

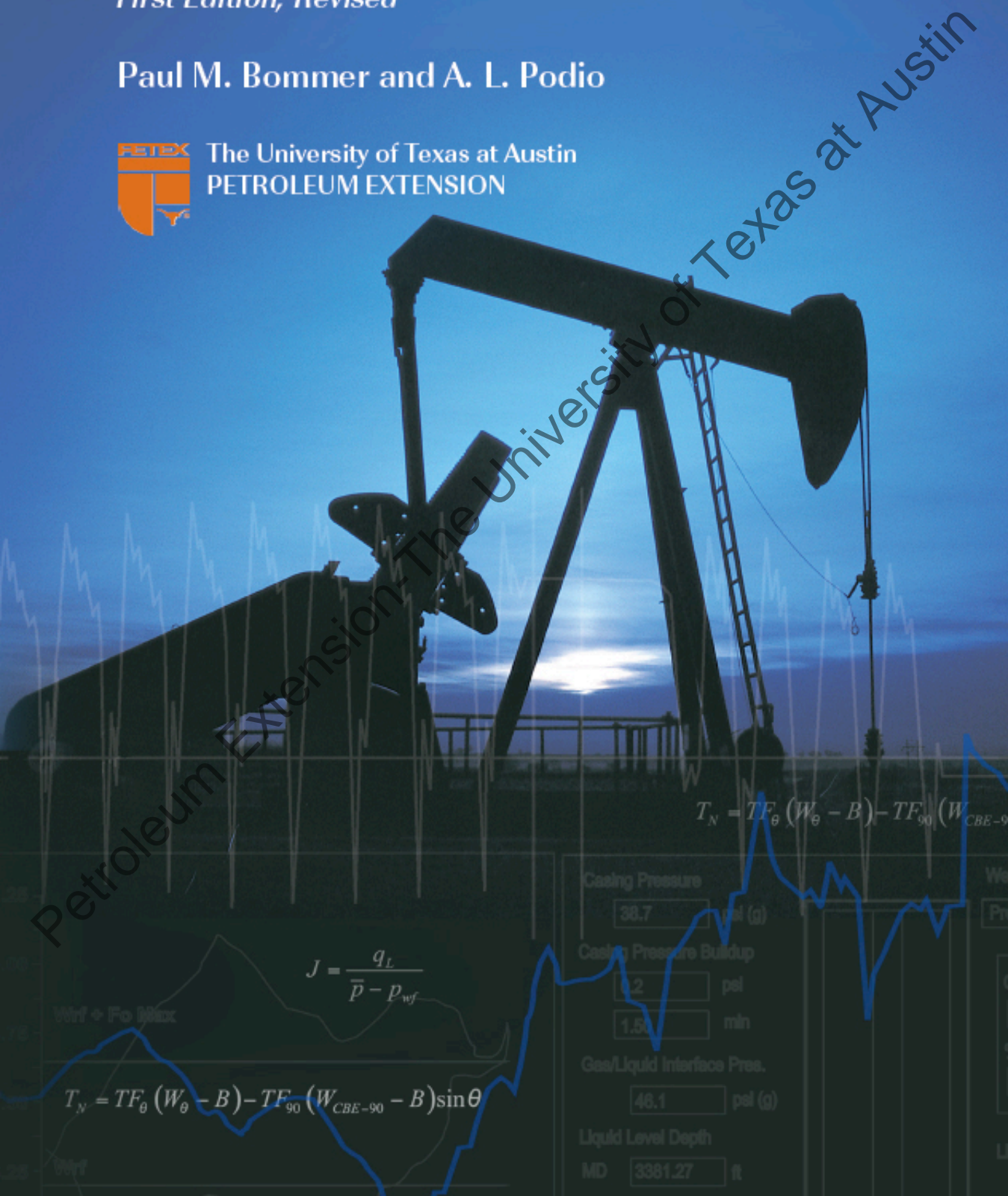
The Beam Lift Handbook

First Edition, Revised

Paul M. Bommer and A. L. Podio



The University of Texas at Austin
PETROLEUM EXTENSION



Petroleum Extension - The University of Texas at Austin

$$T_N = TF_{\theta} (W_{\theta} - B) - TF_{90} (W_{CBE-90} - B)$$

$$J = \frac{q_L}{\bar{p} - p_{wf}}$$

$V_{wf} \leftarrow F_o \text{ Max}$

$$T_N = TF_{\theta} (W_{\theta} - B) - TF_{90} (W_{CBE-90} - B) \sin \theta$$

Casing Pressure	<input type="text" value="38.7"/>	psi (g)
Casing Pressure Buildup	<input type="text" value="2"/>	psi
	<input type="text" value="1.5"/>	min
Gas/Liquid Interface Pres.	<input type="text" value="46.1"/>	psi (g)
Liquid Level Depth	<input type="text" value="3381.27"/>	ft

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*by Paul M. Bommer
and A. L. Podio*

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Contents

Figures	x
Tables	xviii
Foreword	xxi
Preface	xxiii
Acknowledgments	xxv
About the Authors	xxvii
Introduction	xxix
Reference	xxxi
1. Beam Lift Goals and System Design	1-1
Goals	1-1
Unconstrained Design	1-4
Example 1, <i>Initial Reservoir Pressure Just Above the Bubble Point</i>	1-4
Example 2, <i>Shallow Well Pumping From Reservoir Undergoing Successful Waterflood</i>	1-18
Constrained Design	1-22
Example 3, <i>Casing Size Limits Tubing Size</i>	1-22
Example 4, <i>Maximum Production Using Available Equipment</i>	1-25
Example 5, <i>Gear Box Capacity Constraint</i>	1-28
Example 6, <i>Flowing While Pumping</i>	1-30
Example 7, <i>Coal Bed Methane Pumping</i>	1-32
Example 8, <i>Pumping From Highly Deviated Wells</i>	1-33
References	1-38
Bibliography	1-38
2. Monitoring and Analysis of Performance	2-1
Recommended Practices for the Monitoring and Analysis of Pumping	
System Performance	2-1
Dynamometer Analysis	2-1
Collecting Dynamometer Data	2-6
Data Quality Control	2-7
Analyzing the Dynamometer Data	2-8
Polished Rod Power	2-8
Valve Test	2-11
Fluid Load and Working Fluid Level	2-11
Wellbore Pressures	2-12
Maximum Gear Box Torque and Counterbalance Condition	2-13
Permissible Load Diagram	2-16
Fluid Slippage and TV Leakage	2-16
The TV Test	2-17
Leakage Rate Calculation	2-20
TV Test for Liquid-Filled Pump	2-21
TV Test With Partial Liquid Fillage	2-23
SV Leakage	2-25
SV Test	2-26

Examples of Dynamometer Field Data of Typical Rod Lift Systems Operating	
Both Correctly and Incorrectly	2-27
Normal Operation, Full Pump, Anchored Tubing	2-32
Normal Operation, Full Pump, Unanchored Tubing	2-34
Gas Interference	2-35
Fluid Pound	2-38
Leaking TV	2-40
Leaking SV	2-41
Temporarily Pumped Off	2-44
Plugged Intake	2-46
Deep Pumping	2-48
Loose Tubing Anchor	2-50
Heavy Oil, 10 API Gravity	2-50
High Pumping Rate, Shallow Pump	2-53
Flumping Well	2-55
Deep Rod Part	2-56
Middle Taper Rod Part	2-58
Stuck Plunger	2-61
Very High Fluid Level	2-64
High Pumping Speed, 14 API Oil	2-66
Delayed Closure of TV	2-68
Erratic TV Operation	2-70
Pounding During Upstroke	2-72
Hole in Pump Barrel, Bottom Hold-Down Pump	2-74
Tagging on Downstroke	2-76
Tagging on Downstroke, Unanchored Tubing	2-78
Tagging on Downstroke, Fiberglass Rods	2-80
Wellbore Friction	2-82
Deviated Wellbore With Air-Balanced Unit	2-84
Overloaded Gear Box	2-86
Hydraulic Surface Unit	2-89
Fifth-Order Pumping (Harmonics)	2-90
Rotaflex® Unit	2-92
Bending Polished Rod	2-95
Matching Pump Rate to Reservoir Rate	2-97
Identification of Pumped-Off Condition	2-99
Timers	2-100
Pump-Off Control Systems	2-103
Variation of Pumping Speed	2-104
Variable Frequency Drives	2-104
Variable Speed Pumping in Hydraulic Pumping Units	2-105
References	2-105
Bibliography	2-106
3. Troubleshooting and Analysis Guidelines	3-1
Observations at the Well	3-2
Analysis of Fluid Level Record	3-4
Analysis of Dynamometer Record	3-6
Valve Tests	3-10
Historical Comparison	3-10
Best Practices	3-10

Achieving High Volumetric Efficiency	3-10
Handling Gas in the Pump	3-11
Dealing With Sand and Solids	3-11
Rod and Tubing Wear	3-12
Corrosion	3-12
References	3-12
Bibliography	3-12
4. Engineering Basics	4-1
Mass, Length, Time, and Other Measurements	4-1
Mass	4-1
Length	4-1
Time	4-1
Area	4-1
Volume	4-1
Flow Rate	4-1
Density	4-1
Force	4-2
Pressure	4-2
Viscosity	4-2
Work	4-3
Power	4-3
Compressibility	4-3
Permeability	4-3
Units Conversion	4-3
Web-Based Units Calculators	4-7
Mechanics of Materials	4-7
Fluid Characteristics	4-9
Liquid Density	4-9
Gas Density	4-10
Gas Deviation Factor	4-11
Phase Behavior	4-11
The Bubble Point	4-12
Solution Gas–Oil Ratio and Oil Formation Volume Factor	4-13
Oil Density With Dissolved Gas	4-16
Viscosity	4-16
Single-Phase Flow in Pipe	4-17
Multiphase Flow in Pipe	4-20
References	4-23
Bibliography	4-23
5 Well Testing	5-1
The Purpose of Well Testing	5-1
Well Test Data to Collect	5-1
Use of the Data to Create Productivity Index	5-9
Data Uncertainty	5-17
Well Testing Best Practices	5-19
References	5-19
Bibliography	5-20
6. The Downhole Pump	6-1
The Function of the Downhole Pump	6-2

Pump Rate and Efficiency	6-3
Types of Subsurface Pumps	6-5
Types of Rod or Insert Pumps	6-8
Operation of the Plunger Pump	6-8
Plunger Loads	6-11
Differential Pressure Loading of the Pump Assembly	6-13
Guidelines for Selection of Subsurface Pumps	6-17
Allowable Pump Setting Depths	6-22
Burst Loading	6-23
Axial Loading	6-23
Collapse Loading	6-24
Factors of Safety	6-25
Typical Pump Setting Depths	6-25
Pump Size Limitations	6-27
Materials for Subsurface Plunger Pumps	6-27
Common Types of Corrosion	6-28
Abrasion	6-29
Barrels	6-30
Plungers	6-31
Valve Cages	6-32
Hold-Down Seal Assemblies	6-37
Pump Anchor	6-38
Seating Nipples	6-38
Special Pumps and Associated Hardware	6-38
Reducing Pressure Above the TV Using a Sliding Top Valve	6-41
Mechanical Actuation of TV	6-42
Multistage Compression	6-42
Tubing Pressure Transfer to Barrel Using a Variable Slippage Pump®	6-44
Venting Gas From Barrel to Annulus Using a Gas Vent Pump™	6-44
Pumping Fluids with Solids	6-44
Pump Failure Tracking	6-50
References	6-52
Bibliography	6-52
7. Sucker Rods	7-1
Steel Sucker Rod Classification	7-3
Sucker Rod Couplings	7-5
Sucker Rod Loads	7-6
Fatigue	7-9
Sucker Rod Life	7-14
Axial Compression	7-19
Sinker Bars	7-22
FRP (Fiberglass) Sucker Rods	7-23
Sucker Rod Design	7-24
Rod Sizes and the Tapered Rod String	7-25
Dynamic Loads	7-32
Fluid Inertia	7-38
Design Method Comparison	7-39
Sucker Rod Guides	7-41
Deviated Wells	7-43
Rod Bending Loads	7-43

Rod Guides in Deviated Sections	7-44
Friction	7-44
Compression and Buckling	7-45
Pumps	7-46
Pressure Drawdown and Inflow Performance	7-46
Polished Rods	7-47
Sucker Rod Failure	7-47
Corrosive Attack	7-50
Corrosion Control	7-52
Corrosion Monitoring	7-52
Paraffin	7-53
Specialty Rods	7-53
Hollow Rods	7-53
Continuous Rods	7-54
Best Practices for Sucker Rods	7-54
References	7-56
Bibliography	7-57
8. Pumping Units	8-1
Beam-Balanced and Crank-Balanced Pumping Units	8-1
Type I Levers	8-1
Type III Levers	8-5
American Petroleum Institute (API) Unit Designations	8-7
Specialty Units	8-7
Choice of Unit Type	8-8
The Gear Box	8-17
Pumping Speed Control	8-21
Torque Calculations	8-25
Counterbalance	8-30
Balancing the Unit	8-40
Structures, Bearings, and Bases	8-44
Efficiency	8-44
Alternative Pumping Units, Long-Stroke Units	8-48
Alternative Pumping Units, Hydraulic Pumping Units	8-50
Best Practices	8-51
References	8-51
Bibliography	8-51
9. Prime Movers	9-1
Loads Carried by the Prime Mover	9-1
Prime Mover Sizing	9-1
Starting Power	9-1
Running Power	9-2
Internal Combustion Engines	9-4
Two-Stroke Engines	9-5
Four-Stroke Engines	9-9
Power and Efficiency	9-13
Electric Motors	9-14
Input Power	9-14
Output Power	9-15
Motor Efficiency	9-15
Motor Slip	9-15

Torque	9-16
Service Factor	9-18
Motor Controls	9-19
Intermittent Service	9-19
Total System Efficiency	9-20
General Statements About Cost	9-20
References	9-21
Bibliography	9-21
10. Downhole and Wellhead Equipment	10-1
The Pump Intake	10-1
Filling the Barrel With Liquid	10-1
Flow Rate Through the SV	10-1
Choked Pump	10-3
Pressure Drop Through Valve and Cage	10-5
Gas Interference	10-11
Downhole Gas Separators	10-12
Basic Functioning of Downhole Gas Separators	10-12
Gas Bubble Slip Velocity	10-13
Natural Gas Separator	10-16
Poor Boy Gas Separator	10-17
Packer Separator	10-19
Cup Separator	10-21
Collar-Size Separator	10-22
Results of Laboratory Tests on Downhole Gas Separators	10-26
Effect of Using Centrifugal Forces to Separate Gas From Liquid	10-27
Effect of Wellbore Inclination	10-28
Downhole Separation in Horizontal and Lateral Wellbores	10-28
Solids Exclusion	10-30
Screens	10-30
Tubing Anchors	10-32
Wellheads	10-33
Best Practices	10-35
References	10-37
Bibliography	10-37
11. Data Acquisition Tools and Data Quality Control	11-1
Dynamometer	11-1
Objective of Dynamometer Measurements	11-1
Types of Dynamometer Instruments	11-2
Determination of Polished Rod Position	11-10
Acoustic Fluid Level Surveys and Calculation of Producing and Static	
Bottomhole Pressures	11-16
Objectives of Fluid Level Measurements	11-16
Acoustic Wave Propagation in Wellbores	11-17
Acoustic Velocity in Hydrocarbon Gases	11-18
Acoustic Wave Reflection	11-19
Acoustic Pulse Generation	11-22
Conversion of Pulse Travel Time to Distance	11-23
Fluid and Pressure Distribution in Pumping Wells	11-26
Calculation of Pressure Distribution	11-27
Quality Control of Pressure Calculations	11-34

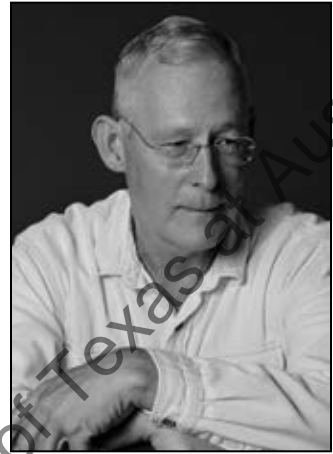
Guidelines	11-35
Calculation of SBHP in Pumping Wells	11-36
Motor Power or Current Measurements and Analysis	11-38
Electrical Safety	11-38
Motor Current Measurement	11-39
Analysis of Motor Current for a Single Pump Stroke	11-40
Motor Power Measurements	11-41
Torque Calculation From Power	11-43
Best Practices	11-45
References	11-45
Bibliography	11-46
12. Design Methods	12-1
Predictive Methods	12-1
First Method: Computer Solution of the One-Dimensional (1-D) Wave Equation	12-2
Second Method: API Recommended Practice 11L (API RP11L)	12-2
Third Method: Classical Method for Conventional Units (Type I Lever)	12-12
Numerical Example Comparing the Methods	12-16
Solution of Numerical Example Using the 1-D Wave Equation	12-16
Solution of Numerical Example Using the API RP11L Method	12-18
Solution of Numerical Example Using the Classical Method	12-21
Computational Accuracy Compared With Measured Results	12-24
Diagnostic Methods	12-27
Best Practices	12-30
References	12-32
Bibliography	12-32
Post Script	P-1
Appendix: Figure Credits	A-1
Glossary	G-1
Index	I-1

About the Authors

Paul M. Bommer is a Senior Lecturer in Petroleum Engineering at The University of Texas at Austin. He received his Bachelor's (1976), Master's (1977), and Doctoral (1979) degrees in petroleum engineering, all from The University of Texas at Austin.

