TOTAL WELL MANAGEMENT
A METHODOLOGY FOR MAXIMIZING OIL PRODUCTION AND MINIMIZING OPERATING COSTS

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ABSTRACT

A procedure is described that allows an operator to identify those beam pumped wells which are capable of producing more oil and are operating at reduced efficiency. The logical sequence of steps to be followed in acquiring performance data such as fluid level, pressure, dynamometer, power, etc. and the criteria to be used in determining the causes of inefficiency are presented with the objective of maximizing oil production and minimizing operating expense.

INTRODUCTION

The need to increase off production, reduce operating costs and increase net income from beam pumped wells, requires an integrated analysis of the pumping system including the performance and interaction of all the elements: the reservoir, the wellbore, the downhole pump, the rod string, the beam pump and the prime mover. Such system analysis can now be undertaken efficiently using portable laptop-based data acquisition systems in conjunction with appropriate transducers and a suite of analysis software 1.

Field experience undertaking such analysis in numerous wells has resulted in the development of a procedure which insures that good results are obtained with the minimum of effort. It is the objective of this paper to outline this procedure or methodology with the hope that it will be of use to production personnel throughout the industry. The end result of such system analysis should be the complete visualization of the performance of a given pumping well at a given time and a set of recommendations to be followed if significant improvements can be achieved.

In general the following steps should be undertaken:

1. Establish the well's inflow performance to determine if additional production is available.
2. Determine the overall system efficiency as a means to identify wells which are inefficient and thus are candidates for mechanical/electrical changes to improve performance.
3. Analyze performance of downhole pump and downhole gas separator.
4. Analyze mechanical loading of rods and pumping unit.
5. Analyze performance of prime mover.
6. Design possible modifications to improve existing systems.
7. Implement cost effective changes and verify improvement.

Although such procedure is greatly facilitated through the use of the Well Analyzer System[1] which includes all the necessary hardware and software components, it can be undertaken with a number of other devices and components currently commercially available from other manufacturers.

METHODOLOGY

The steps to be followed in defining the performance of the system should result in the maximum of information with a minimum of time and effort. This is facilitated by, having access to accurate and timely information about the well's characteristics, completion, well tests, etc. Although this may be initially time consuming it is generally a task that has to be completed only once. Some sort of data base management system is helpful in maintaining this information current. The information should be organized by well into a summary Well Data File which can be accessed by most of the application programs that are likely to be used. This eliminates having to re-enter the data. Figure (1) shows an example of such Well Data File.

Basic Survey

Certain basic measurements are necessary to identify those wells that are the most likely candidates for improvement. Experience has shown that this can be accomplished cost effectively by establishing the well's inflow performance (by measurement of the liquid level depth and casing pressure), performing dynamometer analysis and measuring the overall efficiency of the pumping system. This requires only the measurement of input power to the prime mover, acquisition of polished rod load and position data, determination of the producing BHP and accurate well test data. [2,3] Overall Efficiency is defined as the ratio of the ideal power required to lift the produced fluids (oil and water from the depth of the pump intake, taking into account the effect of the pressure at the pump intake) divided by the power supplied to the prime mover.[4]

Figure 2 shows the result of a Power survey obtained with the Well Analyzer in conjunction with power probes. Using the Well Analyzer system, it is possible to obtain Power and Dynamometer Data simultaneously or separately. The power measurement can also be obtained using commercially available power measurement systems and the efficiency calculated. Producing BHP is obtained from a fluid level and casing pressure measurement and then computed taking into account the effect of annular gaseous liquid column if present [5]. Figure 3 shows the result of such survey. If a digital acoustic fluid level survey is not available, the calculation of the PBHP from strip chart liquid level depth and casing pressure measurement can be performed on any PC using the program IPA or AWP which can be obtained free of charge from Echometer Company.

The dynamometer measurement is made with a polished rod transducer [6] which is easily installed in less than a minute by a single technician. This provides at the well site the capability of also determining the performance of the downhole pump. The analysis of the downhole pump operation is undertaken by calculation of the pump dynamometer card. This analysis is shown in Figure 4. Standing and traveling valve measurements give indiciation of fluid leakage at the pump. In Figure 5, the dashed vertical line indicates the measured load five seconds later than the measured load indicated by the solid vertical fine. A decrease in load is an indication that pump leakage is occurring. The rate of load change (lb./sec) is converted to an equivalent pump leakage rate and is displayed at the bottom left of the screen in terms of Bbls. of liquid per day. Three traveling valve tests followed by two standing valve tests show both valve checks and a comparison of the respective loads. The polished rod transducer, offers a rapid and convenient dynamometer analysis with sufficient accuracy for the basic analysis.

The basic survey will indicate whether the efficiency of the pumping system is adequate and whether a low producing bottom hole pressure is present in the well. If either of these conditions is not satisfied there is an indication that modification of the system or operating parameters could be beneficial and allow improved operation. The following decision table can be utilized with the basic analysis to determine the proper action to be undertaken.

Efficiency Greater than 35%			Efficiency Less than 35%		
Low Producing BHP and low Fluid Level	High Producing BHP (Fluid Level or Casing Pressure)	High Producing BHP (Fluid Level or Casing Pressure)	Low Producing BHP and Low Fluid Level	Low Producing BHP and Low Fluid Level	High Producing BHP (Fluid Level or Casing Pressure)
Well OK	Pump Full	Low Pump Fillage	Pump Full	Low Pump Fillage	Low Pump Fillage
	Study oil production potential	Study Gas Interference	Study component efficiency	Study time clock or POC	Study Gas Interference

The dynamometer measurements may indicate severly overloaded or underloaded components in the pumping system. Excessively overloaded components will experience failure. Excessively underloaded components will result in low system efficiency. The basic analysis should also include verification that system components are properly loaded.
Without including the compilation of well data, and acquisition and processing of the acoustic, pressure, dynamometer, and motor power/current data can be accomplished in about 45 minutes per well. This rapid basic analysis should be sufficient to properly analyze the performance of the system in more than 90% of the wells which need to be tested.

