COMPUTER SIMULATION OF ROD PUMPING WELLS

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INTRODUCTION

The use of simulation in petroleum engineering is not new; pipeline and refinery simulation and simulation of reservoir performance have been widely used in the past. However, in recent years there have been major improvements in the ability to simulate rod pumping situations, such as the use of mathematical expressions and equations (derived from API RP 11L) to capture succinctly complex interrelationships which heretofore could not be easily related. The model is then manipulated on the computer to see what might happen in reality if the relationships were fixed or varied in specific ways.

Because every system is in some state of dynamic adaptation to its *environment* (everything outside the system boundaries that has some influence on the system), there will always be problems to be solved. This is where the use of an abstract system simulation model proves advantageous. Simulation is just a numerical method used as a means of finding successive states of a situation or system by repeatedly applying the rules by which the system is operated.

SYSTEMS APPROACH

Definitions

Since the use of system simulation is a form of systems analysis, which is relatively new, it might be useful to discuss the "systems approach" briefly.

Simply put, systems analysis is the analysis of a total system. The following terms are used to define a total system:

1. CONSTRAINT - a limitation placed on the operation of the system. Some control may be exerted on some constraints.
2. COMPONENT - an object, or entity, described by a fixed collection of parameters called attributes. Components exist and have numerical values (attributes) that describe the state of the system.
3. ATTRIBUTE - a property of a component—they describe with numerical values.
4. SET - a collection of individual components.
5. RELATIONSHIP - bonds that link components and attributes in the system process.
6. ENVIRONMENT - the set of all components outside the system that can influence the system. For practical purposes, environments are limited by specific boundaries; otherwise they might be considered infinite.
7. STATE - the complete description of a system's components, attributes, constraints and relationships at a point in time. System dynamics are represented by changes of state.
8. TOTAL SYSTEM - an on-going process composed of a set of components with given relationships between the components and their attributes and a given number of constraints with the objective of producing a specific result in a given environment.
9. SUBSYSTEM - a component process of a total system—may be further subdivided into more detailed subsystems.
10. OBJECTIVE-defines the purpose for which all system components, attributes, and relationships have been organized.

A total system may best be illustrated by considering a rod pumping situation as a system as shown in Table 1. Notice that many of the attributes can become constraints and vice versa. For instance, consider a well with a high fluid level and operated by a 456 pumping unit. If the torque is only 345,000 in-lb and the rod stress is near the allowed limit of say 33,000 psi, then the 456,000 in.-lb capacity of the gear box is an attribute, and the maximum allowed stress is the constraint. If the measured torque were 455,000 in.-lb and the stress were only 28,000 psi, then the 456,000 gear box capacity would be a constraint, and the maximum allowed stress of 33,000 psi would be an attribute.

There are other parameters of a system to be considered which are not shown in Table 1. Nothing has been mentioned of the system objectives: feedback and control, or systems management. With the exception of objectives, these are beyond the scope of this paper. Rod pumping objectives are generally considered to be: (1) "x" barrels of fluid per day; (2) "x" cents per barrel; (3) "x" dollars per month operating cost; (4) "x" months of pump life; and (5) "x" months of rod life. The immediate concern using simulation is the barrels per day objective. Properly applied, simulation will help achieve the other four.

SIMULATION OF ROD PUMPING SYSTEMS

*Basic Rod Pumping Model — S*PRED*A or C*PRED*A*

The basic rod pumping model, S*PRED*A (sucker rod predictions - API) is based on API RP

TABLE 1—SYSTEMS APPROACH TO SUCKER ROD PUMPING

ENVIRONMENT	COMPONENTS	ATTRIBUTES	CONSTRAINTS
Well Depth (PBTD)	Sucker rod string*	Length & Design*	Tubing Size and:
Deviation		Tensile Strength*	Tensile Strength*
Casing		Max.Allow.Stress*	Max.Allow.Stress*
Perfs or O-H		Goodman Diagram*	Goodman Diagram*
Type of completion		Delta Stress Level*	Delta Stress Level*
Location	couplings &		Couplings and pins
Climate	pins subsystems		failure history
B.H.T.	centralizers or		rod-coupling-piston effect
B.H.P.	scrapers subsystems		rod-tubing friction effect
Inflow Performance Relationship			
	Pumping Unit*		
	gear box*	Torque Capacity*	Torque Capacity*
	beam*	Beam Capacity*	Beam Capacity*
	geometry*		Restricts Max SPM
	Tubing:	Size & Length*	Casing restricts size
			Restricts plunger size
			Restricts Rod Coupling Size
	Anchored*	Size & Type	Anchor may restrict free
	or		gas movement, may scale up
	Un-anchored*		Un-anchored - increases loads,
			torque; decreases plunger stroke
	seating nipple	Size & Type	
	Down-Hole Pump		
	Plunger*	Size & Length*	Restricted by tubing size
	Barrel	Size & Length	Material selection critical to
	Balls & Seats	Size & Type	all components
	Hold down	Size & Type	
	Fluid Level*	Feet to surface	Pump-off condition
	G/O Separator	Size & Type	Casing restricts size,
			Downward velocity of fluid
			and upward velocity of gas
			CRITICAL parameters
	Stroke* & SPM*	Length* & Speed*	Max SPM* for a given stroke
			and geometry.
	Chemical Treating	Dosage	Fluid Properties: Corrosion,
			scale, paraffin, emulsion