He spent over twenty-five years in industry as an oil and gas operator and consultant in Texas and in other parts of the United States. He and his brother Peter (The University of Texas, BS-PGE, 1978) are co-owners of Bommer Engineering Company.

He is a third generation oil man following both his father (The University of Texas, BS-PGE, 1950), who was a highly regarded petroleum engineer in Texas as the principal owner of Viking Drilling Company in San Antonio, and his paternal grandfather, who was a field superintendent in Oklahoma, East Texas, and on the Texas Gulf Coast for Stanolind Oil Company (later Amoco). As with many of her generation of oilfield families, his mother (The University of Texas, BS-HEc, 1949) made sandwiches for the crews and curtains for the tool pusher's trailer, created a home, and raised the kids.



A. L. Podio is currently a Research Professor in the Petroleum and Geosystems Engineering Department at the University of Texas at Austin where he has taught and directed research in the areas of drilling and production since 1971. He holds a Bachelor of Science degree in Mining and Petroleum Engineering from the University of the Andes in Bogota, Colombia, and a Bachelor of Science, Master of Science, and PhD in Petroleum Engineering from the University of Texas at Austin. He is a registered Professional Engineer in Texas, has been a distinguished speaker and technical editor for the Society of Petroleum Engineers, has published numerous articles international journals, and holds seven U.S. patents.

Beam Lift Goals And System Design

GOALS

It is important to state the goals of beam lift and then design the equipment to meet the goals. It is perhaps even more important not to forget the goals of beam lift when well conditions change.

The first goal of beam lift is stated as follows:

1. The primary goal of beam lift, indeed of any artificial lift device, is to produce all of the liquid that a reservoir can flow into the bottom of the well on a continuous basis, as long as no harm is done to the reservoir or the well equipment.

This goal is based on the underlying assumption that the value of the well is directly proportional to the ultimate hydrocarbon recovery from the well. The maximum ultimate recovery from the well will be achieved if the first goal is met.

The reservoir has a maximum *flow rate* that can be sustained by the current pressure in the reservoir. Equation 1.1, which shows the simple relation of the *productivity index* (J), demonstrates this.

$$J = \frac{q}{\bar{p} - p_{wf}} \quad \text{Eq. 1.1}$$

$$J = \text{productivity index} \left(\frac{\text{stock tank barrels [STB]/day}}{\text{psi}} \right)$$

$$q = \text{liquid flow rate} \left(\frac{\text{STB}}{\text{day}} \right)$$

$$\bar{p} = \text{average reservoir pressure (psi)}$$

$$p_{wf} = \text{flowing pressure inside the wellbore at the perforations (psi)}$$

Productivity index is an elegant and powerful tool that can be used to describe the flow capabilities of a reservoir at a particular time. It includes implicitly all of the influences of the reservoir and the completion outside of the wellbore. The data required to establish the productivity index are readily available from well tests. The productivity index concept is applicable to a reservoir that is producing liquids that are largely gas free. This is the case for wells that are producing from reservoirs where the pressure is above the *bubble point* or for reservoir fluids that do not contain significant gas in solution.

If the pressure in the reservoir is below the bubble point and if a significant volume of *free gas* flows from the reservoir, a better inflow performance model is either Vogel's Equation or Fetkovich's Approximation¹. Vogel's Equation is shown as equation 1.2.

$$q = q_{\max} \left[1 - 0.2 \frac{p_{wf}}{\bar{p}} - 0.8 \left(\frac{p_{wf}}{\bar{p}} \right)^2 \right] \quad \text{Eq. 1.2}$$

$$q_{\max} = \text{maximum liquid rate} \left(\frac{\text{STB}}{\text{day}} \right) \text{ at } p_{wf} = 0 \text{ psi.}$$

2

Monitoring and Analysis of Performance

Correct diagnosis of trouble and inefficiencies in a pumping well can result in increased production and/or savings in operational and remedial costs. The general objective is to have maximum production for each investment, operation, and repair dollar.

Before any form of maintenance or repairs is undertaken, the specific trouble or the reason a pumping well is not producing the expected volume of fluid should be determined; *dynamometers* and *fluid level* instruments are the principal tools used for this purpose. As such, it is desirable to maintain accurate and timely records of well production rate, the *water–oil ratio*, and the *gas–oil ratio* in order to identify easily those wells that require attention and further study. Unfortunately, the relatively common practice of commingling flow from different wells on a lease or in an area into a common surface processing facility, with no ability to isolate individual streams, makes identification of the troubled well more difficult and inefficient. When the tank *gauge* displays a 24-hour volume increase that is lower than expected, it becomes necessary to identify the well or wells not operating normally. This procedure involves first identifying surface units that might be inoperable due either to a lack of power or to other mechanical problems or identifying either unusual visible or audible operational characteristics or other unusual features, as discussed in chapter 3. Having identified the likely well or wells not performing as expected, the next step is to perform various measurements at the surface, including fluid level and dynamometer records.

RECOMMENDED PRACTICES FOR THE MONITORING AND ANALYSIS OF PUMPING SYSTEM PERFORMANCE

- Monitoring and testing actual production of the well on a regular schedule is fundamental to keeping artificial lift systems operating at peak performance and efficiency. Details and guidelines are discussed in chapter 5.
- Basic routine measurements at the surface (for example, dynamometer, fluid level, and power measurements) are used for monitoring the operation of the rod pumping system in real time. Details are discussed in chapter 11.
- Diagnostic analysis of the surface measurements are used to troubleshoot problems detected. Guidelines are discussed in chapter 3.

Dynamometer Analysis

The best way to monitor the performance of a pump and pumping equipment is using dynamometer analysis. This is the most accurate method because the data used are the actual loads carried by the rods at the surface, as a response to the performance of the pump, in relation to the productivity of the formation and *wellbore pressure*. For this reason, correct analysis of the dynamometer record also requires accurate knowledge of the corresponding distribution of fluids and pressure in the well. Details of fluid level measurements and analysis are discussed in chapter 11.

The dynamometer, which is described in greater detail in chapter 11, is a device that records the weight carried by the polished rod during a stroke. The load at the polished rod is the reaction to the forced motion of the pump plunger transmitted from the surface via the rod string.

3

Troubleshooting and Analysis Guidelines

“Walking beam activated sucker rod pumps are the most idiot proof artificial lift method devised by man to date.” Fred Gipson, 1989 Southwestern Petroleum Short Course¹

The nature of rod pumping has an inherently forgiving aspect. For this reason, rod pumping requires special effort in order to visualize the true performance of a pumping unit that appears to be operating normally. This effort is undertaken in order to identify potential problems and operating conditions that can result in failures or that can prevent the objective of producing all the fluid being delivered to the well by the reservoir in the most efficient and cost-effective manner from being achieved. The purpose of this chapter is to outline methods and procedures that facilitate the evaluation of the current performance of a pumping system so that appropriate remedies may be applied as necessary.

Various surveys of operators and service companies² have indicated that the most common problems related to rod pumping include the following (in order of decreasing frequency):

- An inability to maintain a high volumetric efficiency
- Difficulty in handling gas in the pump
- Sand and solids in the pump
- Excessive rod and tubing wear
- Corrosion

The presence of the first four problems listed above can be identified using detailed analysis of fluid level and dynamometer records, from which the conditions in the wellbore and the pump can be correctly visualized. The final problem listed—corrosion—is addressed in chapter 7, and prevention of this problem involves the proper selection of materials and the addition of chemicals to retard corrosion rates.

In order to successfully analyze and identify the root causes of the problems mentioned above, accurate data is a necessity. The first step in acquiring accurate data is to create a detailed wellbore diagram that describes the mechanical completion and the hardware installed in the well. The next step is to complete this diagram with the current distribution of fluids and pressures in the wellbore, the performance of the pump, and the loads supported by the rods and surface unit. Usually, the software application that is used to analyze the dynamometer and fluid level data will include the necessary tools to generate the needed reports; otherwise, there are various software packages that can help in constructing and managing well data.

Ideally, the following information should be compiled and checked for accuracy:

- Wellbore description
- Artificial lift system description
- Artificial lift system predictive design
- Fluid properties
- Recent and representative well test
- Static reservoir pressure or fluid level

4

Engineering Basics

This chapter is a review and a source of both material on engineering fundamentals and petroleum engineering correlations that are useful in beam lift calculations. A conversion table is included for those wishing to use SI units (<http://physics.nist.gov/cuu/Units/units.html>) instead of U.S. units (<http://ts.nist.gov/weightsandmeasures/publications/appxc.cfm>).

MASS, LENGTH, TIME, AND OTHER MEASUREMENTS

The basic units of measurement are *mass*, *length*, and *time*. All other parameters are combinations of these three base measurements. Other base measurements include electric current [*ampere (A)*], temperature [degrees *Kelvin (K)*], luminous intensity [*candela (cd)*], and amount of material [*gmole (mol)*].

Mass

Mass (*m* or *M*) is the amount of matter in an object and a physical constant of an object or substance. The unit for mass is *pound-mass (lb_m)* in the U.S. system and *kilograms (kg)* in the SI system.

Length

Length (*l* or *L*) is the linear measurement of an object, typically the longest dimension. The unit for length is feet in the U.S. system and *metres (m)* in the SI system.

Time

Time (*t* or *T*) is the interval of an event. The unit for time is *seconds (sec)* in both the U.S. and SI systems.

Area

Area (A) is the size of a surface in units of L^2 . The unit for area is acres for land and inches² or feet² for cross sections of pipe or rod in the U.S. system and m² in the SI system.

Volume

Volume (V) is the capacity of a container or vessel in units of L^3 . The unit for volume is feet³, gallons, or barrels in the U.S. system and m³ in the SI system.

Flow Rate

Flow rate (q) is the volume exiting a conduit per unit time in units of L^3/T . The unit for flow rate is feet³/sec, feet³/day, or bbl/day in the U.S. system and m³/sec in the SI system.

Density

Density (ρ) is the mass of a substance per unit volume in units of M/L^3 . The unit for density is lb_m/ft³ or lb_m/gallon in the U.S. system and kg/m³ in the SI system.

5

Well Testing

THE PURPOSE OF WELL TESTING

It is not possible, other than by sheer luck, to make an optimal artificial lift system design without an understanding of the flow capability of the well to be produced. Well tests are the simplest and surest way to obtain this understanding. While conducting well tests, it might be possible to uncover problems, including near-wellbore damage (*skin*)^{1,2} or problems with the completion such as perforations that are covered with sand or closed because of *scale*. Remedies to these problems might improve the productivity of the well.

The main goal of well testing is to ascertain the maximum production rate that the reservoir can deliver into the bottom of the well on a sustained basis. Additional well testing—involving monitoring the loads on the equipment and the liquid level in the well—is necessary after the installation of the beam-lift equipment. Testing completed after installation is covered in chapters 2 and 11.

Well Test Data to Collect

One or more flow rates from the reservoir and the corresponding pressure at the bottom of the well must be measured while the flow is occurring. It is also necessary to determine the static pressure in the reservoir, but this can be calculated from the well test data and does not necessarily have to be measured directly.

Flow Rates

If the well is still flowing to the surface, it is possible to record the flow rate of oil, water, and gas. A different rate (larger or smaller) can be determined by simply changing the size of the choke in the well. It is important that the flow rate and pressure from the well be allowed to stabilize before the data are accepted. Only stabilized rates and pressures have true meaning when predicting well performance.

If the well has ceased to flow to the surface, some means of artificially lifting the well to obtain representative test data is required. Rates and pressures must be stabilized when testing with artificial lift if reasonable predictions of reservoir performance are to be made.

When rates and pressures are stabilized, liquid rates, gas rates, and pressure cease to change. Many reservoirs that require artificial lift are in a state of continuous pressure decline as fluid is produced from the reservoir. Therefore, even though a rate and a flowing pressure might be stable one day, that rate and pressure could change over time. (Predicting rate and pressure decline is discussed in chapter 1.) So, a stable rate and pressure means that the rate and pressure have stopped changing for the short term. This might take minutes, hours, or even days to establish as the pressure in the well and reservoir adjusts to a different flow rate. The well test must continue at a given rate until the flowing pressure at the bottom of the well ceases to change for the short term, as previously stated. In wells in which the test equipment is capable of more rate than the reservoir can flow into the bottom of the well, the daily output from the

6

The Downhole Pump

This chapter gives details of the basic design and operation of the downhole *plunger pump* commonly used in rod pumping installations, as illustrated in figure 6.1. The system includes a subsurface plunger pump that is axially driven over a linear stroke by a rod string connected to a surface unit that is operated by a prime mover.

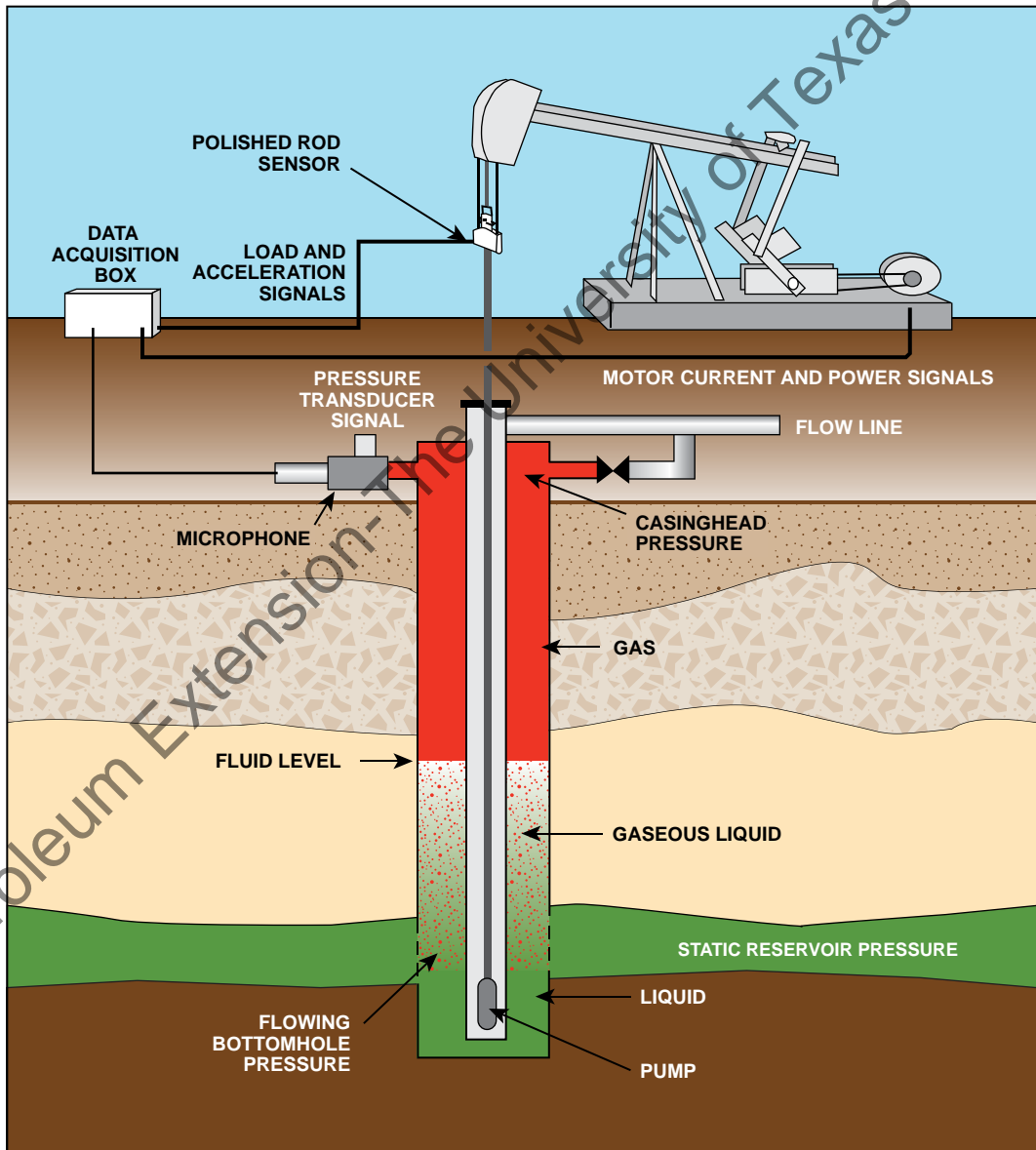


Figure 6.1 The rod pumping system, including wellbore, reservoir, and surface unit

The subsurface pump is attached to a tubing string that delivers the pumped fluids to a surface flow line connected to a *gathering network*. Fluid flows into the wellbore from an underground geologic formation and is driven by the difference in pressure between the wellbore [flowing bottomhole pressure (BHP)] and the pressure in the reservoir away from the well (average reservoir pressure). Fluids entering the wellbore accumulate in the casing and in the annular space between the casing and the tubing and segregate based on their densities; gas percolates to the upper part and liquids accumulate at the bottom. The pump action causes whatever fluid (oil, water, or gas) is present in the wellbore at the depth of the pump intake to be admitted to the pump and then discharged into the bottom of the tubing string for transmission to the top of the well. Gas that reaches the top of the annulus flows out into the surface flow line and mixes with the fluid produced from the *tubing head*.

