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Design and Optimization of Sucker Rod Pump Using Prosper

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Abstract: **Worldwide, as conventional oil resources are depleted, beam pumping system is becoming the common type of artificial lift method for onshore wells. Production testing of beam pumped wells is an important diagnostic tool to detect potential production problem and for monitoring reservoir performance. In addition, the well test data and the inflow performance relationship (IPR) combined with the production system.**

Also when larger population of beam pumping wells are connected to central batteries, it is difficult to determine the daily production of each well or to identify the cause of low production in the battery, as there is not any easy way to identify which well is affected. The new method continuously infers the production and by analyzing the down hole pumps card data.

The complete design of a sucker rod pumping system is an involved trial and error process. An "optimum" design requires that the engineer specify pump size and type; rod string size, taper, and material; surface unit type and size, gear box rating, beam rating, and stroke length; and prime mover type and size. The procedure requires that the engineer first assume an appropriate combination of pump, rod, unit, and prime mover and then perform calculations which lead to refining that initial assumption.

Keywords: **Design, Sucker rod pump, Installation, Pumping system, PROSPER.**

1. STEPS IN THE DESIGN OF SUCKER ROD INSTALLATION

Objective: - The main objective of designing sucker rod pump is to lift the fluid from the Downhole formation.

Primary design factors that are considered when designing sucker rod pump are

1) Desired mass rate,q , bbl/day
2) Net lift of fluid,L_N , ft

Knowing these two factors help us to estimate the optimized plunger size which results in

a) Minimum rod loads $W_R(1+\alpha)$,lb
b) Minimum torque on gear box, T_p ,in,lb
c) Minimum input power requirements, H_b ,hp

Once plunger size is determined, tubing size ,(A_t) rod sizes (A_{r1},$A_{r2,....}$) and lengths (L_1,$L_{2,......}$), stroke size (S), pumping speed (N), torque rating (T_p) of the unit and power rating of the prime mover (H_b) are calculated.

Such interdependency of these variables makes their selection extremely difficult if design problem were approached entirely from the mathematical standpoint without benefit of previous experience.

Assumptions to Well Conditions:- If certain assumptions to well conditions are made then it becomes possible to prepare charts and tables (Lubinski and Blenkarn) which greatly reduce the efforts necessary in designing a pumping installation. Generally made assumptions are

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1) Specific gravity (G) of well fluids is 1.00, and

2) Net lift (L_N), working fluid level (D) and pump setting depth (L) are same

$$L_N = D + \frac{2.31P_t}{G} = D = L$$

But it must be realized that chart values may have to be adjusted to fit a particular situation. For example, tubing already present in the well to be put on pump dictates the maximum pump size, which might be smaller than the optimum size indicated by the selection chart.

Minimum information required for installing pump constitutes

a) Fluid production rate, q

b) Depth to pump, L

c) Working fluid level

d) which is if not known, assume to be equivalent to pump setting depth,

d) Volumetric efficiency of pump (Usually 0.8 for design purposes), E_v

e) Specific gravity of fluid, G

1.1 Following steps are involved in designing a pumping installation

1. From maximum anticipated fluid production and estimated volumetric efficiency, calculate pump displacement (V)

$V=q/E_v$

2. From Fig 1 estimate API pumps size and stroke length.

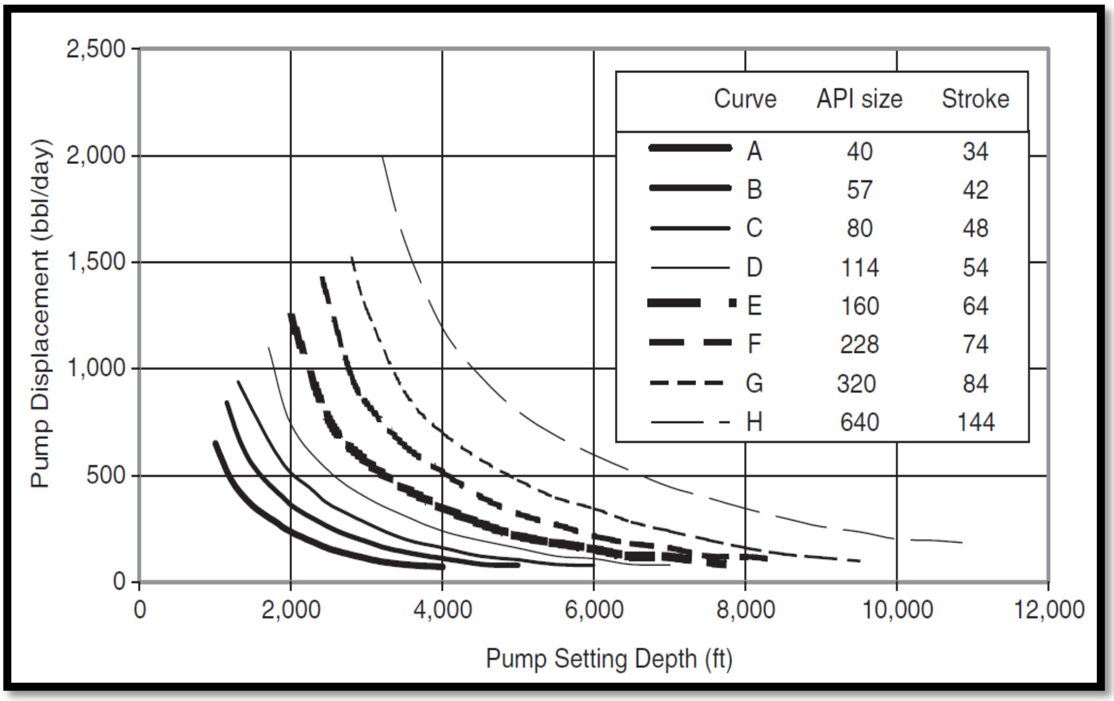

Figure 1 Sucker rod pumping unit selection chart (Kelley and Willis, 1954).

3. From Tables 1 to 8 select tubing size (A_t), plunger size (A_P), rod sizes (A_r) and pumping speed (N) corresponding to pump setting depth (L).