*Used in simulation models.

11L. The curves from this bulletin have been mathematically described to the computer as high order polynomial equations. This is the raw material for the model. The user of the program actually completes the model, describing it to the computer in the form of input. The input required by the computer to complete the model is: (1) BPD or SPM (the user enters one, the computer solves for the other); (2) depth and fluid level; (3) specific gravity; (4) stroke length; (5) torque capacity; (6) plunger size; and (7) API sucker rod or Corod number. In addition to the normal description, there are several options to further refine the model: (1) unit geometry—conventional, Mark II, air balance; (2) sinker bars; (3) anchored or unanchored tubing; (4) speed variation of the prime mover; and (5) a design option on the rods—enter your own option or the computer will use an API design for each plunger and rod string combination. This particular model has only three constraints: a maximum SPM for the unit geometry and stroke length; a rod stretch factor (Fo/Sk) of 0.5 and a maximum dimensionless pumping speed factor (N/No') of 0.5. (It is assumed that the reader is familiar with the API RP 11L and its terms.) An annotated sample run of C*PRED*A is presented in Illustration I. The first part of the run shows the input as it was entered in conversational mode. The small italic print discusses the input.

Test of Correspondence

No matter how sophisticated a solution may appear, since it is based on a model which is itself but an abstraction of concrete events from the real world, its usefulness will be proportional to the "goodness of fit" between the model and the events abstracted. Table 2 shows four case histories used to test the correspondence (degree of variance) between the real (measured values from Delta II dynamometer surveys) and the models (S*PRED*A and C*PRED*A). All of the options available in "building" the models were used at one time or another in the four cases.

The purpose of using the case approach is to reveal the general nature of the simulation method in a semi-realistic setting. In reading the cases, it is important to look beyond the particular problem setting to the broader possibilities that this method opens. There are new possibilities of exploring *before the fact* which might happen if certain actions were taken, if certain systems were installed, or if certain events were to occur by chance or through direct cause.

In Table 2, the correspondence between the measured values of the pumping systems and the models is very good. The general model used (_*PRED*A) is a descriptive model which is flexible enough to represent almost any conceivable rod pumping system. Some facet of that versatility is demonstrated in each of the examples. The basic model used in _*PRED*A is the basis for the other models: *OPTM*A, *MBPD*A, *DHSA*A. It is reasonable to assume that the correspondence achieved with _*PRED*A would be carried through in the other models.

Optimization of Rod Pumping Systems

Change, and the effects of change, are of paramount importance in many problems that concern us. In most engineering problems, there are many variables to be considered. It is not often that we wish to consider the effects of all of them varying simultaneously, although this could be done with the computer. But, frequently we are concerned with the effects of changing more than one; sometimes one at a time, sometimes several at once. At times the only "right" analysis is one that assigns the change in a variable which depends on two others, to each of those separately, and to the pair jointly. For example, the problem could be to calculate the relationship between polished rod horsepower, SPM, and plunger size in trying to pump a given amount of fluid per day. It is precisely this matter of joint variation that makes multivariable problems (such as optimizing rod pumping) difficult to think about. Often the problem is to find among many possibilities the alternative which is "best" according to some criterion. Such models can be built (and they have many forms), but they all share the common property that within them is an explicit criterion for measuring "goodness" and some means for finding which of a number of choices is the "best". Models having this property are called *optimization* models. In the case of the general optimization model _*OPTM*A, it was necessary to find some index that would provide a means of comparing the numerous ways to get, e.g., 300 BFPD from 5500 ft. Here are the obvious objectives in a given pumping situation: (1) We want to pump a certain number of barrels of fluid per day; (2) We want to get them with a *minimum* number of strokes; and (3) We want a *minimum* stress and