Detailed Performance Analysis

Some of the wells will require a more detailed analysis. For example, the dynamometer survey could be undertaken using an accurately calibrated (0.1% accuracy) horseshoe type load cell. This will allow obtaining data which can then be imported into a wave equation computer model of the pumping system, with the objective of matching the measured performance to the predictive software. This is a desired step if the predictive program is to be used to explore different rod string configurations, pump sizes, pumping parameters, and motor characteristics. Note however, that installing and removing the horseshoe transducer is more difficult and time consuming than using the polished rod transducer.

Inflow Performance

Additional surveys may be required to characterize the inflow performance of the well. This seems to be one of the most deficient areas in most fields. Very few operators have access to accurate IPR for their wells. Static BHP surveys are seldom undertaken since few operators are willing to shut in wells for extended periods of time. For this reason it is recommended that as part of the Total Well Management effort, a policy be instituted so that every time that a well is shut in for an extended period for pulling or workovers, that a static fluid level survey be performed prior to putting the well back on production. If this data is accumulated consistently it should be possible to have a relatively accurate estimate of the static bottom hole pressure throughout the field. Since multi-rate flow tests are also not performed with

any frequency, an IPR model is likely to be used as a means to establish the producing efficiency of the well. As seen in Figure 3, a common model is the Vogel IPR. It is used to determine the percent of maximum production that a well is making. In some cases this model may be overly conservative. The IPA program allows the user to also explore the effect of using a linear PI model or a Fetkovich IPR.

Mechanical Loading of Rods and Beam Pump

It is important to maintain the loading of the rods within the recommended guidelines for the well's service factors and the corresponding rod's characteristics. Modified Goodman diagram analysis is presented as part of the surface dynamometer card for the top most taper as seen in Figure 6. The operator can also select to show rod loadings at the top of each taper if desired. If a more detailed analysis is required due to having observed mechanical failures then the dynamometer data should be exported to a rod string analysis program (Rodmaster, Srod, Roddiag, etc.).

Proper loading of the beam and the gear reducer is equally important. An underloaded unit operates at low mechanical efficiency. An overloaded unit requires excessive maintenance. Torque loading is established more efficiently from an instantaneous power survey rather than from dynamometer measurements. The measurement is very simple and faster than having to install a load cell. Also it is more likely to be representative of the unit's performance without the need of exactly matching the unit's geometry to a library of pumping units. Probably in recent years, torque analysis using dynamometer load measurements have been performed on less than 5% of the wells in the World, mainly due to the expense and difficulty of performing the dynamometer test and correctly analyzing the data.

The objective of balancing the pumping unit is to minimize the loading of the gear reducer and to reduce energy use by equalizing the power requirements over the complete stroke. The unit should be balanced so that the torque required to raise the rods and the fluid on the upstroke is equal to the torque required on the downstroke when the cranks and counterweights are lifted. When balanced the pumping speed increases. The system can be balanced for minimum power usage instead of upstroke and downstroke balance by use of the power sensor or predictive software if desired.

The direct measurement of the input power to the electric motor is converted to torque through a simple calculation as shown in Figure 7. An arbitrary sinusoidal torque of the same frequency as the pumping speed and in phase with the counterweights (180 degrees out of phase with the measured torque) is superimposed to the upstroke and downstroke peak torques. The resulting torque corresponds to the torque that would be observed if the counterweights were moved on the crank a distance equal to the applied torque divided by the weight of the counterweight. The software undertakes this calculation automatically and adjusts the counterbalance in small increments until the upstroke and downstroke peak torques are equal.

The resulting **Balanced Torque** is plotted on the figure using the dashed lines. The counterbalance change (CB CHANGE FOR BALANCE) is displayed in thousands of inch-LB indicating whether it should be increased or decreased. The program also indicates the distance and direction of the counterweight movement required to change the counterbalance by the recommended amount of torque. When multiple counterweights are used, each counterweight will have to be moved by the distance displayed by the program. In the example above (Figure 7), the program was given a total weight for four counterweights of 5324 LB. and it recommends a movement of 16 inches IN, so each of the four counterweights will have to be moved 16 inches inwards. [7]

Performance of the prime mover

The objective of acquiring power data is to determine the efficiency with which the pumping unit is being operated from both standpoints of energy utilization and of mechanical loading. In particular the following can be studied:

- The operator can determine whether the motor is properly sized or oversized.
- The actual power expended can be compared to the electrical power billed, and the actual cost of operating each well can be determined.
- The effect of variation in counterbalance position in relation to power expended can be used as a means for minimizing cost.
- The effect of direction of rotation on power cost can be established.
- The effect of pump pounding on power expenditure can be analyzed.
- The power used per unit of volume pumped can be determined and used as a measure of efficiency when comparing different operating conditions (pumping speed and stroke length for example).

Figure 2 presents the information related to energy utilization. At the left are displayed as a function of time, the variation of the current and the instantaneous power, over one complete stroke of the pumping unit. Note that at the top of the graph is indicated the position of the polished rod. Time increases from left to right. Thus the first half of the plot corresponds to the up-stroke and the second half to the downstroke. The horizontal dashed line corresponds to zero power and current. Values below this line indicate electrical generation.