4. Calculate fractional length of each section of the rod string, using data of Tables 9 and 10

5. Calculate the length of each section of the rod string to nearest 25 feet.

Table 1 DESIGN DATA FOR API SIZE 40 UNIT WITH 34-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	in.	in.	in.	strokes/min
1000-1100	2 ¾	3	⅞	24-19
1100-1250	2 ½	3	⅞	24-19
1250-1650	2 ¼	2 ½	¾	24-19
1650-1900	2	2 ½	¾	24-19
1900-2150	1 ¾	2 ½	¾	24-19
2150-3000	1 ½	2	⅝-¾	24-19
3000-3700	1 ¼	2	⅝-¾	22-18

Table 2 DESIGN DATA FOR API SIZE 57 UNIT WITH 42-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	in.	in.	in.	strokes/min
1150-1300	2 ¾	3	⅞	24-19
1300-1450	2 ½	3	⅞	24-19
1450-1850	2 ¼	2 ½	¾	24-19
1850-2200	2	2 ½	¾	24-19
2200-2500	1 ¾	2 ½	¾	24-19
2500-3400	1 ½	2	⅝-¾	23-18
3400-4200	1 ¼	2	⅝-¾	22-17
4200-5000	1	2	⅝-¾	21-17

Table 3 DESIGN DATA FOR API SIZE 80 UNIT WITH 48-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	in.	in.	in.	strokes/min
1400-1550	2 ¾	3	⅞	24-19
1550-1700	2 ½	3	⅞	24-19
1700-2200	2 ¼	2 ½	¾	24-19
2200-2600	2	2 ½	¾	24-19
2600-3000	1 ¾	2 ½	¾	23-18
3000-4100	1 ½	2	⅝-¾	23-18
4100-5000	1 ¼	2	⅝-¾	21-17
5000-6000	1	2	⅝-¾	19-17

Table 4 DESIGN DATA FOR API SIZE 114 UNIT WITH 54-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	in.	in.	in.	strokes/min
1700-1900	2 ¾	3	⅞	24-19
1900-2100	2 ½	3	⅞	24-19
2100-2700	2 ¼	2 ½	¾	24-19
2700-3300	2	2 ½	¾	23-18
3300-3900	1 ¾	2 ½	¾	22-17
3900-5100	1 ½	2	⅝-¾	21-17
5100-6300	1 ¼	2	⅝-¾	19-16

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Table 5 DESIGN DATA FOR API SIZE 160 UNIT WITH 64-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	**in.**	**in.**	**in.**	**strokes/min**
2000-2200	2 ¾	3	⅞	24-19
2200-2400	2 ½	3	⅞	23-19
2400-3000	2 ¼	2 ½	¾-⅞	23-19
3000-3600	2	2 ½	¾-⅞	23-18
3600-4200	1 ¾	2 ½	¾-⅞	22-17
4200-5400	1 ½	2	⅝-¾-⅞	21-17
5400-6700	1 ¼	2	⅝-¾-⅞	19-15
6700-7750	1	2	⅝-¾-⅞	17-15

Table 6 DESIGN DATA FOR API SIZE 228 UNIT WITH 74-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	**in.**	**in.**	**in.**	**strokes/min**
2400-2600	2 ¾	3	⅞	24-20
2600-3000	2 ½	3	⅞	23-18
3000-3700	2 ¼	2 ½	¾-⅞	22-17
3700-4500	2	2 ½	¾-⅞	21-16
4500-5200	1 ¾	2 ½	¾-⅞	19-15
5200-6800	1 ½	2	⅝-¾-⅞	18-14
6800-8000	1 ¼	2	⅝-¾-⅞	16-13
8000-8500	1 ⁄	2	⅝-¾-⅞	14-13

Table 7 DESIGN DATA FOR API SIZE 320 UNIT WITH 84-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	**in.**	**in.**	**in.**	**strokes/min**
2800-3200	2 ¾	3	⅞	23-18
3200-3600	2 ½	3	⅞	21-17
3600-4100	2 ¼	2 ½	¾-⅞-1	21-17
4100-4800	2	2 ½	¾-⅞-1	20-16
4800-5600	1 ¾	2 ½	¾-⅞-1	19-16
5600-6700	1 ½	2 ½	¾-⅞-1	18-15
6700-8000	1 ¼	2 ½	¾-⅞-1	17-13
8000-9500	$1^{1}/_{6}$	2 ½	¾-⅞-1	14-11

Table 8 DESIGN DATA FOR API SIZE 640 UNIT WITH 144-INCH STROKE

(After Kelley and Willis)

Pump Depth	Plunger Size	Tubing Size	Rod Sizes	Pumping Speed
ft	in.	in.	in.	strokes/min
3200-3500	2 ¾	3	⅞-1	18-14
3500-4000	2 ½	3	⅞-1	17-13
4000-4700	2 ¼	2 ½	¾-⅞-1	16-13
4700-5700	2	2 ½	¾-⅞-1	15-12
5700-6600	1 ¾	2 ½	¾-⅞-1	14-12
6600-8000	1 ½	2 ½	¾-⅞-1	14-11
8000-9600	1 ¼	2 ½	¾-⅞-1	13-10
9600-11,000	1 $^{1}/_{16}$	2 ½	¾-⅞-1	12-10

Table 9 DATA FOR DESIGN OF TAPERED SUCKER ROD STRING

Rod sizes in string, in.	Values of R[a]
⅝-¾	$R_1 = 0.759-0.0896\ A_P$ $R_2 = 0.241+0.0896\ A_P$
¾-⅞	$R_1 = 0.627-0.1393\ A_P$ $R_2 = 0.199+0.0737\ A_P$
⅞-1	$R_1 = 0.627-0.1393\ A_P$ $R_2 = 0.199+0.0737\ A_P$
⅝-¾-⅞	$R_1 = 0.627-0.1393\ A_P$ $R_2 = 0.199+0.0737\ A_P$ $R_3 = 0.175+0.0655\ A_P$
¾-⅞-1	$R_1 = 0.664-0.0894\ A_P$ $R_2 = 0.175+0.0478\ A_P$ $R_3 = 0.155+0.0416\ A_P$
¾-⅞-1-1⅛	$R_1 = 0.582 – 0.1110\ A_P$ $R_2 = 0.158+0.0421\ A_P$ $R_3 = 0.137+0.0364\ A_P$ $R_3 = 0.123+0.0325\ A_P$