THE FUNCTION OF THE DOWNHOLE PUMP

To be able to clearly visualize the operation and function of the downhole pump, it is useful to analyze the pressure distribution in the various parts of the pumping system by creating pressure-versus-depth diagrams for the annulus and for the tubing. An example of this type of schematic diagram, called a pressure traverse, is presented in figure 6.2.

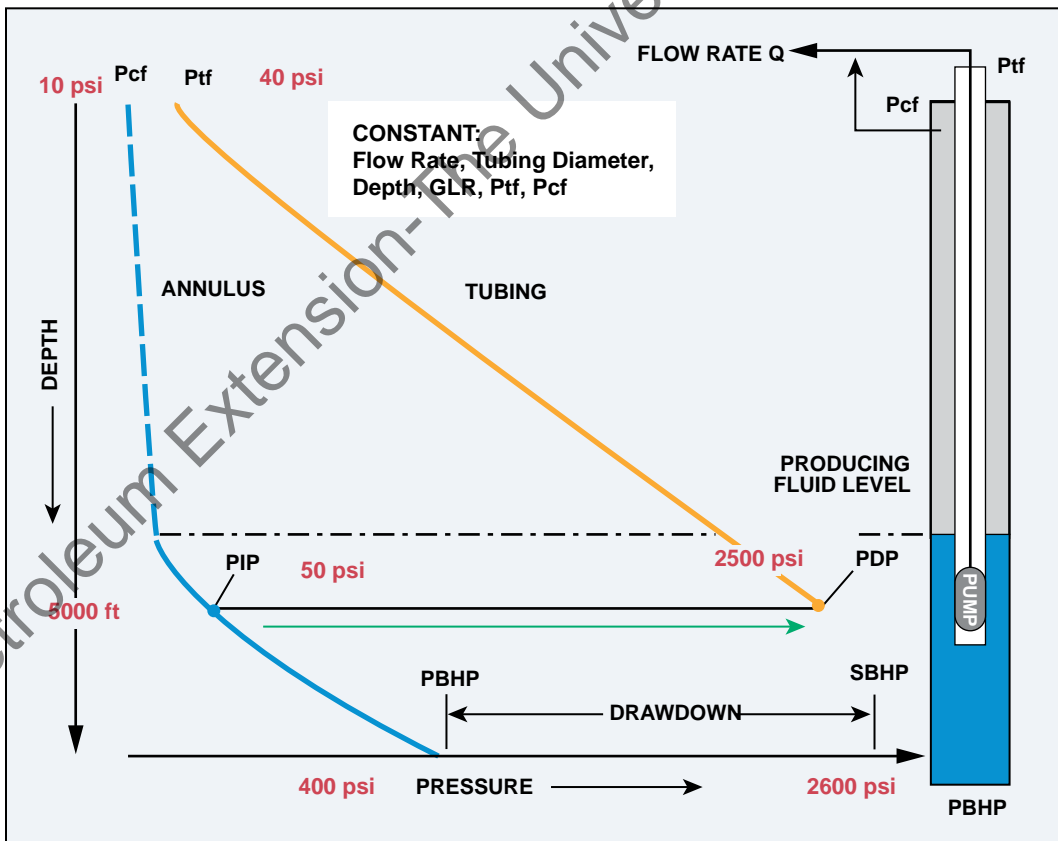


Figure 6.2 Schematic diagram illustrating the pressure-versus-depth traverses in a well produced by pumping

7

Sucker Rods

Sucker rods are jointed steel rods or, in some cases, fiber-reinforced plastic (FRP) rods (also called fiberglass rods) that connect the pump plunger at the bottom of the well to the polished rod that is connected to the pumping unit at the surface. The rods are pulled up through the stroke length by the motion of the pumping unit and fall back into the well on the downstroke as a result of gravity. The objective is to transmit this motion to the pump plunger at the bottom of the well, thereby causing it to move the fluid from the wellbore into the pump barrel and discharge it through the pump into the bottom of the tubing at a pressure that allows the fluid to flow to the surface.

Steel sucker rods are commonly manufactured in lengths of 25 ft, although longer rods are possible. The 25-ft length fits the *working room* in the *derrick* of most *workover rigs*; during trips out of the hole, rods can be hung in triples from the *rod basket*. Figure 7.1 shows a short sucker rod (pony rod) with the parts labeled.

Common rod diameters and weights (including the couplings) for both steel and FRP rods are given in table 7.1.

Table 7.1 shows that FRP rods weigh considerably less than steel rods of the same size. The table also shows that FRP rods have much larger elastic constants than steel rods of the same size.

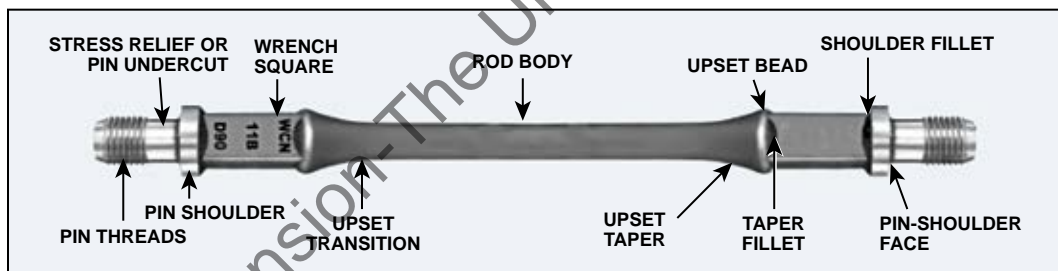


Figure 7.1 Sucker rod terminology

Table 7.1
Sucker Rod Sizes and Elastic Constants

Diameter (inches)	Steel Rods		FRP Rods	
	Weight (lb _r /ft)	Elastic Constant [inches/lb _r (ft)] × 10 ⁻⁶	Weight (lb _r /ft)	Elastic Constant [inches/lb _r (ft)] × 10 ⁻⁶
0.5*	0.726	1.99	–	–
0.625*	1.135	1.27	–	–
0.75	1.634	0.883	0.48	4.308
0.875	2.224	0.649	0.64	3.168
1.0	2.904	0.497	0.8	2.425
1.125*	3.676	0.393	–	–
1.25*	4.538	0.318	1.29	1.552
1.5	6.262	0.27	–	–

* = discontinued or limited availability

8

Pumping Units

Pumping units are the machines installed at the surface that lift the rods and fluid the length of the surface stroke at the desired pumping speed. This is the only function of the pumping unit. The rods fall back into the well during the downstroke as a result of gravity. The motion imparted to the rods causes the pump plunger to cycle.

To achieve the function of picking up the rods and fluid for the desired length at the desired speed, the pumping unit must accomplish several associated tasks. First, the pumping unit must be structurally strong enough to support the upstroke and downstroke loads. Second, the pumping unit must convert the rotary motion of the prime mover to the linear motion required at the polished rod. Third, the pumping unit must convert the speed of the prime mover to the desired speed for the pump. And finally, in order to minimize the size and capacity of the pumping unit gear box, the pumping unit supplies a counterbalancing load that offsets a portion of the load being carried by the polished rod.

There are several types of pumping units, the most common of which are the *beam-balanced pumping unit* and the *crank-balanced pumping unit*. Other types are the *long-stroke pumping unit* and the *surface-hydraulic pumping unit*. These types will be discussed in the sections that follow.

BEAM-BALANCED AND CRANK-BALANCED PUMPING UNITS

Beam-balanced and crank-balanced units are the most common types of pumping units. They are robust and, when properly designed and maintained, have service lives of many decades.

Type I Levers

The oldest pumping unit design is the type I lever unit, as shown in figures 8.1 and 8.2. Oilfield applications of this design can be traced back to the early *cable tool rigs*, in which the *walking beam* was used to raise and lower the cable tools while drilling and, afterwards, could be used during production to operate a pump in the well.

The walking beam is a structural steel beam that pivots on a center bearing (sometimes called a *saddle bearing*) on top of a support called the samson post. The samson post provides the pivot point for the lever and the clearance necessary for a given stroke length. These structural components must be strong enough to lift the weight of the fluid and the rods and the additional dynamic loads associated with motion. The beam must support the load and resist bending forces caused by the motion of the unit and the attached loads.

On the front of the walking beam, the *horsehead* serves as the connector for the wire rope *bridle* and carrier bar. The horsehead is curved so that the rods will rise and fall vertically; this keeps the polished rod from bending when the unit is correctly aligned with the wellhead. The polished rod is clamped above the carrier bar using a friction polished rod clamp. The clamp rides on top of the carrier bar and is held in place by the weight carried by the polished rod. The clamp is not secured to the carrier bar in any other way and can separate from the carrier bar during the downstroke if the horsehead is falling faster than the free-fall velocity of the rods into the well.

9

Prime Movers

The power required to start and keep a pumping unit in motion is provided by an external source called a prime mover. Any power source can be used—from windmills and water wheels to steam engines, electric motors, and internal combustion engines. The two most widely used types of prime movers, electric motors and internal combustion engines, are discussed in this chapter.

LOADS CARRIED BY THE PRIME MOVER

When the pumping unit is in motion, the polished rod load is a cyclical load. The cyclical load creates a cyclical torque on the gear reducer and a cyclical load on the prime mover. The gear reducer torque is normally a positive number, but it can also be a negative number, depending on the counterbalance load. A positive torque on the gear reducer requires power from the prime mover to keep the unit in motion. A negative torque on the gear reducer means that the power in the gears is now driving the prime mover. This torque reversal can often be heard in the gear box as an audible clank when the load on the gear teeth moves from the front to the back of the gear teeth. Depending on the pumping loads and the counterbalance required, it might be impossible to eliminate the torque reversal in the gear box. Proper counterbalance combined with pumping speed control (as discussed in chapter 8) will limit the periods and magnitude of negative torque.

If an electric motor is the prime mover, current is delivered to the motor from the transmission line during periods of positive gear reducer torque. During periods of negative torque on the gear reducer, the electric motor is driven as a generator and delivers current back to the line. Some power companies will not issue credit for power delivered back to the line, even though they do receive the power back. To prevent the meters from running backward, power companies place *detents* in the meters.

If an internal combustion engine is being used as the prime mover, the engine will provide power to overcome positive torque in the gear box. During periods of negative torque, the engine is driven by the power coming from the gear box and will speed up as the load on the engine goes to zero. Although not probable, it is possible that the engine can be driven to a speed that will damage the clutch, valves, or rods in the engine. Most engines can survive sizeable *overspeeding* for a few seconds, so damage is not normally an issue.

PRIME MOVER SIZING

The prime mover must be able to supply sufficient power to start the pumping unit from a dead stop and then keep the unit in motion.

Starting Power

The power required to start a unit from a dead stop is related to the torque required at the gear reducer and the inertia that must be overcome in order to accelerate the articulating elements of the unit and the rods to the desired pumping speed. This is impossible to predict in advance

Downhole and Wellhead Equipment

THE PUMP INTAKE

A great deal of effort and resources are normally expended in the process of designing the pumping system—selecting the pump, the rod string, the surface unit, the prime mover, etc.—in order to develop a detailed installation plan that is then forwarded to the field crew for execution. However, at the time that the hardware is run into the well, it is unlikely that the designer is present at the site or that a major effort is made to verify that the design plan is implemented without alterations, which might be required due to unforeseen circumstances. These factors often result in inconsistencies between the actual configuration of the pumping system and the recorded description of the hardware that is installed in the well. In particular, there is very little thought and design effort devoted to monitoring the hardware that is installed at or below the pump intake, even though this hardware is perhaps the most important element controlling the efficiency of the pumping system.

The pump can only displace the fluid that is able to enter the barrel through the standing valve (SV). The time available to fill the barrel is on average only a few seconds for the majority of applications (about 3 seconds when pumping at 10 spm, depending on the geometry of the pumping unit). However, the hardware installed below the pump often consists of whatever was used before or whatever was available on location at the time the pump was run. With regard to design, it is recommended that more consideration be given to issues such as filling the pump barrel with liquid and designing the appropriate intake system.

Filling the Barrel With Liquid

In order to achieve efficient operation, the pump intake design objective should be to ensure that every upstroke of the plunger yields a barrel completely filled with liquid. Then, assuming that other losses—such as those resulting from slippage, valve leaks, tubing leaks, etc.—are negligible, the volume of liquid that enters the pump is transferred to the tubing and eventually should be produced at the surface.

The three main causes of incomplete liquid fillage are as follows:

- insufficient inflow from the reservoir to meet pump displacement (pumped-off well)
- restricted inflow due to frictional losses through the pump intake (choked pump)
- flow of a gas–liquid mixture entering through the SV (*gas interference*)

The first of the three causes was addressed as a speed control issue in chapter 8. The other two causes are addressed in this chapter.

Flow Rate Through the SV

Assuming that there is sufficient liquid outside the SV to fill the volume of the barrel at the top of the plunger stroke, the rate at which the liquid has to flow through the pump intake is dependent on the plunger velocity multiplied by the cross-sectional area of the plunger. The velocity of the plunger depends primarily on the pumping speed and the geometry of the pumping unit,

Data Acquisition Tools and Data Quality Control

From the time when rod pumping first began to be used in oilfield production operations, it became necessary to understand the performance of the pumping system and the well based on observations and measurements that could be carried out at the surface. This understanding included qualitative visual and auditory observations and quantitative measurements of mechanical, pressure, and flow variables related to the pumping cycle. Knowledge of the position of the wellbore fluid relative to the depth of the pump intake was also required in order to evaluate the performance of the artificial lift system. Two sets of tools were developed early on and refined over time to achieve these goals: the dynamometer and the *acoustic fluid level instrument*.

DYNAMOMETER

The dynamometer generates a dynagraph, which is a “record of the forces existing at the top of the rod system with respect to the stroke cycle”¹.

The force at the top of the rods is the sum of all the effective forces that result from the forced motion of the polished rod by the cyclical movement of the pumping unit. This includes forces applied by the downhole pump to the rods, friction forces, inertial forces, vibration forces, buoyancy, and others as they exist at any point during the pumping cycle.

Objective of Dynamometer Measurements

The objective of analyzing the dynamometer graph is to understand and to visualize the performance of the pumping system. This analysis can be divided into two main tasks, as follows:

- The loads applied to the mechanical elements of the system are analyzed. This includes a study of the loading of the surface unit, gear reducer, power transmission, and prime mover, and the mechanical loading of the rod string.
- The performance of the downhole pump is analyzed. This includes pump volumetric efficiency, operation of the valves, liquid fillage, plunger travel, leakage, etc.

The first part of the objective is achieved by transforming the forces measured at the polished rod to the corresponding forces, torque, or stresses that are developed at the various points in the mechanical system. This requires having a detailed description of the pumping unit’s geometry, gear box capacity, transmission, motor, rod string, etc.

The second part of the objective is achieved by transforming the measured load and position of the polished rod to the load and position of the pump plunger, which is achieved by accounting for the elasticity and dynamics of the rod string.

Accurate measurement of the polished rod load and position is a requirement for quantitative analysis of dynamometer records. However, some insight into the operation of the pumping system can be achieved through inspection of qualitative dynamometer cards, based on the prior experience of the analyst.