On the right side of the screen are summarized the principal efficiency parameters. The operating cost is also calculated on the basis of a barrel of fluid pumped and a stock tank barrel of oil produced. These values are calculated from the production rates which were entered in the well data file and based on the most recent well test. It should be noted that often well test data is not as accurate as one may desire.

Motor Performance

The performance of an induction motor subjected to the cyclical loading of a beam pumping system is described by values averaged over one pump stroke. An important measurement of motor loading is the ratio of thermal amps to nameplate FL amps. Experience has shown that the tendency is to oversize electrical motors installed on beam pumping systems. The reasoning varies but in general it can be said that most operators are more concerned with providing abundant starting torque than the efficiency of the prime mover. In general if a motor is considerably oversized for a given pumping system it should be replaced with an appropriately sized NEMA D or energy efficient NEMA B motor. This will reduce the operating cost by reducing the consumption, electrical demand charge and line losses during both consumption and generation.[8,9] Also, the smaller motor will have greater slip which will reduce torque and beam loading (assuming a constant average SPM) and will improve the electrical power factor.

Analysis Report

The detailed analysis should be summarized in a written report that includes all the measurements, the performance data, test data etc. Conclusions and recommendations should be recorded accurately since they will be the basis for future analysis. The well should be prioritized for the need of undertaking an optimization study. Again the criterion should be the probability of increased production and minimizing operating cost.

Design Optimization Study

The objective of the study is either to modify the pumping system to reduce overloading of some parameter (such as torque or rod stress) or to modify the system to better match its pumping capacity to the productivity of the well.

The level of complexity of the optimization study may vary greatly depending on the availability of personnel, time and software. Predictive programs for design of beam pumped systems vary in complexity and flexibility. The simplest corresponds to implementation of the API RP11L procedure while the most complex includes solution of the wave equation in deviated wellbores. Regardless of the model that is used, the first step is to replicate with the predictive program, the surface dynamometer, that was measured on the well. A reasonable match will indicate that the model is sufficiently complex to include the majority of the parameters that influence the mechanical performance of the system. In addition, a good match is an indication that the input data (rod tapers, unit geometry, etc.) is reasonably correct. The criteria for a match should include the polished rod loads, power, plunger travel, and pump displacement. If the software generates a surface dynamometer diagram and is capable of importing the measured dynamometer data, then the shape of the diagram should be matched as close as possible, in addition to matching the load levels. With the more, complex software it is possible to modify a large number of parameters) friction at pump, damping factors, plunger clearance, inertia effects, stuffing box friction, pump fillage, etc.) in trying to achieve a closer match. The matching procedure is generally by trial and error (some automatic matching software is being tested) and thus it is often difficult to know when to stop trying to get a closer match. Experience shows that a good match of the shape of the upstroke portion of the curve is easier to obtain than for the downstroke.

Sensitivity study

Generally the type of problem indicated by the measured performance will give an indication of which parameters should be varied. The starting point should always be those parameters that can be changed with a minimum of expenditure. For example if rod loads are excessive, then direction of rotation, pumping speed and stroke length should be varied in this order. If this does not produce the desired reduction, then the rod string configuration and pump plunger should be varied, and so on.

Some advanced software provide multiple data set run capability that generates graphic, as shown in Figure (8) and table output of the various combinations of parameters. Generally it is more practical to study the effect of changes in only one parameter at a time. It is also recommended that a log be kept of the sequence of changes in input and resulting change in the computed variable of interest. This will reduce the risk of duplication and will produce a faster convergence to the desired solution. Modification of downhole parameters, such as pump depth, pump size etc. will require adjusting the pump intake pressure which is a function of the inflow performance of the formation. it is therefore very important that the IPR be known with reasonable confidence. Ideally a detailed study should include a

transient pressure test which will yield information about wellbore skin and accurate Static Bottom Hole pressure. Automatic acquisition of fluid level variation and casing pressure during a buildup (or drawdown) test has been developed for several years[10] and is used by a number of operators but is still being applied on a limited basis because of the reluctance to shut in wells for relatively extended periods of time. Transient testing of a certain number of wells in a given field should be part of the Total Well Management effort if accurate prediction of well performance is required.

Economic analysis

The cost effectiveness of the changes that would be required in order to improve the efficiency of the system needs to be evaluated. In this analysis must be included both the expected increases in production as well as the reduction in operating expenses either as a result of improved efficiency or reduced energy costs. It has been observed that reduction in power utilization on a lease-wide basis is often accompanied by reduced overall power demand. This may be translated into lower demand costs as well as possible basis for rate negotiation with the utility company.

Other effects of optimized design, such as reduction in Pulling jobs, reduction of equipment wear, etc. are more difficult to quantify but should be considered in the analysis. It has been observed that operators that maintain accurate data bases of workovers, rod failures, pump repairs, well tests, etc. have a definite advantage in correlating failures to certain operating conditions, materials used, suppliers, etc. and are able to quantify the effect of these variables and take them into account in the Total Well Management procedure.

Implementation and Verification of Optimized Design

This step is perhaps the most important in the process but often is neglected. It is necessary to insure and verify that the optimized design is implemented without arbitrary modification. This is principally a problem which is solved by adequate internal communications. Similarly feedback on the result of the changes must be obtained, recorded in the appropriate data base, and analyzed by the operating and design personnel.

WELL ANALYSIS SUMMARY

The power, acoustic, pressure and dynamometer tests shown in Figures 2 through 7 give considerable information about well V11 shown in figure 1. This data can be obtained in about 45 minutes.