Table 10 PUMP PLUNGER DATA

Diameter,	Area	Pumping Constant,
in.	sq in.	bbl/day/in./spm
1	0.785	0.116
$1^{1}/_{16}$	0.886	0.131
1 ¼	1.227	0.182
1 ½	1.767	0.262
1 ¾	2.405	0.357
$1^{25}/_{32}$	2.488	0.369
2	3.142	0.466
2 ¼	3.976	0.590
2 ½	4.909	0.728
2 ¾	5.940	0.881
3 ¾	11.045	1.639
4 ¾	17.721	2.630

6. Calculate acceleration factor

$\alpha = SN^2/70{,}500$

7. Determine effective plunger stroke

$$S_p = S + 40.8\frac{L^2\alpha}{E} - 5.20\frac{GDA_p}{E}\left[\frac{L}{A_t} + \frac{L_1}{A_1} + \frac{L_2}{A_2} + \cdots\right]$$

8. Using estimated volumetric efficiency, calculate the maximum probable production rate and check it against the desired production rate

$q = K\ S_P\ N\ E_v$

9. Calculate dead weight of the rod string

$W_r = L_1M_1+L_2M_2+L_3M_3+\ldots\ldots..$

10. Calculate fluid load

$W_f = 0.433G(LA_P – 0.294W_r)$

11. Determine peak polished rod load and check it against the maximum bean load for the unit selected.

$W_{max} = W_f + W_r\ (1+\alpha)$

12. Calculate maximum stress at the top of the rod string ad check it against the maximum permissible working stress for the unit selected

Maximum rod stress = W_{Max} / A_3

13. Calculate ideal counterbalance effect and check it against the counterbalance available for the unit selected

$C_i = 0.5W_f + W_r(1\text{-}0.127G)$

14. From the manufacturer's literature determine the position of counter weight to obtain the ideal counterbalance effect.

15. On the assumption that unit will no more than 5 per cent out of counterbalance effect, calculate the peak torque on the gear reducer and check it against the API rating of the unit selected

$T_P = (W_{Max} - 0.95\ C_i)\ (S/2)$

16. Calculate the hydraulic horsepower, friction horsepower and brake horsepower of the prime mover and select prime mover

$H_h = 7.36 * 10^{-6}\ qGL$

$H_f = 6.31 * 10^{-7}\ W_rSN$

$H_b = 1.5\ (H_h + H_f)$

17. From the manufacturer's literature obtain the gear reduction ratio and unit sheave size for the unit selected, and the speed of the prime mover. From this determine engine sheave size to obtain the desired pumping speed.

$d_e = Zd_u\ (N/N_e)$

If at any step, the unit or any component of the unit is found to be either undersized or over-sized as to load, torque, or production capacity, the design should be changed accordingly.

2. PROSPER

PROSPER is a well performance, design and optimisation program which is part of the Integrated Production Modelling Toolkit (IPM). This tool is the industry standard well modelling with the major operators worldwide.

PROSPER is designed to allow the building of reliable and consistent well models, with the ability to address each aspect of well bore modelling viz, PVT (fluid characterisation), VLP correlations (for calculation of flow-line and tubing pressure loss) and IPR (reservoir inflow).

PROSPER provides unique matching features, which tune PVT, multiphase flow correlations and IPRs to match measured field data, allowing a consistent well model to be built prior to use in prediction (sensitivities or artificial lift design). PROSPER enables detailed surface pipeline performance and design: Flow Regimes, Hydrates Flag, Pipeline Stability Studies, Slug Size and Frequency.

2.1 APPLICATIONS:

1) Design and optimise well completions including multi-lateral, multi-layer and horizontal wells
2) Design and optimise tubing and pipeline sizes
3) Design, diagnose and optimise Gas lifted, Hydraulic pumps, PCP, Jet Pump and ESP wells
4) Flow Assurance Studies - well and surface pipelines
5) Generate lift curves for use in reservoir simulators
6) Calculate pressure losses in wells, flow lines and across chokes