TABLE 2—RELATES THE CORRESPONDENCE (ACCURACY) BETWEEN THE MODEL (*PRED*A) AND THE REAL WORLD (MEASURED VALUES FROM THE DELTA II DYNAMOMETER TECHNIQUE)

*CONDITIONS	C.R.L. 21			PNL 24-31C			TW #1			UDH 47-11S		
*Pumping Unit	C-228			M-456			M-912			AB-1500		
*Rod String	86 SKROD			62 COROD			86 SKROD			86 SKROD		
*PLGR X STK X SPM	1.75 X 64 X 14.0			2 X 128 X 10.0			1.5 X 216 X 9.5			1.5 X 192 X 7.89		
*Depth	6356			8714			6571			8005		
*F.L./Sp.G.	5771/1.0			7764/.92			6571/1.0			7900/1.0		
*Sinker Bars	No			No			No			200' of 1.5"		
*Speed Variation	No			No			No			13.5%		
*Tubing Anchored	Yes			Yes			No			Yes		
*	REAL	MODEL	DIFF.	REAL	MODEL	DIFF.	REAL	MODEL	DIFF.	REAL	MODEL	DIFF.
*Peak PRL (lbs)	19740	19159	-581	27035	27745	+710	25981	25523	-458	28399	27780	-619
*Min PRL (lbs)	9020	8301	-791	10447	10986	+539	5060	4530	-530	10065	10948	+883
*PRHP (Hp)	11.3	10.4	-.9	20.3	21.9	+1.6	47.1	46.4	-.7	28.3	29.9	+1.6
*Torque(1000 in-lb)	177	167	10	438	441	+3	1190	1165	-25	906	912	+6
*Plgr Stk (in)	54	47	-7	95	94	-1	Unk.	211	---	178	182.0	+4
*BFPD (bbl)	190 w/gas	224	+34	435	440	+5	560	525	-35	365	376	+10

The usefulness of the output from a model will be proportional to the "goodness" of fit (correspondence) between the model and the events abstracted. The goal in model building is to construct a reliable representation of the real world. A model said to represent a real world phenomenon must yield, in its intermediate and end results, output that justifies this claim. Correspondence, or failure of correspondence, is judged through the discrimination of differences in output (measured values) and output model (predicted values), evaluation of observed differences, and articulation of differences. In the table above, the correspondence (or goodness of fit) between the measured values of a rod pumping situation and the model is very good. The model used (*PRED*A) is a descriptive model which is flexible enough to represent almost any conceivable rod pumping system. Some facet of that versatility is demonstrated in each of the four examples shown. The basic equations used in *PRED*A are the basis for the other models (*MBPD*A, *OPTM*A, DHSA*A). It is safe to assume that the correspondence achieved with *PRED*A would be carried through in the other models.

stress range on the rods, *minimum* torque on the gear box and *minimum* horsepower consumed.

The following optimization index is a means to these ends:

OPTIMIZATION INDEX = (BPD/SPM) /(Stress x DSL x Torque x (PRHP/SPM))

Where:

- BPD = fluid production required
- SPM = strokes per min. to get the BPD
- Stress = maximum stress on rods
- DSL = Delta stress level = max stress + stress range
- Torque = in-lb peak torque on gear box
- PRHP = polished rod horsepower (It is necessary to minimize hp on a per stroke basis because of the multivariable relationship between PRHP, plunger size and SPM)

Illustrations II(a) through II(g) represent a set of sample runs of S*OPTM*A and C*OPTM*A. The thought processes of the authors are shown as numbered remarks, as the reader progresses through the samples. The user has increased flexibility with the S*OPTM*A and C*OPTM*A models. In addition to the options used in _*PRED*A, the user can control the constraints in the model. He can derate the rod string in case he has slim-hole couplings or corrosion, by reducing the tensile strength, maximum allowed stress, Delta stress level and Goodman Diagram (represented mathematically in the model).

Maximization of Rod Pumping Systems

As more and more production comes from waterfloods, and as pumping units and tubing become more and more difficult to purchase, it becomes increasingly important to maximize production without overloading the present pumping equipment. One such method for maximizing production is found in the models S*MBPD*A and C*MBPD*A. These models are used to calculate the *maximum* BFPD attainable with a given pumping unit, stroke length, depth and fluid level without exceeding any of the constraints the user builds into the model. It will test from one to four rod strings with several plunger sizes. Here again these models have all the modeling options discussed in the _*PRED*A and the constraint options of _*OPTM*A. Illustrations III(a) through III(d) show the thought processes as the runs of S*MBPD*A and C*MBPD*A were made.