12

Design Methods

Please note that this chapter is not a recommendation for any particular commercial service or design software. Instead, it is a reference source, a discussion of and a comparison between design methods, new and old.

PREDICTIVE METHODS

Predictive methods are mathematical models based on assumed pump conditions that estimate, at a minimum, the loads on the rods and pumping unit and the necessary counterbalance, gear box size, and prime mover power for the pumping unit. The rod stress fluctuation is then plotted on the American Petroleum Institute (API) Modified Goodman Diagram (MGD) in order to make sure that the rod loads are at or below the recommended maximum loading. Some computer programs can include the influence of wellbore deviation and other pump fillage anomalies in order to predict the shape of the surface dynamometer card.

The fundamental data set necessary to estimate the rod loads, pumping unit size, and power requirement includes the following:

- Q = desired surface liquid production rate (STB/day)
- B_o = oil formation volume factor (bbl/STB)
- γ_f = fluid specific gravity (relative to fresh water)
- μ_f = fluid viscosity at pump intake conditions (cp)
- L = pump setting depth (ft from the surface)
- L_n = working fluid level or net lift (ft from the surface)
- S = surface stroke length (inches)
- D_p = pump plunger diameter (inches)
- C = plunger-barrel clearance (inches)
- L_p = plunger length (ft)
- e = pump volumetric efficiency (fraction $\cong 0.9$)
- D_t = tubing internal diameter (inches)
- d_i = rod diameters in the rod string (inches)
- Pumping unit type = type I or III lever

The initial estimate for pumping speed can be obtained using equation 12.1.

$$N = \frac{QB_o}{0.1166eD_p^2S} \quad \text{Eq. 12.1}$$

N = pumping speed (spm)

Index

- abrasion, 6-29, 7-19
- absolute pressure, 4-2
- acceleration loads, 8-14
- acceleration of gravity, 4-2
- accelerometers, 8-25, 11-12 to 11-14
- AccuPump Beam program, 12-2
- acoustic determination of depth to liquid, 11-26
- acoustic fluid level surveys
 - acoustic pulse generation, 11-22 to 11-23
 - acoustic velocity from gas gravity or composition, 11-25
 - acoustic velocity in hydrocarbon gases, 11-18
 - acoustic wave propagation in wellbores, 11-17 to 11-18
 - acoustic wave reflection, 11-19 to 11-22
 - calculation of pressure distribution, 11-27 to 11-33
 - calculation of SBHP in pumping wells, 11-36 to 11-38
 - collar count method, 11-24 to 11-25
 - distance to known wellbore anomaly, 11-25
 - fluid level measurements objectives, 11-16 to 11-17
 - fluid and pressure distribution in pumping wells, 11-26 to 11-27
 - fraction of liquid in gaseous column, 11-30 to 11-33
 - gas gravity, 11-30
 - pulse travel time to distance, 11-23 to 11-26
 - quality control of pressure calculations, 11-34 to 11-35
- acoustic impedance mismatch, 11-19
- acoustic pulse generation, 11-22 to 11-23
- acoustic record, 11-21
- acoustic surveys
 - bottomhole pressure (BHP) calculation, 11-17
 - deviated wellbores, 11-35
 - fluid level determination, 2-12
 - well potentials calculation, 11-17
- acoustic velocity, 11-17
 - from gas gravity or composition, 11-25
 - of gases, 11-18 to 11-19
 - in hydrocarbon gases, 11-18
- acoustic wave propagation in wellbores, 11-17 to 11-18
- acoustic wave reflection, 11-19 to 11-22
- acoustic well sounder, 5-7
- air-balanced geometry, 8-5
- air-balanced pumping units, 8-30, 8-31, 12-10, 12-11 to 12-12
- air-pressure counterbalance effect, 8-38
- Ajax engine, 9-6
- alignment, 2-95
- allowable setting depth (ASD), 6-22
- American Iron and Steel Institute (AISI), 7-4
- American Petroleum Institute (API). *see* API (American Petroleum Institute)
- ammeter, 8-43
- ampere, 4-1
- amplitude, 11-19
- analysis of dynamometer record, 3-6 to 3-10
- analysis of fluid level record, 3-4 to 3-5
- analysis of motor current for a single pump stroke, 11-40 to 11-41
- anchored tubing, 2-2, 12-13
- angular velocity, 8-35
- annual flow pattern through eccentric tubing, 10-21
- annular gaseous liquid column, 11-29
- annular liquid percentage, 11-34
- annular pressure, 2-12
- anode, 7-50
- API (American Petroleum Institute), 1-10
 - gravity (degrees), 4-10
 - polished rod, 11-8
 - unit designation, 8-7
- API class C rods, 7-3
- API class D rods, 7-3
- API class K rods, 7-3
- API gravity, 11-34
- API modified Goodman Diagram (MGD)
 - vs. 1-D wave equation, 12-20
- axial compression, 7-12, 7-23
- and constant life diagram, 2-9
- corrosion service factor, 7-12
- fatigue strength, 7-23
- fatigue stress, 7-14 to 7-15
- FRP rods, 7-23
- maximum rod stress, 1-16, 7-55
- rod loading, 1-11
- rod stress fluctuation, 7-13, 7-15, 7-40, 12-1
- rod string design, 7-32
- rod taper stress, 2-8, 7-25, 7-55
- service factor, 1-14
- sucker rod design, 7-24

- API Recommended Practice 11AR, 6-22
- API Recommended Practice 11L (RP11L)
vs. 1-D wave equation, 7-38, 12-19, 12-30
- air-balanced units, 12-11 to 12-12
- assumptions, 7-38
- vs. classical method, 12-30
- comparison, 7-39
- conventional units, 12-10 to 12-11
- development of, 7-34
- limitations of, 7-55
- Mark II units, 12-12
- Neely's method, 7-29
- origins and factors used in, 12-2 to 12-12
- vs. QRod simulation, 1-15
- steel sucker rod design, 12-4 to 12-6
- API RHT pump, 6-44
- API RWT pump, 6-44
- API Specification 11AX, 6-28
- API Sucker-Rod Pump Repair/New Pump Log
form, 6-52
- API type SM coupling, 7-5
- API type T coupling, 7-5
- Archimedes' Principle, 7-6
- Archimedes screw, 10-27
- area, 4-1, 4-4
- area increases, 11-19
- articulating inertial torque, 8-29
- articulating structure torque, 8-28
- artificial lift, *xxix*
- asphaltene, 10-26, 10-31
- auxiliary equipment, *xxix*
- average acoustic velocity, 11-23, 11-24
- average joint length, 11-24, 11-35
- average reservoir pressure, 1-2, 1-7, 2-12, 5-8, 5-14
- axial compression, sucker rods, 7-19 to 7-22
- axial compression force, 7-19, 7-20
- axial loading, 6-13, 6-23
- axial stresses, 7-8
- back-pressure, 1-32
- ball and seat assemblies, 6-34
- balancing the unit, 8-40 to 8-44
- balls and seats, 6-33 to 6-36
- Barlow's Equation, 6-23
- barrels, *xxix*
materials and recommended applications, 6-30
to 6-31
yield strength of materials, 6-30
- Basquin Equation, 7-14
- Basquin relation, 7-14
- beam deflection, 11-9 to 11-10
- beam lift
goals, 1-1 to 1-4
system design, 1-4 to 1-38
- beam load, 2-8
- beam pumping, *xxix*
- beam ratings, 2-8
- beam-balanced geometry, 8-4
- beam-balanced pumping units, 8-1 to 8-51
- bearing failure, 8-44
- Beggs and Brill correlation, 4-19
- Beggs and Robinson correlation, 4-15
- belt velocity, 8-22
- bending polished rod, 2-95 to 2-97
- best practices
data acquisition tools and data quality control,
11-45
design methods, 12-30 to 12-32
downhole pump and wellhead equipment, 10-35
to 10-36
1-D wave equation, 12-30
predictive design methods, 12-30 to 12-32
pumping units, 8-51
sucker rods, 7-54 to 7-56
troubleshooting and analysis guidelines, 3-10
to 3-12
well testing, 5-19
- BHP. *see* bottomhole pressure (BHP)
- bhp. *see* brake horsepower (bhp)
- blowout preventer, 10-34, 10-35
- bottom hold-down rod pump, 6-15 to 6-16
- bottom-discharge valve, 6-46 to 6-47
- bottomhole pressure (BHP)
acoustic fluid level measurements, 11-16 to
11-17
flowing, 1-4, 1-25, 1-36, 2-12, 5-5 to 5-9
producing, 2-101, 2-102
stabilized flowing, 5-3
static, 2-75
- bottomhole pressure gauge, 5-5
- bottomhole temperature, 11-34
- brake, 2-6
- brake horsepower (bhp), 9-7, 12-11, 12-15
- brass, 6-31
- breakdown torque, 9-16
- bridle, 8-1
- brine, 6-11
- brine specific gravity, 11-35
- British thermal units (Btus), 4-3
- bubble point
about, 4-12

- formation volume factor, 4-14
- pressure above, 5-9 to 5-11
- pressure below, 5-11 to 5-15
- productivity index, 1-1
- bubble point pressure, 10-11
- buckling, 7-19, 7-25, 7-45, 7-56, 12-18
- buckling forces, 1-10, 1-20, 7-20, 8-15
- bull plug, 10-17
- buoyed rod weight, 2-7, 7-6
- burst loading, 6-23

- cable-tool rigs, 8-1
- calculations
 - bottomhole pressure (BHP), 11-17
 - cyclical load factor (CLF), 8-47
 - leakage rate, 2-20 to 2-21
 - pressure, 11-32 to 11-34
 - pressure distribution, 11-27 to 11-29
 - pumping speed, 12-21
 - quality control of pressure, 11-34 to 11-35
 - SBHP in pumping wells, 11-36 to 11-38
 - sinker bars, 12-21
 - system loads, 12-22
 - torque, 8-25 to 8-29, 11-43 to 11-45
 - well potentials, 11-17
- camshaft, 9-8
- capacitors, 9-15
- carbon dioxide (CO₂), 5-2, 9-5
- carbon dioxide (CO₂) corrosion, 7-51
- carbon monoxide (CO), 9-5
- carbon steel, 6-30
- carbon steel-carbonitrided, 6-30
- carbonic acid, 5-2
- carbonitrided tubes, 6-30
- carburetor, 9-6
- cards. *see* dynamometer cards
- carrier bar, 2-6, 7-47, 8-1
- casing diameter, 11-35
- casing packer, 6-50
- casing pressure, 3-3
- casing pump, 6-50, 6-51
- casing size limiting tubing size, constrained design, 1-22 to 1-25
- casing valve, 3-3
- casinghead pressure, 3-4, 11-27, 11-28, 11-34
- casing-tubing annulus, 1-2
- cathode, 7-50
- Cavins centrifugal separator, 10-27
- centipoise, 4-3
- centrifugal forces for separation, 10-27
- centrifugal separators, 10-12

- check valves, 3-2
- chokes, 1-6, 1-32, 5-1
- chromatographic analysis of, of wellbore gas, 11-25
- chrome-plated internal surface, 6-31
- churn, 10-21
- clamp meters, 11-39 to 11-40
- class C rods, 7-3
- class D rods, 1-11, 7-3
- class K rods, 7-3
- classical method
 - vs. 1-D wave equation, 12-23
 - for conventional (type I lever), 12-12 to 12-15
 - numerical example, 12-21 to 12-23
 - obsolescence of, 12-30
- clogging, 10-26
- closed cage
 - design pressure drop, 10-5
 - pressure drop through, 10-7
 - valves, 6-35
- cloud point, 7-53
- clutch, 9-4
- coal bed methane, 1-32
- coal bed methane pumping, 1-32 to 1-33
- coiled tubing, 5-2
- collapse loading, 6-24 to 6-25
- collar count method, 11-24 to 11-25
- collar echoes, 11-21
- collar-size separator, 10-22 to 10-25
- combination rod couplings, 7-6
- combustion stroke, 9-5
- compressed air, 8-6
- compressibility, 4-3
- compression, 7-25
- compression and buckling, 7-45 to 7-46
- compression ratio, 6-40
- compression stroke, 9-5, 9-6
- compressive force, 1-29, 12-16
- computational accuracy compared with measured results, 12-24 to 12-27
- computer simulations, 1-15
- computer solution of one-dimensional (1-D) wave equation, 12-2
- connecting rods, *xxix*
- constant life diagrams, 2-8, 2-9, 7-15 to 7-18
- constrained design
 - casing size limiting tubing size, 1-22 to 1-25
 - coal bed methane pumping, 1-32 to 1-33
 - flowing while pumping, 1-30 to 1-32
 - gear box capacity restraint, 1-28 to 1-30
 - maximum production with available equipment, 1-25 to 1-28

- pumping from highly deviated wells, 1-33 to 1-38
- continuous pressure decline, 5-1
- continuous rods, 1-35, 7-43, 7-44, 7-54
- conventional units, 12-10 to 12-11
- correlations, 11-30 to 11-31
- corrodents, 6-28
- corrosion, 3-12, 5-2
- corrosion byproducts, 6-44
- corrosion control, 7-52
- corrosion fatigue, 6-28
- corrosion inhibitors, 7-52
- corrosion monitoring, 7-52 to 7-53
- corrosion pit, 7-48
- corrosion types, 6-28
- corrosion-inhibiting films, 6-27
- corrosion-resistant steel, 6-30
- corrosive attack, 7-50 to 7-51
- corrosive environment, 1-14
- Coulomb friction, 7-20, 7-34 to 7-37, 7-41, 7-44 to 7-45
- counterbalance
 - about, 8-30 to 8-31
 - air-balanced pumping units, 8-38 to 8-39
 - beam-balanced units, 8-36 to 8-38
 - crank-balanced pumping units, 8-31 to 8-36
 - net gear box torque, 8-39 to 8-40
- counterbalance effect
 - by air-pressure, 8-38
 - effective counterbalance effort, 8-25
 - polished rod, 8-43
 - weights on, 12-14
- counterbalance effect test, 8-33 to 8-34
- counterbalance load, 2-6, 12-12
- counterbalance torque, 8-31, 8-37
- counterbalance value, 2-14 to 2-15
- counterbalancing, 9-7, 11-43
- counterweight-heavy, 2-14
- counterweights, 2-14, 2-15, 11-40
- couplings
 - API type SM, 7-5
 - API type T, 7-5
 - combination rod, 7-6
 - polished rod, 7-5 to 7-6
 - slim-hole, 7-5
 - sucker rod, 7-5 to 7-6, 7-25, 7-55
- crank angle, 8-11, 8-15, 8-16
- crank heavy, 2-60
- crank offset, 8-33
- crank rotation, vs. polished rod position, 11-15
- crank-balanced geometry, 8-3, 8-4
- crank-balanced pumping units, 8-1, 8-31 to 8-36
- crankcase, 9-7
- crank-heavy unit, 11-44
- crank-mounted weights, 8-38
- cranks, 8-3, 8-6, 12-14
- cricondentherm point, 4-12
- critical point, 4-11 to 4-12
- crossover point, 11-21
- cup separator, 10-21 to 10-22
- cup-type hold-downs, 6-37
- cup-type separator, 10-23
- current data, 11-40
- current probes, 11-39 to 11-40
- cyclical load, 4-8, 9-1
- cyclical load factor (CLF)
 - calculation, 8-47
 - for electric motors, 9-3
 - empirical, 9-4
 - for engines, 9-4
- cyclical torque, 9-1
- cylinder, 9-4
- damping coefficients, 7-36, 12-24
- damping factor, 2-53
- Darcy's law, 5-9, 5-14
- data acquisition, tools and data quality control
 - acoustic fluid level surveys, 11-16 to 11-38
 - best practices, 11-45
 - dynamometers, 11-1 to 11-16
 - motor power or current measurements and analysis, 11-38 to 11-43
 - torque calculation from power, 11-43 to 11-45
- data quality control, 2-7 to 2-8
- data uncertainty, 5-17 to 5-18
- data recording methods, 11-15
- dead space, 6-40
- dead volume, 3-11
- decline rate, 1-8
- deep pumping, 2-48 to 2-49
- deep rod part, 2-56 to 2-59
- default downstroke friction equivalent, 1-15
- delayed closure of TV, 2-68 to 2-69
- Delta-X, 11-2
- density
 - definition, 4-1
 - of gases, 4-10
 - of gas-liquid mixture, 1-36
 - and heat content for fuels, 8-47
 - of liquids, 4-9 to 4-10
 - unit conversions, 4-5
- depletion, 2-97