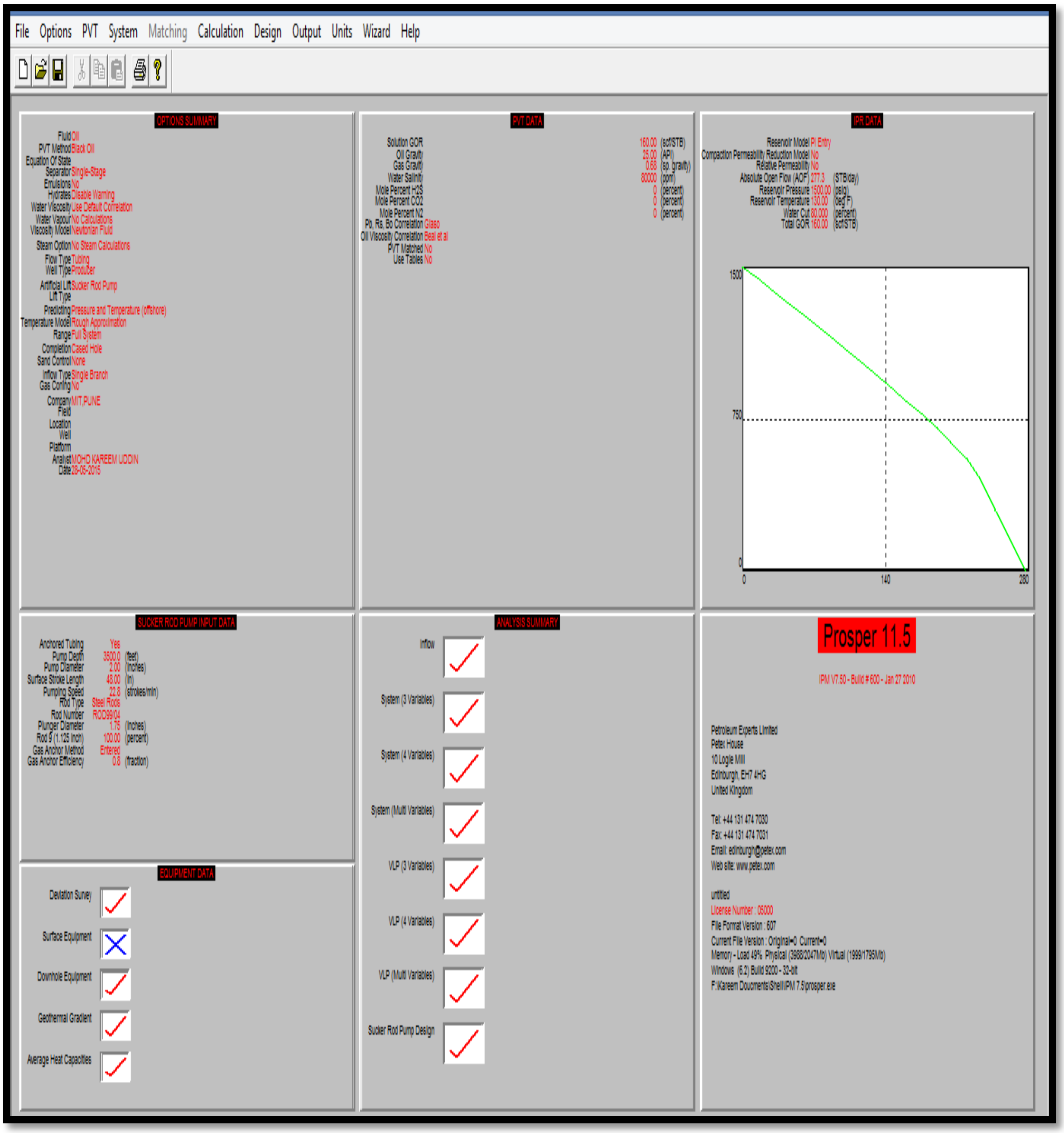

Figure: - 2 PROSPER First Page (Overview)

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2.2 INFLOW PERFORMANCE MODELS (IPR):

1) Multilateral well models
2) Single branch (Simple) inflows
3) Several proprietary inflow models for various fluids

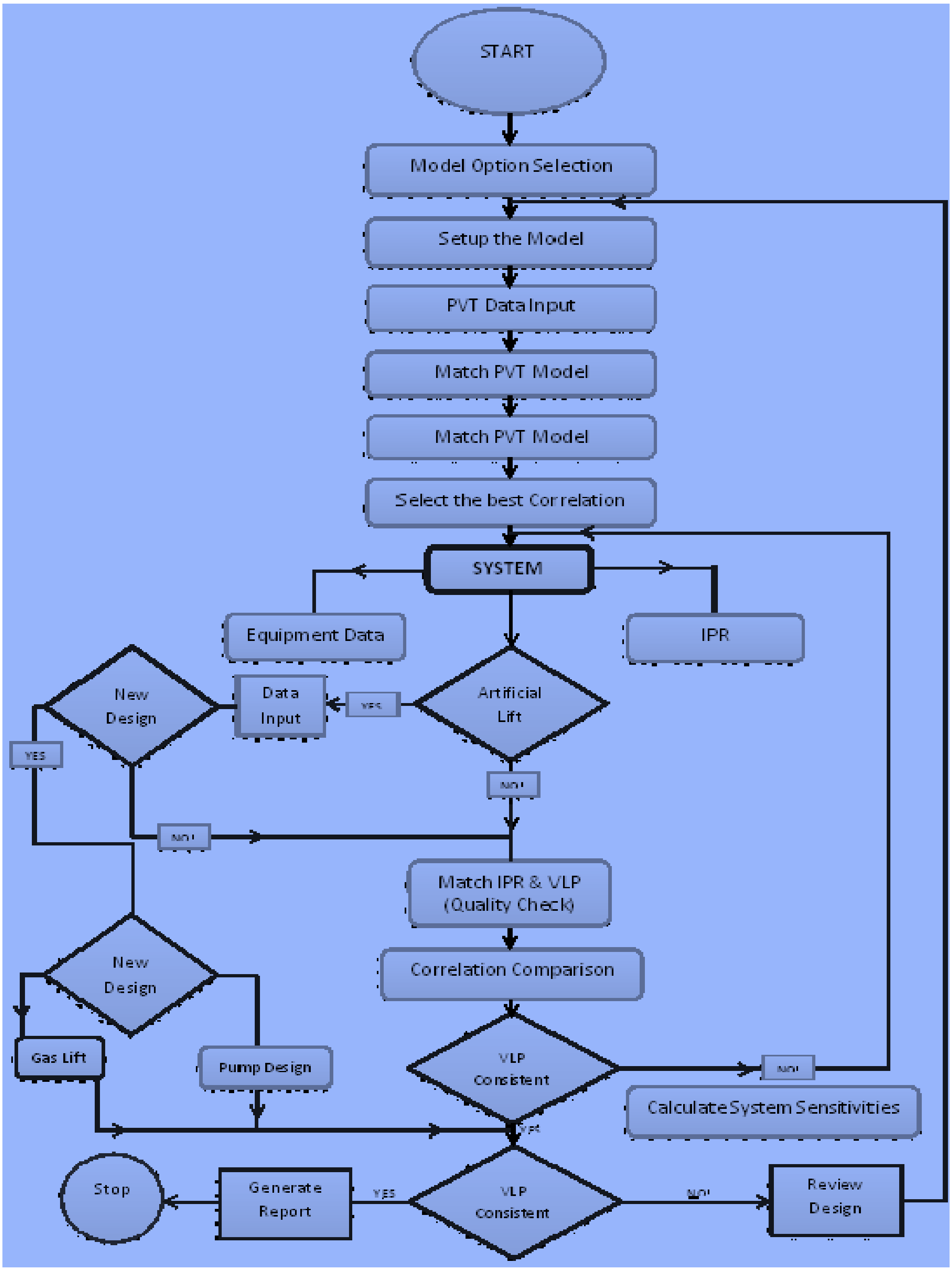

Fig: -3 artificial lift design workflow in PROSPER

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3. COMPUTER MODELLING OF SUCKER ROD PUMPING

3.1 Fluid Data:

Model	Black Oil
Reservoir Fluid	Water and Oil
Separator	Single Stage
Solution GOR	160 scf/stb
Oil Gravity (API)	25^{o}
Gas Gravity (sp. gravity)	0.68
Water Salinity	80,000
Mole Per cent H2S	0
Mole Per cent CO2	0
Mole Per cent N2	0
Pb, Rs, Bo Correlation	Glaso
Oil Viscosity correlation	Beal et al
Water Cut, %	80