The reader should be cautioned against extrapolating the results of these sample runs to other systems. For example, shortening the stroke will not be of any particular benefit if the limiting constraint on production is anything but a torque constraint.

CONCLUSIONS

The range of potential activities that can profitably employ simulation is very broad. Simulation can be used to predict *future* possible behavior, to understand the *effects of change* in a system, to *compare* systems, to *examine* the relationships which exist in a system, and to investigate the facts about a pumping system before even running a dynamometer.

Simulation can be used to *optimize* pumping conditions by finding the best way to pump a given BFPD with minimum rod stresses, stress range, torque and horsepower consumption. Another example would be to *maximize* BFPD in a waterflood without exceeding the allowed limits (constraints) on torque, rod stress, etc. Another approach would be to make comparisons between certain systems: (1) anchored or unanchored tubing; (2) high slip vs nominal slip prime movers; (3) Corod vs sucker rods; or (4) combinations thereof.

The cost of experimentation in the real world is prohibitive compared to simulation with a computer model. Second, actual changes and interactions often take much time before their effects are recognized. Third, simulation models help engineers to better understand the multitude of interacting variables and interrelationships involved in rod pumping systems. And finally, simulation can be used to find the "best" of all pumping conditions or maximize production with present pumping equipment.

ILLUSTRATION NO. I

```
(Input is in a conversational mode, user responces are underscored.)
C*PRED*A     17:26MDT     02/27/74

LOCATION? NL 24-31C

INPUT BPD OR SPM? SPM (The  program will calculate the BPD.)
 (If "BPD" had been the responce, the program would have calculated the SPM required.)
ENTER SPM,DEPTH,FLUID LEVEL? 10,8714,7764
 (Items are separated by commas and no commas are used in the thousands.)
SINKER BARS? NO
 (If "YES" the program would have then asked for dimensions of the sinker bars.)
ENTER PLPG, COROD NO., STK LNGTH, SP.G.? 2,62,128,.92

UNIT (1-C, 2-MII, 3-AB) AND TORQ CAPACITY? 2,456

TUBING ANCHORED? YES
 (If "NO" the program would have asked for tubing size.)
HI-SLIP? NO
 (If "YES" the program would have asked for percent speed variation expected.)
API ROD DESIGN-YES/NO? NO
 (If "YES" the program would have used a standard API tapered design.)

CORОD STRING DESIGN--SMALLEST ROD FIRST, IN FEET

? 2971,1561,1474,1397,1311

===============

                 CORОD PUMPING SYSTEM PREDICTIONS:

LOADS, PROD.,ETC, BASED ON THE API-RP-11L, MODIFIED FOR GEOMETERY AND/OR
SPEED VARIATIONS WHEN NECESSARY.

LOCATION:PNL 24-31C

COROD NO. 62 STRING WGT = 17005  LB/FT = 1.95146 SP.G. = 0.92

MARK II UNIT WITH 456000  IN-LBS TORQUE CAPACITY

PLNGR =2.00  STK =128  SPM =10.0  BPD = 440

DEPTH = 8714   FLUID LEVEL = 7764

ER = 7.54063E-7   1/KR = 6.57091E-3

FO =9714   FO/SKR =.499   KRF/SKR =.770   FO/KR =63.8

N/NO =.351   FC =1.246   N/NOP =.282

ROD STRETCH =63.8  OVRTVL = 30.1  PLGR TVL = 94.3

 10.0 SPM = 5266512 STKS PER YEAR OR  1.9 YEARS TO 10 MILLION STKS

RP-11L CALCULATIONS:

FIG 4.1= .6768      BFPD =  440
                PLGR STK = 94.3

FIG 4.2= .6542      PPRL =27745
                   MXSTR =35327      DSL =56666

FIG 4.3= .2062      MPRL =10986
                   MNSTR =13988      RNG = 60.4 %

FIG 4.4= .3539      TORQ = 441226
                     CBE =21051

FIG 4.5= .3457      PRHP = 21.9

 HO= 3.55      NAT FREQ= 35.53
 2.5= 14.2      3.5= 10.2      4.5= 7.9

 YOUR DESIGN -- NO. 62 :    1311    1397    1474    1561    2971
 ROD PERCENTAGES:           15.0    16.0    16.9    17.9    34.1
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S*OPTM*A 16:39MDT 02/14/74

UNIT ~(1-C,2-M,3-AB)? 1
INPUT BPD OR SPM? BPD
ENTER BPD,DEPTH,FLUID LEVEL? 300,5500,5000
ENTER PLNG-SMALLEST,LARGEST,MAX TORQUE? 1.25,2,320
MIN TENSILE STR, MAX ALLOWED STR? 115000,34000
