

# Optimization of Rod String Design for the Sucker Rod Pumping System in Mann Oil Field

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The reciprocating motion from the surface pumping unit is transferred to the subsurface pump through the sucker rod string. Among the artificial methods, the sucker rod pumping is very popular one. Sucker rod pumping wells have many production problems because it is usually operated by mechanical means. All rod string failures can be classified into two recognizable groups: tensile and fatigue failures. When sucker rod fails in tensile stress, such as in the case of stuck pump, there is no mystery about the cause of failure. Fatigue is affected by maximum stress, and number of reversals. Improper handling of sucker rods can also cause rod failures and corrosion may eventually destroy sucker rods. In most wells, frequent replacements of sucker rods constitute serious economic problems. It is necessary to eliminate such problems to cut the cost of production less and servicing cost.

## 2. Background History of Mann Oil Field

Mann Oil field is situated on the northern plunging end of the 30 miles long Mann-Minbu structural trend in proved oil province of the Central Burma Basin. (approximate Latitude N 20° 9' and Longitude E 94° 51'). The length and width of the producing area is about 10 miles and 1 mile respectively. It was discovered in April 1970 by well 1, sited just north of Mann Chaung. Upper member of 4700 ft sand from the Padaung formation was perforated and produced initially 280 barrels oil per day. Systematic development drilling with pressure maintenance schemes, for obtaining maximum ultimate recovery, closely following the early stage of 24711 barrels in October 1979. As of 1<sup>st</sup> April 1977, 646 wells

## ABSTRACT

This research aimed to present properly rod string design and to prevent rod failures in sucker rod pumping wells. The great majority of the world's oil wells need some kinds of artificial lift methods to produce the oil to the surface. Sucker rod string should be properly designed to provide failure free pumping operation for an extended period of time. Rod string design usually aims at the determination of (1) the rod sizes to be used in the string, (2) the length of individual taper sections and (3) the rod material to be used and (4) the maximum allowable stress for rod string. If improper design of sucker rod string is employed and the working or actual stress is greater than the permissible stress, the rod string will be in premature rod failure. Detail calculations are performed with a proper consideration of actual well conditions by using geological configuration and the historical production data from Mann oil Field in Myanmar. In this research paper, some theories of the West's method, Neely's method and Equal Service Factor method are used to design by using of the well data to install the proper design and improve the production rate.

**KEYWORDS:** sucker string design, rod side, stress, failure and production rate

## 1. INTRODUCTION

In sucker rod pumping system, sucker rod is the connecting link between the surface pumping unit and the subsurface pump, which is located at or near the bottom of the oil well.

drilled and 105.678 million barrels oil produced. It is now production about 3800 barrels oil per day from 185 wells.

In this structure, oil exploration has been started since 1909. Many shallow wells had been drilled along the structure in Minbu, Shwelinbin, Htaukshabin, Palanyon Ywathaya, Htontaung and Peppi areas before the SecondWorld War was estimated to be about 3 million barrels. In 1962,1965,1968 and 1975 the geological, geophysical and seismic surveys were carried out. The first well was drilled on the northern part of the Mann Oil Field on 10.2.1970.



Figure. Central Myanmar Basin of Mann Oil Field  
Source: Mann Oil Field (2017-2018)

To increase the ultimate recovery, Secondary Recovery methods were applied at early stage of development works. Water injection from well 69 into 3700 ft sand has been started since 10.1.1975. thereafter total thirty projects of water injection from 76 wells have been already carried out and reached the maximum daily injection of 43839 barrels in March 1981. Presently 11 projects have been injecting 2000 bl barrel from 3 injectors. As of April 1997, the cumulative injection volume was 102.93 million barrels of water.

