight increase in minimum loads. Dynamometer cards become more oval in shape and rapid load changes become more gradual with higher slip. A more dramatic decrease takes place in peak torque if the units is properly counter balanced. However, down hole pump stroke may decrease which will result in a lower production rate. Also overall power consumption can actually increase - increasing energy costs. Thus the designer must decide what is most beneficial. Use of the more sophisticated computer programs which will analyze slip may give the designer a better answer. I recommend that you use actual field data for the specific case. Use of the API RP 11L will, in general, give results that are on the high side.

The designer should be careful in using API RP 11L for design of special geometry units such as the Lufkin Mark II. Maximum and minimum polished rod loads will be about the same but peak torques will significantly differ from conventional units. The formulas recommended by Lufkin seem to be reasonable and thus the computer program should give the designer a good basis to decide whether special geometry units should be further evaluated. Again the more sophisticated computer programs may be worthwhile.

The program can be successfully used to design for directional wells that are to be pumped with conventional sucker rod systems. There are a couple of key points in making the design to be considered: friction and gradient. Excessive friction cannot be tolerated and the system must be properly designed. Use as large a tubing as feasible and anchor the tubing in tension. Consider rod guides in the worst dog-leg portions of the hole. Also check to ensure that the stuffing box friction is minimal. The gradient (or the fluid level) must be altered in the design. Use the actual measured depth as the pump depth. Calculate the pressure on the pump by using the true vertical depth and divide by the measured depth to get a pseudo gradient. Then use APIROD to analyze the sucker rod pumping system the same as for straight holes.

SHALLOW WELLS

Use of API RP 11L to design shallow sucker rod pumping systems was found to be inaccurate by many designers. A study of the API RP 11L design method revealed several sources of errors. We need to review these problems and make some compensations for shallow wells.

Probably the most significant error results since the design curves for peak and minimum polished rod loads, peak torque and horsepower ignored shallow well conditions. The lower limit for the non-dimensional load (Fo/Skr) was 0.1; however, for shallow wells the value of Fo/Skr may be 0.01 or even lower with corresponding low non-dimensional speeds (N/No'). To solve this problem, a number of designers and programmers drew in lines for non-dimensional loads of zero (Fo/Skr = 0). This appears easier than it actually is since at very shallow depths the value of Skr becomes very large and the value of Fo/Skr approaches zero for all speeds. A better approach is to draw in a non-dimensional load of 0.01. These low values were obtained from Shell's wave equation computer program. The results were checked with actual data from a few shallow wells. Non-dimensional load values less than .01 are assumed equal to 0.01. The revised values are listed in Table B.

Another source of error for shallow wells in API RP 11L, was the omission of flow line pressure. This can be compensated for by adjusting the gradient, but few designers have used this practice. For example, ignoring a 100 psig flow line pressure on 1000 foot wells with a 2.75 plunger will result in a 14 percent error in the traveling valve load. The revised APIROD program permit entering the flow line pressure.

As previously covered in the design section, API RP 11L ignored the weight of the polished rod and the pump plunger. This is often a load of 100 pounds mass that needs to be added to the weight of the rods (W). This is very minor for deeper wells but can cause error of 9 percent in the standing valve load in a 1000 foot well with 5/8 inch rods.

Fluid acceleration, viscosity, and gas interference can alter significantly the loading conditions in shallow wells. Often it is the shallow wells that have the large plungers which produce at high enough rates for fluid acceleration to become important. It is also the shallow well that normally has the high (greater than 200 CP) oils that introduce serious errors. Also in shallow thermal wells, pump fillage is often less than 75 percent and this can result in errors. These type wells will require more sophisticated computer programs for design or ample field data to adjust the API RP 11L procedure.

CONCLUSIONS

1. The designer must first select an approximate displacement with the corresponding tubing and rod strings. Use of API Bulletin 11L3 will aid the designer in getting started.

2. The program APIROD was revised and is now more user friendly. It calculates the operating characteristics for pumping systems and can be used for design or surveillance.

3. APIROD, which runs on an IBM personal computer, will give accurate results using the procedures outlined in API RP 11L.

4. The program will give conservative results if high slip prime movers are used. It can be used to predict loads for air-balanced units and Mark II units.