TUBING ANCHORED? NO
TUBING SIZE: (1) = 2 IN., (2) = 2-1/2 IN., (3) = 3 IN.? 2
API ROD DESIGN--YES/NO? YES
INITIAL SKROD NO., FINAL SKROD NO., STK? 76,76,100
DESIGN ID? OBSCURITY PETROLEUM
HI-SLIP? NO
CONSTRAINT CHANGE? NO
==========

ILLUSTRATION II(a)

Objective - Produce 300 BFPD
Environment - 5500' Deep, 5000' F.L.
C-320-100 unit.

SUCKER ROD PUMPING OPTIMIZATION TABLE

DATE: 02/14/74

LOADS, PROD., ETC. BASED ON API-RP-11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DEPTH= 5500 FT FLUID LEVEL= 5000 SP.G.= 1

BPD 300 MAX ALLOWED STRESS = 34000 SYSTEM DERATOR = 1.00
MAX ALLOWED DSL= 57500

CONVENTIONAL PUMPING UNIT WITH A 100 INCH STROKE AND
320000 INCH POUNDS TORQUE CAPACITY.

**** NOTE: CALCULATIONS MODIFIED FOR UNANCHORED TUBING.

① Use unanchored tubing first try.

COMPUTED FOR OBSCURITY PETROLEUM

SKROD PLNGR SPM MXLOAD MXSTR PCTRNG DSL TORQUE INDEX

SKROD 76 W/ 1.25 PLGR--MX TORQUE = 402585
SKROD 76 W/ 1.5 PLGR--MX TORQUE = 369225
SKROD 76 W/ 1.75 PLGR--MX TORQUE = 360265
SKROD 76 W/ 2 PLGR--MX TORQUE = 336464

② Whoops! Nothing worked. Try again with tubing anchored.

ILLUSTRATION II(b)
(Input deleted - space limitations)

③ Everything same as above, except tubing is anchored.

SKROD	PLNGR	SPM	MXLOAD	MXSTR	PCTRNG	DSL	TORQUE	INDEX
SKROD 76 W/ 1.25 PLGR--MX TORQUE = 369173								
SKROD 76 W/ 1.5 PLGR--MX TORQUE = 328051								
SKROD 76 W/ 1.75 PLGR--MX TORQUE = 321618								
76	2.00	8.3	16185	26930	59.2	43052	280516	502.48 ⇐

④ Not much better, but one rod/plunger combo did work.

⑤ Since torque is the limiting constraint lets shorten the stroke.

CHANGE STK? YES
ENTER STK LNGTH, MAX TORQUE? 86,320
==========

⑥ Now we're moving. Only trouble is the high index is with a 2 in. plunger. In 2 3/8" tubing that would require a tubing pump.

ILLUSTRATION II(c)

SKROD	PLNGR	SPM	MXLOAD	MXSTR	PCTRNG	DSL	TORQUE	INDEX
76	1.25	18.3	17541	29187	81.0	52818	317543	154.86 ✓
76	1.50	14.8	17115	28478	74.0	49548	298021	229.20
76	1.75	11.9	17430	29002	68.7	48914	278234	296.61 ⇐ I
76	2.00	10.1	16670	27737	63.0	45209	251904	453.09 ⇐ T

Let's try a prime mover with some extra slip. (Read on)

S*OPTM*A 15:53MDT 02/14/74

UNIT ~(1-C,2-M,3-AB)? 1
INPUT BPD OR SPM? BPD
ENTER BPD,DEPTH,FLUID LEVEL? 300,5500,5000
ENTER PLNG-SMALLEST,LARGEST,MAX TORQUE? 1.25,2,320
MIN TENSILE STR, MAX ALLOWED STR? 115000,34000
TUBING ANCHORED? YES
API ROD DESIGN--YES/NO? YES
INITIAL SKROD NO., FINAL SKROD NO., STK? 76,76,100
DESIGN ID? OBSCURITY PETROLEUM
HI-SLIP? Y YES
% SPEED VARIATION? 18 *(User enters pct speed variation)*
CONSTRAINT CHANGE? NO
==========

ILLUSTRATION II(d)

SUCKER ROD PUMPING OPTIMIZATION TABLE

DATE: 02/14/74

LOADS, PROD., ETC. BASED ON API-RP-11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DEPTH= 5500 FT FLUID LEVEL= 5000 SP.G.= 1

BPD 300 MAX ALLOWED STRESS = 34000 SYSTEM DERATOR = 1.00
MAX ALLOWED DSL= 57500

CONVENTIONAL PUMPING UNIT WITH A 100 INCH STROKE AND
320000 INCH POUNDS TORQUE CAPACITY.

PRIME MOVER WITH 18.0% SPEED VARIATION

⑦ (Only the speed variation has been changed from II(c).)

COMPUTED FOR OBSCURITY PETROLEUM

SKROD	PLNGR	SPM	MXLOAD	MXSTR	PCTRNG	DSL	TORQUE	INDEX
SKROD 76 W/ 1.25 PLGR--MX TORQUE = 334375								
76	1.50	12.2	16260	27056	67.0	45181	305966	288.98
76	1.75	9.7	16851	28038↑	67.5	46954↑	304302↓	321.86 ⇐ 3
76	2.00	8.2	15864	26397↓	60.7	42410↓	264844↓	536.56 ⇐ 1

⑧ Well, that raised all the indices. Lets shorten the stroke. The arrows (↑) indicate changes from the line above.

CHANGE STK? YES
ENTER STK LNGTH, MAX TORQUE? 86,320
==========

ILLUSTRATION II(e)

SKROD	PLNGR	SPM	MXLOAD	MXSTR	PCTRNG	DSL	TORQUE	INDEX
76	1.25	17.6	16361	27223	75.3	47726	281530	200.15
76	1.50	14.7	16585	27596↑	75.4	48404↑	276673↓	252.55
76	1.75	12.0	17081	28421↑	70.4	48422↑	265964↓	311.17 ⇐ 4
76	2.00	10.2	16407	27299↓	64.6	44924↓	241398↓	471.44 ⇐ 2

CHANGE STK? NO
RUN AGAIN? NO

⑩ No help at all. Sure hate to use a tubing pump just to optimize. (So using some human-type judgement) Lets go with the 2nd "best" instead (actually #3) set the 1.75" X 100" X 9.7 SPM.

⑪ Or we could try Corod and a Mark II