### 3. Sucker Rod String

The sucker rod string is the most vital part of the beam pumping system, since it provides the link between the surface pumping unit and the subsurface pump. Sucker rods strings are cylindrical in form, either 25 or 39 ft long and available in six standard diameters 1/2, 5/8, 3/4, 1 and 1 1/8 inches. The most important data of API rods are given in Table 1, in which the cross - sectional area of rod bodies, average rod weights and the elastic constants for different rod sizes are listed. [4]

The rod string is composed of individual sucker rods connected to each other, until the required pumping depth is reached. When the surface pumps are depth greater than approximately 3500ft, they are usually desirable used the taper rod strings. Taper rod strings are used to decrease the stress on the rods above the bottom section. The smallest diameter rod is placed at the bottom of the string, immediately above the plunger, since the rod load is least at that point. At lesser depths, where rod load is greater, larger rod sizes are used. [2]

TABLE I SUCKER ROD DATA

Rod Size	Metal Area	Weight in Air	Elastic Constant
in	sq.in	lb/ft	in/(lb-ft)
1/2	0.196	0.726	$1.990 \times 10^{-6}$
5/8	0.307	1.135	$1.290 \times 10^{-6}$
3/4	0.442	1.634	$0.883 \times 10^{-6}$
7/8	0.601	2.224	$0.649 \times 10^{-6}$
1	0.785	2.904	$0.497 \times 10^{-6}$
1 1/8	0.994	3.676	$0.393 \times 10^{-6}$

In designing a tapered rod string, the maximum anticipated stress must be checked against the safe allowable working stress. The maximum stress at the top of the entire rod string is given by the following equation;

$$\text{Stress at the top} = \frac{\text{Peak polished rod load}}{A_{\text{top}}}$$

Where,  $A_{\text{top}}$  = the cross section area of the top section of the rod string. The stress at the top must never exceed maximum allowable stress for the particular rod being used, nor should the allowable stress range be exceeded. The most meaningful method for evaluating rod loading is based on the API modified Goodman diagram in Figure.1. The Goodman diagram pictorially represents the fact that higher rod stresses are allowable if stress ranges are low. On the other hand, if stress range is high, the allowable rod stress must be decreased. [3]

### 4. Failures of Sucker Rod Strings

All sucker rod string failures can be classified into two easily recognizable groups: tensile and fatigue failures. Tensile failures are rare and are caused by the overstressing of rods.

When a great pull force is applied to the string, rod stresses can exceed the material's tensile strength, causing a tensile break. Most rod string failures are fatigue type breaks that amount to 99% of the total failures. The fatigue failure is a brittle type break occurring at an average load much below the ultimate strength of the material, after a great number of load reversals. It starts on the surface of rod at some stress raiser (a nick, bent, corrosion pit, etc.) as a small crack. [4]

The principal cause of sucker rod body failure is overstressing. Fatigue is affected by maximum stress, range of stresses, and number of reversals. Breaks in the rod body are almost exclusively fatigue failures caused by mechanical or corrosive damages or a combination of both. Mechanical damage is classified as surface damage, wear, flexing and damage occurring in bent rods. In crooked wells, or in unanchored tubing, rod body wear can be excessive and can also accentuate rod failures. Rod flexing during the pumping cycle can be a source of mechanical body failures. The rod string is supposed to move in a vertical direction only, and lateral movement induces a flexing action that can increase the danger of fatigue failures. [1], [7]

The sucker rod joint is a friction-loaded, shoulder connection between the pin and coupling. In order to provide a firm connection, the pin shoulder face should always stay in contact with the coupling. Most joint failures arise from loss of tightness and the corresponding separation of the pin shoulder face from the coupling. In this situation, one of the joining elements, the rod pin or coupling, eventually will fail in fatigue. These failures usually occur with the same frequency in either the pin or the coupling. Practically all pin failures are fatigue failures, the most common cause of pin breaks being stress corrosion fatigue. Fatigue failures of sucker rod pins constitute 99% of all pin failures. All these breaks can be attributed to the loss of tightness in the joint due to improper makeup. The main causes of coupling failures are the same as for pin failures, fatigue. [1], [4]

### 5. Methods of Sucker rod string Designs

#### 5.1. West's Method

In several heavily load wells, union oil C. noted a large percentage of rod failures occurring in the lower section of the tapered rod strings. This triggered an evaluation of the current methods of taper rod string design to see if improvements could be made in this area.