5. The program was revised to give better results for shallow wells.

6. For conditions that are significantly different than outlined in API RP 11L, the more sophisticated computer programs may give more realistic values.

7. Actual field data should be collected and used to evaluate the design.

REFERENCES

(1) API RP 11L, "API Recommended Practice for the Design Calculation for Sucker Rod Pumping Systems (Conventional Units)", Third Edition, February, 1977, Supplement 1, March 1979

(2) Clegg, Joe D., "Gas Interference in Rod Pumped Wells", Southwestern Petroleum Short Course, April 1979.

(3) Gibbs, S.G., "Predicting the Behavior of Sucker Rod Pumping Systems", JPT, May 1963

(4) Clegg, Joe D., "Artificial Lift-Producing at High Rates", Southwestern Petroleum Short Course, April 1985

(5) API Bulletin 11L3, "Sucker Rod Pumping System Design Book"

(6) API RP 11BR, "API Recommended Practice for the Care and Handling of Sucker Rods", Sixth Edition, June 1984

(7) Griffin, Fred, "An Update on Pumping Unit Sizing as Recommended by API RP 11L", Petroleum Society of CIM, Banff, Canada, June 1975

(8) Gipson, F. W. and Howard Swain, "The Beam Pumping Design Chain", Southwestern Petroleum Short Course, April 1985

ACKNOWLEDGMENTS

I wish to thank Shell Oil Company for permission to publish this paper.

Table A
Calculation Comparison

	API RP 11L	GIBSON-SWAIM
PUMPING SPEED-SPM	16	10.22
LENGTH OF STROKE-INCHES	54	145
PLUNGER DIAMETER-INCHES	1.5	1.75
SPECIFIC GRAVITY	0.9	1.02
PUMP DEPTH-FEET	5000	8715
FLUID LEVEL-FEET	4500	8715
RODS:7/8"-FEET	1690	3268
RODS:3/4"-FEET	3310	5447
TUBING ANCHORED	NO	YES

	RP 11L	APIROD	G-S	APIROD
1.Wr	1.833	1.833	1.855	1.8553
2.Er	.804E-6	.8039E-6	.795E-6	.795E-7
3.Fc	1.082	1.083	1.088	1.089
4.Et	.307E-6	.3067E-6	.221E-6	.221E-6
5.Fo	3098	3098	9256	9255
6.1/kr	4.02E-3	4.0198E-3	.6928E-4	.693E-4
7.Skr	13433	13433	20928	20922
8.Fo/Skr	.231	.2306	.4423	.44236
9.N/No	.326	.327	.364	.364
10.N/NO'	.301	.302	.334	.334
11.1/kt	1.535E-3	1.5337E-3	2.21E-5	1.92E-3
12.Sp/S	.86	.865	.75	.763
13.Sp	41.7	42	108.6	111
14.PD	175	176	396.3	405
15.W	9165	9267	16166	16268
16.Wrf	8110	8199	14055	14144
17.Wrf/Skr	.604	.61	.672	.676
18.F1/Skr	.465	.466	.68	.6788
19.F2/Skr	.213	.2149	.245	.244
20.2T/S2kr	.37	.37	.44	.437
21.F3/Skr	.29	.292	.43	.426
22.Ta	.997	.991	1.03	1.023
23.PPRL	14356	14458	28286	28345
24.MPRL	5249	5312	8928	9039
25.PT	133793	132987	687631	678107
26.PRHP	8.5	8.57	33.74	33.42
27.CBE	10239	10332	19804	19897

Table B
Non-dimensional Factors

N/No	Sp/S Fo/Skr=.01	F1/Skr Fo/Skr=.01	F2/Skr Fo/Skr=.01	2T/S2kr Fo/Skr=.01	F3/Skr Fo/Skr=.01
0.000	1.000	0.010	0.000	0.030	0.040
0.050	0.993	0.018	0.012	0.045	0.045
0.100	1.005	0.040	0.028	0.060	0.055
0.150	1.020	0.065	0.049	0.080	0.065
0.200	1.040	0.094	0.083	0.110	0.080
0.250	1.080	0.122	0.080	0.120	0.100
0.300	1.120	0.190	0.148	0.160	0.120
0.350	1.060	0.253	0.281	0.280	0.180
0.400	1.160	0.291	0.261	0.260	0.180
0.450	1.260	0.444	0.300	0.310	0.240
0.500	1.440	0.580	0.415	0.410	0.333