```
UNIT TYPE(1-C,2-M,3-AB)? 2
INPUT BPD OR SPM? BPD
ENTER BPD,DEPTH,FLUID LEVEL? 300,5500,5000
ENTER PLNG-SMALLEST,LARGEST,MAX TORQUE? 1.25,2,320
TUBING ANCHORED? YES
API ROD DESIGN--YES/NO? YES
INITIAL CORUD NO., FINAL CORUD NO., STK? 52,42,100
DESIGN ID? OBSCURITY PETROLEUM
HI-SLIP? NO
CONSTRAINT CHANGE? NO
==========
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Illustration II(f)

CORUD SYSTEM OPTIMIZATION TABLE

LOADS, PROD, ETC. BASED ON API-RP11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DATE: 02/14/74

DEPTH= 5500 FT FLUID LEVEL= 5000 SP.G.= 1

BPD = 300 MAX ALLOWED STRESS = 34000 SYSTEM DERATOR = 1.00

MAX DSL ALLOWED = 42500

MARK II PUMPING UNIT WITH A 100 INCH STROKE AND 320000 INCH POUNDS TORQUE CAPACITY.

② Except for the Corod and the Mark II unit with no speed variation everything is the same as II(c).

COMPUTED FOR OBSCURITY PETROLEUM

CORUD	PLNGR	SPM	PKLOAD	MXSTR	PCTMXS	DSL	TORQUE	INDEX
52	1.25	15.0	14814	21461	73.2	37161	262944	443.87
42	1.25	15.1	14612	24300	79.2	43538	293694	211.37
52	1.50	11.2	15052	21806	64.1	35700	257057	606.84 ⇐ 1 ⑬ Looks good!
42	1.50	11.3	14708	24460	69.3	41414	269186	443.39
52	1.75	9.0	16042	23240	61.6	37569	272137	595.39 ⇐ 3
42	1.75	9.0	15059	25044	66.8	41784	276113	490.57
52	2.00	7.7	17505	25359	61.1	40981	297120	409.91
42	2.00	7.7	16839	29006	64.6	46097	296683	406.63

```
CHANGE STK? YES
ENTER STK LNGTH, MAX TORQUE? 120,320
```

⑭ Since torque is on other data, Lets lengthen the stroke.

