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RESEARCH PAPER

Sizing, Parametric Investigation and Analysis of Automated Sucker Rod Pump using Beam Pump Simulators

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Abstract

Reciprocating piston artificial lift systems are widely adopted especially, for onshore wells. Matching the pump mode to well and reservoir conditions reduces the pumping cost and increases the efficiency of production. Parameters influencing the energy requirement of sucker-rod lifted oil wells are investigated in this study, and new insights are provided for the parametric investigation of design variables required for sizing beam-pumped wells. Two (2) artificial lift simulators are integrated for automated sizing of beam-pumped systems. A sucker-rod artificial lift system is optimally sized for a case study oil well, to obtain the minimum API rating of the pumping unit, sustain the target production rate, and determine the corresponding minimum prime mover required to drive the pump sustainably. Compared to using a single simulator for the case study, the integrated approach reduces the damped and polished rod horsepower by 54.9% and 26.5% respectively, for a corresponding decrease in minimum NEMA D motor size by 38.6%. These key performance indicators demonstrate the benefits of simulator integration in automated sizing of beam pumps.

Keywords:
Artificial Lift Simulator,
Energy Requirement,
Parametric Investigation,
PROSPER,
QRod,
Sucker-Rod Pump

Introduction

Globally, conventional hydrocarbon resources are being steadily depleted, with a growing need for an artificial lift for production management [1]. Oil price is projected to settle between $(40-60)/barrel in the next two decades [2]. Hence at every phase during the life of a well, the need to minimize the cost of production, increase energy return on investment, improve pump volumetric efficiency, prolong pump life and improve overall production efficiency, cannot be overemphasized [3-6].

Deployment of artificial lift (gas or beam pumping) to extend the life of a producing well [7,8] is vital to maintain production at the desired level, particularly where the natural drive of the well is sufficiently depleted, and reservoir pressure becomes insufficient to produce at the desired flow rate. Artificially lifted wells consist of about 87% of all oil-producing wells worldwide, and roughly 71% of these wells are of the beam-pumped system [9]. The popularity of the sucker-rod pumping system is primarily due to its durable, simple, flexible, and familiar operation to most operators [3,10,11].

The design of optimum beam-pumped artificial lift systems is a classic problem that has attracted a lot of research effort, and a proactive attempt to solve the problem entails adopting a holistic and integrated approach [12,4]. Due to the relative ease of installation and maintenance of electric motors compared to gas engines, the former is increasingly adopted as

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the prime mover to drive beam-pumped wells [13]. Electricity cost is one of the most significant, if not the highest operating expense, especially for old oil wells [14], and accounts for about 33.38% of the total power consumption. Electric power bills typically range from 20-35% of the direct cost of petroleum production [13]. Well and reservoir conditions introduce certain constraints to fluid production, and optimal artificial lift design aims to produce fluids economically while working around the imposed constraints [15]. This work presents a simplified approach to obtaining the energy requirement of the electric motor required to drive the downhole pumps.

A typical sucker-rod pumping system consists of a surface transmission system and a subsurface (or downhole) system. The surface components include the prime mover (motor), gearbox, reciprocating pump unit, polished rod, and wellhead. The metal rod string, tubing, and downhole pumps are components of the subsurface equipment [16,17]. The prime mover could be a fuel-powered internal combustion engine or an electric motor, whose rotational motion is converted by the surface unit into the reciprocating linear motion of the rod string within the tubing [18]. The downhole pump consists of a barrel or cylinder and a plunger or piston. The direction of energy transfer is such that the oscillating motion of the rod string causes the plunger to be displaced within the barrel. The subsurface pump has two (2) check valves: a traveling valve and a stationary valve, which systematically work together to transfer well fluids into the tubing, and cumulatively displace fluid to the surface [16,11].

In the design, installation, and operation of beam-pumped wells; the pumping mode is specified by the unique selection of pump size, pumping speed, stroke length, and sucker rod string design [15]. The satisfactory performance and favorable interaction of the reservoir, wellbore, subsurface, and surface equipment, demands that the pumping system is sized to optimize production (increase production/minimize cost) [4]. The optimal design of a sucker-rod pumped artificial lift system implies that the parameters of the pumping system are correctly determined, and the equipment is carefully selected to produce the fluid economically and also attain other goals set by the well operator [15]. The dynamic nature of the reservoir, fluid, well, and pump conditions places a demand for continuous parametric investigation (in addition to production tests) throughout the life of a producing well, to ensure that production is both sustainable and profitable [15], alluded to the fact that the power requirements and cost could be significantly small when the pumping mode is appropriately selected.

Optimal design and accurate selection of the appropriate pumping mode could include lifting a target rate from the well under optimum conditions and matching the pump behaviour to the inflow rate of the well. When the pump behaviour is specified, the aim is to size the beam pump to the inflow or target rate of the well. An operating point could also be obtained for the well such that the deliverability of the reservoir (inflow performance relationship) is matched with the vertical lift performance of the well [19].

The inflow performance relationship or reservoir deliverability is deduced from the productivity index of the well. In contrast, the vertical lift performance or pump deliverability is determined from the pump characteristic curve. Given specific operational conditions, an intersection point between the inflow and outflow performance can be obtained to indicate the operating point/production rate of the well and the corresponding flowing bottom hole pressure [20]. The pumping unit must be sized to match the well conditions, and the pumping modes dynamically adjusted to suit the reservoir conditions [1].

Methodology

It is economically imperative to perform feasibility studies on stripper wells and marginal oil fields requiring an artificial lift. This work aims to estimate the energy requirement of a case study well by integrating two simulators: QRod™ (Quick Rod) and PROSPER™ (Production and System Performance Analysis Software). The number of trials or iterations required to attain the minimum API pump rating is reduced. QRod™ will initially be used to ascertain a provisional minimum API rating of the beam pumping unit and the size of the NEMA D motor (high slip electric motor). The tentative size is then combined with other design input parameters in PROSPER™ to obtain a more robustly sized unit. The case study is an onshore well "X" that requires an artificial lift to sustain production. The goal is to perform preliminary studies that will help in accurately selecting an optimal pumping mode and hence properly size the sucker rod system, to keep the well producing sufficient volumes profitably at a reduced cost.

Automated Sizing Methodologies of Sucker Rod Pump Artificial Lift System

One significant challenge in analyzing the operation of a sucker rod pump arises from the elastic behavior of the rod strings. The polished rod stroke length (at the surface) is significantly different from the stroke length at the downhole pump and surface parameters cannot be directly used to estimate pump displacement [15]. Modelling of viscous and mechanical friction in addition to rod elasticity, results in a one-dimensional wave equation, with pumping action denoted by stress waves or elastic forces traveling at the speed of sound along the string length [21].

Automated sizing of a sucker rod pumped system uses Fourier analysis (harmonic analysis) to determine the position of the rod string, the amount of load, and the type of load that the rod string is subjected to downhole. The plot of rod load versus rod position is presented as a measured or predicted dynamometer card, which is useful for monitoring, predicting, and diagnosing production problems [22,23]. Modelling the rod string as ideal slender bars (with the pumping action represented by stress waves traveling along the rod length) results in a 1-dimensional damped wave equation, which takes rod elasticity and friction into account in predicting the useful work done downhole, the position and load on the rod string in the subsurface. The elastic behavior of the sucker-rod is defined by the wave equation [21].