- derrick, 7-1
- design method comparison, 12-23
- design methods
- best practices, 12-30 to 12-32
 - computational accuracy compared with measured results, 12-24 to 12-27
 - diagnostic methods, 12-27 to 12-30
 - numerical example comparing the methods, 12-16 to 12-23
 - predictive methods, 12-1 to 12-15
- design of sucker rods, rod sizes and tapered rod string, 7-25 to 7-32
- design programs, 7-44
- detents, 9-1
- deviated wellbore
- air-balanced unit, 2-84 to 2-85
 - pressure calculations, 11-35
 - variable speed system, 2-105
- deviated wells
- compression and buckling, 7-45 to 7-46
 - Coulomb friction, 7-36
 - friction, 7-44 to 7-45
 - pumps, 7-46
 - rod bending loads, 7-43
 - rod guide placement, 12-2
 - rod guides in deviated sections, 7-44
 - sucker rods, 7-41 to 7-46
 - wellbore friction in, 2-84
- deviation profile, 1-34
- dew point, 4-12
- diagnostic analysis of rod lift systems, 2-4
- diagnostic methods, 12-27 to 12-30
- diagnostic mode, 12-2
- differential pressure loading
- bottom hold-down rod pump, 6-15 to 6-16
 - top hold-down rod pump, 6-14 to 6-15
 - traveling barrel rod pump, 6-16 to 6-17
 - tubing pump, 6-13
- dimensionless groups
- downstroke dynamic load, 12-8
 - example of, 12-3
 - fluid and upstroke dynamic load, 12-7
 - peak torque, 12-8
 - solution dimensionless groups, 12-19
- dimensionless output groups, 12-10
- dip arm, 9-7
- dip tube, 10-13
- dip tube diameter effect, 10-26
- dip tube dimensions, 10-36
- direct polished rod position measurement, 11-11
- direct-rod load measurement, 11-2 to 11-5
- discharge coefficient, 6-36
- distance to known wellbore anomaly, 11-25
- D-Jax wireless EZ draw dynamometer, 11-7
- donut load cell, 11-2
- double valves, 6-36 to 6-37
- Double-Displacement Pump[®], 6-47 to 6-48
- double-reduction gear box, 8-7, 8-17, 8-18, 8-19
- downhole dynamometer tools, 2-5
- downhole gas separators, 10-12 to 10-35. *see also* natural gas separators
- downhole pump and wellhead equipment
- best practices, 10-35 to 10-36
 - gas interference, 10-11 to 10-12
 - gas separators, downhole, 10-12 to 10-35
 - pump intake, 10-1 to 10-11
- downhole pump displacement, 11-43
- downhole pump submergence, 11-26 to 11-27
- downhole pumps. *see also* materials for subsurface plunger pumps
- about, 6-1 to 6-2
 - abrasion, 6-29
 - barrels, 6-30 to 6-31
 - corrosion, 6-28
 - factors of safety, 6-25
 - function of, 6-2 to 6-3
 - Gas Vent Pump[™], 6-44
 - hold-down seal assemblies, 6-37
 - mechanical actuation of TV, 6-42
 - multistage compression, 6-42 to 6-43
 - plungers, 6-31
 - pump anchor, 6-38
 - pump failure tracking, 6-50 to 6-52
 - pumping fluids with solids, 6-44 to 6-50
 - rate and efficiency, 6-3 to 6-5
 - seating nipples, 6-38
 - setting depths, allowable, 6-22 to 6-25
 - setting depths, typical, 6-25 to 6-26
 - size limitations, 6-27
 - sliding top valve, 6-41
 - special pumps and associated hardware, 6-38 to 6-41
 - subsurface types, 6-5 to 6-22
 - tubing pressure transfer to barrel, 6-44
 - valve cages, 6-32 to 6-37
 - variable slippage pump[®], 6-44
 - venting gas from barrel to annulus, 6-44
- downhole screens, 10-31
- downhole separator, 3-10
- downstroke dynamic loads, 12-8
- downstroke friction coefficient, 12-16
- downstroke speed, 8-15

- drag, 7-32. *see also* friction
- drawdown, 1-3
- drawworks, 5-2
- dynagraph, 11-1
- dynagraph analysis, 11-5
- dynamic forces, 7-7
- dynamic loads. *see also* inertia loads
 - consideration of, 2-4
 - Neely's method, 7-29
 - reduction of, 1-16, 8-49
 - vs. static loads, 12-24
 - sucker rods, 7-32 to 7-38
- dynamic rod stretch, 1-29
- dynamometer, 8-25, 8-43
- dynamometer analysis, 2-1 to 2-5, 12-16, 12-24 to 12-27
- dynamometer analysis flow chart
 - fluid level above pump, 3-6
 - fluid level at pump, 3-7
- dynamometer card simulation, 12-30
 - vs. measured, 12-26
- dynamometer cards
 - choked pump, 10-4
 - data recording, 11-15
 - deep pumping, 2-48
 - downhole pump displacement, 11-43
 - effective plunger stroke, 2-100
 - field data examples, 2-28 to 2-31
 - fluid flow rate, 3-8
 - fluid level, 3-4
 - ideal, 2-4
 - loose tubing anchor, 2-50
 - normal operations, full pump and anchored tubing, 2-32
 - plugged intake, 2-46
 - polished rod power, 2-8, 8-45
 - program predictions, 12-1, 12-2, 12-26, 12-28
 - pump fillage, 11-8
 - qualitative analysis, 11-1, 11-5
 - surface, 1-17, 1-23, 2-2, 2-4, 2-7
 - SV test, 2-26
 - unanchored tubing, 2-21 to 2-22
 - valve leakage test, 3-8
- dynamometer data
 - after balancing, 2-87
 - analysis, 2-8
 - collection, 2-6
- dynamometer field data of rod lift systems
 - about, 2-27
 - bending polished rod, 2-95 to 2-97
 - deep pumping, 2-48 to 2-49
 - deep rod part, 2-56 to 2-59
 - delayed closure of TV, 2-68 to 2-69
 - deviated wellbore, air-balanced unit, 2-84 to 2-85
 - dynamometer quick diagnostic reference, 2-28 to 2-31
 - erratic TV operation, 2-70 to 2-71
 - fifth order pumping harmonics, 2-90 to 2-92
 - fluid pound, 2-38 to 2-39
 - flumping well, 2-55 to 2-56
 - gas interference, 2-35 to 2-37
 - heavy oil, 10 API gravity, 2-50 to 2-53
 - high pumping rate, shallow pump, 2-53 to 2-55
 - high pumping speed, 2-66 to 2-67
 - hole in pump barrel, bottom hold-down pump, 2-74 to 2-75
 - hydraulic surface unit, 2-89 to 2-90
 - leaking standing valve (SV), 2-41 to 2-43
 - leaking TV, 2-40 to 2-41
 - loose tubing anchor, 2-50
 - middle taper rod part, 2-58 to 2-61
 - normal operation, full pump and anchored tubing, 2-32 to 2-33
 - normal operation, full pump and unanchored tubing, 2-34 to 2-35
 - overloaded gear box, 2-86 to 2-88
 - plugged intake, 2-46 to 2-47
 - pounding during upstroke, 2-72 to 2-73
 - pumped-off condition, temporarily, 2-44 to 2-45
 - Rotaflex® unit, 2-92 to 2-95
 - stuck plunger, 2-61 to 2-63
 - tagging on downstroke, 2-76 to 2-77
 - tagging on downstroke, fiberglass rods, 2-80 to 2-81
 - tagging on downstroke, unanchored tubing, 2-78 to 2-79
 - very high fluid level, 2-64 to 2-65
 - wellbore friction, 2-82 to 2-83
- dynamometer measurements, 11-43
- dynamometer quick diagnostic reference, 2-28 to 2-31
- dynamometer test and fluid level test, 11-45
- dynamometer types
 - direct rod load measurement, 11-2 to 11-5
 - donut load cell, 11-2
 - horseshoe load cell, 11-3
 - hydraulic lift load cell, 11-4
 - indirect rod load measurement, 11-6 to 11-10
 - proving ring load cell, 11-5
- dynamometers
 - measurement objective, 11-1

- polished rod position determination, 11-10 to 11-16
 - reliance upon, 2-1
 - types of, 11-2 to 11-10
- eccentric annulus, 10-22
- eccentric separator, 10-30
- eccentric tubing, annual flow pattern through, 10-21
- eccentric tubing separator construction, 10-24
- eccentric tubing separators, 10-24
- eccentricity, 10-22
- echo, 11-19
- Echometer, 1-11, 12-2
- Echometer (TWM software), 12-28
- Echometer Well Analyzer system, 11-16
- effective counterbalance effort, 8-37, 8-42
- efficiency. *see also* pump volumetric efficiency
- overall pumping efficiency, 8-44 to 8-48
 - power conversion, 11-43
 - pumping speed, 11-43
- elastic constant, 2-35
- elasticity, 4-8
- electric motors
- cyclical load factor (CLF) for, 9-3
 - input power, 9-14 to 9-15
 - motor controls, 9-19
 - motor efficiency, 9-15
 - motor slip, 9-15 to 9-16
 - output power, 9-15
 - as prime mover, xxx, 9-1
 - service factor, 9-18 to 9-19
 - torque, 9-16 to 9-18
- electric power consumption, 2-98
- electric submersible pump (ESP), 5-16
- electrical demand, 2-100 to 2-101
- electrical power measurements, 3-10, 11-44
- electrical safety, 11-38 to 11-39
- electrical shock, 11-38
- electrolyte, 7-50
- embrittlement, 6-28
- emissions, 9-5
- emulsion, 4-16
- endurance limit stress, 6-23
- Energy Resources Conservation Board of Canada, 11-27
- energy utilization, 11-42
- engineering basics
- fluid characteristics, 4-9 to 4-21
 - measurement units, 4-1 to 4-3
 - mechanics of materials, 4-7 to 4-9
 - units conversion, 4-3 to 4-7
 - web-based units calculators, 4-7
- engines
- cyclical load factor (CLF) for, 9-4
 - speed control, 9-10
- environmental effects, 7-15, 7-16
- equalizer bar, 8-2, 8-6
- equalizer bearing, 8-2, 8-10, 8-11, 8-12
- equation of state, 11-30
- equation of state models, 11-25
- equipment selection, 1-8 to 1-11
- erosion/corrosion, 6-28
- erratic TV operation, 2-70 to 2-71
- exhaust port, 9-6
- exhaust stroke, 9-9
- exhaust valve, 9-9
- external sheaves, 8-21 to 8-22
- external upset end, 11-21
- factors of safety, 6-25
- failure mechanisms, 6-28
- Fanning friction equation, 10-10
- fatigue, 4-8, 7-9 to 7-13, 7-47
- fatigue break, 7-10
- fatigue cracks, 7-12
- fatigue failures, from bending, 7-48
- fatigue strength, 7-11
- fatigue stress, 7-11
- Fetkovich's Approximation, 1-1
- fiberglass rods. *see* FRP rods
- fiber-reinforced plastic rods. *see* FRP rods
- field natural gas, 9-5
- fifth order pumping harmonics, 2-90 to 2-92
- filling barrel with liquid, 10-1
- fill-up rates, 3-8, 3-9
- fill-up test, 3-8
- fill-up time, 3-4
- filters, 10-31, 10-36
- finer, 1-32
- finishes, 7-46
- flanged wellhead, 10-33
- flexible cup, 5-3
- flow line, 3-2
- flow potential, 5-10
- flow rates
- definition, 4-1
 - and flowing bottomhole pressure, 1-36
 - vs. production rate, 6-34
 - of reservoir, 1-1
 - test data, 5-1 to 5-5
 - through SV, 10-1 to 10-3

- unit conversions, 4-5
 - well testing, 5-1
- flow regime (pattern), 4-19 to 4-21
- flowback of fines, 10-31
- flowing bottomhole pressure (BHP), 1-4, 1-25, 1-36, 2-12
- flowing life end, 1-34
- flowing while pumping, 1-30 to 1-32
- fluid and pressure distribution in pumping wells, 11-25 to 11-27
- fluid and upstroke dynamic load, 12-7
- fluid characteristics
 - about, 4-9
 - bubble point, 4-12
 - gas, 4-18 to 4-19
 - gas density, 4-10
 - gas deviation factor, 4-11
 - liquids, 4-16 to 4-18
 - multi-phase flow in pipe, 4-19 to 4-21
 - oil density with dissolved gas, 4-15
 - oil formation volume factor, 4-13 to 4-14
 - phase behavior, 4-11 to 4-12
 - single-phase flow in pipe, 4-16 to 4-19
 - solution gas-oil ratio, 4-13 to 4-14
 - viscosity, 4-15 to 4-16
- fluid distribution
 - calculation of pressure distribution, 11-27 to 11-33
 - calculation of quality control of pressure, 11-34 to 11-36
 - in pumping well, 11-26 to 11-27
 - in static well, 11-36
- fluid flow rate, 10-2
- fluid inertia, 7-38, 12-2
- fluid jetting, 6-37
- fluid leakage, 2-17
- fluid level analysis, 3-4
- fluid level depth, 11-35
- fluid level instruments, 2-1, 11-24
- fluid level measurements objectives, 11-16 to 11-17
- fluid level stability, 11-28
- fluid level survey, 11-29
- fluid level test, and dynamometer test, 11-45
- fluid load, 1-11, 1-29, 2-3, 2-11 to 2-12
- fluid pound, 1-16, 2-38 to 2-39, 7-48
- fluid slippage and TV leakage, 2-16 to 2-17
- fluid specific gravity, 7-7
- flumping, 1-30, 2-55, 2-71
- flumping well, 2-55 to 2-56
- flywheel, 9-7
- force, 4-2
- Ford engines, 9-10, 9-12
- formation damage, 1-32
- formation packs, 10-31
- formation volume factor, 1-10, 1-26, 4-13 to 4-14
- four-stroke engines
 - about, 9-9 to 9-13
 - advantages of, 9-11
 - disadvantages of, 9-13
- fraction of liquid in gaseous column, 11-30 to 11-33
- fraction of polished rod stroke, pump stroke as, 12-7
- fracturing proppants, 1-32
- free gas, 1-1, 10-12
- frequency, 11-21
- frequency factors, 12-3
- friction
 - Coulomb friction, 7-20, 7-21, 7-34 to 7-36, 7-41, 7-44 to 7-45
 - dynamic loads, 7-32 to 7-38
 - Fanning friction, 4-17, 7-21, 10-10
 - friction coefficients, 1-15, 7-40, 7-43, 12-16, 12-31
 - friction factors, 4-17 to 4-19
 - mechanical friction, 1-10, 1-20
 - predictive model default values, 12-24
 - pump friction, 1-10, 7-7, 7-8, 7-32, 7-35, 7-39, 12-16, 12-28, 12-31
 - rod friction, 1-32, 2-84, 12-16
 - stuffing box friction, 2-83, 7-7, 7-33
 - types of, 7-36
 - viscous, 2-67, 6-36, 7-36, 10-9
 - wellbore friction, 2-82 to 2-83
- friction coefficient, downstroke and upstroke, 12-16
- friction cups, 6-7
- friction factor, 4-17 to 4-19
- friction in the well, 9-3
- frictional loads, 2-4
- FRP rods
 - about, 7-23 to 7-24
 - compression failure, 7-19
 - compression loads, 1-29
 - corrosion, 7-52
 - design, 1-30
 - service life of, 7-23
 - weight and elastic constants, 7-1 to 7-2
- fuel flow rate, 8-46
- fuel gas injection, 9-6
- fuels, density and heat content for, 8-47
- full-load torque, 9-16