The power test indicated an overall system efficiency of 28%. The electrical cost of operation is $218 per month. This well is the only well on this lease, and the utility company electric meter is not ratcheted and gives credit for power generation. The 30HP motor could be replaced with a 15 HP motor.

The acoustic test indicates 2322 feet of gasified liquid column above the pump. The casinghead pressure increased 0.8 psi in two minutes, when the casing valves were closed, due to casing flowing upward in the casing annulus. This casing pressure buildup rate is used to calculate that 64% liquid is present in the gasified liquid column. The corresponding producing bottomhole pressure is 692 PSIG. The producing rate efficiency of 73% of maximum rate shows that it should be possible to produce an additional 10 BOPD. Approximately 20 MCF per day of gas are produced up the casing annulus, which aerates the liquid in the casing annulus and also reduces the performance of the "Poor Boy" gas separator.

The pump card indicates that the pump is approximately 68% liquid filled, with gas compression occurring during the downstroke. Gas interference in the pump is clearly a problem in this well. The traveling valve test

indicates that the traveling valve and plunger are in good condition. Three traveling valve tests were performed during the three minute data acquisition period followed by two standing valve tests. Note that the standing valve is also in good condition.

The surface dynamometer card indicates that the beam is loaded to 46% of rating and that the top "D" grade rods are operating at 67% of permissible load (modified Goodman) for a service factor of 0.85.

The gearbox torque analysis computed from the motor power data indicates that the downstroke peak torque is 272,000 inch-pounds while the upstroke torque is 116,000 inch-pounds. The gear box is not overloaded but the unit is out of balance.

The motor current analysis shows that more current is used to raise the cranks than the rods. The unit is crank heavy. The thermal amps used by the motor are below the motors amp rating. The motor is loaded to approximately 50% of capacity.

The above shows that the well is being produced at reasonable efficiency but improvement in production rate and overall performance is possible:

First, the pump is not being filled with liquid even though additional liquid is present in the casing annulus. A better downhole gas separator should be used. See reference 11. An additional 10 BOPD are available. Also the casinghead pressure should be reduced to flow line pressure to reduce wellbore back pressure and increase the production rate.

Second, the pumping unit is crank-heavy. The unit should be balanced so that the power required on the upstroke is approximately equal to the power required on the downstroke. A better balanced condition will reduce gear box loading and reduce electrical power consumption. Four weights are present on the cranks which have a total weight of 5,324 pounds. Since the counterbalance should be decreased by approximately 84,000 inch pounds, the four counterweights should be moved inward approximately 16 inches.

Implementing these changes will increase oil production and improve the overall system efficiency with greater pump fillage and better balance of the pumping unit.

TOTAL WELL MANAGEMENT COMMITMENT

This approach to well management requires a commitment on the part of operating personnel to the concept of the well as a system of interrelated elements, each of which can have a major effect in changing the efficiency of the system. This concept is relatively foreign to the majority of operators for which a "well" comprises the pumping unit only, or the downhole pump only, or the rods only, depending on their past experience and responsibility. Therefore, successful application of the Total Well Management concept generally includes some training of the operating personnel. This is especially necessary if effective application of modem data acquisition hardware and software is to be introduced in an operation which has been using limited resources.

SUMMARY

Operation of pumping wells using the concept of Total well Management results in a more complete understanding of the performance of a given well. At all times the operator should be able to obtain and
supply answers to the questions outlined in Table 1.

Implementation of this concept can result in significant increases in oil production and reductions in operating cost as shown by results obtained in a number of West Texas fields.

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TABLE 1 – QUESTIONS ANSWERED BY TOTAL WELL MANAGEMENT PROCEDURE

From Motor Power Surveys

What is the overall efficiency of the pumping system?	Is the motor over / under sized for the unit and the load?
What is the power use during a pump stroke?	What is the torque loading?
What is the apparent motor current?	Is the unit properly balanced?
Is the motor generating electricity at some time during the stroke?	What movement of the counterweights is required in order to balance the unit?
What is the exact power consumption, KWH/day, $/month, $/BBL?	

From Acoustic Surveys

Is there liquid above the pump? At what depth is the top of the liquid column?	What is the percent of the maximum oil rate that is currently being produced?
Is gas flowing up the annulus? If yes, at what rate?	What is the maximum rate that could be produced from the well?
What is the casing-head pressure? Is it changing with time?	What is the sound speed in the annular gas?
What is the percent liquid in the annular fluid column?	What is the average gravity of the gas in the annulus?
What is the pressure at the formation?	Are there any restrictions or anomalies in the annulus above the liquid level?

From Dynamometer Measurements:

Is the well pumped off?	Are the maximum and minimum polished rod loads within the capacity of the pumping unit and the rods?
What is the percent pump fillage?	What is the polished rod horsepower?
Are the traveling and/or standing valves leaking?	Is the maximum torque less than the gearbox specification?
What is the pump displacement in barrels per day?	Is the unit properly balanced?
What is the effective pump plunger travel?	What movement of the counterweights is required in order to balance the unit?
What is the current pumping speed?	What is the weight of the rods in the fluid?
What is the fluid load on the pump?	Does the pumping system require a detailed analysis and/or redesign?
Is the downhold gas separator operating efficiently?	

From Predictive Dynamometer Design Programs:

Is the pumping system operating as expected?	What effect will changes in pump stroke, diameter or pumping speed have on the performance of the pumping system?
Is the predicted dynamometer in agreement with the measured dynamometer?	Is the pumping unit better suited for a different well?
Is the well file data accurate?	Would fiberglass rods be more desirable?
Can the pumping performance be improved?	