Parametric Investigation

Some of the design input parameters have significant impacts on the sizing of the beam-pumped artificial lift system. A parametric investigation is performed in QRod™ to determine these specific parameters, quantify their influence on overall system objectives, and ensure that the parameters chosen are neither impractical nor uneconomical [15].

Effect of Pump Geometry on Energy Requirement

Fig. 1 shows API gravity versus energy requirement for different geometries. As shown in Fig. 1, it is observed that Mark II has a significantly lower energy requirement than the conventional units: clockwise (CWconv) and counterclockwise (CCWconv) [15]. This is irrespective of the API gravity of the produced fluid considered. Air-balanced geometry has the least energy rating of the four geometries considered; followed by mark II, counterclockwise conventional, and clockwise conventional units respectively, in order of increasing energy requirements. Air-balanced units are typically deployed for portability and well testing [15], and they have an advantage over crank-balanced units where space and weight requirements are crucial. Air-balanced units are usually preferred for wells that require larger unit sizes or longer pump strokes.

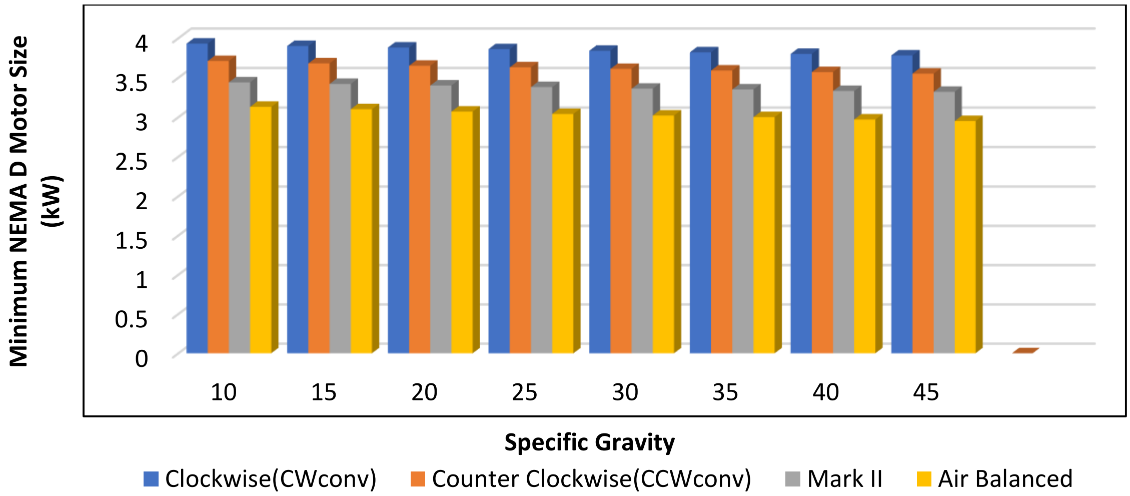


Fig. 1. API gravity versus Energy requirement for different geometries

Hence in pump selection and sizing for minimum energy requirement, the mark II pump is preferred to decrease the power requirement. The geometry of the pumping unit is demonstrated to have a profound impact on the energy requirement and the corresponding size of prime mover required. There is a significant reduction in the energy requirement as one transitions from heavy oil (10^0) to lighter oil (45^0).

Effect of API Rod Number on Energy Requirement of Pumping Unit

Fig. 2 shows API rod number as a function of minimum polished rod size, stroke rate, and prime mover rating. It can be deduced from Fig. 2, that with an increase in the tapering from 65 to 97, there is a corresponding increase in the energy requirement and a decrease in the stroke rate required to sustain a target level of production. This is understandable as the mass per unit length of the rod string is expected to increase from a tapering of 65 to 97.

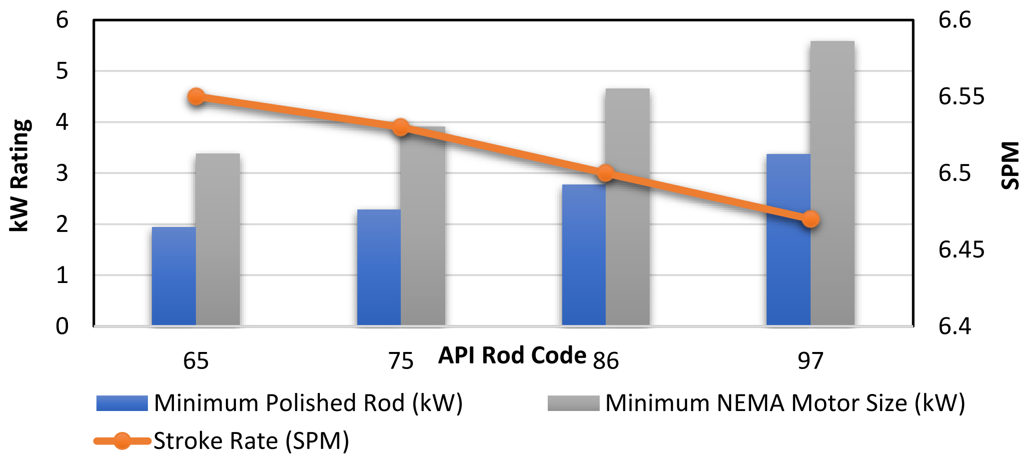


Fig. 2. API rod number as a function of minimum polished rod size, stroke rate, and prime mover rating

Fig. 3 Prime mover rating as a function of pump diameter. It is observed from Fig. 3 that irrespective of the pump diameter chosen, the energy requirement consistently increases with tapering for API rod numbers 65, 75, 86 to 97. Such that the rating of the electric motor (prime mover) decreases with increases in the diameter of the pumps from 1.06, 1.25 to 1.5 inches. The minimum electric motor prime mover rating, generally decreases with an increase in pump diameter, as shown in Fig. 3.

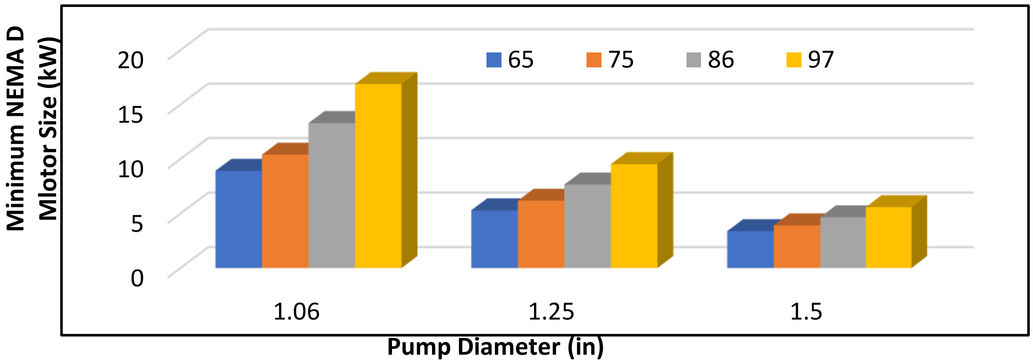


Fig. 3. Prime mover rating as a function of pump diameter (at respective API rod numbers)

The tapering criterion for the design of the sucker rod string greater than or equal to 3500 feet is satisfied by implementing significant tapering in the rod string; so that any potential rod failure will concentrate at the point of maximum stress. Given the desired production level, It can be deduced from Figs. 2 & 3 that the equivalent stroke rate generally decreases with an increase in the API rod number. Hence for our design at a well depth of 3,500ft, the tapering criterion is adopted, and an API rod number of 65 is chosen to result in the least pump and prime mover rating, with a correspondingly maximum stroke rate (strokes per minute). The motor sizes also increase from API rod number 65, 75, 86 to 97.