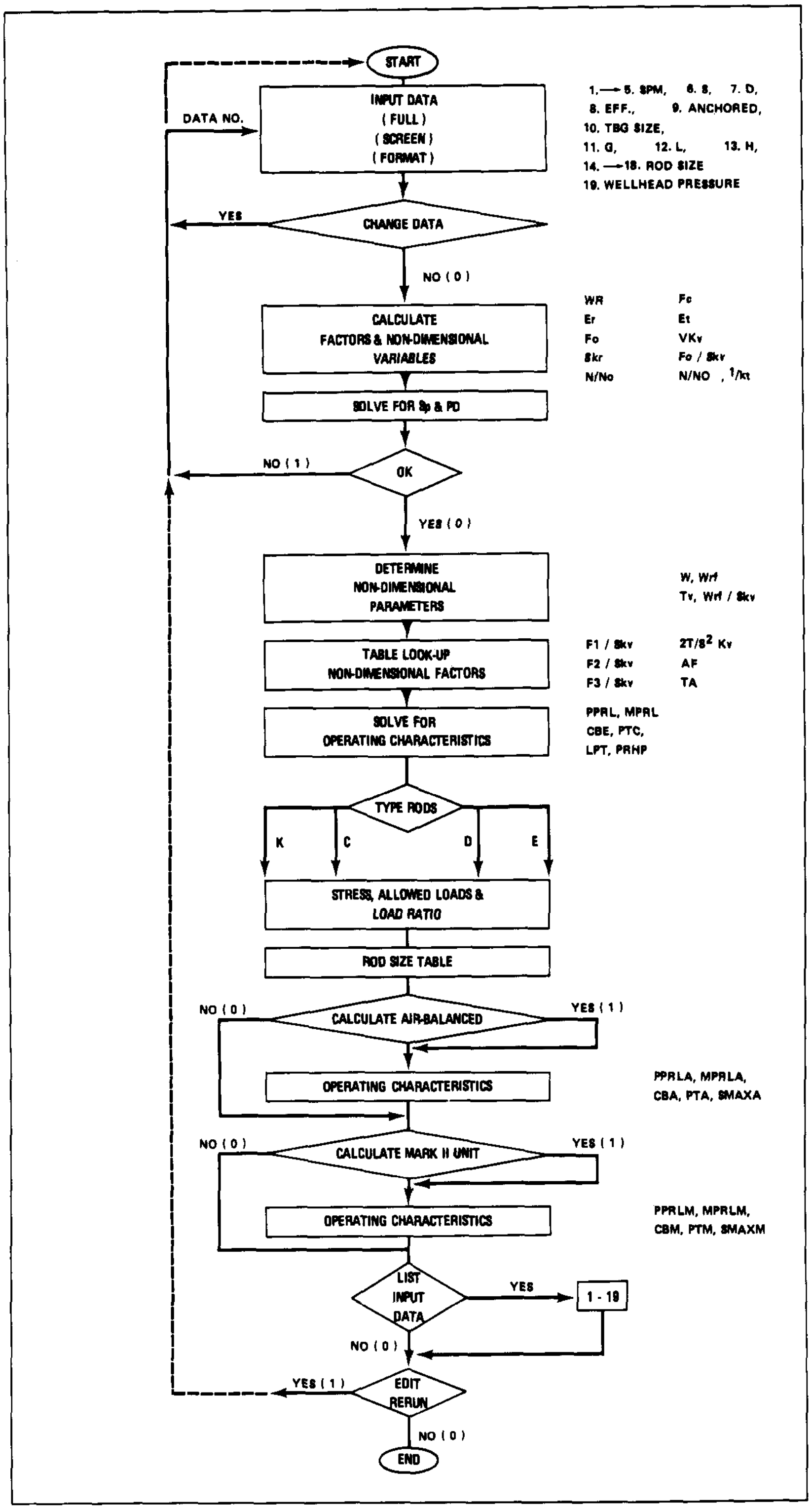

Figure 1 - APIROD flow chart

PROGRAM API-ROD WELL:LUFKIN EXAMPLE BY:JOE CLEGG DATE:01-07-1986

DATA NO. INPUT VARIABLES	BASE	CHANGE
1. N: FIRST PUMP SPEED	: 6	
2. N: SECOND PUMP SPEED	: 6.5	
3. N: THIRD PUMP SPEED	: 7	
4. N: FOURTH PUMP SPEED	: 7.3	
5. N: FIFTH PUMP SPEED	: 7.6	
6. S: LENGTH OF STROKE IN INCHES =	168	
7. D: PLUNGER DIAMETER IN INCHES =	1.75	
8. EFF: EFFICIENCY OF PUMP, A RATIO=	1	
9. IF TUBING ANCHORED TYPE 0; IF NOT TYPE 1	0	
10. TBG:TUBING SIZE (OD) IN INCHES=	2.875	
11. G: SPECIFIC GRAVITY OF FLUID=	1	
12. L: PUMP DEPTH IN FEET=	8650	
13. H: FLUID LEVEL IN FEET FROM SURFACE =	8650	
14. ROD LENGTH OF 9/8 IN. RODS IN FEET	0	
15. ROD LENGTH OF 8/8 IN. RODS IN FEET	2543	
16. ROD LENGTH OF 7/8 IN. RODS IN FEET	2595	
17. ROD LENGTH OF 6/8 IN. RODS IN FEET	3511	
18. ROD LENGTH OF 5/8 IN. RODS IN FEET	0	
19. WELLHEAD TUBING PRESSURE IN PSIG	0	

ENTER DATA NO. TO BE CHANGED------------------TYPE 0 TO RUN?

Figure 2

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PROGRAM API-ROD WELL:LUFKIN EXAMPLE BY:JOE CLEGG DATE:01-07-1986

CALCULATE FACTORS AND NON-DIMENSIONAL VARIABLES

Wr = 2.184429 LB/FT Fc = 1.165
Er = 6.99395E-07 IN/LB-FT Et = 2.207506E-07 IN/LB-FT
FO = 9006 LBS 1/Kr = 6.049067E-03 IN/LB
SKr = 27772 LBS FO/SKR = .3242835 MUST NOT EXCEED .6