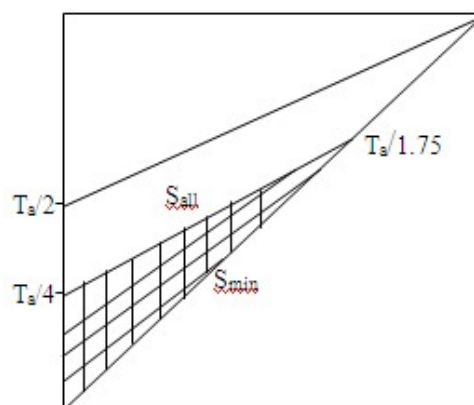


Figure. 1 Modified Goodman diagram

In current API accepted method of rod string design entails the use of the Goodman diagram (figure .1) which is based on the formula.

$$S_{all} = \left( \frac{T_a}{4} + 0.5625 S_{min} \right) SF \quad (1)$$

Where,  $S_{all}$  = Allowable stress, psi  
 $S_{min}$  = minimum stress, psi  
 $T_a$  = minimum tensile stress, psi  
 $SF$  = service factor, dimension

The service factor is generally based on past experience for field or area based on historical data of rod breakage. If this data is not available then the following service factors are recommended. [4]

**TABLE II SERVICE FACTORS FOR DIFFERENT ENVIRONMENTS AND ROD GRADES**

Environment	Service factor	
	Grade C	Grade D
Non- corrosive	1.00	1.00
Salt Water	0.65	0.90
Hydrogen Sulfide	0.5	0.70

Source: Ga'bor Tak'as (1992)

The method of designing the rod string is to determine the minimum and maximum polished rod loads and then, utilizing the Goodman diagram, find a suitable strength rod based on its minimum ultimate tensile strength. When these conditions apply to the top rod only, the tapered string is designed so that the maximum stress,  $S_{max}$ , is equal in the top of each size section, when actually the load range is decreasing for each decrease in section size. By applying this existing method, lower rod sections are often overstressed.

In the new method of rod string design this decrease of load range is accounted for so that the actual stress to allowable stress ratio is the same in the top of each rod size section. Since the load range affects the allowable stress in each rod size section it is desirable that the ratio of  $S_{max}$  to  $S_{min}$  be the same at the top of each section.

$$R = \frac{S_{max}}{S_{all}} = \frac{PRL}{(PRL)_{all}} \quad (2)$$

Where,  $R$  = Ratio of maximum to allowable stress  
 $PRL$  = Peak rod load, lb  
 $(PRL)_{all}$  = Allowable peak load, lb

If the type rod selection is of adequate strength, it is obvious that  $R \leq 1.00$  by setting  $R \leq SF$  (assumed service factor),  $SF$  can be eliminated from the deviation (if  $SF=80\%$ ,  $R \leq 0.8$ ). If  $R$ , when calculated, is greater than  $SF$ , a new average string weight is assumed and the calculation of  $R$  is repeated, the rods are overloaded and a stronger rod will be needed. By calculating  $R$  first, this determination can be made before the entire string is designed.

By breaking down  $R$  using the conventional rod design criterion,

$$PRL = Dw_f + Lwf \quad (3)$$

Where,  $D$  = Depth of fluid, ft  
 $W_f$  = weight of fluid per foot, lb/ft  
 $L$  = Length of rod string, ft  
 $W$  = average weight per foot of rod string, lb/ft  
 $f$  = Impulse factor  $\{(SN^2/70500) + 1\}$