Effect of Pump diameter and API Gravity On Minimum Rating of Prime Mover

Fig. 4 shows the effect of pump diameter on minimum NEMA motor size in QRod™. It can be observed from Fig. 4 that the energy requirement (minimum prime mover size in kW) generally decreases with an increase in the API gravity, from 10^0 to 45^0. API gravity of 25 is adopted in sizing the artificial lift system. In general, for a specific API gravity, the horsepower needed for a given rod type decreases with an increase in pump diameter (from 1.06 to 1.5 inches), being higher for lower API (heavier fluids) and lower for higher API gravity (lighter fluids). Based on the mentioned figures, the pump size of 1.50 inches is chosen for the design as it is the widest rod pump that can practically run in a 2.375 or ($2\frac{3}{8}$) inches anchored tubing.

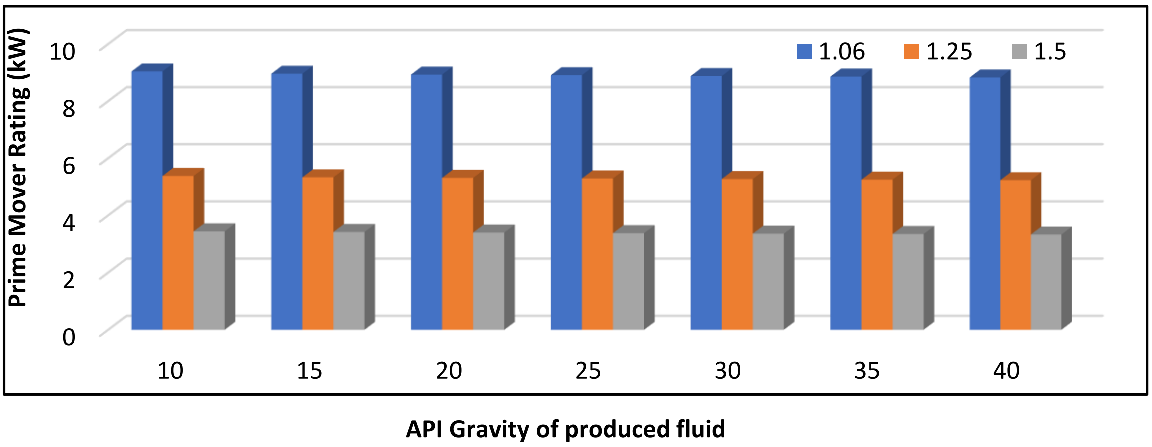


Fig. 4. Effect of pump diameter on minimum NEMA motor size in QRod™

Effect of the rod material on the stretch of the rod string

Excessive rod stretch is undesirable as it reduces the effective stroke length; hence sinker bars are adopted to increase the overtravel between the pump and the plunger and therefore compensate for excessive rod stretch [26] as can be seen in Figs. 5a and 5b. The proportion of the plunger stroke that is effective in lifting fluids is the effective plunger stroke (inches) given by [15]:

Effective plunger stroke (inch) = polished rod stroke + plunger over-travel – (rod stretch + tubing stretch) (1)

PPRL	6,187.7 lb	MPRL	3,429.0 lb	Fo	470.6 lb
Pump Stroke Length	72.76 in	Static Stretch	1.83 in	Overtravel	0.59 in
Fo/Skr	0.025	Kr	257 lb/in	Kt	1277 lb/in

(a)

PPRL	7,216.3 lb	MPRL	3,741.0 lb	Fo	470.6 lb
Pump Stroke Length	73.27 in	Static Stretch	2.03 in	Overtravel	1.30 in
Fo/Skr	0.027	Kr	232 lb/in	Kt	1277 lb/in

(b)

Fig. 5. Static stretch and overtravel in rod string, a) steel and b) fiberglass

When combination rods containing fiberglass sucker-rods are used, the regular operation is significantly dependent on rod diameter. If the fiberglass diameter is too small, it can result in too much rod stretch, and from Eq. 1, this reduces the pump displacement and minimizes the stroke length available to do useful work at the pump [27]. For deep wells, fiberglass rods are generally considered more economical for fluid production than steel rods [18].

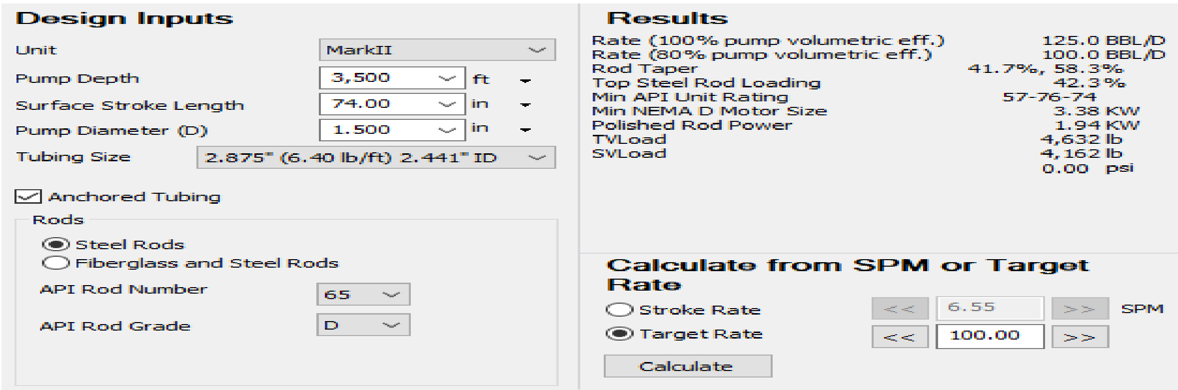
When the sucker-rod length is significantly longer or its diameter is sufficiently small, excessive stretch becomes inevitable, plunger stroke is limited, and crude oil production minimized, hence compensation for production loss may require increased pumping speed [31].

The behavior of the sucker rod pump is such that pumping (resulting from the lifting of the fluid) and stretching of the elastic rod, only occurs for the upstroke [24]. During the downstroke, rod compression occurs, and the fluid mass is not considered [25]. Solid steel or fiberglass could be used as material for the rod. From Figs. 6a and 6b, the use of fiberglass sucker rods can lead to a significant reduction in rod loading (from 42.3% to 31.5%). It even practically eliminates corrosion [18,26]. Aside from the fact that fiberglass material is not considered where pump friction is significant, another drawback is that fiberglass often results in excessive stretch which limits the productive capacity of the pump or even completely negates pump displacement [27].