From Transient Pressure Surveys:

What is a good estimate of reservoir pressure?	Is there any wellbore damage?
What is the flowing bottom-hole pressure?	Is the well fractured?
What is the pressure buildup rate?	Does the well require a detailed pressure transient analysis?
Is there annular afterflow of liquid/gas when the well is shut in?	

<< WELL FILE INFORMATION >>

WELL: V11	Company: COBRA	Name: TOM	Lease: CADDO

MFGR: Lufkin Conventional C-320-256-100 Rotation: CCW
Stroke Length= 100.5 (in) Ave. Joint= 31.7 (ft) Pump Diameter= 1.25 (in)
Pressure Datum= 5226 (ft) Tubing Anchor= (ft) Pump Intake= 5115 (ft)
Casing OD= 5.5 (in) Tubing OD= 2.375 (in) Power: 480 (Volts) 60 (Hz) 3 phase
Motor Type: TOSHIBA NEMA D Power Cost: 5 (¢/KWH)
Motor= 30 (HP) Full Load: 38 (Amps) Run Time= 24 (hrs/D) SPM= 8.6
Counterbalance Effect (Weights Level)= 9.39 (Klbs)
BOPD= 27 BWPD= 60 MCF/D= 30 TEMP DEG (F) Surface= 70 Bottom= 140
OIL= 30 (API) Water= 1.05 (SG) Tubing Pressure=50 (psig)
Casing Pres.= 114. (psig) Buildup= .813 (psi) / 2 Minutes
SBHP= 1500 (psig) Method: ESTIMATED PBHP= 708 (psig) Date: 03-09-95
Comment: FOUR 3CRO WEIGHTS = 1331# EACH TOTAL WEIGHT = 5324# PERF=5221-26FT
GAS SEPARATOR SN + 3FT PERF SUB + 30 FT JOINT 8FT 1"GAS ANCHOR EFF MAR95

Damping= .05	TOP TAPER	TAPER2	TAPER3	TAPER4	TAPER5
Length (ft)	1000	3875	200		
Diameter (in)	.875	.75	.875		
Rod Type	D	D	D		