- galling, 7-5, 7-50
- galvanic corrosion, 6-28, 7-51
- gas anchors, 10-12
- gas and liquid accumulations, 10-29
- gas bubble slip velocity, 10-13 to 10-16
- gas bubbles, 10-13 to 10-14
- Gas Chaser Pump™, 6-42 to 6-43
- gas density, 4-10
- gas deviation factor, 4-11
- gas flow vs. pressure increase, 11-32
- gas gravity, 11-30
- gas gun, 11-22 to 11-23
- gas hold-up, 4-19
- gas in the pump, 3-11
- gas interference
 - about, 10-11 to 10-12
 - cause of, 2-53
 - conditions resulting in, 3-4, 3-8
 - dynamometer cards, 12-29
 - effects of, 2-35 to 2-37, 3-10
 - elimination, 1-8
 - high pump submergence, 2-92
 - liquid fillage, 10-1
 - pump volumetric efficiency, 1-35
 - TV closure, 2-68
- gas lift, 1-32, 5-2
- gas locking, 6-8, 6-39 to 6-41
- gas oil ratio (GOR), 4-12 to 4-14, 5-12, 6-3
- gas separators
 - about, 10-12
 - basic functioning of, 10-12 to 10-13
 - centrifugal forces for separation, 10-27
 - collar-size separator, 10-22 to 10-25
 - cup separator, 10-21 to 10-22
 - gas bubble slip velocity, 10-13 to 10-16
 - horizontal vs. lateral wellbores, 10-28 to 10-30
 - for inclined wellbore, 10-29
 - laboratory tests of, 10-26
 - natural gas separators, 10-16 to 10-17
 - packer separator, 10-19 to 10-20
 - poor boy separator, 10-17 to 10-18
 - screens, 10-31
 - solids exclusion, 10-30 to 10-31
 - tubing anchors, 10-32 to 10-33
 - wellbore inclination effect, 10-28
 - wellheads, 10-33 to 10-35
- gas vent holes, 10-26, 10-36
- Gas Vent Pump™, 6-44
- gas viscosity, 4-16
- gaseous liquid column height, 11-35
- gases, density of, 4-10
- gas-lift valve, 5-2
- gas-liquid fraction, 11-35
- gas-liquid mixture
 - density of, 1-36
 - leakage rates of, 2-25
- gas-liquid ratio, 2-13
- gas-liquid separation, 1-37, 7-46
- gas-liquid separators, 2-56, 4-21
- gas-oil ratio, 2-1
- gathering network, 6-2
- gauge, 2-1
- gauge pressure, 4-2
- gear box
 - about, 8-17 to 8-21
 - data sheet, 8-18
 - function of, *xxix*
 - gears in, 8-3
 - loading, 1-25
 - location of, 8-6
 - speed reduction of, 8-19
 - sprocket and chain, 8-19
- gear box and power requirements, 1-37
- gear box capacity restraint, 1-28 to 1-30
- gear box overload, 2-86, 2-88
- gear box sheaves, 8-21 to 8-23, 8-51, 9-4
- gear box torque
 - acceleration loads, 8-15
 - and counterbalance condition, 2-13 to 2-15
 - counterweights, 2-87
 - instantaneous torque, 11-43
 - maximum torque, 2-14 to 2-15, 8-44, 12-10
 - peak torque, 2-3
- gear lubrication, 8-23
- gear ratio, 8-18, 8-20
- gear reducer, 1-24
- gear box torque and counterbalance condition,
 - recommended practices for performance monitoring and analysis, 2-13 to 2-15
- Gilbert correlation, 11-30
- Gilbert cup separator, 10-22
- Goodman Diagram, original, 7-11. *see also* API
 - modified Goodman Diagram
- grams, 4-3
- gravel packs, 3-11, 10-31, 10-36
- gravity-driven separators, 10-12, 10-35
- guidelines, 11-35
- Hagedorn and Brown correlation, 4-19, 5-5
- Haigh diagrams, 7-15
- Hall effect sensor, 11-14, 11-15
- Hall-Yarborough correlation, 4-11

- Harbison-Fischer tests, 10-8 to 10-11
- hardness of pump materials, 6-29
- harmonics, 2-90
- heat loading, 11-41
- heat-treated tubes, 6-30
- heavy oil, 2-50, 2-52 to 2-53
- helix, 10-27
- high fluid level, 2-64 to 2-65
- high pumping rate with shallow pump, 2-53 to 2-55
- high pumping speed, 2-66 to 2-67
- high-efficiency valves, 10-5
- high-slip motors, 9-18
- high-strength rods, 1-11, 1-13
- historical comparison, 3-10
- hold-down seal assemblies, 6-5, 6-37
- hold-downs, types of, 6-37
- hole in pump barrel, 2-74 to 2-75
- hollow rods, 7-53 to 7-54
- Hooke's Law, 2-3, 4-8, 7-35, 7-38, 11-7
- horizontal shale wells, production trend, 1-33
- horizontal vs. lateral wellbores, 10-28 to 10-30
- horizontal wellbores, 10-29
- horsehead, 8-1, 8-7
- horsepower-hours, 4-3
- horseshoe load cell, 11-3
- hydraulic diameter, 4-17
- hydraulic lift load cell, 11-4
- hydraulic power, 6-3
- hydraulic power requirements, 8-44 to 8-45
- hydraulic pressure, 11-6 to 11-7
- hydraulic pumping power, 9-3
- hydraulic sensing method, 11-6
- hydraulic surface units, 2-89 to 2-90
- hydrogen embrittlement, 7-51
- hydrogen sulfide (H₂S), 6-28
- hydrogen sulfide pitting, 7-50
- hydrostatic pressure, 6-23
- hysteresis, 11-7
- ignition device, 9-4
- inclined flow, 4-21
- inclined wellbore, gas separators for, 10-29
- inclinometer, 11-11
- incomplete liquid fillage, 10-1, 10-4
- indirect polished rod position determination
 - accelerometer, 11-12 to 11-14
 - date recording methods, 11-15
 - inclinometer, 11-11
 - timing of stroke, 11-14 to 11-15
- indirect rod load measurement
 - beam deflection, 11-9 to 11-10
 - hydraulic pressure, 11-6 to 11-7
 - polished rod strain, 11-7 to 11-9
- induction stroke, 9-9
- inertia loads, 2-4
- inertial sensor, 11-12
- inertial torque, 8-28, 8-35 to 8-36
- inflow performance relationship (IPR) curves, 1-2, 1-4, 1-5
- initial equipment loads, 1-11 to 1-16
- initial equipment selection, 1-8 to 1-11
- initial reservoir above bubble point, 1-4 to 1-8
- injection pressure, 5-2
- input power, 9-14 to 9-15
- instantaneous power, 11-41, 11-42, 11-43
- instantaneous torque, 11-43
- intake port, 9-6
- intake stroke, 9-9
- intermittent flow out the casing, 2-56
- intermittent operation, 2-98 to 2-100
- intermittent service, 9-19 to 9-20
- intermittently operated pumps, 6-46
- internal combustion engines
 - about, 9-4 to 9-5
 - four-stroke engines, 9-9 to 9-13
 - power and efficiency, 9-13 to 9-14
 - as prime mover, xxx, 9-1
 - two-stroke engines, 9-5 to 9-9
- interval timers, 2-100, 3-10
- inverted echo, 11-20
- inverted polarity, 11-20
- iron count, 7-52
- iteration in analysis, 12-28
- iterative approach, 1-22
- iterative solution, 4-19
- jackshaft, 1-16, 8-22 to 8-23, 8-25
- Johnson-Fagg dynamometer, 11-5
- joint length, 11-24
- K bars. *see* sinker bars
- kilowatt-hours, 4-3
- kinematics, 7-35
- kinetic energy, 8-28
- laboratory tests
 - anchor gas perforation effects, 10-16
 - cup-type separator, 10-21
 - downhole gas separators, 10-26

- pressure drop through valve and cage, 10-5 to 10-6
- standing valve (SV), 10-5
- Texas Twister separator, 10-27
- viscosity, 10-8
- wellbore inclination effect, 10-29
- laminar flow, 4-17 to 4-18
- landing nipple, 2-58
- leak testing. *see* TV test
- leakage rate calculation, 2-20 to 2-21
- leakage rates, 2-23, 2-25
- leaking SV, 2-41 to 2-44
- leaking TV, 2-40 to 2-41
- leaks, causes of, 2-26 to 2-27
- length, 4-1, 4-4
- Leutert dynamometer, 11-6
- liquid hold-up, 4-19, 4-21
- liquid level sounder, 5-6
- liquid percentage in annular gaseous column, 2-25, 11-35
- liquid velocity, 10-16
- liquids, 4-9 to 4-10, 4-16 to 4-18
- load cells, 11-2 to 11-5
- load sensor, 2-6
- loads
 - carried by prime movers, 9-1
 - measured and predicted, 12-24
- locked rotor torque, 9-16
- Loc-No Plunger®, 6-42
- long stroke pumping units, 8-48 to 8-50
- loose tubing anchor, 2-50
- low API gravity oil, 2-50, 2-52 to 2-53, 2-66 to 2-67
- low-profile pumping units, 8-7, 8-8
- lubrication, 8-44
- Lufkin Industries, 8-45, 12-2, 12-27
- Lufkin Quick Dyno sensor, 11-7
- luminous intensity, 4-1

- makeup torque, 7-5, 7-49
- mandrel, 5-2
- manual actuation of TV, 6-42
- Mark II pumping units
 - API Recommended Practice 11L (RP11L), 12-2, 12-10
 - crank balanced geometry, 8-6
 - crank effort, 8-33
 - equalizer bearing position, 8-11 to 8-12
 - equations for, 12-12
 - vs Reverse Mark pumping units, 8-3 to 8-4
 - Reverse Mark pumping units, 8-11 to 8-12
 - rotation direction, 8-27
 - upstroke acceleration, 8-14
 - velocity profile, 8-32
- mass, 4-1, 4-4
- materials for subsurface plunger pumps
 - about, 6-27 to 6-28
 - abrasion, 6-29
 - barrels, 6-30 to 6-31
 - corrosion types, 6-28
 - hold-down seal assemblies, 6-37
 - manual activation of TV, 6-42
 - multi-stage compression, 6-42 to 6-43
 - plungers, 6-31
 - pump anchor, 6-38
 - seating nipples, 6-38
 - sliding top valve, 6-41
 - valve cages, 6-32 to 6-37
- maximum production using available equipment, 1-25 to 1-28
- maximum stress, 7-10
- maximum tensile strength, 7-4
- maximum torque, 9-2, 12-15
- McCoy correlation, 11-30, 11-33
- mean stress for load fluctuation, 7-10
- measured dynamometer comparison, 12-26
- measurement objective, 11-1
- measurement units, 4-1 to 4-3
- mechanical damage, 7-49
- mechanical friction, 7-20
- mechanical hold-downs, 6-37
- mechanical wear, 6-28
- mechanics of materials, 4-7 to 4-9
- middle taper rod part, 2-58 to 2-61
- millidarcy, 4-3
- Mills' equation, 7-34
- minimum polished rod load (MPRL), 2-8
- minimum stress, 7-10
- mixture specific gravity, 7-7
- modified API Goodman Diagram. *see* API modified Goodman Diagram
- modified Goodman Diagram. *see* API modified Goodman Diagram
- modified method, 12-16
- moment arm, 8-3
- moments of inertia, rotating, 8-29, 8-36
- monel, 6-31
- Moody charts, 4-17
- Morrow's equation, 7-14
- motor controls, 9-19
- motor current measurement, 11-39 to 11-40
- motor current probe, 11-39
- motor efficiency, 8-46, 9-15

- motor power measurements, 11-41 to 11-43
- motor power or current measurements and analysis
 - about, 11-38
 - analysis of motor current for a single pump stroke, 11-40 to 11-41
 - electrical safety, 11-38 to 11-39
 - motor current measurement, 11-39 to 11-40
 - motor power measurements, 11-41 to 11-43
- motor slip, 9-14, 9-15 to 9-16
- motor start-up power and cycle time, 2-101 to 2-102
- motors, installation and operating costs, 9-20 to 9-21
- mud anchors, 10-13, 10-26
- mufflers, 9-9
- multi-phase flow in pipe, 4-19 to 4-21
- multirate production test, 5-16
- multistage compression, 6-42 to 6-43

- National Electric Manufacturers Association (NEMA), 2-101, 8-46, 9-14
- natural gas separators, 10-16 to 10-17, 10-35
- natural gravity separation, 10-12
- Neely's method, 7-29, 7-34
- negative torque, 9-17
- NEMA service factor, 9-18
- NEMA type B motors, 9-18
- NEMA type C motors, 9-18
- NEMA type D motors, 2-101, 2-102, 8-46, 9-17, 9-18
- net gear box torque, 2-14, 8-30, 8-31, 8-39 to 8-40, 12-14
- net torque, 8-20 to 8-21, 8-29, 12-15
- newtons, 4-2
- Newton's Second Law of Motion, 4-2, 4-7, 7-34, 7-35
- nitric oxides (NO_x), 9-5
- nitrogen, 5-2
- noise abatement, 9-9
- non-API high strength rods, 7-3
- normal operation
 - full pump and anchored tubing, 2-32 to 2-33
 - full pump and unanchored tubing, 2-34 to 2-35
- normal polarity echo, 11-20
- Norris, 7-41
- numerical integration, 2-9
- numerical solution
 - using 1-D wave equation, 12-16 to 12-18
 - using API RP11L method, 12-18 to 12-21
 - using classical method, 12-21 to 12-23
- observations at the well, 3-2 to 3-4
- oil and water mixtures properties, 4-16
- oil density with dissolved gas, 4-15 to 4-16
- oil formation volume factor, 4-13 to 4-14
- oil gravity, 4-10
- oil permeability, 5-14
- oil viscosity, 4-15
- oil-brine interface, 11-37
- 1-D wave equation
 - vs. API RP11L (Recommended Practice JLL) method, 12-19, 12-20
 - best practices, 12-30
 - dynamometer card simulation, 12-27
 - solution of numerical using, 12-46 to 12-18
- online Tool Box
 - API RP11L method, 12-3
 - axial compression force, 7-20
 - buckling forces, 1-10, 1-20
 - compression forces, 1-29
 - materials in, xxvi
 - pressure drop through SV, 10-10
 - pumping units geometry, 8-13
 - rod buckling, 7-21
 - torque factor calculations, 8-40
 - unit conversions, 4-7
- on-site waste oil, 9-9, 9-13
- open cages, 6-33
- operating cost, 11-42
- output liquid fraction, 10-28
- output power, 9-15
- output shaft, 8-2
- overbalanced units, 11-40, 11-44
- overloaded gear box, 2-86 to 2-88
- oversized tubing pump, 6-47 to 6-49
- overspeeding, 9-1
- overstress, 7-48
- overtravel, 2-55, 6-4
- oxidation, 7-51

- packer, 5-2
- packer separator, 10-19 to 10-20, 10-30
- Paintearth separator, 10-25
- Pampa pump, 6-45
- pantograph, 11-5
- paraffin, 7-52, 7-53, 10-19, 10-34
- partial pump fillage, 2-102, 2-103. *see also*
 - dynamometer field data of rod lift systems
- pascals, 4-2
- pascal-seconds, 4-3
- peak polished rod load (PPRL), 2-8
- peak torque, 2-14, 12-8

- percentage cycle timer, 2-100, 2-102 to 2-103
- perforations, 1-2, 10-16, 10-18
- performance monitoring and analysis
 - pump rate match with reservoir rate, 2-97 to 2-105
 - recommended practices, 2-1 to 2-27
- permeability, 1-6, 4-3, 4-6
- Permian Basin, 11-33
- permissible load, 2-16
- permissible load diagram, 2-16
- phase behavior, 4-11 to 4-12
- phase converter, 9-14
- phase diagram, 4-11
- piston, 2-2
- piston rings, 9-9
- pitman arms, 8-3, 8-6
- pitting corrosion, 6-28
- planimeter, 2-8
- plugged intake, 2-46 to 2-47
- plunger displacement, 10-2
- plunger loads, 2-2, 6-11 to 6-13
- plunger pumps
 - design and operation, 6-1
 - elements of, 6-5
 - operation, 6-8 to 6-11
- plunger stroke, 6-4, 12-10, 12-13
- plunger velocity, 10-2
- plungers, *xxix*
 - rules of thumb for, 6-31
 - sizes, 1-9
- polished rod
 - acceleration and velocity vs. time, 11-12
 - acceleration vs. time, 11-12
 - counterbalance effect, 8-43
 - load at, 2-1
 - vs. time, 11-13
- polished rod clamps, 2-6
- polished rod hp, 2-10, 8-48, 12-10
- polished rod lubricator, 1-32, 10-34
- polished rod position
 - crank angle vs., 8-11, 8-16
 - crank rotation vs., 11-15
 - time vs., 8-16
 - velocity vs. time, 11-14
- polished rod position determination
 - about, 11-10
 - direct polished rod position determination, 11-11
 - indirect polished rod position determination, 11-11 to 11-16
- polished rod power, 2-8 to 2-10, 12-9
- polished rod strain, 11-7 to 11-9
- polished rod surface cards, 2-4
- polished rods, 1-15, 7-47
- pony rods, 6-7, 7-41
- poor boy separator, 10-17 to 10-18
- portable analog dynamometer recorder, 11-16
- positive displacement device (pump), *xxix*
- positive torque, 9-1
- potentiometer, 8-25
- pound-force, 4-2
- pounding during upstroke, 2-72 to 2-73
- pounds per square inch absolute (psia), 4-2
- pounds per square inch gauge (psig), 4-2
- power
 - conversion efficiency, 11-43
 - definition, 4-3
 - and efficiency, 9-13 to 9-14
 - unit conversions, 4-6
- power (kw) measurements, 11-38
- power bands, 8-3
- power belts, 8-21
- power factor, 9-15
- power stroke, 9-5
- predicted surface dynamometer card, 12-17
- predictive methods
 - about, 12-1 to 12-2
 - API recommended practice 11L (APR RP11L), 12-2 to 12-12
 - classical method for conventional (type I lever), 12-12 to 12-15
 - computer solution of one-dimensional (1-D) wave equation, 12-2
- predictive mode, 12-2
- predictive model default values, 12-24
- pressure
 - definition, 4-2
 - in pumping well, 11-26
 - unit conversions, 4-5
- pressure at the bottom of the tubing string (PBT), 2-3, 2-17
- pressure balance in static well, 11-36
- pressure bomb, 1-4
- pressure drawdown, 6-3
- pressure drawdown and inflow performance, 7-46 to 7-47
- pressure drop
 - liquid submergence, 10-3
 - through closed cage, 10-7
 - through standing valve (SV), 10-9 to 10-10
 - through TV assemblies, 10-8
- pressure drop though valve and cage
 - Harbison-Fischer tests, 10-8 to 10-11