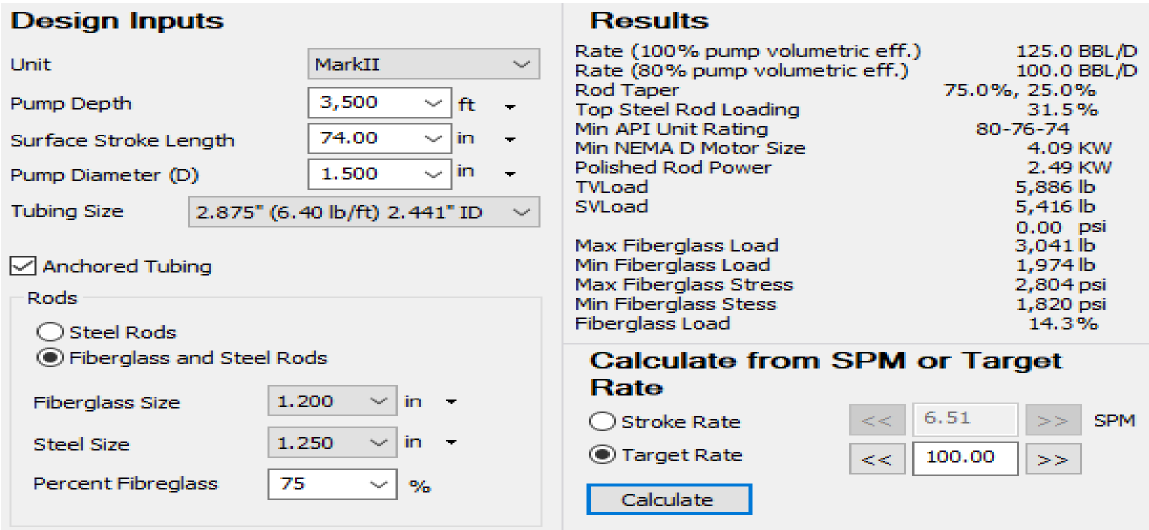
Quick Rod (QRod™)

QRod™ (Quick Rod) is a tool that mathematically simulates or imitates the motion of the pumping unit. A damped wave equation describes the movement of the rod string, and the solution to the partial differential equation (expressing the action of the rod string) is obtained. The load applied by the pump on the rod string is determined using the pump intake pressure. It uses surface boundary conditions as an approximation for the motion of the surface unit. The propagating stress waves influence the resultant loading of the rod string, the torque required, power demands, and dynamometer card plots obtained. QRod™ uses a wave equation to synthesize the surface and pump dynamometer loads, determine in-balance gearbox torque, counterbalance, and determines the plunger velocity for a stroke. Given the pump setting depth and target production rate; the effect of changing parameters (such as tubing anchor, stroke length, stroke rate, and pump diameter) on pump displacement, rod string loading, surface unit and motor size requirements can be readily ascertained and the artificial lift system designed, as shown in Fig. 7. Some distinctive features of QRod™ are as follows:

- the option for tapered steel rod strings and fiberglass/steel combination strings is provided,
- sinker bars can be adjusted to increase the overtravel and compensate for the negation of pump displacement due to excessive rod stretch,
- the effect of pump diameter and clearance on pump slippage can be considered in the simulation of pump operation.



(a)



(b)

Fig. 6. Design inputs and results using a) steel and b) fiberglass

After conducting the parametric investigation in QRod™, for the minimum production level of 100bbl/day, the input and default parameters are selected that will optimize the energy requirement of the sucker-rod pumped artificial lift system and also minimize the corresponding prime mover rating (minimum NEMA D motor size), as shown in Fig. 7.

Production and System Performance Analysis Software (PROSPER™)

PROSPER™ is a production and system performance analysis software, useful for optimizing already existing system designs and assessing the effect of variation in system parameters. It finds application in modelling existing wells (diagnostic) and for the optimal design of new wells (prediction). It is used to model inflow performance (IPR) for the reservoir(s) of various configurations with completions that are usually complex and deviated. It is a very robust software that can be used to design, optimize, and troubleshoot many artificial lift options including the sucker-rod or beam pumps. The approach to sizing the artificial lift system is shown in Fig. 8.

The workflow in Fig. 8 is briefly summarized as follows:

- the properties of the produced fluid are matched with standard fluid correlations,
- the well and downhole equipment are modelled,
- the appropriate model for the IPR is selected to determine the producing bottom hole pressure,
- the initial design conditions for the sucker rod pump are provided,
- the simulation is executed, and results obtained are considered,

the process is repeated continuously (iteratively) until the design expectations are satisfied [34].