Figure 1 - Example of Well Data File

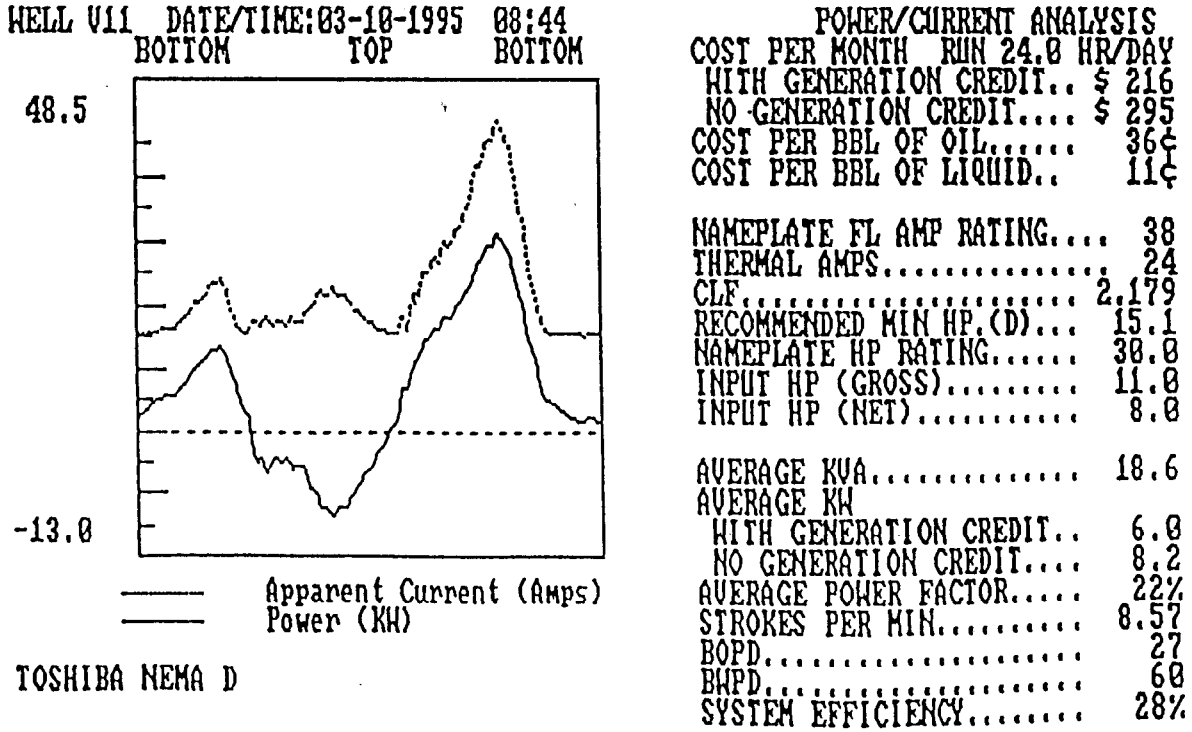

Figure 2 - Instantaneous Motor Power and Current During a Pumping Stroke

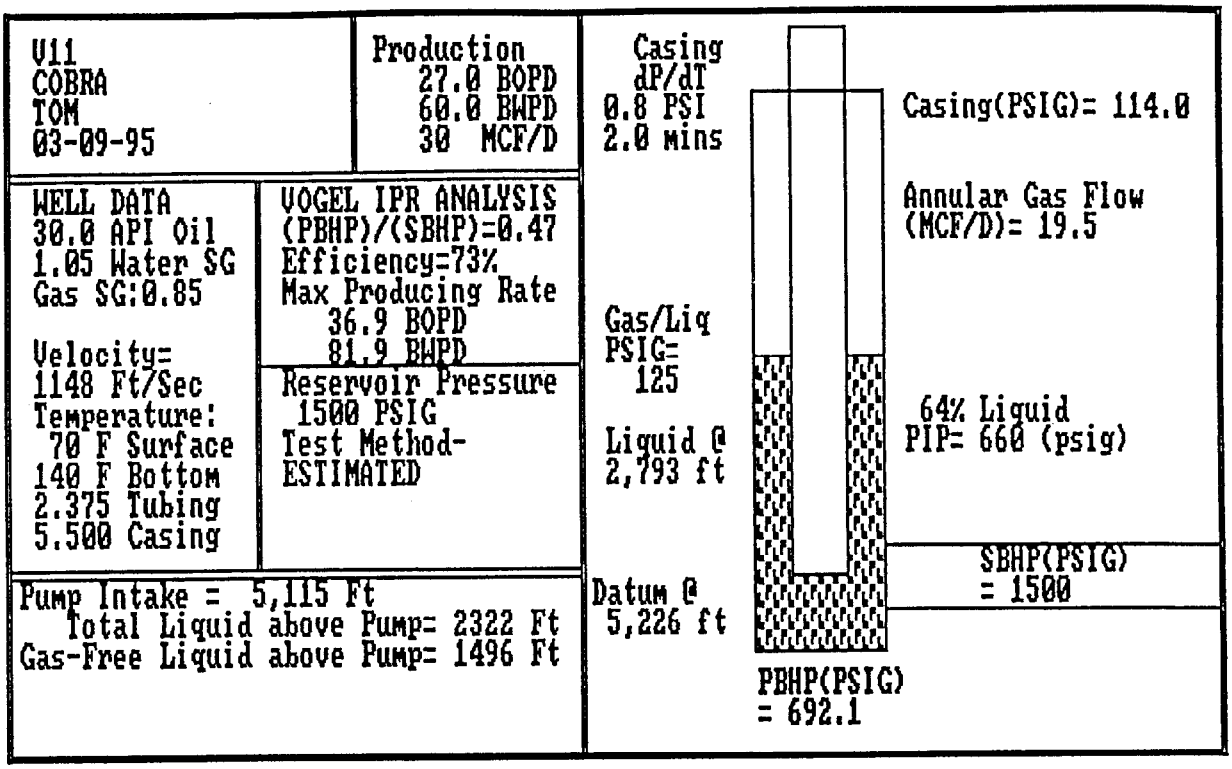

Figure 3 - Well Performance Analysis
Showing Measured and Calculated Pressures and Well IPR

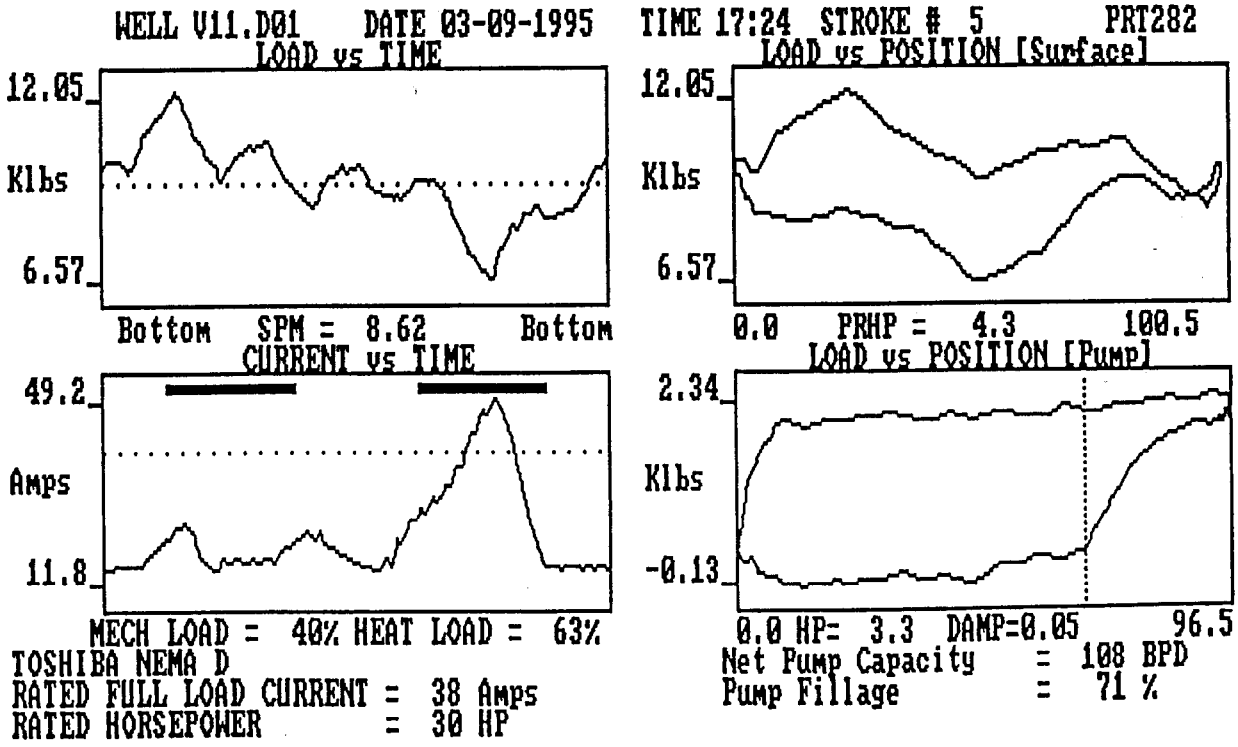

Figure 4 - Dynamometer Analysis Showing Surface and Pump Cards,
Motor Current and Polished Rod Load per Stroke