$S$  = Stroke Length, in  
 $N$  = Pumping speed, spm

$$(PRL)_{all} = A_n \frac{T_a}{4} + 0.5625(MRL) \quad (4)$$

Where,  $A_n$  = Area of top rod section, sq.in  
 $MRL$  = Minimum rod load, lb

The impulse factor on the down stroke,  $F_D$  is  $1 - (SN^2/70500)$ . Substituting  $(SN^2/70500) = f - 1$ , we that  $F_D = 1 - (f - 1) = 2 - f$ . Therefore,  $MRL = Lw(2 - f)$

$$(PRL)_{all} = A_n \frac{T_a}{4} + 0.5625(Lw)(2 - f), \text{ and}$$

$$R = \frac{Dw_f + Lwf}{A_n \frac{T_a}{4} + 0.5625Lw(2 - f)}$$

$$L_1 = \frac{Dw_f - RA_1 \frac{T_a}{4}}{w_1 \{0.5625R(2 - f) - f\}} \quad (5)$$

Using the same equations, the equation for length ( $L_n$ ) of any section can be derived as follows;

$$L_n = \frac{(PRL)_{n-1} - R \left\{ A_n \frac{T_a}{4} + 0.5625(MRL)_{n-1} \right\}}{w_n \{0.5625R(2 - f) - f\}} \quad (6)$$

Where,  $(PRL)$  and  $(MRL)$  are the maximum and minimum loads in the previous rod section, respectively, lb

$A_n$  = cross sectional area of the actual taper section, sq.in

$T_a$  = minimum tensile strength of the rod material, psi

$W_n$  = average rod weight in air of actual taper, lb/ft

By assuming an average weight per foot,  $w$ , for the entire rod string,  $R$ , can be calculated and then the section lengths  $L_1, L_2, L_3, \dots, L_n$ . If calculated lengths do not equal the design depth, assume a different average weight per foot and recalculate to converge to correct to the total length. A higher weight per foot should be used if the sum of section length is less than the total length. [4], [5], [6]

## 5.2. Neely's Method

The design parameter for the new method is to equalize the stress at the top of each size rod based on the API modified Goodman diagram. The modified stress is equal to the maximum stress on the upstroke minus 9/16 of the minimum stress during the downstroke. Neely's introduced the concept of modified stress and defined it as follows;

$$S_{mod} = S_{max} - 0.5625S_{min}$$

$$PRL = Dw_f + Lwf = F_o + Lwf$$

$$MRL = Lw(2 - f)$$

$$S_{mod@S1} = \frac{F_o + L_1wf - 0.5625L_1w(2 - f)}{A_1} \quad (7)$$



$$S_{mod@S2} = \frac{F_o + (L_1 + L_2)wf - 0.5625(L_1 + L_2)w(2-f)}{A_2} \quad (8)$$

$$S_{mod@S3} = \frac{F_o + (L_1 + L_2 + L_3)wf - 0.5625(L_1 + L_2 + L_3)w(2-f)}{A_3} \quad (9)$$

Neely's design procedure attempts to equalize this modified stress at the top of each taper section. Therefore, the taper lengths of each section are calculated based on these above Equation (7),(8),(9) and after some mathematical derivations the following formula are developed;

$$L_1 = \frac{S_{mod}A_1 - F_o}{w_1\{f - 0.5625(2-f)\}} \quad (10)$$

Using the same equation, the equation for length ( $L_n$ ) of any section can be derived as follows

$$L_n = \frac{S_{mod}A_n - (Lw)_{(n-1)}\{f - 0.5625(2-f)\} - F_o}{w_n\{f - 0.5625(2-f)\}} \quad (11)$$

Where,  $(Lw)_{n-1}$  = the length and the weight in previous section respectively, lb

$S_{mod}$  = modified stress, psi

$A_n$  - cross section area of the actual taper section, sq.in

$W_n$  = average rod weight in air of actual taper, lb/ft

By assuming an average weight per foot,  $w$ , for the entire rod string, can be calculated and then the section lengths  $L_1, L_2, L_3 \dots L_n$ . [4]

### 5.3. The Equal Service Factor Method

The string design method developed by Gault and Ta'kacs overcomes the drawbacks of pervious produce, giving a more theoretically sound design method while requiring only moderate computation time. The goal of the proposed design is to have the same degree of safety in every taper section. The actual service factors will all be the same and a rod string designed this way will be subjected to a uniform level of fatigue loading all along the string.