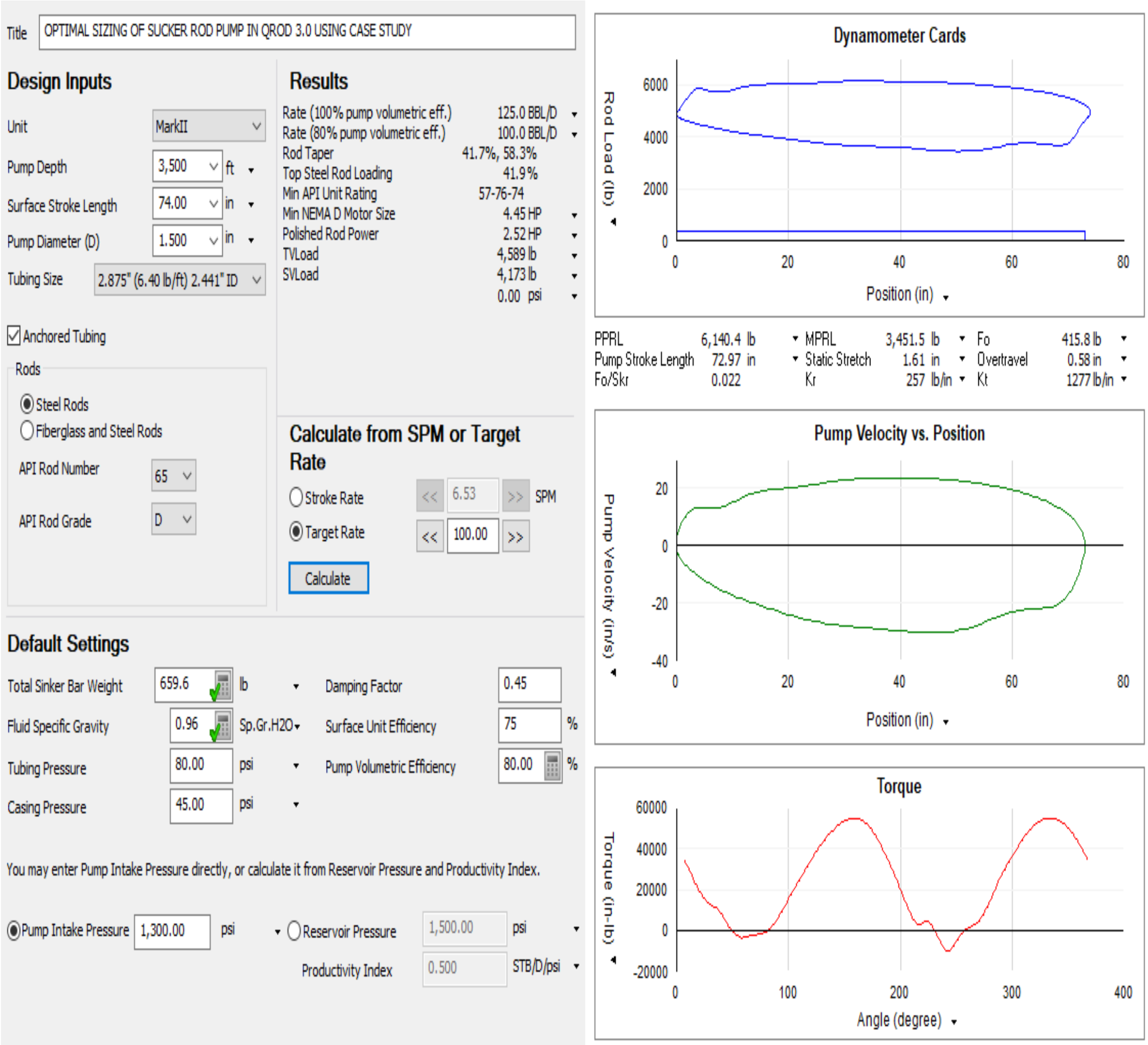


Fig. 7. Sucker-rod pump artificial lift design in QRod™

Integrated Sizing Procedure (PROSPER™ Integrated with QRod™)

The challenge with designing artificial lift systems using PROSPER™ simulator alone is that the design is highly iterative, as it requires several unsuccessful attempts of trial and error before a practical solution can be found and even many more iterations before an optimal design can be attained. An alternative simulator (QRod™) helps to reduce iteration time, by first performing a parametric investigation after which the parameters selected are applied in PROSPER™ software to obtain a more efficient sizing, as shown in Fig. 9.

The workflow from Fig. 8 (based on sizing using PROSPER™ alone) is integrated with the results obtained from Fig. 7 to obtain a modified workflow, shown in Fig. 9. The process of achieving this integration is further explained in detail below.

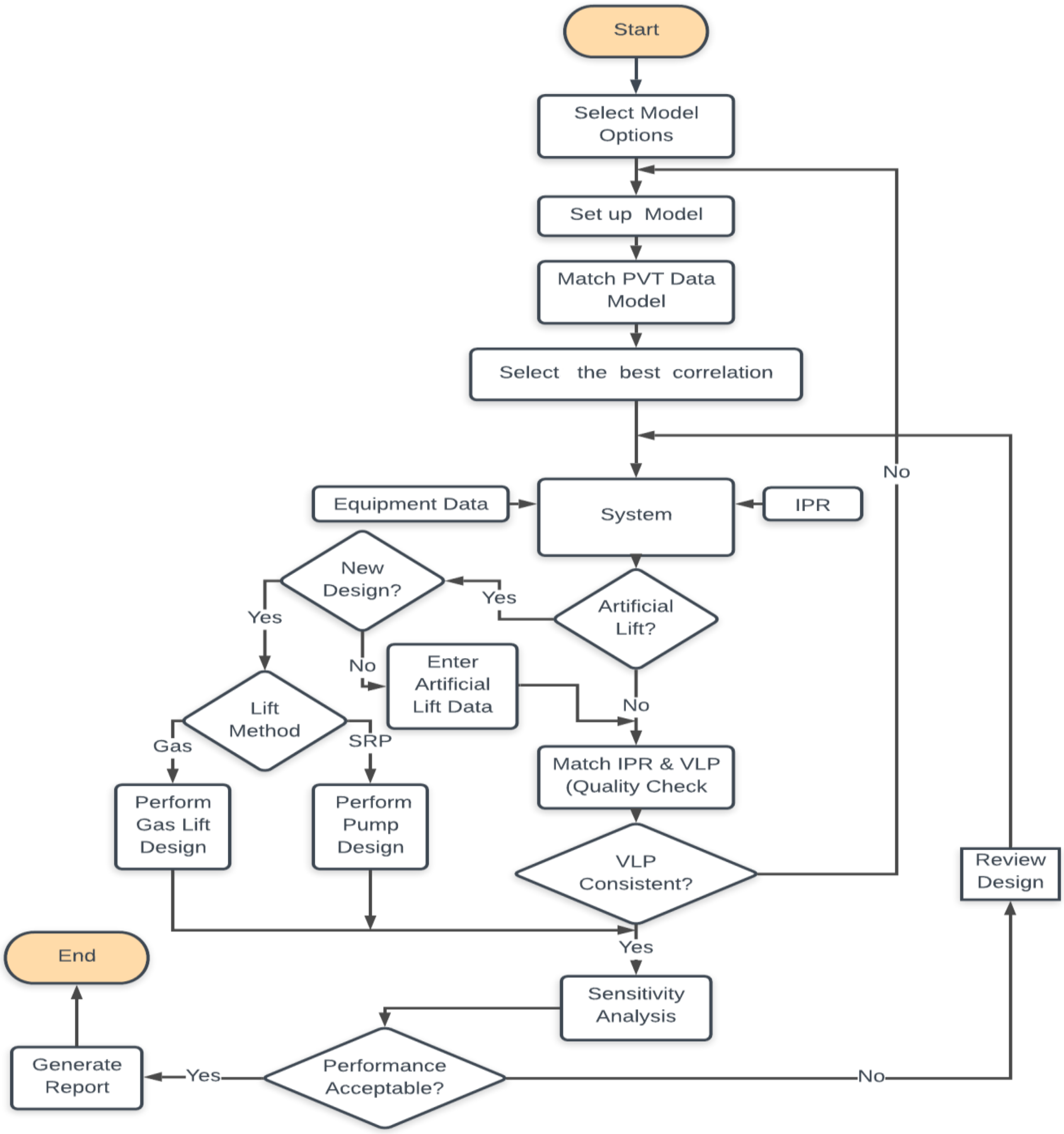


Fig. 8. Iterative Sucker-rod pump (SRP) artificial lift design workflow in PROSPER™

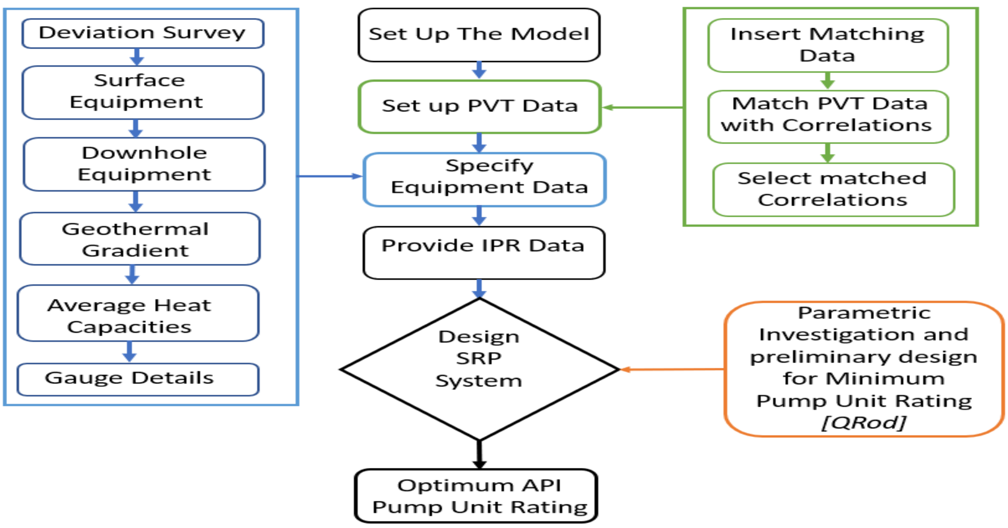


Fig. 9. Modified PROSPER™ Workflow (With QRod™ Integrated)

PVT Data Input

The fluid type for the petroleum system is oil and water, modelled as black oil, a single-stage separator is adopted, and the fluid viscosity is modelled as Newtonian. The design procedure begins by inserting the PVT properties, shown in Fig. 10, followed by the selection of the correlation or regression that most closely matches the field data in terms of bubble point, gas-oil ratio, oil formation volume factor, and oil viscosity.