Equipment Data:-

1) Deviation Survey

MD, ft	TVD, ft
0	0
3500	3500

2) Downhole Equipment:-

EquipmentType,ft	Measured Depth,inch	Tubing ID,inch	Tubing Inside Roughness,inch	Tubing OD,inch	Casing ID,inch	Casing Inside Roughness,inch
Xmas	0	N/A	N/A	N/A	N/A	N/A
Tubing	3500	2.441	0.0012	2.625	6.3	0.0012

3) Geothermal Gradient:-

Measured Depth in ft	Static Ambient Temperature
0	60
3500	130

Overall Heat Transfer Coefficient: 8 Btu/h/ft2/F

3.2 INFLOW PERFORMANCE RELATION:

Inflow Performance Data:-

Reservoir model	PI Entry
Reservoir pressure	1500 psig
Reservoir Temperature	130 degF
Water Cut	80 %
Total GOR	160 scf/stb
Compaction Permeability model:	NO
Relative Permeability	NO
Productivity Index	0.25 stb/d/psi

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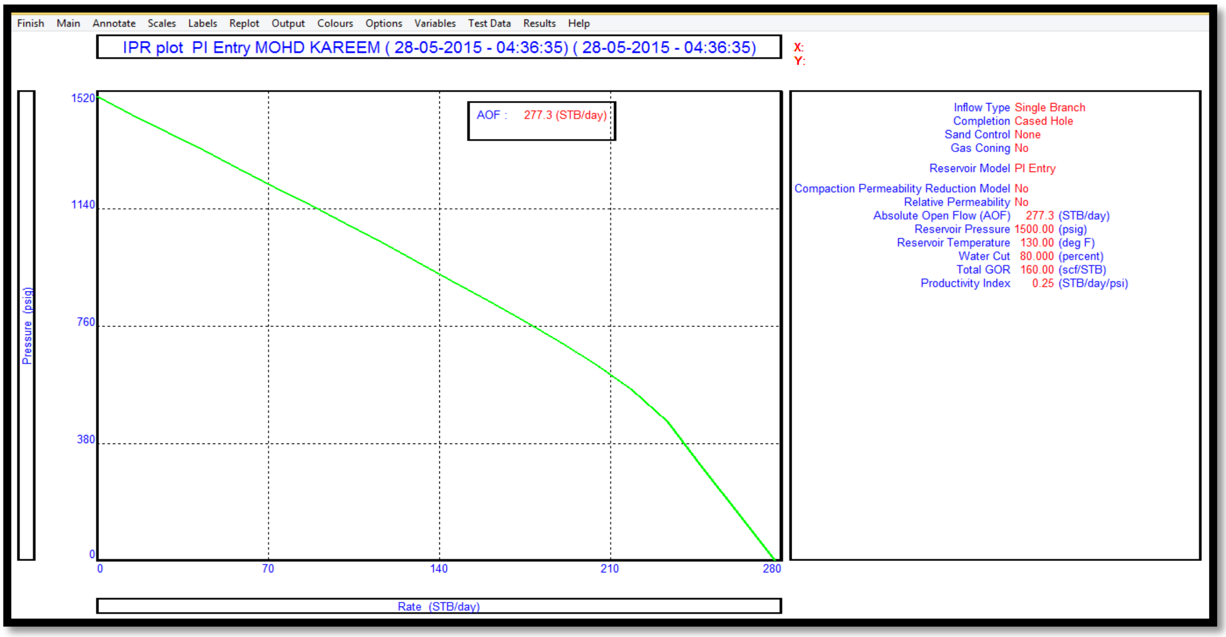

3.3 SRP-DESIGN PARAMETERS:

Anchored Tubing	Yes
Pump depth	3500 ft
Pump Diameter	2 inches
Surface stroke length	48 inches
Pump Speed	12 strokes / minutes
Rode Selection - Rod type:	Steel Rods
Rod Number	ROD99/04
Gas Anchor Method	Entered
Gas Anchor Efficiency	0.8 (fraction)
Type	Poor Boy
Annulus Area	1.5 in^2

Further deign parameters are:

Calculation mode:	Enter Production Rate, Estimate Stroke Rate
Pumping Unit Selection:	LUFKIN C-320-305-100 LC044
Rod Grad:	D
Service Factor:	Non-corrosive
Pump Intake Pressure Method:	Entered
Mid Perforation Depth:	3500 ft
Design Input - Unit type:	Conventional Clockwise
Design Input - Anchored tubing	Yes
Design Input – Mid Point Perforation depth	3500 ft
Design Input - Pump Depth	3500 ft
Design Input – Pump Volumetric Efficiency:	80%
Design Input - Unit Efficiency	75%
Design Input - Pump Diameter	2"
Design Input - Surface Stroke length	48 "
Design Input -Bottom Hole Temperature	130 degF
Design Input - Well Head Temperature	90 degF
Design Input - Well Head Pressure	100 psig