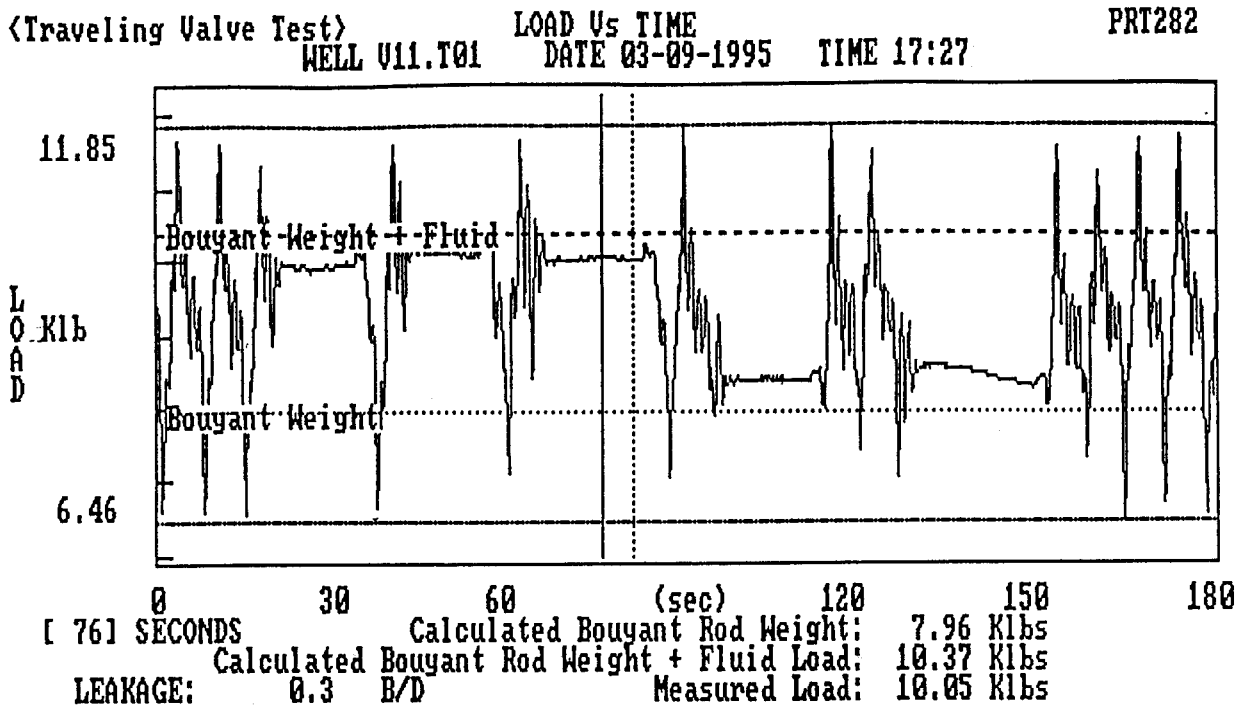

Figure 5 - Dynamometer Analysis of Traveling Valve and Standing Valve Performance