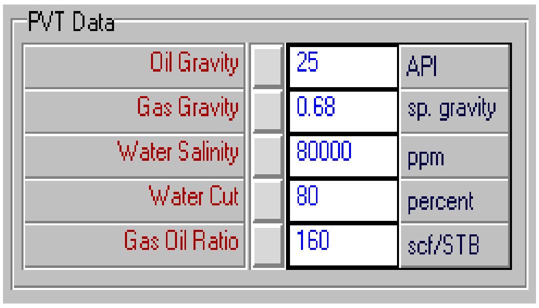


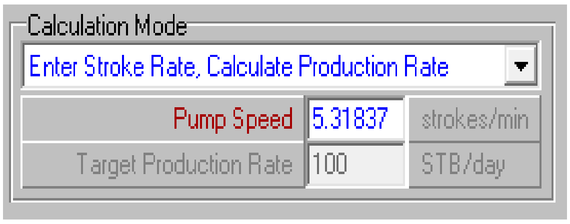
Fig. 10. PVT data inputs in PROSPER™

Before the artificial lift system is designed, the well path and downhole equipment are thoroughly described. Details such as the deviation survey, the surface equipment, the downhole equipment, geothermal gradient, average heat capacity, and gauge details are required. For the deviation survey, a vertical well is chosen; the model in this sizing does not account for surface equipment.

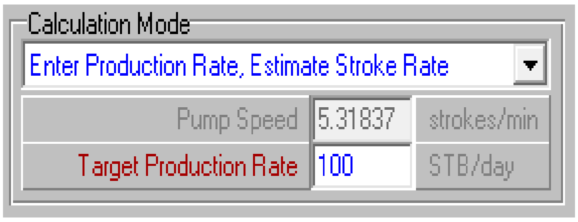
Modelling the fluid as black oil implies that the fluid is considered undersaturated hence productivity index (PI) reservoir model is user-defined, after which the IPR curve is estimated. Any change in the properties will require that the IPR is recalculated and the absolute open flow potential (AOFP) used as the maximum possible (theoretical flow rate).

There are two calculation models provided in artificial lift simulators QRod™ and PROSPER™ concerning production rate, as shown in Fig. 11, PROSPER™ software can be used for both the diagnostic and predictive models.

- In the diagnostic model, the stroke rate is provided, while we calculate/predict production rate (measure surface loads and predict pump performance) as shown in Fig. 11a.
- In the predictive model, the production rate is provided, while the stroke rate is predicted (assume pump performance and predict surface loads), as shown in Fig. 11b.



(a)



(b)

Fig. 11. Predictive Model in PROSPER™, a) diagnostic and b) predictive

In the diagnostic model, a realistic stroke rate is provided, and the resulting production rate is computed, but in the predictive model, a target production rate is used in the design of the artificial lift system. The target or desired production rate is chosen, and the software is used to determine the stroke rate required and the corresponding size of the artificial lift to sustain production. In this work, we will be using the simulators in the predictive model.

Non-corrosive (grade D) tapered rod (6/5) is chosen (as determined from the parametric investigation). The diameter of the plunger and the thickness of the rod are provided when the rod type is specified. The plunger diameter must be less than the pump diameter, with enough tolerance or pump clearance for oil slippage. The percentages of each rod string section deduced from QRod™, and PROSPER™ are practically identical (41.7%, 58.3% in QRod™, and 42%, 58% in PROSPER™), with PROSPER™ providing more details in terms of the diameter of each rod section, as shown in Fig. 12.

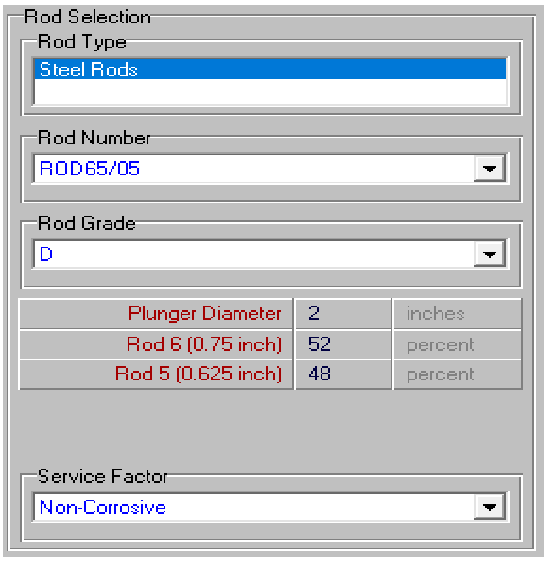


Fig. 12. Rod selection in PROSPER™

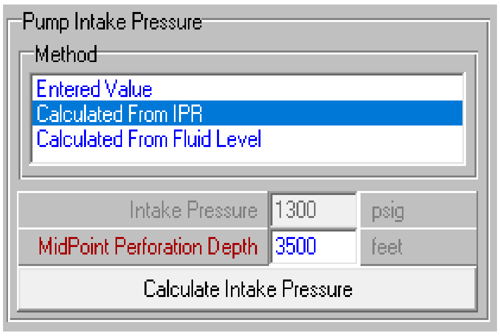


Fig. 13. Pump intake PROSPER™

In specifying the pump intake pressure, the value can be:

- entered directly into the simulator,
- calculated from the IPR curve, or
- derived from the fluid gradient.

IPR curve and the design rate specified are used to estimate the pressure which will be required to produce the design rate from the producing interval. This decision assumes that the mid-perforation depth is the same as the pump intake depth, as shown in Fig. 13.

The design is executed, and the actual liquid production rate is 140.08 STB/day. The obtained design outcomes do not flag any cautions or indicate any parameters to be out of range. Therefore, the design is acceptable considering the constraints and input requirements.

The pressures and temperatures are then provided for the system, as well as the surface stroke length and pump diameter, as shown in Fig. 14. The tubing is specified as anchored to maximize the pump displacement and minimize loading on the rod string.