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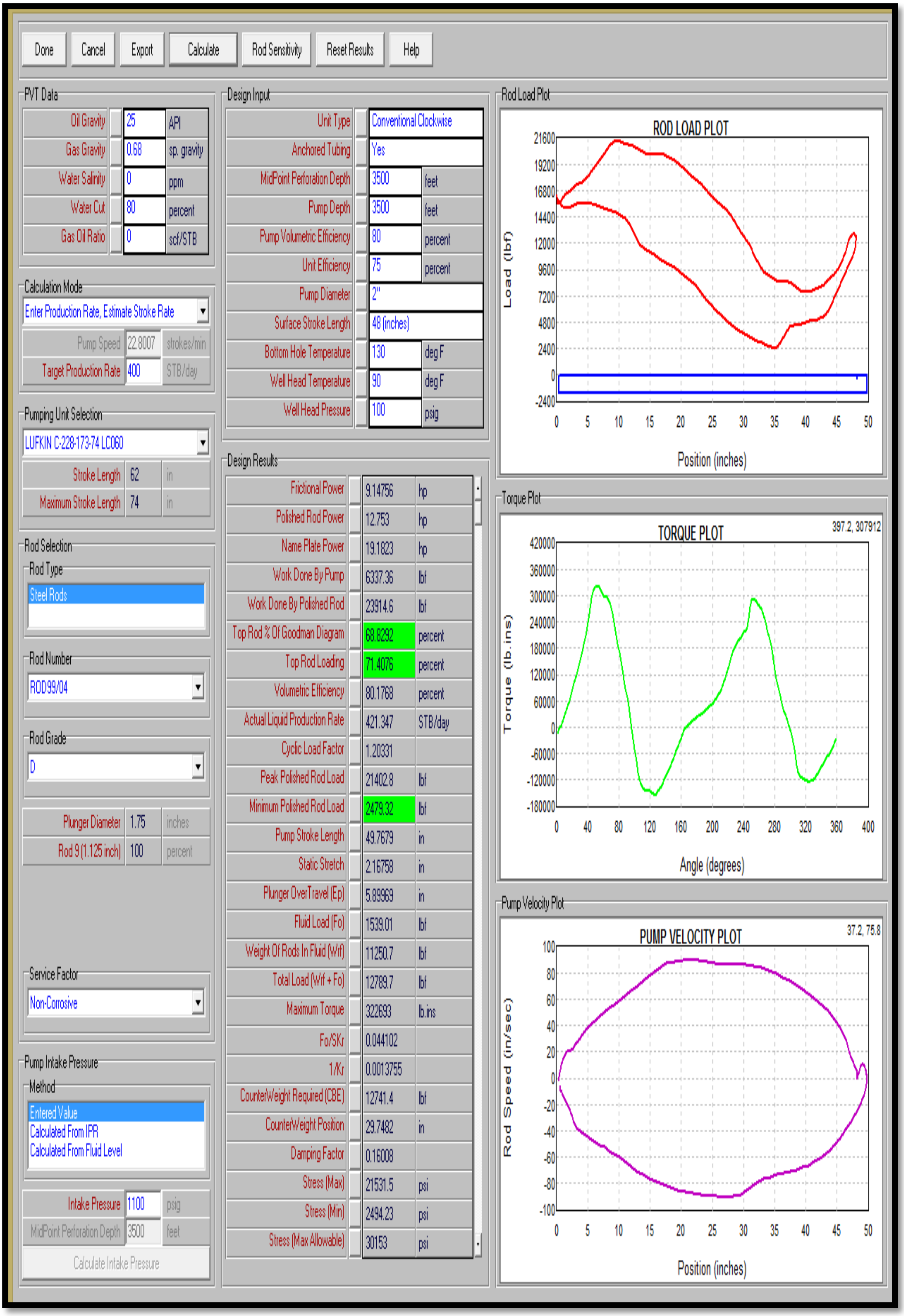
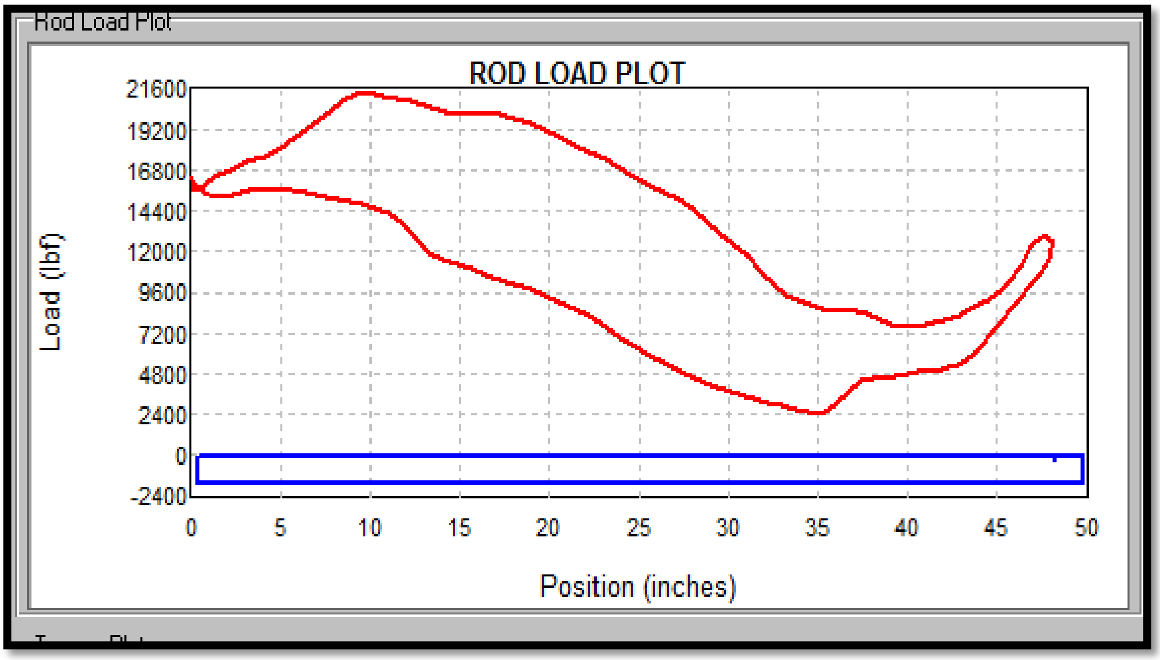
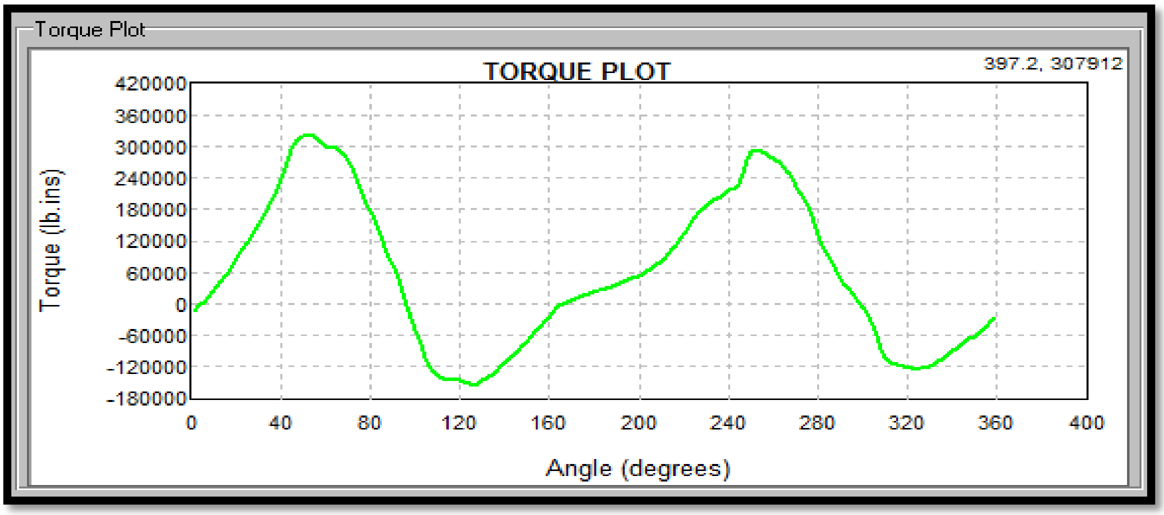