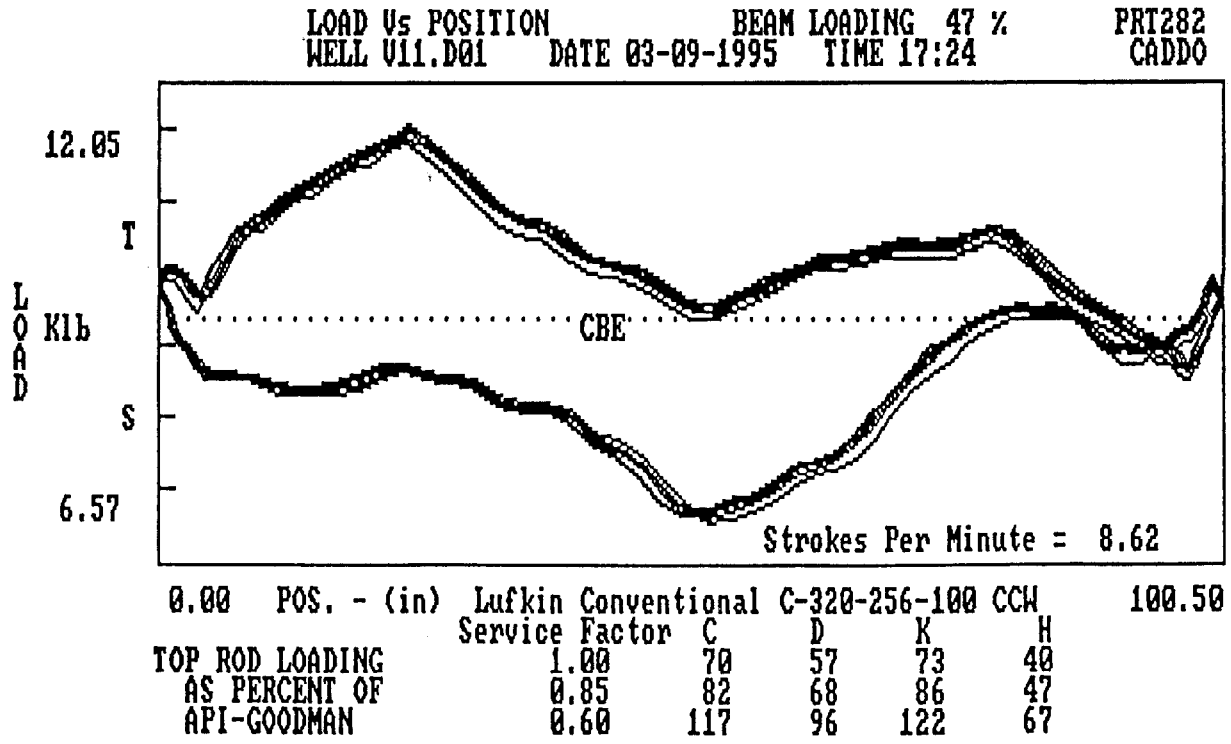

Figure 6 - Dynamometer Analysis Showing Surface Card, Beam Loading and Rod Loading

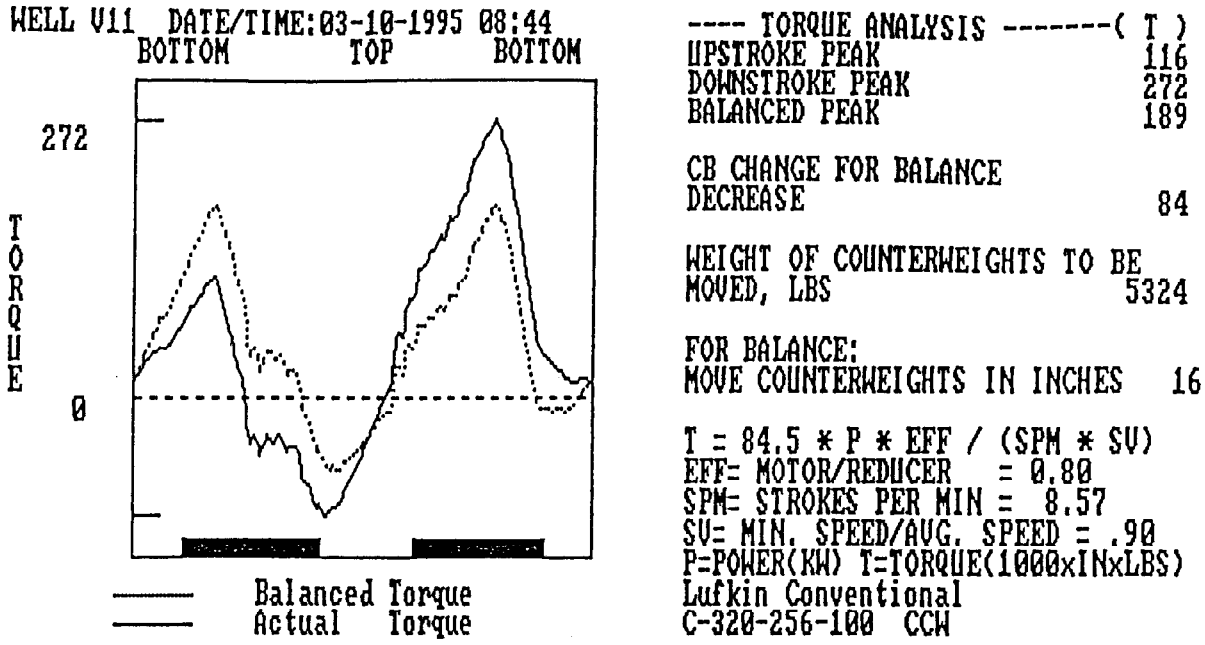

Figure 7 - Torque Analysis From Motor Power Measurement

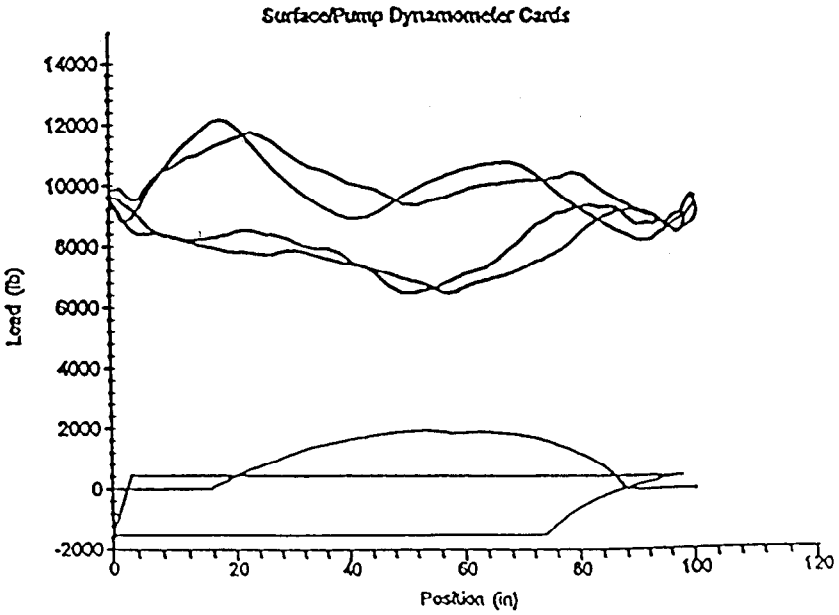

Figure 8 - Predicted and Actual Dynamometer Cards