The polished rod loads, which reflect the sum of forces acting at the top of the rod string, are calculated by the RP11L, producer as given bellows;

$$PPRL = W_{rf} + F_o + F_{du} \text{ and } MRL = W_{rf} - F_{dd}$$

Where,  $PPRL$  = maximum polished rod load, lb

$MPRL$  = minimum polished rod load, lb

$W_{rf}$  = buoyant rod string weight, lb and

$F_o$  = fluid load on plunger, lb

The rod loads in the top section of the  $i^{th}$  taper can now be written up by considering the distribution of dynamic forces as detailed before;

$$F_{max(i)} = F_o + \sum_{j=1}^i w_j L_j [1 - 0.128(SpGr)] + \frac{F_{du}}{W_r} \sum_{j=1}^i w_j L_j$$

$$F_{min(i)} = \sum_{j=1}^i w_j L_j [1 - 0.128(SpGr)] - \frac{F_{dd}}{W_r} \sum_{j=1}^i w_j L_j \quad (12)$$

Where,  $L_j$  = length of the  $j^{th}$  taper, ft

$W_j$  = average rod weight of the  $i^{th}$  taper, lb/ft

$Sp.gr$  = specific gravity of the produced fluid

$W_r$  = total rod string weight in air, lb

The rod stresses are calculated based on these equations and after some mathematics derivations the following formulas are developed.

$$S_{max(i)} = \frac{1}{A_i} \left\{ F_o + \left( \frac{F_{du}}{W_r} + 1 - 0.128(SpGr) \right) \sum_{j=1}^i w_j L_j \right\} \quad (13)$$

$$S_{min(i)} = \frac{1}{A_i} \left\{ \left( \frac{F_{du}}{W_r} + 1 - 0.128(SpGr) \right) \sum_{j=1}^i w_j L_j \right\} \quad (14)$$

Where,  $A_{maxi}$  = cross sectional of rods in the  $i^{th}$  taper, sq.in. Equation (13) and (14) can be combined into a single formula that is valid for a given taper section and does not contain the length of the taper.

$$S_{max(i)} = \frac{F_o}{A_i} + S_{min(i)} - \frac{\frac{F_{du}}{W_r} + 1 - 0.128(SpGr)}{1 - 0.128(SpGr) - \frac{F_{dd}}{W_r}} \quad (15)$$

iven the value of  $S_{max}$  and  $S_{min}$ , this can be calculated by using equation (16) which describes the allowable stress for the rod material;

$$SF_{act} = \frac{S_{max}}{\frac{T_a}{4} + 0.5625 S_{min}} \quad (16)$$

The above solution will give the following values for the required minimum rod stresses,  $S_i^*$  of the individual tapers.

$$S_i^* = \frac{SF_{act} \frac{T_a}{4} - \frac{F_o}{A_i}}{\frac{\frac{F_{du}}{W_r} + 0.128(SpGr)}{1 - 0.128(SpGr) - \frac{F_{dd}}{W_r}} - (0.5625) SF_{act}} \quad (17)$$

To find the actual taper lengths satisfying the conditions of the design method, one has to substitute the  $S_i$  value just calculated in to equation (15) which gives the minimum rod stress as a function of taper length. Solving that equation for the  $i^{th}$  taper length, one arrives at the following final formula;

$$L_i = \frac{1}{W_i} \left\{ \frac{A_i S_i^*}{1 - 0.128(SpGr) - \frac{F_{dd}}{W_r}} - \sum_{j=1}^{i-1} w_j L_j \right\} \quad (18)$$

The above equation enable one to calculate, starting from arbitrary rod string design, the required taper lengths which satisfy the goal set forth in the design method.

After having reached the necessary total rod string length, a final check is made on the value of  $SF_{act}$ . The reason for this is that the design procedure sets no limit to service factor values, only tries to set them equal in the tapers. In cases where the required  $SF$  is lower than the actual  $SF_{act}$ , a stronger rod material has to be selected. Then the whole design procedure is repeated with this new rod grade. [4]

## 6. Methods

The most suitable methods are determined by various point of view to obtain proper design. The well data are collected to calculate proper design sucker rod string from Mann Oil Field.