NO/NO = .212 .229 .247 .258 .268
IF NO/NO OR N/No'IS > THAN .5; THEN PROGRAM CHANGES VALUE TO .499
1/Kt = 1.909492E-03 IN/LB TUBING STRETCH IF UNANCHORED = 17.19689 INCHES
SOLVE FOR SP AND PR

ITEM	N(1)	N(2)	N(3)	N(4)	N(5)
SPM =	6	6.5	7	7.3	7.6
NO/NO =	.212	.229	.247	.258	.268
N/NO' =	.182	.197	.212	.221	.23
SP/S =	.756	.77	.773	.772	.772
SP (IN.)=	127	129	130	130	130
PD (BPD)=	272	299	325	339	353

IF PUMP DISPLACEMENT NOT APPROPRIATE, CHANGE INPUT VALUES
to copy screen press <shift PrtSc>: TYPE 0 TO CONTINUE; OTHERWISE TYPE 1?

CALCULATE NON-DIMENSIONAL PARAMETERS AND MAKE TABLE LOOK-UP

W = 18995 LBS Wrf (Sv)= 16563 LBS Tv = 25569 LBS WRF/SKR = .596

ITEM	N(1)	N(2)	N(3)	N(4)	N(5)
F1/SKr =	.4591	.4693	.4801	.4895	.499
F2/SKR =	.1334	.1471	.1616	.1699	.1773
2T/S2Kr=	.315	.325	.336	.343	.35
F3/SKr =	.271	.278	.286	.288	.288
AF =	.003	0	-.003	-.004	-.005
Ta =	1.009	1	.991	.988	.985

CALCULATE OPERATING CHARACTERISTICS FOR CONVENTIONAL UNITS

ITEM	N(1)	N(2)	N(3)	N(4)	N(5)	
SPM =	6	6.5	7	7.3	7.6	
PPRL =	29313	29596	29896	30157	30421	LBS
MPRL =	12858	12477	12075	11844	11639	LBS
CBE =	22329	22329	22329	22329	22329	LBS
PTC =	741460	758175	776782	790564	804249	IN-LB
LPT =	760221	790897	823330	846060	867728	IN-LB
PRHP =	19.19	21.33	23.63	24.82	25.84	HP

to copy screen press <shift PrtSc>:

Figure 3

```
to copy screen press <shift PrtSc>:  INPUT ROD TYPE: K, C, D, or E :? D

ROD TABLE FOR TYPE  D RODS

ITEM       N(1)          N(2)          N(3)          N(4)          N(5)
SPM     =  6             6.5           7             7.3           7.6
SMAX    =  37341         37701         38084         38416         38752  PSI
SMIN    =  16379         15894         15382         15087         14826  PSI

ALLOWED=   37963         37690         37402         37236         37089  PSI
LOAD R =   .9836156      1.000292      1.018234      1.03169       1.044838

SIZE (1/8)= 9/8          8/8          7/8          6/8          5/8 IN.
LENGTH =     0            2543         2595         3511          0 FT.
% RATIO =    0            .2939884     .3           .405896       0 FT.

to copy screen press <shift PrtSc>


FOR AIR BALANCED UNIT CALCULATION TYPE 1; TO SKIP TYPE 0:? 1
OPERATING CHARACTERISTICS FOR AIR BALANCED UNITS

ITEM       N(1)          N(2)          N(3)          N(4)          N(5)

PPRLA  =   28751         28992         29247         29469         29693  LBS
MPRLA  =   12296         11873         11425         11156         10910  LBS
CBA    =   21754         21658         21556         21531         21519  LBS
PTA    =   711802        727848        745711        758942        772079 IN-LB
SMAXA  =   36625         36932         37257         37540         37825  PSI

to copy screen press <shift PrtSc>
FOR MARK II UNIT CALCULATION TYPE 1; TO SKIP TYPE 0:? 1
OPERATING CHARACTERISTICS FOR MARK II UNITS

ITEM       N(1)          N(2)          N(3)          N(4)          N(5)
PPRLM  =   28377         28589         28814         29010         29208  LBS
MPRLM  =   11920         11470         10990         10700         10430  LBS
CBM    =   22504         22321         22126         22040         21967  LBS
PTM    =   507637        538598        571578        593850        615192 IN-LB
SMAXM  =   36149         36419         36705         36955         37207  PSI
DO NOT USE LESS THAN ONE SIZE SMALLER REDUCER THAN FOR CONVENTIONAL UNIT
to copy screen press <shift PrtSc>:FOR INPUT DATA LIST TYPE 1;IF NOT TYPE 0:?
```

Figure 4

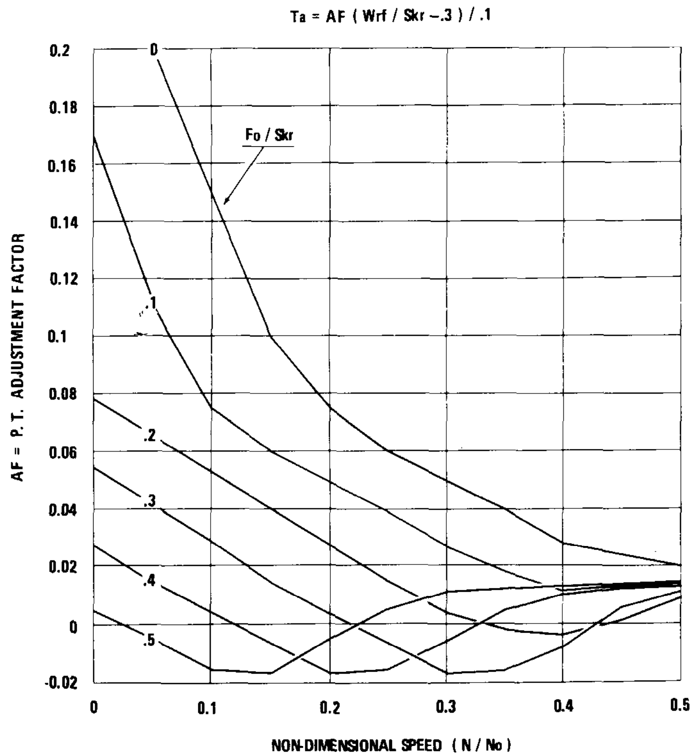

Figure 5 - API peak torque adjustment