Illustration No. II(g)

CORUD	PLNGR	SPM	PKLOAD	MXSTR	PCTMXS	DSL	TORQUE	INDEX
52	1.25	12.3	14444	20925	67.1	34959	298308	486.12
42	1.25	12.2	14198	23612	73.0	40853	314090	349.48
52	1.50	9.4	14843	21502	60.7	34554	294106	596.04 ⇐ 2
42	1.50	9.4	14463	24048	65.4	39767	304976	453.09

```
CORUD NO. 52 WITH 1.75 IN. PLNGR - TORQUE= 325388
CORUD NO. 42 WITH 1.75 IN. PLNGR - TORQUE= 329527

CORUD NO. 52 WITH 2 IN. PLNGR - TORQUE= 358830
CORUD NO. 42 WITH 2 IN. PLNGR - TORQUE= 358928
```

⑮ This 2nd best index is only 10 below the "best" shown with the 100" stroke plus it runs nearly 2 SPM slower.

```
CHANGE STK? NO
RUN AGAIN? NO
```

123

```
S*MBPD*A     09:57MDT     02/15/74

UNIT TYPE:(1-C,2-M,3-AB)? 3
DEPTH,F.L.,STK,MAX TORQUE,NO. OF STRINGS? 8500,6500,192,912,2
INPUT MIN TENSILE STR, MAX ALLOWED STR? 125000,34000
DESIGN I.D.? OBLIVIAN OIL
TUBING ANCHORED? YES
SKROD STRING NUMBERS? 86,76
HI-SLIP? NO
CONSTRAINT CHANGE? YES
INPUT SYSTEM DERATOR, S.G., INITIAL PLNGR, MAX PLNGR
? .85,1,1.25,2.25
==========
```

① Using 1" skrods w/ slim-hole couplings, rods are de-rated 15%.

Illustration No. III (a)

Objective: Oblivian Oil needs 350-400 BFPD from 8500' (initial F.L. at 6500'). Find maximum production attainable with an A.B. 912-192, 2⅞" tubing.

SUCKER ROD PUMPING SYSTEMS

MAXIMUM PRODUCTION TABLE

LOADS, PROD., ETC. BASED ON API-RP11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DATE: 02/15/74

COMPUTED FOR OBLIVIAN OIL

DEPTH= 8500 FLUID LEVEL= 6500 FLUID SP.G.= 1

SYSTEM DERATOR= 0.85 MAX STRESS= 34000 MAX ALLOWED DSL= 53125.

AIR BALANCE PUMPING UNIT WITH A 192 INCH STROKE AND 912000 INCH POUNDS TORQUE CAPACITY.

SKROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
86	1.25	9.2	329	32058	52826	825404	.1170	.3269
86	1.50	7.8	375 ⇐	33025	53062	827902	.1650	.2778
86	1.75	5.9	351	33914	52737	799921	.2200	.2112
86	2.00	2.5	166	33922	48619	667766	.2790	.0920
SPM DOWN TO 2								
76	1.25	6.2	208	33930	50800	548431	.1280	.2217
76	1.50	3.6	154	33907	48146	495485	.1930	.1306
SPM DOWN TO 2								

② The 86 skrod w/ the 1.5" plngr [illegible] good. What if the well [illegible] down?

SUCKER ROD PUMPING SYSTEMS

MAXIMUM PRODUCTION TABLE

Illustration III(b)

LOADS, PROD., ETC. BASED ON API-RP11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DATE: 02/15/74

COMPUTED FOR OBLIVIAN OIL

DEPTH= 8500 FLUID LEVEL= 8200 FLUID SP.G.= 1 ③ Same as above except F.L.

SYSTEM DERATOR= 0.85 MAX STRESS= 34000 MAX ALLOWED DSL= 53125.

AIR BALANCE PUMPING UNIT WITH A 192 INCH STROKE AND 912000 INCH POUNDS TORQUE CAPACITY.

SKROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
86	1.25	8.5	291	32434	52859	831346	.1480	.3024
86	1.50	6.6	297 ⇐	33442	52927	819466	.2090	.2358
86	1.75	3.6	184	33926	50229	718505	.2780	.1306
SPM DOWN TO 2								
76	1.25	4.9	153	33992	49817	527983	.1620	.1761
SPM DOWN TO 2								

④ This won't do! Oblivian has got to have at least 350 BFPD. Lets try Corod.

C*MBPD*A   10:04MDT   02/15/74

UNIT TYPE:(1-C,2-M,3-AB)? 3
DEPTH,F.L.,STK,MAX TORQUE,NO. OF STRINGS? 8500,83_200,192,912,2
DESIGN I.D.? OBLIVIAN OIL
TUBING ANCHORED? YES
COROD STRING NUMBERS? 72,62
HI-SLIP? NO
CONSTRAINT CHANGE? NO
==========

⑤ Everything as before except we are using Corod and without any couplings, no de-rating is needed.