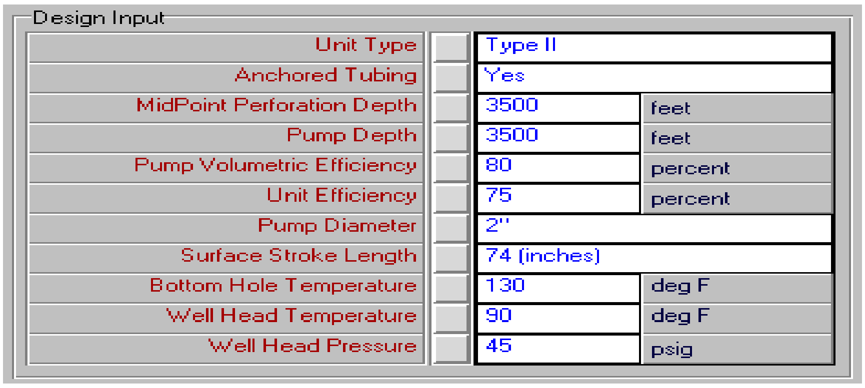


Fig. 14. Pump input parameters in PROSPER

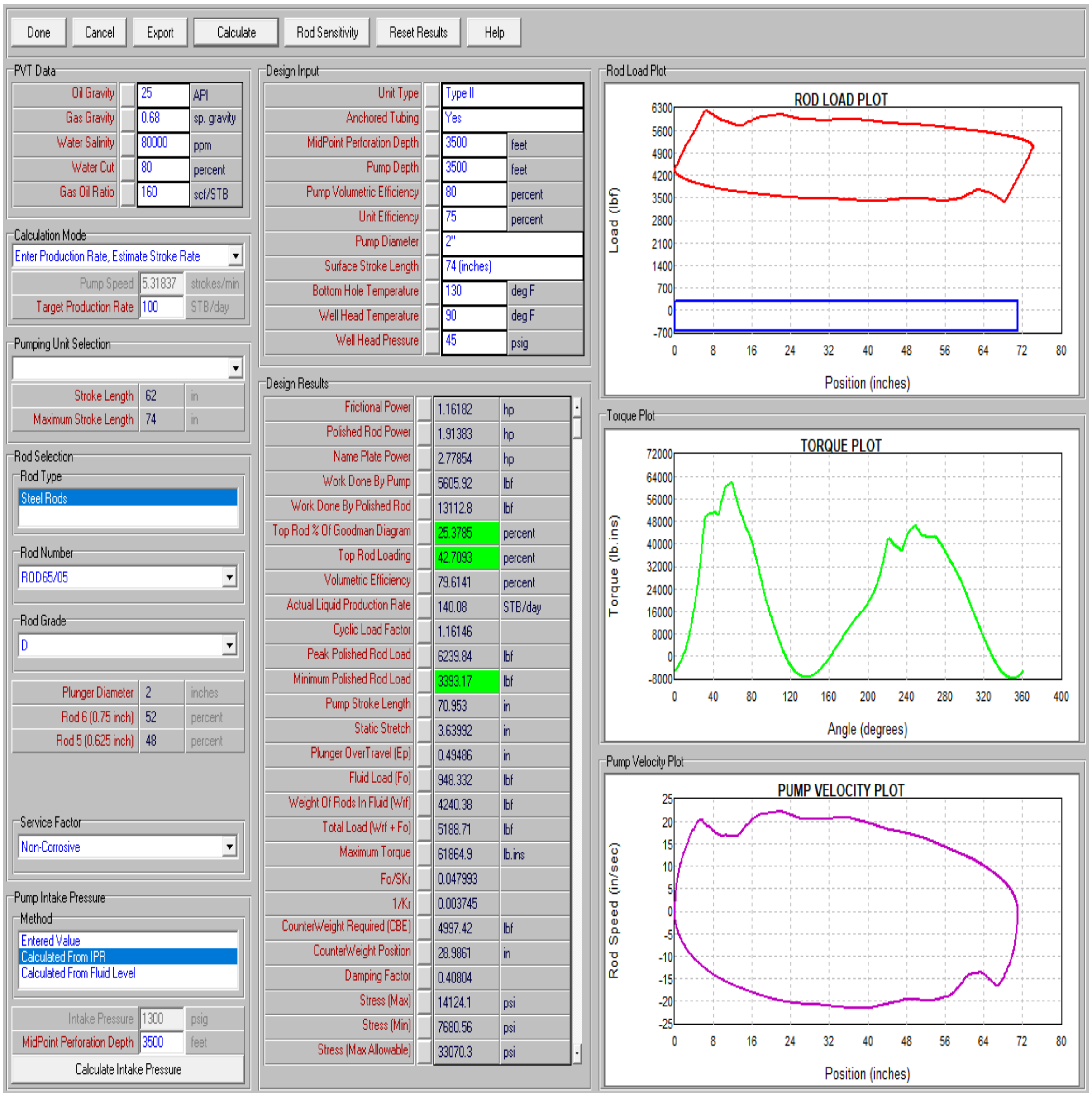


Fig. 15. Sucker-rod pump artificial lift design in PROSPER™

The pressures and temperatures are then provided for the system, as well as the surface stroke length and pump diameter, as shown in Fig. 14. The tubing is specified as anchored to maximize the pump displacement and minimize loading on the rod string.

Discussion of Results

Three sets of plots are typically obtained from artificial lift simulators, namely:
- rod displacement versus load/tension (pump dynamometer card),
- angular displacement versus mechanical torque (torque plot), and
- pump position versus pump velocity (velocity plot).

By identifying the indices without integration and comparing it with the integrated performance obtained with simulators, conclusions can be drawn (shown in Fig. 15). The comprehensive design from the integrated workflow is given in Fig. 15 showing the design results. As shown in Fig. 16, three indices will be used in comparing the performance of the pump size obtained from the two design stages.
- Damped horsepower
- Cyclic load factor
- Prime mover rating

Table 1. Showing key indices, comparing a single simulator with an integrated approach

Simulator	Min. NEMA D Motor Size (HP)	Polished Rod Power	Damped Horsepower	Cyclic Load Factor	Theoretical efficiency (%)
QRod™	4.53	2.60	1.93	1.31	57.40
QRod™ + PROSPER™	2.78	1.91	0.87	1.09	68.71