- laboratory tests, 10-5
- pressure gauges
 - bottomhole pressure gauge, 5-5
 - wireline-conveyed pressure gauge, 5-6
- pressure gradient, 4-7
- pressure increase vs. gas flow, 11-32
- pressure pulse generation, 11-22
- pressure traverse, 5-6, 6-2
- primary windings, 11-39
- prime movers, *xxix*
 - bhp requirements for, 12-15
 - changes in speed, 12-2
 - costs relating to, 9-20 to 9-21
 - electric motors, 9-14 to 9-19
 - intermittent service, 9-19 to 9-20
 - internal combustion engines, 9-4 to 9-14
 - loads carried by, 9-1
 - power required, 2-10
 - sizing, 9-1 to 9-4
 - total system efficiency, 9-20
- prime movers sizing
 - running power, 9-2 to 9-4
 - starting power, 9-1 to 9-2
- processing of solids, 1-33
- produced solids, 10-19, 10-36
- produced water analysis, 7-52
- produced water-oil ratio, 11-27, 11-37
- producing BHP, 11-27
- producing formation, *xxix*
- producing pressure, 3-4
- Production and Lift Technology, 12-2
- production decline rate, 1-8
- production rate
 - vs. flow rates, 6-34
 - forecast, 1-33
 - free gas and projections of, 1-2
 - iterative approach, 1-22
 - maximum, 1-18
 - at pumping speed, 1-16
- production rate adjustment, 1-16 to 1-18
- production stabilization, 11-34
- production trend, horizontal shale wells, 1-33
- productivity index, 1-1, 1-2, 1-18, 1-22, 5-9 to 5-16
- productivity index creation, 5-9 to 5-16
- progressing cavity pump, 11-26
- proppant, 10-31
- proving ring load cell, 11-5
- pull rod, 2-58
- pull-in torque, 9-16
- pulling job, 2-13
- pull-up torque, 9-16
- pulse generator, 11-23
- pulse travel time to distance, 11-23 to 11-24
- pump, *xxix*
 - pump anchor, 6-38
 - pump compression ratio, 3-11
 - pump cycle off-times, 2-101
 - pump depth, 1-8
 - pump discharge pressure (PDP), 6-3
 - pump displacement, 1-8
 - pump dynamometer cards, 2-4
 - simulated, 12-29
 - pump efficiency, 6-34
 - pump failure tracking, 6-50 to 6-52
 - pump fillage
 - analysis of, 2-2, 2-17, 2-95, 11-5
 - annular gas flow rate, 2-33
 - detection of, 11-8
 - partial, 2-101 to 2-104
 - POC systems, 2-103 to 2-104
 - predictive methods, 12-1
 - simulations, 12-29
 - timers, 2-100
 - trends regarding, 3-10
 - pump friction, 12-16
 - pump intake
 - best practices, 10-35 to 10-36
 - downhole pump and wellhead equipment, 10-1 to 10-11
 - filling barrel with liquid, 10-1
 - flow rate through standing valve (SV), 10-1 to 10-3
 - pressure drop through valve and cage, 10-5 to 10-11
 - pump intake pressure (PIP)
 - analysis of, 11-27
 - annulus surface pressure, 1-18
 - casing pressure, 1-11
 - definition, 6-3
 - elements driving, 10-3
 - fluid load, 2-3
 - iterative approach, 1-22
 - rule of thumb for, 5-10
 - as volume indicator, 1-27
 - well potential, 2-4
- pump materials, 6-28, 6-29
- pump performance, 3-9, 7-46
- pump position, 1-35 to 1-36
- pump pounding, 2-72 to 2-73
- pump rate, 7-21
- pump rate and efficiency, 6-3 to 6-5
- pump rate match with reservoir rate

- about, 2-97 to 2-98
- pumped-off condition identification, 2-99 to 2-100
- timers, 2-100 to 2-103
- variable frequency drives, 2-104 to 2-105
- variation of pumping speed, 2-104
- pump rod, 2-2
- pump setting depths
 - about, 6-22
 - allowable, 6-22 to 6-25
 - axial loading, 6-23
 - burst loading, 6-23
 - choices for, 1-34
 - collapse loading, 6-24 to 6-25
 - typical, 6-25 to 6-26
- pump size limitations, 6-27
- pump slippage, 6-4
- pump stroke, as fraction of polished rod stroke, 12-7
- pump stroke length, 12-10
- pump tagging, 2-76 to 2-81
- pump tagging fiberglass rods, 2-80 to 2-81
- pump volumetric efficiency
 - calculation of, 6-4, 6-5
 - deviated wells, 1-35 to 1-37
 - dynamometer test, 6-4
 - gas interference, 1-35
 - performance analysis, 11-1
 - problems with, 3-1
 - rod stretch effects on, 2-49
 - valve leakage, 3-8
- pumped-off condition, 2-44 to 2-45, 2-99 to 2-100
- pumped-off status, 1-2
- pumping cycles, 6-8 to 6-11
- pumping efficiency, 8-44
- pumping fluids with solids
 - about, 6-44
 - bottom-discharge valve, 6-46 to 6-47
 - casing pump, 6-50, 6-51
 - Double-Displacement Pump®, 6-47 to 6-48
 - oversized tubing pump, 6-47 to 6-49
 - Pampa pump, 6-45
 - pump failure tracking, 6-50 to 6-52
 - pumping large flow rates, 6-47
 - Sand Pro Pump®, 6-46
 - stroke-through pump, 6-45
 - Texas stripper pump, 6-46
 - three-tube pump, 6-46
- pumping from highly deviated wells
 - about, 1-33 to 1-35
 - design choice, 1-37 to 1-38
 - gear box and power requirements, 1-37
 - pump position, 1-35 to 1-36
 - pump speed, 1-36 to 1-37
 - sucker rod design, 1-36 to 1-37
- pumping large flow rates, 6-47
- pumping speed
 - calculations for, 12-21
 - control, 8-21 to 8-25
 - estimate of, 12-1 to 12-2
 - production rate at, 1-16
 - rod life, 7-16
 - slow pumping speed, 2-97
 - stroke length and, 2-13, 12-10
 - and sucker rod design, 1-36 to 1-37
 - variation, 2-104
 - very slow, 8-22
- pumping tee, 10-33
- pumping units, *xxix*
 - alternatives, 8-48 to 8-50
 - American Petroleum Institute (API) unit designation, 8-7
 - balancing the unit, 8-40 to 8-44
 - best practices, 8-51
 - component nomenclature, 6-9
 - counterbalance, 8-30 to 8-40
 - deviated wells, 7-45 to 7-46
 - efficiency, 8-44 to 8-48, 12-11, 12-19
 - gear box, 8-17 to 8-21
 - hydraulic units, 8-50
 - long stroke units, 8-48 to 8-50
 - pressure drawdown and inflow performance, 7-46 to 7-47
 - pumping speed control, 8-21 to 8-25
 - specialty units, 8-7 to 8-8
 - structures, bearings and bases, 8-44
 - torque calculations, 8-25 to 8-29
 - Type I levers, 8-1 to 8-4
 - Type III levers, 8-5 to 8-6
 - unit type choice, 8-8 to 8-17
- pumping well classification, 11-28
- pumping wells
 - acoustic velocity, 11-18
 - blowout preventer, 10-34
 - downhole pressure sensor, 11-16
 - gas interference, 10-11
 - pressure and fluid distribution, 11-26
 - pressure calculations, 11-27
 - specialty rods, 7-53
 - troubleshooting, 2-1
 - water flooding, 11-29
 - water hammer, 7-38
- pumping with high gas-to-liquid ratios, 6-39 to 6-41
- pump-off control systems (POCs), 2-103 to 2-104

- pump-off controllers (POCs), 2-98, 3-10, 10-30, 11-2, 11-27
 pump-off time, 3-4
 pushrods, 9-8
 Pwf (back pressure held against the reservoir), 1-3, 1-36

 QRod, 1-11
 vs. RODSTAR, 1-16
 QRod program, 12-2
 quality control of pressure calculations
 fluid level depth, 11-35
 height of the gaseous liquid column, 11-35
 percentage of liquid in annular gaseous column, 11-35
 production stabilization, 11-35

 rabbit, 2-47
 radial loading, 6-13
 real gas law, 4-9, 11-30
 reciprocating equipment, 1-3
 recommended practices for performance
 monitoring and analysis. *see also* best practices
 data quality control, 2-7 to 2-8
 dynamometer analysis, 2-1 to 2-5
 dynamometer data analysis, 2-8
 dynamometer data collection, 2-6
 dynamometer field data of rod lift systems, 2-27 to 2-97
 fluid load and working fluid level, 2-11 to 2-12
 fluid slippage and TV leakage, 2-16 to 2-17
 gear box torque and counterbalance condition, 2-13 to 2-15
 leakage rate calculation, 2-20 to 2-21
 permissible load diagram, 2-16
 polished rod power, 2-8 to 2-10
 standing valve (SV) leakage, 2-25 to 2-26
 standing valve (SV) test, 2-26 to 2-27
 traveling valve (TV) test, 2-17 to 2-20
 traveling valve (TV) test for liquid-filled pump, 2-21 to 2-23
 traveling valve (TV) test with partial liquid-fillage, 2-23 to 2-25
 valve test, 2-11
 wellbore pressures, 2-12 to 2-13
 reducer torque, 9-1
 reductions in area (restrictions), 11-21
 reed valve, 9-6
 repair log nomenclature, 6-50
 reservoir pressure, 1-2, 2-101, 4-14, 11-36
 reservoir productivity index, 2-12

 reservoirs
 lower-permeability and high pressure, 1-31
 problem of new, 1-31
 unsteady flow, 1-31 to 1-32
 resin-coated proppant, 10-31, 10-36
 respacing to remove tag, 2-81
 Reverse Mark geometry, 8-3, 8-4
 Reverse Mark pumping units, 8-11, 8-14
 equalizer bearing position, 8-11 to 8-12
 vs. Mark II pumping units, 8-3 to 8-4
 upstroke acceleration, 8-14
 reversing gear, 8-48
 Reynolds Number, 4-17 to 4-18
 ringed plungers, 7-46
 rod acceleration, 6-4
 rod and tubing wear, 3-12
 rod axial stress, 7-9
 rod basket, 7-1
 rod bending loads, 7-43
 rod blowout preventer, 10-33, 10-36
 rod boxes, 7-5
 rod damping, predictive model default values, 12-24
 rod design, 12-12
 rod diameter selection, 7-26
 rod displacement, 7-37
 rod failures, 2-50, 2-73
 rod fatigue, 2-92, 7-43
 rod float, 2-105
 rod guides, 7-41, 7-43, 7-44, 7-56
 rod heavy condition, 8-40, 11-44
 rod life, 7-11, 7-54, 12-20
 rod lift systems, diagnostic analysis of, 2-5
 rod load trends, 2-104
 rod or insert pumps, 6-8
 rod pump, 6-5, 6-6
 rod pumping, most common problems, 3-1
 rod pumping system, 6-1
 rod section length design, 7-27 to 7-32
 rod sizes and tapered rod string
 diameter selection, 7-26
 rod section length design, 7-27 to 7-32
 rod taper selection, 7-26
 rod stresses, 2-8, 12-12
 maximum, 7-55
 rod string, *xxix*
 rod string code, 7-26
 rod string design, 7-24 to 7-25
 rod string dynamic loads, 7-56
 rod taper, 2-5, 7-26, 7-27
 rod weight, 2-3

- RODIAG (Theta Enterprises), 12-29
- RODSTAR
- accuracy, 7-39
 - calculation of equipment loads, 1-11
 - loads measured and predicted from, 12-24
 - program, 12-16
 - vs. QRod, 1-16
 - software, 1-15, 12-2
- Rotaflex® unit, 2-92 to 2-95, 8-48
- rotary crank counterbalance torque, 8-36
- rotary moment of inertia, 8-35
- rotating moments of inertia, 8-29, 8-36
- rotation direction, 8-15, 8-27
- rotators, 3-11
- round tip travel time (RTTT), 11-23, 11-27
- rubber elements, 10-34
- rubbers, 3-2
- rules of thumb. *see also* best practices
- belt velocity, 8-22, 8-24 to 8-25
 - liquid capacity of a gas separator, 10-14
 - oilfield engine fuel flow rate, 8-46
 - plungers, 6-31
 - pump intake pressure (PIP), 5-10
 - pump submergence depth, 7-46
 - rod guide placement, 7-56
 - swab testing, 5-3
- run time trend, 2-104
- running power, 9-2 to 9-4
- rust, 7-51
- safe stress load, 7-13
- samson post, 7-32, 8-1, 8-6, 8-7
- sand, 1-8, 6-12, 6-44, 6-45, 10-31
- buildup, 6-18
- sand and solids, 3-11
- Sand Pro Pump®, 6-46
- sand screen, 10-31
- sand volumes, 1-3
- Sandia National Laboratory, 6-13, 10-5
- sandy wells, 6-19, 6-20
- scale, 5-1, 6-44, 6-45, 10-19, 10-21, 10-25
- buildup, 6-18
- scale particles, 6-12
- screens, 10-31, 10-36
- sealing packers, 10-19
- seating assembly, 6-8
- seating nipples, 6-5, 6-8, 6-38
- secondary windings, 11-39
- selection guidelines for subsurface pump types
- stationary-barrel bottom-anchor rod pumps, 6-18 to 6-19
 - stationary-barrel top-anchor rod pumps, 6-19 to 6-20
 - traveling-barrel bottom-anchor rod pumps, 6-20 to 6-22
 - tubing pumps, 6-17 to 6-18
- semiconductor strain gauges, 11-8
- separate entry port geometry, 10-26
- separators, 1-6, 1-31, 1-32. *see also* gas separators
- annular area, 10-36
 - centrifugal, 10-12
 - collar-size, 10-22 to 10-25
 - cup, 10-21 to 10-22
 - cup-type, 10-23
 - efficiency, 10-36
 - fluid entry ports, 10-35
 - Gilbert cup, 10-22
 - gravity-driven, 10-12, 10-35
 - natural gas, 10-16 to 10-17, 10-35
 - packer, 10-19 to 10-20, 10-30
 - Paintearth, 10-25
 - pool boy, 10-17 to 10-18
 - snorkel-type, 10-19 to 10-20
 - spirit packer-style, 10-20
 - static centrifugal, 10-27
 - test, 5-5
 - Texas Twister, 10-27
- service factors, 1-14, 6-25, 7-32, 9-18 to 9-19
- service life, 7-23, 7-25
- shaft speed, 9-15
- shale wells, 1-33
- shallow depth, high rate, 2-53 to 2-55
- shallow wells, 1-18 to 1-22
- sheaves, 8-3
- sheaving, purpose of, xxx
- shock load, 1-16
- shut-in time, 2-6, 5-8
- side forces, 7-44
- Sidekicker Valve, 6-42
- simulated dynamometer comparison, 12-26
- simulated pump card, 12-29
- single-phase flow in pipe, 4-16 to 4-19
- single-phase liquid, 4-12
- single-phase power, 9-14
- sinker bars
- buckling forces, 7-21 to 7-22, 7-56, 12-18
 - calculations for, 12-21
 - compression forces, 7-22, 12-18
 - design of, 7-22, 12-21
 - in deviated wells, 7-46
 - with FRP rods, 7-23