ILLUSTRATION No III (c)

COROD PUMPING SYSTEMS

MAXIMUM PRODUCTION TABLE

LOADS, PROD., ETC. BASED ON API-RP11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DATE: 02/15/74

COMPUTED FOR OBLIVIAN OIL

DEPTH= 8500 FLUID LEVEL 8200 FLUID SP.G.= 1

SYSTEM DERATOR= 1 MAX STRESS= 34000 MAX ALLOWED DSL = 62500

AIR BALANCE PUMPING UNIT WITH A 192 INCH STROKE AND 212000 INCH POUNDS TORQUE CAPACITY.

COROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
72	1.25	[12.0]	448	30555	50770	962145	.1457	.3114
72	1.50	10.3	512 ⇐	32224	52936	[911409]	.2640	.2620
72	1.75	8.0	499	[33948]	54038	909220	.2670	.2110

SPM DOWN TO 2

COROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
62	1.25	[12.0]	446	31657	53862	901796	.1527	.2324
62	1.50	10.2	428 ⇐	33068	55131	[926922]	.2150	.2340
62	1.75	7.2	439	[33979]	54095	849213	.2850	.2010

SPM DOWN TO 2

⑥ Too Much! Let's use a smaller gear box and a shorter stroke :

ILLUSTRATION III (d)

AIR BALANCE PUMPING UNIT WITH A 168 INCH STROKE AND 640000 INCH POUNDS TORQUE CAPACITY.

COROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
72	1.25	10.7	341	28732	45403	[639945]	.1670	.2810
72	1.50	8.4	349 ⇐	30079	46352	[639009]	.2330	.2190
72	1.75	5.7	283	32010	47947	[639456]	.3050	.1520

SPM DOWN TO 2

COROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
62	1.25	10.4	324	29332	47006	[636659]	.1740	.2890
62	1.50	8.4	344	30735	48227	[638809]	.2460	.2320
62	1.75	5.9	291	32602	49819	[637525]	.3260	.1660

SPM DOWN TO 2

⑦ This system just doesn't quite make it. Torque is the limiting constraint what if we shorten the stroke?

CHANGE STK? YES
ENTER STK LNGTH, MAX TORQUE? 144,640
==========

COROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
72	1.25	[13.9]	379	29829	48713	611052	.1943	.3596
72	1.50	13.0	464 ⇐	32120	52481	[637858]	.2720	.3370
72	1.75	10.8	445	[33962]	54531	615695	.3560	.2920

SPM DOWN TO 2

COROD	PLNGR	SPM	BPD	MAXSTR	DSL	TORQUE	FO/SK	N/NOP
62	1.25	[13.9]	397	30849	51350	621984	.2036	.3838
62	1.50	13.0	484 ⇐	33057	55003	[638997]	.2870	.3600
62	1.75	9.8	389	[33946]	54542	571434	.3800	.2720

SPM DOWN TO 2

⑧ Thats better. The AB 640-144 w/ the 62 Corod will do. Now let's use C*OPTMA to find the best way.

ILLUSTRATION III (f)

COROD SYSTEM OPTIMIZATION TABLE

LOADS, PROD, ETC. BASED ON API-RP11L, MODIFIED FOR GEOMETRY AND/OR SPEED VARIATIONS WHEN NECESSARY.

DATE: 02/27/74

⑨ Environment & constraints same as III (e)

DEPTH= 8500 FT FLUID LEVEL= 8200   SP.G.= 1

⇒ BPD = 375 MAX ALLOWED STRESS = 34000 SYSTEM DERATOR = 1.00

MAX DSL ALLOWED = 62500

AIR BALANCE PUMPING UNIT WITH A 144 INCH STROKE AND 640000 INCH POUNDS TORQUE CAPACITY.

COMPUTED FOR OBLIVIAN OIL

[COROD NO. 72 WITH 1.06 IN. PLNGR - SPM= 16.09
[COROD NO. 62 WITH 1.06 IN. PLNGR - SPM= 15.63

COROD	PLNGR	SPM	MXLOAD	MXSTR	PCTRNG	DSL	TORQUE	INDEX
72	1.25	13.9	24906	29828	63.3	48710	610978	100.44
62	1.25	13.5	24034	30602	65.6	50687	610283	94.94
72	1.50	11.2	25854	30962 ↑	58.8	49175 ↑	580836 ↓	121.82
62	1.50	11.2	24952	31769	61.8	51413	580015 ↓	112.15
72	1.75	9.1	27609	33065 ↑	56.5	51747 ↑	580212 ↓	124.45 ⇐
62	1.75	9.5	26555	33810	60.1	54118	566982 ↓	113.46

⑩ The 72 w/ the 1.75" is the best.

CHANGE STK? NO
RUN AGAIN? NO