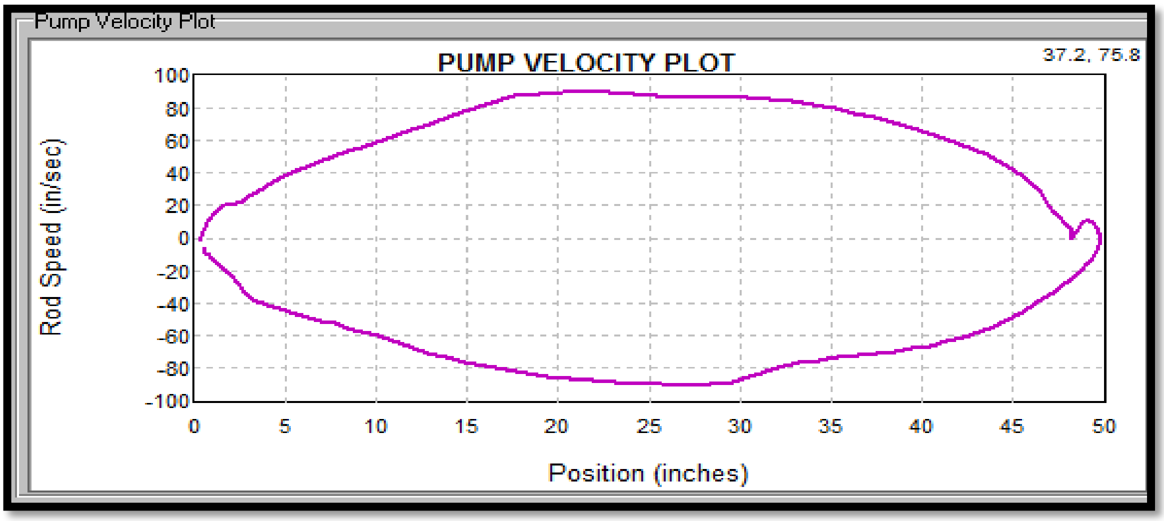
Figure: - 4 Complete Design of Sucker Rod Pump (SRP)

3.4 DESIGN RESULTS.

Frictional Power	9.14756 (hp)
Polished Rod Power	12.753 (hp)
Name Plate Power	19.1823 (hp)
Work Done By Pump	6337.36 (lbf)
Work Done By Polished Rod	23914.6 (lbf)
Top Rod % Of Goodman Diagram	68.8292 (percent)
Top Rod Loading	71.4076 (percent)
Volumetric Efficiency	80.1768 (percent)
Actual Liquid Production Rate	421.347 STB/day
Cyclic Load Factor	1.20331
Peak Polished Rod Load	21402.8 (lbf)
Minimum Polished Rod Load	2479.32 (lbf)
Pump Stroke Length	49.7679 (in)
Static Stretch	2.16758 (in)
Plunger OverTravel (Ep)	5.89969 (in)
Fluid Load (Fo)	1539.01 (lbf)
Weight Of Rods In Fluid (Wrf)	11250.7 (lbf)
Total Load (Wrf + Fo)	12789.7 (lbf)
Maximum Torque	322693 (lb.ins)
Fo/SKr	0.044102
1/Kr	0.0013755
CounterWeight Required (CBE)	12741.4 (lbf)
CounterWeight Position	29.7482 (in)
Damping Factor	0.16008
Stress (Max)	21531.5 (psi)
Stress (Min)	2494.23 (psi)
Stress (Max Allowable)	30153 (psi)
Torsional Effectiveness (ITE)	15.3744 (percent)
Lift Efficiency (LE)	75.1964 (percent)
Economic Index (EI)	596.838







3.5 ROD SENSITIVITY RUN:

Following picture and plot shows the variation of production rates and horse power requirements with rod types.

SUCKER ROD PUMP DESIGN - ROD SENSITIVITY (untitled)

Done | Cancel | Export | Calculate | Help

Results

Rod Index	Rod Name	Production	Horsepower	BBL / HP
4	ROD44/05	1226.62	15.7556	77.8532
15	ROD54/05	1197.91	17.5194	68.3764
22	ROD55/05	763.112	11.6453	65.5299
37	ROD65/05	675.66	11.3462	59.5497
46	ROD66/05	574.399	10.4582	54.923
57	ROD75/05	504.123	11.5074	43.8085
63	ROD76/05	529.328	10.4068	50.8638
73	ROD77/05	486.605	10.5553	46.1004
88	ROD86/05	507.489	11.0756	45.8204
96	ROD87/05	469.612	10.8129	43.4308
107	ROD88/05	444.807	11.435	38.8986
124	ROD97/05	461.221	11.5722	39.8558
133	ROD98/05	435.806	11.754	37.0771
144	ROD99/05	421.375	12.7539	33.039
163	ROD108/05	457.114	13.2277	34.5572
173	ROD109/05	433.39	13.6404	31.7725