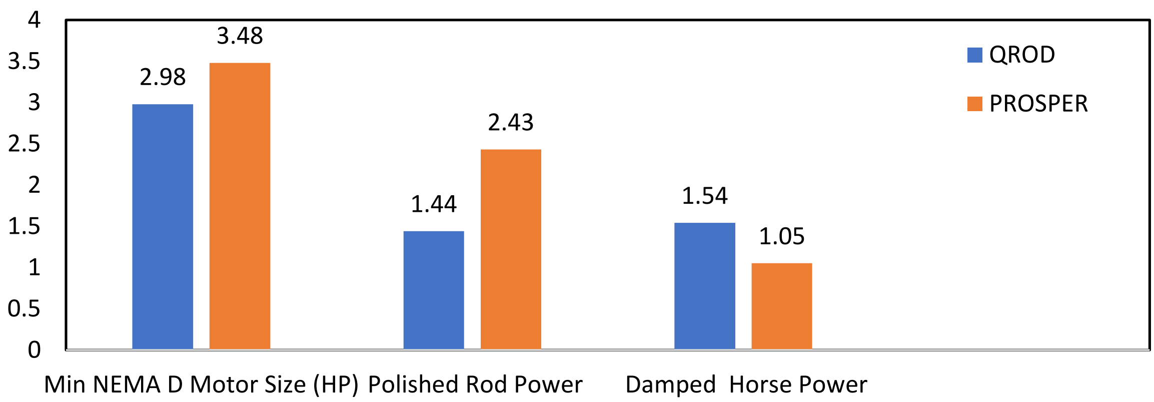


Fig. 16. Key indices and performance indicators

From Table 1, the damped horsepower is higher in the motor sized with QRod™ alone, than with the integrated approach (QRod™ + PROSPER™). Electric motor prime movers subjected to constant load have an equal root-mean-square and average current. In contrast, the RMS current is always higher than the average current for cyclic or fluctuating loads as experienced in a rod pump. The damage due to overheating is minimized by oversizing (derating) the chosen electric motor, hence an electric motor with a higher capacity than is required is selected to drive the cyclic load [29], this implies that a prime mover with sufficient starting torque, is chosen over one with high efficiency [5]. The measure of the evenness or variation of the current drawn by the motor or torsional load on the gear reducer is the cyclic load factor (CLF) [29]. The cyclic load factor is always greater than 1. For one pumping cycle, CLF provides a parameter to estimate the net torque on a gear reducer. It is defined as the ratio of the root-mean-square torque to the average net torque [15,30]:

$$\text{Cyclic Load Factor (CLF)} = \frac{\text{Motor HP } \times \text{Unit Efficiency}}{\text{Polished Rod HorsePower}} = \frac{\text{Root Mean Square Current}}{\text{Average Current}} = \frac{\text{Root Mean Square Power}}{\text{Average Power}} \quad (2)$$

Considering the effect of the cyclic load factor in derating the electric motor prime mover and considering a safety factor of 1.15 [31], the electric motor is rated, as shown in Table 2.

Table 2. Derating of High slip electric motor

HP	1 kW = 0.746HP	CLF	SF	Motor = (kW x CLF x SF)
2.78	2.07	1.09	1.15	2.59

The CLF is also significantly higher in the motor sized with QRod™ alone than with the integrated approach. With smaller CLF values, the pumping utilizes available power more efficiently [32]. Hence, the overall theoretical efficiency in the motor sized with the integrated approach is significantly higher than that sized with QRod™ alone.

Rod Sensitivity Analysis

By rod sensitivity analysis as shown in Table 3, the various API rod numbers are evaluated for both uniform rod strings and tapered rod strings. The production rates which are obtainable from the strings and the energy requirements for each corresponding rod type are considered.

Table 3. Sucker rod pump design - Rod Sensitivity

Rod Index	Rod Name	Production (BBL/D)	Horsepower (Hp)	BBL/Hp/D
4	44/05	190.74	1.85	103.24
15	54/05	185.39	2.13	87.11
22	55/05	138.87	1.69	82.51
37	65/05	140.09	1.91	73.19
46	66/05	121.89	1.84	66.28
57	75/05	123.31	2.43	50.66
63	76/05	122.40	2.03	60.42
73	77/05	113.39	2.11	53.77
88	86/05	122.97	2.30	53.39
96	87/05	113.63	2.27	50.15
107	88/05	109.24	2.47	44.17
124	97/05	113.92	2.51	45.42
133	98/05	109.38	2.62	41.82
144	99/05	106.46	2.90	36.72
163	108/05	109.53	2.84	38.62
173	109/05	106.54	3.03	35.15

Fig. 17 shows the production rate of different rod types. As can be seen from Table 3 and Fig. 17, comparing rod indices 4, 15, 22, and 37 correspondings to rod names 44/05, 54/05, 55/05, and 65/05. Although 44/05 and 55/05 have very high production rates, uniform diameter rod string (from the top of the well to the bottom) are usually deployed for well depth less than 2000ft [33]. With well depth greater than or equal to 3500ft, the design of rod string imposes the criterion for tapering; hence 54/05 would be the next best option, but since it is not available in both sucker-rod pump simulators (QRod™ and PROSPER™), 65/05 is chosen for implementing the optimal design.

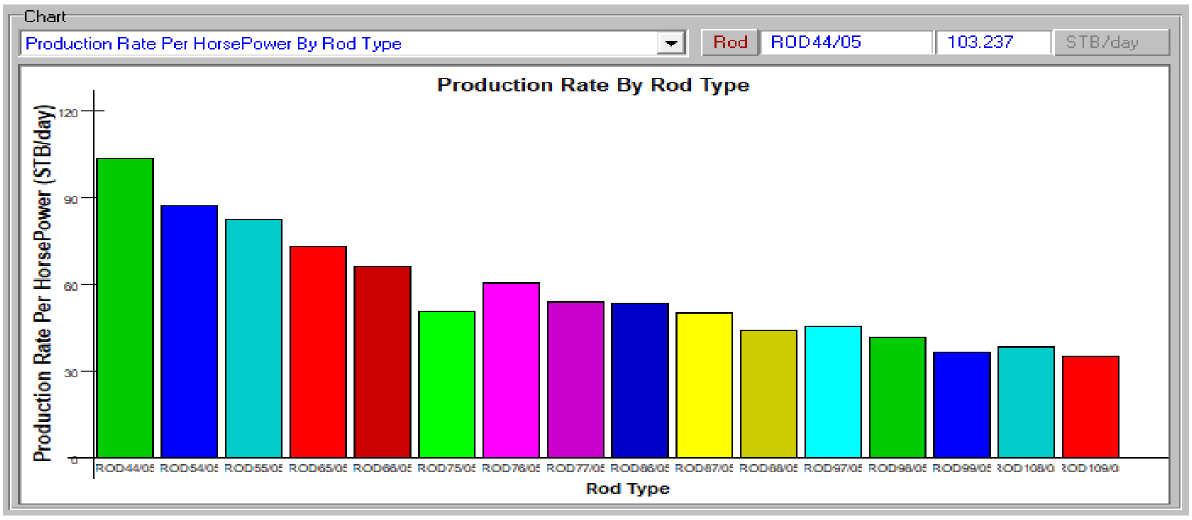


Fig. 17. Production rate per horsepower required by rod type

Conclusion

This study presents new insights into parameters affecting the sizing of beam-pumped units. It also deploys an integrated methodology that minimizes the need for iteration in one simulator alone, making it possible to perform a feasibility study at low cost and come to a single optimal motor design size, in limited trials. PROSPER™ has very robust PVT (fluid correlation) and deliverability options but adopts an iterative process in the sizing of artificial lift systems. Hence if a parametric investigation is performed in QRod™ and integrated with the workflow in PROSPER™, it becomes relatively easier to size the unit in PROSPER™ and complete the design with fewer iterations. Each simulation platform has its unique advantages, merits, and strengths in sizing applications. By integrating both simulators, the authors do not imply that one simulation platform is superior to the other. The findings presented for the case study well shows that the integrated approach reduces the damped horsepower and the polished rod horsepower by 54.9% and 26.5% respectively for a corresponding decrease in minimum NEMA D motor size by 38.6%. These key performance indicators are used to demonstrate the benefits of simulator integration in the sizing of beam-pumped oil wells.

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