**TABLE III Well Data From Mann Oil Field**

Production Data	Well #M-A	Well#M-C
Pump Setting Depth	5525 ft	3950 ft
Plunger size	1.5 in	1.5 in
Stroke Length	74 in	48 in
Pumping Speed	17 spm	18 spm
Liquid sp.gr	1.0	1.0
Min:Tensile Strength	100,000 psi	100,000 psi
API rod no.	75	65
API Grade	C	C
Service Factor	0.9	0.8

**TABLE IV COMPARISON OF ROD STRING DESIGN RESULTS WELL M#A**

Rod Size	West's Method		Neely's Method		Equal Service Factor Method	
in.	Length, ft	LR, %	Length, ft	LR, %	Length, ft	LR, %
7/8	1625	39.2	1675	39.3	1525	23.3
3/4	1825	33.4	1875	33.6	1725	20.1
5/8	2075	22.8	1975	22.1	2275	14.4
Load ratio=MRL/PRL	0.392		0.393		0.233	
Max: Stress, psi	26311		26269		26850	
Allowable Stress, psi	27719		27763		25667	
Stress Ratio = $S_{max}/S_{min}$	0.949		0.953		1.046	

**TABLE V COMPARISON OF ROD STRING DESIGN RESULTS WELL M#B**

Rod Size	West's Method		Neely's Method		Equal Service Factor Method	
in.	Length, ft	LR, %	Length, ft	LR, %	Length, ft	LR, %
7/8	1575	39.2	1625	39.3	1475	22.2
3/4	1775	33.4	1825	33.3	1650	19.2
5/8	1025	22.8	1925	22.1	2250	12.9
Load ratio=MRL/PRL	0.392		0.393		0.222	
Max: Stress, psi	25582		25742		26453	
Allowable Stress, psi	27575		27618		25473	
Stress Ratio = $S_{max}/S_{min}$	0.927		0.932		1.0384	

**TABLE VI COMPARISON OF ROD STRING DESIGN RESULTS WELL M#C**

Rod Size	West's Method		Neely's Method		Equal Service Factor Method	
in.	Length, ft	LR, %	Length, ft	LR, %	Length, ft	LR, %
3/4	1650	43.7	1725	43.8	1525	26.4
5/8	2300	33.1	2250	32.6	2425	20.69
Load ratio=MRL/PRL	0.437		0.438		0.264	
Max: Stress, psi	21622		21719		22058	
Allowable Stress, psi	22254		24282		22615	
Stress Ratio = $S_{max}/S_{min}$	0.971		0.894		0.975	

## 7. Findings

In this research paper, West's Method, Neely's Method and Equal Service Factor Method are presented by using well the data from M#A, M#B, in Mann Oil field. The designs are compared based on the maximum and minimum stress at the top of each taper and the length of individual taper section the results are shown in tables. The maximum working stress should be less than the allowable stress. Usually the possible rod failure is assumed by checking up the working or actual stress of the rod string. According to rod string design results, the maximum working stresses from Neely's method and Equal Service Factor method are greater than

West's method. When the stress ratios of individual method are compared by West's method, this stress ratio is more favourable than Neely's method and Equal Service factor method.

## 8. Conclusions

Based on the research paper, the author concludes that optimization design for sucker rod string could be applied directly in any oil fields. To get an optimum operation criteria, some or all of the several parameters described in this research paper, should be understood and must be

considered in designing a sucker rod string. Prevention of the sucker rod failure is a common practice to improve the productivity of the well and to prolong service life of sucker rod. The proper handling and proper design are necessary to prevent the sucker rod failures. By studying the sucker rod string design, the pumping well operation would not only save the time but also the oil production would be economic and profitable. The author would like to recommend to further study for improving oil production rate and to install the proper design by using West's Method.

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