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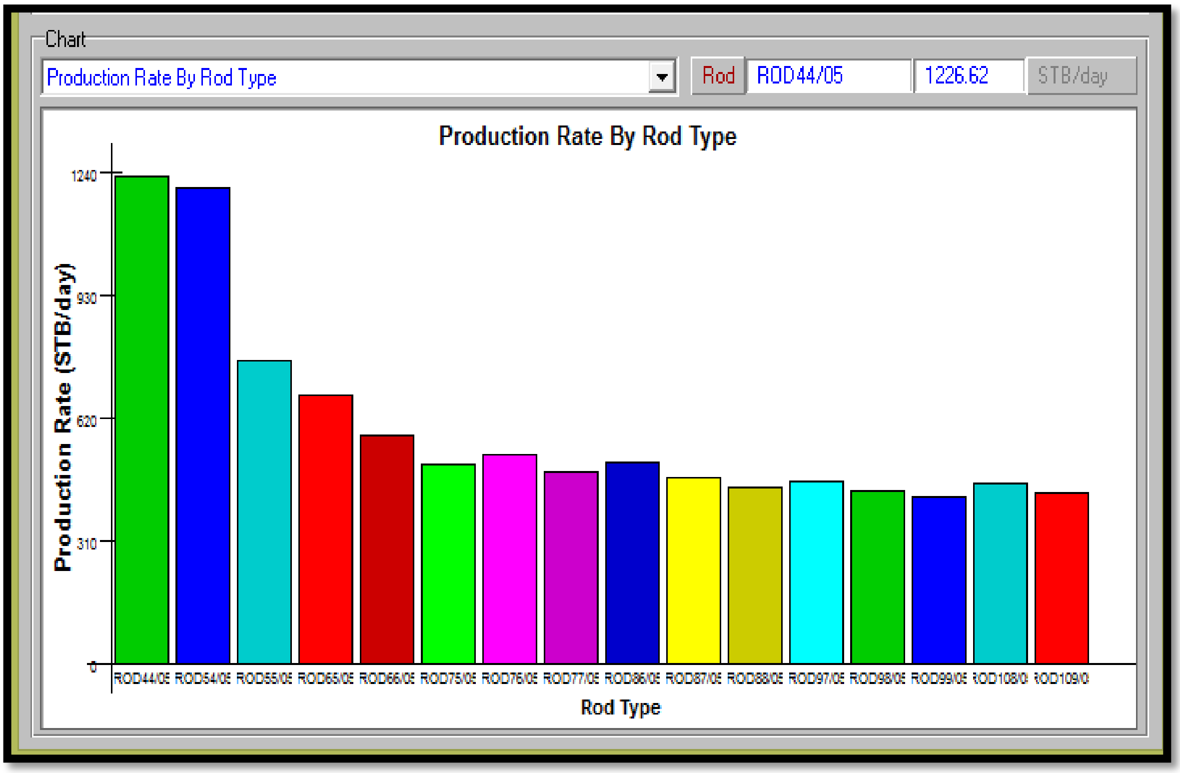
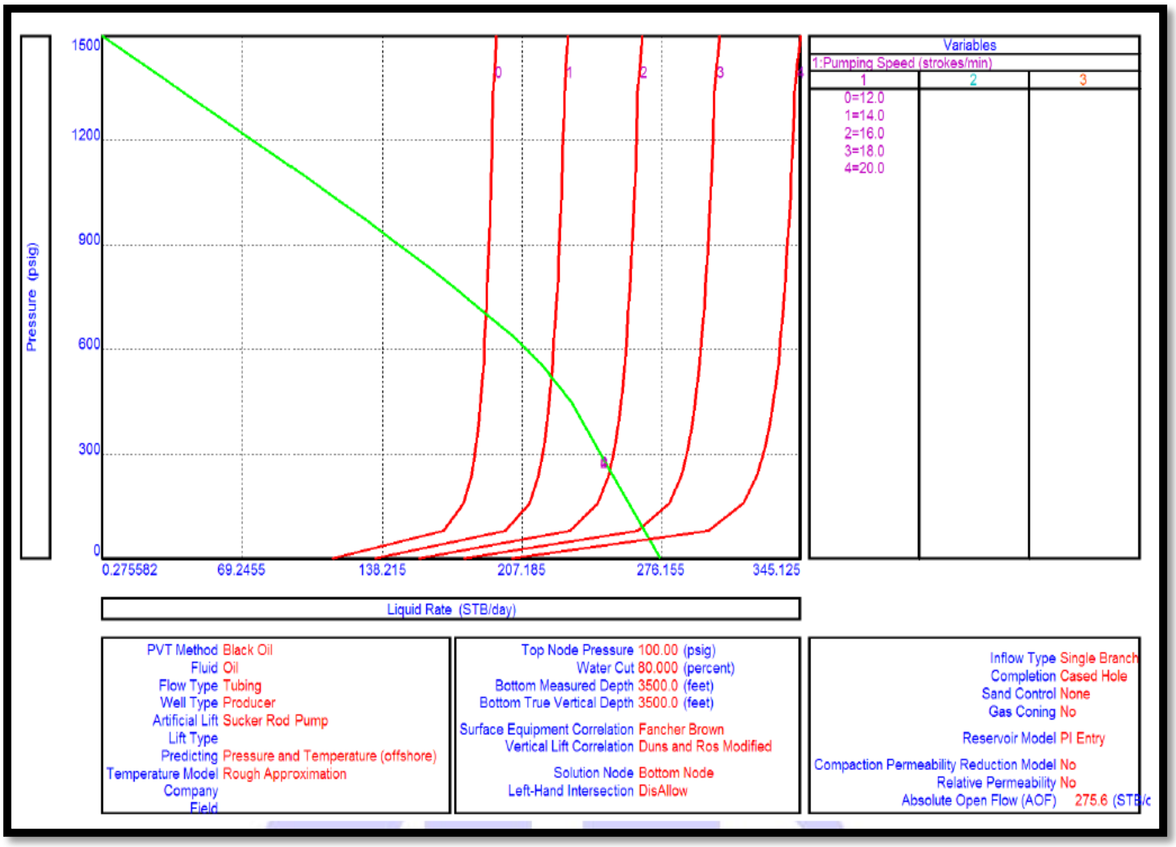


3.6 PUMPING SPEED SENSITIVITY:

In the same way, different pumping speeds on the behalf of vertical lift performance can be checked.

4. INFLOW (IPR) V OUTFLOW (VLP) PLOT



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