- length of, 12-16
- weight of, 12-16, 12-18
- sizing prime movers, 9-1 to 9-4
- skin, 5-1
- sliding top valve, 6-41
- slim-hole coupling, 7-5
- slip, 9-18
- slip velocity, 10-13 to 10-16
- slippage, 2-7, 7-46
- Slonneger's equation, 7-34
- slots, multiple rows, 10-26
- slug flow, 1-32, 10-21
- slugs, 1-31
- smokestack gasses, 9-5
- snorkel-type separator, 10-19 to 10-20
- software, 1-11. *see also* QRod; RODSTAR
- solids, 6-41, 6-44, 6-45
- solids buildup, 6-46
- solids exclusion, 10-30 to 10-31
- solution gas, 4-13
- solution gas-oil ratio, 4-13 to 4-14
- sonic velocity, 11-17, 11-18, 11-19
- sound polarity inversion, 11-20
- sound waves inside tubes, 11-20
- sounders, 5-6, 5-7
- spark plugs, 9-4
- special-purpose pumping units, 8-7 to 8-8
- specialty rods
 - continuous rods, 7-54
 - hollow rods, 7-53 to 7-54
- specific gravity, 1-10, 2-11 to 2-12
- speed converter, *xxix*
- speed of stress wave propagation, 7-36
- speed reduction
 - benefits of, 1-16
 - external sheaves, 8-21
 - of gear box, 8-19
 - gear box capacity, 8-3, 8-17
 - ratio, 8-20
- speed variation factor, 11-43
- spirit packer-style separator, 10-20
- split-jaw ammeter, 11-39
- sprocket-and-chain gear box, 8-19
- SROD program, 7-44, 12-2
- stabilized flowing BHP, 5-3
- stabilized operation, 11-27
- standing valve (SV)
 - checks, 2-7, 2-22, 2-52
 - flow rate through, 10-1 to 10-3
 - intermittent bottomhole pressure, 1-31
 - laboratory tests, 10-5
 - leakage rates, 2-11
 - leaks/leakage, 2-19, 2-25 to 2-26, 2-27, 2-41 to 2-43
 - malfunction indicator, 2-26
 - pressure drop through, 10-10
 - pressure loss, 10-9
 - screw-type, 6-33
 - tests, 2-19, 2-26 to 2-27, 3-10, 7-6
 - viscous friction, 10-9
- starting inertia, 9-2
- starting power, 9-1 to 9-2, 9-19
- static bottomhole pressure (SBHP), 3-4, 5-2, 11-27, 11-29, 11-37
- static centrifugal separator, 10-27
- static load, 4-8
- static pressure, 2-13, 5-1
- static reservoir pressure, 5-8, 11-45
- static well
 - conditions, 11-37
 - fluid distribution in, 11-36
 - pressure balance in, 11-36, 11-37
- stationary-barrel bottom-anchor rod pumps, 6-18 to 6-19
- stationary-barrel top-anchor rod pumps, 6-19 to 6-20
- steady-state flow, 1-30
- steady-state gas flow, 4-18
- steel rod classification, 7-3 to 7-4
- stock tank conditions, 4-13
- Stokes' Law, 10-13
- strain, 7-4
- strain gauge load cell, 8-25
- strain gauges, 11-2
- strainer nipple, 2-47
- stress, 4-7
- stress concentration point, 7-9
- stress fluctuation, 7-28
- stress corrosion cracking, 6-28
- stress-equal-at-the-top method, 7-31, 7-39
- stress-equal-at-the-top-of-each-rod-taper-method, 12-12
- stress-strain diagram, 7-4
- stroke comparison, 8-12
- stroke length, 1-8, 2-13, 8-9
- stroke-through pump, 6-45
- structural imbalance, 8-31, 8-39
- structures, bearings, and bases, 8-44
- stuck plunger, 2-61 to 2-63
- stuck pump, 7-48, 7-49
- stuffing box, 10-34

- subsurface pump types. *see also* materials for subsurface plunger pumps
- differential pressure loading, 6-13 to 6-17
 - downhole pump, 6-5 to 6-22
 - plunger loads, 6-11 to 6-13
 - plunger pump operation, 6-8 to 6-11
 - rod or insert pumps, 6-8
 - selection guidelines for, 6-17 to 6-22
- sucker rod couplings, 7-5 to 7-6, 7-25, 7-56
- sucker rod design, 7-24 to 7-32, 7-47 to 7-50
- sucker rod guides, 7-41 to 7-42
- sucker rod life, 7-14 to 7-19
- sucker rod loads, 7-6 to 7-9
- Sucker Rod Pumping Research, 7-34
- sucker rod rotator, 10-34 to 10-35
- sucker rods
- about, *xxxi*, 7-1 to 7-3
 - axial compression, 7-19 to 7-22
 - best practices, 7-54 to 7-56
 - corrosion control, 7-52
 - corrosion monitoring, 7-52 to 7-53
 - corrosive attack, 7-50 to 7-51
 - couplings, 7-5 to 7-6
 - design method comparison, 7-39 to 7-40
 - design methods, 7-31, 7-39
 - design of, 7-24 to 7-32
 - deviated wells, 7-43 to 7-47
 - dynamic loads, 7-32 to 7-38
 - failure, 7-47 to 7-50
 - fatigue, 7-9 to 7-13
 - fluid inertia, 7-38 to 7-39
 - FRP (fiberglass) sucker rods, 7-23 to 7-24
 - guides, 7-41 to 7-42
 - life, 7-14 to 7-19
 - loads, 7-6 to 7-9
 - mechanical properties, 4-9
 - paraffin, 7-53
 - polished rods, 7-47
 - sinker bars, 7-22 to 7-23
 - sizes and elastic constants, 7-1
 - specialty rods, 7-53 to 7-54
 - steel rod classification, 7-3 to 7-4
 - terminology, 7-1
 - sulfate-reducing bacteria, 7-51
 - sulfide stress, 6-28
 - sump, 9-7, 9-9
 - supervisory control and data acquisition, 11-2
 - surface equipment, *xxix*
 - surface production rate, 12-10
 - surface temperature, 11-35
 - surface-hydraulic pumping units, 8-1
 - swab cup, 5-2, 5-4, 5-6
 - swab cup assemblies, 5-4
 - swab line, 5-6, 5-7
 - swab testing, 5-2
 - swabbing unit, 5-2
 - sweet oil, 1-14
 - synchronous speed, 9-15 to 9-16
 - system design
 - about, 1-1 to 1-4
 - constrained design, 1-22 to 1-38
 - unconstrained design, 1-4 to 1-22
 - system loads, calculations for, 12-22
- tachometer, 8-43
- tagging down, 6-8
- tagging on downstroke
- about, 2-76 to 2-77
 - tagging on downstroke, 2-24
 - tagging on downstroke, FRP rods, 2-80 to 2-81
 - tagging on downstroke, unanchored tubing, 2-78 to 2-79
- tail, 8-2
- tail bearing, 8-2
- tangential stress, 6-23
- tank model, 1-7, 1-8
- tapered tubing, 11-25
- tapers, fatigue strength, 7-29 to 7-30
- temperature, 4-1
- tensile load, 4-7
- test data
- BHP, 5-5 to 5-9
 - flow rates, 5-1 to 5-5
- test pumping system, 5-2
- test pumping units, trailer-mounted, 5-2
- test separator, 5-5
- test tanks, 5-5
- tests. *see also* laboratory tests; standing valve (SV) test; traveling valve (TV) test; valve tests; well testing
- dynamometer test, 11-45
 - fill-up test, 3-8
 - flow rates test data, 5-1 to 5-5
 - fluid level test, 11-45
 - Harbison-Fischer tests, 10-8 to 10-11
 - static and pumping, 1-18
 - Walker Liquid Level Depression Test, 11-30, 11-35
 - water flow-path tests, 10-26
- Texas stripper pump, 6-46
- Texas Twister separator, 10-27
- Theta Enterprises, 1-11, 7-39, 12-2, 12-27, 12-29

- thread-on wellhead, 10-33
- threads, 7-47
- three-phase induction motors, 9-14
- three-phase power, 9-14
- three-tube pump, 6-46
- throughput volume, 2-26
- time
 - about, 4-1
 - vs. polished rod acceleration, 11-12
 - vs. polished rod acceleration and velocity, 11-13
 - vs. polished rod load, 11-13
 - vs. polished rod position and velocity, 11-14
 - polished rod position vs., 8-16
 - unit conversions, 4-4
- timers
 - intermittent service, 2-98
 - motor start-up power and cycle time, 2-101 to 2-102
 - percentage cycle timer, 2-102 to 2-103
 - pumping speed variation, 2-104
 - pump-off control systems (POCs), 2-103 to 2-104
 - shorter or longer pump cycle off-times, 2-101
 - stabilized operation, 11-27
 - types of, 2-100 to 2-101
 - variable frequency drives, 2-104 to 2-105
 - variable speed pumping, 2-105
- timing of stroke, 11-14 to 11-15
- top hold-down rod pump, 6-14 to 6-15
- torque. *see also* gear box torque; net gear box torque
 - articulating inertial, 8-29
 - articulating structure, 8-28
 - breakdown, 9-16
 - calculation from power, 11-43 to 11-45
 - calculations, 8-25 to 8-29, 11-43 to 11-45
 - counterbalance, 8-31, 8-37
 - cyclical, 9-1
 - electric motors, 9-16 to 9-18
 - full load, 9-16
 - inertia, 8-28, 8-35 to 8-36
 - instantaneous, 11-43
 - locked rotor, 9-16
 - maximum, 9-2, 12-15
 - negative, 9-17
 - net, 8-20 to 8-21, 8-29, 12-15
 - peak, 2-14, 12-8
 - positive, 9-1
 - pull-in, 9-16
 - pull-up, 9-16
 - reducer, 9-1
 - rotary crank counterbalance, 8-36
 - torque adjustment factor, 12-9
 - torque analysis, 11-43
 - torque calculation from power, 11-43 to 11-45
 - torque calculations, pumping units, 8-25 to 8-29
 - torque converter, gear box as, *xxix*
 - torque factor, 8-15, 8-25 to 8-27
 - torque factor calculations, online Tool Box, 8-40
 - torque reversal, 8-31
 - total entry port area, 10-26
 - total system efficiency, 9-20
 - trailer-mounted pumping units, 8-7, 8-8
 - transformer action, 11-39
 - trapezoid rule, 2-9, 8-45
 - traveling barrel pump, 6-17, 6-45
 - traveling barrel rod pump, 6-16 to 6-17
 - traveling valve (TV)
 - bottomhole pressure (BHP), 1-31
 - checks, 2-7, 2-52
 - delayed closure, 2-68 to 2-69
 - fluid load, 7-6
 - high viscosity oil, 10-4
 - leakage rates, 2-11
 - leaks, 2-22, 2-40 to 2-41
 - Loc-No Plunger®, 6-42
 - manual actuation of, 6-42
 - pressure drop through assemblies, 10-8
 - pumping cycles, 2-2
 - Sidekicker Valve, 6-42
 - vapor compression, 10-5
 - traveling valve (TV) test
 - steps and requirements of, 2-17 to 2-20
 - TV test for liquid-filled pump, 2-21 to 2-23
 - TV test with partial liquid-fillage, 2-23 to 2-25
 - traveling-barrel bottom-anchor rod pumps, 6-20 to 6-22
 - tree assembly, 10-33
 - trend analysis parameters, 2-104
 - troubleshooting and analysis guidelines
 - about, 3-1
 - analysis of dynamometer record, 3-6 to 3-10
 - analysis of fluid level record, 3-4 to 3-5
 - best practices, 3-10 to 3-12
 - corrosion, 3-12
 - gas in the pump, 3-11
 - historical comparison, 3-10
 - observations at the well, 3-2 to 3-4
 - rod and tubing wear, 3-12
 - sand and solids, 3-11
 - valve tests, 3-10
 - volumetric efficiency, 3-10
 - true vertical depth (TVD), 1-3, 11-29, 11-35

- tubing
 - coiled, 5-2
 - outside diameter, 11-35
 - unanchored motion of, 10-32
- tubing anchors, 10-32 to 10-33, 10-36, 11-25
- tubing head, 6-2
- tubing pumps
 - components of, 6-7
 - configuration of, 6-17 to 6-18
 - differential pressure, 6-13 to 6-14
 - elements of, 6-5
 - oversized, 6-47
 - selection guidelines, 6-17
 - tagging in, 6-09
- tubing stretch, 2-20 to 2-21, 6-4, 12-13
- tubing string, 7-6
- tubing tally, 11-24
- tubulars, 5-2
- turbulent flow, 4-17 to 4-18
- two-phase flow, 1-4
- two-stage hollow-valve rod pump, 6-43
- two-stroke engines
 - about, 9-5 to 9-7
 - advantages of, 9-8 to 9-9
 - disadvantages of, 9-9
 - vs. four stroke engines, 9-7
 - for pumping units, 9-6
- type A wells, 11-28
- type B wells, 11-28
- type C wells, 11-28
- type I lever pumping units, 12-2
- type I levers, 8-1 to 8-4
- type III lever pumping units, 12-2
- type III levers, 8-5, 8-6
- ultrahigh-slip motors, 9-19
- unanchored tubing motion, 10-32
- unconstrained design
 - initial reservoir above bubble point, 1-4 to 1-17
 - shallow well pumping with waterflood, 1-18 to 1-22
- unconventional pumping unit, geometry, 1-27
- unconventional resource wells, 1-33
- unit conversions, 4-3 to 4-7
- University of Texas at Austin, 10-6
- unset tubing anchor, 2-50 to 2-51
- unsteady flow, 1-30
- unswept volume, 6-40
- upstroke
 - equalizer bearing position, 8-6 to 8-7, 8-10, 8-11
 - fluid pound, 2-68
 - friction coefficient, 12-16
 - maximum load during, 7-27
- valve and seat dimensions, 6-35
- valve assembly (cage, ball, seat), 10-5
- valve cages
 - balls and seats, 6-33 to 6-36
 - double valves, 6-36 to 6-37
 - hold-down seal assemblies, 6-37
 - materials for subsurface plunger pumps, 6-32 to 6-37
 - valve and seat dimensions, 6-35
- valve rod bushing, 6-8
- valve rod guide, 6-8
- Vand equation, 4-16
- variable frequency drives, 2-104 to 2-105
- Variable Slippage Pump[®], 6-44
- variable speed pumping, 2-105
- variable-speed drives, 8-23
- Vasquez-Beggs correlation, 4-12, 4-13
- velocity curve, 11-12
- velocity profile, 8-32
- vertical lift performance (VLP), 1-4 to 1-6
- very high fluid level, 2-64 to 2-65
- very slow pumping speeds, 8-22
- viscosity
 - about, 4-2 to 4-3
 - computed effect of, 10-7
 - emulsion, 4-16
 - gas viscosity, 4-16
 - oil and water mixtures properties, 4-16
 - oil viscosity, 4-15
 - at reservoir conditions, 10-4
 - unit conversions, 4-6
 - water viscosity, 4-15
- viscous drag, 2-4, 7-20
- viscous friction, 7-36, 10-9
- Vogel's Equation, 1-1, 1-4, 5-12 to 5-14
- Vogel's Relation, 5-14
- voltage leads, 11-41
- volume, 4-1, 4-5
- volumetric efficiency. *see* pump volumetric efficiency
- Walker Liquid Level Depression Test, 11-30, 11-35
- walking beam, 8-1, 8-2
- water cut, 7-38
- water flow-path tests, 10-26
- water hammer, 7-38
- water production capacity, of coal seam, 1-32

- water viscosity, 4-15
- water-alternating-gas flooding, 2-35
- waterflood, 1-18
- waterflood well, 1-22
- water-oil contact, 1-3
- water-oil ratio, 2-1
- wattmeter, 8-43
- Waukesha engines, 9-10
- wear by abrasion, 6-28
- Web-based units calculators, 4-7
- weight addition, 8-37
- weight bars. *see* sinker bars
- weight-heavy units, 11-40
- weights on crank, 12-14
- weir, 10-13
- well deviation. *see* deviated wells
- well load, 8-26
- well potentials, acoustic surveys, 11-17
- well production rate, records of, 2-1
- well stabilization, 11-29
- well testing
 - best practices, 5-19
 - data uncertainty, 5-17 to 5-18
 - pressure above the bubble point, 5-9 to 5-11
 - pressure below the bubble point, 5-11 to 5-15
 - productivity index creation, 5-9 to 5-16
 - purpose of, *xxxi*
 - reservoir productivity index, 5-9
 - test data, 5-1 to 5-9
- well types and free gas, 11-28 to 11-29
- wellbore friction, 2-82 to 2-86
- wellbore gas, 11-25
- wellbore inclination effect, 10-28
- wellbore pressure, 2-1, 2-12 to 2-13, 11-29
- wellheads, *xxix*, 10-33 to 10-35
- wireline-conveyed pressure gauge, 5-6
- work, 4-3, 4-6
- working room, 7-1
- workover rigs, 7-1
- workovers, 3-2
- wrist pin, 8-3

- yield strength, 4-8, 7-4
- Young's modulus, 7-2

- zero load, 2-7

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